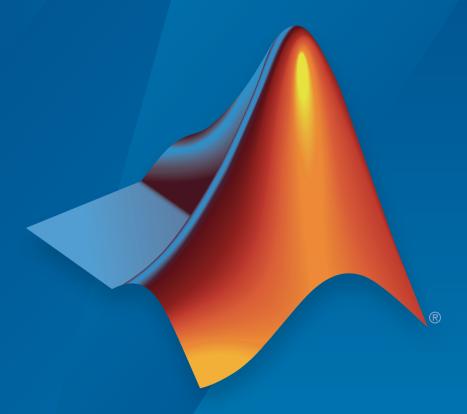# SimPowerSystems™
Reference (Specialized Technology)

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Contents

Blocks — Alphabetical List

abc to Alpha-Beta-Zero, Alpha-Beta-Zero to abc

Perform transformation from three-phase (abc) signal to αβ0 stationary reference frame or the inverse

Library

Control and Measurements/Transformations

Description

The abc to Alpha-Beta-Zero block performs a Clarke transform on a three-phase abc signal. The Alpha-Beta-Zero to abc block performs an inverse Clarke transform on the αβ0 components.

$$
\begin{bmatrix} u_\alpha \\ u_\beta \\ u_0 \end{bmatrix} = \begin{bmatrix} \dfrac{2}{3} & -\dfrac{1}{3} & -\dfrac{1}{3} \\ 0 & \dfrac{1}{\sqrt{3}} & \dfrac{-1}{\sqrt{3}} \\ \dfrac{1}{3} & \dfrac{1}{3} & \dfrac{1}{3} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix}
$$

The inverse transformation is given by
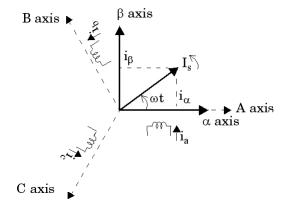
$$
\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ -\dfrac{1}{2} & \dfrac{\sqrt{3}}{2} & 1 \\ -\dfrac{1}{2} & -\dfrac{\sqrt{3}}{2} & 1 \end{bmatrix} \begin{bmatrix} u_\alpha \\ u_\beta \\ u_0 \end{bmatrix}
$$

Assume that u_a, u_b, u_c quantities represent three sinusoidal balanced currents:

$$i_a = I \sin(\omega t)$$

$$i_b = I \sin\left(\omega t - \frac{2\pi}{3} \right)$$

$$i_c = I \sin\left(\omega t + \frac{2\pi}{3} \right)$$
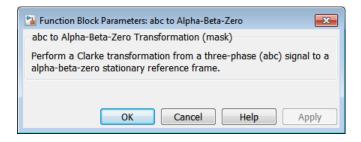
These currents are flowing respectively into windings A, B, C of a three-phase winding, as the figure shows.
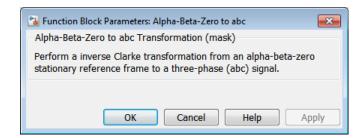
In this case, the i_α and i_β components represent the coordinates of the rotating space vector I_s in a fixed reference frame whose α axis is aligned with phase A axis. I_s amplitude is proportional to the rotating magnetomotive force produced by the three currents. It is computed as follows:

$$I_s = i_\alpha + j \cdot i_\beta = \frac{2}{3}\left(i_a + i_b \cdot e^{\frac{j2\pi}{3}} + i_c \cdot e^{-\frac{j2\pi}{3}} \right)$$

Dialog Box and Parameters
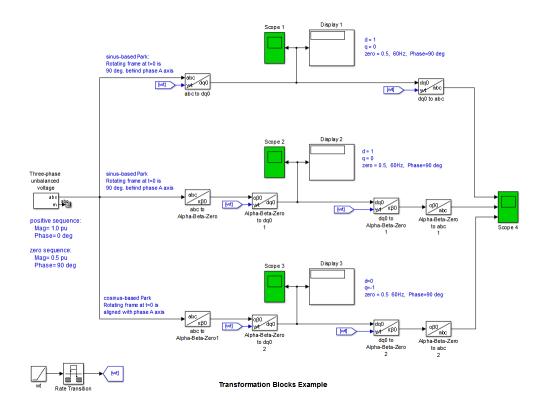
The block has no parameters.

Example

The power_Transformations example shows various uses of blocks performing Clarke and Park transformations.

Transformation Blocks Example

Introduced in R2013a

abc to dq0, dq0 to abc

Perform transformation from three-phase (abc) signal to dq0 rotating reference frame or the inverse

Library

Control and Measurements/Transformations

Description
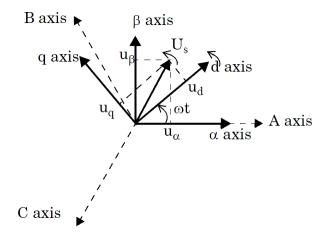
The abc to dq0 block performs a Park transformation in a rotating reference frame.

The dq0 to abc block performs an inverse Park transformation.

The block supports the two conventions used in the literature for Park transformation:

* Rotating frame aligned with A axis at t = 0. This type of Park transformation is also known as the cosinus-based Park transformation.

- Rotating frame aligned 90 degrees behind A axis. This type of Park transformation is also known as the sinus-based Park transformation. Use it in SimPowerSystems™ models of three-phase synchronous and asynchronous machines.

Deduce the dq0 components from abc signals by performing an abc to αβ0 Clarke transformation in a fixed reference frame. Then perform an αβ0 to dq0 transformation in a rotating reference frame, that is, −(ω.t) rotation on the space vector Us = u_α + j · u_β.

The abc-to-dq0 transformation depends on the dq frame alignment at t = 0. The position of the rotating frame is given by ω.t (where ω represents the dq frame rotation speed).

When the rotating frame is aligned with A axis, the following relations are obtained:

$$U_s = u_d + j \cdot u_q = \left(u_\alpha + j \cdot u_\beta\right) \cdot e^{-j\omega t} = \frac{2}{3} \cdot \left(u_a + u_b \cdot e^{\frac{j2\pi}{3}} + u_c \cdot e^{\frac{j2\pi}{3}}\right) \cdot e^{-j\omega t}$$

$$u_0 = \frac{1}{3}\left(u_a + u_b + u_c\right)$$

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos(\omega t) & \cos\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) \\ -\sin(\omega t) & -\sin\left(\omega t - \frac{2\pi}{3}\right) & -\sin\left(\omega t + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix}$$

Inverse transformation is given by

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & -\sin(\omega t) & 1 \\ \cos\left(\omega t - \frac{2\pi}{3}\right) & -\sin\left(\omega t - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\omega t + \frac{2\pi}{3}\right) & -\sin\left(\omega t + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix}$$

When the rotating frame is aligned 90 degrees behind A axis, the following relations are obtained:

$$U_s = u_d + j \cdot u_q = \left(u_\alpha + j \cdot u_\beta \right) \cdot e^{-j\left(\omega t - \frac{\pi}{2} \right)}$$

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = \begin{bmatrix} \sin(\omega t) & -\cos(\omega t) & 0 \\ \cos(\omega t) & \sin(\omega t) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix}$$

Inverse transformation is given by

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} \sin(\omega t) & \cos(\omega t) & 1 \\ \sin\left(\omega t - \frac{2\pi}{3} \right) & \cos\left(\omega t - \frac{2\pi}{3} \right) & 1 \\ \sin\left(\omega t + \frac{2\pi}{3} \right) & \cos\left(\omega t + \frac{2\pi}{3} \right) & 1 \end{bmatrix} \begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix}$$

Dialog Box and Parameters

Rotating frame alignment (at wt=0)

Select the alignment of rotating frame a t = 0 of the d-q-0 components of a three-phase balanced signal:

$$u_a = \sin(\omega t); \; u_b = \sin\left(\omega t - \frac{2\pi}{3}\right); \; u_c = \sin\left(\omega t + \frac{2\pi}{3}\right)$$

(positive-sequence magnitude = 1.0 pu; phase angle = 0 degree)

When you select `Aligned with phase A axis`, the d-q-0 components are d = 0, q = −1, and zero = 0.

When you select `90 degrees behind phase A axis`, the d-q-0 components are d = 1, q = 0, and zero = 0.

Inputs and Outputs

abc

The vectorized abc signal.

dq0

The vectorized dq0 signal.

wt
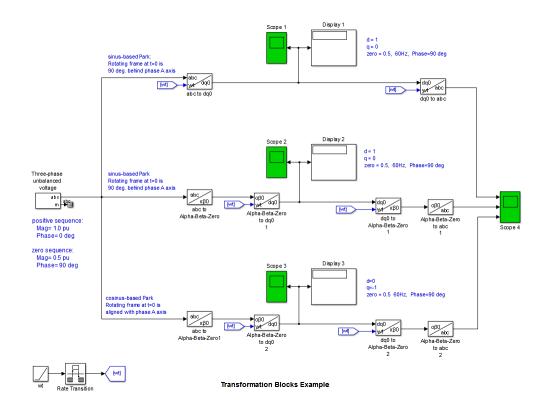
The angular position of the dq rotating frame, in radians.

Example

The power_Transformations example shows various uses of blocks performing Clarke and Park transformations.

Transformation Blocks Example

Introduced in R2013a

abc_to_dq0 Transformation

Perform Park transformation from three-phase (abc) reference frame to dq0 reference frame

Library

powerlib_extras/Measurements, powerlib_extras/Discrete Measurements

Note: The Transformations section of the Control and Measurements library contains the abc to dq0 block. This is an improved version of the abc_to_dq0 Transformation block. The new block features a mechanism that eliminates duplicate continuous and discrete versions of the same block by basing the block configuration on the simulation mode. If your legacy models contain the abc_to_dq0 Transformation block, they continue to work. However, for best performance, use the abc to dq0 block in your new models.

Description

The abc_to_dq0 Transformation block computes the direct axis, quadratic axis, and zero sequence quantities in a two-axis rotating reference frame for a three-phase sinusoidal signal. The following transformation is used:

$$V_d = \frac{2}{3}\left(V_a \sin(\omega t) + V_b \sin(\omega t - 2\pi / 3) + V_c \sin(\omega t + 2\pi / 3)\right)$$

$$V_q = \frac{2}{3}\left(V_a \cos(\omega t) + V_b \cos(\omega t - 2\pi / 3) + V_c \cos(\omega t + 2\pi / 3)\right)$$

$$V_0 = \frac{1}{3}\left(V_a + V_b + V_c\right),$$

where ω = rotation speed (rad/s) of the rotating frame.

The transformation is the same for the case of a three-phase current; you simply replace the V_a, V_b, V_c, V_d, V_q, and V_0 variables with the I_a, I_b, I_c, I_d, I_q, and I_0 variables.

This transformation is commonly used in three-phase electric machine models, where it is known as a Park transformation [1]. It allows you to eliminate time-varying inductances by referring the stator and rotor quantities to a fixed or rotating reference frame. In the case of a synchronous machine, the stator quantities are referred to the rotor. I_d and I_q represent the two DC currents flowing in the two equivalent rotor windings (d winding directly on the same axis as the field winding, and q winding on the quadratic axis), producing the same flux as the stator I_a, I_b, and I_c currents.
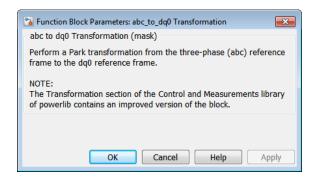
You can use this block in a control system to measure the positive-sequence component V_1 of a set of three-phase voltages or currents. The V_d and V_q (or I_d and I_q) then represent the rectangular coordinates of the positive-sequence component.

You can use the Math Function block and the Trigonometric Function block to obtain the modulus and angle of V_1:

$$|V_1| = \sqrt{V_q^2 + V_d^2}$$
$$\angle V_1 = \operatorname{atan2}\left(V_q \,/\, V_d\right).$$

This measurement system does not introduce any delay, but, unlike the Fourier analysis done in the Sequence Analyzer block, it is sensitive to harmonics and imbalances.

Dialog Box and Parameters

Function Block Parameters: abc_to_dq0 Transformation

abc to dq0 Transformation (mask)

Perform a Park transformation from the three-phase (abc) reference frame to the dq0 reference frame.

NOTE:
The Transformation section of the Control and Measurements library of powerlib contains an improved version of the block.

OK   Cancel   Help   Apply

Inputs and Outputs

abc

> Connect to the first input the vectorized sinusoidal phase signal to be converted [phase A phase B phase C].

sin_cos

> Connect to the second input a vectorized signal containing the [sin(ωt) cos(ωt)] values, where ω is the rotation speed of the reference frame.

dq0
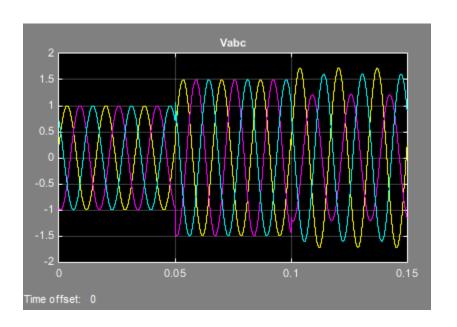
> The output is a vectorized signal containing the three sequence components [d q o], in the same units as the abc input signal.

Example
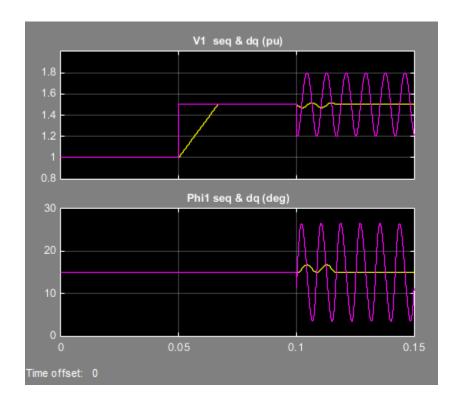
The power_3phsignaldq example uses a Three-Phase Programmable Generator block to generate a 1 pu, 15 degrees positive sequence voltage. At 0.05 second, the positive sequence voltage is increased to 1.5 pu and at 0.1 second an imbalance is introduced by the addition of a 0.3 pu negative sequence component with a phase of −30 degrees. The magnitude and phase of the positive-sequence component are evaluated in two different ways:
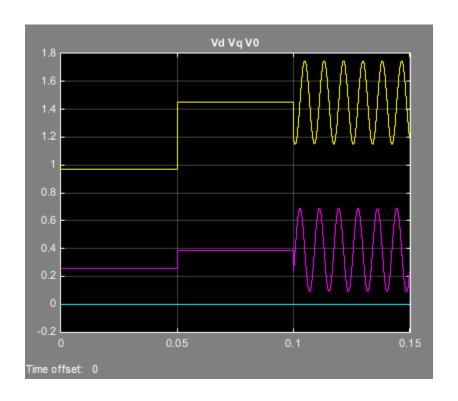
- Sequence calculation of phasors using Fourier analysis
- abc-to-dq0 transformation using the abc to dq0 block (an improved version of the abc_to_dq0 Transformation block).

Start the simulation and observe the instantaneous signals Vabc (Scope1), the signals returned by the Sequence Analyzer (Scope2), and the abc to dq0 (Scope3) blocks.

The Sequence Analyzer, which uses Fourier analysis, is immune to harmonics and imbalance. However, its response to a step is a one-cycle ramp. The abc-to-dq0 transformation is instantaneous. However, an imbalance produces a ripple at the V1 and Phi1 outputs.

References

[1] Krause, P. C. *Analysis of Electric Machinery*. New York: McGraw-Hill, 1994, p.135.

See Also
abc to dq0, dq0 to abc | dq0_to_abc Transformation

Introduced in R2013a

AC Current Source

Implement sinusoidal current source

Library

Fundamental Blocks/Electrical Sources
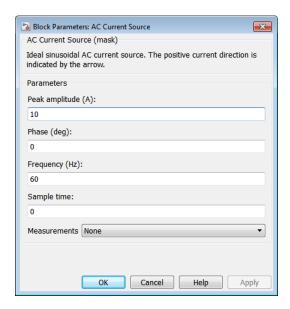
Description

The AC Current Source block implements an ideal AC current source. The positive current direction is indicated by the arrow in the block icon. The generated current I is described by the following relationship:

$$I = A\sin(\omega t + \phi), \quad \omega = 2\pi f, \quad \phi = \text{Phase in radians}.$$

Negative values are allowed for amplitude and phase. A zero frequency and a 90 degree phase specify a DC current source. You cannot enter a negative frequency; the software returns an error in that case, and the block displays a question mark in the block icon. You can modify the first three block parameters at any time during the simulation.

Dialog Box and Parameters

Peak amplitude

The peak amplitude of the generated current, in amperes (A).

Phase

The phase in degrees (deg). Specify a frequency of 0 and a phase of 90 degrees to implement a DC current source.

Frequency

The source frequency in hertz (Hz). Specify a frequency of 0 and a phase of 90 degrees to implement a DC current source.

Sample time

The sample period in seconds (s). The default is 0, corresponding to a continuous source.

Measurements
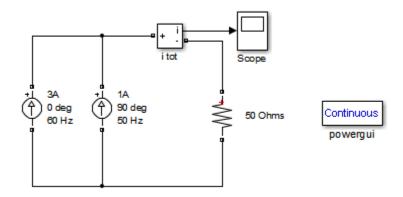
Select Current to measure the current flowing through the AC Current Source block.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurement is identified by a label followed by the block name.

Measurement	Label
Current	Isrc:

Example

The power_accurrent example uses two AC Current Source blocks in parallel to sum two sinusoidal currents in a resistor.

See Also

Controlled Current Source, Multimeter

Introduced before R2006a

1-19

AC1A Excitation System

Implements IEEE type AC1A excitation system model

Library

Fundamental Blocks/Machines/Excitation Systems (sps_avr)

Description
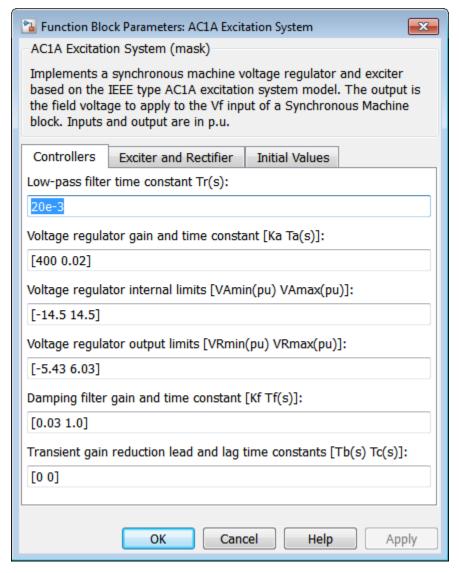
This block models an ac alternator driving a diode rectifier to produce the field voltage Vf required by the Synchronous Machine block. A non-controlled voltage regulator provides a voltage in p.u. with a lower limit of zero imposed by the diode rectifier.

This block is an adaptation of the AC1A excitation system of the IEEE® 421 standard, copyright IEEE 2005, all rights reserved.

Dialog Box and Parameters

- "Controllers Tab" on page 1-22
- "Exciter and Rectifier Tab" on page 1-22

- "Initial Values Tab" on page 1-23

Controllers Tab

Low-pass filter time constant

The time constant Tr of the first-order system representing the stator terminal voltage transducer.

Voltage regulator gain and time constant

The gain Ka and time constant Ta of the first-order system representing the main regulator.

Voltage regulator internal limits

The voltage regulator internal limits VAmin and VAmax, in p.u.

Voltage regulator output limits

The voltage regulator output limits VRmin and VRmax, in p.u.

Damping filter gain and time constant

The gain Kf and time constant Tf of the first-order system representing the derivative feedback.

Transient gain reduction lead and lag time constants

The time constants Tb and Tc of the first-order system representing the lead-lag compensator.

Exciter and Rectifier Tab

Exciter gain and time constant

The gain Ke and time constant Te of the first-order system representing the exciter.

Exciter alternator voltage values

The exciter saturation function is defined as a multiplier of exciter alternator output voltage to represent the increase in exciter excitation requirements due to saturation [1]. The saturation function is determined by specifying two voltage points,Ve1 and Ve2 in p.u., on the air-gap line and no-load saturation curve and providing the corresponding two saturation multipliers SeVe1 and SeVe2.

Typically, the voltage Ve1 is a value near the expected exciter maximum output voltage, Ve2 value is about 75% of Ve1 [1].

Exciter saturation function values

The exciter saturation function is defined as a multiplier of exciter alternator output voltage to represent the increase in exciter excitation requirements due to saturation [1]. The saturation function is determined by specifying two voltage points, Ve1 and Ve2 in p.u., on the air-gap line and no-load saturation curve and providing the corresponding two saturation multipliers SeVe1 and SeVe2.

SeVe1 and SeVe2 multipliers are equal to C-B / B, C is the value of exciter field current on the no-load saturation curve corresponding to the specified Ve voltage, and B is the value of exciter field current on the air-gap line corresponding to the selected Ve voltage [1].

If you do not want to model the saturation effect, set SeVe1 and SeVe2 values to zero.

Demagnetizing factor Kd

The gain Kd represents the demagnetizing factor, a function of exciter alternator reactances.

Rectifier loading factor Kc

The gain Kc represents the rectifier loading factor proportional to the commutating reactance.

Initial Values Tab

Initial values of terminal voltage and field voltage

The initial values of terminal voltage Vt0 and field voltage Efd0, both in p.u. Initial terminal voltage is normally set to 1 pu. The Vt0 and Efd0 values can be determined using the Powergui Load Flow tool.

Sample time

Specify a value greater than zero to discretize the block at the given sample time. Set to -1 to inherit the simulation type and sample time parameters of the Powergui block.

Ports

Vref

The reference value of the stator terminal voltage, in p.u.

Vt

> The measured value in p.u. of the stator terminal voltage of the controlled Synchronous Machine block.

Ifd

> The measured value in p.u. of the stator field current of the controlled Synchronous Machine block.

Vstab

> Connect this input to a power system stabilizer to provide additional stabilization of power system oscillations. When you do not use this option, connect to a Simulink® ground block. The input is in p.u.

Efd

> The field voltage to apply to the Vf input of the controlled Synchronous Machine block. The output is in p.u.

Example

The power_machines example contains a Configurable Subsystem block that allows you to select between seven types of excitation systems to control the terminal voltage of the Synchronous Machine block. This configurable block refers to the power_machines_lib example library that contains seven pretuned excitation system blocks that fit simulation requirements for this example.

Right-click the EXCITATION configurable block, then select **AC1A** from the **Block Choice** menu to control the Synchronous Machine block using the AC1A Excitation System block.

Diesel Engine Governor

wref (pu)
w (pu)

Pmec (pu)

SM

Wm

SM 3.125 MVA

B2
2.4e3V
1pu
-31.89deg.

Transformer
25 kV / 2400V
6 MVA

Circuit Breaker

B1
25e3V
0.9994pu
-0.4332deg.

Torque (N.m)
7964

ASM
2250 HP

Va
ASM terminal voltage

Va (V)

Is_abc

RPM

ASM

1 MW Load

25 kV
1000 MVA

5 MW Load

Three-phase
to ground Fault

Vf

Vref (pu)

sqrt(u(1)^2 + u(2)^2)
sqrt(u(1)^2 + u(2)^2)

Vd Vq

Id Iq

Ifd

Vref AC1A
Vt
It   Efd
Ifd
Uctab
Not implemented

EXCITATION

Continuous
Ideal Switch
No Snubber

powergui

Emergency Diesel-Generator and Asynchronous Motor
Before running this example you need to perform a Load Flow that
initializes the model to start from steady-state.

?

References

[1] "IEEE Recommended Practice for Excitation System Models for Power System Stability Studies." *IEEE Standard*, Vol. 421, No. 5, 2005 (Revision of IEEE 521.5-1992).

Introduced in R2012b

AC4A Excitation System

Implements IEEE type AC4A excitation system model

Library

Fundamental Blocks/Machines/Excitation Systems (sps_avr)

Description
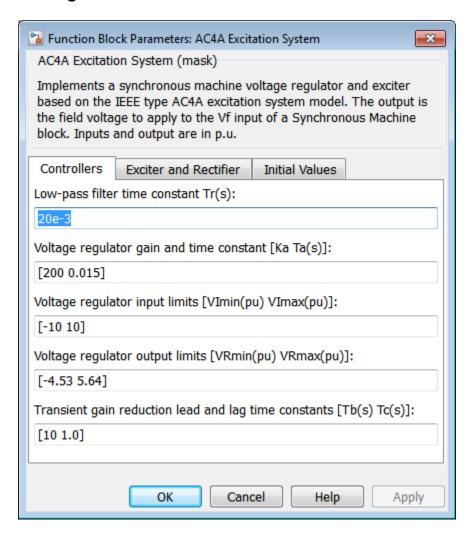
This block models an ac alternator connected to a thyristor rectifier to produce the field voltage Vf required by the Synchronous Machine block. A voltage regulator controls the thyristors and the excitation system stabilization is accomplished by a series lead-lag compensator.

This block is an adaptation of the AC4A excitation system of the IEEE 421 standard, copyright IEEE 2005, all rights reserved.

Dialog Box and Parameters

- "Controllers Tab" on page 1-28
- "Exciter and Rectifier Tab" on page 1-28
- "Initial Values Tab" on page 1-28

Controllers Tab

Low-pass filter time constant

> The time constant Tr of the first-order system representing the stator terminal voltage transducer.

Voltage regulator gain and time constant

> The gain Ka and time constant Ta of the first-order system representing the main regulator.

Voltage regulator input limits

> The voltage regulator input limits VImin and VImax, in p.u.

Voltage regulator output limits

> The voltage regulator output limits VRmin and VRmax, in p.u.

Transient gain reduction lead and lag time constants

> The time constants Tb and Tc of the first-order system representing the lead-lag compensator.

Exciter and Rectifier Tab

Rectifier loading factor Kc

> The gain Kc represents the rectifier loading factor proportional to the commutating reactance.

Initial Values Tab

Initial values of terminal voltage and field voltage

> The initial values of terminal voltage Vt0 and field voltage Efd0, both in p.u. Initial terminal voltage is normally set to 1 pu. The Vt0 and Efd0 values can be determined using the Powergui Load Flow tool.

Sample time

> Specify a value greater than zero to discretize the block at the given sample time. Set to -1 to inherit the simulation type and sample time parameters of the Powergui block.

Ports

Vref

The reference value of the stator terminal voltage, in p.u.

Vt

The measured value in p.u. of the stator terminal voltage of the controlled Synchronous Machine block.

Ifd

The measured value in p.u. of the stator field current of the controlled Synchronous Machine block.

Vstab

Connect this input to a power system stabilizer to provide additional stabilization of power system oscillations. When you do not use this option, connect to a Simulink ground block. The input is in p.u.
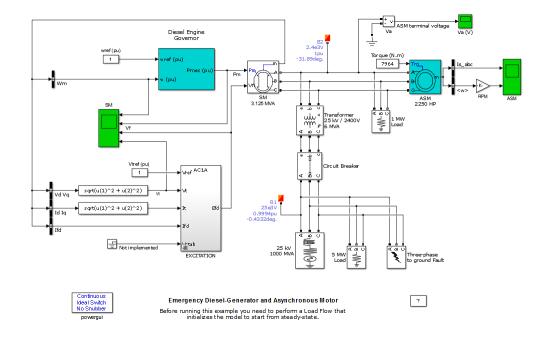
Efd

The field voltage to apply to the Vf input of the controlled Synchronous Machine block. The output is in p.u.

Example

The power_machines example contains a Configurable Subsystem block that allows you to select between seven types of excitation systems to control the terminal voltage of the Synchronous Machine block. This configurable block refers to the power_machines_lib example library that contains seven pretuned excitation system blocks that fit simulation requirements for this example.

Right-click the EXCITATION configurable block, then select **AC4A** from the **Block Choice** menu to control the Synchronous Machine block using the AC4A Excitation System block.

Emergency Diesel-Generator and Asynchronous Motor
Before running this example you need to perform a Load Flow that
initializes the model to start from steady-state.

References

[1] "IEEE Recommended Practice for Excitation System Models for Power System Stability Studies." *IEEE Standard*, Vol. 421, No. 5, 2005 (Revision of IEEE 521.5-1992).
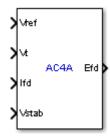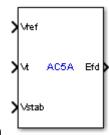
Introduced in R2012b

AC5A Excitation System

Implements IEEE type AC5A excitation system model

Library

Fundamental Blocks/Machines/Excitation Systems (sps_avr)

Description
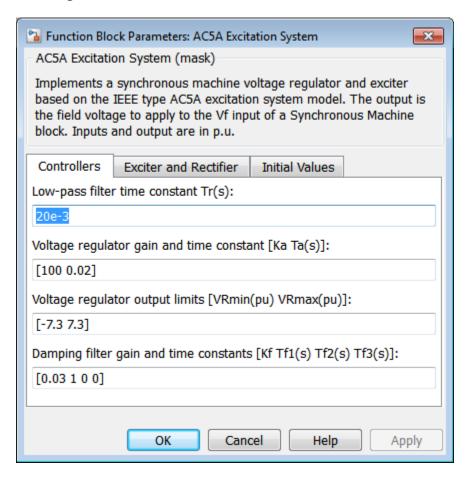
This block models a simplified brushless excitation system where the regulator is supplied from a permanent magnet generator. This model is good to represent simplified systems with rotating rectifiers.

This block is an adaptation of the AC5A excitation system of the IEEE 421 standard, copyright IEEE 2005, all rights reserved.

Dialog Box and Parameters

- "Controllers Tab" on page 1-32
- "Exciter and Rectifier Tab" on page 1-33
- "Initial Values Tab" on page 1-34

Controllers Tab

Low-pass filter time constant

The time constant Tr of the first-order system representing the stator terminal voltage transducer.

Voltage regulator gain and time constant

The gain Ka and time constant Ta of the first-order system representing the main regulator.

Voltage regulator output limits

The voltage regulator output limits VRmin and VRmax, in p.u.

Damping filter gain and time constants

The gain Kf and time constants Tf1, Tf, and Tf3 of the second-order system representing the derivative feedback.

Exciter and Rectifier Tab

Exciter gain and time constant

The gain Ke and time constant Te of the first-order system representing the exciter.

Field voltage values

The exciter saturation function is defined as a multiplier of exciter alternator output voltage to represent the increase in exciter excitation requirements due to saturation [1]. The saturation function is determined by specifying two voltage points, Efd1 and Efd2 in p.u., on the air-gap line and constant resistance load saturation curve and providing the corresponding two saturation multipliers SeEfd1 and SeEfd2.

Typically, the voltage Efd1 is a value near the exciter expected maximum output voltage, Efd2 value is about 75% of Efd1.

Exciter saturation function values

The exciter saturation function is defined as a multiplier of exciter alternator output voltage to represent the increase in exciter excitation requirements due to saturation [1]. The saturation function is determined by specifying two voltage points, Efd1 and Efd2 in p.u., on the air-gap line and Constant Resistance Load saturation curve, and providing the corresponding two saturation multipliers SeEfd1 and SeEfd2.

SeEfd1 and SeEfd2 multipliers are equal to A-B / B, A is the value of exciter field current on the Constant Resistance Load saturation curve corresponding to the selected Efd voltage, and B is the value of exciter field current on the air-gap line corresponding to the selected Efd voltage.

If you do not want to model the saturation effect, set SeVe1 and SeVe2 values to zero.

Initial Values Tab

Initial values of terminal voltage and field voltage

The initial values of terminal voltage Vt0 and field voltage Efd0, both in p.u. Initial terminal voltage is normally set to 1 pu. The Vt0 and Efd0 values can be determined using the Powergui Load Flow tool.

Sample time

Specify a value greater than zero to discretize the block at the given sample time. Set to -1 to inherit the simulation type and sample time parameters of the Powergui block.

Ports

Vref

The reference value of the stator terminal voltage, in p.u.

Vt

The measured value in p.u. of the stator terminal voltage of the controlled Synchronous Machine block.

Vstab

Connect this input to a power system stabilizer to provide additional stabilization of power system oscillations. When you do not use this option, connect to a Simulink ground block. The input is in p.u.
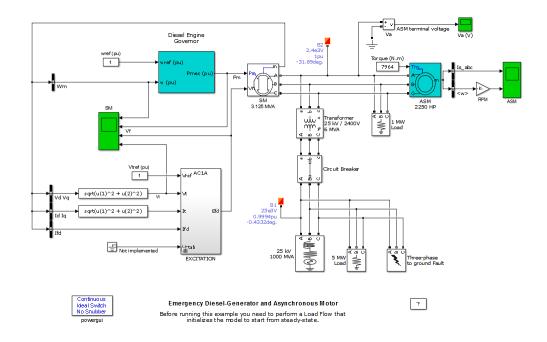
Efd

The field voltage to apply to the `Vf` input of the controlled Synchronous Machine block. The output is in p.u.

Example

The `power_machines` example contains a Configurable Subsystem block that allows you to select between seven types of excitation systems to control the terminal voltage of the Synchronous Machine block. This configurable block refers to the `power_machines_lib` example library that contains seven pretuned excitation system blocks that fit simulation requirements for this example.

Right-click the EXCITATION configurable block, then select **AC5A** from the **Block Choice** menu to control the Synchronous Machine block using the AC5A Excitation System block.

References

[1] "IEEE Recommended Practice for Excitation System Models for Power System Stability Studies." *IEEE Standard*, Vol. 421, No. 5, 2005 (Revision of IEEE 521.5-1992).

Active & Reactive Power

Measure active and reactive powers of voltage-current pair

Library

powerlib_extras/Measurements

A discrete version of this block is available in the powerlib_extras/Discrete Measurements library.

A phasor version of this block is available in the powerlib_extras/Phasor Library.

Note: The Measurements section of the Control and Measurements library contains the Power block. This is an improved version of the Active & Reactive Power block. The new block features a mechanism that eliminates duplicate continuous and discrete versions of the same block by basing the block configuration on the simulation mode. If your legacy models contain the Active & Reactive Power block, they continue to work. However, for best performance, use the Power block in your new models.

Description

The Active & Reactive Power block measures the active power P and reactive power Q associated with a periodic voltage-current pair that can contain harmonics. P and Q are calculated by averaging the V I product with a running average window over one cycle of the fundamental frequency, so that the powers are evaluated at fundamental frequency.

$$P = \frac{1}{T} \int_{t-T}^{t} V(\omega t) \cdot I(\omega t)\, dt$$

$$Q = \frac{1}{T} \int_{t-T}^{t} V(\omega t) \cdot I(\omega t - \pi / 2)\, dt,$$
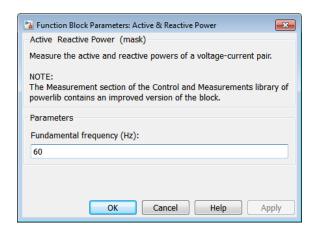
where $T = 1$/(fundamental frequency).

A current flowing into an RL branch, for example, produces positive active and reactive powers.

As this block uses a running window, one cycle of simulation has to be completed before the output gives the correct active and reactive powers.

The discrete version of this block, available in the powerlib_extras/Discrete Measurements library, allows you to specify the initial input voltage and current (magnitude and phase). For the first cycle of simulation, the outputs are held constant using the values specified by the initial input parameters.

Dialog Box and Parameters

Fundamental frequency (Hz)

The fundamental frequency, in hertz, of the instantaneous voltage and current.

Inputs and Outputs

V

The first input is the instantaneous voltage, in volts.

I
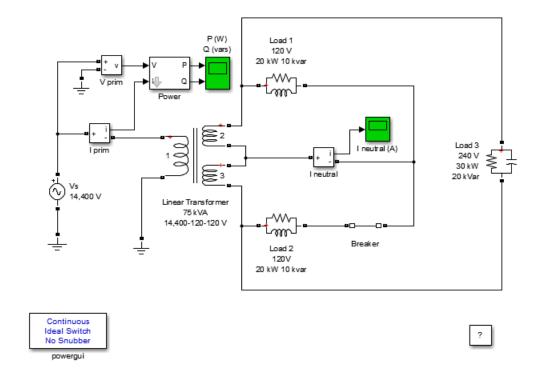
The second input is the instantaneous current, in amperes.

PQ

The output is a vector [P Q] of the active and reactive powers, in watts and vars, respectively.

Example
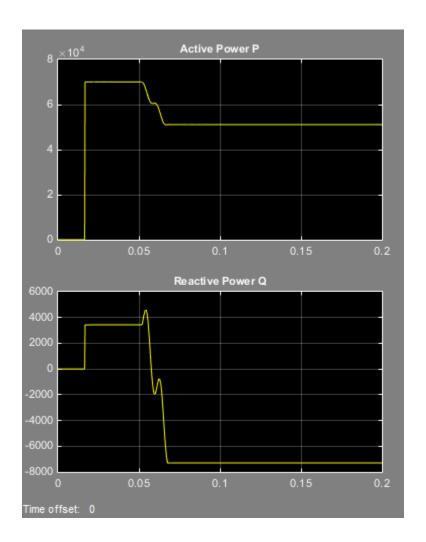
The power_transfo example simulates a three-winding distribution transformer rated at 75 kVA:14400/120/120 V. The transformer primary winding is connected to a high-voltage source of 14400 Vrms. Two identical inductive loads (20 kW-10 kvar) are connected to the two secondary windings. A third capacitive load (30 kW-20 kvar) is fed at 240 V.

Initially, the circuit breaker in series with Load 2 is closed, so that the system is balanced. When the circuit breaker opens, a current starts to flow in the neutral path as a result of the load imbalance.

The active power computed from the primary voltage and current is measured by a Power block (the improved version of the Active & Reactive Powerblock). When the breaker opens, the active power decreases from 70 kW to 50 kW.

See Also
Power
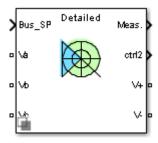
Active Rectifier

Implement three-phase active (PWM) rectifier model for AC motor drives

Library

Electric Drives/Fundamental Drives
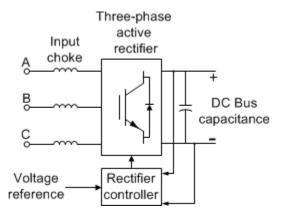
Description
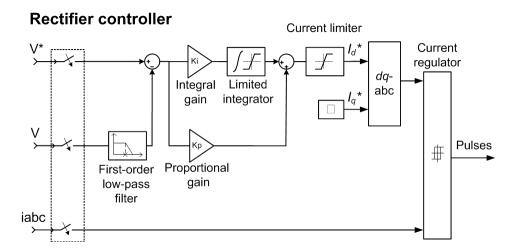
The Active Rectifier block models a standard three-leg (three-phase) PWM rectifier with a controller for regulating the DC bus voltage and AC line currents. It has two operating modes to represent a detailed or an average-value rectifier.

Detailed Mode

In detailed mode, the block is modeled by a Universal Bridge block configured as a three-arm, forced-commutated converter. The rectifier controller is based on a PI regulator connected to the DC bus voltage, as shown in the figure.

The output of this regulator is the direct, that is, active, component of the AC line current. The reactive component of the AC line current is set to zero to operate at unity power factor.
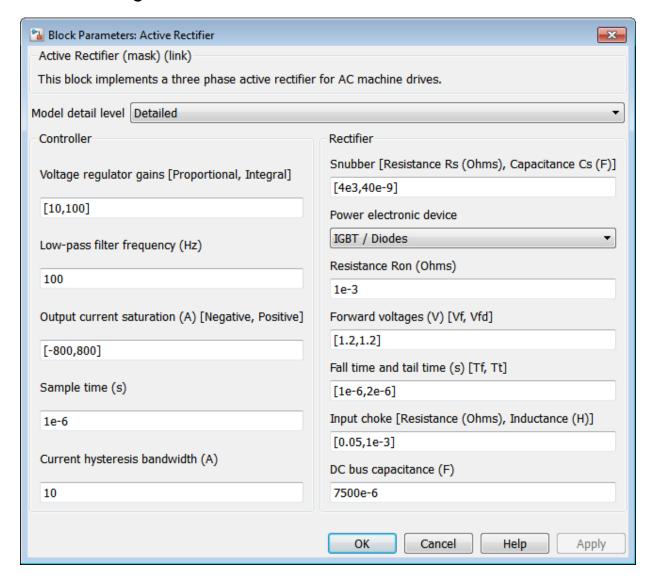
Rectifier controller

The dq-abc block performs the conversion of the dq current components into abc phase variables. The current regulator is a bang-bang current controller with adjustable hysteresis bandwidth.

Average Mode

Average mode allows fast simulations when the high frequency switching actions of the switches are not required. In average mode, the Active Rectifier block models an equivalent average-value model for three-phase inverters. Refer to the Inverter (Three-Phase) block model of the Electric Drives library for more details. The current regulator in the rectifier controller block generates three-level signals (-1, 0, 1), indicating if the average-value PWM rectifier model is supplied by a negative, zero, or positive line voltage (Vab and Vbc). In detailed mode, the rectifier controller block outputs the actual pulses for the rectifier switches.

Dialog Box and Parameters

Block Parameters: Active Rectifier

Active Rectifier (mask) (link)

This block implements a three phase active rectifier for AC machine drives.

Model detail level [Detailed ▼]

Controller

Voltage regulator gains [Proportional, Integral]

[10,100]

Low-pass filter frequency (Hz)

100

Output current saturation (A) [Negative, Positive]

[-800,800]

Sample time (s)

1e-6

Current hysteresis bandwidth (A)

10

Rectifier

Snubber [Resistance Rs (Ohms), Capacitance Cs (F)]

[4e3,40e-9]

Power electronic device

[IGBT / Diodes ▼]

Resistance Ron (Ohms)

1e-3

Forward voltages (V) [Vf, Vfd]

[1.2,1.2]

Fall time and tail time (s) [Tf, Tt]

[1e-6,2e-6]

Input choke [Resistance (Ohms), Inductance (H)]

[0.05,1e-3]

DC bus capacitance (F)

7500e-6

[OK] [Cancel] [Help] [Apply]

Model detail level

Specify the model detail level to use:

- `Detailed` (default)
- `Average`

Voltage regulator gain [Proportional, Integral]

The DC bus voltage controller proportional and integral gains. The default value is `[10,100]`.

Low-pass filter frequency (Hz)

The DC bus voltage measurement low-pass filter cutoff frequency, in hertz. The default value is `100`.

Output current saturation (A) [Negative, Positive]

The DC bus voltage controller maximum negative and positive output, in amperes. The default value is `[-800,800]`.
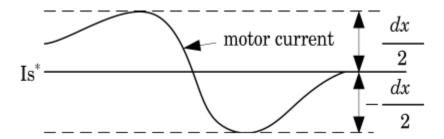
Sample time(s)

The DC bus voltage controller sampling time, in seconds. The sampling time must be a multiple of the simulation time step. The default value is `1e-6`.

Current hysteresis bandwidth A

The current regulator hysteresis bandwidth, in amperes. This value is the total hysteresis bandwidth distributed symmetrically around the current set point. The figure shows a case in which the current set point is Is* and the current regulator hysteresis bandwidth is set to dx.

This parameter is available only when the **Model detail level** parameter is set to `Detailed`. The default value is `10`.

Snubber [Resistance Rs (Ohms), Capacitance Cs (F)]

The value of the snubber resistance and capacitance of the rectifier. The default value is `[4e3,40e-9]`.

Power electronic device

Specify the type of power electronic device to use in the rectifier:

- `IGBT / Diodes` (default)
- `MOSFET / Diodes`
- `GTO / Diodes`

Resistance Ron (Ohms)

Internal resistance of the selected device, in ohms. The default value is `1e-3`.

Forward voltages (V) [Vf, Vfd]

Forward voltages of the forced-commutated devices (IGBT, MOSFET, or GTO) and of the antiparallel diodes, in volts. The default value is `[1.2,1.2]`.

Fall time and tail time (s) [Tf, Tt]

Fall time Tf and tail time Tt, in seconds, for the GTO or the IGBT devices. The default value is `[1e-6,2e-6]`.

Input choke [Resistance (Ohms), Inductance (H)]

The input choke resistance, in ohms, and inductance, in hertz. The default value is `[0.05,1e-3]`.

DC bus capacitance (F)

The DC bus capacitance, in farad. The default value is `7500e-6`.

Inputs and Outputs

`Bus_SP`

DC bus voltage reference, in volts.

`Va, Vb, Vc`

Three-phase terminals on the AC side.

`Meas`

Vector of three measurement signals: DC bus voltage, DC bus current before the DC bus capacitance, and DC bus current after the DC bus capacitance.

`crtl2`

Vector of three measurement signals: *d*-axis current reference, DC bus voltage error, and DC bus voltage reference.

`V+`

Positive terminal on the DC side.

`V-`

Negative terminal on the DC side.

Examples

The Active Rectifier block is used in the AC5 block of the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also
`DC Bus`

More About
· "Electric Drives Library"

Introduced in R2015b

AC Voltage Source

Implement sinusoidal voltage source

Library

Fundamental Blocks/Electrical Sources
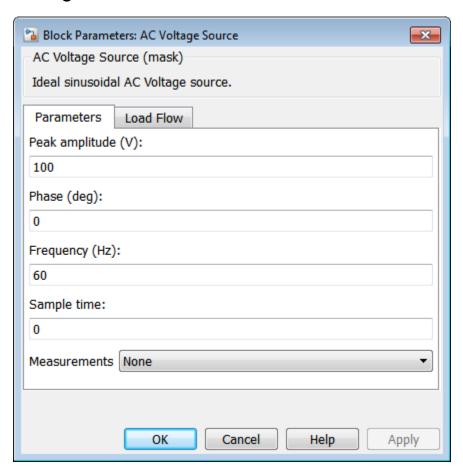
Description

The AC Voltage Source block implements an ideal AC voltage source. The generated voltage U is described by the following relationship:

$$U = A\sin(\omega t + \phi), \quad \omega = 2\pi f, \quad \phi = \text{Phase in radians.}$$

Negative values are allowed for amplitude and phase. A frequency of 0 and phase equal to 90 degrees specify a DC voltage source. Negative frequency is not allowed; otherwise the software signals an error, and the block displays a question mark in the block icon.

Dialog Box and Parameters

Parameters Tab

Peak amplitude

  The peak amplitude of the generated voltage, in volts (V).

Phase

  The phase in degrees (deg).

Frequency

The source frequency in hertz (Hz).

Sample time

The sample period in seconds (s). The default is 0, corresponding to a continuous source.

Measurements

Select Voltage to measure the voltage across the terminals of the AC Voltage Source block.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurement is identified by a label followed by the block name.

Measurement	Label
Voltage	Usrc:

Load Flow Tab

The Load Flow tool of the powergui block uses the parameters on this tab. These load flow parameters affect only model initialization. They do not affect simulation.

The configuration of the **Load Flow** tab depends on the option selected for the **Generator type** parameter.

Generator type

Specify the generator type of the voltage source. The default value is swing.

Select swing to implement a generator controlling the magnitude and phase angle of its terminal voltage. Specify the reference voltage magnitude and angle in the **Swing bus or PV bus voltage** and **Swing bus voltage angle** parameters of the Load Flow Bus block connected to the voltage source terminals.

Select PV to implement a generator controlling its output active power P and voltage magnitude V. Specify P in the **Active power generation P** parameter of the block. Specify V in the **Swing bus or PV bus voltage** parameter of the Load Flow Bus block connected to the voltage source terminals. You can control the minimum and maximum reactive power generated by the block by using the **Minimum reactive power Qmin** and **Maximum reactive power Qmax** parameters.

Select PQ to implement a generator controlling its output active power P and reactive power Q. Specify P and Q in the **Active power generation P** and **Reactive power generation Q** parameters of the block, respectively.

Active power generation P

Specify the desired active power generated by the source, in watts. This parameter is available if you specify **Generator type** as PV or PQ.

Reactive power generation Q

Specify the desired reactive power generated by the source, in vars. This parameter is available only if you specify **Generator type** as PQ.

Minimum reactive power Qmin

This parameter is available only if you specify **Generator type** as PV. This parameter indicates the minimum reactive power the source can generate while keeping the terminal voltage at its reference value. Specify the reference voltage as the **Swing bus or PV bus voltage** parameter of the Load Flow Bus block connected to the source terminals. The default value is -inf, which means that there is no lower limit on the reactive power output.

Maximum reactive power Qmax

This parameter is available only if you specify **Generator type** as PV. This parameter indicates the maximum reactive power the source can generate while keeping the terminal voltage at its reference value. Specify the reference voltage with the **Swing bus or PV bus voltage** parameter of the Load Flow Bus block connected to the source terminals. The default value is inf, which means that there is no upper limit on the reactive power output.

Examples

The power_acvoltage example uses two AC Voltage Source blocks at different frequencies connected in series across a resistor. The sum of the two voltages is read by a Voltage Measurement block.

See Also

Controlled Voltage Source, DC Voltage Source, Multimeter

Introduced before R2006a

Alpha-Beta-Zero to dq0, dq0 to Alpha-Beta-Zero

Perform transformation from αβ0 stationary reference frame to dq0 rotating reference frame or the inverse

Library

Control and Measurements/Transformations

Description
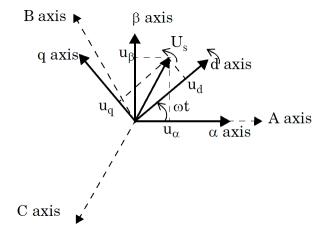
The Alpha-Beta-Zero to dq0 block performs a transformation of αβ0 Clarke components in a fixed reference frame to dq0 Park components in a rotating reference frame.

The dq0 to Alpha-Beta-Zero block performs a transformation of dq0 Park components in a rotating reference frame to αβ0 Clarke components in a fixed reference frame.

The block supports the two conventions used in the literature for Park transformation:

- Rotating frame aligned with A axis at t = 0. This type of Park transformation is also known as the cosinus-based Park transformation.
- Rotating frame aligned 90 degrees behind A axis. This type of Park transformation is also known as the sinus-based Park transformation. Use it in SimPowerSystems models of three-phase synchronous and asynchronous machines.

Knowing that the position of the rotating frame is given by ω.t (where ω represents the frame rotation speed), the αβ0 to dq0 transformation performs a −(ω.t) rotation on the space vector $U_s = u_\alpha + j \cdot u_\beta$. The homopolar or zero-sequence component remains unchanged.

Depending on the frame alignment at t = 0, the dq0 components are deduced from αβ0 components as follows:

When the rotating frame is aligned with A axis, the following relations are obtained:

$$U_s = u_d + j \cdot u_q = \left(u_\alpha + j \cdot u_\beta \right) \cdot e^{-j\omega t}$$

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & \sin(\omega t) & 0 \\ -\sin(\omega t) & \cos(\omega t) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u_\alpha \\ u_\beta \\ u_0 \end{bmatrix}$$

The inverse transformation is given by

$$u_\alpha + j \cdot u_\beta = \left(u_d + j \cdot u_q \right) \cdot e^{j\omega t}$$

$$\begin{bmatrix} u_\alpha \\ u_\beta \\ u_0 \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & -\sin(\omega t) & 0 \\ \sin(\omega t) & \cos(\omega t) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u_d \\ uq \\ u_0 \end{bmatrix}$$

When the rotating frame is aligned 90 degrees behind A axis, the following relations are obtained:

$$U_s = u_d + j \cdot u_q = \left(u_\alpha + j \cdot u_\beta \right) \cdot e^{-j\left(\omega t - \frac{\pi}{2} \right)}$$

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = \begin{bmatrix} \sin(\omega t) & -\cos(\omega t) & 0 \\ \cos(\omega t) & \sin(\omega t) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix}$$

The inverse transformation is given by

$$u_\alpha + j \cdot u_\beta = \left(u_d + j \cdot u_q\right) \cdot e^{j\left(\omega t - \frac{\pi}{2}\right)}$$

The abc-to-Alpha-Beta-Zero transformation applied to a set of balanced three-phase sinusoidal quantities u_a, u_b, u_c produces a space vector U_s whose u_α and u_β coordinates in a fixed reference frame vary sinusoidally with time. In contrast, the abc-to-dq0 transformation (Park transformation) applied to a set of balanced three-phase sinusoidal quantities u_a, u_b, u_c produces a space vector U_s whose u_d and u_q coordinates in a dq rotating reference frame stay constant.

Dialog Box and Parameters

Rotating frame alignment (at wt=0)

Select the alignment of rotating frame, when wt = 0, of the dq0 components of a three-phase balanced signal:

$$u_a = \sin(\omega t); \; u_b = \sin\left(\omega t - \frac{2\pi}{3}\right); \; u_c = \sin\left(\omega t + \frac{2\pi}{3}\right)$$

(positive-sequence magnitude = 1.0 pu; phase angle = 0 degree)

When you select `Aligned with phase A axis`, the dq0 components are d = 0, q = −1, and zero = 0.

When you select `90 degrees behind phase A axis`, the dq0 components are d = 1, q = 0, and zero = 0.

Inputs and Outputs

αβ0

The vectorized αβ0 signal.

dq0

The vectorized dq0 signal.

wt

The angular position, in radians, of the dq rotating frame relative to the stationary frame.

Example

The power_Transformations example shows various uses of blocks performing Clarke and Park transformations.
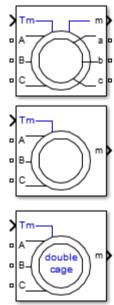
Introduced in R2013a

Asynchronous Machine

Model the dynamics of three-phase asynchronous machine, also known as induction machine

Library

Fundamental Blocks/Machines
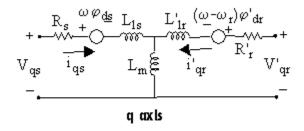
Description

The Asynchronous Machine block implements a three-phase asynchronous machine (wound rotor, single squirrel-cage, or double squirrel-cage). It operates in either generator or motor mode. The mode of operation is dictated by the sign of the mechanical torque:

- If Tm is positive, the machine acts as a motor.
- If Tm is negative, the machine acts as a generator.

The electrical part of the machine is represented by a fourth-order (or sixth-order for the double squirrel-cage machine) state-space model, and the mechanical part by a second-order system. All electrical variables and parameters are referred to the stator, indicated by the prime signs in the following machine equations. All stator and rotor quantities are in the arbitrary two-axis reference frame (dq frame). The subscripts used are defined in this table.
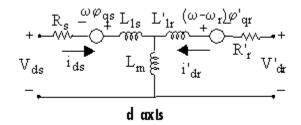
Subscript	Definition
d	d axis quantity
q	q axis quantity
r	Rotor quantity (wound-rotor or single-cage)
r1	Cage 1 rotor quantity (double-cage)
r2	Cage 2 rotor quantity (double-cage)
s	Stator quantity
l	Leakage inductance
m	Magnetizing inductance

Electrical System of the Wound-Rotor or Squirrel-Cage Machine

q axis

$$V_{qs} = R_s i_{qs} + d\varphi_{qs}/dt + \omega\varphi_{ds}$$

$$V_{ds} = R_s i_{ds} + d\varphi_{ds}/dt - \omega\varphi_{qs}$$

$$V'_{qr} = R'_r i'_{qr} + d\varphi'_{qr}/dt + (\omega - \omega_r)\varphi'_{dr}$$

$$V'_{dr} = R'_r i'_{dr} + d\varphi'_{dr}/dt - (\omega - \omega_r)\varphi'_{qr}$$

$$T_e = 1.5p(\varphi_{ds}i_{qs} - \varphi_{qs}i_{ds})$$

d axis

ω — Reference frame angular velocity

ω_r — Electrical angular velocity

$$\varphi_{qs} = L_s i_{qs} + L_m i'_{qr}$$

$$\varphi_{ds} = L_s i_{ds} + L_m i'_{dr}$$
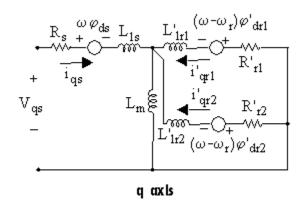
$$\varphi'_{qr} = L'_r i'_{qr} + L_m i_{qs}$$

$$\varphi'_{dr} = L'_r i'_{dr} + L_m i_{ds}$$
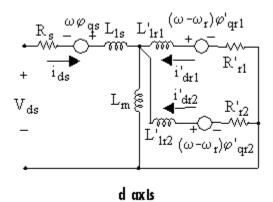
$$L_s = L_{ls} + L_m$$

$$L'_r = L'_{lr} + L_m$$

Electrical System of the Double Squirrel-Cage Machine

q axis

$$V_{qs} = R_s i_{qs} + d\varphi_{qs}/dt + \omega\varphi_{ds}$$

$$V_{ds} = R_s i_{ds} + d\varphi_{ds}/dt - \omega\varphi_{qs}$$

$$0 = R'_{r1} i'_{qr1} + d\varphi'_{qr1}/dt + (\omega - \omega_r)\varphi'_{dr1}$$

$$0 = R'_{r1} i'_{dr1} + d\varphi'_{dr1}/dt - (\omega - \omega_r)\varphi'_{qr1}$$

$$0 = R'_{r2} i'_{qr2} + d\varphi'_{qr2}/dt + (\omega - \omega_r)\varphi'_{dr2}$$

$$0 = R'_{r2} i'_{dr2} + d\varphi'_{dr2}/dt - (\omega - \omega_r)\varphi'_{qr2}$$

$$T_e = 1.5p(\varphi_{ds} i_{qs} - \varphi_{qs} i_{ds})$$

d axis

$$\varphi_{qs} = L_s i_{qs} + L_m(i'_{qr1} + i'_{qr2})$$

$$\varphi_{ds} = L_s i_{ds} + L_m(i'_{dr1} + i'_{dr2})$$

$$\varphi'_{qr1} = L'_{r1} i'_{qr1} + L_m i_{qs}$$

$$\varphi'_{dr1} = L'_{r1} i'_{dr1} + L_m i_{ds}$$

$$\varphi'_{qr2} = L'_{r2} i'_{qr2} + L_m i_{qs}$$

$$\varphi'_{dr2} = L'_{r2} i'_{dr2} + L_m i_{ds}$$

$$L_s = L_{ls} + L_m$$

$$L'_{r1} = L'_{lr1} + L_m$$

$$L'_{r2} = L'_{lr2} + L_m$$

Mechanical System

$$\frac{d}{dt}\omega_m = \frac{1}{2H}(T_e - F\omega_m - T_m)$$

$$\frac{d}{dt}\theta_m = \omega_m$$

The Asynchronous Machine block parameters are defined as follows (all quantities are referred to the stator).
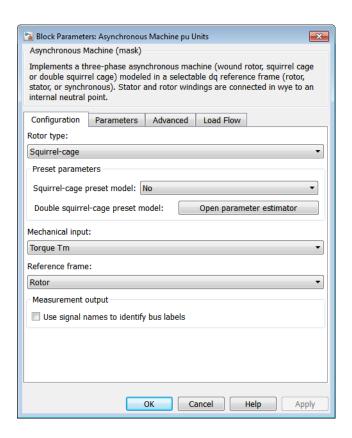
Parameters Common to All Models	Definition
R_s, L_{ls}	Stator resistance and leakage inductance
L_m	Magnetizing inductance
L_s	Total stator inductance
V_{qs}, i_{qs}	q axis stator voltage and current
V_{ds}, i_{ds}	d axis stator voltage and current
ϕ_{qs}, ϕ_{ds}	Stator q and d axis fluxes
ω_m	Angular velocity of the rotor
Θ_m	Rotor angular position
p	Number of pole pairs
ω_r	Electrical angular velocity ($\omega_m \times p$)
Θ_r	Electrical rotor angular position ($\Theta_m \times p$)
T_e	Electromagnetic torque
T_m	Shaft mechanical torque
J	Combined rotor and load inertia coefficient. Set to infinite to simulate locked rotor.
H	Combined rotor and load inertia constant. Set to infinite to simulate locked rotor.
F	Combined rotor and load viscous friction coefficient

Parameters Specific to Single-Cage or Wound Rotor	Definition
L'_r	Total rotor inductance
R'_r, L'_{lr}	Rotor resistance and leakage inductance
V'_{qr}, i'_{qr}	q axis rotor voltage and current
V'_{dr}, i'_{dr}	d axis rotor voltage and current
ϕ'_{qr}, ϕ'_{dr}	Rotor q and d axis fluxes

Parameters Specific to Double-Cage Rotor	Definition
R'_{r1}, L'_{lr1}	Rotor resistance and leakage inductance of cage 1
R'_{r2}, L'_{lr2}	Rotor resistance and leakage inductance of cage 2
L'_{r1}, L'_{r2}	Total rotor inductances of cage 1 and 2
i'_{qr1}, i'_{qr2}	q axis rotor current of cage 1 and 2
i'_{dr1}, i'_{dr2}	d axis rotor current of cage 1 and 2
ϕ'_{qr1}, ϕ'_{dr1}	q and d axis rotor fluxes of cage 1
ϕ'_{qr2}, ϕ'_{dr2}	q and d axis rotor fluxes of cage 2

Dialog Box and Parameters
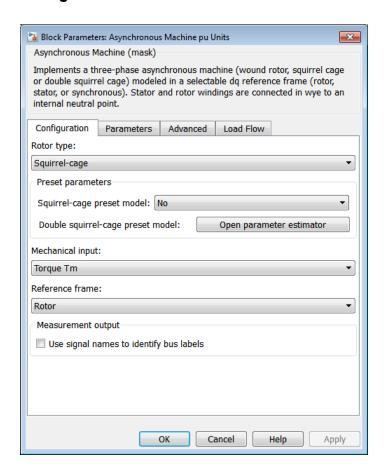
You can choose between two Asynchronous Machine blocks to specify the electrical and mechanical parameters of the model, by using the pu Units dialog box or the SI dialog box. Both blocks are modeling the same asynchronous machine model.

- "Configuration Tab" on page 1-65
- "Parameters Tab" on page 1-70
- "Advanced Tab" on page 1-73
- "Load Flow Tab" on page 1-74

Configuration Tab

Rotor type

Specifies the type of rotor: Wound, Squirrel-cage, or Double squirrel-cage.

Squirrel-cage preset model

For single squirrel-cage machines, provides a set of predetermined electrical and mechanical parameters for various asynchronous machine ratings of power (HP), phase-to-phase voltage (V), frequency (Hz), and rated speed (rpm). To make this parameter available, set the **Rotor type** parameter to Squirrel-cage and click **Apply**.

Select one of the preset models to load the corresponding electrical and mechanical parameters in the entries of the dialog box. The preset models do not include predetermined saturation parameters.

Select No if you do not want to use a preset model, or if you want to modify some of the parameters of a preset model.

When you select a preset model, the electrical and mechanical parameters in the **Parameters** tab of the dialog box become nonmodifiable (unavailable). To start from a given preset model and then modify machine parameters:

1 Select the preset model that you want to initialize the parameters.

2 Change the **Preset model** parameter value to No. This does not change the machine parameters. By doing so, you just break the connection with the particular preset model.

3 Modify the machine parameters as you want, then click **Apply**.

Double squirrel-cage preset model

Click **Open parameter estimator** to open an interface to the power_AsynchronousMachineParams function that gives you access to preset models for double-cage asynchronous machines.

Mechanical input

Select the torque applied to the shaft or the rotor speed as a Simulink input of the block, or to represent the machine shaft by a Simscape™ rotational mechanical port.

Select **Torque Tm** to specify a torque input, in N.m or in pu, and change labeling of the block input to Tm. The machine speed is determined by the machine Inertia J (or inertia constant H for the pu machine) and by the difference between the applied mechanical torque Tm and the internal electromagnetic torque Te. The sign convention for the mechanical torque is: when the speed is positive, a positive torque signal indicates motor mode and a negative signal indicates generator mode.

Select **Speed w** to specify a speed input, in rad/s or in pu, and change labeling of the block input to w. The machine speed is imposed and the mechanical part of the model (Inertia J) is ignored. Using the speed as the mechanical input allows modeling a mechanical coupling between two machines.

The next figure indicates how to model a stiff shaft interconnection in a motor-generator set when friction torque is ignored in machine 2. The speed output of

machine 1 (motor) is connected to the speed input of machine 2 (generator), while machine 2 electromagnetic torque output Te is applied to the mechanical torque input Tm of machine 1. The Kw factor takes into account speed units of both machines (pu or rad/s) and gear box ratio w2/w1. The KT factor takes into account torque units of both machines (pu or N.m) and machine ratings. Also, as the inertia J2 is ignored in machine 2, J2 referred to machine 1 speed must be added to machine 1 inertia J1.

Select **Mechanical rotational port** to add to the block a Simscape mechanical rotational port that allows connection of the machine shaft with other Simscape blocks having mechanical rotational ports. The Simulink input representing the mechanical torque Tm or the speed w of the machine is then removed from the block.

The next figure indicates how to connect an Ideal Torque Source block from the Simscape library to the machine shaft to represent the machine in motor mode, or in generator mode, when the rotor speed is positive.

Reference frame

> Specifies the reference frame that is used to convert input voltages (abc reference frame) to the dq reference frame, and output currents (dq reference frame) to the abc reference frame. You can choose among the following reference frame transformations:
>
> - `Rotor` (Park transformation)
> - `Stationary` (Clarke or αβ transformation)
> - `Synchronous`
>
> The following relationships describe the abc-to-dq reference frame transformations applied to the Asynchronous Machine phase-to-phase voltages.

$$\begin{bmatrix} V_{qs} \\ V_{ds} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2\cos\theta & \cos\theta + \sqrt{3}\sin\theta \\ 2\sin\theta & \sin\theta - \sqrt{3}\cos\theta \end{bmatrix} \begin{bmatrix} V_{abs} \\ V_{bcs} \end{bmatrix}$$

$$\begin{bmatrix} V'_{qr} \\ V'_{dr} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2\cos\beta & \cos\beta + \sqrt{3}\sin\beta \\ 2\sin\beta & \sin\beta - \sqrt{3}\cos\beta \end{bmatrix} \begin{bmatrix} V'_{abr} \\ V'_{bcr} \end{bmatrix}.$$

In the preceding equations, Θ is the angular position of the reference frame, while $\beta = \theta - \theta_r$ is the difference between the position of the reference frame and the position (electrical) of the rotor. Because the machine windings are connected in a three-wire Y configuration, there is no homopolar (0) component. This configuration also justifies that two line-to-line input voltages are used inside the model instead of three line-to-neutral voltages. The following relationships describe the dq-to-abc reference frame transformations applied to the Asynchronous Machine phase currents.

$$\begin{bmatrix} i_{as} \\ i_{bs} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ \dfrac{-\cos\theta + \sqrt{3}\sin\theta}{2} & \dfrac{-\sqrt{3}\cos\theta - \sin\theta}{2} \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \end{bmatrix}$$

$$\begin{bmatrix} i'_{ar} \\ i'_{br} \end{bmatrix} = \begin{bmatrix} \cos\beta & \sin\beta \\ \dfrac{-\cos\beta + \sqrt{3}\sin\beta}{2} & \dfrac{-\sqrt{3}\cos\beta - \sin\beta}{2} \end{bmatrix} \begin{bmatrix} i'_{qr} \\ i'_{dr} \end{bmatrix}$$

$$i_{cs} = -i_{as} - i_{bs}$$

$$i'_{cr} = -i'_{ar} - i'_{br}.$$

The following table shows the values taken by Θ and β in each reference frame (Θ_e is the position of the synchronously rotating reference frame).

Reference Frame	Θ	β
Rotor	Θ_r	0
Stationary	0	$-\Theta_r$
Synchronous	Θ_e	$\Theta_e - \Theta_r$

The choice of reference frame affects the waveforms of all dq variables. It also affects the simulation speed and in certain cases the accuracy of the results. The following guidelines are suggested in [1]:

- Use the stationary reference frame if the stator voltages are either unbalanced or discontinuous and the rotor voltages are balanced (or 0).
- Use the rotor reference frame if the rotor voltages are either unbalanced or discontinuous and the stator voltages are balanced.
- Use either the stationary or synchronous reference frames if all voltages are balanced and continuous.
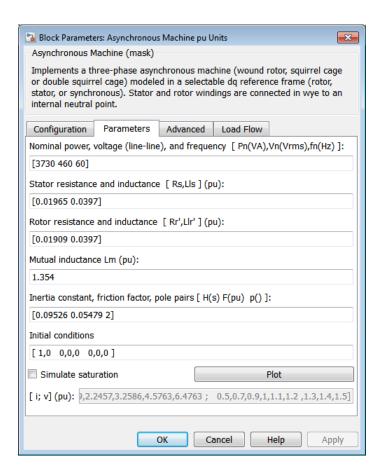
Use signal names to identify bus labels

> When this check box is selected, the measurement output uses the signal names to identify the bus labels. Select this option for applications that require bus signal labels to have only alphanumeric characters.
>
> When this check box is cleared, the measurement output uses the signal definition to identify the bus labels. The labels contain nonalphanumeric characters that are incompatible with some Simulink applications.

Parameters Tab

This tab contains the electrical parameters of the machine. To estimate the electrical parameters of a double-cage asynchronous machine based on standard manufacturer specifications, you can use the `power_AsynchronousMachineParams` function.

Nominal power, voltage (line-line), and frequency

The nominal apparent power Pn (VA), RMS line-to-line voltage Vn (V), and frequency fn (Hz).

Stator resistance and inductance

The stator resistance Rs (Ω or pu) and leakage inductance Lls (H or pu).

Rotor resistance and inductance

The rotor resistance Rr' (Ω or pu) and leakage inductance Llr' (H or pu), both referred to the stator. This parameter is visible only when the **Rotor type** parameter on the **Configuration** tab is set to Wound or Squirrel-cage.

Cage 1 resistance and inductance

The rotor resistance Rr1' (Ω or pu) and leakage inductance Llr1' (H or pu), both referred to the stator. This parameter is visible only when the **Rotor type** parameter on the **Configuration** tab is set to `Double squirrel-cage`.

Cage 2 resistance and inductance

The rotor resistance Rr2' (Ω or pu) and leakage inductance Llr2' (H or pu), both referred to the stator. This parameter is visible only when the **Rotor type** parameter on the **Configuration** tab is set to `Double squirrel-cage`.

Mutual inductance

The magnetizing inductance Lm (H or pu).

Inertia constant, friction factor, and pole pairs

For the **SI units** dialog box: the combined machine and load inertia coefficient J (kg.m^2), combined viscous friction coefficient F (N.m.s), and pole pairs p. The friction torque Tf is proportional to the rotor speed ω (Tf = F.w).

For the **pu units** dialog box: the inertia constant H (s), combined viscous friction coefficient F (pu), and pole pairs p.

Initial conditions

Specifies the initial slip s, electrical angle Θe (degrees), stator current magnitude (A or pu), and phase angles (degrees):

`[slip, th, i`$_{as}$`, i`$_{bs}$`, i`$_{cs}$`, phase`$_{as}$`, phase`$_{bs}$`, phase`$_{cs}$`]`

If the **Rotor type** parameter is set to `Wound`, you can also specify optional initial values for the rotor current magnitude (A or pu), and phase angles (degrees):

`[slip, th, i`$_{as}$`, i`$_{bs}$`, i`$_{cs}$`, phase`$_{as}$`, phase`$_{bs}$`, phase`$_{cs}$`, i`$_{ar}$`, i`$_{br}$`, i`$_{cr}$`, phase`$_{ar}$`, phase`$_{br}$`, phase`$_{cr}$`]`

When the **Rotor type** parameter is set to `Squirrel-cage`, the initial conditions can be computed by the Load Flow tool or the Machine Initialization tool in the Powergui block.

Simulate saturation

Specifies whether magnetic saturation of the rotor and stator iron is simulated or not.

[i;v] (pu)
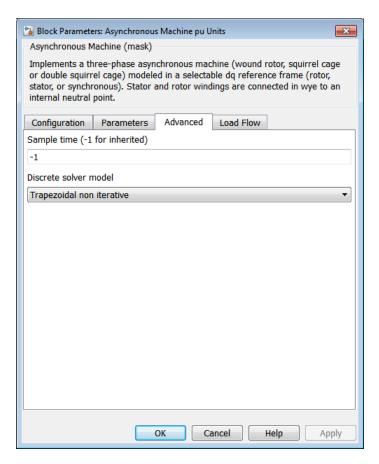
Specifies the no-load saturation curve parameters. Magnetic saturation of the stator and rotor iron (saturation of the mutual flux) is modeled by a piecewise linear relationship specifying points of the no-load saturation curve. The first row of this

matrix contains the values of stator currents. The second row contains values of corresponding terminal voltages (stator voltages). The first point (first column of the matrix) must be different from [0,0]. This point corresponds to the point where the effect of saturation begins.

You must select the **Simulate saturation** check box to simulate saturation. If you do not select the **Simulate saturation** check box, the relationship between the stator current and the stator voltage is linear.

Click **Plot** to view the specified no-load saturation curve.

Advanced Tab

Block Parameters: Asynchronous Machine pu Units

Asynchronous Machine (mask)

Implements a three-phase asynchronous machine (wound rotor, squirrel cage or double squirrel cage) modeled in a selectable dq reference frame (rotor, stator, or synchronous). Stator and rotor windings are connected in wye to an internal neutral point.

| Configuration | Parameters | Advanced | Load Flow |

Sample time (-1 for inherited)

-1

Discrete solver model

Trapezoidal non iterative

OK   Cancel   Help   Apply

Sample time (−1 for inherited)

Specifies the sample time used by the block. To inherit the sample time specified in the Powergui block, set this parameter to `-1`.

Discrete solver model
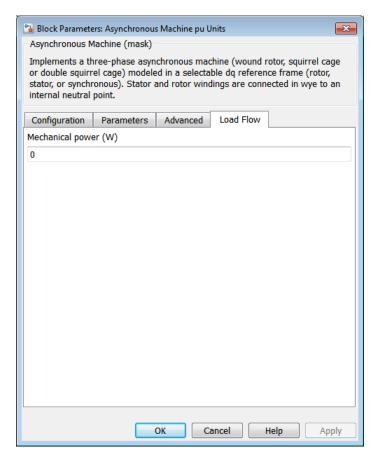
Specifies the integration method used by the block when the **Solver type** parameter of the Powergui block is set to `Discrete`. The choices are: `Forward Euler` (default), `Trapezoidal non iterative`, and `Trapezoidal iterative (alg. loop)`.

For more information on what method you should use in your application, see Simulating Discretized Electrical Systems.

Load Flow Tab

The parameters on this tab are used by the Load Flow tool of the powergui block. These load flow parameters are used for model initialization only. They have no impact on the block model or on the simulation performance.

Mechanical power (W)

> Specify the mechanical power applied to the machine shaft, in watts. When the machine operates in motor mode, specify a positive value. When the machine operates in generator mode, specify a negative value.

Inputs and Outputs

The stator terminals of the Asynchronous Machine block are identified by the letters A, B, and C. The rotor terminals are identified by the letters a, b, and c. The neutral connections of the stator and rotor windings are not available; three-wire Y connections are assumed.

Tm

>The Simulink input of the block is the mechanical torque at the machine's shaft. When the input is a positive Simulink signal, the asynchronous machine behaves as a motor. When the input is a negative signal, the asynchronous machine behaves as a generator.
>
>When you use the SI parameters mask, the input is a signal in N.m, otherwise it is in pu.

w

>The alternative block input (depending on the value of the **Mechanical input** parameter) is the machine speed. When you use the SI parameters mask, the input is a signal in rad/s or in pu.

m
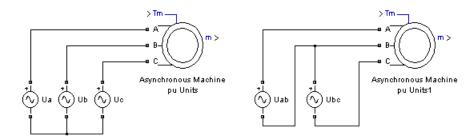
>The Simulink output of the block is a vector containing measurement signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library. Depending on the type of mask that you use, the units are in SI or in pu. The cage 2 rotor signals return null signal when the **Rotor type** parameter on the **Configuration** tab is set to Wound or Squirrel-cage.

Name	Definition	Units
iar	Rotor current ir_a	A or pu
ibr	Rotor current ir_b	A or pu
icr	Rotor current ir_c	A or pu
iqr	Rotor current iq	A or pu
idr	Rotor current id	A or pu
phiqr	Rotor flux phir_q	V.s or pu
phidr	Rotor flux phir_d	V.s or pu
vqr	Rotor voltage Vr_q	V or pu
vdr	Rotor voltage Vr_d	V or pu
iar2	Cage 2 rotor current ir_a	A or pu
ibr2	Cage 2 rotor current ir_b	A or pu
icr2	Cage 2 rotor current ir_c	A or pu
iqr2	Cage 2 rotor current iq	A or pu
idr2	Cage 2 rotor current id	A or pu

Name	Definition	Units
phiqr2	Cage 2 rotor flux phir_q	V.s or pu
phidr2	Cage 2 rotor flux phir_d	V.s or pu
ias	Stator current is_a	A or pu
ibs	Stator current is_b	A or pu
ics	Stator current is_c	A or pu
iqs	Stator current is_q	A or pu
ids	Stator current is_d	A or pu
phiqs	Stator flux phis_q	V.s or pu
phids	Stator flux phis_d	V.s or pu
vqs	Stator voltage vs_q	V or pu
vds	Stator voltage vs_d	V or pu
w	Rotor speed	rad/s
Te	Electromagnetic torque Te	N.m or pu
theta	Rotor angle thetam	rad

Limitations

- The Asynchronous Machine block does not include a representation of the saturation of leakage fluxes. You must be careful when you connect ideal sources to the machine's stator. If you choose to supply the stator via a three-phase Y-connected infinite voltage source, you must use three sources connected in Y. However, if you choose to simulate a delta source connection, you must use only two sources connected in series.

- When you use Asynchronous Machine blocks in discrete systems, you might have to use a small parasitic resistive load, connected at the machine terminals, to avoid numerical oscillations. Large sample times require larger loads. The optimum resistive load is proportional to the sample time. Remember that with a 25 µs time step on a 60 Hz system, the minimum load is approximately 2.5% of the machine nominal power. For example, a 200 MVA asynchronous machine in a power system discretized with a 50 µs sample time requires approximately 5% of resistive load or 10 MW. If the sample time is reduced to 20 µs, a resistive load of 4 MW is sufficient.

Examples

Example 1: Use of the Asynchronous Machine Block in Motor Mode
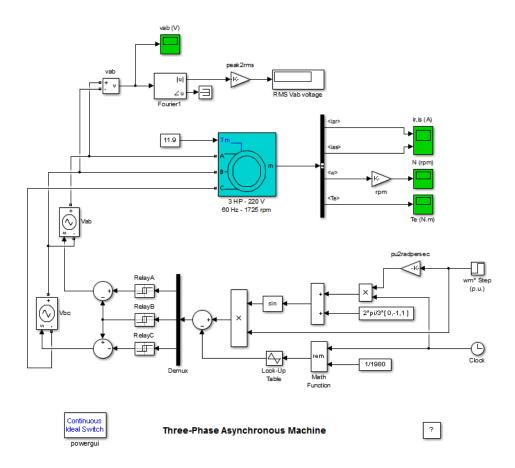
The power_pwm example illustrates the use of the Asynchronous Machine block in motor mode. It consists of an asynchronous machine in an open-loop speed control system.

The machine rotor is short-circuited, and the stator is fed by a PWM inverter, built with Simulink blocks and interfaced to the Asynchronous Machine block through the Controlled Voltage Source block. The inverter uses sinusoidal pulse-width modulation. The base frequency of the sinusoidal reference wave is set at 60 Hz and the triangular carrier wave frequency is set at 1980 Hz. This frequency corresponds to a frequency modulation factor m_f of 33 (60 Hz x 33 = 1980).
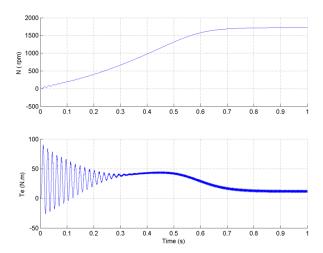
The 3 HP machine is connected to a constant load of nominal value (11.9 N.m). It is started and reaches the set point speed of 1.0 pu at t = 0.9 second.

The parameters of the machine are those found in the preceding **SI Units** dialog box above, except for the stator leakage inductance, which is set to twice its normal value to simulate a smoothing inductor placed between the inverter and the machine. Also, the stationary reference frame was used to obtain the results shown.

Open the `power_pwm` example. In the simulation parameters, a small relative tolerance is required because of the high switching rate of the inverter.
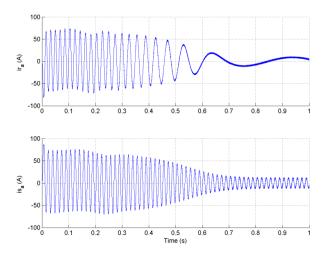
Run the simulation and observe the machine's speed and torque.
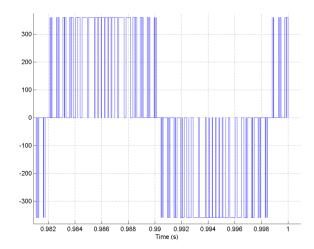
The first graph shows the machine's speed going from 0 to 1725 rpm (1.0 pu). The second graph shows the electromagnetic torque developed by the machine. Because the stator is fed by a PWM inverter, a noisy torque is observed.

However, this noise is not visible in the speed because it is filtered out by the machine's inertia, but it can be seen in the stator and rotor currents.
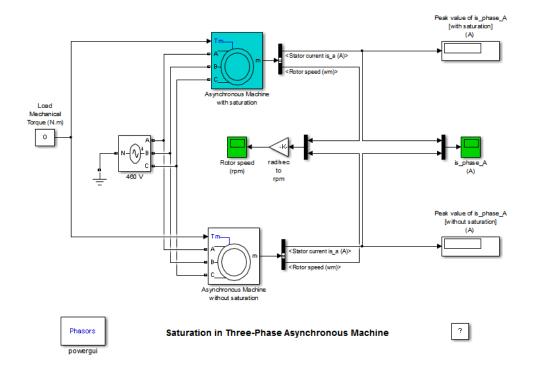
Look at the output of the PWM inverter. Because nothing of interest can be seen at the simulation time scale, the graph concentrates on the last moments of the simulation.

Example 2: Effect of Saturation of the Asynchronous Machine Block

The `power_asm_sat` example illustrates the effect of saturation of the Asynchronous Machine block.

Saturation in Three-Phase Asynchronous Machine
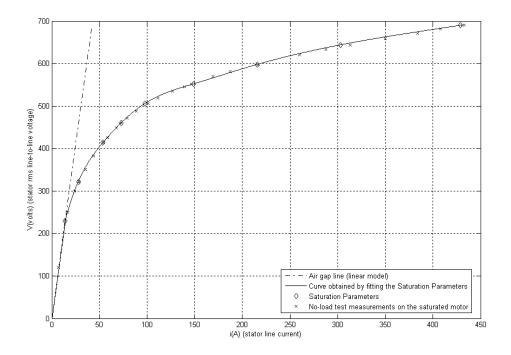
Two identical three-phase motors (50 HP, 460 V, 1800 rpm) are simulated, with and without saturation, to observe the saturation effects on the stator currents. Two different simulations are realized in the example.

The first simulation is the no-load steady-state test. This table contains the values of the **Saturation Parameters** and the measurements obtained by simulating different operating points on the saturated motor (no-load and in steady-state).

Saturation Parameters		Measurements	
Vsat (Vrms L-L)	Isat (peak A)	Vrms L-L	Is_A (peak A)
-	-	120	7.322
230	14.04	230	14.03
-	-	250	16.86
-	-	300	24.04

Saturation Parameters		Measurements	
Vsat (Vrms L-L)	Isat (peak A)	Vrms L-L	Is_A (peak A)
322	27.81	322	28.39
-	-	351	35.22
-	-	382	43.83
414	53.79	414	54.21
-	-	426	58.58
-	-	449	67.94
460	72.69	460	73.01
-	-	472	79.12
-	-	488	88.43
506	97.98	506	100.9
-	-	519	111.6
-	-	535	126.9
-	-	546	139.1
552	148.68	552	146.3
-	-	569	169.1
-	-	581	187.4
598	215.74	598	216.5
-	-	620	259.6
-	-	633	287.8
644	302.98	644	313.2
-	-	659	350
-	-	672	383.7
-	-	681	407.9
690	428.78	690	432.9

The next graph illustrates these results and shows the accuracy of the saturation model. The measured operating points fit well the curve that is plotted from the **Saturation Parameters** data.

You can observe the other effects of saturation on the stator currents by running the simulation with a blocked rotor or with many different values of load torque.

References

[1] Krause, P.C., O. Wasynczuk, and S.D. Sudhoff, *Analysis of Electric Machinery, IEEE Press,* 2002.

[2] Mohan, N., T.M. Undeland, and W.P. Robbins, *Power Electronics: Converters, Applications, and Design*, John Wiley & Sons, Inc., New York, 1995, Section8.4.1.

See Also

Powergui
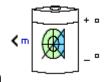
Introduced before R2006a

Battery

Implement generic battery model

Library

Electric Drives/Extra Sources
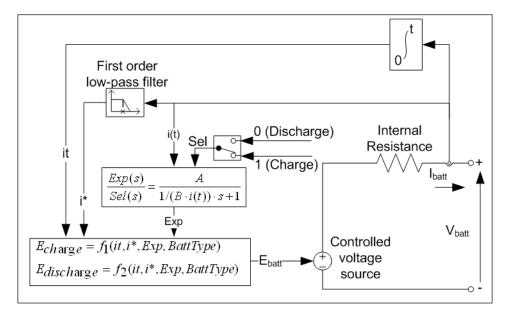
Description

The Battery block implements a generic dynamic model parameterized to represent most popular types of rechargeable batteries.

The equivalent circuit of the battery is shown below:

Lead-Acid Model

Discharge model (i* > 0)

$$f_1\left(it, i^*, i, Exp\right) = E_0 - K \cdot \frac{Q}{Q - it} \cdot i^* - K \cdot \frac{Q}{Q - it} \cdot it + \mathrm{Laplace}^{-1}\left(\frac{Exp(s)}{Sel(s)} \cdot 0\right).$$

Charge Model (i* < 0)

$$f_2\left(it, i^*, i, Exp\right) = E_0 - K \cdot \frac{Q}{it + 0.1 \cdot Q} \cdot i^* - K \cdot \frac{Q}{Q - it} \cdot it + \mathrm{Laplace}^{-1}\left(\frac{Exp(s)}{Sel(s)} \cdot \frac{1}{s}\right).$$

Lithium-Ion Model

Discharge Model (i* > 0)

$$f_1\left(it, i^*, i\right) = E_0 - K \cdot \frac{Q}{Q - it} \cdot i^* - K \cdot \frac{Q}{Q - it} \cdot it + A \cdot \exp(-B \cdot it).$$

Charge Model (i* < 0)

$$f_2\left(it, i^*, i\right) = E_0 - K \cdot \frac{Q}{it + 0.1 \cdot Q} \cdot i^* - K \cdot \frac{Q}{Q - it} \cdot it + A \cdot \exp(-B \cdot it).$$

Nickel-Cadmium and Nickel-Metal-Hydride Model

Discharge Model (i* > 0)

$$f_1\left(it, i^*, i, Exp\right) = E_0 - K \cdot \frac{Q}{Q - it} \cdot i^* - K \cdot \frac{Q}{Q - it} \cdot it + \mathrm{Laplace}^{-1}\left(\frac{Exp(s)}{Sel(s)} \cdot 0\right).$$

Charge Model (i* < 0)

$$f_2\left(it, i^*, i, Exp\right) = E_0 - K \cdot \frac{Q}{|it| + 0.1 \cdot Q} \cdot i^* - K \cdot \frac{Q}{Q - it} \cdot it + \mathrm{Laplace}^{-1}\left(\frac{Exp(s)}{Sel(s)} \cdot \frac{1}{s}\right),$$

where,

E_{Batt} = Nonlinear voltage (V)

E_0 = Constant voltage (V)

Exp(s) = Exponential zone dynamics (V)

Sel(s) = Represents the battery mode. Sel(s) = 0 during battery discharge, Sel(s) = 1 during battery charging.

K = Polarization constant (Ah^{-1}) or Polarization resistance (Ohms)

i* = Low frequency current dynamics (A)

i = Battery current (A)

it = Extracted capacity (Ah)
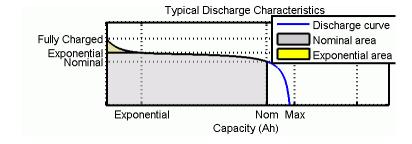
Q = Maximum battery capacity (Ah)

A = Exponential voltage (V)

B = Exponential capacity $(Ah)^{-1}$
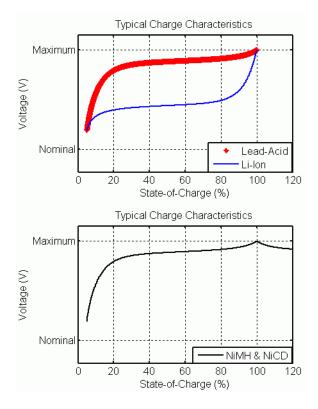
Charge and Discharge Characteristics

The parameters of the equivalent circuit can be modified to represent a particular battery type, based on its discharge characteristics. A typical discharge curve is composed of three sections, as shown in the next figure:
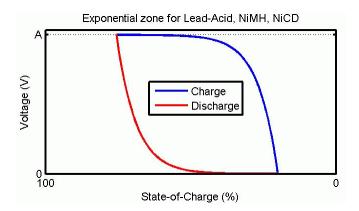
The first section represents the exponential voltage drop when the battery is charged. Depending on the battery type, this area is more or less wide. The second section represents the charge that can be extracted from the battery until the voltage drops below the battery nominal voltage. Finally, the third section represents the total discharge of the battery, when the voltage drops rapidly.

When the battery current is negative, the battery will recharge following a charge characteristic as shown below:

Typical Charge Characteristics

Typical Charge Characteristics

Note that the parameters of the model are deduced from discharge characteristics and assumed to be the same for charging.

The Exp(s) transfer function represents the hysteresis phenomenon for the Lead-Acid, NiCD and NiMH batteries during charge and discharge cycles. The exponential voltage increases when battery is charging, no matter the SOC of the battery. When the battery is discharging, the exponential voltage decreases immediately:

Exponential zone for Lead-Acid, NiMH, NiCD

Temperature Effect

For the lithium-ion battery type, the impact of temperature on the model parameters is represented by the equations

Discharge Model (i* > 0)

$$f_1(it,i*,i,T,T_a) = E_0(T) - K(T) \cdot \frac{Q(T_a)}{Q(T_a) - it} \cdot (i* + it) + A \cdot \exp(-B \cdot it) - C \cdot it$$

$$V_{batt}(T) = f_1(it,i*,i,T,T_a) - R(T) \cdot i$$

Charge Model (i* < 0)

$$f_1(it,i*,i,T,T_a) = E_0(T) - K(T) \cdot \frac{Q(T_a)}{it + 0.1 \cdot Q(T_a)} \cdot i* - K(T) \cdot \frac{Q(T_a)}{Q(T_a) - it} \cdot it + A \cdot \exp(-B \cdot it) - C \cdot i$$

$$V_{batt}(T) = f_1(it,i*,i,T,T_a) - R(T) \cdot i,$$

with

$$E_0(T) = E_0 \Big|_{T_{ref}} + \frac{\partial E}{\partial T}(T - T_{ref})$$

$$K(T) = K\big|_{T_{ref}} \cdot \exp\left(\alpha \left(\frac{1}{T} - \frac{1}{T_{ref}} \right) \right)$$

$$Q(T_a) = Q\big|_{T_a} + \frac{\Delta Q}{\Delta T} \cdot \left(T_a - T_{ref} \right)$$

$$R(T) = R\big|_{T_{ref}} \cdot \exp\left(\beta \left(\frac{1}{T} - \frac{1}{T_{ref}} \right) \right),$$

where:

T_{ref} = Nominal ambient temperature (K)

T = Cell or internal temperature (K)

T_a = Ambient temperature (K)

E/T = Reversible voltage temperature coefficient (*V*/*K*)

α = Arrhenius rate constant for the polarization resistance

β = Arrhenius rate constant for the internal resistance

$\Delta Q/\Delta T$ = Maximum capacity temperature coefficient (Ah/*K*)

C = Nominal discharge curve slope (*V*/Ah). For lithium-ion batteries with less pronounced discharge curves (such as lithium iron phosphate batteries), this parameter is set to zero.

The cell or internal temperature (T) at any given time (t) is expressed as:

$$T(t) = L^{-1}\left(\frac{P_{loss} R_{th} + T_a}{1 + s \cdot t_c} \right),$$

where:
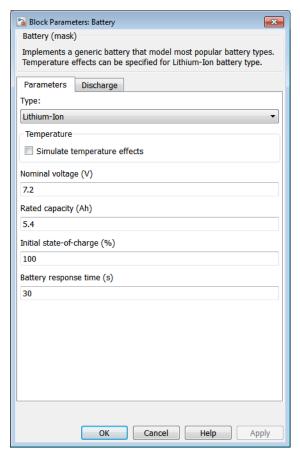
R_{th} = Thermal resistance, cell to ambient (°C/W)

t_c = Thermal time constant, cell to ambient (s)

P_{loss} is the overall heat generated (W) during charge/discharge process and is given by

$$P_{loss} = \left(E_0(T) - V_{batt}(T)\right) \cdot i + \frac{\partial E}{\partial T} \cdot i \cdot T.$$

Dialog Box and Parameters

- "Parameters Tab" on page 1-93
- "Discharge Tab" on page 1-94
- "Temperature Tab" on page 1-96

Parameters Tab

Type

Provides a set of predetermined charge behavior for four types of battery:

- `Lead-Acid`
- `Lithium-Ion`
- `Nickel-Cadmium`
- `Nickel-Metal-Hydride`

Simulate temperature effects

When you select this parameter, the **Temperature** tab becomes visible and displays the thermal model parameters. The Ta input port becomes visible to supply the ambient temperature. The **Simulate temperature effects** parameter is visible only if the **Type** parameter is set to `Lithium-Ion`.

Use a preset battery

The parameter contains a list of 10 predetermined temperature parameters of typical lithium-ion batteries. The parameters in the **Temperature** tab are not accessible when a preset is selected. The **Use a preset battery** parameter is visible only if the **Type** parameter is set to `Lithium-Ion` and **Simulate temperature effects** is selected.

Nominal Voltage (V)

The nominal voltage (*Vnom*) of the battery (volts). The nominal voltage represents the end of the linear zone of the discharge characteristics.

Rated Capacity (Ah)

The rated capacity (*Qrated*) of the battery in ampere-hour. The rated capacity is the minimum effective capacity of the battery.
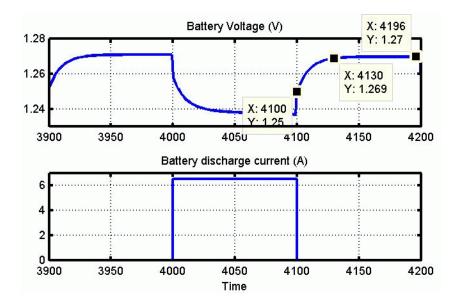
Initial State-Of-Charge (%)

The initial State-Of-Charge (SOC) of the battery. 100% indicates a fully charged battery and 0% indicates an empty battery. This parameter is used as an initial condition for the simulation and does not affect the discharge curve (when the option **Plot Discharge Characteristics** is used).

Battery response time (s)

The response time of the battery (at 95% of the final value).

This value represents the voltage dynamics and can be observed when a current step is applied:

In this example, a battery response time of 30 secs is used.

Discharge Tab

Determined from the nominal parameters of the battery

Load the corresponding parameters in the entries of the dialog box, depending on the selected **Type**, the **Nominal Voltage** and the **Rated Capacity**.

When a preset model is used, the detailed parameters cannot be modified. If you want to modify the discharge curve, select the desired battery type to load the default parameters, and then uncheck the **Determined from the nominal parameters of the battery** checkbox to access the detailed parameters.

Maximum Capacity (Ah)

The maximum theoretical capacity (Q), when a discontinuity occurs in the battery voltage. This value is generally equal to 105% of the rated capacity.

Fully charged Voltage (V)

The fully charged voltage (*Vfull*), for a given discharge current. Note that the fully charged voltage is not the no-load voltage.

Nominal discharge current (A)

The nominal discharge current, for which the discharge curve has been measured. For example, a typical discharge current for a 1.5 Ah NiMH battery is 20% of the rated capacity: (0.2 * 1.5 Ah / 1h = 0.3A).

Internal Resistance

The internal resistance of the battery (ohms). When a preset model is used, a generic value is loaded, corresponding to 1% of the nominal power (nominal voltage * rated capacity of the battery). The resistance is supposed to be constant during the charge and the discharge cycles and does not vary with the amplitude of the current.

Capacity (Ah) @ Nominal Voltage
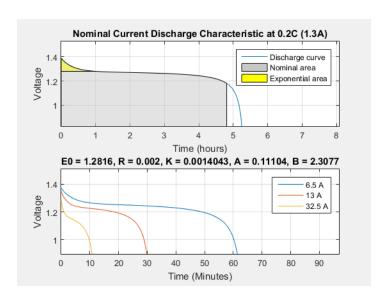
The capacity (*Qnom*) extracted from the battery until the voltage drops under the nominal voltage. This value should be between *Qexp* and *Qmax*.

Exponential zone [Voltage (V), Capacity (Ah)]

The voltage (*Vexp*) and the capacity (*Qexp*) corresponding to the end of the exponential zone. The voltage should be between *Vnom* and *Vfull*. The capacity should be between 0 and *Qnom*.

Plot

Plots a figure containing two graphs. The first graph represents the nominal discharge curve (at the **Nominal Discharge Current**) and the second graph represents the discharge curves at the specified discharge currents.

Discharge current

Allows to specify different values of discharge current. The discharge characteristics for these currents are presented in the second part of the graph.

Units

Choose either `Time` or `Ampere-hour` as the *x*-axis for the plot.

Temperature Tab

This tab is visible only when the **Type** parameter is set to `Lithium-Ion` and **Simulate temperature effect** is selected.

Initial cell temperature

The initial cell or internal temperature of the battery, in Celsius.

Nominal ambient temperature T1

The ambient temperature, in Celsius, at nominal condition of operation. It is assumed that all parameters provided in the **Parameters** tab are obtained at this ambient temperature.

Second ambient temperature T2

The ambient temperature, in Celsius, at a second operating condition, preferably below the nominal ambient temperature.

Maximum capacity

The maximum battery capacity, in amperes hour, at the second ambient temperature.

Initial discharge voltage

The initial discharge voltage at the second ambient temperature, in volts, immediately when the discharge current is applied.

Voltage at 90% maximum capacity

The discharge voltage, in volts, when 90% of the maximum capacity is used, at second ambient temperature.

Exponential zone

The discharge voltage, in volts, and the capacity, in amperes hour, corresponding to the end of the exponential zone, at the second ambient temperature.

Thermal resistance, cell-to-ambient
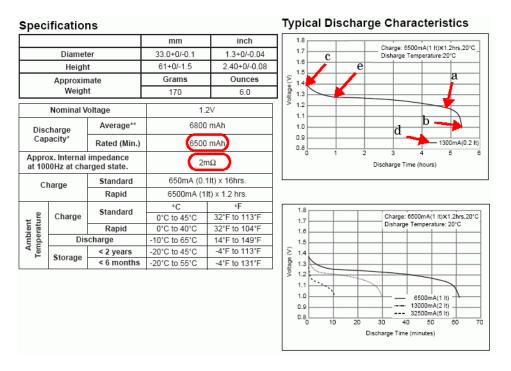
The total thermal resistance, in °C/W, between the cell and ambient points of measurement. It is assumed the cell temperature is equivalent to the average internal temperature of the battery.

Thermal time constant, cell-to-ambient

The temperature response time constant, in seconds, between the cell and ambient points of measurement. You can obtain this value from the ambient temperature step response while the battery is in idle mode.

Extract Battery Parameters From Data Sheets

This section gives an example of detailed parameters extracted from the Panasonic NiMH-HHR650D battery data sheet:

Specifications

		mm	inch
Diameter		33.0+0/-0.1	1.3+0/-0.04
Height		61+0/-1.5	2.40+0/-0.08
Approximate Weight		Grams	Ounces
		170	6.0

Nominal Voltage		1.2V
Discharge Capacity*	Average**	6800 mAh
	Rated (Min.)	6500 mAh
Approx. Internal impedance at 1000Hz at charged state.		2mΩ
Charge	Standard	650mA (0.1lt) x 16hrs.
	Rapid	6500mA (1lt) x 1.2 hrs.

		°C	°F
Ambient Temperature	Charge	Standard	0°C to 45°C	32°F to 113°F
		Rapid	0°C to 40°C	32°F to 104°F
	Discharge		-10°C to 65°C	14°F to 149°F
	Storage	< 2 years	-20°C to 45°C	-4°F to 113°F
		< 6 months	-20°C to 55°C	-4°F to 131°F

Typical Discharge Characteristics

From the specification tables, we obtain the rated capacity and the internal resistance. The other detailed parameters are deduced from the Typical Discharge Characteristics plot:

Parameter	Value
Rated capacity	6.5 Ah
Internal Resistance	2 mΩ
Nominal Voltage [a]	1.18 V
Rated Capacity	6.5 Ah
Maximum Capacity [b]	7 Ah (5.38 h * 1.3A)
Fully Charged voltage [c]	1.39 V
Nominal Discharge Current [d]	1.3 A
Capacity @ Nominal Voltage [a]	6.25 Ah
Exponential Voltage [e]	1.28 V
Exponential Capacity [e]	1.3 Ah

These parameters are approximate and depend on the precision of the points obtained from the discharge curve. A tool, called ScanIt (provided by amsterCHEM, http://www.amsterchem.com) can be used to extract values from data sheet curves.

The discharge curves (the dotted line curves in the following plots) obtained with these parameters are similar to the data sheet curves.

E0 = 1.2816, R = 0.002, K = 0.0014043, A = 0.11104, B = 2.3077

Charge: 6500mA(1 It)✕1.2hrs,20˚C
Disharge Temperature:20˚C

——— 1300mA(0.2 It)

E0 = 1.2816, R = 0.002, K = 0.0014043, A = 0.11104, B = 2.3077

Charge: 6500mA(1 It)✕1.2hrs,20˚C
Disharge Temperature: 20˚C

——— 6500mA(1 It)
········· 13000mA(2 It)
- - - 32500mA(5 It)
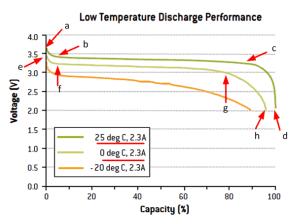
To represent temperature effects of lithium-ion battery type, an additional discharge curve at ambient temperature different from the nominal temperature is required along with the thermal response parameters. The latter are not usually provided on the battery data sheet and may require simple experiments. The following examples show parameters extracted from the A123 Li-iron-phosphate ANR26650M1 and the Panasonic Li-cobalt-oxide CGR 18650 AF battery data sheets.

The figure shows the A123 ANR26650M1 data sheet specifications, which includes the required discharge curve points, along with other required parameters.

Specifications

Nominal capacity and voltage	2.3 Ah, 3.3 V
Internal impedance (1kHz AC)	8 mΩ typical
Internal resistance (10A, 1s DC)	10 mΩ typical
Recommended standard charge method	3A to 3.6V CCCV, 45 min
Recommended fast charge current	10A to 3.6V CCCV, 15 min
Maximum continuous discharge	70A
Pulse discharge at 10 sec	120A
Cycle life at 10C discharge, 100% DOD	Over 1,000 cycles
Recommended pulse charge/discharge cutoff	3.8V to 1.6V
Operating temperature range	-30°C to +60°C
Storage temperature range	-50°C to +60°C
Core cell weight	70 grams

Low Temperature Discharge Performance
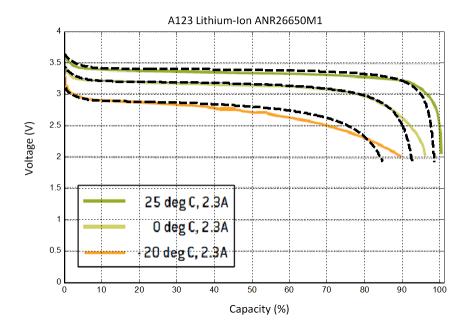
From the data sheet, these parameters are derived for the A123 Li-ion temperature-dependent battery model:

Parameter	Value
Nominal voltage (c)	3.22 V
Rated capacity	2.3 Ah
Maximum capacity (d)	2.3 Ah
Fully charged voltage (a)	3.7 V
Nominal discharge current	2.3 A
Internal resistance	10 mΩ
Capacity @ nominal voltage (c)	2.07 Ah

Parameter	Value
Exponential zone (b)	[3.4 V, 0.23 Ah]
Nominal ambient temperature	25 oC
Second ambient temperature	0 oC
Maximum capacity @ 0 °C (h)	2.208 Ah
Initial discharge voltage @ 0 °C (e)	3.45 V
Voltage @ 90% maximum capacity @ 0 °C (g)	2.8 V
Exponential zone @ 0 °C (f)	[3.22 V, 0.23 Ah]
Thermal resistance, cell-to-ambient (estimated)	0.6
Thermal time constant, cell-to-ambient (estimated)	1000

The figure shows the discharges curves obtained from the simulation (dashed lines) at different ambient temperatures. The model performance is very close to the data sheet results.
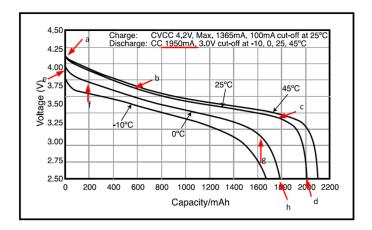
The same approach for parameter extraction is applied to the Panasonic Lithium-Ion CGR18650AF with these specifications:

Specifications

Nominal Voltage		3.6 V
Standard Capacity[1]		2050mAh
Dimensions[2]	Diameter	18.6 + 0/-0.7mm
	Height	65.2 + 0/-1.0mm
	Weight	Approx. 42.5g

[1] After a fresh battery has been charged at constant voltage/constant current (4.2 V, 1365mA (max), 100mA cut-off, 25°C), the average of the capacity (ending voltage of 3 V at 25°C) that is discharged at a standard current (390mA).

[2] Dimensions of a fresh battery
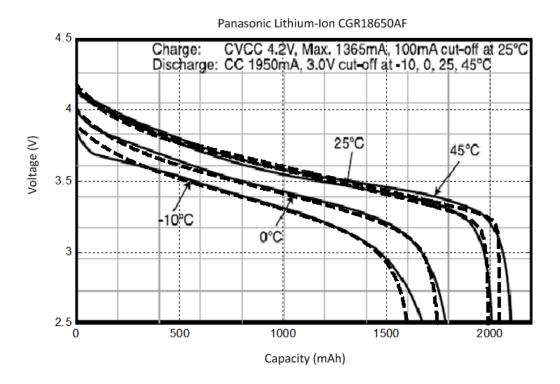
These parameters are extracted for the battery model.

Parameter	Value
Nominal voltage (c)	3.3 V
Rated capacity	2.05 Ah
Maximum capacity (d)	2 Ah
Fully charged voltage (a)	4.2 V
Nominal discharge current	1.95 A
Internal resistance (estimated)	16.5 mΩ
Capacity @ nominal voltage (c)	1.81 Ah
Exponential zone (b)	[3.71 V, 0.6 Ah]
Nominal ambient temperature	25 oC
Second ambient temperature	0 oC
Maximum capacity @ 0 °C (h)	1.78 Ah
Initial discharge voltage @ 0 °C (e)	4 V
Voltage @ 90 % maximum capacity @ 0 °C (g)	3.11 V
Exponential zone @ 0 °C (f)	[3.8 V, 0.2 Ah]

Parameter	Value
Thermal resistance, cell-to-ambient (estimated)	0.06
Thermal time constant, cell-to-ambient (estimated)	1000

The figure shows a good match between the simulated discharge curves (dashed line) and the data sheet curves. The accuracy of the model depends on how precise the selected points from the data sheet discharge curves are.

Panasonic Lithium-Ion CGR18650AF

Cells in Series and/or in Parallel

To model a series and/or parallel combination of cells based on the parameters of a single cell, the parameter transformation shown in the next table can be used. The

Nb_ser variable in mask below corresponds to the number of cells in series, and Nb_par corresponds to the number of cell in parallel:

Parameter	Value
Nominal voltage	1.18*Nb_ser
Rated capacity	6.5*Nb_par
Maximum capacity	7*Nb_par
Fully charged voltage	1.39*Nb_ser
Nominal discharge current	1.3*Nb_par
Internal resistance	0.002*Nb_ser/Nb_par
Capacity @ nominal voltage	6.25*Nb_par
Exponential zone	[1.28*Nb_ser, 1.3*Nb_par]

Block Inputs and Outputs

m

The Simulink output of the block is a vector containing three (or five, when temperature effects is enabled) signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Signal	Definition	Units
Ambient Temperature	The Ambient temperature (available only when temperature effects is enabled)	(°C)
Cell Temperature	The cell or internal temperature (available only when temperature effects is enabled)	(°C)
SOC	The State-Of-Charge of the battery (between 0 and 100%). The SOC for a fully charged battery is 100% and for an empty battery is 0%. The SOC is calculated as: $$SOC = 100\left(1 - \frac{1}{Q}\int_0^t i(t)\,dt\right).$$	%
Current	The Battery current	A
Voltage	The Battery voltage	V

`Ta`

> The input port to supply the ambient temperature to the model. This port is available only if the **Type** parameter is set to `Lithium-Ion` and **Simulate temperature effects** is selected.

Model Validation

Experimental validation of the model shown a maximum error of 5% (when SOC is between 10% and 100%) for charge (current between 0 and 2C) and discharge (current between 0 and 5C) dynamics.

Model Assumptions

- The internal resistance is supposed constant during the charge and the discharge cycles and does not vary with the amplitude of the current. When the temperature effects is enabled for the Lithium-Ion battery type, the internal resistance varies with the internal temperature of the battery.
- The parameters of the model are deduced from discharge characteristics and assumed to be the same for charging.
- The capacity of the battery does not change with the amplitude of current (No Peukert effect).
- The Self-Discharge of the battery is not represented. It can be represented by adding a large resistance in parallel with the battery terminals.
- The battery has no memory effect.

Limitations
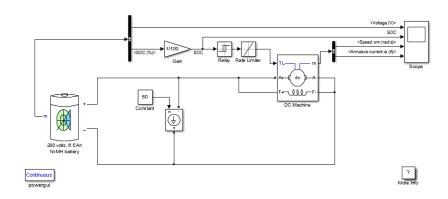
- The minimum no-load battery voltage is 0 volt and the maximum battery voltage is equal to 2*E0.
- The minimum capacity of the battery is 0 Ah and the maximum capacity is Qmax.

Examples
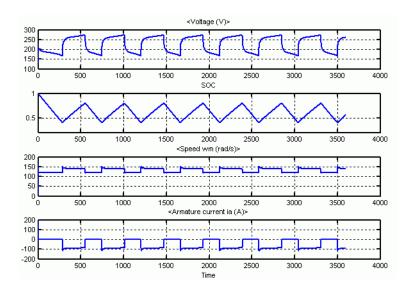
The power_battery example illustrates a 200 volts, 6.5 Ah NiMH battery connected to a constant load of 50 A. The DC machine is connected in parallel with the load and

operates at no load torque. When the State-Of-Charge (SOC) of the battery goes under 0.4 (40%), a negative load torque of 200 Nm is applied to the machine so it acts as a generator to recharge the battery. When the SOC goes over 80%, the load torque is removed so only the battery supplies the 50 amps load.

Ni-MH Battery Model

The simulation produces the followings results:

The battery is discharged by the constant DC load of 50 A. When the SOC drops under 0.4, a mechanical torque of −200 Nm is applied so the machine acts as a generator and provides a current of 100 amps. Hence, 50 amps goes to the load and 50 amps goes to recharge the battery. When the SOC goes over 0.8, the mechanical torque is removed and the machine operates freely. And then the cycle restarts.

References

[1] Tremblay, O., L.-A. Dessaint, "Experimental Validation of a Battery Dynamic Model for EV Applications." *World Electric Vehicle Journal*. Vol. 3, May 13–16, 2009.

[2] Zhu, C., X. Li, L. Song, and L. Xiang, "Development of a theoretically based thermal model for lithium ion battery pack." *Journal of Power Sources*. Vol. 223, pp. 155–164.

[3] Saw, L.H., K. Somasundaram, Y. Ye, and A.A.O. Tay, "Electro-thermal analysis of Lithium Iron Phosphate battery for electric vehicles." *Journal of Power Sources*. Vol. 249, pp. 231–238.

Introduced in R2008a

Bistable

Implement prioritized S-R flip-flop (bistable multivibrator)

Library

Control and Measurements/Logic

Description
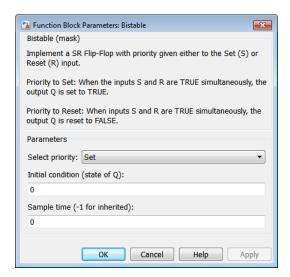
The Bistable block implements the following logic:

- When S input is true and R input is false, the flip-flop goes to the Set state. This is the first stable state, where Q is true.
- When R is true and S is false, the flip-flop goes to the reset state. This is the second stable state, where Q is false.
- When both S and R are true, the flip-flop goes to the prioritized state defined by the **Select priority** parameter.
- When both S and R are false, the flip-flop stays in its previous state.

Dialog Box and Parameters

Select priority

Specify the prioritized state of Q.

Initial condition (state of Q)

Specify the initial value of the output Q.

Sample time (-1 for inherited)

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Inputs and Outputs

S, [S]

The Set input. Must be Boolean. When the **Select priority** parameter value is Set, the input is named [S].

R, [R]

The Reset input. Must be Boolean. When the **Select priority** parameter value is Reset, the input is named [R].

`Q`

Bistable output. The signal is Boolean.

`!Q`
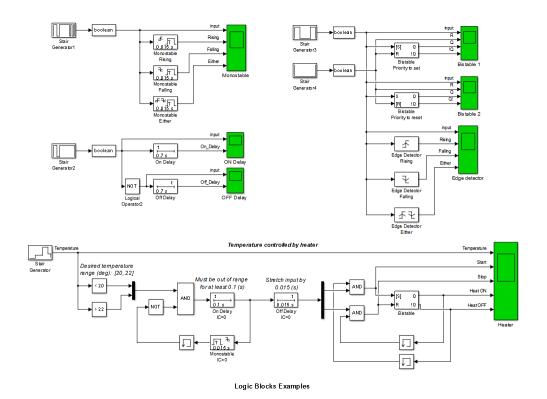
Bistable complement output. The signal is Boolean.

Characteristics

Direct Feedthrough	Yes
Sample Time	Specified in the **Sample Time** parameter
Scalar Expansion	Yes, of parameters
Dimensionalized	Yes
Zero-Crossing Detection	No

Example

The power_Logic example shows the operation of the Bistable block.

Logic Blocks Examples

The model sample time is parameterized with the variable Ts (default value Ts = 50e-3). To simulate a continuous Bistable block, specify Ts = 0 in the MATLAB® Command Window.
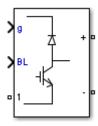
Introduced in R2013a

Boost Converter

Implement boost power converter

Library

Fundamental Blocks/Power Electronics

Description
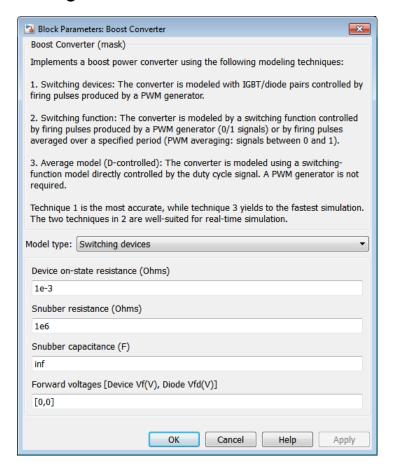
The Boost Converter block implements a boost power converter. You can choose from three model types:

- **Switching devices** — The converter is modeled with IGBT/diode pairs controlled by firing pulses produced by a PWM generator. This model provides the most accurate simulation results.

- **Switching function** — The converter is modeled by a switching-function model. The switches are replaced with two voltage sources and two diodes on the AC side and with two current sources on the DC side.

  The converter is controlled by firing pulses produced by a PWM generator (0/1 signals) or by firing pulses averaged over a specified period (PWM averaging: signals between 0 and 1). Both modes of operation produce harmonics normally generated by a PWM-controlled converter and also correctly simulate rectifying operation as well as blanking time. This model type is well-suited for real-time simulation.

- **Average model (D-controlled)** — The converter is modeled using a switching-function model directly controlled by the duty cycle signal (0 < D < 1). A PWM generator is not required. This model provides the fastest simulations.

Dialog Box and Parameters

Parameters

Model type

Specify the model type to use:

- `Switching devices` (default)
- `Switching function`
- `Average model (D-controlled)`

Device on-state resistance (Ohms)

Internal resistance of the switching devices, in ohms. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `1e-3`.

Snubber resistance (Ohms)

The snubber resistance, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `1e6`.

Snubber capacitance (F)

The snubber capacitance, in farads. Set the snubber capacitance to `0` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `inf`.

Forward voltages [Device Vf (V), Diode Vfd (V)]

The forward voltage of the switching device and of the diode, in volts. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `[0,0]`.

Diode on state resistance (Ohms)

Internal resistance of the diodes, in ohms. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (D-controlled)`. The default value is `1e-3`.

Diode snubber resistance (Ohms)

The snubber resistance, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (D-controlled)`. The default value is `1e6`.

Diode snubber capacitance (F)

The snubber capacitance in farads. Set the snubber capacitance to `0` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (D-controlled)`. The default value is `inf`.

Diode forward voltage (V)

Forward voltage, in volts, across the diode when it is conducting. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (D-controlled)`. The default value is `1e-3`.

Current source snubber resistance (Ohms)

The snubber resistance, in ohms, across the two current sources. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (D-controlled)`. The default value is `inf`.

Inputs and Outputs

`g`

The firing pulse signal to control the converter. This port is visible only when you set the **Model type** parameter to `Switching devices` or `Switching function`.

`D`

The duty cycle signal (a value between 0 and 1) used to control the converter. This port is visible only when you set the **Model type** parameter to `Average model (D-controlled)`.

`BL`

You can block all firing pulses to the converter by applying a signal value of 1 at the BL input.

Examples

See the Power Converters Modeling Techniques example for a comparison of the three converter modeling techniques.

Introduced in R2015b

Breaker

Implement circuit breaker opening at current zero crossing

Library

Fundamental Blocks/Elements

Description

The Breaker block implements a circuit breaker where the opening and closing times can be controlled either from an external Simulink signal (external control mode), or from an internal control timer (internal control mode).

A series Rs-Cs snubber circuit is included in the model. It can be connected to the circuit breaker. If the Breaker block happens to be in series with an inductive circuit, an open circuit or a current source, you must use a snubber.

When the Breaker block is set in external control mode, a Simulink input appears on the block icon. The control signal connected to the Simulink input must be either 0 or 1 (0 to open the breaker, 1 to close it).

When the Breaker block is set in internal control mode, the switching times are specified in the dialog box of the block.

When the breaker is closed, it is represented by a resistance Ron. The Ron value can be set as small as necessary in order to be negligible compared with external components (a typical value is 10 mohms). When the breaker is open, it has an infinite resistance.
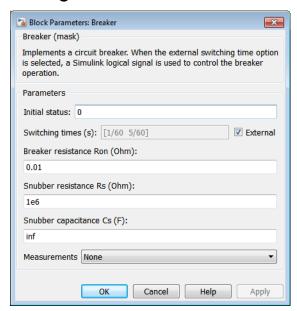
The arc extinction process is simulated by opening the breaker device when its current passes through 0 at the first current zero crossing following the transition of the Simulink control input from 1 to 0.

Operation	Conditions
The Breaker closes when	Control signal goes to 1 (for discrete systems, control signal must stay at 1 for at least 3 times the sampling period)

Operation	Conditions
The Breaker opens when	Control signal goes to 0
	Breaker current passes through 0

Note The Breaker block may not be the appropriate switching device to use for DC circuits. For such applications, it is recommended that you use the Ideal Switch block as a switching device.

Dialog Box and Parameters

Initial status

The initial state of the breaker. A closed contact is displayed in the block icon when the **Initial status** parameter is set to 1, and an open contact is displayed when it is set to 0.

If the breaker initial state is set to 1 (closed), the software automatically initializes all the states of the linear circuit and the Breaker block initial current, so that the simulation starts in steady state.

Switching times

Specifies the vector of switching times when using the Breaker block in internal control mode. At each switching time the Breaker block opens or closes depending on its initial status. For example, if the **Initial status** parameter is 0 (open), the breaker closes at the first switching time, opens at the second switching time, and so on. The **Switching times** parameter is not available if the **External** check box is selected.

External

If selected, adds a Simulink input to the Breaker block for external control of the switching times of the breaker. The switching times are defined by a logical signal (0 or 1) connected to the Simulink input.

Breaker resistance Ron

The internal breaker resistance, in ohms (Ω). The **Breaker resistance Ron** parameter cannot be set to 0.

Snubber resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to inf to eliminate the snubber from the model.

Snubber capacitance Cs

The snubber capacitance, in farads (F). Set the **Snubber capacitance Cs** parameter to 0 to eliminate the snubber, or to inf to get a resistive snubber.

Measurements

Select Branch voltage to measure the voltage across the Breaker block terminals.

Select Branch current to measure the current flowing through the Breaker block. If the snubber device is connected to the breaker model, the measured current is the one flowing through the breaker contacts only.

Select Branch voltage and current to measure the breaker voltage and the breaker current.

Place a Multimeter block in your model to display the selected measurements during the simulation.

In the **Available Measurements** list box of the Multimeter block, the measurement is identified by a label followed by the block name:

Measurement	Label
Branch voltage	Ub:

Measurement	Label
Branch current	Ib:

Limitations

When the block is connected in series with an inductor or another current source, you must add the snubber circuit. In most applications, you can use a resistive snubber (**Snubber capacitance** parameter set to inf) with a large resistor value (**Snubber resistance** parameter set to 1e6 or so). Because of modeling constraints, the internal breaker inductance Ron cannot be set to 0.

You must use a stiff integration algorithm to simulate circuits with the Breaker block. ode23tb with default parameters usually gives the best simulation speed.

For discretized models, the control signal must stay at 1 for a minimum of 3 sampling time periods to correctly close the Breaker block, otherwise the device stays open.

Example

See the power_breaker example for a circuit using the Breaker block.

See Also

Three-Phase Breaker, Three-Phase Fault
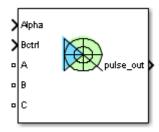
Introduced before R2006a

Bridge Firing Unit (AC)

Implement six pulse firing unit with notch filters for three-phase thyristor bridge

Library

Electric Drives/Fundamental Drives

Description
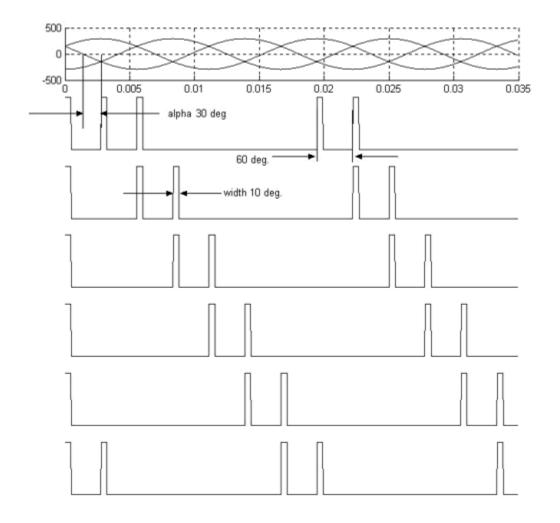
The Bridge Firing Unit (AC) block converts the firing angle, typically provided by a current/voltage controller, to pulses applied to the thyristor gates. The block uses notch filters on voltage measurement to remove voltage harmonics.
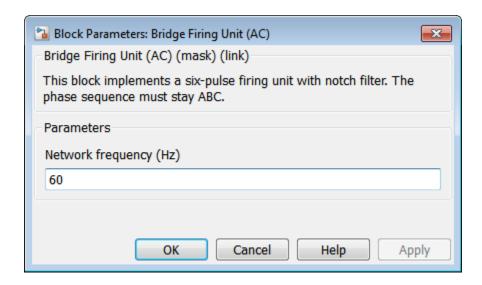
The output of the block is a vector of six pulses individually synchronized with the supply voltage. The pulses are generated alpha (firing angle) degrees after the zero crossings of the thyristor commutation voltages.

The figures show the synchronization of the six pulses for an alpha angle of 30 degrees and pulse width of 10 degrees. The pulses are generated at exactly 30 degrees after the zero crossings of the three line-to-line synchronization voltages.

Two pulses (double-pulsing) are sent to each thyristor—a first pulse when the alpha angle is reached, and a second pulse 60 degrees later when the next thyristor is fired.

Dialog Box and Parameters

Network frequency (Hz)

The frequency of the synchronization voltages, in hertz. It usually corresponds to the frequency of the supply. The default value is 60.

Inputs and Outputs

Alpha

Converter firing angle.

Bctrl

Control signal to disable or enable the output pulses.

A, B, C

Three-phase terminals of the supply.

pulse_out

Gate pulses for the thyristor bridge.

Examples

The Bridge Firing Unit (AC) block is used in the AC1 block of the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

Bridge Firing Unit (DC) | Current Controller (Brushless DC) | Current Controller (DC) | Direct Torque Controller | Field-Oriented Controller | Regulation Switch | Six-Step Generator | Space Vector Modulator | Speed Controller (AC) | Speed Controller (DC) | Speed Controller (Scalar Control) | Vector Controller (PMSM) | Vector Controller (WFSM) | Voltage Controller (DC Bus)

More About

· "Electric Drives Library"

Introduced in R2015b

1-123
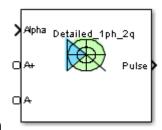
Bridge Firing Unit (DC)

Generate gate signals for single- or three-phase thyristor bridge

Library

Electric Drives/Fundamental Drives

Description
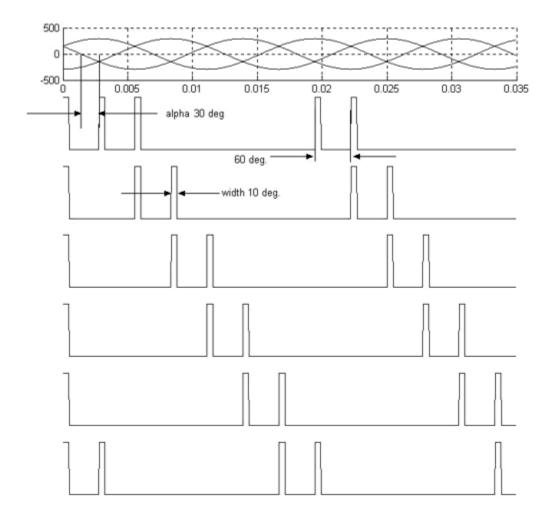
The Bridge Firing Unit (DC) block generates gate signals for a standard two-leg or three-leg thyristor bridge. It features two operating modes: detailed and average. In detailed mode, the block outputs synchronized pulses for each thyristor. In average mode, it outputs the firing angle for the thyristor bridge.

Detailed Mode

In detailed mode, the Bridge Firing Unit (DC) block converts the firing angle provided by the current/voltage controller to pulses to control the thyristor gates. The block contains a low-pass filter on voltage measurement to remove voltage harmonics.

The output of the block is a vector of four pulses (or six pulses for a three-phase supply) individually synchronized with the supply voltage. The pulses are generated alpha degrees (firing angle) after the zero crossings of the thyristor commutation voltages.

The figures show the synchronization of the six pulses for a firing angle of 30 degrees and pulse width of 10 degrees. The pulses are generated at exactly 30 degrees after the zero crossings of the three line-to-line synchronization voltages.
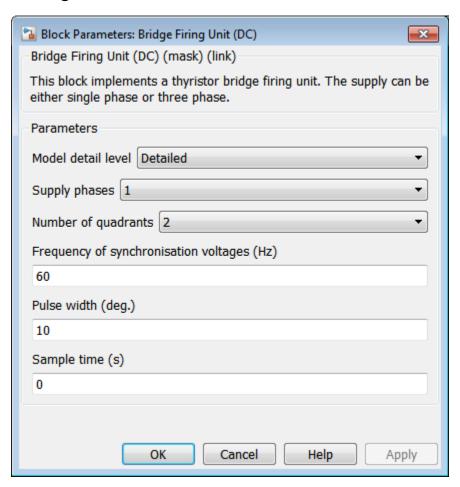
Two pulses (double-pulsing) are sent to each thyristor: a first pulse when the alpha angle is reached, and a second pulse 60 degrees later, when the next thyristor is fired. For the four-quadrant DC drives, the block outputs an additional set of pulses for the antiparallel thyristor converter.

Average Mode

The average model outputs the firing angle value needed by the thyristor converter. For four-quadrant DC drives, the block also outputs a second firing angle for the antiparallel converter.

Dialog Box and Parameters

Model detail level

Specify the model detail level to use:

- `Detailed` (default)
- `Average`

Supply phases

Specify the number of phases—single-phase or three-phase—of the supply device connected at the input of the unit. Choose between 1 and 3. The default value is 1.

Number of quadrants

Specify the operating mode of the unit—2-quadrant or 4-quadrant. Choose between 2 and 4. The default value is 2.

Frequency of synchronization voltages (Hz)

The frequency of the synchronization voltages, in hertz. It usually corresponds to the frequency of the supply. The default value is 60.

Pulse width (deg.)

The width of the pulse, in degrees. The default value is 10.

Sampling time (s)

The sample time of the bridge fire unit, in seconds. The default value is 0.

Inputs and Outputs

`Alpha`

Converter firing angle.

`Alpha_1`

Converter firing angle. This input is visible only when the **Number of quadrants** parameter is set to 4.

`Alpha_2`

Converter firing angle. This input is visible only when the **Number of quadrants** parameter is set to 4.

`A, B, C`

Connect these inputs to the three-phase terminals of the supply. This input is visible only when the **Supply phases** parameter is set to 3.

`A+, A-`

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Connect these inputs to the single-phase terminals of the supply. This input is visible only when the **Supply phases** parameter is set to 1.

Pulse

The gate pulses for the thyristor bridge. This output is visible only when the **Model detail level** parameter is set to Detailed.

Pulse_1

The gate pulse for the thyristor bridge. This output is visible only when the **Model detail level** parameter is set to Detailed and the **Number of quadrants** parameter is set to 4.

Pulse_2

The gate pulse for the thyristor bridge. This output is visible only when the **Model detail level** parameter is set to Detailed and the **Number of quadrants** parameter is set to 4.

Examples

The Bridge Firing Unit (DC) block is used in the DC1, DC2, DC3, and DC4 blocks from the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

Bridge Firing Unit (AC) | Current Controller (Brushless DC) | Current Controller (DC) | Direct Torque Controller | Field-Oriented Controller | Regulation Switch | Six-Step Generator | Space Vector Modulator | Speed Controller (AC) | Speed Controller (DC) | Speed Controller (Scalar Control) | Vector Controller (PMSM) | Vector Controller (WFSM) | Voltage Controller (DC Bus)

More About

- "Electric Drives Library"

Introduced in R2015b

Brushless DC Motor Drive

Implement brushless DC motor drive using Permanent Magnet Synchronous Motor (PMSM) with trapezoidal back electromotive force (BEMF)

Library
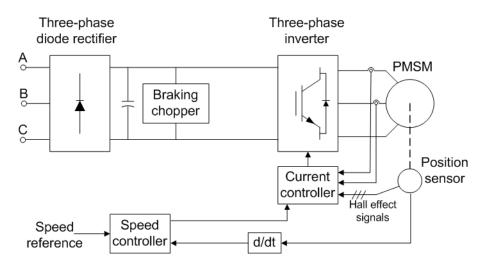
Electric Drives/AC drives

Description
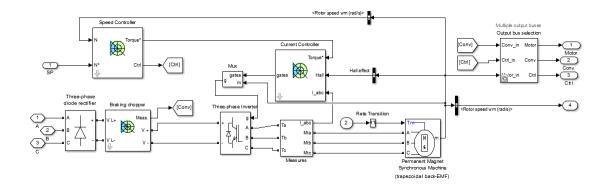
The high-level schematic shown below is built from six main blocks. The PMSM, the three-phase inverter, and the three-phase diode rectifier models are provided with the SimPowerSystems library. The speed controller, the braking chopper, and the current controller models are specific to the Electric Drives library. It is possible to use a simplified version of the drive containing an average-value model of the inverter for faster simulation.

Note In SimPowerSystems software, the Brushless DC Motor Drive block is commonly called the AC7 motor drive.

High-Level Schematic
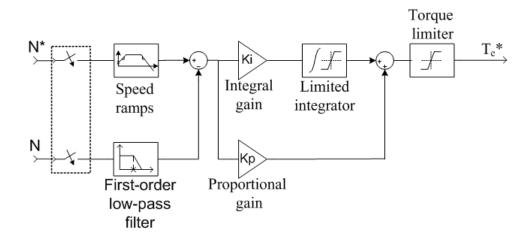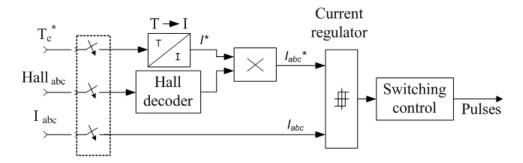
Simulink Schematic

Speed Controller

The speed controller is based on a PI regulator, shown below. The output of this regulator is a torque set point applied to the current controller block.

Current Controller
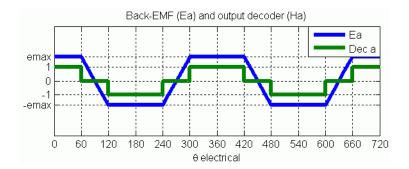
The current controller contains four main blocks, shown below. These blocks are described below.

The *T-I* block performs the conversion from the reference torque to the peak reference current. The relation used to convert torque to current assumes pure rectangular current waveforms. In practice, due to the motor inductance, it is impossible to obtain these currents. Therefore the electromagnetic torque may be lower than the reference torque, especially at high speed.

The *Hall decoder* block is used to extract the BEMF information from the Hall effect signals. The outputs, three-level signals (−1, 0, 1), represent the normalized ideal phase

currents to be injected in the motor phases. These types of currents will produce a constant torque. The following figure shows the BEMF of phase A and the output of the Hall decoder for the phase A.

The *current regulator* is a bang-bang current controller with adjustable hysteresis bandwidth.

The *Switching control* block is used to limit the inverter commutation frequency to a maximum value that you specify.
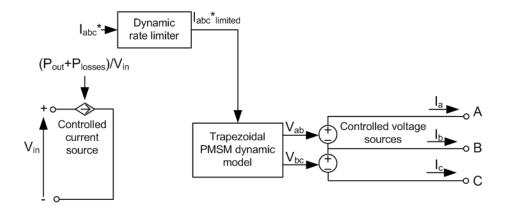
When using the average-value inverter, the *abc* current references are sent to the simplified inverter.

Braking Chopper

The braking chopper block contains the DC bus capacitor and the dynamic braking chopper, which is used to absorb the energy produced by a motor deceleration.

Average-Value Inverter

The average-value inverter is shown in the following figure.

It is composed of one controlled current source on the DC side and of two controlled voltage sources on the AC side. The DC current source allows the representation of the DC bus current behavior described by the following equation:

$I_{dc} = (P_{out} + P_{losses}) / V_{in}$,

with P_{out} being the output AC power, P_{losses} the losses in the power electronic devices, and V_{in} the DC bus voltage.

On the AC side, the voltage sources are fed by the instantaneous voltages provided by the *Trapezoidal PMSM dynamic model* (see PMSM documentation for machine model). This dynamic model takes the reference currents (the rate of these currents has been limited to represent the real life currents), the measured BEMF voltages and the machine speed to compute the terminal voltages to be applied to the machine.

The *dynamic rate limiter* limits the rate of the reference currents when transitions occurs. The rate depends on the inverter saturation degree.

During loss of current tracking due to insufficient inverter voltage, the *dynamic rate limiter* saturates the reference current in accordance to this operation mode.
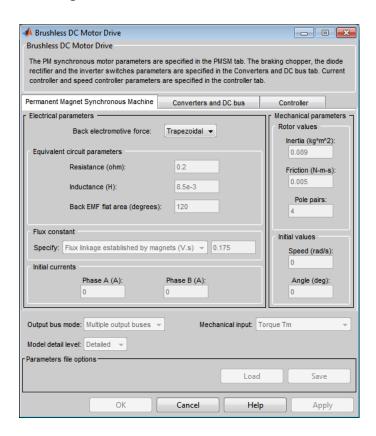
Remarks

The model is discrete. Good simulation results have been obtained with a 2 μs time step. To simulate a digital controller device, the control system has two different sampling times:

- Speed controller sampling time
- Current controller sampling time

The speed controller sampling time has to be a multiple of the current controller sampling time. The latter sampling time has to be a multiple of the simulation time step. The average-value inverter allows the use of bigger simulation time steps since it does not generate small time constants (due to the RC snubbers) inherent to the detailed converter. For a current controller sampling time of 40 μs, good simulation results have been obtained for a simulation time step of 40 μs. The simulation time step can, of course, not be higher than the current controller time step.

Dialog Box

Permanent Magnet Synchronous Machine Tab

The **Permanent Magnet Synchronous Machine** tab displays the parameters of the Permanent Magnet Synchronous Machine block of the Fundamental Blocks (powerlib) library.

Output bus mode

Select how the output variables are organized. If you select **Multiple output buses**, the block has three separate output buses for motor, converter, and controller variables. If you select **Single output bus**, all variables output on a single bus.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Select between the load torque, the motor speed and the mechanical rotational port as mechanical input. If you select and apply a load torque, the output is the motor speed according to the following differential equation that describes the mechanical system dynamics:

$$T_e = J \frac{d}{dt} \omega_r + F \omega_r + T_m.$$

This mechanical system is included in the motor model.

If you select the motor speed as mechanical input, then you get the electromagnetic torque as output, allowing you to represent externally the mechanical system dynamics. The internal mechanical system is not used with this mechanical input selection and the inertia and viscous friction parameters are not displayed.

For the mechanical rotational port, the connection port S counts for the mechanical input and output. It allows a direct connection to the Simscape environment. The mechanical system of the motor is also included in the drive and is based on the same differential equation.

See "Mechanical Coupling of Two Motor Drives".

Converters and DC Bus Tab

Rectifier section

The rectifier section of the Converters and DC bus tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the universal bridge parameters.

Inverter section

The inverter section of the Converters and DC bus tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the universal bridge parameters.

The average-value inverter uses the following parameter.

On-state resistance

The on-state resistance of the inverter switches (ohms).

DC Bus Field — Capacitance

The DC bus capacitance (F).

Braking Chopper Section

Resistance

The braking chopper resistance used to avoid bus over-voltage during motor deceleration or when the load torque tends to accelerate the motor (ohms).

Frequency

The braking chopper frequency (Hz).

Activation Voltage

The dynamic braking is activated when the bus voltage reaches the upper limit of the hysteresis band. The following figure illustrates the braking chopper hysteresis logic.

Deactivation Voltage

The dynamic braking is shut down when the bus voltage reaches the lower limit of the hysteresis band. The chopper hysteresis logic is shown in the following figure.

Controller Tab

Regulation Type

This pop-up menu allows you to choose between speed and torque regulation.

Schematic Button

When you press this button, a diagram illustrating the speed and current controllers schematics appears.

Speed Controller section

Speed cutoff frequency

The speed measurement first-order low-pass filter cutoff frequency (Hz). This parameter is used in speed regulation mode only.

Speed controller sampling time

The speed controller sampling time (s). The sampling time must be a multiple of the simulation time step.

Speed Ramps — Acceleration

The maximum change of speed allowed during motor acceleration (rpm/s). An excessively large positive value can cause DC bus under-voltage. This parameter is used in speed regulation mode only.

Speed Ramps — Deceleration

The maximum change of speed allowed during motor deceleration (rpm/s). An excessively large negative value can cause DC bus overvoltage. This parameter is used in speed regulation mode only.

PI Regulator — Proportional Gain

The speed controller proportional gain. This parameter is used in speed regulation mode only.

PI Regulator — Integral Gain

The speed controller integral gain. This parameter is used in speed regulation mode only.

Torque output limits — Negative

The maximum negative demanded torque applied to the motor by the current controller (N.m).

Torque output limits — Positive

The maximum positive demanded torque applied to the motor by the current controller (N.m).

Current Controller Section

Sampling Time

The current controller sampling time (s). The sampling time must be a multiple of the simulation time step.

Current controller hysteresis band

The current hysteresis bandwidth. This value is the total bandwidth distributed symmetrically around the current set point (A). The following figure illustrates a case where the current set point is Is^* and the current hysteresis bandwidth is set to dx.

This parameter is not used when using the average-value inverter.

Note This bandwidth can be exceeded because a fixed-step simulation is used. A rate transition block is needed to transfer data between different sampling rates. This block causes a delay in the gates signals, so the current may exceed the hysteresis band.

Maximum switching frequency

The maximum inverter switching frequency (Hz). This parameter is not used when using the average-value inverter.

Block Inputs and Outputs

SP

The speed or torque set point. The speed set point can be a step function, but the speed change rate will follow the acceleration / deceleration ramps. If the load torque and the speed have opposite signs, the accelerating torque will be the sum of the electromagnetic and load torques.

Tm or Wm

The mechanical input: load torque (Tm) or motor speed (Wm). For the mechanical rotational port (S), this input is deleted.

A, B, C

The three phase terminals of the motor drive.

Wm, Te or S

The mechanical output: motor speed (Wm), electromagnetic torque (Te) or mechanical rotational port (S).

When the **Output bus mode** parameter is set to **Multiple output buses**, the block has the following three output buses:

Motor

The motor measurement vector. This vector allows you to observe the motor's variables using the Bus Selector block.

Conv

The three-phase converters measurement vector. This vector contains:

- The DC bus voltage
- The rectifier output current
- The inverter input current

All current and voltage values of the bridges can be visualized with the Multimeter block.

Ctrl

The controller measurement vector. This vector contains:

- The torque reference
- The speed error (difference between the speed reference ramp and actual speed)
- The speed reference ramp or torque reference

When the **Output bus mode** parameter is set to **Single output bus**, the block groups the Motor, Conv, and Ctrl outputs into a single bus output.

Model Specifications

The library contains a 3 hp drive parameter set. The specifications of the 3 hp drive are shown in the following table.

3 HP Drive Specifications

Drive Input Voltage		
	Amplitude	220 V
	Frequency	60 Hz
Motor Nominal Values		
	Power	3 hp
	Speed	1650 rpm
	Voltage	300 Vdc
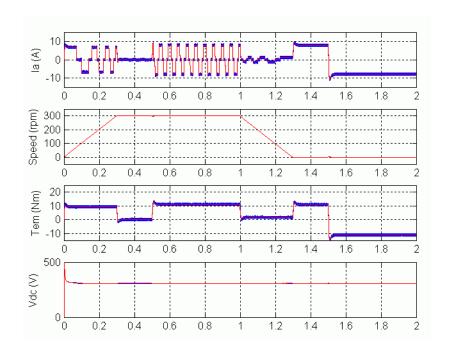
Example

The `ac7_example` example illustrates an AC7 motor drive simulation with standard load condition. At time t = 0 s, the speed set point is 300 rpm.

There are two design tools in this example. The first block calculates the gains of the speed regulator in accordance with your specifications. The second block plots the operating regions of the drive. Open these blocks for more information.

As shown in the following figure, the speed precisely follows the acceleration ramp. At t = 0.5 s, the nominal load torque is applied to the motor. At t = 1 s, the speed set point is changed to 0 rpm. The speed decreases to 0 rpm. At t = 1.5 s., the mechanical load passes from 11 N.m to −11 N.m. The next figure shows the results for the detailed converter and for the average-value converter. Observe that the average voltage, current, torque, and speed values are identical for both models. Notice that the higher frequency signal components are not represented with the average-value converter.

AC7 Example Waveforms (Blue: Detailed Converter, Red: Average-Value Converter)

References

[1] Bose, B. K., *Modern Power Electronics and AC Drives*, Prentice-Hall, N.J., 2002.

[2] Krause, P. C., *Analysis of Electric Machinery*, McGraw-Hill, 1986.

[3] Tremblay, O., *Modélisation, simulation et commande de la machine synchrone à aimants à force contre-électromotrice trapézoïdale*, École de Technologie Supérieure, 2006.
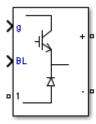
Introduced in R2007a

Buck Converter

Implement buck power converter

Library

Fundamental Blocks/Power Electronics

Description
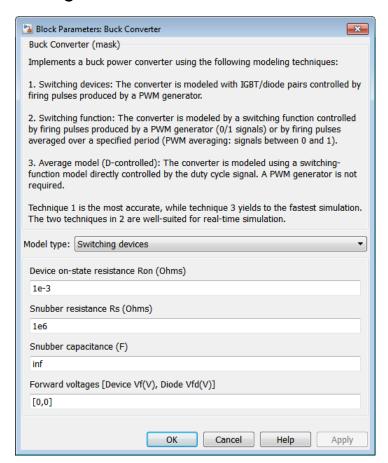
The Buck Converter block implements a buck power converter. You can choose from three model types:

- **Switching devices** — The converter is modeled with IGBT/diode pairs controlled by firing pulses produced by a PWM generator. This model provides the most accurate simulation results.

- **Switching function** — The converter is modeled by a switching-function model. The switches are replaced with two voltage sources and two diodes on the AC side and with two current sources on the DC side.

  The converter is controlled by firing pulses produced by a PWM generator (0/1 signals) or by firing pulses averaged over a specified period (PWM averaging: signals between 0 and 1). Both modes of operation produce harmonics normally generated by a PWM-controlled converter and also correctly simulate rectifying operation as well as blanking time. This model type is well-suited for real-time simulation.

- **Average model (D-controlled)** — The converter is modeled using a switching-function model directly controlled by the duty cycle signal (0 < D < 1). A PWM generator is not required. This model provides the fastest simulations.

Dialog Box and Parameters

Parameters

Model type

Specify the model type to use:

- `Switching devices` (default)
- `Switching function`
- `Average model (D-controlled)`

Device on-state resistance (Ohms)

Internal resistance of the switching devices, in ohms. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `1e-3`.

Snubber resistance (Ohms)

The snubber resistance, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `1e6`.

Snubber capacitance (F)

The snubber capacitance, in farads. Set the snubber capacitance to `0` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `inf`.

Forward voltages [Device Vf (V), Diode Vfd (V)]

The forward voltage of the switching device and of the diode, in volts. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `[0,0]`.

Diode on-state resistance (Ohms)

Internal resistance of the diodes, in ohms. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (D-controlled)`. The default value is `1e-3`.

Diode snubber resistance (Ohms)

The snubber resistance, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (D-controlled)`. The default value is `1e6`.

Diode snubber capacitance (F)

The snubber capacitance, in farads. Set the snubber capacitance to `0` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (D-controlled)`. The default value is `inf`.

Diode forward voltage (V)

Forward voltage, in volts, across the diode when it is conducting. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (D-controlled)`. The default value is `1e-3`.

Current source snubber resistance (Ohms)

The snubber resistance across the two current sources, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (D-controlled)`. The default value is `inf`.

Inputs and Outputs

g

The firing pulse signal to control the converter. This port is visible only when you set the **Model type** parameter to `Switching devices` or `Switching function`.

D

The duty cycle signal (a value between 0 and 1) used to control the converter. This port is visible only when you set the **Model type** parameter to `Average model (D-controlled)`.

BL

You can block all firing pulses to the converter by applying a signal value of 1 at the BL input.

Examples

See the Power Converters Modeling Techniques example for a comparison of the three converter modeling techniques.

Introduced in R2015b

Chopper

Implement DC chopper model for DC motor drives

Library

Electric Drives/Fundamental Drives

Description

The Chopper block models a standard half-bridge (one leg, two IGBTs) or full-bridge (two legs, four IGBTs) converter model. It has two operating modes to represent a detailed or an average-value chopper.

Each operating mode has multiple instances depending on the DC motor drive type (two- or four-quadrant operation).
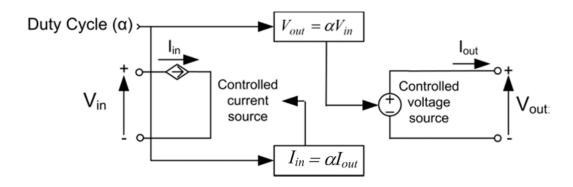
Detailed Mode

In detailed mode, the block is modeled by a Universal Bridge block configured as a half-bridge (one arm) or full-bridge (two arms) IGBT converter. The half-bridge IGBT converter model is used for one- or two-quadrant DC drives. The full-bridge converter model is for four-quadrant DC drives.

Average Mode

Average mode is used for fast simulations, where the high frequency switching actions of the switches is not required. The Chopper block implements an average-value half-bridge or full-bridge IGBT converter model. The average-value model can be one of these types:

- Half-bridge, one-, or two-quadrant DC drive — The converter is composed of one controlled current source on the DC source side and one controlled voltage source on the motor side, as shown in the figure.

The current source allows the representation of the average input current value following this equation:

$I_{in} = \alpha I_{out}$

where α is the duty cycle value of IGBT 1 and I_{out} the armature current value.

For one-quadrant DC drives, when $I_{out} \leq 0$,

$I_{in} = I_{out}$
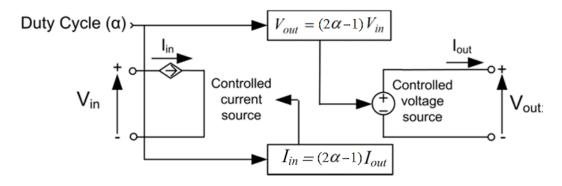
The voltage source on the motor side represents the average voltage value following this equation:

$V_{out} = \alpha V_{in}$

For one-quadrant DC drives, when $I_{out} \leq 0$,

$V_{out} = V_{in}$

with V_{in} being the input voltage.

- Full-bridge, four-quadrant DC drive — This model is similar to the half-bridge, two-quadrant DC drive model, with the only difference being in the expressions of the average input current and output voltage, as shown in the figure.

$$V_{out} = (2\alpha - 1) V_{in}$$

$$I_{in} = (2\alpha - 1) I_{out}$$
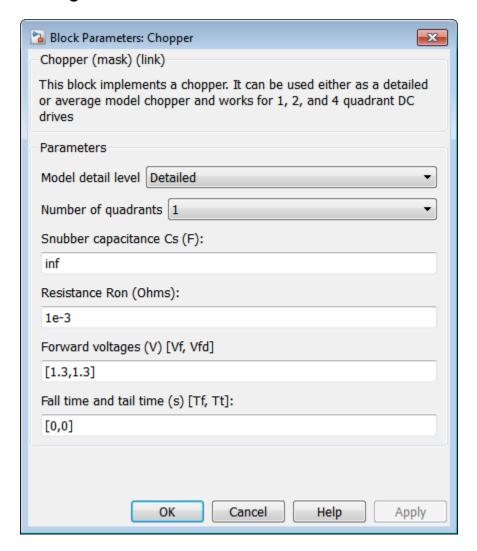
The average input current and output voltage are given by, respectively:

$I_{in} = (2\alpha - 1)I_{out}$
$V_{out} = (2\alpha - 1)V_{in}$

with α being the duty cycle value of IGBT 1 and IGBT 4.

Dialog Box and Parameters

Mode detail level

Specify the model detail level to use:

- Detailed (default)

- Average

Number of quadrants

Select from these operating quadrants:

- `1` — One quadrant
- `2` — Two quadrants (default)
- `4` — Four quadrants

Snubber resistance Rs (Ohms)

The value of the snubber resistance of the rectifier. When you set the **Model detail level** parameter to `Detailed`, this parameter is visible only when you set the **Number of quadrants** parameter to `4`. When you set the **Model detail level** parameter to `Average`, this parameter is visible only when you set the **Number of quadrants** parameter to `2` or `4`. The default value is `0`.

Snubber capacitance Cs (F)

The value of the snubber capacitance of the rectifier, in farad. The default value is `inf`.

Resistance Ron (Ohms):

Internal resistance of the selected device, in ohms. The default value is `1e-3`.

Forward voltages (V) [Vf, Vd]

Forward voltages, in volts, of the forced-commutated devices (IGBT, MOSFET, or GTO) and of the antiparallel diodes. The default value is `[1.3,1.3]`.

Fail time and tail time (s) [Tf, Tt]

Fall time Tf and tail time Tt, in seconds, for the GTO or the IGBT devices. The default value is `[0,0]`.

Inputs and Outputs

`g`

The gate input for the controlled switch devices. Pulses are sent to upper and lower switches of the half- or full-bridge converter. This port is visible only when you set the **Model detail level** parameter to `Detailed`.

`Duty Cycle`

The duty cycles required by IGBT 1 and IGBT 2 of a half-bridge converter. This port is visible only when you set the **Model detail level** parameter to `Average` and the **Number of quadrants** parameter to `1` or `2`.

Duty Cycles

The duty cycles required by IGBT 1 and 4 and IGBT 2 and 3 of the full-bridge converter. This port is visible only when you set the **Model detail level** parameter to `Average` and the **Number of quadrants** parameter to `4`.

+

The positive terminal on the DC source side.

-

The negative terminal on the DC source side.

A

The bridge-converter output terminals on the motor side.

B

The bridge-converter output terminals on the motor side. This port is visible only when you set the **Number of quadrants** parameter to `4`.

Examples

The Chopper block is used in the DC5, DC6, and DC7 blocks from the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also
Circulating Current Inductors | Inverter (Five-Phase) | Inverter (Three-Phase) | Thyristor Converter

More About
· "Electric Drives Library"
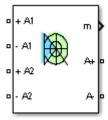
Introduced in R2015b

Circulating Current Inductors

Implement circulating current inductors for four-quadrant thyristor bridge converter

Library
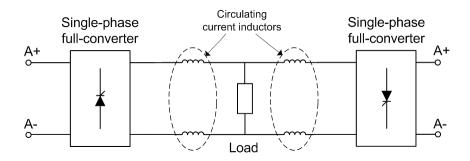
Electric Drives/Fundamental Drives
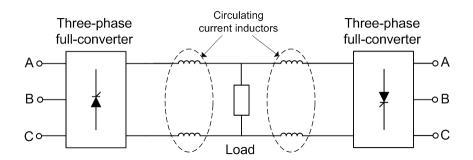
Description

Circulating current inductors, commonly referred as inter-group-reactors (IGR), in a four-quadrant thyristor bridge converter, limit the circulating current in dual thyristor converters when the latter operates in circulating current mode.
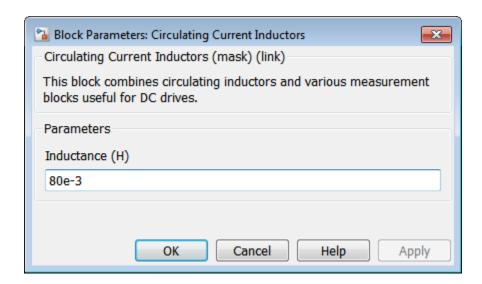
The Circulating Current Inductors block consists of two pairs of inductors connected to each converter output for the single-phase configuration and for the three-phase configuration, respectively.

The circulating current produced by the instantaneous voltage difference at the terminal of both converters is limited by these inductors.

Dialog Box and Parameters

Inductance (H)

>The inductance, in henry, of each circulating current inductor. The default value is 80e-3.

Inputs and Outputs

`+A1, -A1`

Connect these terminals to the positive and negative terminals on the DC side of the positive thyristor bridge converter.

`+A2, -A2`

Connect these terminals to the positive and negative terminals on the DC side of the negative thyristor bridge converter.

`m`

Vector containing four measurement signals: the output DC voltages Vdc1 and Vdc2 and the currents Idc1 and Idc2 of the thyristor bridge converters.

Examples

The Circulating Current Inductors block is used in the DC2 and DC4 blocks from the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

`Chopper` | `Inverter (Five-Phase)` | `Inverter (Three-Phase)` | `Thyristor Converter`

More About

- "Electric Drives Library"

Introduced in R2015b

Connection Port

Create Physical Modeling connector port for subsystem

Library

Fundamental Blocks/Elements
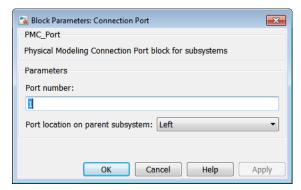
Description

The Connection Port block, placed inside a subsystem composed of SimPowerSystems blocks, creates a Physical Modeling open round connector port ○ on the boundary of the subsystem. Once connected to a connection line, the port becomes solid ●. Once you begin the simulation, the solid port ● becomes an electrical terminal port, an open square □.

You connect individual SimPowerSystems blocks and subsystems made of SimPowerSystems blocks to one another with SimPowerSystems connection lines, instead of regular Simulink signal lines. These are anchored at the open, round connector ports ○. Subsystems constructed of SimPowerSystems blocks automatically have such open round connector ports. You can add additional connector ports by adding Connection Port blocks to your subsystem.

Dialog Box and Parameters

Port number

This field labels the subsystem connector port created by the block. Multiple connector ports on the boundary of a single subsystem require different numbers as labels. The default value for the first port is 1.

Port location on parent subsystem

Choose which side of the parent subsystem boundary the port is placed on. The choices are Left or Right. The default is Left.

Introduced before R2006a

Controlled Current Source

Implement controlled current source

Library

Fundamental Blocks/Electrical Sources
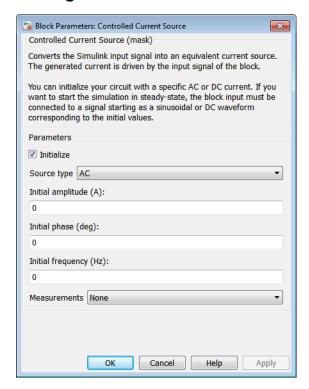
Description

The Controlled Current Source block converts the Simulink input signal into an equivalent current source. The generated current is driven by the input signal of the block. The positive current direction is as shown by the arrow in the block icon.

You can initialize the Controlled Current Source block with a specific AC or DC current. If you want to start the simulation in steady state, the block input must be connected to a signal starting as a sinusoidal or DC waveform corresponding to the initial values.

Note The Simulink input signal needs to be a complex value (phasor) when you are using the Controlled Current Source block in a phasor simulation, because in this case, SimPowerSystems software does not automatically convert the input signal from time-domain into complex (phasor) signal.

Dialog Box and Parameters

Initialize

If selected, initializes the Controlled Current Source block with the specified **Initial current**, **Initial phase**, and **Initial frequency** parameters.

Source type

The **Source type** parameter is not visible if the **Initialize** parameter is not selected.

The type of current source. Select AC to initialize the Controlled Current Source Block as an AC current source. Select DC to initialize the Controlled Current Source block as a DC current.

Initial current

The **Initial current** parameter is not visible in the dialog box if the **Initialize** parameter is not selected. The initial peak current for the initialization of the source, in amperes (A).

Initial phase

The initial phase for the initialization of the source, in degrees. The **Initial phase** parameter is not visible in the dialog box if the **Source type** parameter is set to **DC**.

Initial frequency

The initial frequency for the initialization of the source, in hertz (Hz). The **Initial frequency** parameter is not visible in the dialog box if the **Source type** parameter is set to **DC**.

Measurements
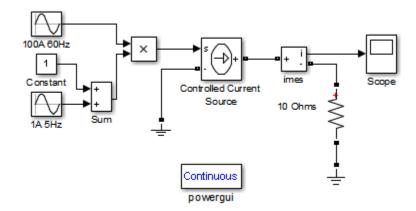
Select `Current` to measure the current flowing through the Controlled Current Source block.
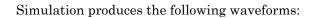
Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurement is identified by a label followed by the block name:

Measurement	Label
Current	`Isrc:`

Example
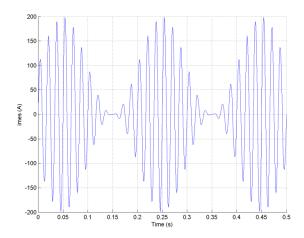
The `power_controlcurr` example uses a Controlled Current Source to generate a 60 Hz current modulated at 5 Hz.

Simulation produces the following waveforms:

See Also

AC Current Source, Controlled Voltage Source, Multimeter

Introduced before R2006a

Controlled Voltage Source

Implement controlled voltage source

Library

Fundamental Blocks/Electrical Sources
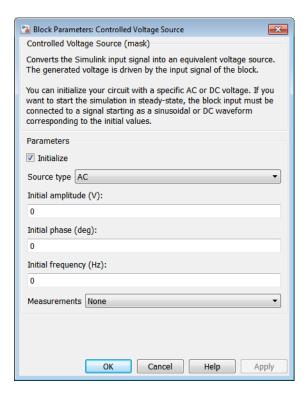
Description

The Controlled Voltage Source block converts the Simulink input signal into an equivalent voltage source. The generated voltage is driven by the input signal of the block.

You can initialize the Controlled Voltage Source block with a specific AC or DC voltage. If you want to start the simulation in steady state, the Simulink input must be connected to a signal starting as a sinusoidal or DC waveform corresponding to the initial values.

Note The Simulink input signal needs to be a complex value (phasor) when you are using the Controlled Voltage Source block in a phasor simulation, because in this case, SimPowerSystems software does not automatically convert the input signal from time-domain into complex (phasor) signal.

Dialog Box and Parameters

Block Parameters: Controlled Voltage Source

Controlled Voltage Source (mask)

Converts the Simulink input signal into an equivalent voltage source. The generated voltage is driven by the input signal of the block.

You can initialize your circuit with a specific AC or DC voltage. If you want to start the simulation in steady-state, the block input must be connected to a signal starting as a sinusoidal or DC waveform corresponding to the initial values.

Parameters

☑ Initialize

Source type | AC ▾

Initial amplitude (V):

0

Initial phase (deg):

0

Initial frequency (Hz):

0

Measurements | None ▾

[OK] [Cancel] [Help] [Apply]

Initialize

If selected, initializes the Controlled Voltage Source block with the specified **Initial voltage**, **Initial phase**, and **Initial frequency** parameters.

Source type

The **Source type** parameter is not available if the **Initialize** parameter is not selected.

The type of voltage source. Select AC to initialize the Controlled Voltage Source block with an AC voltage source. Select DC to initialize the Controlled Voltage Source Block with a DC voltage.

Initial voltage

The **Initial voltage** parameter is not available if the **Initialize** parameter is not selected. The initial voltage for the initialization of the source, in volts (V).

Initial phase

The **Initial phase** parameter is not available if the **Source type** parameter is set to **DC**. The initial phase for the initialization of the source, in degrees.

Initial frequency

The initial frequency for the initialization of the source, in hertz (Hz). The **Initial frequency** parameter is not available in the dialog box if the **Source type** parameter is set to **DC**.

Measurements

Select `Voltage` to measure the voltage across the terminals of the Controlled Voltage Source block.
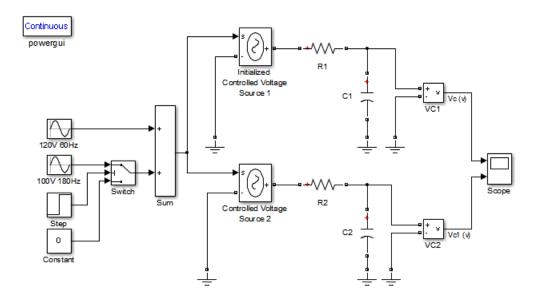
Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurement is identified by a label followed by the block name:

Measurement	Label
Voltage	Usrc:

Example
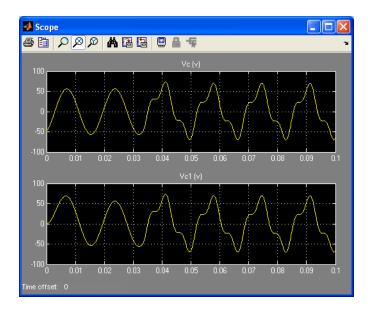
The power_controlvolt example uses Controlled Voltage Source blocks to generate a 60 Hz sinusoidal voltage containing a third harmonic. One Controlled Voltage Source block is initialized as a 120 V AC voltage source with an initial frequency of 60 Hz and initial phase set to 0. The second Controlled Voltage Source block is not initialized.

At t = 0.0333 s, a 100 V-180 Hz sinusoidal signal is added to the 120 V Simulink signal. The resulting capacitor voltages are compared on a Scope block.

The Vc voltage starts in steady state, whereas the Vc1 voltage contains a DC offset.

See Also

AC Current Source, Controlled Current Source, Multimeter
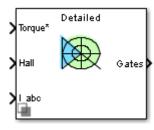
Introduced before R2006a

Current Controller (Brushless DC)

Implement current/torque controller model for brushless DC machine.

Library

Electric Drives/Fundamental Drives

Description
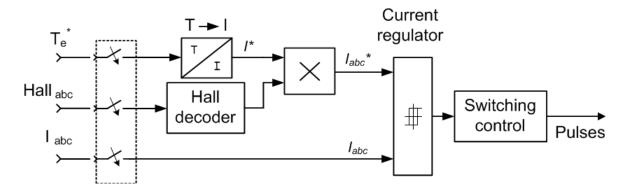
The Current Controller (Brushless DC) block represents a hysteresis current controller for use with a brushless DC machine. It has two operating modes to represent a detailed or an average-value inverter.

Detailed Model
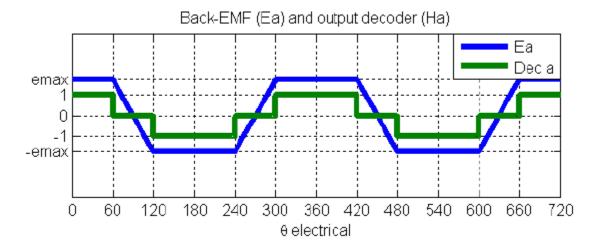
In detailed mode, the Current Controller (Brushless DC) block contains four main blocks:

Current controller

The T to I block performs the conversion from the reference torque to the peak reference current. The relation that converts torque to current assumes pure rectangular current waveforms. In practice, due to the motor inductance, you cannot obtain these currents. Therefore the electromagnetic torque might be lower than the reference torque, especially at high speed.

The Hall decoder block extracts the BEMF information from the Hall Effect sensor signals. It represents the normalized ideal phase currents to be injected in the motor phases. The figure shows the BEMF of phase A and the output of the Hall decoder for the phase A.

Back-EMF (Ea) and output decoder (Ha)
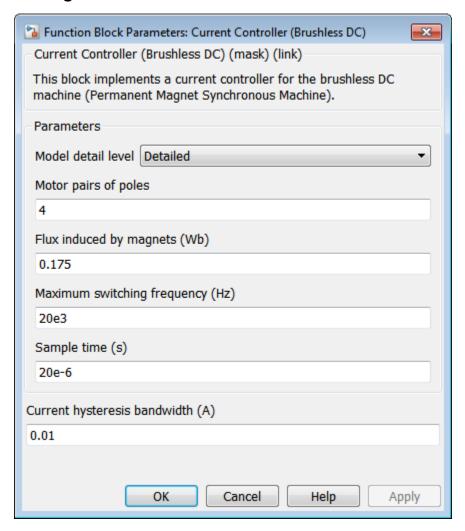
The Current regulator block is a bang-bang current controller with adjustable hysteresis bandwidth. The Switching control block limits the inverter commutation frequency to a maximum value that you specify. In a detailed model, the Current Controller (Brushless DC) block outputs the actual pulses for the inverter switches.

Average Model

In average mode, the Current Controller (Brushless DC) block does not model the high-frequency switching actions of the power switches. The output of the block is the three-phase motor current references of the machine controlled by the average-value inverter.

Dialog Box and Parameters

Model detail level

Specify the model detail level to use:

- Detailed (default)
- Average

Motor pairs of poles

The number of pole pairs of the machine controlled by the current controller. The default value is 4.

Flux induced by magnets (Wb)

The constant flux, in weber, per pole pairs induced in the stator windings by the magnets of the machine. The default value is 0.175.

Maximum switching frequency (Hz)

The maximum inverter switching frequency, in hertz. This parameter is available only when the **Model detail level** parameter is set to Detailed. The default value is 20e3.
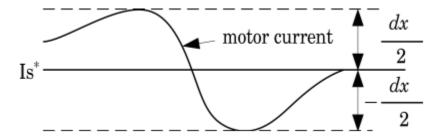
Sampling time (s)

The current controller sampling time, in seconds. The sampling time must be a multiple of the simulation time step. The default value is 20e-6.

Current hysteresis bandwidth (A)

The current regulator hysteresis bandwidth, in ampere. This parameter is enabled only when the **Model detail level** parameter is set to Detailed. This value corresponds to the total hysteresis bandwidth distributed symmetrically around the current set point.

The default value is 0.01.

Inputs and Outputs

`Torque*`

Torque reference, typically provided by a speed controller.

`Hall`

Hall Effect sensor signals for phase A, B, and C.

`I_abc`

The three line currents of the brushless DC machine.

`Sig`

The three reference currents (iabc*) required by the average-value inverter. This output is visible only when the **Model detail level** parameter is set to `Average`.

`Gates`

Pulses for the six inverter switches. This output is visible only when the **Model detail level** parameter is set to `Detailed`.

Examples

The Current Controller (Brushless DC) block is used in the AC7 block in the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

```
Bridge Firing Unit (AC) | Bridge Firing Unit (DC) | Current Controller
(DC) | Direct Torque Controller | Field-Oriented Controller |
Regulation Switch | Six-Step Generator | Space Vector Modulator | Speed
Controller (AC) | Speed Controller (DC) | Speed Controller (Scalar
Control) | Vector Controller (PMSM) | Vector Controller (WFSM) |
Voltage Controller (DC Bus)
```

More About

·   "Electric Drives Library"
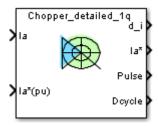
Introduced in R2015b

Current Controller (DC)

Implement PI current controller model for DC machine

Library

Electric Drives/Fundamental Drives

Description
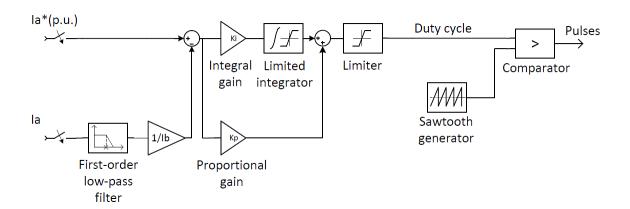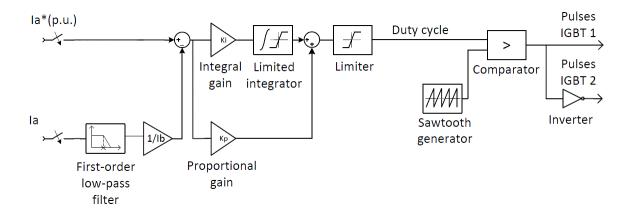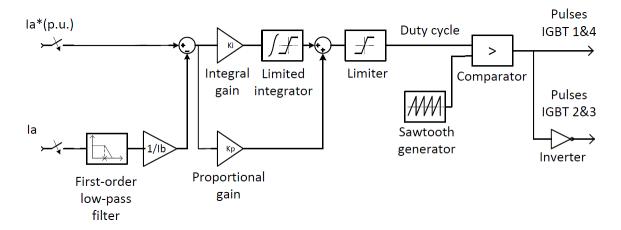
The Current Controller (DC) block models a PI current controller for use with a DC machine. The block has multiple instances, depending on the DC drive type (chopper DC drive or thyristor-based DC drive) and operating quadrants (one-, two-, or four-quadrant). It has two operating modes to represent a detailed or an average-value current controller.

Detailed Mode

The figure shows the models of the detailed Current Controller (DC) block for one-, two-, and four-quadrant chopper DC drives, respectively.
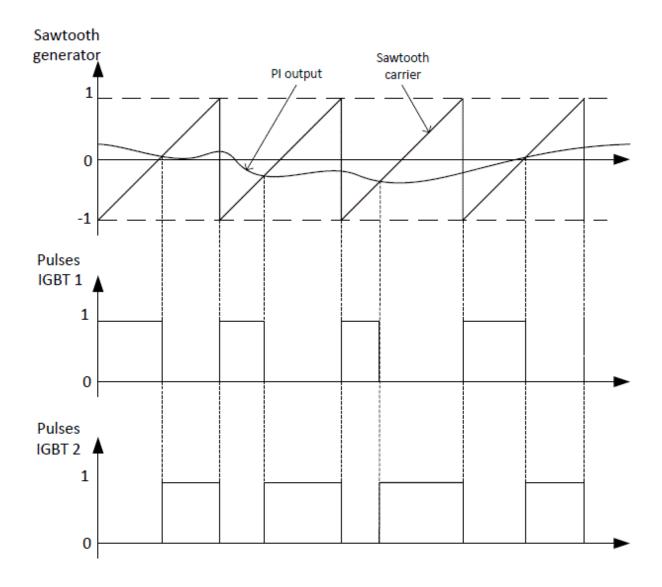
The inputs of the DC current controller block are the current reference (in pu) and the armature current flowing through the motor. The current reference is typically provided by a speed or torque controller. The armature current input is filtered by a first-order low-pass filter.

The duty cycle of the chopper is computed with a PI regulator. The duty cycle is compared with a fixed frequency sawtooth carrier signal to obtain the required gate pulses (PWM) for the chopper devices (IGBT 1 and IGBT 2). The figure shows PWM signal generation for a two-quadrant chopper DC drive.

Average Model

The Average Current Controller (DC) model is normally used with average-value DC chopper models where the high-frequency switching actions of the power switches are not represented.
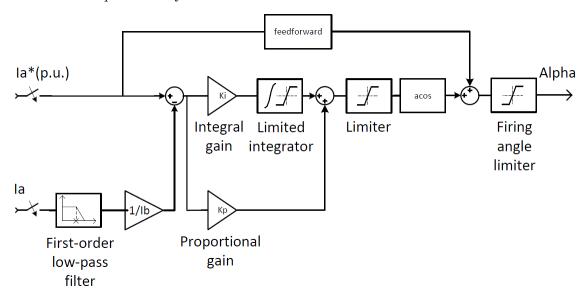
The Average Current Controller (DC) block is similar to the detailed model. However, there is no PWM signal generation. The output of the Average Current Controller (DC) block is the duty cycle of the IGBTs. For a two-quadrant operation, two duty cycles are computed for IGBT 1 and IGBT 2. For a four-quadrant operation, two duty cycles are computed for IGBT 1 and IGBT 4 and for IGBT2 and IGBT 3.
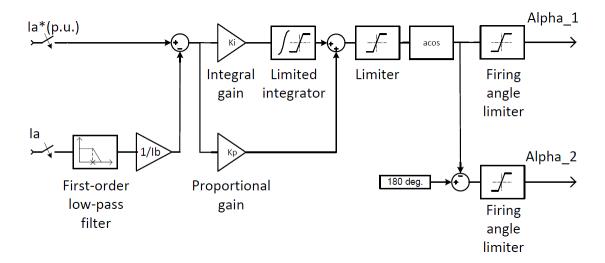
Current Controller (DC) for Chopper DC Drives

For chopper DC drives, the block outputs actual pulses (detailed mode) or duty cycle (average mode) for the DC chopper.

Current Controller (DC) for Thyristor-Based DC Drives

For thyristor-based DC drives, the Current Controller (DC) block outputs the firing angle for the thyristor bridge converter. The figure shows the models for a two-quadrant and four-quadrant thyristor-based DC drive.

A PI regulator computes the appropriate firing angle for the thyristor bridge. For two-quadrant operation, a feed-forward term is added to the firing angle to compensate for nonlinearities appearing during discontinuous conduction.

For four-quadrant thyristor-based drives, the DC current controller outputs two firing angles (Alpha_1 and Alpha_2) for the two antiparalleled thyristor bridges. The sum of the firing angles is 180 degrees at all times. This setting ensures opposite average voltages at each converter DC output terminal and maintains identical average voltages at the DC motor armature.

Dialog Box and Parameters

Function Block Parameters: Current Controller (DC)

Current Controller (DC) (mask) (link)

This block implements a PI current regulator for a DC machine.

Parameters

Drive type `Chopper based`

Model detail level `Detailed`

Number of quadrants `1`

Base quantities

Power (VA)
`5*746`

Voltage (V)
`240`

Controller gains

Proportional
`2`

Integral
`200`

Low-pass filter cutoff frequency (Hz)
`500`

Switching frequency (Hz)
`5e3`

Controller sample time (s)
`20e-6`

Network sample time (s)
`1e-6`

OK   Cancel   Help   Apply

Drive type

Specify the drive type to use:

- `Chopper based` (default)
- `Rectifier based`

Model detail level

Select between the detailed and the average-value model. This parameter is available only when the **Drive type** parameter is set to `Chopper based`.

Select one of these values:

- `Detailed` (default)
- `Average`

Number of quadrants

Specify the number of operating quadrants to use. Select between 1, 2, and 4.

The default value is 2.

Power (VA)

Base power in volt amperes of the DC machine, typically equivalent to the nominal power. The default value is `5*746`.

Voltage (V)

Base voltage in volts of the DC machine, typically equivalent to the nominal voltage. The default value is `240`.

Proportional

The PI controller proportional gain. The default value is 2.

Integral

The PI controller integral gain. The default value is `200`.

Low-pass filter cutoff frequency (Hz)

The cutoff frequency, in hertz, of the low-pass filter used to filter the armature current measurement. The default value is `500`.

Switching frequency (Hz)

The switching frequency, in hertz, of the DC chopper. This parameter is available only when the **DC drive type** parameter is set to `Chopper based` and the **Detail level** parameter is set to `Detailed`.

The default value is `5e3`.

Firing angle limits

The lower and upper limits of the firing angle, in degrees. This parameter is available only when the **Drive type** parameter is set to `Rectifier based`.

Controller sample time (s)

The current controller sampling time, in seconds. The sampling time must be a multiple of the simulation time step. The default value is `20e-6`.

Network sample time (s)

The time step used for the simulation, in seconds. The default value is `1e-6`.

Inputs and Outputs

`la`

The measured armature current (A).

`la*(pu)`

Armature current reference in per-unit, typically provided by a speed/torque controller.

`d_i`

Armature current reference error (difference between the reference and the actual machine current).

`la*`

Armature current reference (A).

`Pulse`

PWM pulse signal required by the one-quadrant DC chopper. This port is visible only when the **Drive type** parameter is set to `Chopper based`, the **Model detail level** parameter is set to `Detailed`, and the **Number of quadrants** parameter is set to `1`.

`Pulses`

PWM pulse signal required by the two-quadrant DC chopper or the four-quadrant DC chopper. This port is visible only when the **Drive type** parameter is set to `Chopper based`, the **Model detail level** parameter is set to `Detailed`, and the **Number of quadrants** parameter is set to `2` or `4`.

`Dcycle`

Duty cycle required by the one-quadrant DC chopper. This port is visible only when the **Drive type** parameter is set to `Chopper based`, the **Model detail level** parameter is set to `Average`, and the **Number of quadrants** parameter is set to `1`.

Dcycles

The duty cycles required by the two-quadrant DC chopper or the four-quadrant DC chopper. This port is visible only when the **Drive type** parameter is set to `Chopper based`, the **Model detail level** parameter is set to `Average`, and the **Number of quadrants** parameter is set to `2` or `4`.

Alpha

The firing angle required by the one-quadrant thyristor bridge or the two-quadrant thyristor bridge converter. This port is visible only when the **Drive type** parameter is set to `Thyristor based` and the **Number of quadrants** parameter is set to `1` or `2`.

Alpha_1

The firing angle required by the first antiparalleled thyristor bridge in a four-quadrant DC drive. This port is visible only when the **Drive type** parameter is set to `Thyristor based` and the **Number of quadrants** parameter is set to `4`.

Alpha_2

The firing angle required by the second antiparalleled thyristor bridge in a four-quadrant DC drive. This port is visible only when the **Drive type** parameter is set to `Thyristor based` and the **Number of quadrants** parameter is set to `4`.

Examples

The Current Controller (DC) block is used in the DC1 to DC7 blocks from the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

Bridge Firing Unit (AC) | Bridge Firing Unit (DC) | Current Controller (Brushless DC) | Direct Torque Controller | Field-Oriented Controller | Regulation Switch | Six-Step Generator | Space Vector Modulator | Speed

Controller (AC) | Speed Controller (DC) | Speed Controller (Scalar Control) | Vector Controller (PMSM) | Vector Controller (WFSM) | Voltage Controller (DC Bus)

More About

*   "Electric Drives Library"

Introduced in R2015b

Current Measurement

Measure current in circuit

Library

Fundamental Blocks/Measurements
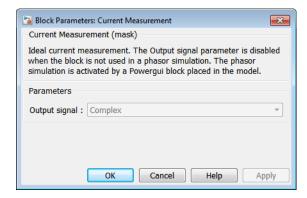
Description

The Current Measurement block is used to measure the instantaneous current flowing in any electrical block or connection line. The Simulink output provides a Simulink signal that can be used by other Simulink blocks.

Dialog Box and Parameters

Output signal

> Specifies the format of the output signal when the block is used in a phasor simulation. The **Output signal** parameter is disabled when the block is not used in a phasor simulation. The phasor simulation is activated by a Powergui block placed in the model.

Set to `Complex` to output the measured current as a complex value. The output is a complex signal.

Set to `Real-Imag` to output the real and imaginary parts of the measured current. The output is a vector of two elements.

Set to `Magnitude-Angle` to output the magnitude and angle of the measured current. The output is a vector of two elements.

Set to `Magnitude` to output the magnitude of the measured current. The output is a scalar value.

Example

The power_currmeasure example uses four Current Measurement blocks to read currents in different branches of a circuit. The two scopes display the same current.

See Also

powergui, Three-Phase V-I Measurement, Voltage Measurement
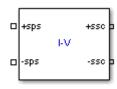
Introduced before R2006a

Current-Voltage Simscape Interface

Ideal coupling between SimPowerSystems and Simscape electrical circuits

Library

Fundamental Blocks/Interface Elements

Description

The Current-Voltage Simscape Interface block connects SimPowerSystems circuits with electrical elements from the Simscape Foundation library. This block preserves current through the block and voltage across the block, conserving electrical power.

- On the SimPowerSystems side, the electrical connector ports +sps and -sps act like a controlled current source, feeding current from the Simscape side to the connected SimPowerSystems elements, while maintaining the voltage across the block.

- On the Simscape side, the electrical connector ports +ssc and -ssc act like a controlled voltage source, feeding voltage from the SimPowerSystems side to the connected Simscape elements, while maintaining the current through the block.

The following figure gives an overview of the interface.
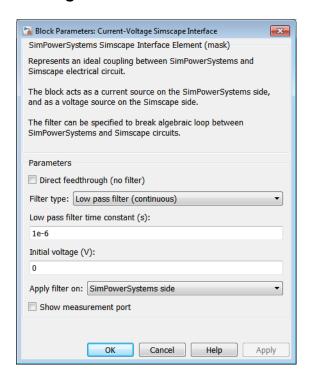
The block measures the voltage between the +sps and -sps ports and propagates it to the +ssc and -ssc ports, preserving the polarity. The block also measures the current flowing from the +ssc to the -ssc port and propagates it from the -sps to the +sps port.

You can specify a filter to break the algebraic loop between SimPowerSystems and Simscape ports. You can specify the filter as a first order continuous transfer function or as a discrete unit delay block. You can apply it on the SimPowerSystems side, to the measured voltage, or on the Simscape side, to the measured current. Depending on the measured signal where the filter is applied, the other signal is always a direct feedthrough.

If you do not specify a filter, direct feedthrough is applied on both measured signals. However, this configuration results in an algebraic loop containing the Voltage Measurement, Controlled Voltage Source, Current Sensor, and Controlled Current Source blocks, which might cause numerical issues.

Dialog Box and Parameters

Direct feedthrough (no filter)

If selected, direct feedthrough is applied between SimPowerSystems and Simscape ports on both sides.

Filter type

Set this parameter to `Low pass filter (continuous)` to implement a first order continuous transfer function filter between SimPowerSystems and Simscape ports.

Set this parameter to `Unit delay (discrete)` to implement a discrete unit delay filter between SimPowerSystems and Simscape ports.

Set this parameter to `First-order input filtering` to implement a first order continuous transfer function filter with first-order filtering of the Simulink-PS Converter block that provides one derivative. You can apply this filter only on the SimPowerSystems side.

Set this parameter to `Second-order input filtering` to implement a first order continuous transfer function filter with second-order filtering on the Simulink-PS Converter block that provides derivatives one and two. You can apply this filter only on the SimPowerSystems side.

The **Filter type** parameter is not visible when the **Direct feedthrough (no filter)** check box is selected.

Low pass filter constant (s)

Specify the low pass filter time constant of the filter, in seconds. This parameter is visible only when the **Filter type** parameter is set to `Low pass filter (continuous)`, to `First-order input filtering`, or to `Second-order input filtering`.

Sample time of unit delay (s)

Specify the sample time of the unit delay filter, in seconds. This parameter is visible only when the **Filter type** parameter is set to `Unit delay (discrete)`.

Initial voltage (V)

Specify the initial voltage value of the measured SimPowerSystems voltage.

This parameter is visible only when you apply the filter on the SimPowerSystems side.

Initial current (A)

Specify the initial current value of the measured Simscape current.

This parameter is visible only when you apply the filter on the Simscape side.

Apply filter on

Set this parameter to `SimPowerSystems side` to apply the filter on the measured SimPowerSystems voltage.

Set this parameter to `Simscape side` to apply the filter on the measured Simscape current.

The **Apply filter on** parameter is not visible when the **Direct feedthrough (no filter)** check box is selected, when the **Filter type** is set to `First-order input filtering`, or when the **Filter type** is set to `Second-order input filtering`.

Show measurement port

If selected, adds a Simulink output to the block that returns the SimPowerSystems current and voltage and to the Simscape current and voltages in a bus signal.

Limitations

When simulating SimPowerSystems models along with Simscape blocks, select the Simulink solver carefully.

Use `ode23tb` solver for solving SimPowerSystems circuits containing switches or nonlinear element. If you use other stiff solvers, SimPowerSystems software gives you the following warning:

```
Warning: You have required continuous-time simulation of a system containing
switches or nonlinear elements. The ode23tb variable-step stiff solver with
relative tolerance set to 1e-4 is recommended in order to get best accuracy
and simulationperformance. For some highly nonlinear models it may be
necessary to set the "Solver reset method" parameter to "Robust".
See "Improving Simulation Performance" chapter in SimPowerSystems documentation
for additional information on how to select an appropriate integration method.
```

However, if you use the `ode23tb` solver for solving models containing Simscape blocks, Simscape software gives you the following warning:

```
Warning: The solver chosen is not recommended if the model is stiff, which is
typical for models containing Simscape components. These solvers are typically
preferred for Simscape models:ode23t, ode15s or ode14x (fixed-step). To disable
this diagnostic,change the explicit solver diagnostic setting on the Simscape
panel of the model Configuration Parameters.
```

Although the Simscape warning can be disabled, as described in the warning message, the SimPowerSystems warning cannot be disabled with regular configuration parameters. To disable the SimPowerSystems warning when you choose a solver other than `ode23tb`, select the Powergui block in your model, then, at the MATLAB Command line, type:

```
set_param(gcb,'FunctionMessages','on')
```

Example

The power_SSCmodeling example provides a sample of interfacing SimPowerSystems and Simscape models. The example contains two similar circuits. The top circuit model uses the SimPowerSystems Breaker block for switching off the RL loads. The circuit at the bottom is identical in all respects, but it uses a Simscape model of the circuit breaker.

The Simscape Circuit Breaker subsystem in the bottom circuit contains the Current-Voltage Simscape Interface block, which connects the + and - ports of the Simscape Circuit breaker block to the SimPowerSystems + and - ports.

For the Simscape solver, this subsystem is a simple circuit consisting of a circuit breaker connected in parallel with a Controlled Voltage Source block. The Solver Configuration block and the Simscape Electrical Reference ground blocks are both required to simulate this Simscape model. This ground block is independent of the SimPowerSystems ground block found on the top level of the block diagram, and does not connect the negative terminal of the circuit breaker to the SimPowerSystems electric ground.

For the SimPowerSystems software, this subsystem is a simple controlled current source controlled by an external signal.

By running the example, you can observe the differences between the two implementations of a circuit breaker device. The Simscape Circuit breaker block is also demonstrated in the Simscape ssc_circuitbreaker example model.

See Also

Current-Voltage Simscape Interface (gnd), Voltage-Current Simscape Interface, Voltage-Current Simscape Interface (gnd)

Introduced in R2011b

Current-Voltage Simscape Interface (gnd)

Ideal coupling between SimPowerSystems and Simscape electrical circuits

Library

Fundamental Blocks/Interface Elements

Description

The Current-Voltage Simscape Interface (gnd) block connects SimPowerSystems circuits with electrical elements from the Simscape Foundation library. This block preserves current through the block and voltage across the block, conserving electrical power.

- On the SimPowerSystems side, the electrical connector port sps acts like a controlled current source referred to the ground, feeding current from the Simscape side to the connected SimPowerSystems elements.

- On the Simscape side, the electrical connector port ssc acts like a controlled voltage source referred to the ground, feeding voltage from the SimPowerSystems side to the connected Simscape elements.

The following figure gives an overview of the interface.

The block measures the voltage between the `sps` port and SimPowerSystems electrical reference and propagates it to the `ssc` port, preserving the polarity with respect to the Simscape electrical reference. The block also measures the current flowing from the `ssc` port to the Simscape electrical reference and propagates it to the `sps` port.

You can specify a filter to break the algebraic loop between SimPowerSystems and Simscape ports. You can specify the filter as a first order continuous transfer function or as a discrete unit delay block. You can apply the filter on the SimPowerSystems side, to the measured voltage, or on the Simscape side, to the measured current. Depending on the measured signal where you apply the filter, the other signal is always a direct feedthrough.

If you do not specify a filter, direct feedthrough is applied on both measured signals. However, this configuration results in an algebraic loop containing the Voltage Measurement, Controlled Voltage Source, Current Sensor, and Controlled Current Source blocks, which might cause numerical issues.

Dialog Box and Parameters

Direct feedthrough (no filter)

If selected, direct feedthrough is applied between SimPowerSystems and Simscape ports on both sides.

Filter type

Set this parameter to `Low pass filter (continuous)` to implement a first order continuous transfer function filter between SimPowerSystems and Simscape ports.

Set this parameter to `Unit delay (discrete)` to implement a discrete unit delay filter between SimPowerSystems and Simscape ports.

Set this parameter to `First-order input filtering` to implement a first order continuous transfer function filter with first-order filtering of the Simulink-PS Converter block that provides one derivative. You can apply this filter only on the SimPowerSystems side.

Set this parameter to `Second-order input filtering` to implement a first order continuous transfer function filter with second-order filtering of the Simulink-PS Converter block that provides derivatives one and two. You can apply this filter only on the SimPowerSystems side.

The **Filter type** parameter is not visible when the **Direct feedthrough (no filter)** check box is selected.

Low pass filter constant (s)

Specify the low pass filter time constant of the filter, in seconds. This parameter is visible only when the **Filter type** parameter is set to `Low pass filter (continuous)`, to `First-order input filtering`, or to `Second-order input filtering`.

Sample time of unit delay (s)

Specify the sample time of the unit delay filter, in seconds. This parameter is visible only when the **Filter type** parameter is set to `Unit delay (discrete)`.

Initial voltage (V)

Specify the initial voltage value of the measured SimPowerSystems voltage.

This parameter is visible only when you apply the filter on the SimPowerSystems side.

Initial current (A)

Specify the initial current value of the measured Simscape current.

This parameter is visible only when you apply the filter on the Simscape side.

Apply filter on

Set this parameter to `SimPowerSystems side` to apply the filter on the measured SimPowerSystems voltage.

Set this parameter to `Simscape side` to apply the filter on the measured Simscape current.

The **Apply filter on** parameter is not visible when the **Direct feedthrough (no filter)** check box is selected, when the **Filter type** is set to `First-order input filtering`, or when the **Filter type** is set to `Second-order input filtering`.

Show measurement port

If selected, adds a Simulink output to the block that returns the SimPowerSystems current and voltage and to the Simscape current and voltages in a bus signal.

Limitations

When simulating SimPowerSystems models along with Simscape blocks, select the Simulink solver carefully.

Use the `ode23tb` solver for solving SimPowerSystems circuits containing switches or nonlinear element. If you use other stiff solvers, SimPowerSystems software gives you the following warning:

```
Warning: You have required continuous-time simulation of a system containing
switches or nonlinear elements. The ode23tb variable-step stiff solver with
relative tolerance set to 1e-4 is recommended in order to get best accuracy
and simulationperformance. For some highly nonlinear models it may be
necessary to set the "Solver reset method" parameter to "Robust".
See "Improving Simulation Performance" chapter in SimPowerSystems documentation
for additional information on how to select an appropriate integration method.
```

However, if you use the `ode23tb` solver for solving models containing Simscape blocks, Simscape software gives you the following warning:

```
Warning: The solver chosen is not recommended if the model is stiff, which is
typical for models containing Simscape components. These solvers are typically
preferred for Simscape models:ode23t, ode15s or ode14x (fixed-step). To disable
this diagnostic,change the explicit solver diagnostic setting on the Simscape
panel of the model Configuration Parameters.
```

Although the Simscape warning can be disabled, as described in the warning message, the SimPowerSystems warning cannot be disabled with regular configuration parameters. To disable the SimPowerSystems warning when you choose a solver other than `ode23tb`, select the Powergui block in your model, then, at the MATLAB Command line, type:

```
set_param(gcb,'FunctionMessages','on')
```

Example

See the power_SSCmodeling example for an example of interfacing SimPowerSystems and Simscape models using the Current-Voltage Simscape Interface block.

See Also

`Current-Voltage Simscape Interface`, `Voltage-Current Simscape Interface`, `Voltage-Current Simscape Interface (gnd)`

Introduced in R2011b

DC Bus

Implement DC bus model that includes resistive braking chopper

Library

Electric Drives/Fundamental Drives
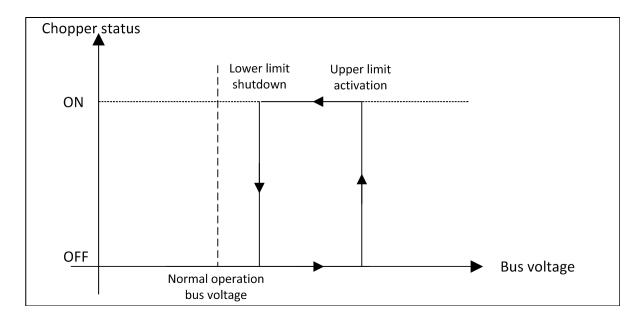
Description

The DC Bus block has two operating modes. The most common mode implements a capacitive DC bus with a proportional controller. The braking resistance is switched based on activation and shutdown voltages, which you supply as parameters. For the second operating mode, a smoothing inductor is added to the DC bus to filter out high-current harmonics generally present in six-step motor drives. A resistive braking chopper is modeled in both cases.

Capacitive DC Bus with Proportional Control
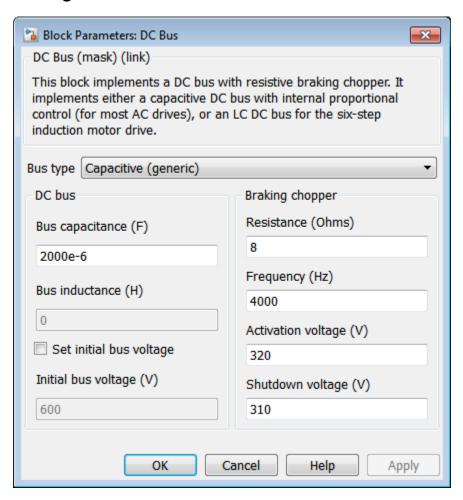
In this mode, the DC bus voltage is maintained within a range determined by the activation and shutdown voltages. As shown in the figure, the braking chopper is activated when the bus voltage reaches the upper limit of the hysteresis band. When the bus voltage reaches the lower limit of the hysteresis band, the braking chopper shuts down.

Chopper status

Lower limit
shutdown

Upper limit
activation

ON

OFF

Normal operation
bus voltage

Bus voltage

LC DC Bus for Six-Step Induction Motor Drive

In this mode, the DC bus voltage is kept as constant as possible. A thyristor rectifier ahead of the DC bus regulates the DC bus voltage. When the rectifier is close to its operating limits, the braking chopper further regulates the DC bus voltage. The smoothing inductor filters the current harmonics content generated by the thyristor rectifier.

Dialog Box and Parameters

Bus type

Specify the bus type to use:

- Capacitive (generic) (default)
- LC (for six-step drive)

Bus capacitance (F)

DC bus capacitance (F). The default value is `2000e-6`.

Bus inductance (H)

DC bus inductance (H). This parameter is required and available only when the **Bus type** parameter is set to `LC (for six-step drive)`. The default value is `2000e-6`.

Set initial bus voltage

Select to specify an initial voltage for the DC bus capacitor. Otherwise, the voltage is initialized at zero. The default value is not selected.

Initial bus voltage (V)

Initial bus voltage, in volts. This parameter is required and available only when the **Set initial bus voltage** check box is selected. The default value is `600`.

Resistance (ohms)

The braking resistance, in ohms. The default value is `8`.

Frequency (Hz)

The frequency at which the braking resistance is switched on and off, in hertz. The default value is `4000`.

Activation voltage (V)

The voltage at which the braking chopper is enabled, in volts. This value must be greater than or equal to the shutdown voltage. This parameter is required and available only when the **Bus type** parameter is set to `Capacitive (generic)`. The default value is `320`.

Shutdown voltage (V)

The voltage at which the braking chopper is disabled, in volts. Use a value less than or equal to the activation voltage. This parameter is required and available only when the **Bus type** parameter is set to `Capacitive (generic)`. The default value is `310`.

Inputs and Outputs

`P_chop`

Duty cycle of the braking chopper, typically provided by a DC bus voltage controller. This input is visible only when the **Bus type** parameter is set to `LC (for six-step drive)`.

`Brak_crtl`

This binary signal enables (1) or disables (0) the braking chopper. This input is visible only when the **Bus type** parameter is set to `LC (for six-step drive)`.

`in+`

The positive input port. It is usually connected to the positive output port of the rectifier.

`in-`

The negative input port. It is usually connected to the negative output port of the rectifier.

`Meas`

A vector containing these measurement signals:

- I rectifier (A): the current entering the DC bus on the rectifier side
- V rectifier (V): the voltage across the DC bus on the rectifier side. This signal is present only in the output vector when the **Bus type** parameter is set to `LC (for six-step drive)`.
- I bus (A): the current exiting the DC bus on the inverter side.
- V bus (V): the voltage across the DC bus on the inverter side. If the **Bus type** parameter is set to `Capacitive (generic)`, this voltage is also the rectifier-side voltage.

`Out+`

The positive output port. It is usually connected to the positive input port of the inverter.

`Out-`

The negative output port. It is usually connected to the negative input port of the inverter. Note that the in– and Out– ports are exactly the same electrical node.

Examples

The DC Bus block is used in the AC1 and AC3 blocks in the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also
Active Rectifier

More About
- "Electric Drives Library"
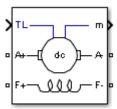
Introduced in R2015b

DC Machine

Implement wound-field or permanent magnet DC machine

Library

Fundamental Blocks/Machines

Description

The DC Machine block implements a wound-field or permanent magnet DC machine.

For the wound-field DC machine, access is provided to the field terminals (F+, F−) so that the machine model can be used as a shunt-connected or a series-connected DC machine. The torque applied to the shaft is provided at the Simulink input T_L.

The armature circuit (A+, A−) consists of an inductor La and resistor Ra in series with a counter-electromotive force (CEMF) E.

The CEMF is proportional to the machine speed.
$E = K_E\omega$

K_E is the voltage constant and ω is the machine speed.

In a separately excited DC machine model, the voltage constant K_E is proportional to the field current I_f:
$K_E = L_{af}I_f,$

L_{af} is the field-armature mutual inductance.

The electromechanical torque developed by the DC machine is proportional to the armature current I_a.

$T_e = K_T I_a,$

K_T is the torque constant. The sign convention for T_e and T_L is:
T_e , $T_L > 0$: Motor mode
T_e , $T_L < 0$: Generator mode

The torque constant is equal to the voltage constant.
$K_T = K_E.$

The armature circuit is connected between the A+ and A− ports of the DC Machine block. It is represented by a series Ra La branch in series with a Controlled Voltage Source and a Current Measurement block.

In the wound-field DC machine model, the field circuit is represented by an RL circuit. It is connected between the F+ and F− ports of the DC Machine block.

In the permanent magnet DC machine model, there is no field current as the excitation flux is established by the magnets. K_E and K_T are constants.
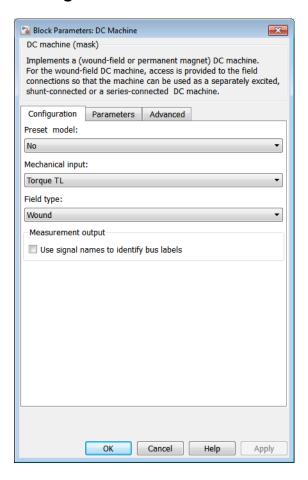
The mechanical part computes the speed of the DC machine from the net torque applied to the rotor. The speed is used to implement the CEMF voltage E of the armature circuit.

The mechanical part implements this equation:

$$J\frac{d\omega}{dt} = T_e - T_L - B_m\omega - T_f,$$

J = inertia, B_m = viscous friction coefficient, and T_f = Coulomb friction torque.

Dialog Box and Parameters

- • "Configuration Tab" on page 1-206
- • "Parameters Tab" on page 1-209
- • "Advanced Tab" on page 1-210

Configuration Tab

Preset model

Provides a set of predetermined electrical and mechanical parameters for various DC machine ratings of power (HP), DC voltage (V), rated speed (rpm), and field voltage (V).

The preset models are available only for the wound-field DC machine model.

Select one of the preset models to load the corresponding electrical and mechanical parameters in the entries of the dialog box. Select No if you do not want to use a preset model, or if you want to modify some of the parameters of a preset model.

When you select a preset model, the electrical and mechanical parameters in the **Parameters** tab of the dialog box become unmodifiable (unavailable). To start from a given preset model and then modify machine parameters.:

1   Select the preset model that you want to initialize the parameters.

2   Change the **Preset model** parameter value to No. This does not change the machine parameters. By doing so, you break the connection with the particular preset model.

3   Modify the machine parameters as you want, then click **Apply**.

Mechanical input
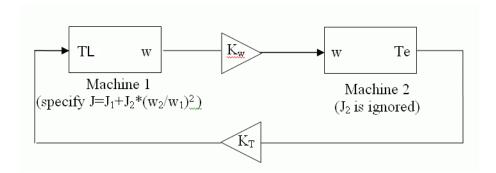
Select the torque applied to the shaft or the rotor speed as a Simulink input of the block, or represent the machine shaft by a Simscape rotational mechanical port.

Select **Torque TL** to specify a torque input, in N.m, and change labeling of the block input to TL. The machine speed is determined by the machine Inertia J and by the difference between the applied mechanical load torque TL and the internal electromagnetic torque Te. The sign convention for the mechanical torque is: when the speed is positive, a positive torque signal indicates motor mode and a negative signal indicates generator mode.

Select **Speed w** to specify a speed input, in rad/s, and change labeling of the block input to w. The machine speed is imposed and the mechanical part of the model (Inertia J) is ignored. Using the speed as the mechanical input allows modeling a mechanical coupling between two machines.
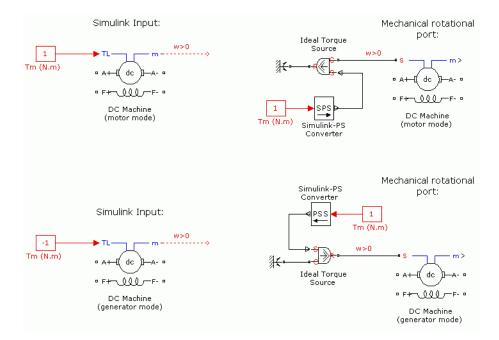
The next figure indicates how to model a stiff shaft interconnection in a motor-generator. The speed output of machine 1 (motor) is connected to the speed input of machine 2 (generator), while machine 2 electromagnetic torque output Te is applied to the mechanical load torque input TL of machine 1. The Kw factor takes into

account speed units of both machines (rad/s) and gear box ratio. The KT factor takes into account torque units of both machines (N.m) and machine ratings. Also, as the inertia J2 is ignored in machine 2, J2 referred to machine 1 speed must be added to machine 1 inertia J1.

Select **Mechanical rotational port** to add to the block a Simscape mechanical rotational port that allows connection of the machine shaft with other Simscape blocks having mechanical rotational ports. The Simulink input representing the mechanical torque TL or the speed w of the machine is then removed from the block.

The next figure indicates how to connect an Ideal Torque Source block from the Simscape library to the machine shaft to represent the machine in motor mode, or in generator mode, when the rotor speed is positive.

Field type

Select between the wound-field and the permanent magnet DC machine.

Use signal names to identify bus labels

When this check box is selected, the measurement output uses the signal names to identify the bus labels. Select this option for applications that require bus signal label to have only alphanumeric characters.

When this check box is cleared, the measurement output uses the signal definition to identify the bus labels. The labels contain nonalphanumeric characters that are incompatible with some Simulink applications.

Parameters Tab

Armature resistance and inductance [Ra La]

The armature resistance Ra, in ohms, and the armature inductance La, in henries.

Field resistance and inductance [Rf Lf]

The field resistance Rf, in ohms, and the field inductance Lf, in henries. This parameter is visible only when the **Field type** parameter on the **Configuration** tab is set to `Wound`.

Field armature mutual inductance Laf

The field armature mutual inductance, in henries. This parameter is visible only when the **Field type** parameter on the **Configuration** tab is set to `Wound`.

Specify

For a permanent magnet DC machine, select the machine constant that you want to specify for block parameterization. The values are `Torque constant` and `Back-emf constant`. This parameter is visible only when the **Field type** parameter on the **Configuration** tab is set to `Permanent magnet`.

Torque constant

The torque per current constant of the permanent magnet DC machine, in N.m/A. This parameter is only visible when the **Field type** parameter on the **Configuration** tab is set to `Permanent magnet` and the **Specify** parameter above is set to `Torque constant`.

Back-emf constant

The voltage per speed constant of the permanent magnet DC machine, in V/rpm. This parameter is only visible when the **Field type** parameter on the **Configuration** tab is set to `Permanent magnet` and the **Specify** parameter above is set to `Back-emf constant`.

Total inertia J

The total inertia of the DC machine, in kg.m^2.

Viscous friction coefficient Bm

The total friction coefficient of the DC machine, in N.m.s.

Coulomb friction torque Tf

The total Coulomb friction torque constant of the DC machine, in N.m.

Initial speed

Specifies an initial speed for the DC machine, in rad/s, in order to start the simulation with a specific initial speed. To start the simulation in steady state, the initial value of the input torque signal T_L must be proportional to the initial speed.

Advanced Tab

Sample time (–1 for inherited)

Specifies the sample time that the block uses. To inherit the sample time specified in the Powergui block, set this parameter to -1.

Inputs and Outputs

TL

The block input is the mechanical load torque, in N.m.

w

The alternative block input (depending on the value of the **Mechanical input** parameter) is the machine speed, in rad/s.

m

The output of the block is a vector containing measurement signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Name	Definition	Units
w	Speed wm	rad/s
iA	Armature current ia	A
iF	Field current if	A
Te	Electrical torque Te	N.m

Example

The power_dcmotor example illustrates the starting of a 5 HP 240 V DC machine with a three-step resistance starter.

References

[1] *Analysis of Electric Machinery,* Krause et al., pp. 89–92.

See Also

Asynchronous Machine, Synchronous Machine

Introduced before R2006a

DC Voltage Source

Implement DC voltage source

Library

Fundamental Blocks/Electrical Sources
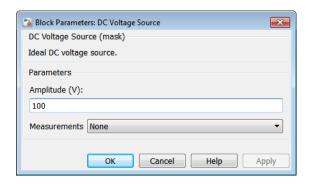
Description

The DC Voltage Source block implements an ideal DC voltage source. The positive terminal is represented by a plus sign on one port. You can modify the voltage at any time during the simulation.

Dialog Box and Parameters

Amplitude

The amplitude of the source, in volts (V).

Measurements
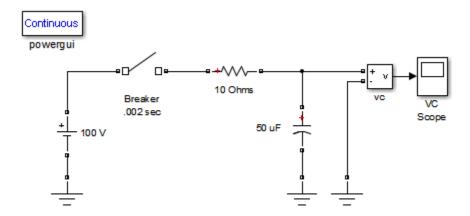
Select `Voltage` to measure the voltage across the terminals of the DC Voltage Source block.
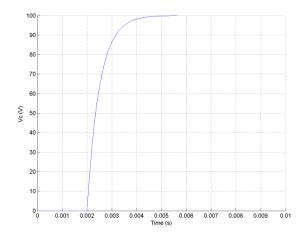
Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurement is identified by a label followed by the block name:

Measurement	Label
Voltage	Usrc:

Example

The power_dcvoltage example illustrates the simulation of the transient response of a first-order RC circuit.

See Also

AC Voltage Source, Controlled Voltage Source
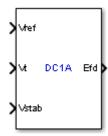
Introduced before R2006a

DC1A Excitation System

Implements IEEE type DC1A excitation system model

Library

Fundamental Blocks/Machines/Excitation Systems (sps_avr)

Description
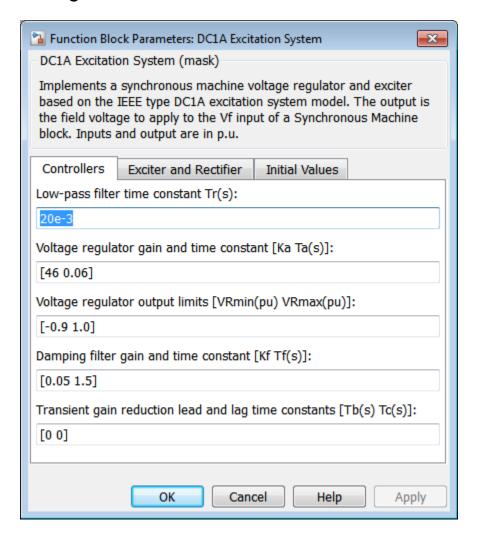
This block models a field controlled dc-commutator exciter with continuously acting voltage regulator. It uses self-excited shunt fields with a voltage regulator operating in a buck-boost mode. You can use this model to represent other types of excitation systems when detailed data is not available or when a simplified model is required [1].

This block is an adaptation of the DC1A excitation system of the IEEE 421 standard, copyright IEEE 2005, all rights reserved.

Dialog Box and Parameters

- "Controllers Tab" on page 1-218
- "Exciter and Rectifier Tab" on page 1-218
- "Initial Values Tab" on page 1-219

Controllers Tab

Low-pass filter time constant

The time constant Tr of the first-order system representing the stator terminal voltage transducer.

Voltage regulator gain and time constant

The gain Ka and time constant Ta of the first-order system representing the main regulator.

Voltage regulator output limits

The voltage regulator output limits VRmin and VRmax, in p.u.

Damping filter gain and time constant

The gain Kf and time constant Tf of the first-order system representing the derivative feedback.

Transient gain reduction lead and lag time constants

The time constants Tb and Tc of the first-order system representing the lead-lag compensator.

Exciter and Rectifier Tab

Exciter gain and time constant

The gain Ke and time constant Te of the first-order system representing the exciter.

Field voltage values

The exciter saturation function is defined as a multiplier of exciter alternator output voltage to represent the increase in exciter excitation requirements due to saturation [1]. The saturation function is determined by specifying two voltage points, Efd1 and Efd2 in p.u., on the air-gap line and constant resistance load saturation curve, and providing the corresponding two saturation multipliers SeEfd1 and SeEfd2.

Typically, the voltage Efd1 is a value near the expected exciter maximum output voltage. The Efd2 value is about 75% of Efd1.

Exciter saturation function values

The exciter saturation function is defined as a multiplier of exciter alternator output voltage to represent the increase in exciter excitation requirements due to saturation. The saturation function is determined by specifying two voltage points, Efd1 and

Efd2 in p.u., on the air-gap line and Constant Resistance Load saturation curve and providing the corresponding two saturation multipliers SeEfd1 and SeEfd2.

SeEfd1 and SeEfd2 multipliers are equal to A-B / B, A is the value of exciter field current on the Constant Resistance Load saturation curve corresponding to the selected Efd voltage, and B the value of exciter field current on the air-gap line corresponding to the selected Efd voltage [1].

If you do not want to model the saturation effect, set SeVe1 and SeVe2 values to zero.

Initial Values Tab

Initial values of terminal voltage and field voltage

The initial values of terminal voltage Vt0 and field voltage Efd0, both in p.u. Initial terminal voltage is normally set to 1 pu. The Vt0 and Efd0 values can be determined using the Powergui Load Flow tool.

Sample time

Specify a value greater than zero to discretize the block at the given sample time. Set to -1 to inherit the simulation type and sample time parameters of the Powergui block.

Ports

Vref

The reference value of the stator terminal voltage, in p.u.

Vt

The measured value in p.u. of the stator terminal voltage of the controlled Synchronous Machine block.

Vstab

Connect this input to a power system stabilizer to provide additional stabilization of power system oscillations. When you do not use this option, connect to a Simulink ground block. The input is in p.u.

Efd

The field voltage to apply to the Vf input of the controlled Synchronous Machine block. The output is in p.u.

Example

The `power_machines` example contains a Configurable Subsystem block that allows you to select between seven types of excitation systems to control the terminal voltage of the Synchronous Machine block. This configurable block refers to the `power_machines_lib` example library that contains seven pretuned excitation system blocks that fit simulation requirements for this example.

Right-click the EXCITATION configurable block, then select **DC1A** from the **Block Choice** menu to control the Synchronous Machine block using the DC1A Excitation System block.

References

[1] "IEEE Recommended Practice for Excitation System Models for Power System Stability Studies." *IEEE Standard*, Vol. 421, No. 5, 2005 (Revision of *IEEE 521.5-1992*).
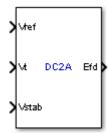
Introduced before R2006a

DC2A Excitation System

Implements IEEE type DC2A excitation system model

Library

Fundamental Blocks/Machines/Excitation Systems (sps_avr)

Description
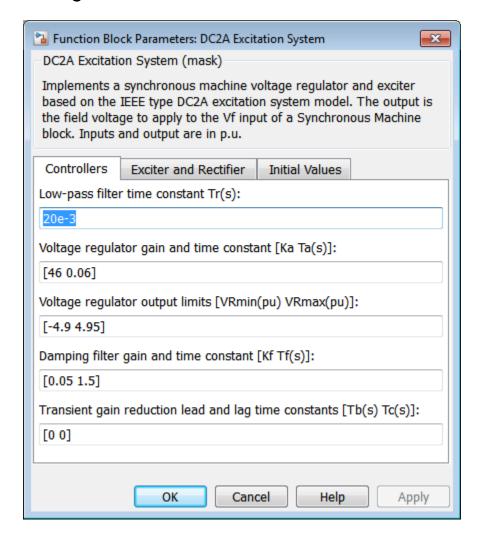
This block models a field controlled dc-commutator exciter with continuously acting voltage regulators supplied from the generator or auxiliaries bus voltage. The voltage regulator output limits are proportional to terminal voltage Vt.

This block is an adaptation of the DC2A excitation system of the IEEE 421 standard, copyright IEEE 2005, all rights reserved.

Dialog Box and Parameters

- "Controllers Tab" on page 1-224
- "Exciter and Rectifier Tab" on page 1-224
- "Initial Values Tab" on page 1-225

Controllers Tab

Low-pass filter time constant

The time constant Tr of the first-order system representing the stator terminal voltage transducer.

Voltage regulator gain and time constant

The gain Ka and time constant Ta of the first-order system representing the main regulator.

Voltage regulator output limits

The voltage regulator output limits VRmin and VRmax, in p.u.

Damping filter gain and time constant

The gain Kf and time constant Tf of the first-order system representing the derivative feedback.

Transient gain reduction lead and lag time constants

The time constants Tb and Tc of the first-order system representing the lead-lag compensator.

Exciter and Rectifier Tab

Exciter gain and time constant

The gain Ke and time constant Te of the first-order system representing the exciter.

Field voltage values

The exciter saturation function is defined as a multiplier of exciter alternator output voltage to represent the increase in exciter excitation requirements due to saturation [1]. The saturation function is determined by specifying two voltage points, Efd1 and Efd2 in p.u, on the air-gap line and Constant Resistance Load Saturation curve, and providing the corresponding two saturation multipliers SeEfd1 and SeEfd2

Typically, the voltage Efd1 is a value near the expected exciter maximum output voltage. The Efd2 value is about 75% of Efd1.

Exciter saturation function values

The exciter saturation function is defined as a multiplier of exciter alternator output voltage to represent the increase in exciter excitation requirements due to saturation. The saturation function is determined by specifying two voltage points, Efd1 and

Efd2 in p.u., on the air-gap line and Constant Resistance Load saturation curve, and providing the corresponding two saturation multipliers SeEfd1 and SeEfd2.

SeEfd1 and SeEfd2 multipliers are equal to A-B / B, A is the value of exciter field current on the Constant Resistance Load saturation curve corresponding to the selected Efd voltage, and B the value of exciter field current on the air-gap line corresponding to the selected Efd voltage [1].

If you do not want to model the saturation effect, set SeVe1 and SeVe2 values to zero.

Initial Values Tab

Initial values of terminal voltage and field voltage

The initial values of terminal voltage Vt0 and field voltage Efd0, both in p.u. Initial terminal voltage is normally set to 1 pu. The Vt0 and Efd0 values can be determined using the Powergui Load Flow tool..

Sample time

Specify a value greater than zero to discretize the block at the given sample time. Set to -1 to inherit the simulation type and sample time parameters of the Powergui block.

Ports

Vref

The reference value of the stator terminal voltage, in p.u.

Vt

The measured value in p.u. of the stator terminal voltage of the controlled Synchronous Machine block.

Vstab

Connect this input to a power system stabilizer to provide additional stabilization of power system oscillations. When you do not use this option, connect to a Simulink ground block. The input is in p.u.

Efd

The field voltage to apply to the Vf input of the controlled Synchronous Machine block. The output is in p.u.

Example

The `power_machines` example contains a Configurable Subsystem block that allows you to select between seven types of excitation systems to control the terminal voltage of the Synchronous Machine block. This configurable block refers to the `power_machines_lib` example library that contains seven pretuned excitation system blocks that fit simulation requirements for this example.

Right-click the EXCITATION configurable block, then select **DC2A** from the **Block Choice** menu to control the Synchronous Machine block using the DC2A Excitation System block.

References

[1] "IEEE Recommended Practice for Excitation System Models for Power System Stability Studies." *IEEE Standard*, Vol. 421, No. 5, 2005 (Revision of *IEEE 521.5-1992*).

Introduced before R2006a

Digital Flickermeter

Implement digital flickermeter as described in IEC 61000-4-15 standard.

Library

Control and Measurements/Measurements

Description
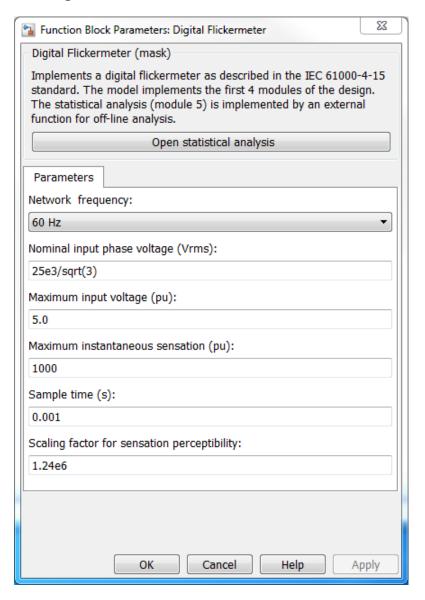
The Digital Flickermeter block implements a digital flickermeter as described in the IEC 61000-4-15 standard. The model implements the first four modules of the design. The statistical analysis (module 5) is implemented by an external function for offline analysis of recorded simulation signal.

Note: You must have a Control System Toolbox™ license to use the Digital Flickermeter block.

Dialog Box and Parameters

Open statistical analysis

Opens the Statistical Analysis of Instantaneous Flicker Level module tool.

Network frequency

The frequency of the analyzed signal. Choose between `60 Hz` and `50 Hz`. The default value is `60 Hz`.

Nominal input phase voltage (Vrms)

The nominal voltage value of the analyzed signal, in volts rms. The default value is `25e3/sqrt(3)`.

Maximum input voltage (pu)

The maximum input voltage value of the input voltage adaptor (module 1), in per unit. The default value is `5.0`.

Maximum instantaneous sensation (pu)

The maximum value of the instantaneous flicker sensation measured by the block, in per unit. The default value is `1000`.

Sample time (s)

The sampling rate used to compute the instantaneous flicker sensation. The default value is `0.001`.

Scaling factor for sensation perceptibility

The scaling factor of the flickermeter for measuring the sensation perceptibility. The default value is `1.24e6`.

Inputs and Outputs

`enable`

Set this input to 1 to enable the flicker measurement. The flickermeter is normally enabled after a given period of time, when the analyzed signal (input U) is stable.

`U`

Connect this input to the analyzed signal.

`S5`

Outputs the instantaneous flicker sensation measured for the analyzed signal.

`m`

This output contains these measurements:
    Output 1: Half-cycle, rms-normalized voltage (pu)
    Output 2: Weighted voltage fluctuation

Output 3: Square root of Output_5
Output 4: One-minute dose (integral) of instant perception
Output 5: Instantaneous flicker sensation (Output S5)
u: The analyzed signal
Init: initialization period time

Examples

The Flickermeter on a Distribution STATCOM example shows a flickermeter device that measures the instantaneous flicker sensation on the terminal voltage of a STATCOM unit.

The Flickermeter Statistical Analysis Module example shows a method to compute short-term flicker severity of a phase-to-ground voltage taken from one feeder of a given remote community.

References

[1] *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 15: Flickermeter – Functional and design specifications.*,IEC-61000-4-15, 2003-02.

[2] Gutierrez, J. J., J. Ruiz, A. Lazkano, and L. A. Leturiondo. "Measurement of Voltage Flicker: Application to Grid-connected Wind Turbines." In *Advances in Measurement Systems*, edited by Milind Kr Sharma, 365–380. InTech, DOI: 10.5772/8731, 2010. Available from: http://www.intechopen.com/books/advances-in-measurement-systems/measurement-of-voltage-flicker-application-to-grid-connected-wind-turbines.

See Also
power_flicker

Introduced in R2015b

Diode

Implement diode model

Library

Fundamental Blocks/Power Electronics

Description
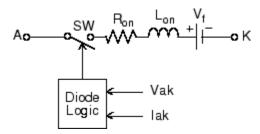
The diode is a semiconductor device that is controlled by its own voltage Vak and current Iak. When a diode is forward biased (Vak > 0), it starts to conduct with a small forward voltage Vf across it. It turns off when the current flow into the device becomes 0. When the diode is reverse biased (Vak < 0), it stays in the off
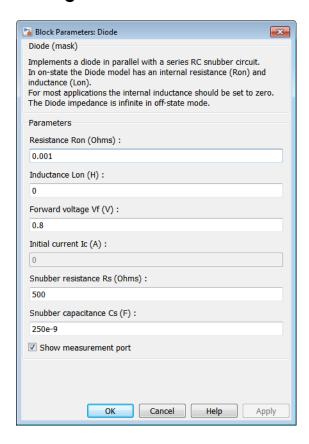
state.

The Diode block is simulated by a resistor, an inductor, and a DC voltage source connected in series with a switch. The switch operation is controlled by the voltage Vak and the current Iak.

The Diode block also contains a series Rs-Cs snubber circuit that can be connected in parallel with the diode device (between nodes A and K).

Dialog Box and Parameters

Resistance Ron

The diode internal resistance Ron, in ohms (Ω). The **Resistance Ron** parameter cannot be set to 0 when the **Inductance Lon** parameter is set to 0.

Inductance Lon

The diode internal inductance Lon, in henries (H). The **Inductance Lon** parameter cannot be set to 0 when the **Resistance Ron** parameter is set to 0.

Forward voltage Vf

The forward voltage of the diode device, in volts (V).

Initial current Ic

Specifies an initial current flowing in the diode device. It is usually set to 0 in order to start the simulation with the diode device blocked. If the **Initial Current IC** parameter is set to a value greater than 0, the steady-state calculation considers the initial status of the diode as closed.

Initializing all states of a power electronic converter is a complex task. Therefore, this option is useful only with simple circuits.

Snubber resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to `inf` to eliminate the snubber from the model.

Snubber capacitance Cs

The snubber capacitance in farads (F). Set the **Snubber capacitance Cs** parameter to `0` to eliminate the snubber, or to `inf` to get a resistive snubber.

Show measurement port

If selected, adds a Simulink output to the block returning the diode current and voltage.

Inputs and Outputs

m

The Simulink output of the block is a vector containing two signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Signal	Definition	Units
1	Diode current	A
2	Diode voltage	V

Assumptions and Limitations

The Diode block implements a macro model of a diode device. It does not take into account either the geometry of the device or the complex physical processes underlying

the state change [1]. The leakage current in the blocking state and the reverse-recovery (negative) current are not considered. In most circuits, the reverse current does not affect converter or other device characteristics.
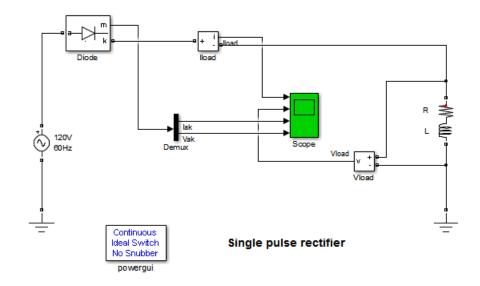
Depending on the value of the inductance Lon, the diode is modeled either as a current source (Lon > 0) or as a variable topology circuit (Lon = 0). The Diode block cannot be connected in series with an inductor, a current source, or an open circuit, unless its snubber circuit is in use.

Use the powergui block to specify either continuous simulation or discretization of your electrical circuit containing diodes. When using a continuous model, the `ode23tb` solver with a relative tolerance of 1e-4 is recommended for best accuracy and simulation speed.

The inductance Lon is forced to 0 if you choose to discretize your circuit.
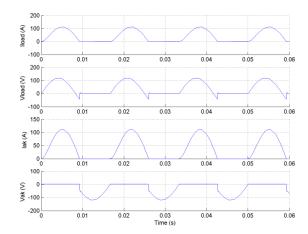
Example

The `power_diode` example illustrates a single pulse rectifier consisting of a Diode block, an RL load, and an AC Voltage source block.

Single pulse rectifier

Simulation produces the following results.

References

[1] Rajagopalan, V., *Computer-Aided Analysis of Power Electronic Systems*, Marcel Dekker, Inc., New York, 1987.

[2] Mohan, N., T.M. Undeland, and W.P. Robbins, *Power Electronics: Converters, Applications, and Design*, John Wiley & Sons, Inc., New York, 1995.

See Also

Thyristor, Universal Bridge
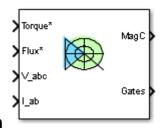
Introduced before R2006a

Direct Torque Controller

Implement direct torque and flux controller (DTFC or DTC) model

Library

Electric Drives/Fundamental Drive Blocks
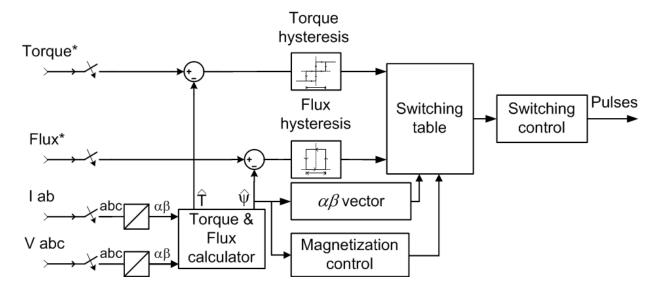
Description

The Direct Torque and Flux controller (DTC) directly controls the torque and stator flux of a machine, using inverter voltage vectors typically selected from an optimal switching table. For an explanation, see "Direct Torque Control".

The DTC block consists of six main blocks, as shown in the figure.

The Torque & Flux calculator block estimates the motor flux αß components and the electromagnetic torque. This calculator is based on motor equation synthesis.

The αß vector block finds the sector of the αß plane in which the flux vector lies. The αß plane is divided into six different sectors spaced by 60 degrees.
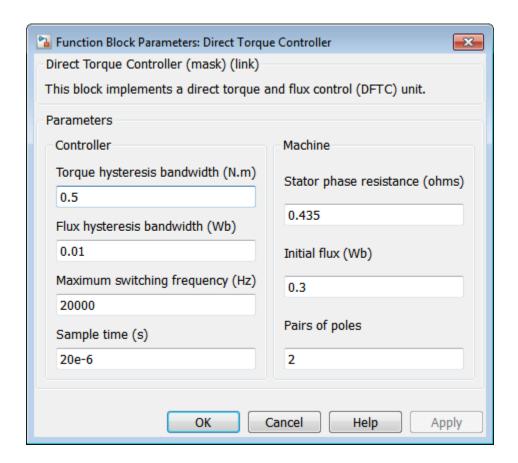
The Flux and Torque Hysteresis blocks contain a two-level hysteresis comparator for flux control and a three-level hysteresis comparator for the torque control.

The Switching table block contains two lookup tables that select a specific voltage vector in accordance with the output of the Flux and Torque hysteresis comparators. This block also produces the initial flux in the machine.

The Switching control block limits the inverter commutation frequency to a maximum value that you specify.
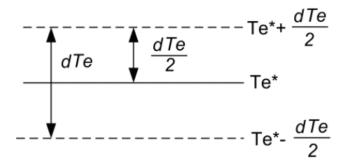
The magnetization control unit contains the logic for switching between magnetization and normal operation modes.

Dialog Box and Parameters
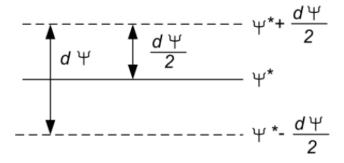
Torque hysteresis-band width (N.m)

> The torque hysteresis bandwidth, in newton-meter. This value is the total bandwidth distributed symmetrically around the torque set point. The figure shows a case where the torque set point is Te* and the torque hysteresis bandwidth is set to dTe. The default value is 0.5.

Flux hysteresis-band width (Wb)

The stator flux hysteresis bandwidth, in webers. This value is the total bandwidth distributed symmetrically around the flux set point. The figure shows a case where the flux set point is ψ* and the torque hysteresis bandwidth is set to dψ. The default value is `0.01`.

Maximum switching frequency (Hz)

The maximum inverter switching frequency, in hertz. The default value is `20000`.

Sample time (s)

The controller sampling time, in seconds. The sampling time must be a multiple of the simulation time step. The default value is `20e-6`.

Stator phase resistance (ohms)

The stator resistance, in ohms. The default value is `0.435`.

Initial flux (Wb)

The initial stator flux for the machine, in webers. The default value is `0.3`.

Pairs of poles

The number of pole pairs. The default value is 2.

Inputs and Outputs

Torque*

The torque reference, typically provided by a speed controller.

Flux*

The flux reference, typically provided by a speed controller.

V_abc

The three-phase voltages of the induction machine.

I_ab

The line currents Ia and Ib of the induction machine.

MagC

This binary signal indicates if the machine is magnetized enough to be started (1) or not (0).

Gates

The pulses for the six inverter switches.

Examples

The Direct Torque Controller block is used in the AC4 block of the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

Bridge Firing Unit (AC) | Bridge Firing Unit (DC) | Current Controller (Brushless DC) | Current Controller (DC) | Field-Oriented Controller | Regulation Switch | Six-Step Generator | Space Vector Modulator | Speed Controller (AC) | Speed Controller (DC) | Speed Controller (Scalar

Control) | Vector Controller (PMSM) | Vector Controller (WFSM) | Voltage Controller (DC Bus)

More About

- "Electric Drives Library"

Introduced in R2015b

Discrete Shift Register

Implement serial-in, parallel-out shift register

Library

Control and Measurements/Additional Components

Description
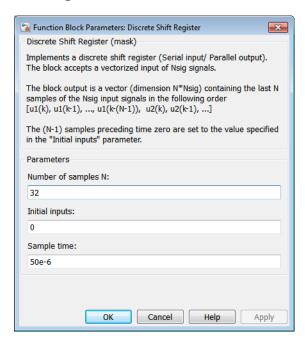
The Discrete Shift Register block outputs a vector containing the last N samples of the input signal. When the input contains more than one signal, the block outputs the last N samples of each signal in the following order:
Out = [u1(k), u1(k−1), u1(k−2), u1(k−3), u2(k), u2(k−1), u2(k−2), u2(k−3)]

This example shows the block output for an input containing two signals, represented by u1 and u2, and a number of samples N = 4, represented by the k to k−3 indices. The dimension of the output vector is $4 \times 2 = 8$.

Dialog Box and Parameters

Function Block Parameters: Discrete Shift Register

Discrete Shift Register (mask)

Implements a discrete shift register (Serial input/ Parallel output). The block accepts a vectorized input of Nsig signals.

The block output is a vector (dimension N*Nsig) containing the last N samples of the Nsig input signals in the following order [u1(k), u1(k-1), ..., u1(k-(N-1)), u2(k), u2(k-1), ...]

The (N-1) samples preceding time zero are set to the value specified in the "Initial inputs" parameter.

Parameters

Number of samples N:

32

Initial inputs:

0

Sample time:

50e-6

OK | Cancel | Help | Apply

Number of samples N

Specify the number of samples, or stages, of the register. The minimum value is 1.

Initial inputs

Specify the initial value of the N-1 samples preceding time 0. Enter a scalar value or a vector of the same size as the input signal.

Sample time

Specify the time interval between the samples.

Characteristics

Direct Feedthrough	Yes
Sample Time	Discrete
Dimensionalized	Yes

Scalar Expansion	Yes, of the parameter **Initial inputs**
Zero-Crossing Detection	No

Example

The power_DiscreteShiftRegister example shows various uses of the Discrete Shift Register block.

Introduced in R2013a

Discrete System

Discretize state-space model of circuit

Library

powerlib

Description

Note This block is now obsolete. Use the Powergui block to replace this block.

See Also

powergui

Discrete Variable Time Delay

Delay signal by variable time value

Library

Control and Measurements/Additional Components

Description
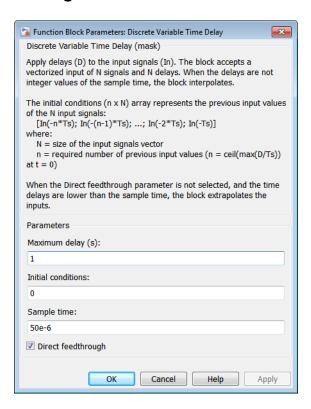
The Discrete Variable Time Delay block delays the input signal by the value specified in the D input. At each simulation time step, the Discrete Variable Time Delay block saves the time and the input value in an internal buffer and outputs the previous input value determined by the delay input.

When the delay input is not an integer of the time step, the Discrete Variable Time Delay block performs linear interpolation. When the **Direct feedthrough** parameter is selected, the delay can be less than the simulation time step.

Dialog Box and Parameters
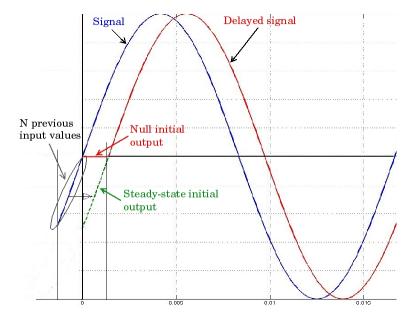
Maximum delay (s)

Specify the expected maximum delay of the D input delay, in seconds. The **Maximum delay** parameter determines the input buffer size. When the maximum delay is exceeded, the delay is clipped to the maximum delay value.

Initial conditions

Specify the initial conditions of the signal. The block outputs the specified values until the first delayed sample of signal is out.

Set to 0 to implement null initial output, or specify the N previous input values of signal to start from steady-state. The required number of input values is N = ceil(D1/Ts) where D1 is the value of the delay at t = 0, and Ts the sample time value. The figure shows the details of the initial conditions.

Suppose, for example, that the signal is a 60 Hz sine wave, the initial delay is set to $D1 = 10*Ts$ by the D input of the block, and the sample time is equal to 50e-6 s. The N previous input values of the signal are determined as follows:

```
N = ceil(10*Ts)/Ts; % N=10
t = [-N*Ts:Ts:-1*Ts]; % time vector of the N previous inputs
S_init = sin(2*pi*60*t); % The N previous input values of signal
```

Sample time

Specify the time interval between the samples.

Direct feedthrough

When this check box is selected, the block can handle a delay less than the simulation time step. Otherwise the block extrapolates the input values.

Inputs and Outputs

In

The signal. The input can be a scalar signal or a vector of signals. The dimension of the In and D inputs must be the same.

D

The value of the delay to apply to the signal. The input can be a scalar delay signal or a vector of delay signals. The dimensions of the In and D inputs must be the same.

Out

Returns the delayed signal.

Characteristics

Direct Feedthrough	Yes
Sample Time	Discrete
Scalar Expansion	Yes, of input D and of the **Initial conditions** parameter
Dimensionalized	Yes
Zero-Crossing Detection	No

Example

The power_DiscreteVariableTimeDelay example shows various uses of the Discrete Variable Time Delay block.
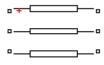
Introduced in R2013a

Distributed Parameter Line

Implement N-phase distributed parameter transmission line model with lumped losses

Library

Fundamental Blocks/Elements
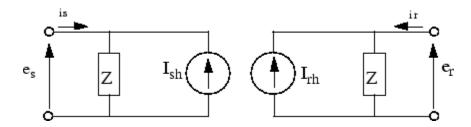
Description

The Distributed Parameter Line block implements an N-phase distributed parameter line model with lumped losses. The model is based on the Bergeron's traveling wave method used by the Electromagnetic Transient Program (EMTP) [1]. In this model, the lossless distributed LC line is characterized by two values (for a single-phase line): the surge impedance $Z_c = \sqrt{l / c}$ and the wave propagation speed $v = 1 / \sqrt{lc}$. l and c are the per-unit length inductance and capacitance.

The figure shows the two-port model of a single-phase line.

For a lossless line ($r = 0$), the quantity $e + Z_c i$, where e is the line voltage at one end and i is the line current entering the same end, must arrive unchanged at the other end after a transport delay τ.

$$\tau = \frac{d}{v}$$

where d is the line length and v is the propagation speed.

The model equations for a lossless line are:

$$e_r(t) - Z_c\, i_r(t) = e_s(t - \tau) + Z_c\, i_s(t - \tau)$$

$$e_s(t) - Z_c\, i_s(t) = e_r(t - \tau) + Z_c\, i_r(t - \tau)$$

knowing that

$$i_s(t) = \frac{e_s(t)}{Z} - I_{sh}(t)$$

$$i_r(t) = \frac{e_r(t)}{Z} - I_{rh}(t)$$

In a lossless line, the two current sources I_{sh} and I_{rh} are computed as:

$$I_{sh}(t) = \frac{2}{Z_c} e_r(t - \tau) - I_{rh}(t - \tau)$$

$$I_{rh}(t) = \frac{2}{Z_c} e_s(t - \tau) - I_{sh}(t - \tau)$$

When losses are taken into account, new equations for I_{sh} and I_{rh} are obtained by lumping $R/4$ at both ends of the line and $R/2$ in the middle of the line:

R = total resistance = $r \times d$

The current sources I_{sh} and I_{rh} are then computed as follows:

$$I_{sh}(t) = \left(\frac{1+h}{2}\right)\left(\frac{1+h}{Z}e_r(t-\tau) - hI_{rh}(t-\tau)\right) + \left(\frac{1-h}{2}\right)\left(\frac{1+h}{Z}e_s(t-\tau) - hI_{sh}(t-\tau)\right)$$

$$I_{rh}(t) = \left(\frac{1+h}{2}\right)\left(\frac{1+h}{Z}e_s(t-\tau) - hI_{sh}(t-\tau)\right) + \left(\frac{1-h}{2}\right)\left(\frac{1+h}{Z}e_r(t-\tau) - hI_{rh}(t-\tau)\right)$$

where

$$Z = Z_C + \frac{r}{4}$$

$$h = \frac{Z_C - \frac{r}{4}}{Z_C + \frac{r}{4}}$$

$$Z_C = \sqrt{\frac{l}{c}}$$
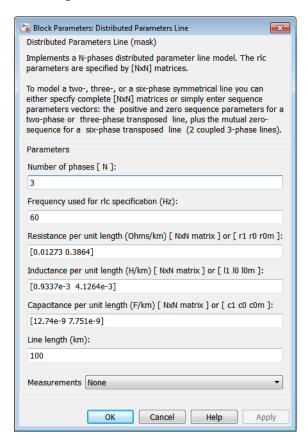
$$\tau = d\sqrt{lc}$$

r, l, c are the per unit length parameters, and d is the line length. For a lossless line, $r = 0$, $h = 1$, and $Z = Z_c$.

For multiphase line models, modal transformation is used to convert line quantities from phase values (line currents and voltages) into modal values independent of each other. The previous calculations are made in the modal domain before being converted back to phase values.

In comparison to the PI section line model, the distributed line represents wave propagation phenomena and line end reflections with much better accuracy. See the comparison between the two models in the Example section.

Dialog Box and Parameters

Number of phases N

> Specifies the number of phases, N, of the model. The block icon dynamically changes according to the number of phases that you specify. When you apply the parameters or close the dialog box, the number of inputs and outputs is updated.

Frequency used for rlc specifications

> Specifies the frequency used to compute the per unit length resistance r, inductance l, and capacitance c matrices of the line model.

Resistance per unit length

> The resistance r per unit length, as an N-by-N matrix in ohms/km (Ω/km).

For a symmetrical line, you can either specify the N-by-N matrix or the sequence parameters. For a two-phase or three-phase continuously transposed line, you can enter the positive and zero-sequence resistances [*r1 r0*]. For a symmetrical six-phase line you can enter the sequence parameters plus the zero-sequence mutual resistance [*r1 r0 r0m*].

For asymmetrical lines, you must specify the complete N-by-N resistance matrix.

Inductance per unit length

The inductance *l* per unit length, as an N-by-N matrix in henries/km (H/km).

For a symmetrical line, you can either specify the N-by-N matrix or the sequence parameters. For a two-phase or three-phase continuously transposed line, you can enter the positive and zero-sequence inductances [*l1 l0*]. For a symmetrical six-phase line, you can enter the sequence parameters plus the zero-sequence mutual inductance [*l1 l0 l0m*].

For asymmetrical lines, you must specify the complete N-by-N inductance matrix.

Capacitance per unit length

The capacitance *c* per unit length, as an N-by-N matrix in farads/km (F/km).

For a symmetrical line, you can either specify the N-by-N matrix or the sequence parameters. For a two-phase or three-phase continuously transposed line, you can enter the positive and zero-sequence capacitances [*c1 c0*]. For a symmetrical six-phase line you can enter the sequence parameters plus the zero-sequence mutual capacitance [*c1 c0 c0m*].

For asymmetrical lines, you must specify the complete N-by-N capacitance matrix.

Note The `powergui` block provides a graphical tool for the calculation of the resistance, inductance, and capacitance per unit length based on the line geometry and the conductor characteristics.

Line length

The line length, in km.

Measurements

Select `Phase-to-ground voltages` to measure the sending end and receiving end voltages for each phase of the line model.

Place a Multimeter block in your model to display the selected measurements during the simulation.

In the **Available Measurements** list box of the Multimeter block, the measurement is identified by a label followed by the block name:
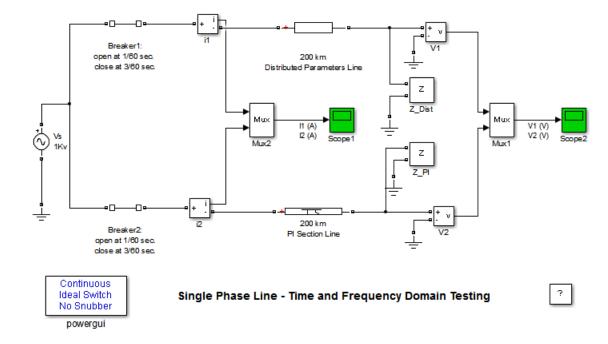
Measurement	Label
Phase-to-ground voltages, sending end	`Us_ph1_gnd:`, `Us_ph2_gnd:`, `Us_ph3_gnd:`, etc.
Phase-to-ground voltages, receiving end	`Ur_ph1_gnd:`, `Ur_ph2_gnd:`, `Ur_ph3_gnd:`, etc.

Limitations
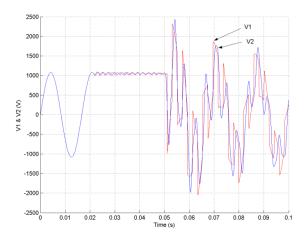
This model does not represent accurately the frequency dependence of RLC parameters of real power lines. Indeed, because of the skin effects in the conductors and ground, the *R* and *L* matrices exhibit strong frequency dependence, causing an attenuation of the high frequencies.

Example
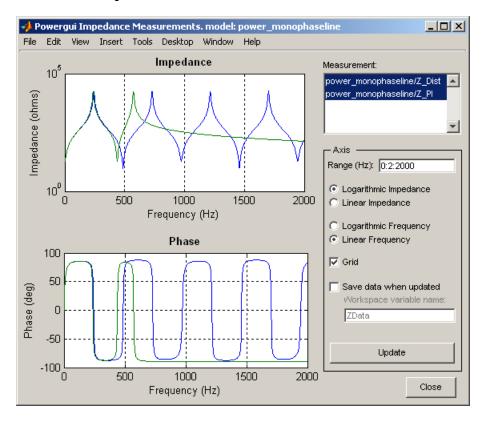
The power_monophaseline example illustrates a 200 km line connected on a 1 kV, 60 Hz infinite source. The line is de-energized and then reenergized after 2 cycles. The simulation is performed simultaneously with the Distributed Parameter Line block and with the PI Section Line block.

The receiving end voltage obtained with the Distributed Parameter Line block is compared with the one obtained with the PI Section Line block (two sections).

Open the Powergui. Click the **Impedance vs Frequency Measurement** button. A new window appears, listing the two Impedance Measurement blocks connected to your circuit. Set the parameters of **Impedance vs Frequency Measurement** to compute impedance in the [0,2000] Hz frequency range, select the two measurements in the list, then click the **Update** button.

The distributed parameter line shows a succession of poles and zeros equally spaced, every 486 Hz. The first pole occurs at 243 Hz, corresponding to frequency $f = 1/(4 * T)$, where

T = traveling time = $l\sqrt{lc}$ = 1.028 ms

The PI section line only shows two poles because it consists of two PI sections. Impedance comparison shows that a two-section PI line gives a good approximation of the distributed line for the 0 to 350 Hz frequency range.

References

[1] Dommel, H., "Digital Computer Solution of Electromagnetic Transients in Single and Multiple Networks," *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-88, No. 4, April, 1969.

See Also

PI Section Line

Introduced before R2006a

dq0_to_abc Transformation

Perform Park transformation from dq0 reference frame to abc reference frame

Library

powerlib_extras/Measurements, powerlib_extras/Discrete Measurements

---

Note: The Transformations section of the Control and Measurements library contains the dq0 to abc to block. This is an improved version of the dq0_to_abc Transformation block. The new block features a mechanism that eliminates duplicate continuous and discrete versions of the same block by basing the block configuration on the simulation mode. If your legacy models contain the dq0_to_abc Transformation block, they will continue to work. However, for best performance, use the dq0 to abc block in your new models.

Description

The dq0_to_abc Transformation block performs the reverse of the so-called Park transformation, which is commonly used in three-phase electric machine models. It transforms three quantities (direct axis, quadratic axis, and zero-sequence components) expressed in a two-axis reference frame back to phase quantities. The following transformation is used:

$$V_a = V_d \sin(\omega t) + V_q \cos(\omega t) + V_0$$
$$V_b = V_d \sin(\omega t - 2\pi / 3) + V_q \cos(\omega t - 2\pi / 3) + V_0$$
$$V_c = V_d \sin(\omega t + 2\pi / 3) + V_q \cos(\omega t + 2\pi / 3) + V_0,$$

where ω = rotation speed (rad/s) of the rotating frame.
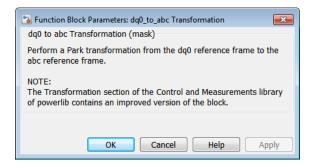
The transformation is the same for the case of a three-phase current; you simply replace the V_a, V_b, V_c, V_d, V_q, and V_0 variables with the I_a, I_b, I_c, I_d, I_q, and I_0 variables.

The dq0_to_abc Transformation block is used in the model of the Synchronous Machine block where the stator quantities are referred to the rotor. The Park transformation then eliminates time-varying inductances by referring the stator and rotor quantities to a fixed or rotating reference frame. The I_d and I_q currents represent the two DC currents flowing in the two equivalent rotor windings (d winding on the same axis as the field winding, and q winding in quadratic) producing the same flux as the stator I_a, I_b, and I_c currents.

Dialog Box and Parameters

Function Block Parameters: dq0_to_abc Transformation

dq0 to abc Transformation (mask)

Perform a Park transformation from the dq0 reference frame to the abc reference frame.

NOTE:
The Transformation section of the Control and Measurements library of powerlib contains an improved version of the block.

OK   Cancel   Help   Apply

Inputs and Outputs

dq0

Connect to the first input a vectorized signal containing the sequence components [d q 0] to be converted.

sin_cos

Connect to the second input a vectorized signal containing the [sin(ωt) cos(ωt)] values, where ω is the rotation speed of the reference frame.

abc

The output is a vectorized signal containing the three-phase sinusoidal quantities [phase A phase B phase C], in the same units as the dq0 input signal.

Example

See the example of the abc_to_dq0 Transformation block for an example using the dq0 to abc block (the improved version of the dq0_to_abc Transformation block).

References

[1] Krause, P. C. *Analysis of Electric Machinery*. New York: McGraw-Hill, 1994, p.135.

See Also
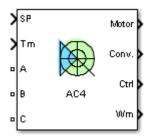
abc to dq0, dq0 to abc | abc_to_dq0 Transformation

DTC Induction Motor Drive

Implement direct torque and flux control (DTC) induction motor drive model
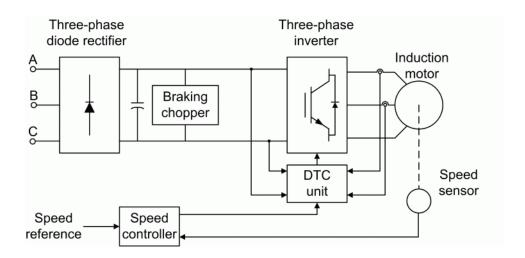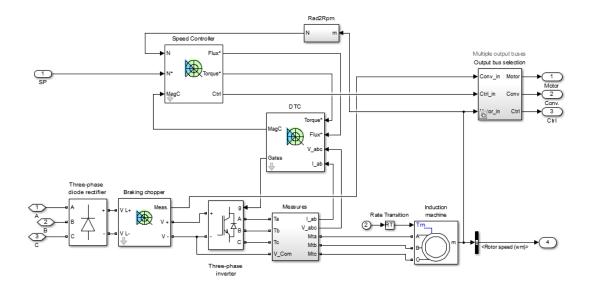
Library

Electric Drives/AC drives

Description

The high-level schematic shown below is built from six main blocks. The induction motor, the three-phase inverter, and the three-phase diode rectifier models are provided with the SimPowerSystems library. More details on these three blocks are available in the reference sections of each block. The speed controller, the braking chopper, and the DTC controller models are specific to the drive library.

Note In SimPowerSystems software, the DTC Induction Motor Drive block is commonly called the AC4 motor drive.

High-Level Schematic
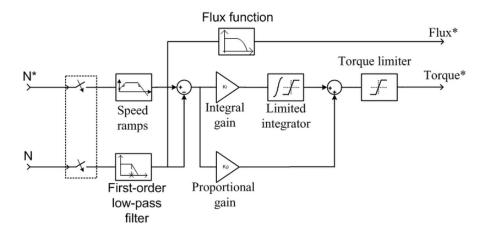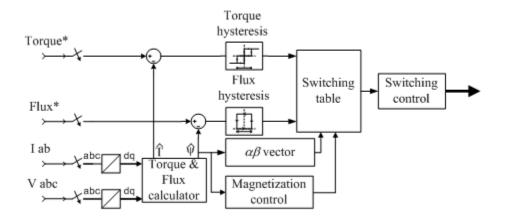
Simulink Schematic

Speed Controller

The speed controller is based on a PI regulator, shown below. The output of this regulator is a torque set point applied to the DTC controller block.

DTFC Controller

The Direct Torque and Flux Control (DTFC) controller contains five main blocks, shown below. These blocks are described below.

The *Torque & Flux calculator* block is used to estimate the motor flux αβ components and the electromagnetic torque. This calculator is based on motor equation synthesis.

The αβ *vector* block is used to find the sector of the αβ plane in which the flux vector lies. The αβ plane is divided into six different sectors spaced by 60 degrees.

The *Flux & Torque Hysteresis* blocks contain a two-level hysteresis comparator for flux control and a three-level hysteresis comparator for the torque control. The description of the hysteresis comparators is available below.

The *Switching table* block contains two lookup tables that select a specific voltage vector in accordance with the output of the *Flux & Torque Hysteresis* comparators. This block also produces the initial flux in the machine.

The *Switching control* block is used to limit the inverter commutation frequency to a maximum value specified by the user.

Braking Chopper

The braking chopper block contains the DC bus capacitor and the dynamic braking chopper, which is used to absorb the energy produced by a motor deceleration.

Remarks

The model is discrete. Good simulation results have been obtained with a 2 μs time step. In order to simulate a digital controller device, the control system has two different sampling times:

- The speed controller sampling time
- The D.T.C. controller sampling time
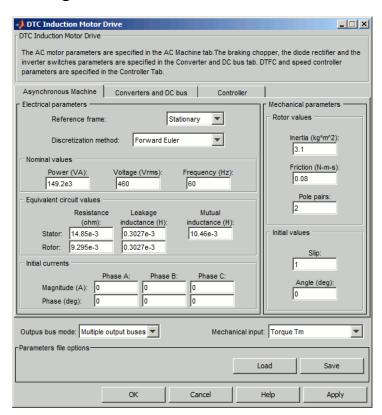
The speed controller sampling time has to be a multiple of the D.T.C. sampling time. The latter sampling time has to be a multiple of the simulation time step.

Dialog Box

Asynchronous Machine Tab

The **Aynchronous Machine** tab displays the parameters of the Aynchronous Machine block of the Fundamental Blocks (powerlib) library.

Output bus mode

Select how the output variables are organized. If you select **Multiple output buses**, the block has three separate output buses for motor, converter, and controller variables. If you select **Single output bus**, all variables output on a single bus.

Mechanical input

Select between the load torque, the motor speed, and the mechanical rotational port as mechanical input. If you select and apply a load torque, the output is the motor speed according to the following differential equation that describes the mechanical system dynamics:

$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

If you select the motor speed as mechanical input, then you get the electromagnetic torque as output, allowing you to represent externally the mechanical system dynamics. The internal mechanical system is not used with this mechanical input selection and the inertia and viscous friction parameters are not displayed.

For the mechanical rotational port, the connection port S counts for the mechanical input and output. It allows a direct connection to the Simscape environment. The mechanical system of the motor is also included in the drive and is based on the same differential equation.

See "Mechanical Coupling of Two Motor Drives".

Converters and DC Bus Tab

Rectifier Section

The rectifier section of the Converters and DC Bus tab displays the parameters of the rectifier block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the rectifier parameters.

Inverter Section

The inverter section of the Converters and DC Bus tab displays the parameters of the Inverter block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the inverter parameters.

DC-Bus Capacitance

The DC bus capacitance (F).

Braking Chopper section: Resistance

The braking chopper resistance used to avoid bus over-voltage during motor deceleration or when the load torque tends to accelerate the motor (Ω).

Braking Chopper section: Frequency
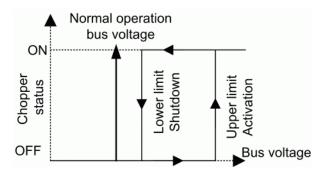
The braking chopper frequency (Hz).

Braking Chopper section: Activation Voltage

The dynamic braking is activated when the bus voltage reaches the upper limit of the hysteresis band. The following figure illustrates the braking chopper hysteresis logic.

Braking Chopper section: Shutdown Voltage

The dynamic braking is shut down when the bus voltage reaches the lower limit of the hysteresis band. The Chopper hysteresis logic is shown below:

Controller Tab

Regulation type

This parameter allows you to choose between speed and torque regulation.

Schematic

When you press this button, a diagram illustrating the speed and current controllers schematics appears.

Speed Controller section

Speed cutoff frequency

The speed measurement first-order low-pass filter cutoff frequency (Hz). This parameter is used in speed regulation mode only.

Speed controller sampling time

The speed controller sampling time (s). The sampling time must be a multiple of the simulation time step.

Speed Ramps — Acceleration

The maximum change of speed allowed during motor acceleration (rpm/s). An excessively large positive value can cause DC bus under-voltage. This parameter is used in speed regulation mode only.

Speed Ramps — Deceleration

The maximum change of speed allowed during motor deceleration (rpm/s). An excessively large negative value can cause DC bus overvoltage. This parameter is used in speed regulation mode only.

PI Regulator — Proportional Gain

The speed controller proportional gain. This parameter is used in speed regulation mode only.

PI Regulator — Integral Gain

The speed controller integral gain. This parameter is used in speed regulation mode only.

Torque output limits — Negative

The maximum negative demanded torque applied to the motor by the current controller (N.m).

Torque output limits — Positive

The maximum positive demanded torque applied to the motor by the current controller (N.m).

DTC Controller Section

Maximum switching frequency

The maximum inverter switching frequency (Hz).

Initial machine flux
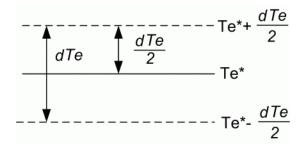
The desired initial stator flux established before the DTC drive module begins to produce an electromagnetic torque. This flux is produced by applying a constant voltage vector at the motor terminals (Wb).

DTC sampling time

The DTC controller sampling time (s). The sampling time must be a multiple of the simulation time step.
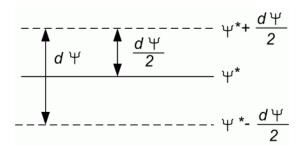
Hysteresis bandwidth — Torque

The torque hysteresis bandwidth. This value is the total bandwidth distributed symmetrically around the torque set point (N.m). The following figure illustrates a case where the torque set point is Te* and the torque hysteresis bandwidth is set to dTe.

Hysteresis bandwidth — Flux

The stator flux hysteresis bandwidth. This value is the total bandwidth distributed symmetrically around the flux set point (Wb). The following figure illustrates a case where the flux set point is ψ* and the torque hysteresis bandwidth is set to dψ.

Note This bandwidth can be exceeded because a fixed-step simulation is used. A rate transition block is needed to transfer data between different sampling rates. This block causes a delay in the gate signals, so the current may exceed the hysteresis band.

Block Inputs and Outputs

SP

> The speed or torque set point. The speed set point can be a step function, but the speed change rate will follow the acceleration / deceleration ramps. If the load torque and the speed have opposite signs, the accelerating torque will be the sum of the electromagnetic and load torques.

Tm or Wm

> The mechanical input: load torque (Tm) or motor speed (Wm). For the mechanical rotational port (S), this input is deleted.

A, B, C

> The three phase terminals of the motor drive.

Wm, Te or S

> The mechanical output: motor speed (Wm), electromagnetic torque (Te) or mechanical rotational port (S).

When the **Output bus mode** parameter is set to **Multiple output buses**, the block has the following three output buses:

Motor

> The motor measurement vector. This vector allows you to observe the motor's variables using the Bus Selector block.

Conv

> The three-phase converters measurement vector. This vector contains:
>
> - The DC bus voltage
> - The rectifier output current
> - The inverter input current
>
> Note that all current and voltage values of the bridges can be visualized with the Multimeter block.

Ctrl

> The controller measurement vector. This vector contains:
>
> - The torque reference
> - The speed error (difference between the speed reference ramp and actual speed)
> - The speed reference ramp or torque reference

When the **Output bus mode** parameter is set to **Single output bus**, the block groups the Motor, Conv, and Ctrl outputs into a single bus output.

Model Specifications

The library contains a 3 hp and a 200 hp drive parameter set. The specifications of these two drives are shown in the following table.

Drive Specifications
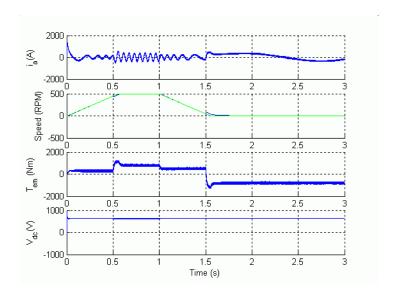
		3 HP Drive	200 HP Drive
Drive Input Voltage			
	Amplitude	220 V	460 V
	Frequency	60 Hz	60 Hz
Motor Nominal Values			
	Power	3 hp	200 hp
	Speed	1705 rpm	1785 rpm
	Voltage	220 V	460 V

Example

The ac4_example example illustrates the simulation of an AC4 motor drive with standard load condition.

At time t = 0 s, the speed set point is 500 rpm. As shown in the following figure, the speed precisely follows the acceleration ramp. At t = 0.5 s, the nominal load torque is applied to the motor. At t = 1 s, the speed set point is changed to 0 rpm. The speed decreases to 0 rpm. At t = 1.5 s., the mechanical load passes from 792 N.m to −792 N.m.

References

[1] Bose, B. K., *Modern Power Electronics and AC Drives*, Prentice-Hall, N.J., 2002.

[2] Grelet, G. and G. Clerc, *Actionneurs électriques*, Éditions Eyrolles, Paris, 1997.

[3] Krause, P. C.,*Analysis of Electric Machinery*, McGraw-Hill, 1986.

Introduced in R2006a

Edge Detector

Detect change in logical signal state

Library

Control and Measurements/Logic

Description
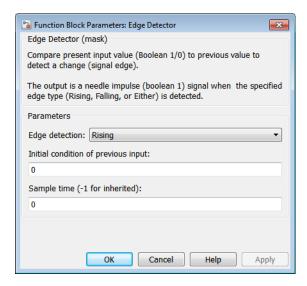
The Edge Detector block outputs a needle impulse when a change in the logical input is detected.

The Edge Detector block can be programmed to detect a rising edge (when the input goes from false to true), a falling edge (when the input goes from true to false), or either edge (any change in input is detected).

Dialog Box and Parameters

Function Block Parameters: Edge Detector

Edge Detector (mask)

Compare present input value (Boolean 1/0) to previous value to detect a change (signal edge).

The output is a needle impulse (boolean 1) signal when the specified edge type (Rising, Falling, or Either) is detected.

Parameters

Edge detection: Rising

Initial condition of previous input:

0

Sample time (-1 for inherited):

0

OK   Cancel   Help   Apply

Edge detction

Select the detection criteria triggering the output impulse.

Initial condition of previous input

Specify the initial value of the previous input. The Edge Detector block can detect an edge at t = 0 if the input is different from the specified value.

Sample time (-1 for inherited)

Specify the sample time of the block, in seconds. Set to **0** to implement a continuous block.

Inputs and Outputs

The input signal must be a Boolean signal. The output is Boolean.

Characteristics

Direct Feedthrough	Yes

Sample Time	Specified in the **Sample Time** parameter
Scalar Expansion	Yes
Dimensionalized	Yes
Zero-Crossing Detection	Yes

Example

The power_Logic example shows the operation of the Edge Detector block.

The model sample time is parameterized with the variable Ts (default value Ts = 50e-3). To simulate a continuous Edge Detector block, specify Ts = 0 in the MATLAB Command Window.
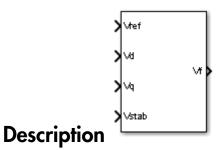
Introduced in R2013a

Excitation System
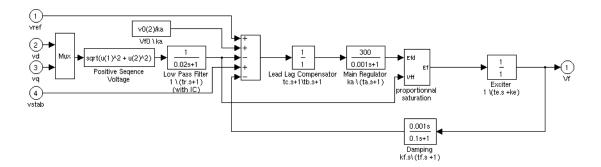
Provide excitation system for synchronous machine and regulate its terminal voltage in generating mode

Library

Fundamental Blocks/Machines

Description
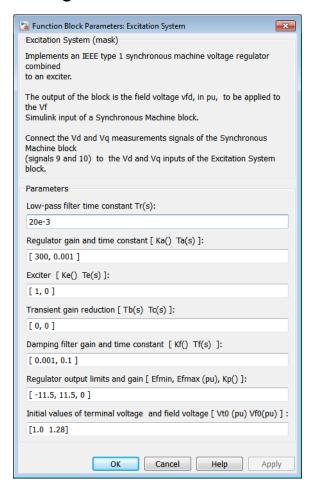
The Excitation System block is a Simulink system implementing a DC exciter described in [1], without the exciter's saturation function. The basic elements that form the Excitation System block are the voltage regulator and the exciter.

The exciter is represented by the following transfer function between the exciter voltage Vfd and the regulator's output ef:

$$\frac{V_{fd}}{ef} = \frac{1}{Ke + sTe}.$$

Dialog Box and Parameters

Low-pass filter time constant

The time constant Tr, in seconds (s), of the first-order system that represents the stator terminal voltage transducer.

Regulator gain and time constant

The gain Ka and time constant Ta, in seconds (s), of the first-order system representing the main regulator.

Exciter

The gain Ke and time constant Te, in seconds (s), of the first-order system representing the exciter.

Transient gain reduction

The time constants Tb, in seconds (s), and Tc, in seconds (s), of the first-order system representing a lead-lag compensator.

Damping filter gain and time constant

The gain Kf and time constant Tf, in seconds (s), of the first-order system representing a derivative feedback.

Regulator output limits and gain

Limits Efmin and Efmax are imposed on the output of the voltage regulator. The upper limit can be constant and equal to Efmax, or variable and equal to the rectified stator terminal voltage Vtf times a proportional gain Kp. If Kp is set to 0, the former applies. If Kp is set to a positive value, the latter applies.

Initial values of terminal voltage and field voltage

The initial values of terminal voltage Vt0 (pu) and field voltage Vf0 (pu). When set correctly, they allow you to start the simulation in steady state. Initial terminal voltage should normally be set to 1 pu. Both Vt0 and Vf0 values are automatically updated by the load flow utility of the Powergui block.

Example

See the Hydraulic Turbine and Governor block.

Inputs and Outputs

`vref`

The desired value, in pu, of the stator terminal voltage.

`vd`

v_d component, in pu, of the terminal voltage.

vq

v_q component, in pu, of the terminal voltage.

vstab

Connect this input to a power system stabilizer to provide additional stabilization of power system oscillations.

Vf

The field voltage, in pu, for the Synchronous Machine block.

References

[1] "Recommended Practice for Excitation System Models for Power System Stability Studies," *IEEE Standard 421.5-1992,* August, 1992.

See Also

Generic Power System Stabilizer, Hydraulic Turbine and Governor, Multiband Power System Stabilizer, Steam Turbine and Governor, Synchronous Machine
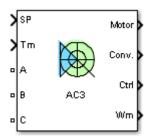
Introduced before R2006a

Field-Oriented Control Induction Motor Drive

Implement field-oriented control (FOC) induction motor drive model
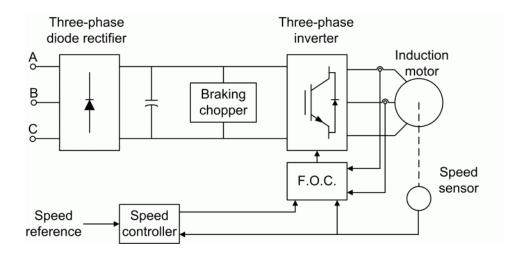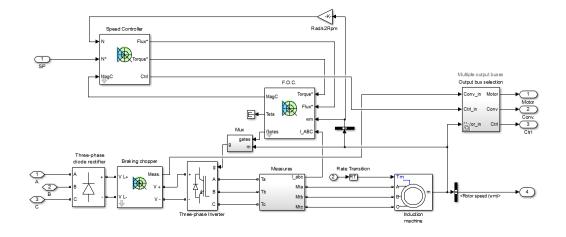
Library

Electric Drives/AC drives

Description

The high-level schematic shown below is built from six main blocks. The induction motor, the three-phase inverter, and the three-phase diode rectifier models are from blocks provided in the SimPowerSystems library. The speed controller, the braking chopper, and the FOC models are from blocks provided in the Electric Drives library. It is possible to use a simplified version of the drive containing an average-value model of the inverter and allowing faster simulation.

Note In SimPowerSystems software, the Field-Oriented Control Induction Motor Drive block is commonly called the **AC3** motor drive.

High-Level Schematic
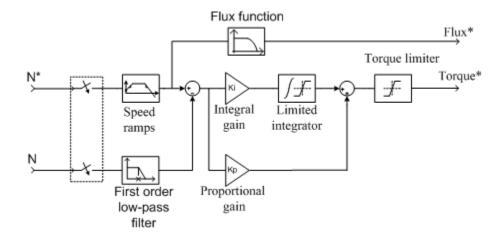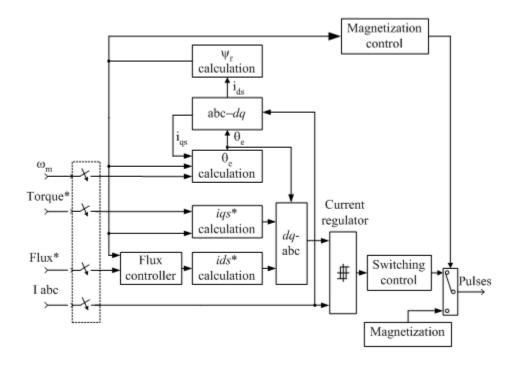
Simulink Schematic

Speed Controller

The speed controller is based on a PI regulator, shown below. The outputs of this regulator are set points for the torque and the flux applied to the FOC block.

Field Oriented Controller

The FOC block contains eleven main blocks. These blocks are described below in the Indirect Vector Control Simulink Schematic.

The ψr *calculation* block is used to estimate the motor's rotor flux. This calculation is based on motor equation synthesis.

The Θe *calculation* block is used to find the phase angle of the rotor flux rotating field.

The *abc-dq* block performs the conversion of *abc* phase variables into *dq* components of the rotor flux rotating field reference frame.

The *dq-abc* block performs the conversion of the *dq* component of the rotor flux rotating field reference frame into *abc* phase variables.

The *iqs*calculation* block uses the calculated rotor flux and the torque reference to compute the stator current quadrature component required to produce the electromagnetic torque on the motor's shaft.

The *ids*calculation* block uses the rotor flux reference to compute the stator current direct component required to produce the rotor flux in the machine.

The *current regulator* is a bang-bang current controller with adjustable hysteresis band width.

The *switching control* block is used to limit the inverter commutation frequency to a maximum value specified by the user.

The *flux controller* is used to control the flux dynamics and to reduce the steady-state flux error.

The *magnetization vector* unit contains the vector used to create the motor initial flux.
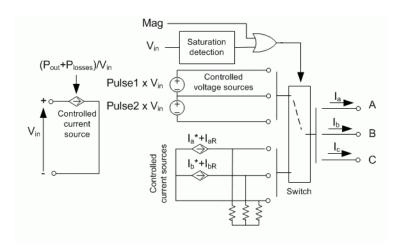
The *magnetization control* unit contains the logic used to switch between the magnetization and normal operation mode.

Braking Chopper

The braking chopper block contains the DC bus capacitor and the dynamic braking chopper, which is used to absorb the energy produced by a motor deceleration.

Average-Value Inverter

The average-value inverter is shown in the following figure.

It is composed of one controlled current source on the DC side and of two controlled current sources and two controlled voltage sources on the AC side. The DC current source allows the representation of the average DC bus current behavior following the next equation:

$I_{dc} = (P_{out} + P_{losses}) / V_{in}$,

with P_{out} being the output power and P_{losses} the losses in the power electronics devices and V_{in} the DC bus voltage.

On the AC side, the current sources represent the average phase currents fed to the motor. The regulation being fast, the current values are set equal to the current references sent by the current regulator. A small current is injected to compensate the current drawn by the three-phase load (needed because of the inverter current sources in series with inductive motor).

During loss of current tracking due to insufficient inverter voltage, the currents are fed by two controlled voltage sources. These voltage sources represent the square wave mode and allow good representation of the phase currents during inverter saturation. Each voltage source outputs either Vin or 0, depending on the values of the pulses (1 or 0) sent by the current controller.

Remarks

The model is discrete. Good simulation results have been obtained with a 2 μs time step. To simulate a digital controller device, the control system has two different sampling times:

- Speed controller sampling time
- FOC sampling time

The speed controller sampling time has to be a multiple of the FOC sampling time. The latter sampling time has to be a multiple of the simulation time step. The average-value inverter allows the use of bigger simulation time steps since it does not generate small time constants (due to the RC snubbers) inherent to the detailed converter. For an FOC sampling time of 60 μs, good simulation results have been obtained for a simulation time step of 60 μs. This time step can, of course, not be higher than the FOC time step.

Dialog Box and Parameters

- "Asynchronous Machine Tab" on page 1-289
- "Converters and DC Bus Tab" on page 1-290
- "Controller Tab" on page 1-292

Asynchronous Machine Tab

The **Asynchronous Machine** tab displays the parameters of the Asynchronous Machine block of the Fundamental Blocks (powerlib) library.

Output bus mode

Select how the output variables are organized. If you select **Multiple output buses**, the block has three separate output buses for motor, converter, and controller variables. If you select **Single output bus**, all variables output on a single bus.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Select between the load torque, the motor speed and the mechanical rotational port as mechanical input. If you select and apply a load torque, the output is the motor speed according to the following differential equation that describes the mechanical system dynamics:

$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

If you select the motor speed as mechanical input, then you get the electromagnetic torque as output, allowing you to represent externally the mechanical system dynamics. The internal mechanical system is not used with this mechanical input selection and the inertia and viscous friction parameters are not displayed.

For the mechanical rotational port, the connection port S counts for the mechanical input and output. It allows a direct connection to the Simscape environment. The mechanical system of the motor is also included in the drive and is based on the same differential equation.

See "Mechanical Coupling of Two Motor Drives".

Converters and DC Bus Tab

Rectifier Section

The **Rectifier** section of the **Converters and DC Bus** tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the universal bridge parameters.

Inverter Section

The **Inverter** section of the **Converters and DC Bus** tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the universal bridge parameters.

The average-value inverter uses the following parameters.

Source frequency

The frequency of the three-phase voltage source (Hz).

On-state resistance

The on-state resistance of the inverter switches (ohms).

DC Bus Field — Capacitance

The DC bus capacitance (F).

Braking Chopper section

Resistance

The braking chopper resistance used to avoid bus over-voltage during motor deceleration or when the load torque tends to accelerate the motor (ohms).

Frequency

The braking chopper frequency (Hz).

Activation Voltage

The dynamic braking is activated when the bus voltage reaches the upper limit of the hysteresis band (V). The following figure illustrates the braking chopper hysteresis logic.

Deactivation Voltage

The dynamic braking is shut down when the bus voltage reaches the lower limit of the hysteresis band (V). The Chopper hysteresis logic is shown in the next figure.

Controller Tab

Regulation Type

This pop-up menu allows you to choose between speed and torque regulation.

Schematic Button

When you press this button, a diagram illustrating the speed and current controllers schematics appears.

Speed Controller section

Speed cutoff frequency

The speed measurement first-order low-pass filter cutoff frequency (Hz). This parameter is used in speed regulation mode only.

Speed controller sampling time

The speed controller sampling time (s). The sampling time must be a multiple of the simulation time step.

Speed Ramps — Acceleration

The maximum change of speed allowed during motor acceleration (rpm/s). An excessively large positive value can cause DC bus under-voltage. This parameter is used in speed regulation mode only.

Speed Ramps — Deceleration

The maximum change of speed allowed during motor deceleration (rpm/s). An excessively large negative value can cause DC bus overvoltage. This parameter is used in speed regulation mode only.

PI Regulator — Proportional Gain

The speed controller proportional gain. This parameter is used in speed regulation mode only.

PI Regulator — Integral Gain

The speed controller integral gain. This parameter is used in speed regulation mode only.

Torque output limits — Negative

The maximum negative demanded torque applied to the motor by the current controller (N.m).

Torque output limits — Positive

The maximum positive demanded torque applied to the motor by the current controller (N.m).

Field Oriented Control Section

Flux Controller — Proportional gain

The flux controller proportional gain.

Flux Controller — Integral gain

The flux controller integral gain.

Flux output limits — Positive

The flux controller maximum positive output (Wb).

Flux output limits — Negative

The flux controller maximum negative output (Wb).

Lowpass filter cutoff frequency

The flux estimation first-order filter cutoff frequency (Hz).
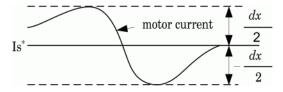
Sampling Time

The FOC controller sampling time (s). The sampling time must be a multiple of the simulation time step.

Current controller hysteresis band

The current hysteresis bandwidth. This value is the total bandwidth distributed symmetrically around the current set point [A]. The following figure illustrates a case where the current set point is Is^* and the current hysteresis bandwidth is set to dx.

This parameter is not used when using the average-value inverter.

Maximum Switching Frequency

The maximum inverter switching frequency (Hz). This parameter is not used when using the average-value inverter.

Block Inputs and Outputs

SP

The speed or torque set point. The speed set point can be a step function, but the speed change rate will follow the acceleration / deceleration ramps. If the load torque and the speed have opposite signs, the accelerating torque will be the sum of the electromagnetic and load torques.

Tm or Wm

The mechanical input: load torque (Tm) or motor speed (Wm). For the mechanical rotational port (S), this input is deleted.

A, B, C

The three phase terminals of the motor drive.

Wm, Te or S

The mechanical output: motor speed (Wm), electromagnetic torque (Te) or mechanical rotational port (S).

When the **Output bus mode** parameter is set to **Multiple output buses**, the block has the following three output buses:

Motor

The motor measurement vector. This vector allows you to observe the motor's variables using the Bus Selector block.

Conv

The three-phase converters measurement vector. This vector contains:

- The DC bus voltage
- The rectifier output current
- The inverter input current

Note that all current and voltage values of the bridges can be visualized with the Multimeter block.

Ctrl

The controller measurement vector. This vector contains:

- The torque reference
- The speed error (difference between the speed reference ramp and actual speed)
- The speed reference ramp or torque reference

When the **Output bus mode** parameter is set to **Single output bus**, the block groups the Motor, Conv, and Ctrl outputs into a single bus output.

Model Specifications

The library contains a 3 hp and a 200 hp drive parameter set. The specifications of these two drives are shown in the following table.

3 HP and 200 HP Drive Specifications

		3 HP Drive	200 HP Drive
Drive Input Voltage			
	Amplitude	220 V	460 V
	Frequency	60 Hz	60 Hz
Motor Nominal Values			
	Power	3 hp	200 hp
	Speed	1705 rpm	1785 rpm
	Voltage	220 V	460 V

Example

The `ac3_example` example illustrates an AC3 motor drive simulation with standard load conditions for the detailed and average-value models.

At time t = 0 s, the speed set point is 500 rpm. As shown in the following figure, the speed precisely follows the acceleration ramp. At t = 0.5 s, the nominal load torque is applied to the motor. At t = 1 s, the speed set point is changed to 0 rpm. The speed decreases to 0 rpm. At t = 1.5 s, the mechanical load passes from 792 N.m to −792 N.m. Notice that the results of the average-value model are similar to those of the detailed model except that the higher frequency signal components are not represented with the average-value converter.

AC3 Example Waveforms (Blue : Detailed Converter, Red : Average-Value Converter)

References

[1] Bose, B. K., *Modern Power Electronics and AC Drives*, Prentice-Hall, N.J., 2002.

[2] Grelet, G., and G. Clerc,*Actionneurs électriques*, Éditions Eyrolles, Paris, 1997.

[3] Krause, P. C.,*Analysis of Electric Machinery*, McGraw-Hill, 1986.
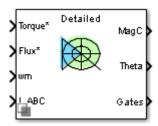
Introduced in R2006a

Field-Oriented Controller

Implement a field-oriented controller model based on indirect or feedforward vector control strategy

Library

Electric Drives/Fundamental Drive Blocks
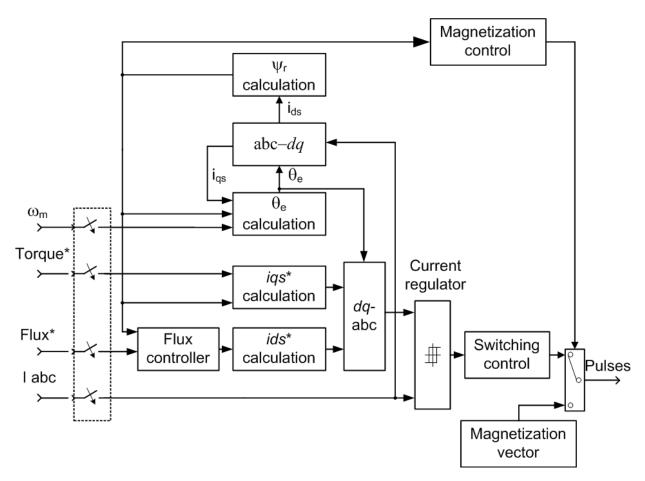
Description

The Field-Oriented Controller block makes an AC machine-based drive behave like a DC machine-based drive in terms of controlling the torque and the flux independently. For an explanation, see "Flux-Oriented Control".

The Field-Oriented Controller model has two operating modes. It generates pulses for either a detailed or average-value inverter.

Detailed Model

In detailed mode, the Field-Oriented Controller block contains 11 main blocks as shown in the figure.

- The ψr calculation block estimates the motor's rotor flux. This calculation is based on motor equation synthesis.
- The Θe calculation block finds the phase angle of the rotor flux rotating field.
- The abc-dq block performs the conversion of abc phase variables into dq components of the rotor flux rotating field reference frame.
- The dq-abc block performs the conversion of the dq components of the rotor flux rotating field reference frame into abc phase variables.
- The iqs* calculation block uses the calculated rotor flux and the torque reference to compute the stator current quadrature component required to produce the electromagnetic torque on the motor's shaft.

- The ids* calculation block uses the rotor flux reference to compute the stator current direct component required to produce the rotor flux in the machine.

- The current regulator is a bang-bang current controller with adjustable hysteresis bandwidth.
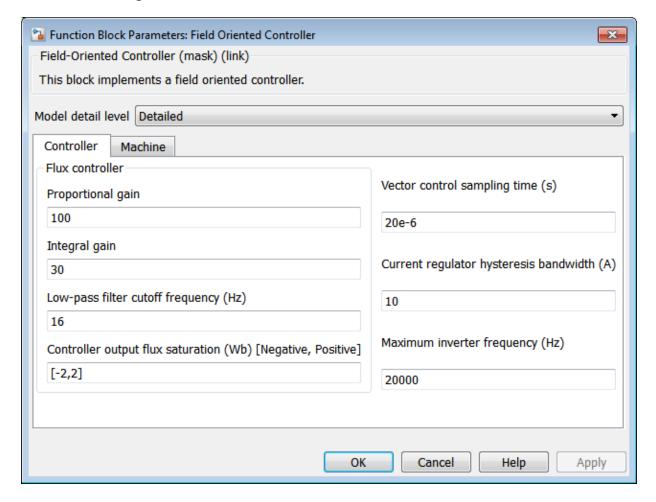
- The switching control block limits the inverter commutation frequency to a maximum value.

- The flux controller controls the flux dynamics and reduces the steady-state flux error.

- The magnetization vector unit contains the vector used to create the motor initial flux.

- The magnetization control unit contains the logic for switching between magnetization and normal operation modes.

Average Model

In average mode, the high-frequency switching actions of the power switches are not represented.

Average mode is similar to detailed mode except that there is no switching control block and the pulses generated by the current regulator are three-level signals (-1, 0, 1) indicating whether the average-value inverter applies a negative, zero, or positive DC bus voltage (Vdc) to the machine during inverter saturation. In detailed mode, the Field Oriented Controller block outputs the actual pulses for the inverter switches.

Dialog Box and Parameters

Function Block Parameters: Field Oriented Controller

Field-Oriented Controller (mask) (link)

This block implements a field oriented controller.

Model detail level Detailed

Controller | Machine

Flux controller

Proportional gain

100

Integral gain

30

Low-pass filter cutoff frequency (Hz)

16

Controller output flux saturation (Wb) [Negative, Positive]

[-2,2]

Vector control sampling time (s)

20e-6

Current regulator hysteresis bandwidth (A)

10

Maximum inverter frequency (Hz)

20000

OK | Cancel | Help | Apply

Model detail level

Specify the model detail level to use:

- Detailed (default)

- Average

Controller Tab

Proportional gain

The flux controller proportional gain. The default value is 100.

Integral gain

The flux controller integral gain. The default value is 30.

Low-pass filter cutoff frequency (Hz)

The flux estimation first-order filter cutoff frequency, in hertz. The default value is 16.

Controller output flux saturation (Wb) [Negative, Positive]
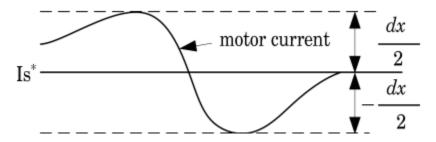
The flux controller maximum negative and positive output, in webers. The default value is [-2,2].

Vector control sampling time (s)

The controller sampling time, in seconds. The sampling time must be a multiple of the simulation time step. The default value is 20e-6.

Current regulator hysteresis-bandwidth (A)

The current regulator hysteresis bandwidth, in amperes. This value is the total hysteresis bandwidth distributed symmetrically around the current set point. The figure shows a case where the current set point is Is* and the current regulator hysteresis-band width is set to dx.

This parameter is available only when the **Model detail level** parameter is set to Detailed. The default value is 10.

Maximum inverter frequency (Hz)

The maximum inverter switching frequency, in hertz. This parameter is available only when the **Model detail level** parameter is set to `Detailed`. The default value is `20000`.

Machine Tab

Rotor resistance Rr' (ohms)

The rotor resistance referred to the stator, in ohms. The default value is `9.295e-3`.

Rotor leakage inductance Llr' (H)

The rotor leakage inductance referred to the stator, in henry. The default value is `0.3027e-3`.

Mutual inductance Lm (H)

The magnetizing inductance, in henry. The default value is `10.46e-3`.

Pairs of poles

The number of pole pairs. The default value is `2`.

Initial flux (Wb)

The initial flux for the machine, in webers. The default value is `0.73`.

Inputs and Outputs

`Torque*`

The torque reference, typically provided by a speed controller.

`Flux*`

The flux reference, typically provided by a speed controller.

`wm`

The mechanical angular speed of the induction machine.

`I_ABC`

The three line currents of the induction machine.

`MagC`

This binary signal indicates if the machine is magnetized enough to be started (1) or not (0).

`Theta`

The phase angle of the rotor flux.

sig*

A vector containing measurement signals:

- Vmode — A logical value indicating if the mode is magnetization (1) or normal operation (0).
- we —The electrical angular speed of the rotor flux.
- iabc* — The three reference currents.
- pulses* — Two three-level signals (-1, 0, 1) indicating if the average-value inverter applies a negative, zero, or positive DC bus voltage (Vdc) to the machine.

This output is visible only when the **Model detail level** parameter is set to Average.

Gates

The pulses for the six inverter switches. This output is visible only when the **Model detail level** parameter is set to Detailed.

Examples

The Field-Oriented Controller block is used in the AC3 block of the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

Bridge Firing Unit (AC) | Bridge Firing Unit (DC) | Current Controller (Brushless DC) | Current Controller (DC) | Direct Torque Controller | Regulation Switch | Six-Step Generator | Space Vector Modulator | Speed Controller (AC) | Speed Controller (DC) | Speed Controller (Scalar Control) | Vector Controller (PMSM) | Vector Controller (WFSM) | Voltage Controller (DC Bus)

More About

- "Electric Drives Library"

Introduced in R2015b

First-Order Filter

Implement first-order filter

Library

Control and Measurements/Filters

Description

Depending on the **Filter type** selected in the block menu, the First-Order Filter block implements the following transfer function:

Low-pass filter:

$$H(s) = \frac{1}{1 + Ts}$$
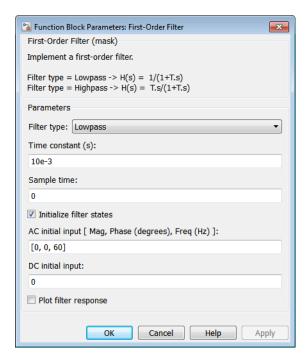
High-pass filter:

$$H(s) = \frac{Ts}{1 + Ts}$$

s = Laplace operator

T = time constant

The key characteristics of the First-Order Filter block are:

- Input accepts a vectorized input of N signals, thus implementing N filters. This feature is particularly useful for designing controllers in three-phase systems (N = 3).
- You can initialize filter states for specified DC and AC inputs.
- It enables you to compute and plot filter response.

Dialog Box and Parameters

Filter type

Specify the type of filter: `Lowpass` or `Highpass`.

Time constant (s)

Specify the filter time constant, in seconds.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Initialize filter states

When this check box is selected, the filter states are initialized according to the **AC initial input** and **DC initial input** parameters.

AC initial input: [Mag, Phase (degrees), Freq (Hz)]

Specify the magnitude of the initial AC component of the input signal, its phase, in degrees, and its frequency, in hertz.

When the input is vectorized (N signals), specify an N-by-3 matrix, where each row of the matrix corresponds to a particular input.

The **AC initial input** parameter is visible only when the **Initialize filter states** parameter is selected.

DC initial input

Specify the value of the initial DC component of the input signal. When the input signal is vectorized, specify a 1-by-N vector, where each value corresponds to a particular input.

The **DC initial input** parameter is visible only when the **Initialize filter states** parameter is selected.

Plot filter response

When this check box is selected, the filter step response and its Bode diagram (magnitude and phase of transfer function as a function of frequency) are plotted in a figure.

Frequency range (Hz): [Start, End, Inc.]

The frequency range used for plotting the filter Bode diagram. Specify a vector containing the starting frequency, the end frequency, and the incremental frequency, in hertz.

The **Frequency range** parameter is visible only when the **Plot filter response** parameter is selected.

Characteristics

Direct Feedthrough	Yes
Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	Yes, of the parameters
States	One state per filter
Dimensionalized	Yes

Example

The power_FirstOrderFilter example shows various uses of the First-Order Filter block using two **Filter type** parameter settings (`Lowpass` and `Highpass`).

The model sample time is parameterized with variable Ts (default value Ts = 50e-6). To simulate continuous filters, specify Ts = 0 at the MATLAB command prompt before you start.
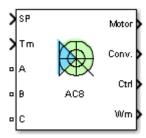
Introduced in R2013a

Five-Phase PM Synchronous Motor Drive

Implement five-phase permanent magnet synchronous motor vector control drive

Library

Electric Drives/AC drives
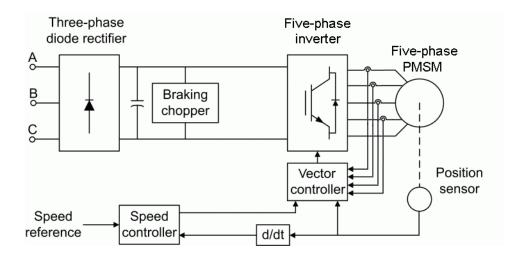
Description

The Five-Phase PM Synchronous Motor Drive block implements an electric drive controlling a five-phase permanent magnet synchronous motor with vector control technique.

Note The Five-Phase PM Synchronous Motor Drive block is commonly called the AC8 motor drive.
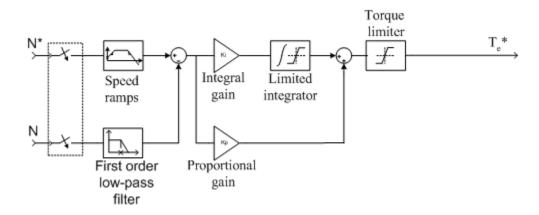
High-Level Schematic

The high-level schematic is built from six main blocks. The five-phase PMSM motor, the five-phase inverter, and the three-phase diode rectifier models are provided in the SimPowerSystems library. The speed controller, the braking chopper, and the vector controller models are specific to the drive library. You can alternatively use a simplified version of the drive containing an average-value model of the inverter for faster simulation.

Speed Controller
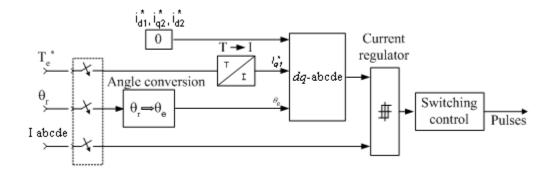
The speed controller is based on a PI regulator. The output of this regulator is a torque set point applied to the vector controller block.

Vector Controller

The vector controller contains four main sections:
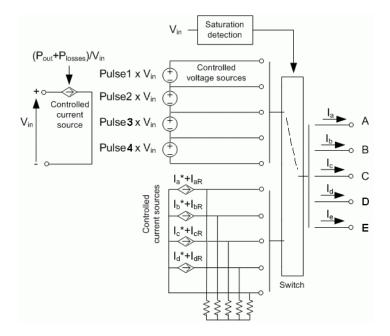
The angle conversion section computes the electrical rotor angle from the mechanical rotor angle. The dq-abcde section converts two dq current components in the rotor reference frame into abcde phase variables. The current regulator section is a bang-bang current controller with adjustable hysteresis bandwidth. The switching control section limits the inverter commutation frequency to a maximum value you specify.

Braking Chopper

The braking chopper contains the DC bus capacitor and the dynamic braking chopper, which is used to absorb the energy produced by the motor deceleration.

Average-Value Inverter

The average-value inverter is shown in the following figure.

On the DC side of the inverter, a controlled current source represents the average DC bus current behavior based on this equation:

$$I_{dc} = (P_{out} + P_{losses}) / V_{in}$$

Where
P_{out} is the output power
P_{losses} is the losses in the power electronic devices,
V_{in} is the DC bus voltage.

On the AC side, four controlled current sources represent the average phase currents that fed the motor. Because the regulation is fast, the current values are set equal to the current references of the current regulator. A small current is injected to compensate for the current drawn by the five-phase resistive load connected in series with the motor.

During loss of current tracking, the currents are fed by four controlled voltage sources that represent the square wave mode and allow good representation of the phase currents during inverter saturation. Each voltage source outputs either Vin or 0, depending on the values of the pulses sent by the current controller.
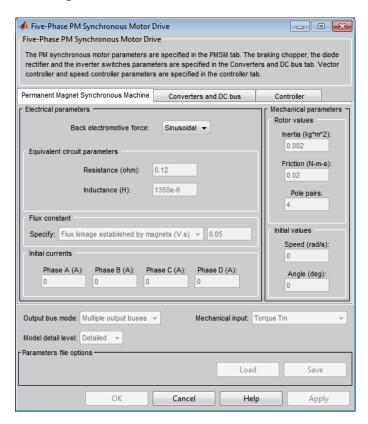
Remarks

The control system has two different sampling times: the speed controller sampling time and the vector controller sampling time.

The speed controller sampling time must be a multiple of the vector controller sampling time and a multiple of the simulation time step. The average-value inverter model has lower time constants, compared to the detailed converter model. Therefore, you can use higher simulation time steps with this type of model. For a vector controller sampling time of 30 µs, good simulation results have been obtained for a simulation time step of 30 µs.

The simulation time step must be lower than the vector controller time step.

The stator currents id1*, iq2*, and id2* are set to 0 inside the vector controller block since only the iq1 current contributes to torque production.

Dialog Box

- "Permanent Magnet Synchronous Machine Tab" on page 1-315
- "Converters and DC Bus Tab" on page 1-316
- "Controller Tab" on page 1-318

Permanent Magnet Synchronous Machine Tab

Electrical parameters, Mechanical parameters

The **Electrical parameters** and the **Mechanical parameters** sections display the parameters of the Synchronous Machine block.

Output bus mode

Select how the output variables are organized. If you select **Multiple output buses**, the block has three separate output buses for motor, converter, and controller variables. If you select **Single output bus**, all variables output on a single bus.

Model detail level

Select between `Detailed` and `Average` inverter models.

Mechanical input

Select between `Torque Tm`, `Speed w`, and the `mechanical rotational port` as the mechanical input.

When you select `Torque Tm`, the block outputs the motor speed according to the following differential equation, describing the mechanical system dynamics:

$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is modeled inside the Synchronous Machine block.

When you select Speed w as the mechanical input, the block outputs the electromagnetic torque, allowing you to model the mechanical system dynamics outside the Five-Phase PM Synchronous Motor Drive block. With this setting, the inertia and viscous friction parameters do not appear in the mask of the block.

When you select `mechanical rotational port`, the block shows the connection port S, which counts for the mechanical input and output. It allows a direct connection to the Simscape environment. The mechanical system of the motor is modeled inside the drive and is based on the same differential equation.

See "Mechanical Coupling of Two Motor Drives".

Converters and DC Bus Tab

Rectifier

The **Rectifier** section of the **Converters and DC bus** tab displays the parameters of the Universal Bridge block.

Inverter

The **Inverter** section of the **Converters and DC bus** tab displays the parameters of the Universal Bridge block that is included in the Power Electronics library of the Fundamental Blocks library.

DC bus – Capacitance

Specify the DC bus capacitance, in farads.

Source frequency

Specify the frequency of the voltage source, in hertz. The **Source frequency** parameter is visible only when the **Model detail level** parameter is set to `Average`.

On-state resistance

Specify the on-state resistance of the inverter devices, in ohms. The **On-state resistance** parameter is visible only when the **Model detail level** parameter is set to `Average`.

Braking Chopper Section

Resistance

Specify the braking chopper resistance, in ohms. Use this resistance to avoid bus overvoltage during motor deceleration or when the load torque tends to accelerate the motor.

Chopper frequency
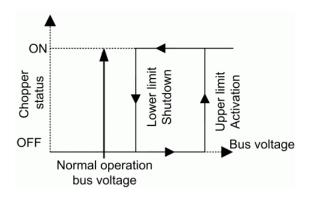
Specify the braking chopper frequency, in hertz.

Activation voltage

The dynamic braking is activated when the bus voltage reaches the upper limit of the hysteresis band. The figure Chopper Hysteresis LogicChopper Hysteresis Logic shows the braking chopper hysteresis logic.

Shutdown voltage

Specify the shutdown voltage, in volts. This value is the point at which the dynamic braking shuts down when the bus voltage reaches the lower limit of the hysteresis band. The chopper hysteresis logic is shown in the following figure.

Chopper Hysteresis Logic

Controller Tab

Regulation type

Specify the type of regulation, `Speed regulation` or `Torque regulation`.

Schematic

Open a diagram showing the speed and vector controllers schematics.

Speed Controller Section

Acceleration

Specify the maximum acceleration allowed for the motor, in rpm/s. An excessively large positive value can cause DC bus undervoltage. This parameter is used only in speed regulation mode.

Deceleration

Specify the maximum change of speed allowed during motor deceleration, in rpm/s. An excessively large negative value can cause DC bus overvoltage. This parameter is used only in speed regulation mode.

Speed cutoff frequency

Specify the speed measurement first-order low-pass filter cutoff frequency, in hertz. This parameter is used only in speed regulation mode.

Speed controller sampling time

Specify the speed controller sampling time, in seconds. The sampling time must be a multiple of the simulation time step.

Proportional gain

Specify the speed controller proportional gain. This parameter is used only in speed regulation mode.

Integral gain

Specify the speed controller integral gain. This parameter is used only in speed regulation mode.

Negative

Specify the maximum negative torque, in newton-meters, applied to the motor by the vector controller (N.m).

Positive

Specify the maximum positive torque, in newton-meters, applied to the motor by the vector controller.

Vector Controller Section
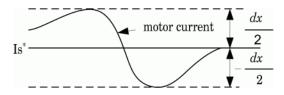
Sampling time

Specify the vector controller sampling time, in seconds. The sampling time must be a multiple of the simulation time step.

Current controller hysteresis band

Specify the current hysteresis bandwidth, in amperes. This value is the total bandwidth distributed symmetrically around the current set point. The following figure shows a case where the current set point is Is* and the current hysteresis bandwidth is set to *dx*.

This parameter is ignored when using the average-value inverter.

Note A Rate Transition block is needed to transfer data between different sampling rates. This block causes a delay in the gate signals, so the current might exceed the hysteresis band.

Maximum switching frequency

Specify the maximum inverter switching frequency, in hertz. This parameter is ignored when using the average-value inverter.

Inputs and Outputs

SP

Outputs the speed or torque set point. The speed set point can be a step function, but the speed change rate follows the acceleration and deceleration ramps. When the load torque and the speed have opposite signs, the accelerating torque is the sum of the electromagnetic and load torques.

Wm, Tm, or S

The mechanical input of the drive: motor speed (Wm), mechanical torque (Tm), or mechanical rotational port (S).

A, B, C

The three phase terminals of the motor drive.

When the **Output bus mode** parameter is set to **Multiple output buses**, the block has the following three output buses:

Motor

The motor measurement vector. This vector allows you to observe the motor's variables using the Bus Selector block.

Conv

The five-phase converter measurement vector. This vector contains:

- The DC bus voltage
- The rectifier output current
- The inverter input current

You can visualize all current and voltage values of the bridges using the Multimeter block.

Ctrl

The controller measurement vector. This vector contains:

- The torque reference

- The speed error (difference between the speed reference ramp and actual speed)
- The speed reference ramp or torque reference

When the **Output bus mode** parameter is set to **Single output bus**, the block groups the Motor, Conv, and Ctrl outputs into a single bus output.

Model Specifications

The library contains a 4.4 kW drive parameter set. The table shows the specifications of the 4.4 kW drive.

Drive Input Voltage:	
Amplitude	160 V (L-L)
Frequency	60 Hz
Motor Nominal Values:	
Power	4.4 kW
Speed	900 rpm
Voltage	160 V (L-N)

Example

The `ac8_example` model shows the simulation of the Five-Phase PM Synchronous Motor Drive block under standard load condition. The `ac8_example_simplified` model shows the simulation of the average-value model under the same load conditions.

The simulation of the two models shows that the motor speed follows precisely the acceleration ramp reference signal.

- At t = 0.5 s, the nominal load torque is applied to the motor.
- At t = 1 s, the speed set point changes to 0 rpm and the speed decreases to 0 rpm.
- At t = 1.5 s, the mechanical load passes from 11 N.m to −11 N.m.

The average voltage, current, torque, and speed values are identical for both models. Notice that the higher frequency signal components are not represented with the average-value converter.

References

[1] Bose, B. K., *Modern Power Electronics and AC Drives*, Upper Saddle River, NJ, Prentice-Hall, 2002.

[2] Krause, P. C., *Analysis of Electric Machinery*, McGraw-Hill, 1986.

[3] Toliyat, H. A., *Analysis and Simulation of Multi-Phase Variable Speed Induction Motor Drives Under Asymmetrical Connections*, Applied Power Electronics Conference and Exposition, Vol. 2, 1996, pp. 586–592.

[4] Beaudart, F., F. Labrique, E. Matagne, D. Telteux, and P. Alexandre, *Control under normal and fault tolerant operation of multiphase SMPM synchronous machines with mechanically and magnetically decoupled phases*, International Conference on Power Engineering, Energy and Electrical Drives, 2009, pp. 461–466.

Related Examples

- AC8 - Five-Phase PM Synchronous 4.4kW Motor Drive
- AC8 - Comparison Between Detailed and Simplified Models
- Five-Phase PM Synchronous Motor Drive during speed regulation

Introduced in R2013a

Fourier

Perform Fourier analysis of signal

Library

Control and Measurements/Measurements

Description

The Fourier block performs a Fourier analysis of the input signal over a running window of one cycle of the fundamental frequency of the signal. The Fourier block can be programmed to calculate the magnitude and phase of the DC component, the fundamental, or any harmonic component of the input signal.

Recall that a signal $f(t)$ can be expressed by a Fourier series of the form

$$f(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} a_n \cos(n\omega t) + b_n \sin(n\omega t)$$

where n represents the rank of the harmonics. ($n = 1$ corresponds to the fundamental component.) The magnitude and phase of the selected harmonic component are calculated by these equations:

$$|H_n| = \sqrt{a_n^2 + b_n^2}$$

$$\angle H_n = \operatorname{atan2}\left(\frac{b_n}{a_n}\right)$$

where

$$a_n = \frac{2}{T} \int_{t-T}^{t} f(t) \cos(n\omega t) dt$$
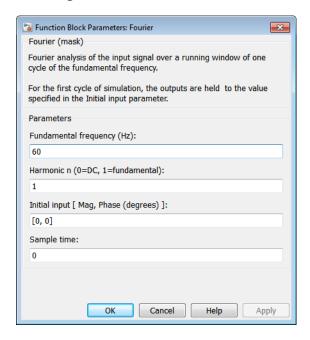
$$b_n = \frac{2}{T} \int_{t-T}^{t} f(t)\sin(n\omega t)dt$$

$$T = \frac{1}{f_1}$$

f_1 : Fundamental frequency

As this block uses a running average window, one cycle of simulation must complete before the outputs give the correct magnitude and angle. For the first cycle of simulation, the outputs are held to the values specified by the initial input parameter.

Dialog Box and Parameters

Fundamental frequency (Hz)

Specify the fundamental frequency, in hertz, of the input signal.

Harmonic n (0 = DC, 1 = fundamental)

Specify the harmonic component for the Fourier analysis. Enter 0 to analyze the DC component. Enter 1 to analyze the fundamental frequency, or enter a number corresponding to the desired harmonic.

Initial input [Mag, Phase (degrees)]

Specify the initial magnitude and phase in degrees of the output signal.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Inputs and Outputs

`Input`

Connect to the signal to be analyzed. Typical input signals are voltages or currents measured by Current Measurement or Voltage Measurement blocks.

`|u|Magnitude`

The first output returns the magnitude of the harmonic component specified, in the same units as the input signal.

$\angle$u `Phase`

The second output returns the phase, in degrees, of the harmonic component specified.

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	Yes, of the parameters
Dimensionalized	Yes

Example

The power_Fourier model shows two applications of the Fourier measurement block. The upper part of the model shows how to use the Fourier block to compute the DC

component, fundamental value, and second and third harmonic content of the same input signal. In the lower part of the model, the block computes the fundamental value (magnitude and phase) of three different inputs. For this application, specify initial values for the three output signals in the dialog box of the mask.

The model sample time is parameterized by the Ts variable set to a default value of 50e-6 s. Set Ts to 0 in the command window to simulate the model in continuous mode.
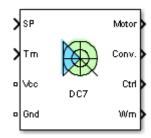
Introduced in R2013a

Four-Quadrant Chopper DC Drive

Implement four-quadrant chopper DC drive

Library
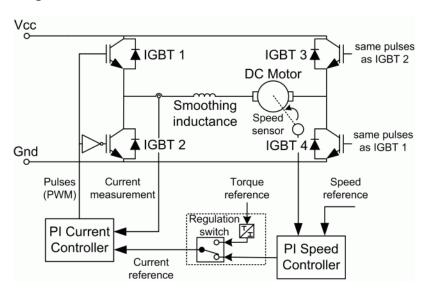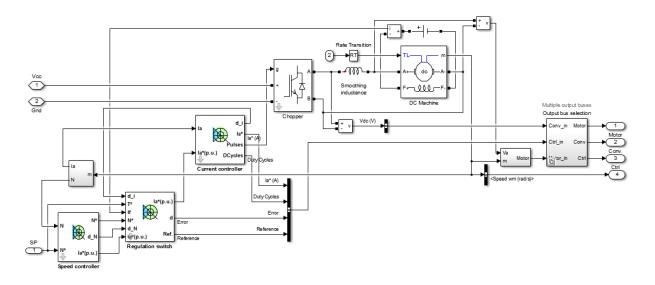
Electric Drives/DC drives

Description

The high-level schematic shown below is built from four main blocks. The DC motor and the IGBT/Diode devices (within the Universal Bridge block) are provided with the SimPowerSystems library. More details on these two blocks are available in the reference sections of these blocks. The two other blocks are specific to the Electric Drives library. These blocks are the speed controller and the current controller. They allow speed or torque regulation. A "regulation switch" block allows you to toggle from one type of regulation to the other. During torque regulation the speed controller is disabled.

Note In SimPowerSystems software, the Four-Quadrant Chopper DC Drive block is commonly called the DC7 motor drive.

High-Level Schematic

Simulink Schematic

Speed Controller

The speed regulator shown below uses a PI controller. The controller outputs the armature current reference (in pu) used by the current controller in order to obtain the electromagnetic torque needed to reach the desired speed. During torque regulation, the speed controller is disabled.

The controller takes the speed reference (in rpm) and the rotor speed of the DC machine as inputs. The speed reference change rate will follow user-defined acceleration and deceleration ramps in order to avoid sudden reference changes that could cause armature over-current and destabilize the system.

The speed measurement is filtered by a first-order low-pass filter.

The current reference output is limited between symmetrical lower and upper limits defined by the user.

Current Controller

The armature current regulator shown below is based on a second PI controller. The regulator controls the armature current by computing the appropriate duty ratios of the fixed frequency pulses of the four IGBT devices (Pulse Width Modulation). This generates the average armature voltage needed to obtain the desired armature current and thus the desired electromagnetic torque. For proper system behavior, the instantaneous pulse values of IGBT devices 1 and 4 are the opposite of those of IGBT devices 2 and 3.
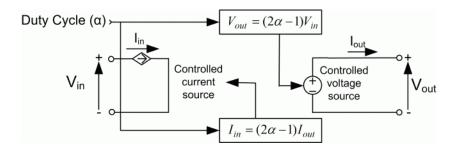
The controller takes the current reference (in pu) and the armature current flowing through the motor as inputs. The current reference is either provided by the speed controller during speed regulation or computed from the torque reference provided by

the user during torque regulation. This is managed by the "regulation switch" block. The armature current input is filtered by a first-order low-pass filter.

The pulse width modulation is obtained by comparison of the PI output and a fixed frequency sawtooth carrier signal (as shown in the figure called Pulse Width Modulation (PWM)).

Average-Value Four-Quadrant Chopper

The average-value converter is shown in the following figure.

It is composed of one controlled current source on the DC source side and one controlled voltage source on the motor side. The current source allows the representation of the average input current value according to the following equation :

$I_{in} = (2a - 1)I_{out}$,

with a being the firing angle value and I_{out} the armature current value. The voltage source on the motor side represents the average voltage value according to the next equation :
$V_{out} = (2a - 1)V_{in}$,

with V_{in} being the input voltage.
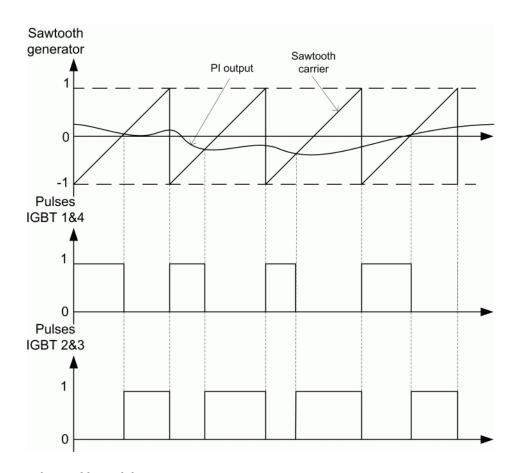
Remarks

The machine is separately excited with a constant DC field voltage source. There is thus no field voltage control. By default, the field current is set to its steady-state value when a simulation is started.

The armature voltage is provided by an IGBT converter controlled by two PI regulators. The converter is fed by a constant DC voltage source. Armature current oscillations are reduced by a smoothing inductance connected in series with the armature circuit.

The model is discrete. Good simulation results have been obtained with a 1 µs time step. In order to simulate a digital controller device, the control system has two different sampling times:

- The speed controller sampling time
- The current controller sampling time

The speed controller sampling time has to be a multiple of the current sampling time. The latter sampling time has to be a multiple of the simulation time step.

Pulse Width Modulation (PWM)

Dialog Box and Parameters

- "DC Machine Tab" on page 1-333
- "Converter Tab" on page 1-334
- "Controller Tab" on page 1-334

DC Machine Tab

The **DC Machine** tab displays the parameters of the DC Machine block of the Fundamental Blocks (powerlib) library.

Output bus mode

Select how the output variables are organized. If you select **Multiple output buses**, the block has three separate output buses for motor, converter, and controller variables. If you select **Single output bus**, all variables output on a single bus.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Select between the load torque, the motor speed and the mechanical rotational port as mechanical input. If you select and apply a load torque, the output is the motor speed according to the following differential equation that describes the mechanical system dynamics:

$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

If you select the motor speed as mechanical input, then you get the electromagnetic torque as output, allowing you to represent externally the mechanical system dynamics. The internal mechanical system is not used with this mechanical input selection and the inertia and viscous friction parameters are not displayed.

For the mechanical rotational port, the connection port S counts for the mechanical input and output. It allows a direct connection to the Simscape environment. The mechanical system of the motor is also included in the drive and is based on the same differential equation.

See "Mechanical Coupling of Two Motor Drives".

Converter Tab

IGBT/Diode Devices section

The IGBT/Diode section of the Converter tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the Universal Bridge block parameters.

Smoothing Inductance

The smoothing inductance value (H).

Field DC Source

The DC motor field voltage value (V).

Controller Tab

Schematic Button

When you press this button, a diagram illustrating the speed and current controllers schematics appears.

Regulation Type

This pop-up menu allows you to choose between speed and torque regulation.

Controller — Speed Controller Subtab

Nominal Speed

The nominal speed value of the DC motor (rpm). This value is used to convert motor speed from rpm to pu (per unit).

Initial Speed Reference

The initial speed reference value (rpm). This value allows the user to start a simulation with a speed reference other than 0 rpm.

Low-Pass Filter Cutoff Frequency

Cutoff frequency of the low-pass filter used to filter the motor speed measurement (Hz).

Sampling Time

The speed controller sampling time (s). This sampling time has to be a multiple of the current controller sampling time and of the simulation time step.

Proportional Gain

The proportional gain of the PI speed controller.

Integral Gain

The integral gain of the PI speed controller.

Acceleration

The maximum change of speed allowed during motor acceleration (rpm/s). Too great a value can cause armature over-current.

Deceleration

The maximum change of speed allowed during motor deceleration (rpm/s). Too great a value can cause armature over-current.

Controller — Current Controller Subtab

Low-Pass Filter Cutoff Frequency

Cutoff frequency of the low-pass filter used to filter the armature current measurement (Hz).

Symmetrical Reference Limit

Symmetrical current reference (pu) limit around 0 pu. 1.5 pu is a common value.

PWM Switching Frequency

The switching frequency of the four IGBT devices (Hz).

Sampling Time

The current controller sampling time (s). This sampling time has to be a submultiple of the speed controller sampling time and a multiple of the simulation time step.

Power and Voltage nominal values

The DC motor nominal power (W) and voltage (V) values. These values are used to convert armature current from amperes to pu (per unit).

Proportional Gain

The proportional gain of the PI current controller.

Integral Gain

The integral gain of the PI current controller.

Block Inputs and Outputs

SP

The speed or torque set point. The speed set point can be a step function, but the speed change rate will follow the acceleration / deceleration ramps. If the load torque and the speed have opposite signs, the accelerating torque will be the sum of the electromagnetic and load torques.

Tm or Wm

The mechanical input: load torque (Tm) or motor speed (Wm). For the mechanical rotational port (S), this input is deleted.

Vcc, Gnd

The DC voltage source electric connections. The voltage must be adequate for the motor size.

Wm, Te or S

The mechanical output: motor speed (Wm), electromagnetic torque (Te) or mechanical rotational port (S).

When the **Output bus mode** parameter is set to **Multiple output buses**, the block has the following three output buses:

Motor

The motor measurement vector. This vector is composed of two elements:

- The armature voltage
- The DC motor measurement vector (containing the speed, armature current, field current, and electromagnetic torque values). Note that the speed signal is converted from rad/s to rpm before output.

Conv

The IGBT/Diode device measurement vector. This vector includes the converter output voltage. The output current is not included since it is equal to the DC motor armature current. Note that all current and voltage values of the converter can be visualized with the Multimeter block.

Ctrl

The controller measurement vector. This vector contains:

- The armature current reference
- The duty cycle of the PWM pulses
- The speed or torque error (difference between the speed reference ramp and actual speed or between the torque reference and actual torque)
- The speed reference ramp or torque reference

When the **Output bus mode** parameter is set to **Single output bus**, the block groups the Motor, Conv, and Ctrl outputs into a single bus output.

Model Specifications

The library contains a 5 hp and a 200 hp drive parameter set. The specifications of these two drives are shown in the following table.

5 HP and 200 HP Drive Specifications

		5 HP Drive	200 HP Drive
Drive Input Voltage			
	Amplitude	280 V	500 V
Motor Nominal Values			
	Power	5 hp	200 hp
	Speed	1750 rpm	1184 rpm

Drive Input Voltage		5 HP Drive	200 HP Drive
	Voltage	240 V	440 V

Example

The `dc7_example` example illustrates the four-quadrant chopper drive used with the 200 hp drive parameter set during speed regulation. A 5 hp parameter set is also available in the library.

The converter is fed by a 515 V DC bus obtained by rectification of a 380 V AC 50 Hz voltage source. In order to limit the DC bus voltage during dynamic braking mode, a braking chopper has been added between the diode rectifier and the DC7 block. The IGBT switching frequency is 5 kHz.

The motor is coupled to a linear load, which means that the mechanical torque of the load is proportional to the speed.

The speed reference is set at 500 rpm at t = 0 s. Observe that the motor speed follows the reference ramp accurately (+400 rpm/s) and reaches steady state around t = 1.3 s.
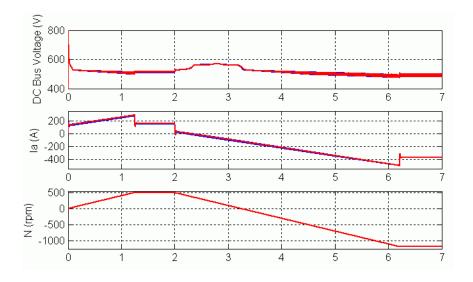
The armature current follows the current reference very well, with fast response time and small ripples. Notice that the current ripple frequency is 5 kHz.

At t = 2 s, speed reference drops to −1184 rpm. The current reference decreases to reduce the electromagnetic torque and causes the motor to decelerate with the help of the load torque.

At t = 2.2 s, the current reverses in order to produce a braking electromagnetic torque (dynamic braking mode). This causes the DC bus voltage to increase.
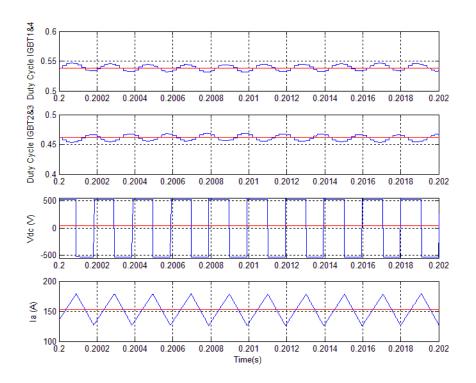
At t = 3.25 s, the motor reaches 0 rpm and the load torque reverses and becomes negative. The negative current now produces an accelerating electromagnetic torque to allow the motor to follow the negative speed ramp (−400 rpm/s). At t = 6.3 s, the speed reaches −1184 rpm and stabilizes around its reference.

The following figure shows the DC bus voltage, armature current, and speed waveforms.

DC7 Example — DC Bus Voltage, Current, and Speed Waveforms (Blue: Detailed Converter, Red: Average-Value Converter)

The next figure shows the duty cycles of the chopper pulses and the corresponding armature voltage and current waveforms during a time interval of 2 ms.

DC7 Example — Duty Cycles, Armature Voltage, and Current Waveforms (Blue: Detailed Converter, Red: Average-Value Converter)

References

[1] Boldea, Ion, and S.A. Nasar, *Electric Drives*, CRC Press LLC, 1999.

[1] Séguier, Guy, *Electronique de puissance*, Dunod, 1999.

Related Examples

- DC7 - Four-Quadrant Chopper 200 HP DC Drive
- Simplified Four-Quadrant Chopper 200 HP Drive
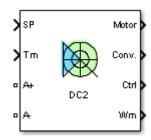
Introduced in R2006a

Four-Quadrant Single-Phase Rectifier DC Drive

Implement single-phase dual-converter DC drive with circulating current

Library

Electric Drives/DC drives

Description
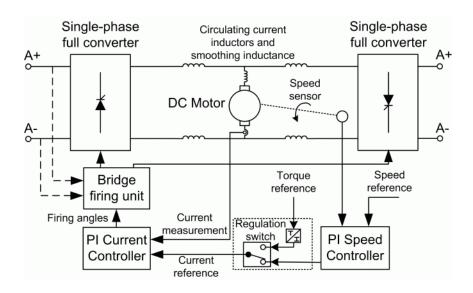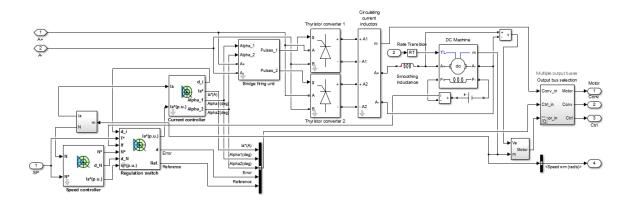
The high-level schematic shown below is built from six main blocks. The DC motor, the two single-phase full converters, and the bridge firing unit are provided with the SimPowerSystems library. More details on these blocks are available in the reference sections of these blocks. The two other blocks are specific to the Electric Drives library. These blocks are the speed controller and the current controller. They allow speed or torque regulation. A "regulation switch" block allows you to toggle from one type of regulation to the other. During torque regulation the speed controller is disabled. It is possible to use a simplified version of the drive, which contains an average-value model of the single-phase dual-converter and allows faster simulation.

Note In SimPowerSystems software, the Four-Quadrant Single-Phase Rectifier DC Drive block is commonly called the **DC2** motor drive.

High-Level Schematic

Simulink Schematic

Speed Controller

The speed regulator shown below uses a PI controller. The controller outputs the armature current reference (in pu) used by the current controller in order to obtain the electromagnetic torque needed to reach the desired speed. During torque regulation, the speed controller is disabled.

The controller takes the speed reference (in rpm) and the rotor speed of the DC machine as inputs. The speed reference change rate will follow user-defined acceleration and deceleration ramps in order to avoid sudden reference changes that could cause armature over-current and destabilize the system. The speed measurement is filtered by a first-order low-pass filter.

The current reference output is limited between symmetrical lower and upper limits defined by the user.

Current Controller

The armature current regulator shown below is based on a second PI controller. The regulator controls the armature current by computing the appropriate thyristor firing angles of the two full converters. This generates the converter output voltages needed to obtain the desired armature current and thus the desired electromagnetic torque.

The controller takes the current reference (in pu) and the armature current flowing through the motor as inputs. The current reference is either provided by the speed controller during speed regulation or computed from the torque reference provided by the user during torque regulation. This is managed by the "regulation switch" block.

The armature current input is filtered by a first-order low-pass filter. An arccosine function is used to linearize the control system. The firing angle can vary between 0 and 180 degrees. You can limit the lower and upper limits to intermediate values.

Both converters operate simultaneously, and the two firing angles are controlled so that the sum of their values stays equal to 180 degrees. This produces opposite average voltages at the converter DC output terminals and thus identical average voltages at the DC motor armature, the converters being connected in antiparallel. One converter is working in rectifier mode while the other is in inverter mode.

Average-Value Single-Phase Rectifier

The average-value single-phase rectifier with circulating current is shown in the following figure.

It is composed of one controlled current source on the AC side and one controlled voltage and current source on the DC side. The AC current source allows the representation of the fundamental single-phase current behavior according to the following equation

$$I_a = \sqrt{2}I_d \sin\left(2\pi ft + \alpha + \alpha_0\right),$$

with α being the firing angle value, α_0 the phase angle of the AC side, f the AC frequency, and I_d the rectified output current value. The DC voltage source represents the average voltage value of the rectified voltage waveform according to the next equation

$$V_d = \frac{2\sqrt{2}}{\pi}V_{\mathrm{rms}}\cos\alpha - 4fLI_d,$$

with V_{rms} being the input RMS voltage value and L being the source inductance value. The controlled current source represents the circulation current due to the instantaneous voltage difference between both converter outputs of the dual-converter. This current is equal to

$$I_{\mathrm{circ}} = \frac{\sqrt{2}}{\pi^2 fL_{\mathrm{circ,tot}}}V_{\mathrm{rms}}(\sin\alpha - \alpha\cos\alpha),$$

with $L_{\mathrm{circ,tot}}$ being the total circulation inductance of the circulation current loop.

Bridge Firing Unit

The bridge firing unit converts the firing angles, provided by the current controller, to two series of four pulses applied respectively to the thyristor gates of each converter. The bridge firing unit block contains a band-pass filter on voltage measurement to remove voltage harmonics. Two discrete synchronized pulse generator blocks generate the pulses of each converter. Their architecture is based on the Discrete Synchronized 6-Pulse Generator block. Refer to the Synchronized 6-Pulse Generator for more information on this block. When using the average-value converter, the bridge firing unit simply outputs the firing angle value needed by the converter.

Remarks

The machine is separately excited with a constant DC field voltage source. There is thus no field voltage control. By default, the field current is set to its steady-state value when a simulation is started.

The armature voltage is provided by two single-phase antiparallel-connected converters controlled by two PI regulators. The circulating current produced by the instantaneous voltage difference at the terminal of both converters is limited by inductors connected between these terminals. Armature current oscillations are reduced by a smoothing inductance connected in series with the armature circuit.

The average-value converter represents the average behavior of a single-phase rectifier for continuous armature current in a dual-converter topology. This model is thus not suitable for simulating DC drives under discontinuous armature current conditions. The converter outputs a continuous voltage value equal to the average-value of the real-life rectified voltage. The armature voltage, armature current and electromagnetic torque ripples are thus not represented. The input currents have the frequency and amplitude of the fundamental current component of the real-life input currents.

The model is discrete. Good simulation results have been obtained with a 4 µs time step. The control system (speed and current controllers) samples data following a user-defined sample time in order to simulate a digital controller device. Keep in mind that this sampling time has to be a multiple of the simulation time step.

The average-value converter allows the use of bigger simulation time steps since it does not generate small time constants (due to the RC snubbers) inherent to the detailed converter. For a controller sampling time of 100 µs good simulation results have been

obtained for a simulation time step of 100 µs. This time step cannot be higher than the controller time step.

Dialog Box and Parameters

- "DC Machine Tab" on page 1-348
- "Converter Tab" on page 1-349
- "Controller Tab" on page 1-350

DC Machine Tab

The **DC Machine** tab displays the parameters of the DC Machine block of the Fundamental Blocks (powerlib) library.

Output bus mode

> Select how the output variables are organized. If you select **Multiple output buses**, the block has three separate output buses for motor, converter, and controller variables. If you select **Single output bus**, all variables output on a single bus.

Model detail level

> Select between the detailed and the average-value inverter.

Mechanical input

> Select between the load torque, the motor speed and the mechanical rotational port as mechanical input. If you select and apply a load torque, the output is the motor speed according to the following differential equation that describes the mechanical system dynamics:

$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

> This mechanical system is included in the motor model.

> If you select the motor speed as mechanical input, then you get the electromagnetic torque as output, allowing you to represent externally the mechanical system dynamics. The internal mechanical system is not used with this mechanical input selection and the inertia and viscous friction parameters are not displayed.

> For the mechanical rotational port, the connection port S counts for the mechanical input and output. It allows a direct connection to the Simscape environment. The mechanical system of the motor is also included in the drive and is based on the same differential equation.

> See "Mechanical Coupling of Two Motor Drives".

Converter Tab

Smoothing Inductance

> The smoothing inductance value (H).

Field DC Source

> The DC motor field voltage value (V).

Circulating Current Inductors

The four circulating current inductors inductance value (H).

Converter sections

The Converter 1 and Converter 2 sections of the Converter tab display the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the Universal Bridge block parameters.

RMS Voltage

RMS voltage of the single-phase voltage source connected to the A+,A− terminals of the drive (V). This parameter is not used when using the detailed rectifier.

Frequency

Frequency of the single-phase voltage source connected to the A+,A− terminals of the drive (Hz). This parameter is not used when using the detailed rectifier.

Source Inductance

Source inductance of the single-phase voltage source connected to the A+,A− terminals of the drive (H). This parameter is not used when using the detailed rectifier.

Phase Angle

Phase angle of the single-phase voltage source connected to the A+,A− terminals of the drive (deg.). This parameter is not used when using the detailed rectifier.

Controller Tab

Schematic Button

When you press this button, a diagram illustrating the speed and current controllers schematics appears.

Regulation Type

This pop-up menu allows you to choose between speed and torque regulation.

Sampling Time

The controller (speed and current) sampling time (s). The sampling time has to be a multiple of the simulation time step.

Controller — Speed Controller Subtab

Nominal Speed

The nominal speed value of the DC motor (rpm). This value is used to convert motor speed from rpm to pu (per unit).

Initial Speed Reference

The initial speed reference value (rpm). This value allows the user to start a simulation with a speed reference other than 0 rpm.

Low-Pass Filter Cutoff Frequency

Cutoff frequency of the low-pass filter used to filter the motor speed measurement (Hz).

Proportional Gain

The proportional gain of the PI speed controller.

Integral Gain

The integral gain of the PI speed controller.

Acceleration

The maximum change of speed allowed during motor acceleration (rpm/s). Too great a value can cause armature over-current.

Deceleration

The maximum change of speed allowed during motor deceleration (rpm/s). Too great a value can cause armature over-current.

Controller — Current Controller Subtab

Power and Voltage nominal values

The DC motor nominal power (W) and voltage (V) values.

The nominal power and voltage values are used to convert armature current from amperes to pu (per unit).

Proportional Gain

The proportional gain of the PI current controller.

Integral Gain

The integral gain of the PI current controller.

Low-Pass Filter Cutoff Frequency

Cutoff frequency of the low-pass filter used to filter the armature current measurement (Hz).

Symmetrical Reference Limit

Symmetrical current reference (pu) limit around 0 pu. 1.5 pu is a common value.

Controller — Bridge Firing Unit Subtab

Alpha Min

Minimum firing angle value (deg.). 20 degrees is a common value.

Alpha Max

Maximum firing angle value (deg.). 160 degrees is a common value.

Frequency of Synchronization Voltages

Frequency of the synchronization voltages used by the discrete synchronized pulse generator block (Hz). This frequency is equal to the line frequency of the single-phase power line. This parameter is not used when using the average-value converter.

Pulse Width

The width of the pulses applied to the thyristor gates (deg.). This parameter is not used when using the average-value converter.

Block Inputs and Outputs

SP

The speed or torque set point. The speed set point can be a step function, but the speed change rate will follow the acceleration / deceleration ramps. If the load torque and the speed have opposite signs, the accelerating torque will be the sum of the electromagnetic and load torques.

Tm or Wm

The mechanical input: load torque (Tm) or motor speed (Wm). For the mechanical rotational port (S), this input is deleted.

A+, A-

The single-phase electric connections. The applied voltage must be adequate for the motor size.

Wm, Te or S

The mechanical output: motor speed (Wm), electromagnetic torque (Te) or mechanical rotational port (S).

When the **Output bus mode** parameter is set to **Multiple output buses**, the block has the following three output buses:

Motor

>   The motor measurement vector. It is composed of two elements:
>
>   - The armature voltage
>   - The DC motor measurement vector (containing the speed, armature current, field current, and electromagnetic torque values). Note that the speed signal is converted from rad/s to rpm before output.

Conv

>   The single-phase converter measurement vector. This vector includes
>
>   - The output voltage of converter 1
>   - The output voltage of converter 2
>   - The output current of converter 1
>   - The output current of converter 2
>
>   Note that all current and voltage values of the detailed bridges can be visualized with the Multimeter block.

Ctrl

>   The controller measurement vector. This vector contains:
>
>   - The armature current reference
>   - The firing angle computed by the current controller
>   - The speed or torque error (difference between the speed reference ramp and actual speed or between the torque reference and actual torque)
>   - The speed reference ramp or torque reference

When the **Output bus mode** parameter is set to **Single output bus**, the block groups the Motor, Conv, and Ctrl outputs into a single bus output.

Model Specifications

The library contains a 5 hp drive parameter set. The specifications of the 5 hp drive are shown in the following table.

5 HP Drive Specifications

Drive Input Voltage		
	Amplitude	320 V
	Frequency	60 Hz
Motor Nominal Values		
	Power	5 hp
	Speed	1750 rpm
	Voltage	240 V

Example

The `dc2_example` example illustrates the single-phase dual-converter drive used with the 5 hp drive parameter set during speed regulation. The converters are fed by a 230 V AC 60 Hz voltage source followed by a linear transformer to boost the voltage to a sufficient value.

DC2 - Four-Quadrant Single-Phase Rectifier 5 HP DC Drive
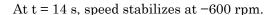
During this simulation, the motor is coupled to a linear load, which means that the mechanical torque produced by the load is proportional to the speed.
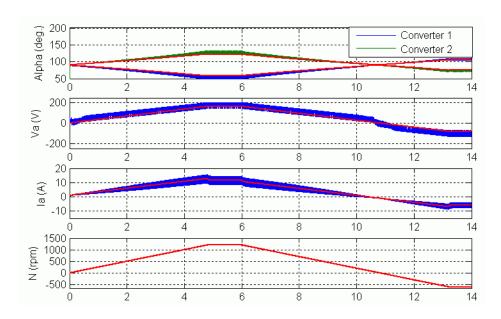
The speed reference is set at 1200 rpm at t = 0 s. Observe that the firing angles are symmetrical around 90 degrees and that the converter average output DC voltages are

of opposite signs. The armature current is supplied by converter 1, and the total current in this converter is the sum of load current and circulating current. Converter 2 simply carries the circulating current.
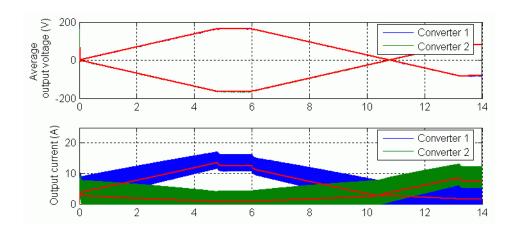
Observe that the motor speed follows the reference ramp accurately (+250 rpm/s) and reaches steady state after 5.5 s. The armature current follows the current reference very well and stabilizes around 12 A.

At t = 6 s, speed reference drops to −600 rpm. The current reference decreases to reduce the electromagnetic torque, and the load torque causes the motor to decelerate. Around t = 8.5 s, the armature current becomes negative and the electromagnetic torque reverses in order to brake the motor down to 0 rpm, the load torque being insufficient to decelerate the motor. The armature current is now provided by converter 2, converter 1 only handling the circulating current. At t = 10.8 s, the motor reaches 0 rpm and the load torque becomes negative. The electromagnetic torque now produces an accelerating torque to allow the motor to follow the negative speed ramp (−250 rpm/s). The armature current is now provided by converter 2, converter 1 only handling the circulating current.

At t = 14 s, speed stabilizes at −600 rpm.

DC2 Example Waveforms (Blue/Green : Detailed Converter, Red : Average- Value Converter)

References

[1] Sen, P.C., *Thyristor DC Drives*, J.Wiley and Sons, 1981.
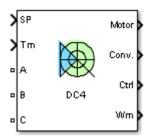
Introduced in R2006a

Four-Quadrant Three-Phase Rectifier DC Drive

Implement three-phase dual-converter DC drive with circulating current

Library

Electric Drives/DC drives

Description
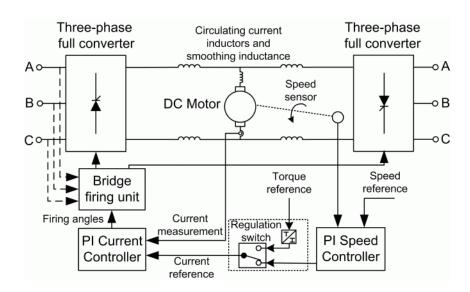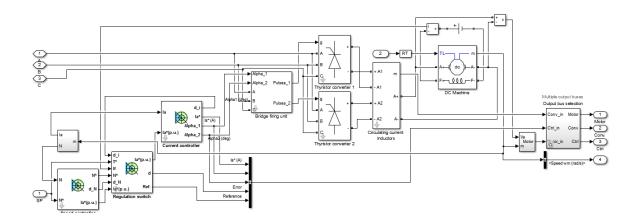
The high-level schematic shown below is built from six main blocks. The DC motor, the two three-phase full converters, and the bridge firing unit are provided with the SimPowerSystems library. More details on these blocks are available in the reference pages for each block. The two other blocks are specific to the Electric Drives library. These blocks are the speed controller and the current controller. They allow speed or torque regulation. A "regulation switch" block allows you to toggle from one type of regulation to the other. During torque regulation the speed controller is disabled. It is possible to use a simplified version of the drive containing an average-value model of the three-phase dual-converter and allowing faster simulation.

Note In SimPowerSystems software, the Four-Quadrant Three-Phase Rectifier DC Drive block is commonly called the **DC4** motor drive.

High-Level Schematic

Simulink Schematic

Speed Controller

The speed regulator shown below uses a PI controller. The controller outputs the armature current reference (in pu) used by the current controller in order to obtain the electromagnetic torque needed to reach the desired speed. During torque regulation, the speed controller is disabled.

The controller takes the speed reference (in rpm) and the rotor speed of the DC machine as inputs. The speed reference change rate will follow user-defined acceleration and deceleration ramps in order to avoid sudden reference changes that could cause armature over-current and destabilize the system. The speed measurement is filtered by a first-order low-pass filter.

The current reference output is limited between symmetrical lower and upper limits defined by the user.

Current Controller

The armature current regulator shown below is based on a second PI controller. The regulator controls the armature current by computing the appropriate thyristor firing angles of the two full converters. This generates the converter output voltages needed to obtain the desired armature current and thus the desired electromagnetic torque.

The controller takes the current reference (in pu) and the armature current flowing through the motor as inputs. The current reference is either provided by the speed controller during speed regulation or computed from the torque reference provided by the user during torque regulation. This is managed by the "regulation switch" block.

1-359

The armature current input is filtered by a first-order low-pass filter. An arccosine function is used to linearize the control system. The firing angle can vary between 0 and 180 degrees. You can limit the lower and upper limits to intermediate values.

Both converters operate simultaneously, and the two firing angles are controlled so that the sum of their values stays equal to 180 degrees. This produces opposite average voltages at the converter DC output terminals and thus identical average voltages at the DC motor armature, the converters being connected in antiparallel. One converter is working in rectifier mode while the other is in inverter mode.

Average-Value Three-phase Rectifier

The simplified converter is shown in the following figure.

Average-Value Three-Phase Rectifier with Circulating Current

It is composed of two controlled current sources on the AC side and one controlled voltage and current source on the DC side. The AC current sources allow the representation of the fundamental three-phase current behaviors according to the following equations

$$I_a = \frac{2\sqrt{3}}{\pi} I_d \sin\left(2\pi ft + \alpha + \alpha_0\right)$$
$$I_b = \frac{2\sqrt{3}}{\pi} I_d \sin\left(2\pi ft + \alpha + \alpha_0 + \frac{2\pi}{3}\right),$$

with a being the firing angle value, a_0 the phase angle of phase A, f the AC frequency and I_d the rectified output current value. The DC voltage source represents the average voltage value of the rectified voltage waveform according to the next equation:

$$V_d = \frac{3\sqrt{6}}{\pi} V_{\text{rms}} \cos\alpha - 6fLI_d,$$

with V_{rms} being the input phase-to-phase RMS voltage value and L being the source inductance value. The controlled current source represents the circulation current due to the instantaneous voltage difference between both converter outputs of the dual-converter. This current is equal to

$$V_d = \frac{3\sqrt{2}}{2\pi^2 f L_{\mathrm{circ,tot}}} V_{\mathrm{rms}} \left(1 - \frac{\pi\sqrt{3}}{6}\sin\alpha + \left(\frac{\pi}{2} - \alpha\right)\cos\alpha \right),$$

with $L_{\mathrm{circ,tot}}$ being the total circulation inductance of the circulation current loop.

Bridge Firing Unit

The bridge firing unit converts the firing angles, provided by the current controller, to two series of six pulses applied respectively to the thyristor gates of each converter. The bridge firing unit block contains a band-pass filter on voltage measurement to remove voltage harmonics. Two Discrete Synchronized 6-Pulse Generator blocks generate the pulses. Refer to the Synchronized 6-Pulse Generator for more information on this block. When using the average-value converter, the bridge firing unit simply outputs the firing angle value needed by the converter.

Remarks

The machine is separately excited with a constant DC field voltage source. There is thus no field voltage control. By default, the field current is set to its steady-state value when a simulation is started.

The armature voltage is provided by two three-phase antiparallel-connected converters controlled by two PI regulators. The circulating current produced by the instantaneous voltage difference at the terminal of both converters is limited by inductors connected between these terminals. No smoothing inductance is placed in series with the armature circuit, the armature current oscillations being quite small due to the three-phase voltage source.

The average-value converter represents the average behavior of a three-phase rectifier for continuous armature current in a dual-converter topology. This model is thus not

suitable for simulating DC drives under discontinuous armature current conditions. The converter outputs a continuous voltage value equal to the average-value of the real-life rectified voltage. The armature voltage, armature current and electromagnetic torque ripples are thus not represented. The input currents have the frequency and amplitude of the fundamental current component of the real-life input currents.

The model is discrete. Good simulation results have been obtained with a 10 µs time step. The control system (speed and current controllers) samples data following a user-defined sample time in order to simulate a digital controller device. Keep in mind that this sampling time has to be a multiple of the simulation time step.

The average-value converter allows the use of bigger simulation time steps, since it does not generate small time constants (due to the RC snubbers) inherent to the detailed converter. For a controller sampling time of 100 µs good simulation results have been obtained for a simulation time step of 100 µs. This time step cannot be higher than the controller time step.

Dialog Box and Parameters

- "DC Machine Tab" on page 1-364
- "Converter Tab" on page 1-365
- "Controller Tab" on page 1-366

DC Machine Tab

The **DC Machine** tab displays the parameters of the DC Machinre block of the Fundamental Blocks (powerlib) library.

Output bus mode

Select how the output variables are organized. If you select **Multiple output buses**, the block has three separate output buses for motor, converter, and controller variables. If you select **Single output bus**, all variables output on a single bus.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Select between the load torque, the motor speed and the mechanical rotational port as mechanical input. If you select and apply a load torque, the output is the motor speed according to the following differential equation that describes the mechanical system dynamics:

$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

If you select the motor speed as mechanical input, then you get the electromagnetic torque as output, allowing you to represent externally the mechanical system dynamics. The internal mechanical system is not used with this mechanical input selection and the inertia and viscous friction parameters are not displayed.

See "Mechanical Coupling of Two Motor Drives".

Converter Tab

Field DC Source

The DC motor field voltage value (V).

Circulating Current Inductors

The four circulating current inductors inductance value (H).

Converter sections

The Converter 1 and Converter 2 sections of the Converter tab display the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the Universal Bridge block parameters.

Phase-to-Phase RMS Voltage

Phase-to-phase rms voltage of the three-phase voltage source connected to the A,B,C terminals of the drive (V). This parameter is not used when using the detailed rectifier.

Frequency

Frequency of the three-phase voltage source connected to the A,B,C terminals of the drive (Hz). This parameter is not used when using the detailed rectifier.

Source Inductance

Source inductance of the three-phase voltage source connected to the A,B,C terminals of the drive (H). This parameter is not used when using the detailed rectifier.

Phase Angle of Phase A

Phase angle of phase A of the three-phase voltage source connected to the A,B,C terminals of the drive (deg). This parameter is not used when using the detailed rectifier.

Controller Tab

Schematic Button

When you press this button, a diagram illustrating the speed and current controllers schematics appears.

Regulation Type

This pop-up menu allows you to choose between speed and torque regulation.

Sampling Time

The controller (speed and current) sampling time (s). The sampling time has to be a multiple of the simulation time step.

Controller — Speed Controller Subtab

Nominal Speed

The nominal speed value of the DC motor (rpm). This value is used to convert motor speed from rpm to pu (per unit).

Initial Speed Reference

The initial speed reference value (rpm). This value allows the user to start a simulation with a speed reference other than 0 rpm.

Low-Pass Filter Cutoff Frequency

Cutoff frequency of the low-pass filter used to filter the motor speed measurement (Hz).

Proportional Gain

The proportional gain of the PI speed controller.

Integral Gain

The integral gain of the PI speed controller.

Acceleration

The maximum change of speed allowed during motor acceleration (rpm/s). Too great a value can cause armature over-current.

Deceleration

The maximum change of speed allowed during motor deceleration (rpm/s). Too great a value can cause armature over-current.

Controller — Current Controller Subtab

Power and Voltage nominal values

The DC motor nominal power (VA) and voltage (V) values. The nominal power and voltage values are used to convert armature current from amperes to pu (per unit).

Proportional Gain

The proportional gain of the PI current controller.

Integral Gain

The integral gain of the PI current controller.

Low-Pass Filter Cutoff Frequency

Cutoff frequency of the low-pass filter used to filter the armature current measurement (Hz).

Symmetrical Reference Limit

Symmetrical current reference (pu) limit around 0 pu. 1.5 pu is a common value.

Controller — Bridge Firing Unit Subtab

Alpha Min

Minimum firing angle value (deg). 20 degrees is a common value.

Alpha Max

Maximum firing angle value (deg). 160 degrees is a common value.

Frequency of Synchronization Voltages

Frequency of the synchronization voltages used by the discrete synchronized 6-pulse generator block (Hz). This frequency is equal to the line frequency of the three-phase power line. This parameter is not used when using the average-value converter.

Pulse Width

The width of the pulses applied to the thyristor gates (deg.). This parameter is not used when using the average-value converter.

Block Inputs and Outputs

SP

The speed or torque set point. The speed set point can be a step function, but the speed change rate will follow the acceleration / deceleration ramps. If the load torque and the speed have opposite signs, the accelerating torque will be the sum of the electromagnetic and load torques.

Tm or Wm

The mechanical input: load torque (Tm) or motor speed (Wm).

A, B, C

The three-phase electric connections. The voltage must be adequate for the motor size.

Wm or Te

The mechanical output: motor speed (Wm) or electromagnetic torque (Te).

When the **Output bus mode** parameter is set to **Multiple output buses**, the block has the following three output buses:

Motor

The motor measurement vector. This vector is composed of two elements:

- The armature voltage
- The DC motor measurement vector (containing the speed, armature current, field current, and electromagnetic torque values). Note that the speed signal is converted from rad/s to rpm before output.

Conv

The three-phase converter measurement vector. It includes:

- The output voltage of converter 1
- The output voltage of converter 2
- The output current of converter 1
- The output current of converter 2

Note that all current and voltage values of the detailed bridges can be visualized with the Multimeter block.

Ctrl

The controller measurement vector. This vector contains:

- The armature current reference
- The firing angle computed by the current controller
- The speed or torque error (difference between the speed reference ramp and actual speed or between the torque reference and actual torque)
- The speed reference ramp or torque reference

When the **Output bus mode** parameter is set to **Single output bus**, the block groups the Motor, Conv, and Ctrl outputs into a single bus output.

Model Specifications

The library contains a 5 hp and a 200 hp drive parameter set. The specifications of these two drives are shown in the following table.

5 HP and 200 HP Drive Specifications

		5 HP Drive	200 HP Drive
Drive Input Voltage			
	Amplitude	230 V	380 V
	Frequency	60 Hz	50 Hz
Motor Nominal Values			
	Power	5 hp	200 hp
	Speed	1750 rpm	1184 rpm

Drive Input Voltage		5 HP Drive	200 HP Drive
	Voltage	240 V	440 V

Example

The `dc4_example` example illustrates the three-phase dual-converter drive used with the 200 hp drive parameter set during torque regulation. A 5 hp parameter set is also available in the library.

The converters are fed by a 380 V AC 50 Hz voltage source.

The motor is coupled to a linear load, which means that the mechanical torque of the load is proportional to the speed.

The initial torque reference is set to 0 N.m and the armature current is null. No electromagnetic torque is produced and the motor stays still.

At t = 0.2 s, the torque reference jumps to 600 N.m. This causes the armature current to rise to about 180 A. The armature current is supplied by converter 1, and the total current in this converter is the sum of load current and circulating current. Converter 2 simply carries the circulating current. Notice that the armature current follows the reference current quite accurately, with fast response time and small overshooting.
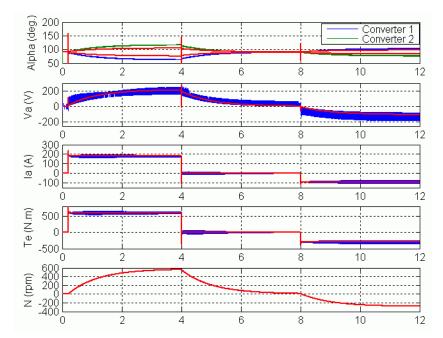
Observe also that the firing angles are symmetrical around 90 degrees and that the converter average output DC voltages are equal but of opposite signs.

The electromagnetic torque produced by the armature current flow causes the motor to accelerate. The speed rises and starts to stabilize around t = 4 s at about 560 rpm, the sum of the load and viscous friction torques beginning to equalize the electromagnetic torque.

At t = 4 s, the torque reference is set to 0 N.m and the load torque causes the motor to decelerate. Notice that the four reactors keep the current oscillations quite small.
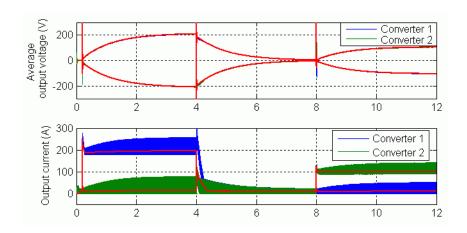
At t = 8 s, the torque reference is set to −300 N.m. The armature current jumps down to −90 A and is now delivered by converter 2 while converter 1 only handles the circulating current. Converter 2 is now working in rectifier mode and converter 1 in inverter mode.

The negative electromagnetic torque produced allows the motor to accelerate in the negative speed plane.

At t = 12 s, speed starts to stabilize around −290 rpm.

DC4 Example Waveforms (Blue/Green : Detailed Converter, Red : Average- Value Converter)

References

[1] Sen, P.C., *Thyristor DC Drives*, J.Wiley and Sons, 1981
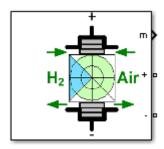
Introduced in R2006a

Fuel Cell Stack

Implement generic hydrogen fuel cell stack model

Library

Electric Drives/Extra Sources
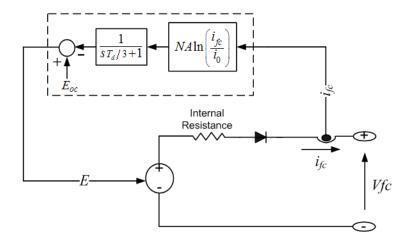
Description

The Fuel Cell Stack block implements a generic model parameterized to represent most popular types of fuel cell stacks fed with hydrogen and air.
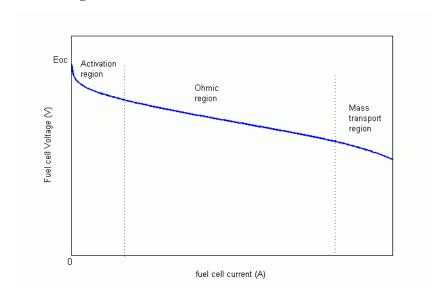
The block represents two versions of the stack model: a simplified model and a detailed model. You can switch between the two models by selecting the level in the mask under **Model detail level** in the block dialog box.

Simplified Model

This model is based on the equivalent circuit of a fuel cell stack shown below:

The simplified model represents a particular fuel cell stack operating at nominal conditions of temperature and pressure. The parameters of the equivalent circuit can be modified based on the polarization curve obtained from the manufacturer datasheet. You just have to input in the mask the value of the voltage at 0 and 1 A, the nominal and the maximum operating points, for the parameters to be calculated. A diode is used to prevent the flow of negative current into the stack. A typical polarization curve consists of three regions:

The first region represents the activation voltage drop due to the slowness of the chemical reactions taking place at electrode surfaces. Depending on the temperature and operating pressure, type of electrode, and catalyst used, this region is more or less wide. The second region represents the resistive losses due the internal resistance of the fuel cell stack. Finally, the third region represents the mass transport losses resulting from the change in concentration of reactants as the fuel is used.

Detailed Model

The detailed model represents a particular fuel cell stack when the parameters such as pressures, temperature, compositions and flow rates of fuel and air vary. You can select which parameters to vary on the **Signal variation** pane on the block dialog box. These variations affect the open circuit voltage (E_{oc}), the exchange current (i_0) and the Tafel slope (A). E_{oc}, i_0 and A are modified as follows:

$$E_{oc} = K_c E_n$$
$$i_0 = \frac{zFk\left(P_{H_2} + P_{O_2}\right)}{Rh} e^{\frac{-\Delta G}{RT}}$$
$$A = \frac{RT}{z\alpha F},$$

where

R = 8.3145 J/(mol K)

F = 96485 A s/mol

z = Number of moving electrons

E_n = Nernst voltage, which is the thermodynamics voltage of the cells and depends on the temperatures and partial pressures of reactants and products inside the stack (V)

α = Charge transfer coefficient, which depends on the type of electrodes and catalysts used

P_{H_2} = Partial pressure of hydrogen inside the stack (atm)

P_{O_2} = Partial pressure of oxygen inside the stack (atm)

k = Boltzmann's constant = 1.38×10^{-23} J/K
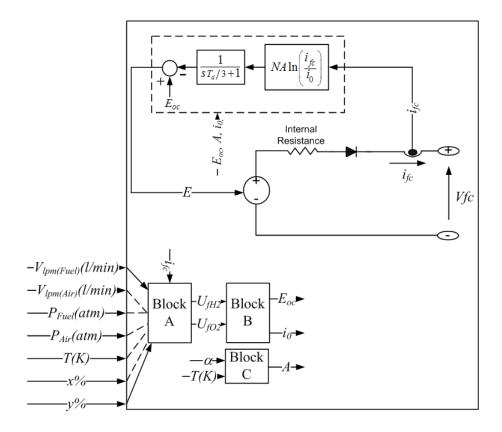
h = Planck's constant = 6.626×10^{-34} J s

ΔG = Size of the activation barrier which depends on the type of electrode and catalyst used

T = Temperature of operation (K)

K_c = Voltage constant at nominal condition of operation

The equivalent circuit is the same as for the simplified model, except that the parameters E_{oc}, i_0 and A have to be updated on-line as shown below:

The rates of conversion (utilizations) of hydrogen (U_{fH2}) and oxygen (U_{fO2}) are determined in Block A as follows:

$$\begin{cases} U_{fH_2} = \dfrac{n^r_{H_2}}{n^{in}_{H_2}} = \dfrac{60000RTNi_{fc}}{zFP_{\text{fuel}}V_{lpm(\text{fuel})}x\%} \\[4mm] U_{fO_2} = \dfrac{n^r_{O_2}}{n^{in}_{O_2}} = \dfrac{60000RTNi_{fc}}{2zFP_{\text{air}}V_{lpm(\text{air})}y\%} \end{cases}$$

where

P_{fuel} = Absolute supply pressure of fuel (atm)

P_{air} = Absolute supply pressure of air (atm)

$V_{lpm(fuel)}$ = Fuel flow rate (l/min)

$V_{lpm(air)}$ = Air flow rate (l/min)

x = Percentage of hydrogen in the fuel (%)

y = Percentage of oxygen in the oxidant (%)

N = Number of cells

The 60000 constant comes from the conversion from the liter/min flow rate used in the model to m3/s (1 liter/min = 1/60000 m3/s).

The partial pressures and the Nernst voltage are determined in Block B as follows:

$$\begin{cases} P_{H_2} = \left(1 - U_{f_{H_2}}\right)x\%P_{\text{fuel}} \\[2mm] P_{H_2O} = \left(w + 2y\%U_{f_{O_2}}\right)P_{\text{air}} \\[2mm] P_{O_2} = \left(1 - U_{f_{O_2}}\right)y\%P_{\text{air}} \end{cases}$$

and

$$
E_n = \begin{cases} 1.229 + (T - 298)\dfrac{-44.43}{zF} + \dfrac{RT}{zF}\ln\left(P_{H_2}P_{O_2}^{1/2}\right) & \text{when } T \le 100^\circ C \\[4mm] 1.229 + (T - 298)\dfrac{-44.43}{zF} + \dfrac{RT}{zF}\ln\left(\dfrac{P_{H_2}P_{O_2}^{1/2}}{P_{H_2O}}\right) & \text{when } T > 100^\circ C \end{cases}
$$

where

P_{H2O} = Partial pressure of water vapor inside the stack (atm)

w = Percentage of water vapor in the oxidant (%)

From the partial pressures of gases and the Nernst voltage, the new values of the open circuit voltage (E_{oc}) and the exchange current (i_0) can be calculated.

Block C calculates the new value of the Tafel slope (A).

The parameters α, ΔG and K_c are calculated based on the polarization curve at nominal conditions of operation along with some additional parameters, such as the low heating value (LHV) efficiency of the stack, composition of fuel and air, supply pressures and temperatures. They can be easily obtained from the manufacturer datasheet.

The nominal rates of conversion of gases are calculated as follows:

$$
U_{f_{H_2}} = \frac{\eta_{\text{nom}}\,\Delta h^0\left(H_2O(\text{gas})\right)N}{zF V_{\text{nom}}}
$$

$$
U_{f_{O_2}} = \frac{60000\,RT_{\text{nom}}N I_{\text{nom}}}{2zF P_{\text{air}_{\text{nom}}}\,V_{lpm(\text{air})_{\text{nom}}} \cdot 0.21}
$$

where

η_{nom} = Nominal LHV efficiency of the stack (%)

$\Delta h^0(H_2O(gas))$ = 241.83 × 10³ J/mol

V_{nom} = Nominal voltage (V)

I_{nom} = Nominal current (A)

$V_{lpm(air)nom}$= Nominal air flow rate (l/min)

P_{airnom}= Nominal absolute air supply pressure (Pa)

T_{nom}= Nominal operating temperature (K)

From these rates of conversion, the nominal partial pressures of gases and the Nernst voltage can be derived. With E_{oc}, i_0 and A known and assuming that the stack operates at constant rates of conversion or utilizations at nominal condition, α, ΔG and K_c can be determined.

If there is no fuel or air at the stack input, it is assumed that the stack is operating at a fixed rate of conversion of gases (nominal rate of conversion), that is, the supply of gases is adjusted according to the current so that they are always supplied with just a bit more than needed by the stack at any load.

The maximum current the stack can deliver is limited by the maximum flow rates of fuel and air that can be reached. Beyond that maximum current, the voltage output by the stack decreases abruptly as more current is drawn.

The dynamics of the fuel cell are represented if you specify the response time and the parameters for flow dynamics (peak utilization and corresponding voltage undershoot) on the **Fuel Cell Dynamics** pane on the dialog box.

The response time (T_d) @ 95% is used to model the "charge double layer" phenomenon due to the build up of charges at electrode/electrolyte interface. This affects only the activation voltage $(NA\ln(i_{fc}/i_0))$ as shown on the equivalent circuits.

The peak utilization $(Uf_{O2(\text{peak})})$ and the corresponding voltage undershoot (V_u) are used to model the effect of oxygen depletion (due to the air compressor delay) on the cell output voltage. The Nernst voltage is modified due to this effect as follows:

$$E_n = \begin{cases} E_n - K\left(U_{f_{O_2}} - U_{f_{O_2}(\text{nom})}\right) & U_{f_{O_2}} > U_{f_{O_2}(\text{nom})} \\ E_n & U_{f_{O_2}} \le U_{f_{O_2}(\text{nom})} \end{cases}$$

where
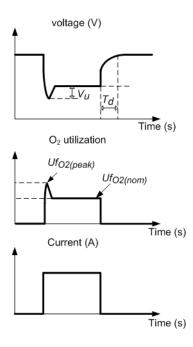
K = voltage undershoot constant

$U_{fO2(\text{nom})}$ = nominal oxygen utilization

K is determined as follows:
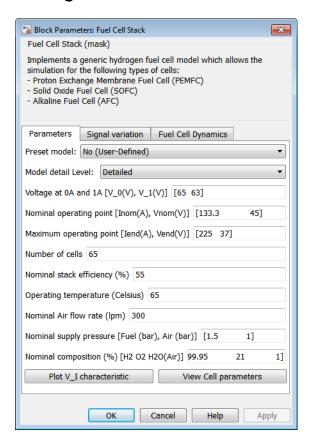
$$K = \frac{V_u}{K_c \left(U_{f_{O_2}(\text{peak})} - U_{f_{O_2}(\text{nom})} \right)}.$$

Current step and interrupt tests must be made on a real stack to represent with accuracy its dynamics. The figure below shows the stack response from these tests and the required parameters (T_d, $Uf_{O2(\text{peak})}$ and V_u).

The response time (T_d) depends on the fuel cell stack itself and is usually given on the datasheet. The parameters for flow dynamics ($Uf_{O2(\text{peak})}$ and V_u) depend on the dynamics of external equipment (compressor, regulator and loads) and they are not provided by manufacturers as their values vary with the user application. For simulation, the user may assume values of $Uf_{O2(\text{peak})}$ between 60% to 70% and V_u between 2-5% of the stack nominal voltage.

Dialog Box and Parameters

- "Parameters Tab" on page 1-381
- "Signal Variation Tab (Detailed Model Only)" on page 1-384
- "Fuel Cell Dynamics Tab" on page 1-384

Parameters Tab

Preset model

Provides a set of predetermined polarization curves and parameters for particular fuel cell stacks found on the market:

- No (User-Defined)
- PEMFC - 1.26 kW - 24 Vdc
- PEMFC - 6 kW - 45 Vdc
- PEMFC - 50 kW - 625 Vdc
- AFC - 2.4 kW - 48 Vdc

Select one of these preset models to load the corresponding parameters in the entries of the dialog box. Select No (User-Defined) if you do not want to use a preset model.

Model detail level

Provide access to the two versions of the model:

- Simplified
- Detailed

When a simplified model is used, there is no variable under the **signal variation** pane

Voltage at 0 A and 1 A

The voltage at 0 A and 1 A of the stack (Volts). Assuming nominal and constant gases utilizations.

Nominal operating point

The rated current (Ampere) and rated voltage (Volts) of the stack. Assuming nominal and constant gases utilizations.

Maximum operating point

The current (Ampere) and voltage (Volts) of the stack at maximum power. Assuming nominal and constant gases utilizations.

Number of cells

The number of cells in series in the stack. This parameter is available only for a detailed model.

Nominal stack efficiency

The rated efficiency of the stack relative to the low heating value (LHV) of water. This parameter is available only for a detailed model.

Operating temperature

The nominal temperature of operation in degrees Celsius. This parameter is available only for a detailed model.

Nominal air flow rate

The rated air flow rate (l/min). This parameter is available only for a detailed model.

Nominal supply pressure

Rated supply pressure (absolute) of fuel and air in bars. This parameter is available only for a detailed model.

Nominal composition
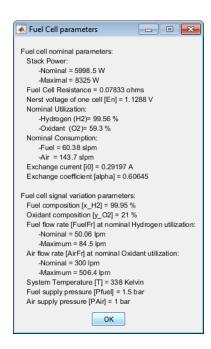
The rated percentage of hydrogen (x) in the fuel, oxygen (y) and water (w) in the oxidant. This parameter is available only for a detailed model.

Plot V-I characteristic

Plots a figure containing two graphs. The first graph represents the stack voltage (Volts) vs current (A) and the second graph represents the stack power (kW) vs current (A). This button is available only for a detailed model.

View cell parameters

Presents the overall parameters of the stack. This button is available only for a detailed model. The dialog box is shown below.

Signal Variation Tab (Detailed Model Only)

The **Signal variation** pane provides a list of parameters that can be varied. Select a checkbox for a variable to input a corresponding signal to the block. The following signals can be input to the block:

Fuel composition

Percentage of hydrogen in the fuel.

Oxidant composition

Percentage of oxygen in the oxidant.

Fuel flow rate

Fuel flow rate in liter per minutes.

Air flow rate

Air flow rate in liter per minutes.

System Temperature

Temperature of operation in Kelvin.

Fuel supply pressure

Fuel supply pressure in bars.

Air supply pressure

Air supply pressure in bars.

Fuel Cell Dynamics Tab

Specify Fuel Cell Dynamics?

Asks whether you want to specify the fuel cell dynamics. Select the checkbox to enter the fuel cell response time in seconds.

Fuel Cell response time (sec)

Enter the response time of the cell (at 95% of the final value). This parameter becomes visible only when the **Specify Fuel Cell Dynamics?** checkbox is selected.

Peak O2 utilization (%)
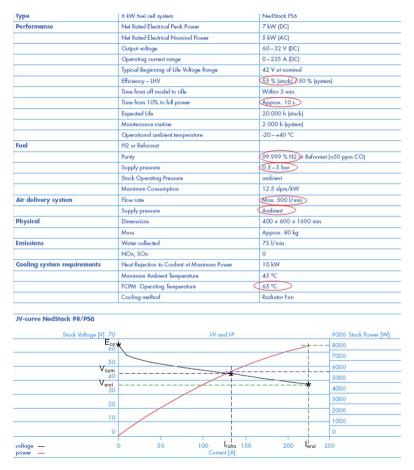
Enter the peak oxygen utilization at nominal condition of operation. This parameter becomes visible only when the **Specify Fuel Cell Dynamics?** checkbox is selected and the **Air flow rate** checkbox is selected under the **Signal variation** pane.

Voltage undershoot (V) @ peak O2 utilization

Enter the voltage undershoot (Volts) at peak oxygen utilization at nominal condition of operation. This parameter becomes visible only when the **Specify Fuel Cell Dynamics?** checkbox is selected and the **Air flow rate** checkbox is selected under the **Signal variation** pane.

How to Extract Parameters from Data Sheet

Here is the procedure to extract parameters from fuel cell stack manufacturer's data sheet. For this example, the NetStack PS6 data sheet from NetStack is used:

Type	6 kW fuel cell system	NedStack PS6
Performance	Net Rated Electrical Peak Power	7 kW (DC)
	Net Rated Electrical Nominal Power	5 kW (AC)
	Output voltage	60 – 32 V (DC)
	Operating current range	0 – 225 A (DC)
	Typical Beginning of Life Voltage Range	42 V at nominal
	Efficiency – LHV	55 % (stack) / 50 % (system)
	Time from off model to idle	Within 3 min.
	Time from 10% to full power	Approx. 10 s
	Expected Life	20.000 h (stack)
	Maintenance routine	2.000 h (system)
	Operational ambient temperature	-20 – +40 °C
Fuel	H2 or Reformat	
	Purity	99.999 % H2 or Reformat (<50 ppm CO)
	Supply pressure	0.5 – 5 bar
	Stack Operating Pressure	ambient
	Maximum Consumption	12.5 slpm/kW
Air delivery system	Flow rate	Max. 500 l/min
	Supply pressure	Ambient
Physical	Dimensions	400 x 600 x 1600 mm
	Mass	Approx. 80 kg
Emissions	Water collected	75 l/min.
	NOx, SOx	0
Cooling system requirements	Heat Rejection to Coolant at Maximum Power	10 kW
	Maximum Ambient Temperature	45 °C
	FCPM Operating Temperature	65 °C
	Cooling method	Radiator Fan

JV-curve NedStack P8/PS6

The rated power of the stack is 6 kW and the nominal voltage is 45 V. The following detailed parameters are deduced from the datasheet.

- Voltage at 0 A and 1 A [E_{oc},V_1] = [65, 63]

- Nominal operating point [I_{nom}, V_{nom}]=[133.3, 45]

- Maximum operating point [I_{end},V_{end}]=[225, 37]

- Nominal stack efficiency (η_{nom})= 55%

- Operating temperature = 65 ^{0}C

- Nominal supply pressure [H2, Air]=[1.5 1]

  If the pressure given is relative to the atmospheric pressure, add 1 bar to get the absolute pressure.

- Nominal composition (%)[H2, O2, H2O(Air)]=[99.999, 21, 1]

  If air is used as oxidant, assume 21% of O_2 and 1% of H_2O in case their percentages are not specified.

- Number of cells

  If not specified, estimate it from the formulae below:

$$N = \frac{2 \cdot 96485 \cdot V_{\text{nom}}}{241.83 \cdot 10^3 \cdot \eta_{\text{nom}}}.$$

  In this case,

$$N = \frac{2 \cdot 96485 \cdot 45}{241.83 \cdot 10^3 \cdot 0.55} = 65.28 = 65 \text{ cells.}$$

- Nominal air flow rate

  If the maximum air flow rate is given, the nominal flow rate can be calculated assuming a constant oxygen utilization at any load. The current drawn by the cell is linearly dependent on air flow rate and the nominal flow rate is given by:

$$V_{lpm(\text{air})_{\text{nom}}} = \frac{I_{\text{nom}} \cdot V_{lpm(\text{air})_{\text{max}}}}{I_{\text{end}}}.$$

In this case,

$$V_{lpm(\text{air})_{\text{nom}}} = \frac{133.3 \cdot 500}{225} = 297 \text{ liters/min.}$$
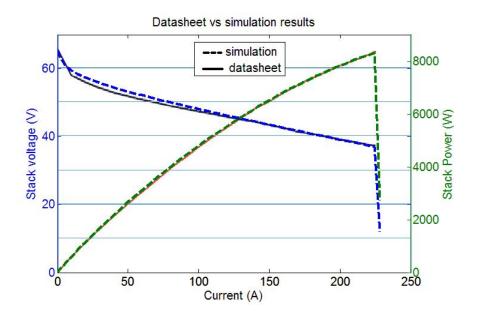
In case no information is given, assume the rate of conversion of oxygen to be 50% (as it is usually the case for most fuel cell stacks) and use the formulae below to determine the nominal air flow rate.

$$V_{lpm(\text{air})_{\text{nom}}} = \frac{60000 R T_{\text{nom}} N I_{\text{nom}}}{2z F P_{\text{air}_{\text{nom}}} \cdot 0.5 \cdot 0.21}.$$

- Fuel cell response time = 10s

Note The parameters $[E_{oc}, V_1]$, $[I_{\text{nom}}, V_{\text{nom}}]$ and $[I_{\text{end}}, V_{\text{end}}]$ are approximate and depend on the precision of the points obtained from the polarization curve. The higher the accuracy of these parameters, the more closed will be the simulated stack voltage to the data sheet curve. A tool, called ScanIt (from amsterchem) can be used to extract precise values from data sheet curves.

With the above parameters, the polarization curve of the stack operating at fixed nominal rate of conversion of gases is closed to the datasheet curves as shown below: The blue dotted line shows the simulated stack voltage and green dotted line shows the simulated stack power.

Datasheet vs simulation results

Above the maximum current, the flow rate of gases entering the stack is maximum and the stack voltage decreases abruptly as more current is drawn.

Block Inputs and Outputs

m

The Simulink output of the block is a vector containing 11 signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Signal	Definition	Units	Symbol	Model detail level (Signal availability)	
				Detailed	Simplified
1	Voltage	V	V_{fc}	Yes	Yes
2	Current	I	I_{fc}	Yes	Yes
3	Stack Efficiency	%	η	Yes	No(Set to 0)

4	Stack consumption [Air, Fuel]	slpm	V_{slpm}	Yes	No(Set to 0)
5	Flow Rate [Air, Fuel]	lpm	Fr_{lpm}	Yes	No(Set to 0)
6	Stack consumption [Air, Fuel]	lpm	V_{lpm}	Yes	No(Set to 0)
7	Utilization [Oxygen, Hydrogen]	%	U_f	Yes	No(Set to 0)
8	Slope of Tafel curve		A	Yes	No(Set to 0)
9	Exchange current	A	i_0	Yes	No(Set to 0)
10	Nernst voltage	V	E_n	Yes	No(Set to 0)
11	Open circuit voltage	V	E_{oc}	Yes	No(Set to 0)

Model Assumptions

- The gases are ideal
- The stack is fed with hydrogen and air
- The stack is equipped with a cooling system which maintains the temperature at the cathode and anode exits stable and equal to the stack temperature
- The stack is equipped with a water management system to maintain the humidity inside the cell at appropriate level at any load
- The cell voltage drops are due to reaction kinetics and charge transport as most fuel cells do not operate in the mass transport region
- Pressure drops across flow channels are negligible
- The cell resistance is constant at any condition of operation

Model Limitations
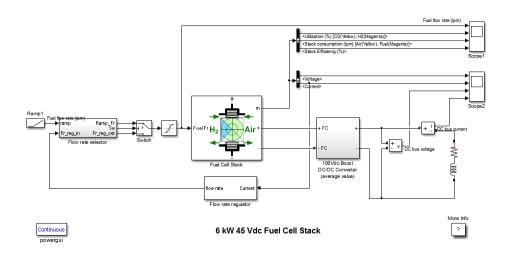
- Chemical reaction dynamics caused by partial pressure changes of chemical species inside the cell are not considered
- The stack output power is limited by the fuel and air flow rates supplied
- The effect of temperature and humidity of the membrane on the internal resistance is not considered
- The flow of gases or water through the membrane is not considered

Example
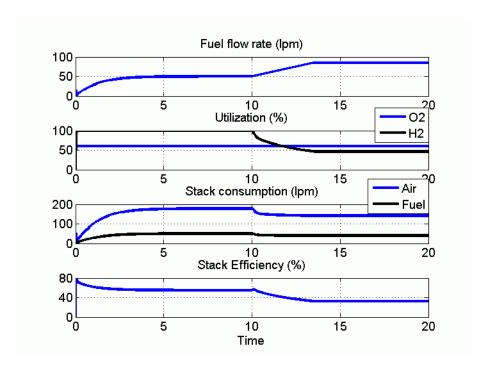
The power_fuel_cell example illustrates a 6 kW, 45 volts Proton Exchange Membrane (PEM) Fuel Cell Stack model feeding a 100Vdc DC/DC converter.

The converter is loaded by an RL element of 6kW with a time constant of 1 sec. During the first 10 secs, the utilization of the hydrogen is constant to the nominal value (Uf_H2 = 99.56%) using a fuel flow rate regulator. After 10 secs, the flow rate regulator is bypassed and the rate of fuel is increased to the maximum value of 85 lpm in order to observe the variation in the stack voltage. That will affect the stack efficiency, the fuel consumption and the air consumption.
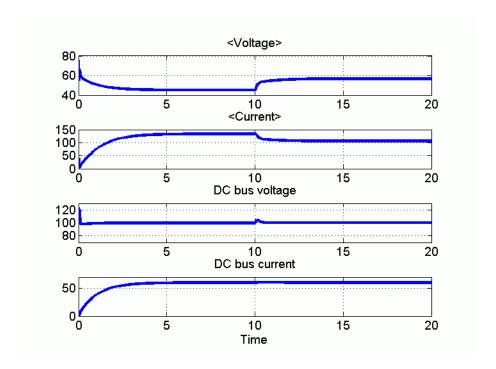
Note As the **Air flow rate** checkbox under Signal variation pane is not selected, the stack will operate at fixed, nominal oxygen utilization (59.3%).

6 kW 45 Vdc Fuel Cell Stack

The simulation produces the followings results:

Results for the Scope1

Results for the Scope2

At t = 0 s, the DC/DC converter applies 100Vdc to the RL load (the initial current of the load is 0A). The fuel utilization is set to the nominal value of 99.56%. The current increases until the value of 133A. The flow rate is automatically set in order to maintain the nominal fuel utilization. Observe the DC bus voltage (Scope2) which is very well regulated by the converter. The peak voltage of 122Vdc at the beginning of the simulation is caused by the transient state of the voltage regulator.

At t = 10 s, the fuel flow rate is increased from 50 liters per minute (lpm) to 85 lpm during 3.5 s reducing by doing so the hydrogen utilization. This causes an increasing of the Nernst voltage so the fuel cell current will decrease. Therefore the stack consumption and the efficiency will decrease (Scope1).

References

[1] Njoya, S. M., O. Tremblay, and L. -A. Dessaint. *A generic fuel cell model for the simulation of fuel cell vehicles*. Vehicle Power and Propulsion Conference, 2009, VPPC '09, *IEEE*. Sept. 7–10, 2009, pp. 1722–29.

[2] Motapon, S.N., O. Tremblay, and L. -A. Dessaint. "Development of a generic fuel cell model: application to a fuel cell vehicle simulation." *Int. J. of Power Electronics*. Vol. 4, No. 6, 2012, pp. 505–22.
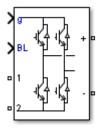
Introduced in R2008a

Full-Bridge Converter

Implement full-bridge power converter

Library

Fundamental Blocks/Power Electronics

Description

The Full-Bridge Converter block implements a full-bridge power converter. You can choose from three model types:

- **Switching devices** — The converter is modeled with IGBT/diode pairs controlled by firing pulses produced by a PWM generator. This model provides the most accurate simulation results.

- **Switching function** — The converter is modeled by a switching-function model. The switches are replaced with two voltage sources and two diodes on the AC side and with two current sources on the DC side.

  The converter is controlled by firing pulses produced by a PWM generator (0/1 signals) or by firing pulses averaged over a specified period (PWM averaging: signals between 0 and 1). Both modes of operation produce harmonics normally generated by a PWM-controlled converter and also correctly simulate rectifying operation as well as blanking time. This model type is well-suited for real-time simulation.

- **Average model (Uref-controlled)** — The converter is modeled using a switching-function model directly controlled by the reference voltage signals (Uref). A PWM generator is not required. This model provides the fastest simulations.

Dialog Box and Parameters

Block Parameters: Full-Bridge Converter

Full-Bridge Converter (mask)

Implements a full-bridge power converter using the following modeling techniques:

1. Switching devices: The converter is modeled with IGBT/diode pairs controlled by firing pulses produced by a PWM generator.

2. Switching function: The converter is modeled by a switching function controlled by firing pulses produced by a PWM generator (0/1 signals) or by firing pulses averaged over a specified period (PWM averaging: signals between 0 and 1).

3. Average model (Uref-controlled): The converter is modeled using a switching-function model directly controlled by the reference voltage. A PWM generator is not required.

Technique 1 is the most accurate, while technique 3 yields to the fastest simulation. The two techniques in 2 are well-suited for real-time simulation.

Model type: Switching devices

Device on-state resistance (Ohms)

1e-3

Snubber resistance (Ohms)

1e6

Snubber capacitance (F)

inf

OK   Cancel   Help   Apply

Parameters

Model type

Specify the model type to use:

- `Switching devices` (default)
- `Switching function`
- `Average model (Uref-controlled)`

Device on-state resistance (Ohms)

Internal resistance of the switching devices, in ohms. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `1e-3`.

Snubber resistance (Ohms)

The snubber resistance, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `1e6`.

Snubber capacitance (F)

The snubber capacitance, in farads. Set the snubber capacitance to `0` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `inf`.

Diode on-state resistance (Ohms)

Internal resistance of the diodes, in ohms. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `1e-3`.

Diode snubber resistance (Ohms)

The snubber resistance, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `1e6`.

Diode snubber capacitance (F)

The snubber capacitance in farads. Set the snubber capacitance to `0` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `inf`.

Diode forward voltage (V)

Forward voltage, in volts, across the diode when it is conducting. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `1e-3`.

Current source snubber resistance (Ohms)

The snubber resistance across the two current sources, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is only enabled when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `inf`.

Inputs and Outputs

`g`

The vectorized gating signal to control the converter. The gating signal contains four firing pulses to control Q1, Q2, Q3, and Q4. This port is visible only when you set the **Model type** parameter to `Switching devices` or `Switching function`.

`Uref`

The reference voltage signal to control the converter. This port is visible only when you set the **Model type** parameter to `Average model (Uref-controlled)`.

`BL`

You can block all firing pulses to the converter by applying a signal value of 1 at the BL input.

Examples

See the Power Converters Modeling Techniques example for a comparison of the three converter modeling techniques.

Introduced in R2015b

Fundamental (PLL-Driven)

Compute fundamental value of signal

Library

Control and Measurements/Measurements

Description

The Fundamental (PLL-Driven) block computes the fundamental value of the input 3 over a running window of one cycle of fundamental frequency given by input 1. The reference frame required for the computation is given by the input 2.

Based on the Fourier analysis of a periodic signal, the fundamental value of a signal $f(t)$ can be expressed as

$$Fundamental(f(t)) = a\cos(\omega_0 t) + b\sin(\omega_0 t)$$

$$a = \frac{2}{T}\int_{(t-T)}^{t} f(t)\cos(\omega_0 t)dt$$

$$b = \frac{2}{T}\int_{(t-T)}^{t} f(t)\sin(\omega_0 t)dt$$

$$T = \frac{1}{f_0} \qquad f_0 : \text{Fundamental frequency}$$

$$\omega_0 = 2\times\Pi\times f_0$$
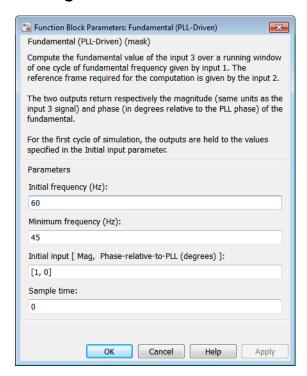
The magnitude and phase of the fundamental is calculated by

$$Magnitude = \sqrt{a^2 + b^2} \qquad Phase = a\tan(b/a)$$

To resolve these equations, the block uses the input 1 (Freq) for f_0 and input 2 (wt) for $\omega_0 t$. These two input signals are normally connected to the outputs of a PLL block.

As this block uses a running average window, one cycle of simulation must complete before the outputs give the correct magnitude and angle. For the first cycle of simulation, the outputs are held to the values specified by the initial input parameter.

Dialog Box and Parameters

Function Block Parameters: Fundamental (PLL-Driven)

Fundamental (PLL-Driven) (mask)

Compute the fundamental value of the input 3 over a running window of one cycle of fundamental frequency given by input 1. The reference frame required for the computation is given by the input 2.

The two outputs return respectively the magnitude (same units as the input 3 signal) and phase (in degrees relative to the PLL phase) of the fundamental.

For the first cycle of simulation, the outputs are held to the values specified in the Initial input parameter.

Parameters

Initial frequency (Hz):

60

Minimum frequency (Hz):

45

Initial input [Mag, Phase-relative-to-PLL (degrees)]:

[1, 0]

Sample time:

0

OK   Cancel   Help   Apply

Initial frequency (Hz)

Specify the frequency of the first cycle of simulation.

Minimum frequency (Hz)

Specify the minimum frequency value that sets the buffer size of the Variable Time Delay block used inside the block to compute the fundamental value.

Initial input [Mag, Phase-relative-to-PLL (degrees)]

Specify the initial magnitude and phase in degrees of the input signal.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Inputs and Outputs

`Freq`

Fundamental frequency (Hz) required by the computation. This input is normally connected to the output Freq of a PLL block.

`wt`

Angle of the reference frame (rad/s) required for the computation. This input is normally connected to the output wt of a PLL block.

`In`

Connects to the signal to be analyzed. Typical input signals are voltages or currents measured by the Current Measurement or Voltage Measurement block.

`|u|Magnitude`

Returns the magnitude of the fundamental in the same unit as the input signal.

`∠u Phase`

Returns the phase of the fundamental, in degrees, relative to the reference frame wt (input 2).

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	Yes, of the parameters
Dimensionalized	Yes, for Input 3 (In)

Example

The power_FundamentalPLLDriven model compares the Fourier block (with a specified fundamental frequency of 60 Hz) output to the Fundamental (PLL-Driven) block output.

The PLL-Driven block outputs accurate magnitude and phase even if the fundamental frequency of the input signal varies during the simulation.

The model sample time is parameterized by the Ts variable set to a default value of 50e-6 s. Set Ts to 0 in the command window to simulate the model in continuous mode.

Introduced in R2013a

Generic Power System Stabilizer

Implement generic power system stabilizer for synchronous machine
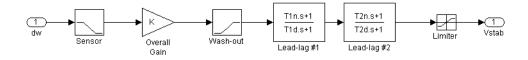
Library

Fundamental Blocks/Machines

Description

Note This block requires that you have a Control System Toolbox license. Otherwise, trying to simulate a model containing this block produces an error.

The Generic Power System Stabilizer (PSS) block can be used to add damping to the rotor oscillations of the synchronous machine by controlling its excitation. The disturbances occurring in a power system induce electromechanical oscillations of the electrical generators. These oscillations, also called power swings, must be effectively damped to maintain the system stability. The output signal of the PSS is used as an additional input (`vstab`) to the Excitation System block. The PSS input signal can be either the machine speed deviation, dw, or its acceleration power, Pa = Pm - Peo (difference between the mechanical power and the electrical power).
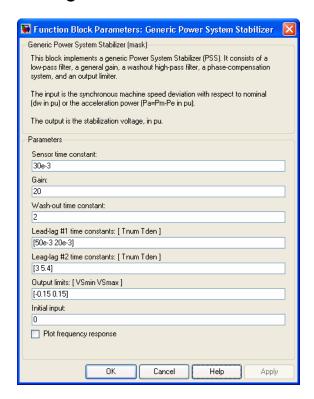
The Generic Power System Stabilizer is modeled by the following nonlinear system:

To ensure a robust damping, the PSS should provide a moderate phase advance at frequencies of interest in order to compensate for the inherent lag between the field excitation and the electrical torque induced by the PSS action.

The model consists of a low-pass filter, a general gain, a washout high-pass filter, a phase-compensation system, and an output limiter. The general gain K determines the amount of damping produced by the stabilizer. The washout high-pass filter eliminates low frequencies that are present in the dw signal and allows the PSS to respond only to speed changes. The phase-compensation system is represented by a cascade of two first-order lead-lag transfer functions used to compensate the phase lag between the excitation voltage and the electrical torque of the synchronous machine.

Dialog Box and Parameters

Sensor time constant

The time constant, in seconds (s), of the first-order low-pass filter used to filter the block's input signal.

Gain

The overall gain K of the generic power system stabilizer.

Wash-out time constant

The time constant, in seconds (s), of the first-order high-pass filter used by the washout system of the model.

Lead-lag #1 time constants: [Tnum Tden]

The numerator time constant T1n and denominator time constant T1d, in seconds (s), of the first lead-lag transfer function.

Lead-lag #2 time constants: [Tnum Tden]

The numerator time constant T2n and denominator time constant T2d, in seconds (s), of the second lead-lag transfer function.

Output limits: [Vsmin Vsmax]

The limits VSmin and VSmax, in pu, imposed on the output of the stabilizer.

Initial input

The initial DC voltage, in pu, of the block's input signal. Specification of this parameter is required to initialize all states and start the simulation in steady state with `vstab` set to zero.

Plot frequency response

If selected, a plot of the frequency response of the stabilizer is displayed when you click the **Apply** button.

Magnitude in dB

The **Magnitude in dB** parameter is not visible if the **Plot frequency response** is not selected. If selected, the magnitude of the frequency response is plotted in dB.

Frequency range

The **Frequency range** parameter is not visible in the dialog box if the **Plot frequency response** is not selected. Specify the frequency range used to plot the frequency response of the stabilizer.

Inputs and Outputs

`In`

Two types of signals can be used at the input `In`:

- The synchronous machine speed deviation dw signal (in pu)

- The synchronous machine acceleration power Pa = Pm - Peo (difference between the machine mechanical power and output electrical power (in pu))

Vstab

The output is the stabilization voltage (in pu) to connect to the Vstab input of the Excitation System block used to control the terminal voltage of the synchronous machine.

Example

See the help text of the power_PSS example model.

References

[1] Kundur, P., *Power System Stability and Control*, McGraw-Hill, 1994, Section 12.5.

See Also

Multiband Power System Stabilizer

Introduced before R2006a

Ground

Provide connection to ground

Library

Fundamental Blocks/Elements
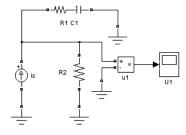
Description

The Ground block implements a connection to the ground.

Example

The power_ground example shows an application of the Ground block.

See Also

Neutral

Introduced before R2006a

Grounding Transformer
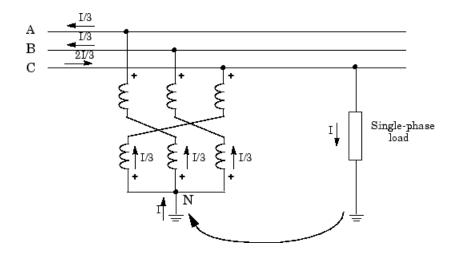
Implement three-phase grounding transformer providing a neutral in three-wire system

Library

Fundamental Blocks/Elements

Description

Grounding transformers are used in utility distribution networks and in some power electronic converters in order to provide a neutral point in a three-wire system. This transformer is a three-phase two-winding transformer with winding 1 and winding 2 connected in zig zag as shown in the figure below.

The figure shows a single-phase load connected between phase C and ground in a three-wire system. The current I absorbed by the load returns to the source through the ground

and the neutral of the grounding transformer. Because of the zig zag connection and the opposite winding polarities of upper and lower windings, the grounding transformer offers a low impedance in zero-sequence while keeping a very high impedance to positive-sequence. In other words, only a zero-sequence current can flow through the three windings. By definition, a zero-sequence current is a set of three-phase currents having same magnitude and phase. Therefore, the neutral current I shares into three equal currents $I/3$. Because the three currents flowing in the grounding transformer are equal, the neutral point stays fixed and the line-to-neutral voltages remain balanced.

The grounding transformer is modeled by three two-winding transformers having a 1:1 voltage ratio. Assume six identical windings with:

R = winding resistances
X = winding leakage reactances
$Rmag$, $Xmag$= parallel resistance and reactance of the magnetizing branch
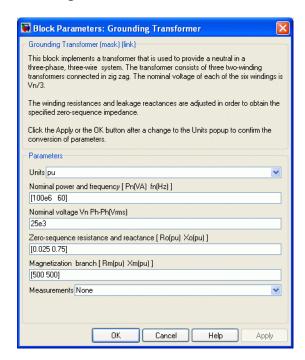
The positive-sequence impedance Z_1 and the zero-sequence impedance Z_0 of the grounding transformer are given by:

$$Z_1 = R_1 + jX_1 = 3\frac{jR_{\text{mag}}X_{\text{mag}}}{\left(R_{\text{mag}} + X_{\text{mag}}\right)}$$
$$Z_0 = R_0 + jX_0 = 2(R + jX).$$

The zero-sequence reactance X_0 is the most important parameter of the grounding transformer. In order to minimize voltage unbalance, reactance X_0 should be kept as low as possible.

Dialog Box and Parameters

Units

Specify the units used to enter the parameters of the Grounding Transformer block. Select pu to use per unit. Select SI to use SI units. Changing the **Units** parameter from pu to SI, or from SI to pu, will automatically convert the parameters displayed in the mask of the block. The per unit conversion is based on the transformer rated power Pn in VA, nominal frequency fn in Hz, and nominal voltage Vn, in Vrms, of the windings.

Nominal power and frequency

The nominal power rating, in volt-amperes (VA), and nominal frequency, in hertz (Hz), of the transformer. Note that the nominal parameters have no impact on the transformer model when the **Units** parameter is set to SI.

Nominal voltage

The nominal phase-to-phase voltage Vn of the Grounding Transformer, in volts RMS (Vrms).

Zero-sequence resistance and reactance

The zero-sequence resistance R0 and the zero-sequence reactance X0 in pu or in ohms.

Magnetization branch

The shunt resistance Rm modeling the transformer core losses and the magnetizing reactance Xm modeling the magnetization current, in pu or ohms.

These values define the active power losses P and the reactive power losses Q required for magnetizing the grounding transformer.

$$P = \frac{V_n^2}{Rm}$$
$$Q = \frac{V_n^2}{Xm}.$$

As the nominal voltage across each of the six windings is the nominal line-to-line voltage divided by 3 (Vn/3), the three impedances effectively connected across one of the two windings on each leg are Rmag=Rm/3 and Xmag=Xm/3.

Measurements

Select `Voltages` to measure the line-to-neutral voltages at the terminals of the Grounding Transformer block.

Select `Currents` to measure the currents flowing into the three terminals of the Grounding Transformer block.

Select `All voltages and currents` to measure voltages and currents.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

Measurement	Label
line-to-neutral voltages	Uan Ubn Ucn
currents	Ian Ibn Icn

Limitations

Saturation of the grounding transformer is not modeled.

See Also

Linear Transformer, Multimeter, Three-Phase Transformer (Two Windings), Three-Phase Transformer (Three Windings)

Introduced in R2008a

GTO

Implement gate turn off (GTO) thyristor model

Library

Fundamental Blocks/Power Electronics
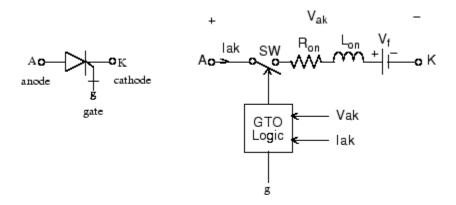
Description

The gate turnoff (GTO) thyristor is a semiconductor device that can be turned on and off via a gate signal. Like a conventional thyristor, the GTO thyristor can be turned on by a positive gate signal ($g > 0$). However, unlike the thyristor, which can be turned off only at a zero crossing of current, the GTO can be turned off at any time by the application of a gate signal equal to 0.

The GTO thyristor is simulated as a resistor Ron, an inductor Lon, and a DC voltage source Vf connected in series with a switch. The switch is controlled by a logical signal depending on the voltage Vak, the current Iak, and the gate signal g.
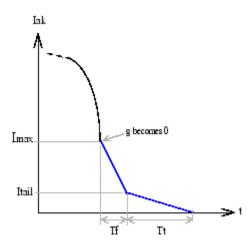
The Vf, Ron, and Lon parameters are the forward voltage drop while in conduction, the forward conducting resistance, and the inductance of the device. The GTO block also
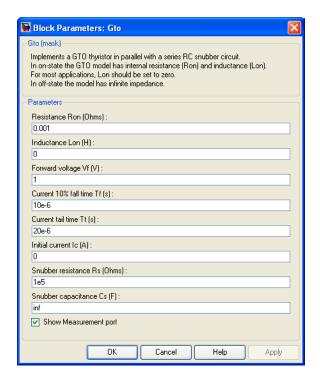
contains a series Rs-Cs snubber circuit that can be connected in parallel with the GTO device (between terminal ports A and K).

The GTO thyristor turns on when the anode-cathode voltage is greater than Vf and a positive pulse signal is present at the gate input (g > 0). When the gate signal is set to 0, the GTO thyristor starts to block but its current does not stop instantaneously.

Because the current extinction process of a GTO thyristor contributes significantly to the turnoff losses, the turnoff characteristic is built into the model. The current decrease is approximated by two segments. When the gate signal becomes 0, the current Iak first decreases from the value Imax (value of Iak when the GTO thyristor starts to open) to Imax/10, during the fall time (Tf), and then from Imax/10 to 0 during the tail time (Tt). The GTO thyristor turns off when the current Iak becomes 0. The latching and holding currents are not considered.

Dialog Box and Parameters

Resistance Ron

> The internal resistance Ron, in ohms (Ω). The **Resistance Ron** parameter cannot be set to **0** when the **Inductance Lon** parameter is set to 0.

Inductance Lon

> The internal inductance Lon, in henries (H). The **Inductance Lon** parameter is normally set to **0** except when the **Resistance Ron** parameter is set to **0**.

Forward voltage Vf

> The forward voltage of the GTO thyristor device, in volts (V).

Current 10% fall time

> The current fall time Tf, in seconds (s). This parameter is not modeled when the **Enable use of ideal switching devices** parameter of the Powergui block is selected.

Current tail time

The current tail time Tt, in seconds (s). This parameter is not modeled when the **Enable use of ideal switching devices** parameter of the Powergui block is selected.

Initial current Ic

You can specify an initial current flowing in the GTO thyristor. It is usually set to 0 in order to start the simulation with the device blocked.

If the **Initial Current IC** parameter is set to a value greater than 0, the steady-state calculation considers the initial status of the GTO as closed. Initializing all states of a power electronic converter is a complex task. Therefore, this option is useful only with simple circuits.

Snubber resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to `inf` to eliminate the snubber from the model.

Snubber capacitance Cs

The snubber capacitance, in farads (F). Set the **Snubber capacitance Cs** parameter to `0` to eliminate the snubber, or to `inf` to get a resistive snubber.

Show measurement port

If selected, add a Simulink output to the block returning the GTO current and voltage.

Inputs and Outputs

g

Simulink signal to control the gate of the GTO.

m

The Simulink output of the block is a vector containing two signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Signal	Definition	Units
1	GTO current	A
2	GTO voltage	V

Assumptions and Limitations

The GTO block implements a macro model of a real GTO thyristor. It does not take into account either the geometry of the device or the underlying physical processes of the device [1].

The GTO block requires a continuous application of the gate signal ($g > 0$) in order to be in the on state (with $Iak > 0$). The latching current and the holding current are not considered. The critical value of the derivative of the reapplied anode-cathode voltage is not considered.

Depending on the value of the inductance Lon, the GTO is modeled either as a current source (Lon > 0) or as a variable topology circuit (Lon = 0). The GTO block cannot be connected in series with an inductor, a current source, or an open circuit, unless its snubber circuit is in use.
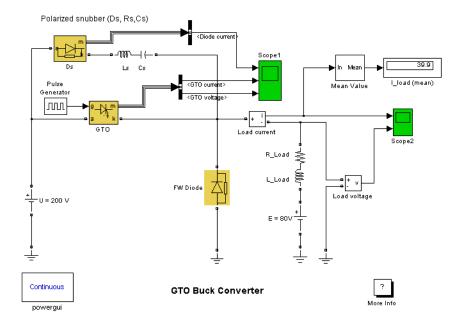
Use the Powergui block to specify either continuous simulation or discretization of your electrical circuit containing GTO blocks. When using a continuous model, the `ode23tb` solver with a relative tolerance of 1e-4 is recommended for best accuracy and simulation speed.

The inductance Lon is forced to 0 if you choose to discretize your circuit.
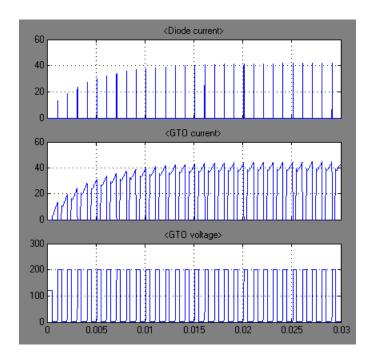
Example
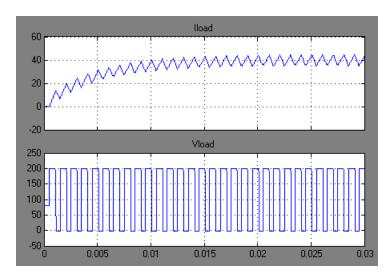
The power_buckconv example illustrates the use of the GTO block in a buck converter topology. The basic polarized snubber circuit is connected across the GTO block. The snubber circuit consists of a capacitor Cs, a resistor Rs, and a diode Ds. The parasitic inductance Ls of the snubber circuit is also taken into consideration.

The parameters of the GTO block are those found in the dialog box section, except for the internal snubber, which is not used (**Rs** = inf; **Cs** = 0). The switching frequency is 1000 Hz and the pulse width is 216 degrees (duty cycle: 60%).

Polarized snubber (Ds, Rs,Cs)

GTO Buck Converter

Run the simulation. Observe the GTO voltage and current as well as the load voltage and current.

References

[1] Mohan, N., T.M. Undeland, and W.P. Robbins, *Power Electronics: Converters, Applications, and Design*, John Wiley & Sons, Inc., New York, 1995.

See Also

IGBT, MOSFET, Three-Level Bridge, Thyristor, Universal Bridge
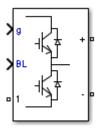
Introduced before R2006a

Half-Bridge Converter

Implement half-bridge power converter

Library

Fundamental Blocks/Power Electronics

Description

The Half-Bridge Converter block implements a half-bridge power converter. You can choose from three model types:

- **Switching devices** — The converter is modeled with IGBT/diode pairs controlled by firing pulses produced by a PWM generator. This model provides the most accurate simulation results.

- **Switching function** — The converter is modeled by a switching-function model. The switches are replaced with two voltage sources and two diodes on the AC side and with two current sources on the DC side.

  The converter is controlled by firing pulses produced by a PWM generator (0/1 signals) or by firing pulses averaged over a specified period (PWM averaging: signals between 0 and 1). Both modes of operation produce harmonics normally generated by a PWM-controlled converter and also correctly simulate rectifying operation as well as blanking time. This model type is well-suited for real-time simulation.

- **Average model (Uref-controlled)** — The converter is modeled using a switching-function model directly controlled by the reference voltage signals (Uref). A PWM generator is not required. This model provides the fastest simulations.

Dialog Box and Parameters

Block Parameters: Half-Bridge Converter

Half-Bridge Converter (mask)

Implements a half-bridge power converter using the following modeling techniques:

1. Switching devices: The converter is modeled with IGBT/diode pairs controlled by firing pulses produced by a PWM generator.

2. Switching function: The converter is modeled by a switching function controlled by firing pulses produced by a PWM generator (0/1 signals) or by firing pulses averaged over a specified period (PWM averaging: signals between 0 and 1).

3. Average model (Uref-controlled): The converter is modeled using a switching-function model directly controlled by the reference voltage. A PWM generator is not required.

Technique 1 is the most accurate, while technique 3 yields to the fastest simulation. The two techniques in 2 are well-suited for real-time simulation.

Model type: Switching devices

Device on-state resistance (Ohms)

1e-3

Snubber resistance (Ohms)

1e6

Snubber capacitance (F)

inf

OK   Cancel   Help   Apply

Parameters

Model type

Specify the model type to use:

- `Switching devices` (default)
- `Switching function`
- `Average model (Uref-controlled)`

Device on-state resistance (Ohms)

Internal resistance of the switching devices, in ohms. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `1e-3`.

Snubber resistance (Ohms)

The snubber resistance, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `1e6`.

Snubber capacitance (F)

The snubber capacitance, in farads. Set the snubber capacitance to `0` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `inf`.

Diode on-state resistance (Ohms)

Internal resistance of the diodes, in ohms. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `1e-3`.

Diode snubber resistance (Ohms)

The snubber resistance, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `1e6`.

Diode snubber capacitance (F)

The snubber capacitance in farads. Set the snubber capacitance to `0` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `inf`.

Diode forward voltage (V)

Forward voltage, in volts, across the diode when it is conducting. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `1e-3`.

Current source snubber resistance (Ohms)

The snubber resistance across the two current sources, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `inf`.

Inputs and Outputs

`g`

A vectorized gating signal to control the converter. The gating signal contains two firing pulses. The first pulse controls Q1 and the second pulse controls Q2. This port is visible only when you set the **Model type** parameter to `Switching devices` or `Switching function`.

`Uref`

The reference voltage signal to control the converter. This port is visible only when you set the **Model type** parameter to `Average model (Uref-controlled)`..

`BL`

You can block all firing pulses to the converter by applying a signal value of 1 at the BL input.

Examples

See the Power Converters Modeling Techniques example for a comparison of the three converter modeling techniques.

Introduced in R2015b

Hydraulic Turbine and Governor
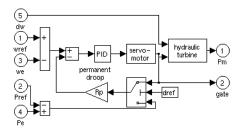
Model hydraulic turbine and proportional-integral-derivative (PID) governor system

Library

Fundamental Blocks/Machines

Description
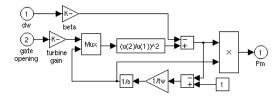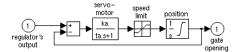
The Hydraulic Turbine and Governor block implements a nonlinear hydraulic turbine model, a PID governor system, and a servomotor [1].
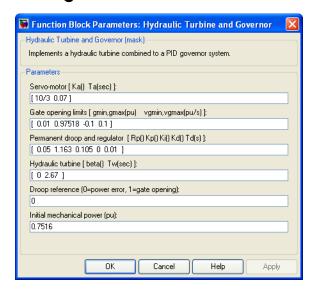
The hydraulic turbine is modeled by the following nonlinear system.

The gate servomotor is modeled by a second-order system.

Dialog Box and Parameters

Servo-motor

The gain Ka and time constant Ta, in seconds (s), of the first-order system representing the servomotor.

Gate opening limits

The limits gmin and gmax (pu) imposed on the gate opening, and vgmin and vgmax (pu/s) imposed on gate speed.

Permanent droop and regulator

The static gain of the governor is equal to the inverse of the permanent droop Rp in the feedback loop. The PID regulator has a proportional gain Kp, an integral gain Ki, and a derivative gain Kd. The high-frequency gain of the PID is limited by a first-order low-pass filter with time constant Td (s).

Hydraulic turbine

The speed deviation damping coefficient ß and water starting time Tw (s).

Droop reference

   Specifies the input of the feedback loop: gate position (set to 1) or electrical power deviation (set to 0).

Initial mechanical power

   The initial mechanical power Pm0 (pu) at the machine's shaft. This value is automatically updated by the load flow utility of the Powergui block.

Inputs and Outputs

wref

   Reference speed, in pu.

Pref

   Reference mechanical power in pu. This input can be left unconnected if you want to use the gate position as input to the feedback loop instead of the power deviation.

we

   Machine actual speed, in pu.

Pe0

   Machine actual electrical power in pu. This input can be left unconnected if you want to use the gate position as input to the feedback loop instead of the power deviation.

dw

   Speed deviation, in pu.

Pm

   Mechanical power Pm for the Synchronous Machine block, in pu.

gate

   Gate opening, in pu.

Example

This power_turbine example illustrates the use of the Synchronous Machine associated with the Hydraulic Turbine and Governor (HTG) and Excitation System blocks. It also demonstrates the use of the Machine Initialization tool of the Powergui block to initialize machine currents and initial mechanical power of the HTG block. A three-phase generator rated 200 MVA, 13.8 kV, 112.5 rpm is connected to a 230 kV network through a Delta-Y 210 MVA transformer. The system starts in steady state with the generator

supplying 150 MW of active power. At t = 0.1 s, a three-phase to ground fault occurs on the 230 kV bus of the transformer. The fault is cleared after six cycles (t = 0.2 s).
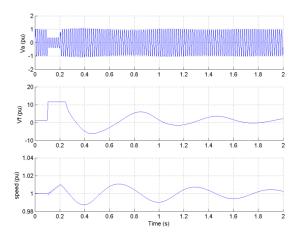
In order to start the simulation in steady state, you must initialize the Synchronous Machine block for the desired load flow. Open the Powergui and select **Machine Initialization**. The machine **Bus type** should be already initialized as `PV generator`, indicating that the load flow is performed with the machine controlling the active power and its terminal voltage. Specify the desired values by entering the following parameters:

- Terminal voltage U AB (Vrms) = 13800
- Active power (watts) = 150e6

Then click the **Compute and Apply** button. The line-to-line machine voltages as well as the phase currents flowing out of the machine are displayed in the tool dialog. The machine reactive power, mechanical power, and field voltage requested to supply the electrical power should also be displayed:

- Q = 3.4 Mvar
- Pmec = 150.32 MW (0.7516 pu)
- Field voltage Vf = 1.291 pu

The Machine Initialization tool also initializes the HTG and Excitation System blocks. Open the HTG block dialog and notice that the initial mechanical power is set to 0.751606 pu. Then open the Excitation System block dialog and note that the initial terminal voltage and field voltage are set respectively to 1.0 and 1.291 pu. Open the four scopes and start the simulation. The simulation starts in steady state.

Observe that the terminal voltage Va is 1.0 pu at the beginning of the simulation. It falls to about 0.4 pu during the fault and returns to nominal quickly after the fault is cleared. This quick response in terminal voltage is due to the fact that the Excitation System output Vf can go as high as 11.5 pu, which it does during the fault. The speed of the machine increases to 1.01 pu during the fault, then it oscillates around 1 pu as the governor system regulates it. The speed takes much longer than the terminal voltage to stabilize, mainly because the rate of valve opening/closing in the governor system is limited to 0.1 pu/s.

References

[1] IEEE Working Group on Prime Mover and Energy Supply Models for System Dynamic Performance Studies, "Hydraulic Turbine and Turbine Control Models for Dynamic Studies," *IEEE Transactions on Power Systems*, Vol.7, No.1, February, 1992, pp. 167-179.

See Also

Excitation System, Steam Turbine and Governor, Synchronous Machine

Introduced before R2006a

Ideal Switch
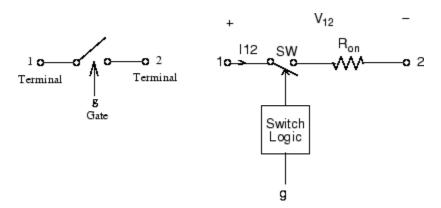
Implement ideal switch device

Library

Fundamental Blocks/Power Electronics

Description

The Ideal Switch block does not correspond to a particular physical device. When used with appropriate switching logic, it can be used to model simplified semiconductor devices such as a GTO or a MOSFET, or even a power circuit breaker with current chopping. The switch is simulated as a resistor Ron in series with a switch controlled by a logical gate signal g.
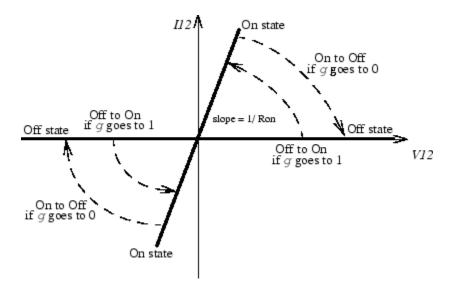
The Ideal Switch block is fully controlled by the gate signal (g > 0 or g = 0). It has the following characteristics:
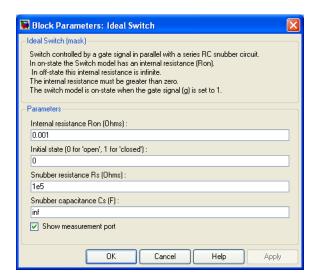
- Blocks any forward or reverse applied voltage with 0 current flow when g = 0
- Conducts any bidirectional current with quasi-zero voltage drop when g > 0
- Switches instantaneously between on and off states when triggered

The Ideal Switch block turns on when a positive signal is present at the gate input (g > 0). It turns off when the gate signal equals 0 (g = 0).

The Ideal Switch block also contains a series Rs-Cs snubber circuit that can be connected in parallel with the ideal switch (between nodes 1 and 2).

Dialog Box and Parameters

Internal resistance Ron

The internal resistance of the switch device, in ohms (Ω). The **Internal resistance Ron** parameter cannot be set to 0.

Initial state

The initial state of the Ideal Switch block. The initial status of the Ideal Switch block is taken into account in the steady-state calculation.

Snubber resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to inf to eliminate the snubber from the model.

Snubber capacitance Cs

The snubber capacitance in farads (F). Set the **Snubber capacitance Cs** parameter to 0 to eliminate the snubber, or to inf to get a resistive snubber.

Show measurement port

If selected, add a Simulink output to the block returning the ideal switch current and voltage.

Inputs and Outputs

g

Simulink signal to control the opening and closing of the switch.

m

The Simulink output of the block is a vector containing two signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Signal	Definition	Units
1	Ideal switch current	A
2	Ideal switch voltage	V
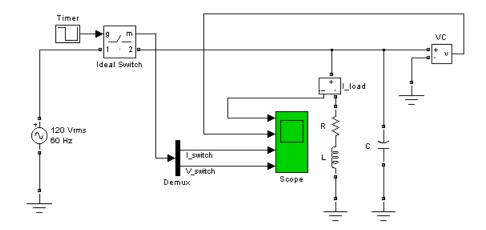
Assumptions and Limitations

The Ideal Switch block is modeled as a current source. It cannot be connected in series with an inductor, a current source, or an open circuit, unless its snubber circuit is in use.

Use the Powergui block to specify either continuous simulation or discretization of your electrical circuit containing ideal switches. When using a continuous model, the ode23tb solver with a relative tolerance of 1e-4 is recommended for best accuracy and simulation speed.

Example

The power_switch example uses the Ideal Switch block to switch an RLC circuit on an AC source (60 Hz). The switch, which is initially closed, is first opened at t = 50 ms (3 cycles) and then reclosed at t = 138 ms (8.25 cycles). The Ideal Switch block has 0.01 ohms resistance and no snubber is used.

Run the simulation and observe the inductor current, the switch current, and the capacitor voltage. Notice the high-frequency overvoltage produced by inductive current chopping. Note also the high switch current spike when the switch is reclosed on the capacitor at maximum source voltage.

References

[1] Mohan, N., T.M. Undeland, and W.P. Robbins, *Power Electronics: Converters, Applications, and Design*, John Wiley & Sons, Inc., New York, 1995.

See Also

Breaker

Introduced before R2006a

IGBT
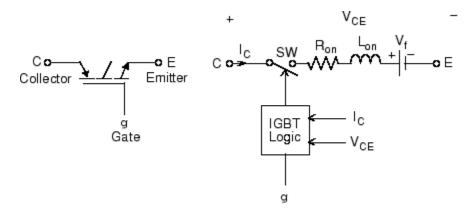
Implement insulated gate bipolar transistor (IGBT)

Library

Fundamental Blocks/Power Electronics

Description
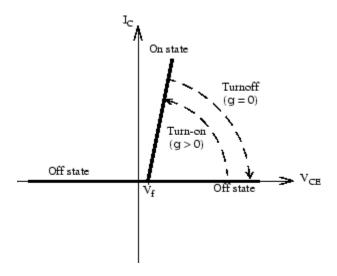
The IGBT block implements a semiconductor device controllable by the gate signal. The IGBT is simulated as a series combination of a resistor Ron, inductor Lon, and a DC voltage source Vf in series with a switch controlled by a logical signal (g > 0 or g = 0)
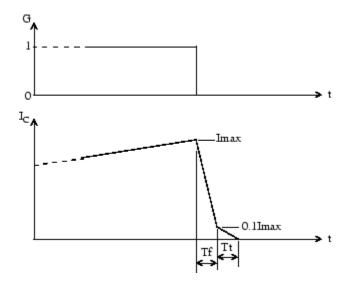
The IGBT turns on when the collector-emitter voltage is positive and greater than Vf and a positive signal is applied at the gate input (g > 0). It turns off when the collector-emitter voltage is positive and a 0 signal is applied at the gate input (g = 0).

The IGBT device is in the off state when the collector-emitter voltage is negative. Note that many commercial IGBTs do not have the reverse blocking capability. Therefore, they are usually used with an antiparallel diode.
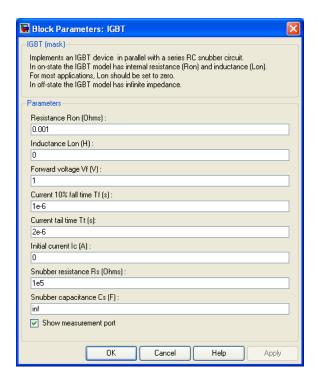
The IGBT block contains a series Rs-Cs snubber circuit, which is connected in parallel with the IGBT device (between terminals C and E).

The turnoff characteristic of the IGBT model is approximated by two segments. When the gate signal falls to 0, the collector current decreases from Imax to 0.1 Imax during the fall time (Tf), and then from 0.1 Imax to 0 during the tail time (Tt).

Dialog Box and Parameters

Resistance Ron

The internal resistance Ron, in ohms (Ω). The **Resistance Ron** parameter cannot be set to 0 when the **Inductance Lon** parameter is set to 0.

Inductance Lon

The internal inductance Lon, in henries (H). The **Inductance Lon** parameter is normally set to 0 except when the **Resistance Ron** parameter is set to 0.

Forward voltage Vf

The forward voltage of the IGBT device, in volts (V).

Current 10% fall time

The current fall time Tf, in seconds (s). This parameter is not modeled when the **Enable use of ideal switching devices** parameter of the Powergui block is selected.

Current tail time

The current tail time Tt, in seconds (s). This parameter is not modeled when the **Enable use of ideal switching devices** parameter of the Powergui block is selected.

Initial current Ic

You can specify an initial current flowing in the IGBT. It is usually set to 0 in order to start the simulation with the device blocked.

If the **Initial Current IC** parameter is set to a value greater than 0, the steady-state calculation considers the initial status of the IGBT as closed. Initializing all states of a power electronic converter is a complex task. Therefore, this option is useful only with simple circuits.

Snubber resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to inf to eliminate the snubber from the model.

Snubber capacitance Cs

The snubber capacitance in farads (F). Set the **Snubber capacitance Cs** parameter to 0 to eliminate the snubber, or to inf to get a resistive snubber.

Show measurement port

If selected, add a Simulink output to the block returning the diode IGBT current and voltage.

Inputs and Outputs

g

Simulink signal to control the opening and closing of the IGBT.

m

The Simulink output of the block is a vector containing two signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Signal	Definition	Units
1	IGBT current	A
2	IGBT voltage	V

Assumptions and Limitations

The IGBT block implements a macro model of the real IGBT device. It does not take into account either the geometry of the device or the complex physical processes [1].

Depending on the value of the inductance Lon, the IGBT is modeled either as a current source (Lon > 0) or as a variable topology circuit (Lon = 0). The IGBT block cannot be connected in series with an inductor, a current source, or an open circuit, unless its snubber circuit is in use.
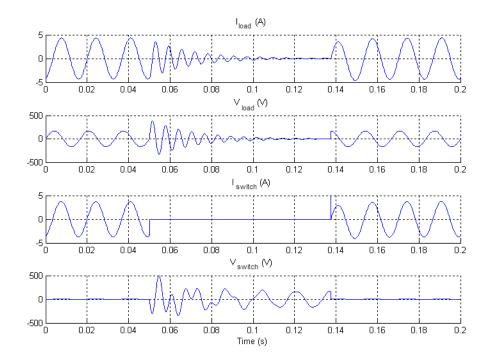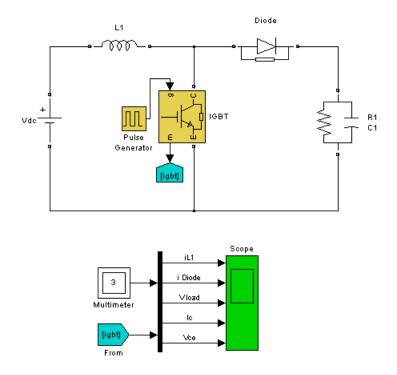
Use the Powergui block to specify either continuous simulation or discretization of your electrical circuit containing IGBT blocks. When using a continuous model, the `ode23tb` solver with a relative tolerance of 1e-4 is recommended for best accuracy and simulation speed.

The inductance Lon is forced to 0 if you choose to discretize your circuit.

Example

The power_igbtconv example illustrates the use of the IGBT block in a boost DC-DC converter. The IGBT is switched on and off at a frequency of 10 kHz to transfer energy from the DC source to the load (RC). The average output voltage (V_R) is a function of the duty cycle (α) of the IGBT switch:
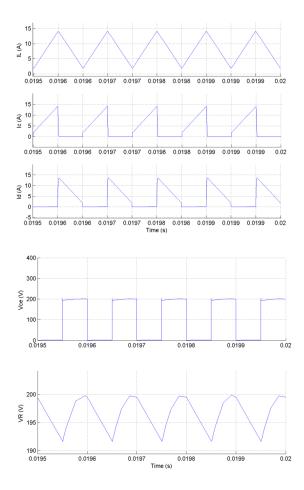
$$V_R = \frac{1}{1-\alpha} V_{dc}$$

In our example, α = 0.5 so that the theoretical value of V_R is 200 V, assuming no voltage drop across the diode and the IGBT.

Run the simulation and observe the inductor current (I_L), the IGBT collector current (I_C), the diode current (I_D), the IGBT device collector-emitter voltage (V_{CE}), and the load voltage (V_R).

The load voltage (197 V) is slightly lower than the theoretical value (200 V) mainly because of the forward voltage (V_f) of the diode (0.8 V) and of the IGBT ($V_f = 1$ V).

References

[1] Mohan, N., T.M. Undeland, and W.P. Robbins, *Power Electronics: Converters, Applications, and Design*, John Wiley & Sons, Inc., New York, 1995.

See Also

GTO, MOSFET, Three-Level Bridge, Thyristor

Introduced before R2006a

IGBT/Diode

Implements ideal IGBT, GTO, or MOSFET and antiparallel diode

Library

Fundamental Blocks/Power Electronics
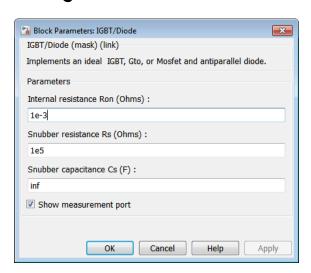
Description

The IGBT/Diode block is a simplified mode of an IGBT (or GTO or MOSFET)/Diode pair where the forward voltages of the forced-commutated device and diode are ignored.

Dialog Box and Parameters

Internal resistance Ron

The internal resistance Ron of the IGBT device, in ohms (Ω).

Snubber resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to `inf` to eliminate the snubber from the model.

Snubber capacitance Cs

The snubber capacitance in farads (F). Set the **Snubber capacitance Cs** parameter to `0` to eliminate the snubber, or to `inf` to get a resistive snubber.

Show measurement port

If selected, add a Simulink output to the block returning the diode IGBT current and voltage.

Inputs and Outputs

`g`

Simulink signal to control the opening and closing of the IGBT.

`m`

The Simulink output of the block is a vector containing two signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Signal	Definition	Units
1	IGBT/Diode current	A
2	IGBT/diode voltage	V

Assumptions and Limitations

The IGBT/Diode block implements a macro model of the real IGBT and Diode devices. It does not take into account either the geometry of the devices or the complex physical processes [1].

The IGBT/Diode block cannot be connected in series with an inductor, a current source, or an open circuit, unless its snubber circuit is in use.

Use the Powergui block to specify either continuous simulation or discretization of your electrical circuit containing IGBT/Diode blocks. When using a continuous model, the `ode23tb` solver with a relative tolerance of 1e-4 is recommended for best accuracy and simulation speed.

Example
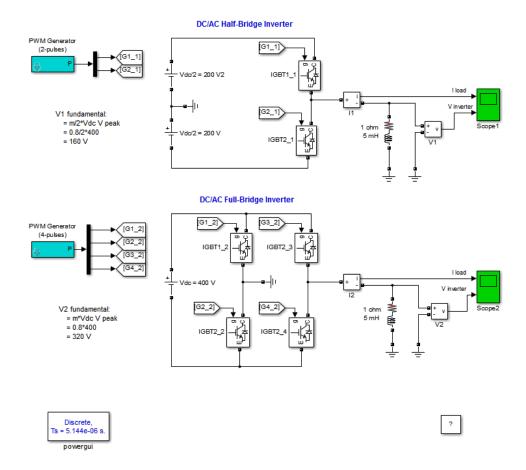
The power_1phPWM_IGBT example illustrates use of the IGBT/Diode block in voltage-sourced converters. The system consists of two independent circuits illustrating single-phase PWM voltage-sourced converters (VSC):

1   Half-bridge converter

2   Full-bridge converter

The converters are built with the IGBT/Diode block which is the basic building block of all VSCs. You may replace these blocks by individual IGBT and diode blocks for a more detailed representation.

VSCs are controlled in open loop with the PWM Generator (2–Level) block available in the Control and Measurements/Pulse & Signal Generators library.

The two circuits use the same DC voltage of 400 Volts, carrier frequency of 1080 Hz and modulation index of 0.8.

Run the simulation and observe the current into the load (trace 1) and the voltage generated by the PWM inverter (trace 2) on the Scope blocks.

See Also

IGBT, Diode

Introduced in R2006a

Impedance Measurement

Measure impedance of circuit as function of frequency

Library

Fundamental Blocks/Measurements

Description $\quad^{\boxed{z}}$

The Impedance Measurement block measures the impedance between two nodes of a linear circuit as a function of the frequency. It consists of a current source Iz, connected between inputs one and two of the Impedance Measurement block, and a voltage measurement Vz, connected across the terminals of the current source. The network impedance is calculated as the transfer function H(s) from the current input to the voltage output of the state-space model.

$$H(s) = \frac{V_z(s)}{I_z(s)}.$$
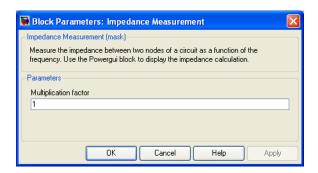
The impedance (magnitude and phase) as function of frequency is displayed by using the Impedance vs Frequency Measurement tool of the Powergui block.

The measurement takes into account the initial states of the Breaker and Ideal Switch blocks. It also allows impedance measurements with Distributed Parameter Line blocks in your circuit.

The source impedances are taken into account in the impedance calculations. By definition, the impedance of voltage sources is 0 (voltage source blocks are considered as short-circuit) and the impedance of current sources is infinite (current source blocks are considered as open-circuit).

In some applications, you may need to manually delete current or voltage source blocks in order to ignore their impact on impedance calculations.

Dialog Box and Parameter

Multiplication factor

> If you use the Impedance Measurement block in a three-phase circuit, you can use the **Multiplication factor** parameter to rescale the measured impedance. For example, measuring the impedance between two phases of a three-phase circuit gives two times the positive-sequence impedance. Therefore you must apply a multiplication factor of 1/2 to the impedance in order to obtain the correct positive-sequence impedance value.

> Similarly, to measure the zero-sequence impedance of a balanced three-phase circuit, you can connect the Impedance Measurement block between ground or neutral and the three phases connected together.

> In that case, you are measuring one third of the zero-sequence impedance and you must apply a multiplication factor of 3 to obtain the correct zero-sequence value.

Limitations

The only nonlinear blocks that are taken into account during the impedance measurement are the Breaker, Three-Phase Breaker, Three-Phase Fault, Ideal Switch, and Distributed Parameter Line blocks. All other nonlinear blocks, such as machines and power electronic devices, are not considered, and they are disconnected during the measurement.

If you plan to connect the Impedance Measurement block in series with an inductance, a current source, or any nonlinear element, you must add a large resistor across the

terminals of the block, because the Impedance Measurement block is simulated as a current source block.

See Also

`power_zmeter`
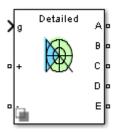
Introduced before R2006a

Inverter (Five-Phase)

Implements five-phase inverter model for five-phase PM Synchronous motor drive

Library

Electric Drives/Fundamental Drive Blocks

Description
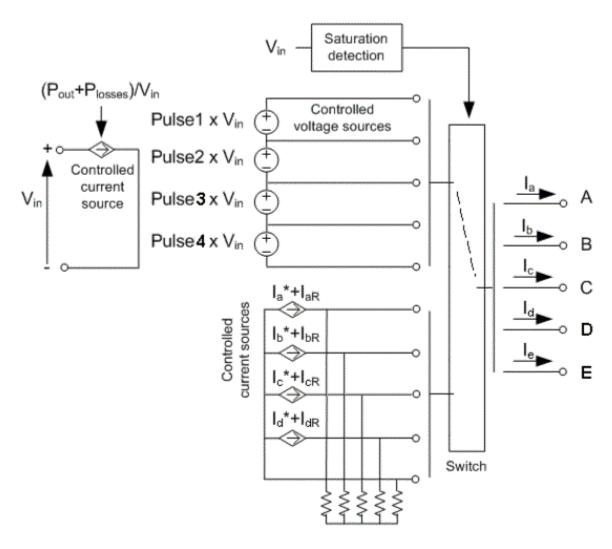
The Inverter (Five-Phase) block models a standard five-leg, two-level inverter model when set to detailed mode or an average-value inverter model when set to average mode.

Detailed mode

In detailed mode, this block consists of five Universal Bridge models configured as single-leg (one leg with two switches), force-commutated converters and connected in parallel.

Average Mode

In average mode, the Inverter (Five-phase) block implements an average-value inverter model where the inverter is represented using current and voltage sources, as shown in the figure.

The average-value model is composed of one controlled current source on the DC side and four controlled current sources and four controlled voltage sources on the AC side. The DC current source allows the representation of the average DC bus current behavior following the equation

$I_{dc} = (P_{ac} + P_{losses}) / V_{in}$,

with P_{losses} being the AC side instantaneous power, P_{losses} the losses in the power electronics devices, and V_{in} the DC bus voltage.

On the AC side, the current sources represent the average phase currents fed to the motor. Because the regulation is fast, the current values are set equal to the current references sent by the current regulator. A small current is injected to compensate for the current drawn by the five-phase load.

During loss of current tracking due to insufficient inverter voltage, the currents are fed by four controlled voltage sources. These voltage sources represent the square wave mode and allow good representation of the phase currents during inverter saturation. Each voltage source outputs either V_{in} or 0, depending on the values of the pulses (1 or 0) sent by the current controller. This mode of operation is detected by the Saturation detection block using the DC bus voltage and the counter electro-motive force generated by the AC machine.

Dialog Box and Parameters

Model detail level

Specify the model detail level to use:

- Detailed (default)

- Average

Snubber resistance Rs (Ohms)

The snubber resistance, in ohms. Set the **Snubber resistance Rs** parameter to `inf` to eliminate the snubbers from the model. The default value is `500`.

Snubber capacitance Cs (F)

The snubber capacitance, in farads. Set the **Snubber capacitance Cs** parameter to `0` to eliminate the snubbers or to `inf` to get a resistive snubber. The default value is `1e-9`.

Power electronic device

Select the type of power electronic device to use in the inverter.

- `GTO / Diodes`
- `MOSFET / Diodes`
- `IGBT / Diodes` (default)

Resistance Ron (Ohms)

Internal resistance of the switch, in ohms. The default value is `1e-3`.

Forward voltages (V) [Vf, Vfd]

Forward voltages, in volts, of the forced-commutated devices (GTO, MOSFET, or IGBT) and of the antiparallel diodes. The default value is `[1.2,1.2]`.

Fall time and tail time (s) [Tf, Tt]

Fall time Tf and tail time Tt, in seconds, for the GTO or the IGBT devices. The default value is `[1e-6,2e-6]`.

Source Frequency (Hz)

Synchronous frequency of the machine (Hz). This parameter is visible only when the **Model detail level** parameter is set to `Average`. The default value is `60`.

Inductance (H)

The armature inductance of the sinusoidal model with round rotor (Ld is equal to Lq). This parameter is visible only when the **Model detail level** parameter is set to `Average`. The default value is `1350e-6`.

Flux induced by magnets (Wb)

The constant flux, in weber, per pole pairs induced in the stator windings by the magnets of the machine. This parameter is visible only when the **Model detail level** parameter is set to `Average`. The default value is `0.05`.

Stator resistance Rs (ohm)

The stator phase resistance Rs, in ohms, of the motor. This parameter is visible only when the **Model detail level** parameter is set to `Average`. The default value is `0.12`.

Pairs of poles

The number of pole pairs of the machine controlled by the inverter. This parameter is visible only when the **Model detail level** parameter is set to `Average`. The default value is `4`.

Inputs and Outputs

g

The gate input for the controlled switch devices. Pulses are sent to upper and lower switches of inverter legs A, B, C, D, and E. This input is visible only when the **Model detail level** parameter is set to `Detailed`.

ctrl

Control signals from the PMSM vector controller. In average mode, the three-phase inverter no longer receives pulses for each switch. The control signals are the AC current references for each phase along with pulses (0 or 1) to enable square wave operating mode. This input is visible only when the **Model detail level** parameter is set to `Average`.

+

The positive terminal on the DC side.

-

The negative terminal on the DC side.

A, B, C, D, E

The five-phase terminals on the AC side.

Examples

The Inverter (Five-Phase) block is used in the AC8 block of the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

Chopper | Circulating Current Inductors | Inverter (Three-Phase) |
Thyristor Converter

More About

- "Electric Drives Library"
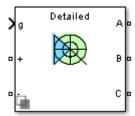
Introduced in R2015b

Inverter (Three-Phase)

Implements a three-phase inverter model for AC Motor Drives

## Library

Electric Drives/Fundamental Drive Blocks

Description

The Inverter (Three-Phase) block models a standard three-leg, two-level inverter model (detailed mode) or an average-value inverter model (average mode). Average mode has multiple instances, depending on the AC motor drive type.

Detailed mode

In detailed mode, the Inverter (Three-Phase) block is an instance of the Universal Bridge block configured as a three-arm (three-phase), forced-commutated converter.

Average Mode
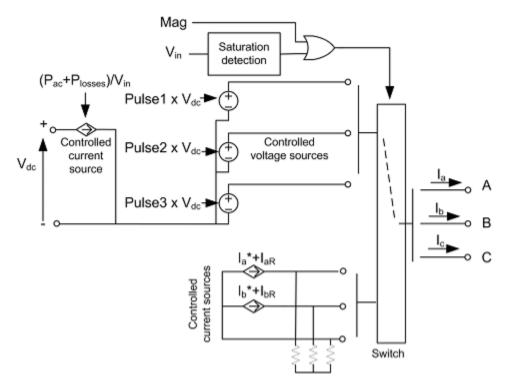
In average mode, the Inverter (Three-Phase) block implements an average-value inverter model for a specific AC drive type. The average-value inverter model can be a current source type with AC current reference signal, voltage source type with an AC voltage reference signal, or voltage source type with AC current reference signal.

Current Source Type with AC Current Reference Signal

This model is used for an AC drive type based on field-oriented control, WFSM vector control, or PMSM vector control.

The inverter is represented by current sources on the AC side during normal operation. The AC current reference signal generates the three-phase currents at the inverter output. When the inverter is saturated, it operates in square-wave mode, and the current sources are replaced with voltage sources. The average-value inverter model of this type is shown in the figure.

The model is composed of one controlled current source on the DC side and of two controlled current sources and three controlled voltage sources on the AC side. The DC current source allows the representation of the average DC bus current behavior following the equation
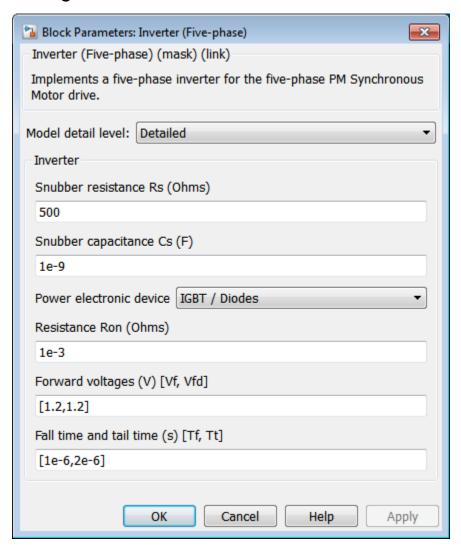
$I_{dc} = (P_{ac} + P_{losses}) / V_{dc}$,

with P_{ac} being the AC side instantaneous power, P_{losses} the losses in the power electronics devices, and V_{dc} the DC bus voltage.

On the AC side, the current sources represent the average phase currents fed to the motor. The current values are set equal to the current references sent by the current
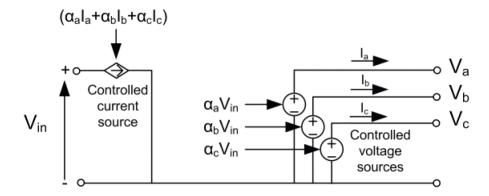
regulator. A small current is injected to compensate for the current drawn by the three-phase load (needed because of the inverter current sources in series with the inductive motor).

The currents are fed by three controlled voltage sources during loss of current tracking due to insufficient inverter voltage. These voltage sources represent the square wave mode and allow good representation of the phase currents during inverter saturation. Each voltage source outputs either V_{in} or 0, depending on the values of the pulses (1 or 0) send by the current controller. This mode of operation is detected from the Saturation detection block using the DC bus voltage and the counter electro-motive force generated by the AC machine.

Voltage Source Type with AC Voltage Reference Signal

This model is used for AC drive type based on space vector modulation.

The inverter is represented with voltage sources on the AC side. The AC voltage reference signal generates the three-phase voltage at the inverter output. The average-value inverter model of this type is shown in the figure.

The model is composed of one controlled current source on the DC side and three controlled voltage sources on the AC side. The DC current source allows the representation of the average DC bus current behavior, following the equation $I_{dc} = a_a I_a + a_b I_b + a_c I_c$,

with a_a, a_b, a_c being the PWM duty cycles (or phase-voltage-to-DC-bus-voltage ratio) of the inverter legs A, B, and C respectively, and I_a, I_b, I_c the corresponding three-phase

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currents. The three AC voltage sources represent the average voltage values of the three-phase inverter voltages V_a, V_b, V_c, following the equation

$V_a = a_a V_{in}$
$V_b = a_b V_{in}$
$V_c = a_c V_{in}$,
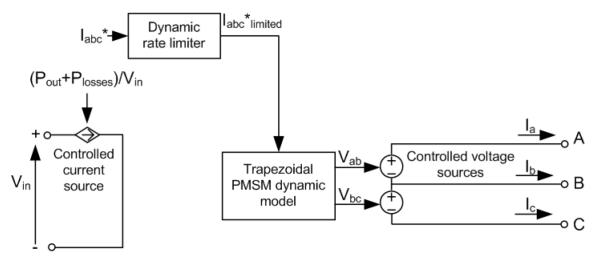
with V_{in} being the input DC bus voltage value.

Voltage Source Type with AC Current Reference Signal

This average-value inverter model is used for the Brushless DC current control AC drive type.

The inverter is represented with voltage sources on the AC side. The AC machine parameters are required together with the AC current reference signal to generate the three-phase voltages at the inverter output. The figure shows the average-value inverter model of this type for a trapezoidal PMSM drive.

The model is composed of one controlled current source on the DC side and two controlled voltage sources on the AC side. The DC current source allows the representation of the DC bus current behavior described by the equation

$I_{dc} = (P_{out} + P_{losses}) / V_{in}$,
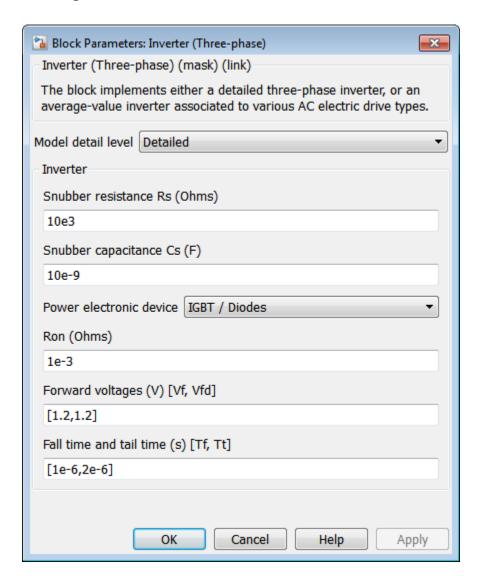
with P_{out} being the output AC power, P_{losses} the losses in the power electronic devices, and V_{in} the DC bus voltage.

On the AC side, the voltage sources are fed by the instantaneous voltages provided by the Trapezoidal PMSM dynamic model (see the PMSM documentation for the machine model). This dynamic model takes the AC reference currents (the rate of these currents has been limited to represent the real-life currents), the measured BEMF voltages, and the machine speed to compute the terminal voltages to apply to the machine.

The dynamic rate limiter limits the rate of the reference currents when transitions occur. The rate depends on the inverter saturation degree.

During loss of current tracking due to insufficient inverter voltage, the dynamic rate limiter saturates the reference current according to this operation mode.

Dialog Box and Parameters

Block Parameters: Inverter (Three-phase)

Inverter (Three-phase) (mask) (link)

The block implements either a detailed three-phase inverter, or an average-value inverter associated to various AC electric drive types.

Model detail level | Detailed

Inverter

Snubber resistance Rs (Ohms)

10e3

Snubber capacitance Cs (F)

10e-9

Power electronic device | IGBT / Diodes

Ron (Ohms)

1e-3

Forward voltages (V) [Vf, Vfd]

[1.2,1.2]

Fall time and tail time (s) [Tf, Tt]

[1e-6,2e-6]

OK   Cancel   Help   Apply

Model detail level

Specify the model detail level to use:

- `Detailed` (default)
- `Average`

Snubber resistance Rs (Ohms)

The snubber resistance, in ohms. Set the **Snubber resistance Rs** parameter to `inf` to eliminate the snubbers from the model. The default value is `10e3`.

Snubber capacitance Cs (F)

The snubber capacitance, in farads. Set the **Snubber capacitance Cs** parameter to `0` to eliminate the snubbers or to `inf` to get a resistive snubber. The default value is `10e-9`.

Power electronic device

Select the type of power electronic device to use in the bridge.

- `GTO / Diodes`
- `MOSFET / Diodes`
- `IGBT / Diodes` (default)

Drive type

Specify the drive type to use. This parameter is visible only when the **Model detail level** parameter is set to `Average`. Select one of these values:

- `Field-oriented control` (default)
- `Space vector modulation`
- `WFSM vector control`
- `PMSM vector control`
- `Brushless DC`

Ron (Ohms)

Internal resistance of the switch, in ohms. The default value is `1e-3`.

Forward voltages (V) [Vf, Vfd]

Forward voltages, in volts, of the forced-commutated devices (GTO, MOSFET, or IGBT) and of the antiparallel diodes. This parameter is available when the selected **Power electronic device** is `GTO/Diodes` or `IGBT/Diodes`. The default value is `[1.2,1.2]`.

Fall time and tail time (s) [Tf, Tt]

Fall time Tf and tail time Tt, in seconds, for the GTO or the IGBT devices. The default value is [1e-6,2e-6].

The default value is[1e-6,2e-6].

Source Frequency (Hz)

Synchronous frequency of the machine, in hertz. This parameter is visible only when the **Model detail level** parameter is set to Average. The default value is 60.

Reference frame

Specifies the reference frame that is used to convert input voltages (abc reference frame) to the dq reference frame, and output currents (dq reference frame) to the abc reference frame. You can choose from the following reference frame transformations:

- Rotor (default)
- Stationary
- Synchronous

This parameter is visible only when the **Model detail level parameter** is set to Average and the **Drive type** parameter is set to Field-oriented control.

Stator [Rs (Ohms), Lls (H)]

The stator resistance, in ohms, and leakage inductance, in henry, of the motor. This parameter is visible only when the **Model detail level** parameter is set to Average and the **Drive type** parameter is set to Field-oriented control .The default value is [14.85e-3,0.3027e-3].

Rotor [Rr' (Ohms) Llr' (H)]

The rotor resistance, in ohms, and leakage inductance, in henry, both referred to the stator. This parameter is visible only when the **Model detail level** parameter is set to Average and the **Drive type** parameter is set to Field-oriented control. The default value is [9.295e-3,0.3027e-3].

Mutual inductance Lm (H)

The magnetizing inductance of the motor, in henry. This parameter is visible only when the **Model detail level** parameter is set to Average and the **Drive type** parameter is set to Field-oriented control. The default value is 10.46e-3.

The default value is10.46e-3.

Inductances (H) [Ld, Lq]

The phase-to-neutral Ld and Lq inductances in the d-axis and q-axis of the sinusoidal model with salient-pole rotor. This parameter is visible only when the **Model detail**

level parameter is set to `Average` and the **Drive type** parameter is set to PMSM `vector control`.

The default value is [0 0].

Inductance (H)

The armature inductance of the sinusoidal model with round rotor (Ld is equal to Lq). This parameter is visible only when the **Model detail level** parameter is set to `Average` and the **Drive type** parameter is set to `Brushless DC`. The default value is `1350e-6`.

Resistance (Ohms)

The stator phase resistance Rs, in ohms, of the motor. This parameter is visible only when the **Model detail level** parameter is set to `Average` and the **Drive type** parameter is set to PMSM `vector control`. The default value is `0`.

Flux induced by magnets (Wb)

The constant flux, in weber, per pole pairs induced in the stator windings by the magnets of the motor. This parameter is visible only when the **Model detail level** parameter is set to `Average` and the **Drive type** parameter is set to PMSM `vector control`. The default value is `0`.

Pairs of poles

The number of pole pairs of the machine controlled by the inverter. This parameter is visible only when the **Model detail level** parameter is set to `Average`. The default value is `2`.

Inputs and Outputs

g

The gate input for the controlled switch devices. Pulses are sent to upper and lower switches of inverter legs A, B, and C. This input is visible only when the **Model detail level** parameter is set to `Detailed`.

ctrl

Control signals from the appropriate controller. In average mode, the Inverter (Three-Phase) block no longer receives pulses, but receives various types of other signals that are drive-type specific. This input is visible only when the **Model detail level** parameter is set to `Average` and the **Drive type** parameter is set to `Field-oriented control`, `WFSM vector control`, or PMSM `vector control`.

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`Duty`

> The PWM duty cycles (or phase-voltage-to-DC-bus-voltage ratio) of the inverter legs A, B, and C. This input is visible only when the **Model detail level** parameter is set to `Average` and the **Drive type** parameter is set to `Space vector modulation`.

`+`

> The positive terminal on the DC side.

`-`

> The negative terminal on the DC side.

`A, B, C`

> The three-phase terminals on the AC side.

Examples

The Inverter (Three-Phase) block is used in the AC1 to AC7 blocks of the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

[2] Erickson, R. W., and D. Maksimovic. *Fundamentals of Power Electronics*, Second Edition. NY: Kluwer Academic Publishers, 2004.

See Also
`Chopper | Circulating Current Inductors | Inverter (Five-phase) | Thyristor Converter`

More About
· "Electric Drives Library"

Introduced in R2015b

Lead-Lag Filter

Implement first-order lead-lag filter

Library

Control and Measurements/Filters

Description

The Lead-Lag Filter block implements the following transfer function:

$$H(s) = \frac{1 + T_1 s}{1 + T_2 s}$$
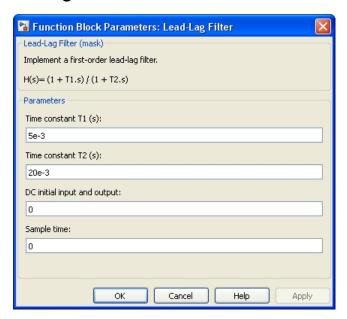
where

s = Laplace operator

T_1, T_2 = time constants

This type of filter is used mainly for implementing lead-lag compensation in control systems. The key characteristics of the Lead-Lag Filter block are:

- Input accepts a vectorized input of N signals, thus implementing N filters. This feature is particularly useful for designing controllers in three-phase systems (N=3).
- The same block is used for continuous or discrete model. Changing the sample time Ts from 0 to a positive value automatically discretizes the filter, and vice versa.
- Filter states can be initialized for specified DC inputs and outputs.

Dialog Box and Parameters

Time constant T1 (s)

Specify the filter time constant(s) T_1 in seconds.

Time constant T2 (s)

Specify the filter time constant(s) T_2 in seconds.

DC initial input and output

Specify the DC initial value of input and output signals. If the input signal is vectorized, specify a 1-by-N vector, where each value corresponds to a particular input.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Characteristics

Direct Feedthrough	Yes

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	Yes, of the parameters
States	One state per filter
Dimensionalized	Yes

Example

The power_LeadLagFilter example shows two uses of a vectorized Lead-Lag Filter.
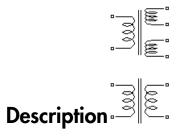
The model sample time is parameterized with variable Ts (default value Ts = 50e-6). To simulate continuous filters, specify Ts = 0 in the MATLAB Command Window before simulating the model.

Linear Transformer
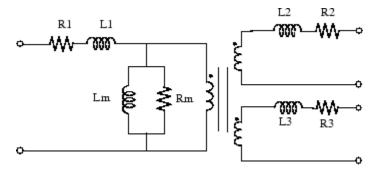
Implement two- or three-winding linear transformer

Library

Fundamental Blocks/Elements

Description

The Linear Transformer block model shown consists of three coupled windings wound on the same core.

The model takes into account the winding resistances (R1 R2 R3) and the leakage inductances (L1 L2 L3), as well as the magnetizing characteristics of the core, which is modeled by a linear (Rm Lm) branch.

The Per Unit Conversion

In order to comply with industry, the block allows you to specify the resistance and inductance of the windings in per unit (pu). The values are based on the transformer

rated power Pn, in VA, nominal frequency fn, in Hz, and nominal voltage Vn, in Vrms, of the corresponding winding. For each winding, the per unit resistance and inductance are defined as

$$R(pu) = \frac{R(\Omega)}{R_{base}}$$

$$L(pu) = \frac{L(H)}{L_{base}}$$

The base impedance, base resistance, base reactance, and base inductance used for each winding are

$$Z_{base} = R_{base} = X_{base} = \frac{(Vn)^2}{Pn}$$

$$L_{base} = \frac{X_{base}}{2\pi fn}$$

For the magnetization resistance Rm and inductance Lm, the pu values are based on the transformer rated power and on the nominal voltage of winding 1.

For example, the default parameters of winding 1 specified in the dialog box section give the following bases:

$$R_{base} = \frac{(735e3)^2}{250e6} = 2161\Omega$$

$$L_{base} = \frac{2161}{2\pi 60} = 5.732H$$

Suppose that the winding 1 parameters are R1 = 4.32 Ω and L1 = 0.4586 H; the corresponding values to be entered in the dialog box are

$$R_1 = \frac{4.32\Omega}{2161\Omega} = 0.002pu$$
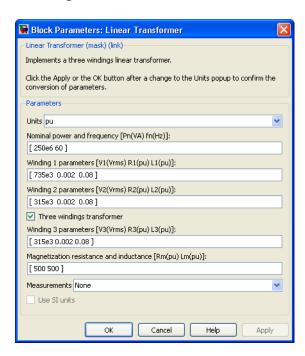
$$L_1 = \frac{0.4586H}{5.732H} = 0.08\,pu$$

To specify a magnetizing current of 0.2% (resistive and inductive) based on nominal current, you must enter per unit values of $1/0.002 = 500$ pu for the resistance and the inductance of the magnetizing branch. Using the base values calculated previously, these per unit values correspond to $Rm = 1.08e6$ ohms and $Lm = 2866$ henries.

Modeling an Ideal Transformer

To implement an ideal transformer model, set the winding resistances and inductances to 0, and the magnetization resistance and inductance (Rm Lm) to `inf`.

Dialog Box and Parameters

Units

Specify the units used to enter the parameters of the Linear Transformer block. Select pu to use per unit. Select SI to use SI units. Changing the **Units** parameter from pu to SI, or from SI to pu, will automatically convert the parameters displayed in the mask of the block. The per unit conversion is based on the transformer rated power Pn in VA, nominal frequency fn in Hz, and nominal voltage Vn, in Vrms, of the windings.

Nominal power and frequency

The nominal power rating Pn in volt-amperes (VA) and frequency fn, in hertz (Hz), of the transformer. Note that the nominal parameters have no impact on the transformer model when the **Units** parameter is set to SI.

Winding 1 parameters

The nominal voltage V, in volts RMS, resistance, in pu or ohms, and leakage inductance, in pu or henries. The pu values are based on the nominal power Pn and on V1. Set the winding resistances and inductances to 0 to implement an ideal winding.

Winding 2 parameters

The nominal voltage V2 in volts RMS, resistance, in pu or ohms, and leakage inductance, in pu or henries. The pu values are based on the nominal power Pn and on V2. Set the winding resistances and inductances to 0 to implement an ideal winding.

Three windings transformer

If selected, implements a linear transformer with three windings; otherwise, it implements a two-windings transformer.

Winding 3 parameters

The **Winding 3 parameters** parameter is not available if the **Three windings transformer** parameter is not selected.

The nominal voltage in volts RMS (Vrms), resistance, in pu or ohms, and leakage inductance in pu or henries. The pu values are based on the nominal power Pn and on V3. Set the winding resistances and inductances to 0 to implement an ideal winding.

Magnetization resistance and inductance

The resistance and inductance simulating the core active and reactive losses. When selected, the pu values are based on the nominal power Pn and on V1. For example, to specify 0.2% of active and reactive core losses, at nominal voltage, use Rm = 500 pu and Lm = 500 pu.

Rm must have a finite value when the inductance of winding 1 is greater that zero.

Measurements

Select `Winding voltages` to measure the voltage across the winding terminals of the Linear Transformer block.

Select `Winding currents` to measure the current flowing through the windings of the Linear Transformer block.

Select `Magnetization current` to measure the magnetization current of the Linear Transformer block.

Select `All voltages and currents` to measure the winding voltages and currents plus the magnetization current.

Place a Multimeter block in your model to display the selected measurements during the simulation.

In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

Measurement	Label
Winding voltages	`Uw1:, Uw2:, Uw3:`
Winding currents	`Iw1:, Iw2:, Iw3:`
Magnetization current	`Imag:`

Limitations

Windings can be left floating (that is, not connected to the rest of the circuit). However, an internal resistor is automatically added between the floating winding and the main circuit. This internal connection does not affect voltage and current measurements.
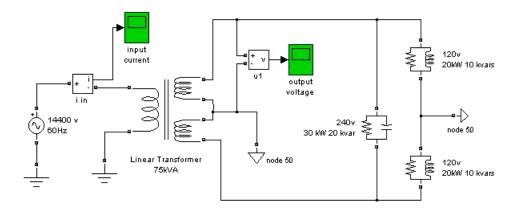
Due to limitations inherent to graph theory and its application to electric network theory as implemented in SimPowerSystems software, the following topologies are unsolvable:

- Loops containing only ideal transformer secondary windings (for example, delta-connected ideal secondary windings of three-phase transformer). To solve this topology issue, you can add a small impedance in series with the loop.

- Loops containing only ideal transformer secondary windings and ideal voltage sources. To solve this topology issue, you can add a small impedance in series with the loop.

- Loops containing only ideal transformer secondary windings and capacitors. To solve this topology issue, you can add a small impedance in series with the loop.

- All topologies where an ideal transformer primary has at least one of its nodes that is connected to elements consisting only of ideal transformer primary windings or current sources (for example, wye-connected three-phase primary windings with floating common point). To resolve this circuit topology, you connect a small resistance to problematic node.

Example

The power_transformer example shows a typical residential distribution transformer network feeding line-to-neutral and line-to-line loads.

See Also

Mutual Inductance, Saturable Transformer, Three-Phase Transformer (Two Windings), Three-Phase Transformer (Three Windings)

Load Flow Bus

Identify and parameterize load flow bus

Library

Measurements

Description

You use the Load Flow Bus block in models to specify the bus locations and parameters to solve a load flow. The Powergui Load Flow tool solves the load flow. SimPowerSystems allows you to perform two types of load flows:

- Positive-sequence load flow applied to a three-phase system. Positive-sequence voltages as well as active power (P) and reactive power (Q) flows are computed at each three-phase bus.

- Unbalanced load flow applied to a mix of three-phase, two-phase, and single-phase systems. Individual phase voltage and PQ flow are computed for each phase.

To perform a positive-sequence load flow, you must define all of the Load Flow Bus blocks in your model with the **Connectors** parameter set to single. For this type of load flow, the load flow blocks are:

- Asynchronous Machine
- Simplified Synchronous Machine
- Synchronous Machine
- Three-Phase Dynamic Load
- Three-Phase Parallel RLC Load
- Three-Phase Programmable Voltage Source

- Three-Phase Series RLC Load
- Three-Phase Source

To perform an unbalanced load flow, you must define all of the Load Flow Bus blocks in your model with the **Connectors** parameter set to one of the following values: ABC, AB, AC, BC, A, B, or C. For an unbalanced load flow, the load flow blocks are:

- AC Voltage Source
- Asynchronous Machine
- Parallel RLC Load
- Series RLC Load
- Synchronous Machine
- Three-Phase Dynamic Load
- Three-Phase Parallel RLC Load
- Three-Phase Series RLC Load
- Three-Phase Source

The Powergui Load Flow tool reports an error if a model contains a mix of Load Flow Bus blocks set to perform a positive-sequence load flow and Load Flow Bus blocks set to perform an unbalanced load flow.

When several load flow blocks are connected together at the same bus, only one Load Flow Bus block is required. You can also connect the Load Flow Bus block at a location where you are interested in monitoring the load flow, even if no load flow blocks are connected at that location.

Implicit Buses (for Positive-Sequence Load Flow Only)

If you omit to connect a Load Flow Bus block to a load flow block, the Load Flow tool will automatically define an implicit (internal) load flow bus for that block. The bus base voltage of this implicit bus is set to the same value as the nominal voltage of the load flow block. When several load flow blocks are connected together, one nominal voltage is arbitrarily selected among the blocks.

Although the Load Flow tool can perform load flow on a model with no Load Flow Bus block in the model (working only with implicit buses), the recommended practice is to connect a Load Flow Bus block everywhere a load flow block exists.
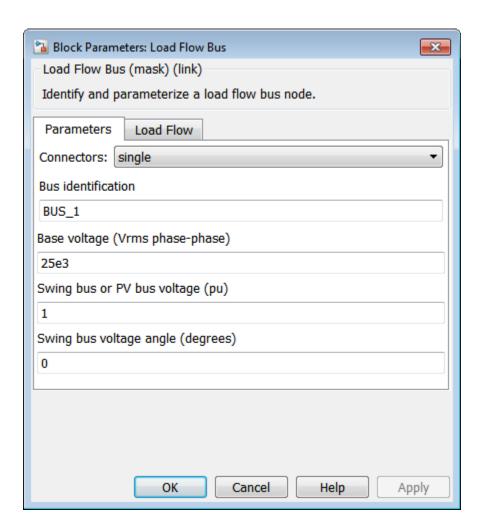
Dialog Box and Parameters

The Load Flow Bus parameters are used for model initialization only. They have no impact on the simulation performance.

The block dialog box contains two tabs:
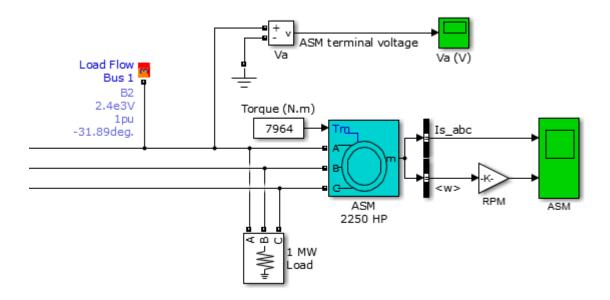
Parameters Tab

Connectors

> When you perform a positive-sequence load flow, you connect a Load Flow Bus block with the **Connectors** parameter specified as single to any phase (A, B, or C) of every load flow block in the model. The icon of the block displays the number 3, indicating that the block is defined to perform a positive-sequence load flow.
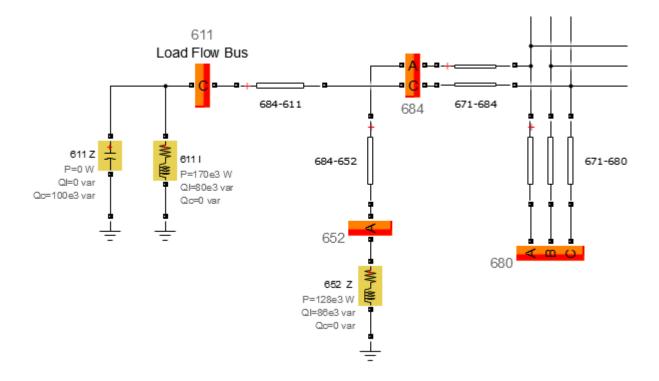
When you perform an unbalanced load flow, you connect a Load Flow Bus block to all phases of every load flow block in the model. Depending on the number of phases, you need to specify the appropriate Connectors parameter by selecting one of these connector combinations:

- Three connectors: ABC
- Two connectors: AB, AC, or BC
- A single connector : A, B, or C
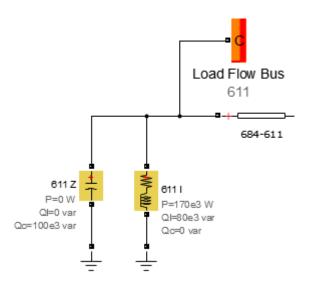
The figure shows examples of Load Flow Bus blocks set to define different phases of a given model, to perform an unbalanced load flow.
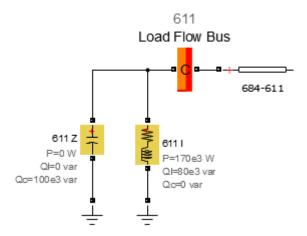
Configuration

When the **Configuration** parameter is set to `on one side`, the block displays the block phase ports only on one side of the block. You can connect the Load Flow Bus block anywhere in the model to identify a connection line as a load flow bus:

When the **Configuration** parameter is set to on both sides, the block displays the block phase ports on both sides of the block. You can connect the Load Flow Bus block in series with other SimPowerSystems blocks to identify a connection line as a load flow bus.

Both options perform the same action, and you can seamlessly use either method to connect the Load Flow Bus blocks.

Bus Identification

Enter a meaningful alphanumeric string. The **Bus Identification** string appears below the block as a block annotation.

Base voltage (Vrms phase-phase)

The base voltage is usually the same as the nominal voltage of the load flow blocks connected to the Load Flow Bus block. The **Base voltage** values appears below the block as a block annotation. This parameter is visible only when the **Connectors** parameter is set to `single`.

Swing bus or PV bus voltage (pu)

Specify the required bus voltage magnitude, in pu. Depending on the bus type of the load flow blocks connected at that bus, this voltage corresponds to the swing bus voltage or the PV bus voltage. This parameter is visible only when the **Connectors** parameter is set to `single`.

Swing bus voltage angle (degrees)

The swing bus voltage angle is used as a reference to compute voltage angles of all other buses in the model. This parameter is visible only when the **Connectors** parameter is set to `single`.

Base voltage (Vrms phase-ground)

The base voltage is usually the same as the nominal voltage of the load flow blocks connected to the Load Flow Bus block. The **Base voltage** values appears below the block as a block annotation. This parameter is visible only when the **Connectors** parameter is not set to `single`.

Swing bus or PV bus voltage, per phase (pu)

Specify the required bus voltage magnitude, in pu, for every phase specified by the **Connectors** parameter. Depending on the bus type of the load flow blocks connected at that bus, this voltage corresponds to the swing bus voltage or the PV bus voltage. This parameter is visible only when the **Connectors** parameter is not set to `single`.

Swing bus voltage angle, per phase (degrees)

Specify the required bus voltage angle, in pu, for every phase specified by the **Connectors** parameter. The swing bus voltage angles are used as a reference to compute voltage angles of all other buses in the model. This parameter is visible only when the **Connectors** parameter is not set to `single`.

Note The bus type (PV, PQ, or swing) is not defined in the mask of the Load Flow Bus block. You can have several machines and voltage source blocks with different generator type parameters connected at the same bus. The Load Flow tool determines the resulting bus type.

Load Flow Tab

Bus voltage section

Phase A

Displays the resulting bus voltage of phase A, in pu, once the load flow is solved. This parameter appears dimmed because it is updated by the Load Flow tool. The parameter value appears below the block as a block annotation.

The value is set to NaN by the Load Flow tool when the load flow solution is not computed for this phase (that is, when the **Connectors** parameter is set to BC, B, or C).

Phase B

Displays the resulting bus voltage of phase B, in pu, once the load flow is solved. This parameter appears dimmed because it is updated by the Load Flow tool. The parameter value appears below the block as a block annotation.

This parameter is visible only when the **Connectors** parameter is not set to single. The value is set to NaN by the Load flow tool when the load flow solution is not computed for this phase (that is, when the **Connectors** parameter is set to AC, A, or C).

Phase C

Displays the resulting bus voltage of phase C, in pu, once the load flow is solved. This parameter appears dimmed because it is updated by the Load Flow tool. The parameter value appears below the block as a block annotation.

This parameter is visible only when the **Connectors** parameter is not set to single. The value is set to NaN by the Load flow tool when the load flow solution is not computed for this phase (that is, when the **Connectors** parameter is set to AB, A, or B).

Bus angle section

Phase A

Displays the resulting bus voltage angle of phase A, in pu, once the load flow is solved. This parameter appears dimmed because it is updated by the Load Flow tool. The parameter value appears below the block as a block annotation.

The value is set to `NaN` by the Load Flow tool when the load flow solution is not computed for this phase (that is, when the **Connectors** parameter is set to `BC`, `B`, or `C`).

Phase B

Displays the resulting bus voltage angle of phase B, in pu, once the load flow is solved. This parameter appears dimmed because it is updated by the Load Flow tool. The parameter value appears below the block as a block annotation.

This parameter is visible only when the **Connectors** parameter is not set to `single`. The value is set to `NaN` by the Load flow tool when the load flow solution is not computed for this phase (that is, when the **Connectors** parameter is set to `AC`, `A`, or `C`).

Phase C

Displays the resulting bus voltage angle of phase C, in pu, once the load flow is solved. This parameter appears dimmed because it is updated by the Load Flow tool. The parameter value appears below the block as a block annotation.

This parameter is visible only when the **Connectors** parameter is not set to `single`. The value is set to `NaN` by the Load flow tool when the load flow solution is not computed for this phase (that is, when the **Connectors** parameter is set to `AB`, `A`, or `B`).

Examples

The power_turbine example contains two Load Flow Bus blocks. The B1 block is connected to the 5 MW Three-Phase Parallel RLC Load and to the Synchronous Machine load flow blocks. The B2 block is connected to the 10 MW Three-Phase Parallel RLC Load and to the Three-Phase Source load flow blocks.

The two blocks display the bus voltages and angles resulting from a load flow solution previously saved with the model. The bus voltage at bus B1 displays `1 pu, -23.67 deg`. Start the simulation, verify it starts in steady state, then zoom on the initial value of the measured voltage Va. You should read an initial voltage of about -0.4015 pu. At the MATLAB command prompt, compute the angle of the measured voltage:

```
asin(-0.4015)*180/pi

ans =
     -23.672
```

You can also take a look at the power_LFnetwork_5bus model. In this model five Load Flow Bus blocks are used. The block labeled B120 is the swing bus.

The power_13NodeTestFeeder example contains Load Flow Bus blocks set to perform an unbalanced load flow for a 13-node test feeder IEEE benchmark model.

See Also

power_loadflow

Machine Measurement Demux

Split measurement signal of machine models into separate signals

Library

Fundamental Blocks/Machines

Description

Note This block is now obsolete. We strongly recommend to use the Bus Selector block from Simulink library to demux the measurement signals of the machine blocks.

Mean

Compute mean value of signal

Library

Control and Measurements/Measurements

Description
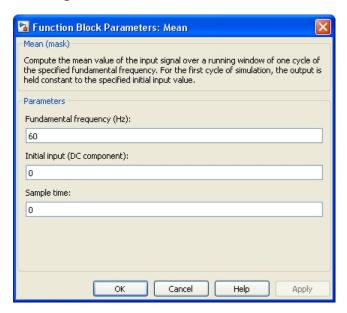
The Mean block computes the mean value of the input signal. The mean value is computed over a running average window of one cycle of the specified fundamental frequency:

$$Mean(f(t)) = \frac{1}{T} \int_{(t-T)}^{t} f(t) \cdot dt$$

$f(t)$: input signal, T = 1/fundamental frequency

As this block uses a running average window, one cycle of simulation must complete before the output gives the correct value. For the first cycle of simulation, the output is held constant to the specified initial input value.

Dialog Box and Parameters

Fundamental frequency (Hz)

Specify the fundamental frequency, in hertz. This value determines the period (1/*F*) of the running average window.

Initial input (DC component)

Specify the input value for the first cycle of simulation.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	Yes, of the parameters
Dimensionalized	Yes

Example

The power_Mean model uses the Mean block to determine the mean value of a DC signal containing a 12th harmonic ripple.

The model sample time is parameterized by the Ts variable set to a default value of 50e-6 s. Set Ts to 0 in the command window to simulate the model in continuous mode.

Mean (Phasor)

Compute mean value of input phasor over a running window of one cycle of specified frequency

Library

Control and Measurements/Measurements

Description
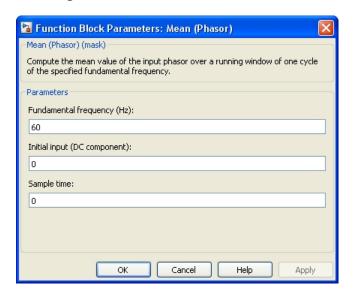
The Mean (Phasor) block filters an AC sinusoidal component that is added to the DC component of a phasor signal. Filtering is performed by computing the average values of real and imaginary parts of the input phasor, using a running window of one cycle of the specified fundamental frequency.

Dialog Box and Parameters

Fundamental frequency (Hz)

Specify the fundamental frequency, in hertz, to determine the period ($1/F$) of the running average window.

Initial input (DC component)

Specify the initial DC component of the input signal. If the input is a vectorized signal, specify a 1-by-N vector, where each value corresponds to a particular input.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Characteristics

Direct Feedthrough	Yes
Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	Yes, of the parameters

States	Two states per filter
Dimensionalized	Yes

Example

The power_PhasorMeasurements example shows the use of the Mean (Phasor) block.

Mean (Variable Frequency)

Compute mean value of signal

Library

Control and Measurements/Measurements

Description
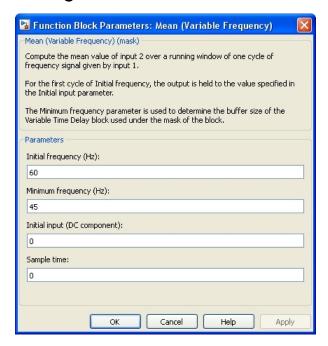
The Mean (Variable Frequency) block computes the mean value of the signal connected to the second input of the block. The mean value is computed over a running average window of one cycle of the frequency of the signal:

$$Mean(f(t)) = \frac{1}{T} \int_{(t-T)}^{t} f(t) \cdot dt$$

$f(t)$: input signal, T = 1/ frequency

This block uses a running average window. Therefore, one cycle of simulation must complete before the block outputs the computed mean value. For the first cycle of simulation, the output is held constant to the specified initial value.

Dialog Box and Parameters

Initial frequency (Hz)

Specify the frequency of the first cycle of simulation.

Minimum frequency (Hz)

The minimum frequency value determines the buffer size of the Variable Time Delay block used inside the block to compute the mean value.

Initial input (DC component)

Specify the initial value of the input during the first cycle of simulation.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Inputs and Outputs

Freq

The frequency of the signal.

`In`

Connects to the signal to be analyzed.

`X`

The mean value of the signal.

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	Yes, of the parameters
Dimensionalized	Yes

Example

The power_MeanVariableFrequency model compares the Mean block to the Mean (Variable Frequency) block for three identical input signals. It shows that, even if the frequency of the input signals varies during the simulation, the Mean (Variable Frequency) block outputs correct values.
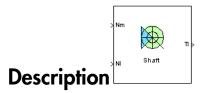
The model sample time is parameterized by the Ts variable with a default value of 50e-6 s. Set Ts to 0 in the command window to simulate the model in continuous mode.

Mechanical Shaft

Implement mechanical shaft

Library

Electric Drives/Shafts and Speed Reducers

Description
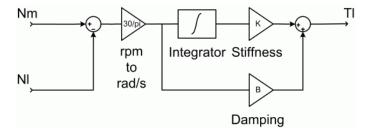
The model outputs the transmitted torque through the shaft regarding the speed difference between the driving side and the loaded side of the shaft.

The transmitted torque T_l is given by the following equation:

$$T_l = K \int (\omega_m - \omega_l)\, dt + B(\omega_m - \omega_l),$$

where K (N.m) is the shaft stiffness, B (N.m.s) is the internal damping, and ω_m and ω_l are the speeds (rad/s) of the driving side and the loaded side, respectively. The following figure shows the internal schematic of the model. In this model the speeds are converted from rpm to rad/s.

Mechanical Shaft Model Schematic

The stiffness is defined as
$K = T / \theta$,

where T is the torsional torque applied to the shaft and θ the resulting angular deflection (rad).

The stiffness can also be determined by
$K = GJ / l$,

where G is the shear modulus, J the polar moment of inertia, and l the length of the shaft.

For steel, the shear modulus G is usually equal to about 80 GPa, and the polar moment of inertia J of a shaft with a circular section of diameter D is given by
$J = \pi D^4 / 32$.

Mechanical shafts have very small angular deflections to avoid bearing problems. As an example, the following table gives the corresponding stiffness for angular deflections of 0.1 degrees at maximum torque with respect to the power and speed of electrical motors connected to the driving end of the shaft. The maximum torque is here assumed to be 1.5 times bigger than the nominal torque.

Shaft Stiffness K
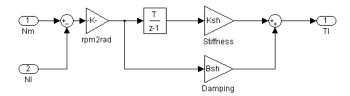
P (HP)	N (rpm)	T (N.m)	Tmax (N.m) (=1.5 T)	K (N.m)
5	1750	20	30	17190
200	1750	815	1223	700730
200	1200	1190	1785	1022730

The damping factor B represents internal friction. This factor increases with the shaft stiffness. As an example, the following table gives some values of B for the stiffness of the preceding table.

Shaft Internal Damping B

K (N.m)	B (N.m.s)
17190	600
700730	24460
1022730	35700

Simulink Schematic
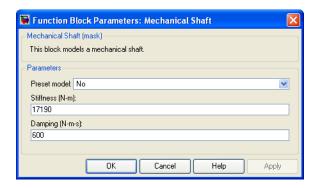
Remarks

The stiffness must be high enough to avoid large angular deflections that could cause misalignment inside the bearings and damage.

For proper simulation results, the internal damping must be high enough to avoid undesired transient speed and torque oscillations.

The model is discrete. Good simulation results have been obtained with a 10 μs time step.

Dialog Box

Preset Model

This pop-up menu allows you to choose preset model parameters.

Stiffness

The stiffness of the shaft (N.m).

Damping

The internal damping of the shaft (N.m.s).

Block Inputs and Outputs

Inputs

The block has two inputs: Nm and Nl.

The first input, Nm, is the speed (rpm) of the driving end of the shaft.

The second input, Nl, is the speed (rpm) of the load connected to the second end of the shaft.

Outputs

The block has one output: Tl.

The Tl output is the torque transmitted from the driving end of the shaft to the load.

Model Specifications

The library contains three preset models. The nominal torques of these mechanical shaft models are shown in the following table:
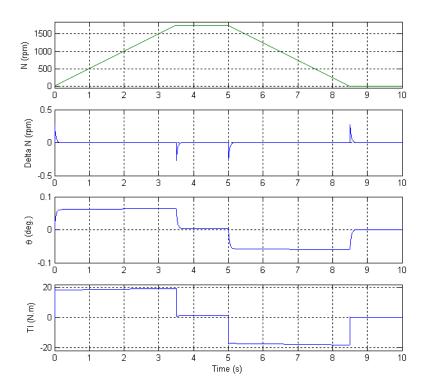
Preset Mechanical Shaft Models
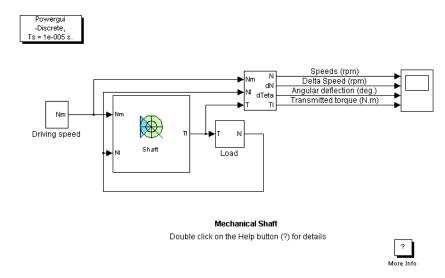
	1st	2nd	3rd
Nominal torque (N.m)	20	815	1190

The preset models have been designed in order to present 0.1 degrees of angular deflection at maximum torque (supposed to be 1.5 times the nominal torque).

Example

The `shaft_example` example illustrates the mechanical shaft model.

Mechanical Shaft
Double click on the Help button (?) for details

The shaft is driven by a variable speed source and is connected to a load. The load has an inertia of 0.35 kg.m2 and a viscous friction term of 0.006 N.m.s.

The shaft has a stiffness of 17190 N.m and an internal damping factor of 600 N.m.s. This shaft is designed to have 0.1 degree of angular deflection for a 30 N.m load torque.

At t = 0 s, the driving speed starts climbing to 1750 rpm with a 500 rpm/s acceleration ramp. The angular deflection jumps to about 0.06 degree and the shaft transmits about 18.5 N.m to the load in order to accelerate it. At t = 0.2 s, the driving and load speeds tend to equalize. During the acceleration phase, the angular deflection increases slowly in order to transmit a higher torque to compensate the viscous friction increase.

At t = 3.5 s, the driving speed settles at 1750 rpm. This reduces the angular deflection and also the transmitted torque, which settles around 1.1 N.m to compensate the viscous friction of the load.

At t = 5 s, the driving speed lowers towards 0 rpm with a −500 rpm/s deceleration ramp. The angular deflection becomes negative and thus the transmitted torque in order to decelerate the load. During the deceleration phase, the angular deflection increases in order to transmit a higher deceleration torque to compensate the reduction of viscous friction.

At t = 8.5 s, the driving speed stabilizes at 0 rpm. This causes the angular deflection to decrease to 0 degree, the transmitted torque becomes null, and the load stops.

The following figure shows the speeds of the driving and loaded sides, the speed difference between both sides, the angular deflection, and the transmitted torque.

References

[1] Norton, Robert L., *Machine Design.* , Prentice Hall, 1998.

[2] Nise, Norman S., *Control Systems Engineering.* , Addison-Wesley Publishing Company, 1995.

Monostable

Implement monostable flip-flop (one-shot multivibrator)

Library

Control and Measurements/Logic

Description
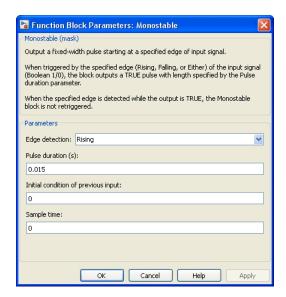
The Monostable block outputs a true pulse when a change in the logical input is detected.

The Monostable block can be programmed to detect a rising edge (when the input goes from false to true), a falling edge (when the input goes from true to false), or either edge (any change in input is detected). The Monostable block ignores any edge occurring when the pulse is true.

Dialog Box and Parameters

Edge detection

Select the detection criteria triggering the output pulse.

Pulse duration (s)

Specify the duration of the output true state. When the **Sample time** parameter is greater than 0, the **Pulse duration** value must be a multiple of the sample time.

Initial condition of previous input

Specify the initial value of the previous input (0 or 1). The Monostable block can detect an edge at t = 0 if the input is different from the specified value.

Sample time

Specify the sample time of the block, in seconds. Set to **0** to implement a continuous block.

Inputs and Outputs

The input signal must be a Boolean signal. The output is Boolean.

Characteristics

Direct Feedthrough	Yes
Sample Time	Specified in the **Sample Time** parameter
Scalar Expansion	Yes, of parameters
Dimensionalized	Yes
Zero-Crossing Detection	Yes (in continuous-time domain)

Example

The power_Logic example shows the operation of the monostable flip-flop.

The model sample time is parameterized with the variable Ts (default value Ts = 5e-3). To simulate a continuous Monostable block, specify Ts = 0 in the MATLAB Command Window.

MOSFET
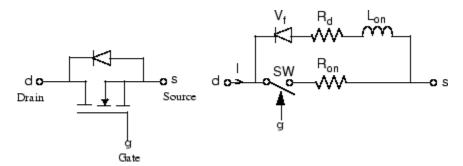
Implement MOSFET model

Library

Fundamental Blocks/Power Electronics

Description

The metal-oxide semiconductor field-effect transistor (MOSFET) is a semiconductor device controllable by the gate signal (g > 0). The MOSFET device is connected in parallel with an internal diode that turns on when the MOSFET device is reverse biased (Vds < 0) and no gate signal is applied (g=0). The model is simulated by an ideal switch controlled by a logical signal (g > 0 or g = 0), with a diode connected in parallel.

The MOSFET device turns on when a positive signal is applied at the gate input (g > 0) whether the drain-source voltage is positive or negative. If no signal is applied at the gate input (g=0), only the internal diode conducts when voltage exceeds its forward voltage Vf.

With a positive or negative current flowing through the device, the MOSFET turns off when the gate input becomes 0. If the current I is negative and flowing in the internal diode (no gate signal or g = 0), the switch turns off when the current I becomes 0.
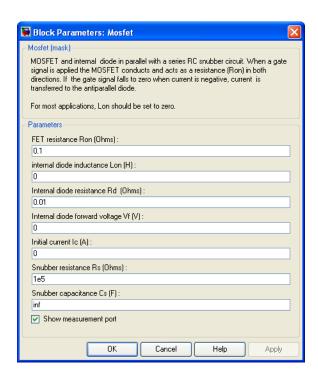
The on state voltage Vds varies

- Vds = Ron*I when a positive signal is applied at the gate input.
- Vds = Rd*I-Vf +Lon*dI/dt when the antiparallel diode is conducting (no gate signal).

The Lon diode inductance is available only with the continuous model. For most applications, Lon should be set to zero for both continuous and discrete models.

The MOSFET block also contains a series Rs-Cs snubber circuit that can be connected in parallel with the MOSFET (between nodes d and s).

Dialog Box and Parameters

FET Resistance Ron

The internal resistance Ron, in ohms (Ω). The **Resistance Ron** parameter cannot be set to **0** when the **Inductance Lon** parameter is set to 0.

Internal diode inductance Lon

The internal inductance Lon, in henries (H). The **Inductance Lon** parameter is normally set to 0 except when the **Resistance Ron** parameter is set to 0.

Internal diode resistance Rd

The internal resistance of the internal diode, in ohms (Ω).

Internal diode forward voltage Vf

The forward voltage of the internal diode, in volts (V).

Initial current Ic

You can specify an initial current flowing in the MOSFET device. It is usually set to 0 in order to start the simulation with the device blocked.

If the **Initial current IC** parameter is set to a value greater than 0, the steady-state calculation considers the initial status of the MOSFET as closed. Initializing all states of a power electronic converter is a complex task. Therefore, this option is useful only with simple circuits.

Snubber resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to inf to eliminate the snubber from the model.

Snubber capacitance Cs

The snubber capacitance, in farads (F). Set the **Snubber capacitance Cs** parameter to 0 to eliminate the snubber, or to inf to get a resistive snubber.

Show measurement port

If selected, add a Simulink output to the block returning the MOSFET current and voltage.

Inputs and Outputs

g

Simulink signal to control the opening and closing of the MOSFET.

m

The Simulink output of the block is a vector containing 2 signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Signal	Definition	Units
1	MOSFET current	A
2	MOSFET voltage	V

Assumptions and Limitations

The MOSFET block implements a macro model of the real MOSFET device. It does not take into account either the geometry of the device or the complex physical processes [1].

Depending on the value of the inductance Lon, the MOSFET is modeled either as a current source (Lon > 0) or as a variable topology circuit (Lon = 0). The MOSFET block cannot be connected in series with an inductor, a current source, or an open circuit, unless its snubber circuit is in use.
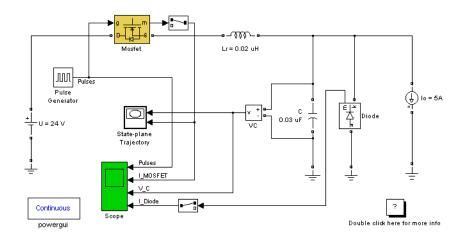
Use the Powergui block to specify either continuous simulation or discretization of your electrical circuit containing MOSFET blocks. When using a continuous model, the ode23tb solver with a relative tolerance of 1e-4 is recommended for best accuracy and simulation speed.

The inductance Lon is forced to 0 if you choose to discretize your circuit.
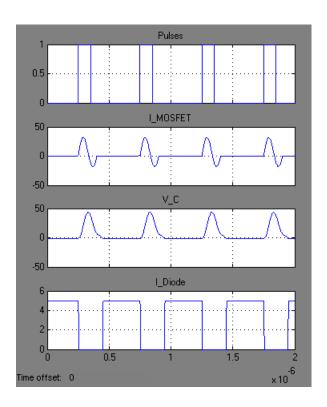
Example

The power_mosconv example illustrates the use of the MOSFET block in a zero-current quasi-resonant switch converter. In such a converter, the current produced by the Lr-Cr resonant circuit flows through the MOSFET and internal diode. The negative current flows through the internal diode that turns off at 0 current [1]. The switching frequency is 2 MHz and the pulse width is 72 degrees (duty cycle: 20%).

MOSFET Converter

Run the simulation and observe the gate pulse signal, the MOSFET current, the capacitor voltage, and the diode current on the four-trace Scope block.

References

[1] Mohan, N., T.M. Undeland, and W.P. Robbins, *Power Electronics: Converters, Applications, and Design*, John Wiley & Sons, Inc., New York, 1995.

See Also

Diode, GTO, Ideal Switch, Three-Level Bridge, Thyristor, Universal Bridge

Multiband Power System Stabilizer

Implement multiband power system stabilizer

Library

Fundamental Blocks/Machines

Description

Note This block requires that you have a Control System Toolbox license. Otherwise, trying to simulate a model containing this block produces an error.

The disturbances occurring in a power system induce electromechanical oscillations of the electrical generators. These oscillations, also called power swings, must be effectively damped to maintain the system's stability. Electromechanical oscillations can be classified in four main categories:
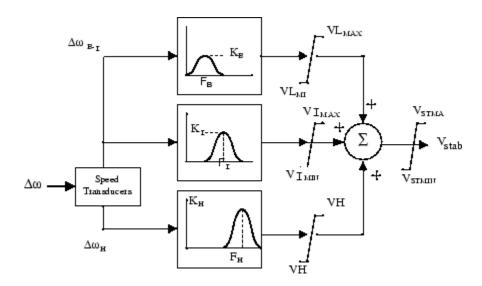
- Local oscillations: between a unit and the rest of the generating station and between the latter and the rest of the power system. Their frequencies typically range from 0.8 to 4.0 Hz.

- Interplant oscillations: between two electrically close generation plants. Frequencies can vary from 1 to 2 Hz.

- Interarea oscillations: between two major groups of generation plants. Frequencies are typically in a range of 0.2 to 0.8 Hz.

- Global oscillation: characterized by a common in-phase oscillation of all generators as found on an isolated system. The frequency of such a global mode is typically under 0.2 Hz.

The need for effective damping of such a wide range, almost two decades, of electromechanical oscillations motivated the concept of the multiband power system stabilizer (MB-PSS).
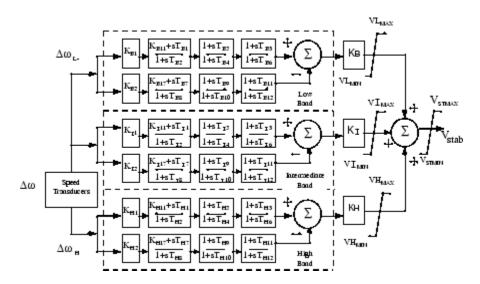
As its name reveals, the MB-PSS structure is based on multiple working bands. Three separate bands are used, respectively dedicated to the low-, intermediate-, and high-frequency modes of oscillations: the low band is typically associated with the power system global mode, the intermediate with the interarea modes, and the high with the local modes.

Each of the three bands is made of a differential bandpass filter, a gain, and a limiter (see the figure called Conceptual Representation). The outputs of the three bands are summed and passed through a final limiter producing the stabilizer output V_{stab}. This signal then modulates the set point of the generator voltage regulator so as to improve the damping of the electromechanical oscillations.

To ensure robust damping, the MB-PSS should include a moderate phase advance at all frequencies of interest to compensate for the inherent lag between the field excitation and the electrical torque induced by the MB-PSS action.

Conceptual Representation

Internal Specifications

The MB-PSS is represented by the IEEE St. 421.5 PSS 4B type model [2], illustrated in the figure called Internal Specifications, with built-in speed transducers whose parameters are fixed according to manufacturer's specifications.

Generally, only a few of the lead-lag blocks in this figure should be used in a given PSS application. Two different approaches are available to configure the settings in order to facilitate the tuning process:

1 Simplified settings:

   Only the first lead-lag block of each frequency band is used to tune the Multiband Power System Stabilizer block. The differential filters are assumed to be symmetrical bandpass filters respectively tuned at the center frequency F_L, F_I, and F_H. The peak magnitude of the frequency responses (see the figure called Conceptual Representation) can be adjusted independently through the three gains K_L, K_I, and K_H. Only six parameters are therefore required for a simplified tuning of the MB-PSS.
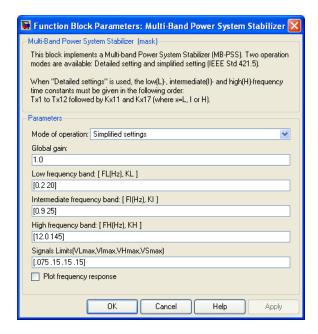
2 Detailed settings:

   The designer is free to use all the flexibility built into the MB-PSS structure to achieve nontrivial controller schemes and to tackle even the most constrained

problem (for example, multi unit plant including an intermachine mode, in addition to a local mode and multiple interarea modes). In this case, all the time constants and gains appearing in the figure called Internal Specifications have to be specified in the dialog box.

Dialog Box and Parameters

Simplified Settings Mode

Global gain

The overall gain K of the multiband power system stabilizer.

Low frequency band: [FL KL]

The center frequency, in hertz, and peak gain of the low-frequency bandpass filter.

Intermediate frequency band: [FI KI]

The center frequency, in hertz, and peak gain of the intermediate- frequency bandpass filter.

High frequency band: [FH KH]

The center frequency, in hertz, and peak gain of the high-frequency bandpass filter.
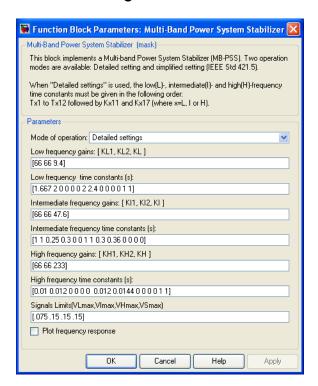
Signal limits [VLmax VImax VHmax VSmax]

The limits imposed on the output of the low-, intermediate-, and high-frequency bands and the limit VSmax imposed on the output of the stabilizer, all in pu.

Plot frequency response

If selected, a plot of the frequency response of the stabilizer is displayed when you click the **Apply** button.

Detailed Settings Mode

Low frequency gains: [KL1 KL2 KL]

The gains of the positive and negative branches of the differential filter in the low-frequency band and the overall gain K_L of the low-frequency band, in pu.

Low frequency time constants

The time constants, in seconds, of the lead-lag blocks in the positive and negative branches of the low-frequency filter. You need to specify the following twelve time constants and two gains:

$[T_{B1} \; T_{B2} \; T_{B3} \; T_{B4} \; T_{B5} \; T_{B6} \; T_{B7} \; T_{B8} \; T_{B9} \; T_{B10} \; T_{B11} \; T_{B12} \; K_{B11} \; K_{B17}]$

Set K_{B11} to 0 in order to make the first block of the positive filter branch a washout block. Set K_{B11} to 1 in order to make the block a lead-lag block.

Set K_{B17} to 0 in order to make the first block of the negative filter branch a washout block. Set K_{B17} to 1 in order to make the block a lead-lag block.

Intermediate frequency gains: [KI1 KI2 KI]

The gains of the positive and negative branches of the differential filter in the intermediate-frequency band and the overall gain K_I of the intermediate-frequency band, in pu.

Intermediate frequency time constants

The time constants, in seconds, of the lead-lag blocks in the positive and negative branches of the intermediate-frequency filter. You need to specify the following twelve time constants and two gains:

$[T_{I1} \; T_{I2} \; T_{I3} \; T_{I4} \; T_{I5} \; T_{I6} \; T_{I7} \; T_{I8} \; T_{I9} \; T_{I10} \; T_{I11} \; T_{I12} \; K_{I11} \; K_{I17}]$

Set K_{I11} to 0 in order to make the first block of the positive filter branch a washout block. Set K_{I11} to 1 in order to make the block a lead-lag block.

Set K_{I17} to 0 in order to make the first block of the negative filter branch a washout block. Set K_{I17} to 1 in order to make the block a lead-lag block.

High frequency gains: [KH1 KH2 KH]

The gains of the positive and negative branches of the differential filter in the high-frequency band and the overall gain K_I of the high-frequency band, in pu.

High frequency time constants

The time constants, in seconds, of the lead-lag blocks in the positive and negative branches of the high-frequency filter. You need to specify the following twelve time constants and two gains:

$[T_{H1} \; T_{H2} \; T_{H3} \; T_{H4} \; T_{H5} \; T_{H6} \; T_{H7} \; T_{H8} \; T_{H9} \; T_{H10} \; T_{H11} \; T_{H12} \; K_{H11} \; K_{H17}]$

Set K_{H11} to 0 in order to make the first block of the positive filter branch a washout block. Set K_{H11} to 1 in order to make the block a lead-lag block.

Set K_{H17} to 0 in order to make the first block of the negative filter branch a washout block. Set K_{H17} to 1 in order to make the block a lead-lag block.

Signal limits [VLmax VImax VHmax VSmax]

The limits imposed on the output of the low-, intermediate-, and high-frequency bands and the limit VSmax imposed on the output of the stabilizer, all in pu.

Plot frequency response

If selected, a plot of the frequency response of the stabilizer is displayed when you click the **Apply** button.

Input and Output

dw

Connect to the first input the synchronous machine speed deviation *dw* signal (in pu).

Vstab

The output is the stabilization voltage, in pu, to connect to the vstab input of the Excitation System block used to control the terminal voltage of the block.

Example

See the help text of the power_PSS example model.

References

[1] Grondin, R., I. Kamwa, L. Soulieres, J. Potvin, and R. Champagne, "An approach to PSS design for transient stability improvement through supplementary damping of the common low frequency," *IEEE Transactions on Power Systems*, 8(3), August 1993, pp. 954-963.

[2] IEEE recommended practice for excitation system models for power system stability studies: *IEEE St. 421.5-2002*(Section 9).

See Also

Generic Power System Stabilizer

Multimeter

Measure voltages and currents specified in dialog boxes of SimPowerSystems blocks

Library

Fundamental Blocks/Measurements

Description

This block measures the voltages and currents specified in the **Measurements** parameter of SimPowerSystems blocks in your model. Choosing voltages or currents through the Multimeter block is equivalent to connecting an internal voltage or current measurement block inside your blocks.
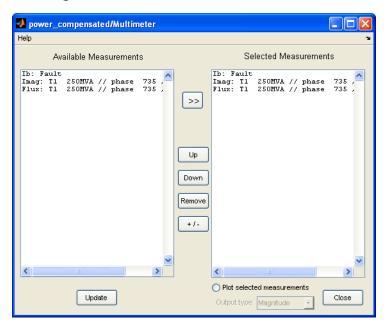
Polarity of Measured Voltages and Currents

The polarity of the measured voltages and current is determined by the + and - terminals of the measured SimPowerSystems blocks. The following table identifies the positive terminals of the SimPowerSystems blocks that do not have the + sign to identify block polarity.

Block	Positive terminal(s)
Mutual Inductance	1 2 3
Three-Phase Mutual Inductance Z1-Z0	ABC
Three-Phase Series RLC Branch	ABC
Three-Phase Parallel RLC Branch	ABC
Three-Phase Breaker	ABC
Breaker	1

For three-phase transformers, the voltage polarities and positive current directions are indicated by the signal labels used in the Multimeter block. For example, Uan_w2 = phase A-to-neutral voltage of the Y connected winding #2 and Iab_w1 = winding current flowing from A to B in the delta-connected winding #1.

Dialog Box and Parameters

Available Measurements

The **Available Measurements** list box shows the measurements in the Multimeter block. Use the **>>** button to select measurements from the **Available Measurements** list box. Click the **Update** button to refresh the list of available measurements.

The measurements in the list box are identified by the name of the block where the measurement is done. The type of measurement (voltage measurement, current measurement, or flux) is defined by a label preceding the block name. For more information, see the Measurements parameter description in the Dialog Box and Parameters section of blocks in your model.

Selected Measurements

The **Selected Measurements** list box shows the measurements sent to the output of the block. You can reorder the measurements by using the **Up**, **Down**, and **Remove** buttons. The **+/–** button allows you to reverse the polarity of any selected measurement.

Plot selected measurements

If selected, displays a plot of selected measurements in a MATLAB figure window. The plot is generated when the simulation stops.

Output type

Specifies the format of the output signals when the block is used in a phasor simulation. The **Output signal** parameter is disabled when the block is not used in a phasor simulation. The phasor simulation is activated by a Powergui block placed in the model.

Set to `Complex` to output the selected measurements as complex values. The outputs are complex signals.
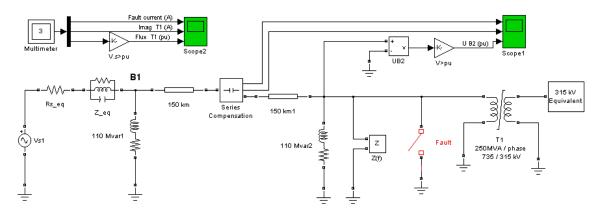
Set to `Real-Imag` to output the real and imaginary parts of the measurements. For each selected measurement, the multimeter outputs the real and imaginary parts.

Set to `Magnitude-Angle` to output the magnitude and angle of the selected measurements. For each selected measurement, the multimeter outputs the magnitude and angle values.

Set to `Magnitude` to output the magnitude of the selected measurements.

Example

The power_compensated example uses a Multimeter block to measure the voltage across the secondary winding of a Saturable Transformer block and the currents flowing through two Series RLC Load blocks.

Drag a Multimeter block into the model. In the dialog box of the 250 MVA block, set the **Measurements** parameter to `All measurements (V,I,flux)`. In the 110 Mvar block, set the parameter to `Branch voltage` and in the 110 Mvar1 block, set it to `Branch voltage and current`.

The output of the Multimeter block is connected to a Scope block in order to display the measurements during the simulation. In addition, you can select the **Plot selected measurements** parameter to display a plot of selected measurements when simulation stops.

Open the Multimeter block dialog box and select the signals you want to observe, as described in the Dialog Box and Parameters section. Notice the labels used to define the available measurements in the Multimeter block. For a description of these labels, see the reference section of the Saturable Transformer block and Series RLC Load block.

Start the simulation. After 0.4 seconds, the simulation stops and a MATLAB figure window opens to display the selected measurements in the Multimeter block.

See Also

Current Measurement, Voltage Measurement

Multi-Winding Transformer

Implement multi-winding transformer with taps

Library

Fundamental Blocks/Elements

Description
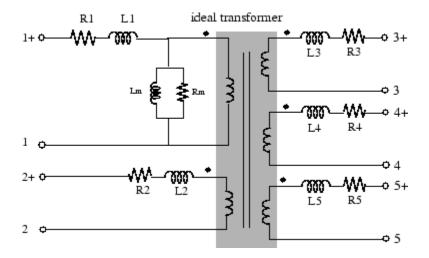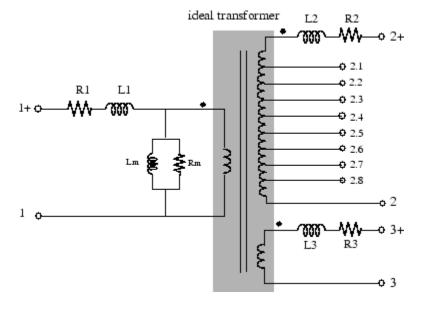
The Multi-Winding Transformer block implements a transformer where the number of windings can be specified for both the primary (left side windings) and the secondary (right side windings).

The equivalent circuit of the Multi-Winding Transformer block is similar to the one of the Linear Transformer block and the saturation characteristic of the core can be specified or not. See the `Saturable Transformer` block reference pages for more details on how the saturation and the hysteresis characteristic are implemented.

The equivalent circuit of a Multi-Windings Transformer block with two primary windings and three secondary windings is shown in the next figure.

You can add equally spaced taps to the first primary winding (the upper-left winding) or to the first secondary winding (the upper-right winding). The equivalent circuit of a Multi-Winding Transformer block with one primary winding and eight taps on the first of the two secondary windings is shown in the next figure.
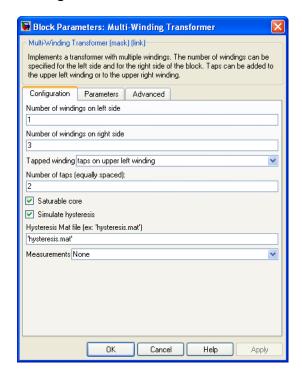
The winding terminals are identified by the corresponding winding number. The first winding is the first one on the primary side (upper-left side) and the last winding is the last one on the secondary side (bottom-right side). The polarity of the windings are defined by a plus sign.

The tap terminals are identified by their winding number followed by a dot character and the tap number. Taps are equally spaced so that voltage appearing at no load between two consecutive taps is equal to the total voltage of the winding divided by (number of taps +1). The total winding resistance and leakage inductance of a tapped winding is equally distributed along the taps.

Dialog Box and Parameters

Configuration Tab

Number of windings on left side

Specifies the number of windings on the primary side (left side) of the transformer.

Number of windings on right side

Specifies the number of windings on the secondary side (right side) of the transformer.

Tapped winding

Select `no taps` if you don't want to add taps to the transformer. Select `taps on upper left winding` to add taps to the first winding on the primary side of the transformer. Select `taps on upper right winding` to add taps to the secondary winding on the right side of the transformer. The number of taps is specified by the **Number of taps (equally spaced)** parameter.

Number of taps (equally spaced)

This parameter is not visible if the **Tapped winding** parameter is set to `no taps`.

If the **Tapped winding** parameter is set to `taps on upper left winding`, you specify the number of taps to add to the first winding on the left side.

If the **Tapped winding** parameter is set to `taps on upper right windings`, you specify the number of taps to add to the first winding on the right side.

Saturable core

If selected, implements a saturable transformer. See also the **Saturation characteristic** parameter on the Parameters tab.

Simulate hysteresis

Select to model hysteresis saturation characteristic instead of a single-valued saturation curve. This parameter is visible only if the **Saturable core** parameter is selected.

Hysteresis Mat file

The **Hysteresis Mat file** parameter is visible only if the **Simulate hysteresis** parameter is selected.

Specify a `.mat` file containing the data to be used for the hysteresis model. When you open the **Hysteresis Design Tool** of the Powergui, the default hysteresis loop and parameters saved in the `hysteresis.mat` file are displayed. Use the **Load** button of the Hysteresis Design tool to load another `.mat` file. Use the **Save** button of the Hysteresis Design tool to save your model in a new `.mat` file.

Measurements

Select `Winding voltages` to measure the voltage across the winding terminals of the Saturable Transformer block.

Select `Winding currents` to measure the current flowing through the windings of the Saturable Transformer block.

Select `Flux and excitation current (Im + IRm)` to measure the flux linkage, in volt seconds (V.s), and the total excitation current including iron losses modeled by Rm.

Select `Flux and magnetization current (Im)` to measure the flux linkage, in volt seconds (V.s), and the magnetization current, in amperes (A), not including iron losses modeled by Rm.

Select `All measurement (V, I, Flux)` to measure the winding voltages, currents, magnetization currents, and the flux linkage.

Place a Multimeter block in your model to display the selected measurements during the simulation.

In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

Measurement	Label
Winding voltages	`U_LeftWinding_1:`, `U_TapWinding_2.1:`, `U_RightWinding_1:`, etc.
Winding currents	`I_LeftWinding_1:`, `I_TapWinding_2.1:`, `I_RightWinding_1:`, etc.
Excitation current	`Iexc:`
Magnetization current	`Imag:`
Flux linkage	`Flux:`

Parameters Tab

Units

Specify the units used to enter the parameters of the Multi-Winding Transformer block. Select pu to use per unit. Select SI to use SI units. Changing the **Units** parameter from pu to SI, or from SI to pu, will automatically convert the parameters displayed in the mask of the block. The per unit conversion is based on the transformer rated power Pn in VA, nominal frequency fn in Hz, and nominal voltage Vn, in Vrms, of the windings.

Nominal power and frequency

The nominal power rating, in volt-amperes (VA), and nominal frequency, in hertz (Hz), of the transformer. Note that the nominal parameters have no impact on the transformer model when the **Units** parameter is set to SI.

Winding nominal voltages

Specify a vector containing the nominal RMS voltages, in Vrms, of the windings on the left side, followed by the nominal RMS voltages of the windings on the right side. You don't have to specify the individual tap nominal voltages.

Winding resistances

Specify a vector containing the resistance values of the windings on the left side, followed by the resistance values of the windings on the right side. You don't have to specify the individual tap resistances.

Winding leakage inductances

Specify a vector containing the leakage inductance values of the windings on the left side, followed by the leakage inductance values of windings on the right side. You don't have to specify the individual tap leakage inductances.

Magnetization resistance Rm

The magnetization resistance Rm, in ohms or in pu.

Magnetization inductance Lm

The **Magnetization inductance Lm** parameter is not accessible if the **Saturable core** parameter on the Configuration tab is selected.

The magnetization inductance Lm, in Henry or in pu, for a nonsaturable core.

Saturation characteristic

This parameter is accessible only if the **Saturable core** parameter on the Configuration tab is selected.

The saturation characteristic for the saturable core. Specify a series of current/ flux pairs (in pu) starting with the pair (0,0).

Advanced Tab

Break Algebraic loop in discrete saturation model

> When you use the block in a discrete system, you will get an algebraic loop. This algebraic loop, which is required in most cases to get an accurate solution, tends to slow down the simulation. However, to speed up the simulation, in some circumstances, you can disable the algebraic loop by selecting **Break Algebraic loop in discrete saturation model**. You should be aware that disabling the algebraic loop introduces a one-simulation-step time delay in the model. This can cause numerical oscillations if the sample time is too large.

Example

The power_OLTCregtransformer example uses three Multi-Winding Transformer blocks to implement a three-phase On Load Tap Changer (OLTC) transformer. Because of long

simulation times required for illustrating operation of the tap changer (simulation time is set to 120 s), the example uses the Phasor simulation method.

Phasor Simulation of On Load Tap Changer (OLTC) Regulating Transformers

A 25 kV distribution network consisting of three 30-km distribution feeders connected in parallel supplies power to a 36 MW /10 Mvar load (0.964 PF lagging) from a 120 kV, 1000 MVA system and a 120kV/25 kV OLTC regulating transformer. The OLTC transformer is used to regulate system voltage at the 25 kV bus.

The same circuit is duplicated to compare the performance of two different models of OLTC transformers:

- Model 1 is a detailed model where all OLTC switches and transformer windings are represented. This model uses three Multi-Winding Transformer blocks to implement a three-phase regulating transformer, with the OLTC connected on the high voltage side (120 kV). This model can be used with either continuous or discrete solvers to get detailed waveshapes or with the phasor simulation method (as in the present example) to observe variations of phasor voltages and currents.

• Model 2 is a simplified phasor model where the transformer and OLTC are simulated by current sources. This model can be used only with the phasor solution method. It is faster to execute and it should be the preferred model for transient stability studies, when several such devices are used in the same system.

Both OLTC transformer models implement a three-phase regulating transformer rated 47 MVA, 120 kV/25 kV, Y/ Delta, with the OLTC connected on the high voltage side (120 kV).

Select the Model 1 transformer block and use the **Edit/Look_under mask** menu to see how the regulating transformer is implemented. The OLTC transformer model is built from three Multi-Winding Transformer blocks. Each phase consists of two main windings (winding 2 = 120 kV and winding 3 = 25 kV) and one regulation winding (tapped winding 1). The seven taps of the regulation winding allow eight steps of voltage variation either in positive or negative direction. Three OLTC subsystems contain switches performing tap selection and reversal of the regulation winding.

Run the example. Double-click the Double click for info block to get details.

Mutual Inductance
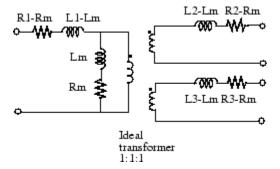
Implement inductances with mutual coupling

Library

Fundamental Blocks/Elements

Description

The Mutual Inductance block can be used to model two- or three-windings inductances with equal mutual coupling, or to model a generalized multi-windings mutual inductance with balanced or unbalanced mutual coupling.
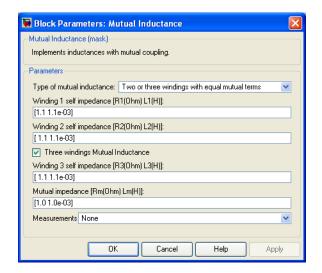
If you choose to model two- or three-windings inductances with equal mutual coupling, you specify the self-resistance and inductance of each winding plus the mutual resistance and inductance. The electrical model for this block in this case is given below:

If you choose to model a general mutual inductance, you need to specify the number of self windings (not just limited to 2 or 3 windings) plus the Resistance and Inductance matrices that define the mutual coupling relationship between the windings (balanced or not).

Dialog Box and Parameters

Two or three windings inductances with equal mutual coupling:

Type of mutual inductance

Set to **Two or Three windings with equal mutual terms** to implement a three-phase mutual inductance with equal mutual coupling between the windings

Winding 1 self impedance

The self-resistance and inductance for winding 1, in ohms (Ω) and henries (H).

Winding 2 self impedance

The self-resistance and inductance for winding 2, in ohms (Ω) and henries (H).

Three windings Mutual Inductance

If selected, implements three coupled windings; otherwise, it implements two coupled windings.
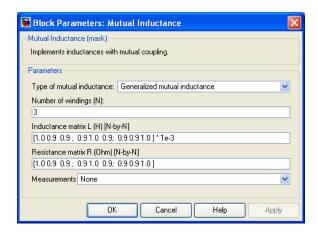
Winding 3 self impedance

The **Winding 3 self impedance** parameter is not available if the **Three windings Mutual Inductance** parameter is not selected. The self-resistance and inductance in ohms (Ω) and henries (H) for winding 3.

Mutual impedance

The mutual resistance and inductance between windings, in ohms (Ω) and henries (H). The mutual resistance and inductance corresponds to the magnetizing resistance and inductance on the standard transformer circuit diagram. If the mutual resistance and reactance are set to `[0 0]`, the block implements three separate inductances with no mutual coupling.

Generalized mutual inductance:

Type of mutual inductance

Set to **Generalized mutual inductance** to implement a multi windings mutual inductance with mutual coupling defined by an inductance and a resistance matrix.

Number of windings

The number of self inductances.

Inductance matrix L

The inductance matrix, in Henrys, that define the mutual coupling relationship between the self windings. It must be a N-by-N symmetrical matrix.

Resistance matrix R

The resistance matrix, in ohms, that define the mutual coupling relationship between the self windings. It must be a N-by-N symmetrical matrix.

Measurements

Select `Winding voltages` to measure the voltage across the winding terminals.

Select `Winding currents` to measure the current flowing through the windings.

Select `Winding voltages and currents` to measure the winding voltages and currents.

Place a Multimeter block in your model to display the selected measurements during the simulation.

In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

Measurement	Label
Winding voltages	Uw1:, Uw2:, Uw3:
Winding currents	Iw1:, Iw2:, Iw3:

Limitations

If you choose to model two or three windings inductances with equal mutual coupling , the following restrictions apply:
$R_1, R_2, ..., R_N \neq R_m$
$L_1, L_2, ..., L_N \neq L_m$.
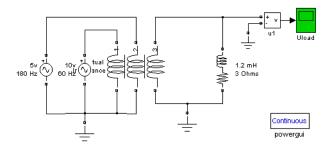
Negative values are allowed for the self- and mutual inductances as long as the self-inductances are different from the mutual inductance.
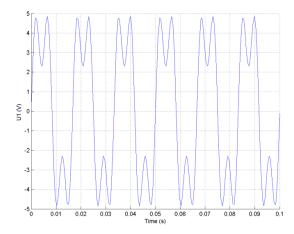
Windings can be left floating (not connected by an impedance to the rest of the circuit). However an internal resistor between the floating winding and the main circuit is automatically added. This internal connection does not affect voltage and current measurements.

Example

The power_mutual example uses three coupled windings to inject a third harmonic voltage into a circuit fed at 60 Hz.

Simulation produces the following load voltage waveform:

See Also

Linear Transformer, Saturable Transformer, Three-Phase Mutual Inductance Z1-Z0

Neutral

Implement common node in circuit

Library
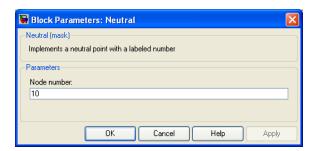
Fundamental Blocks/Elements

Description

The Neutral block implements a common node with a specific node number. You can use this block to create a floating neutral or to interconnect two points without drawing a connection line.

Dialog Box and Parameters
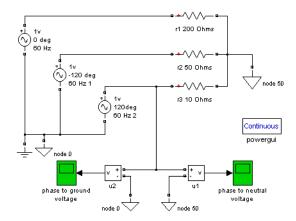
Node number

Specify a number of the neutral node. If the **Node number** parameter is set to 0, the Neutral block makes a connection to ground. The node number is displayed next to the block icon.

Example

The power_neutral example uses three Neutral blocks. One Neutral block is used to refer a Voltage Measurement block to the ground (node 0).

See Also

Ground

One-Quadrant Chopper DC Drive

Implement one-quadrant chopper (buck converter topology) DC drive
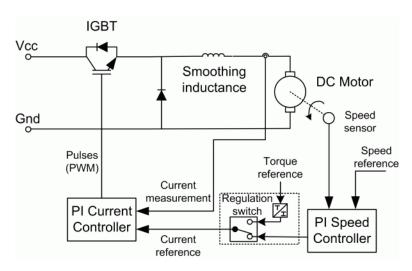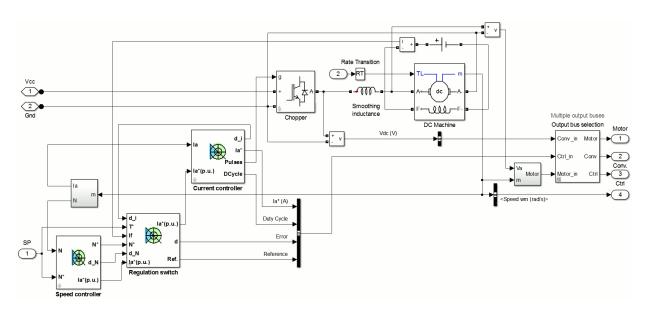
Library

Electric Drives/DC drives

Description

The high-level schematic shown below is built from four main blocks. The DC motor and the IGBT/Diode device (within the Universal Bridge block) are provided with the SimPowerSystems library. More details are available in the reference pages for these blocks. The two other blocks are specific to the Electric Drives library. These blocks are the speed controller and the current controller. They allow speed or torque regulation. A "regulation switch" block allows you to toggle from one type of regulation to the other. During torque regulation the speed controller is disabled. It is possible to use a simplified version of the drive containing an average-value model of the one-quadrant chopper and allowing faster simulation.

Note In SimPowerSystems software, the One-Quadrant Chopper DC Drive block is commonly called the **DC5** motor drive.

High-Level Schematic

Simulink Schematic

Speed Controller

The speed regulator shown below uses a PI controller. The controller outputs the armature current reference (in pu) used by the current controller in order to obtain the electromagnetic torque needed to reach the desired speed. During torque regulation, the speed controller is disabled.

The controller takes the speed reference (in rpm) and the rotor speed of the DC machine as inputs. The speed reference change rate will follow user-defined acceleration and deceleration ramps in order to avoid sudden reference changes that could cause armature over-current and destabilize the system. In order to avoid negative speeds that could induce conduction of the free-wheeling diode, the speed reference has a lower limit of 0 rpm.

The speed measurement is filtered by a first-order low-pass filter.

The current reference output is limited between 0 pu and an upper limit defined by the user.

Current Controller

The armature current regulator shown below is based on a second PI controller. The regulator controls the armature current by computing the appropriate duty ratio of the IGBT fixed frequency pulses (Pulse Width Modulation). This generates the average armature voltage needed to obtain the desired armature current and thus the desired electromagnetic torque.

The controller takes the current reference (in pu) and the armature current flowing through the motor as inputs. The current reference is either provided by the speed

controller during speed regulation or computed from the torque reference provided by the user during torque regulation. This is managed by the "regulation switch" block. The armature current input is filtered by a first-order low-pass filter.

The pulse width modulation is obtained by comparison of the PI output and a fixed frequency sawtooth carrier signal (see the figure called Pulse Width Modulation (PWM)).

Average-Value One-Quadrant Chopper

The average-value converter is shown in the following figure.

It is composed of one controlled current source on the DC source side and one controlled voltage source on the motor side. The current source allows the representation of the average input current value following the next equations:

$I_{in} = aI_{out}$ when $I_{out} > 0$

$I_{in} = I_{out}$ when $I_{out} \leq 0$

with a being the firing angle value and I_{out} the armature current value. The voltage source on the motor side represents the average voltage value following the next equations :

$V_{out} = aV_{in}$ when $I_{out} > 0$

$V_{out} = V_{in}$ when $I_{out} \leq 0$

with V_{in} being the input voltage.
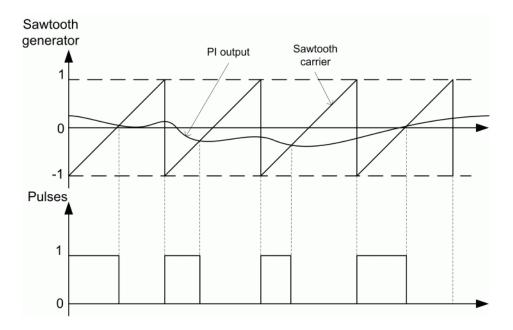
Remarks

The machine is separately excited with a constant DC field voltage source. There is thus no field voltage control. By default, the field current is set to its steady-state value when a simulation is started.

The armature voltage is provided by an IGBT buck converter controlled by two PI regulators. The buck converter is fed by a constant DC voltage source. Armature current oscillations are reduced by a smoothing inductance connected in series with the armature circuit.

The model is discrete. Good simulation results have been obtained with a 1 μs time step. In order to simulate a digital controller device, the control system has two different sampling times:

- The speed controller sampling time
- The current controller sampling time

The speed controller sampling time has to be a multiple of the current sampling time. The latter sampling time has to be a multiple of the simulation time step.

Pulse Width Modulation (PWM)

Dialog Box

DC Machine Tab

The **DC Machine** tab displays the parameters of the DC Machine block of the Fundamental Blocks (powerlib) library.

Output bus mode

Select how the output variables are organized. If you select **Multiple output buses**, the block has three separate output buses for motor, converter, and controller variables. If you select **Single output bus**, all variables output on a single bus.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Select between the load torque, the motor speed and the mechanical rotational port as mechanical input. If you select and apply a load torque, the output is the motor speed according to the following differential equation that describes the mechanical system dynamics:

$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

If you select the motor speed as mechanical input, then you get the electromagnetic torque as output, allowing you to represent externally the mechanical system dynamics. The internal mechanical system is not used with this mechanical input selection and the inertia and viscous friction parameters are not displayed.

For the mechanical rotational port, the connection port S counts for the mechanical input and output. It allows a direct connection to the Simscape environment. The mechanical system of the motor is also included in the drive and is based on the same differential equation.

See "Mechanical Coupling of Two Motor Drives".

Converter Tab

IGBT/Diode Device section

The IGBT/Diode Device section of the Converter tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the Universal Bridge block parameters.

Smoothing Inductance

The smoothing inductance value (H).

Field DC Source

The DC motor field voltage value (V).

Controller Tab

Schematic Button

> When you press this button, a diagram illustrating the speed and current controllers schematics appears.

Regulation Type

> This pop-up menu allows you to choose between speed and torque regulation.

Controller — Speed Controller Subtab

Nominal Speed

> The nominal speed value of the DC motor (rpm). This value is used to convert motor speed from rpm to pu (per unit).

Initial Speed Reference

The initial speed reference value (rpm). This value allows the user to start a simulation with a speed reference other than 0 rpm.

Low-Pass Filter Cutoff Frequency

Cutoff frequency of the low-pass filter used to filter the motor speed measurement (Hz).

Sampling Time

The speed controller sampling time (s). This sampling time has to be a multiple of the current controller sampling time and of the simulation time step.

Proportional Gain

The proportional gain of the PI speed controller.

Integral Gain

The integral gain of the PI speed controller.

Acceleration

The maximum change of speed allowed during motor acceleration (rpm/s). Too great a value can cause armature over-current.

Deceleration

The maximum change of speed allowed during motor deceleration (rpm/s). Too great a value can cause armature over-current.

Controller — Current Controller Subtab

Low-Pass Filter Cutoff Frequency

Cutoff frequency of the low-pass filter used to filter the armature current measurement (Hz).

Reference Limit

Maximum current reference value (pu). 1.5 pu is a common value.

PWM Switching Frequency

The switching frequency of the IGBT device (Hz).

Sampling Time

The current controller sampling time (s). This sampling time has to be a submultiple of the speed controller sampling time and a multiple of the simulation time step.

Power and Voltage nominal values

The DC motor nominal power (W) and voltage (V) values. These values are used to convert armature current from amperes to pu (per unit).

Proportional Gain

The proportional gain of the PI current controller.

Integral Gain

The integral gain of the PI current controller.

Block Inputs and Outputs

`SP`

The speed or torque set point. The speed set point can be a step function, but the speed change rate will follow the acceleration / deceleration ramps. If the load torque and the speed have opposite signs, the accelerating torque will be the sum of the electromagnetic and load torques.

`Tm` or `Wm`

The mechanical input: load torque (Tm) or motor speed (Wm). For the mechanical rotational port (S), this input is deleted.

`Vcc, Gnd`

The DC voltage source electric connections. The voltage must be adequate for the motor size.

`Wm`, `Te` or `S`

The mechanical output: motor speed (Wm), electromagnetic torque (Te) or mechanical rotational port (S).

When the **Output bus mode** parameter is set to **Multiple output buses**, the block has the following three output buses:

`Motor`

The motor measurement vector. This vector is composed of two elements:

- The armature voltage
- The DC motor measurement vector (containing the speed, armature current, field current, and electromagnetic torque values). Note that the speed signal is converted from rad/s to rpm before output.

`Conv`

The IGBT/Diode device measurement vector. This vector includes the converter output voltage. The output current is not included since it is equal to the DC motor armature current. Note that all current and voltage values of the converter can be visualized with the Multimeter block.

Ctrl

The controller measurement vector. This vector contains:

- The armature current reference
- The duty cycle of the PWM pulses
- The speed or torque error (difference between the speed reference ramp and actual speed or between the torque reference and actual torque)
- The speed reference ramp or torque reference

When the **Output bus mode** parameter is set to **Single output bus**, the block groups the Motor, Conv, and Ctrl outputs into a single bus output.

Model Specifications

The library contains a 5 hp drive parameter set. The specifications of the 5 hp drive are shown in the following table.

5 HP Drive Specifications

Drive Input Voltage		
	Amplitude	280 V
Motor Nominal Values		
	Power	5 hp
	Speed	1750 rpm
	Voltage	240 V

Example

The dc5_example example illustrates the one-quadrant chopper drive used with the 5 hp drive parameter set during speed regulation.

One-Quadrant Chopper 5 HP DC Drive

See also 'dc5_example_simplified.mdl' for average-value model

The buck converter is fed by a 280 V DC voltage source and the IGBT switching frequency is 5 kHz.

The speed reference is set at 500 rpm at t = 0 s. Initial load torque is 15 N.m.

Observe that the motor speed follows the reference ramp accurately (+250 rpm/s) and reaches steady state around t = 2.5 s.
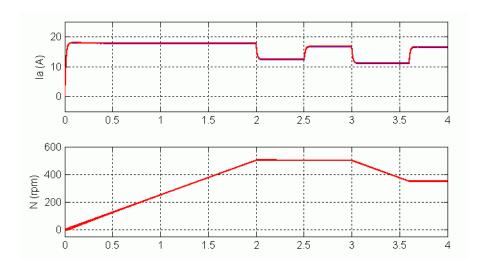
The armature current follows the current reference very well, with fast response time and small ripples. Notice that the current ripple frequency is 5 kHz.

At t = 2.5 s, the load torque passes from 15 N.m to 20 N.m. The motor speed recovers fast and is back at 500 rpm at t = 3 s. The current reference rises to about 16.7 A to generate a higher electromagnetic torque to maintain the speed reference. As observed before, the armature current follows its reference perfectly.

At t = 3 s, the speed reference jumps down to 350 rpm. The armature current lowers in order for the speed to decrease following the negative speed slope (−250 rpm/s) with the help of the load torque.

At t = 4 s, the speed stabilizes around its reference.
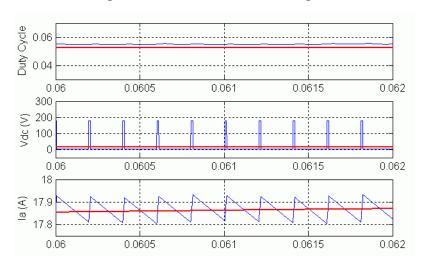
The following figure shows the armature current and speed waveforms.

DC5 Example — Current and Speed Waveforms (Blue: Detailed Converter, Red: Average-Value Converter)

The next figure shows the duty cycle of the chopper pulses and the corresponding armature voltage and current waveforms during a time interval of 2 ms.

DC5 Example — Duty Cycles, Armature Voltage, and Current Waveforms (Blue: Detailed Converter, Red: Average-Value Converter)

References

[1] Boldea, Ion, and S.A. Nasar, *Electric Drives*, CRC Press LLC, 1999.

[2] Séguier, Guy, *Electronique de puissance*, Dunod, 1999.

On/Off Delay

Implement switch-on or switch-off delay

Library

Control and Measurements/Logic
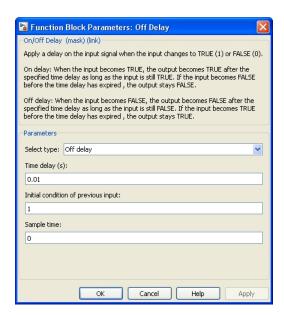
Description

The On/Off Delay block implements the following logic when the **Select type** parameter is set to `On delay`:

- When the input becomes true, the output becomes true after a preset time delay. The output remains true as long as the input is true.
- When the input is false or becomes false, the output becomes false with no delay.
- When the **Initial condition of previous input** parameter is set to `1`, and the input is true at t = 0, the output is true with no delay.

The On/Off Delay block implements the following logic when the **Select type** parameter is set to `Off delay`:

- When the input becomes false, the output becomes false after a preset time delay. The output remains false as long as the input is false.
- When the input is true or becomes true, the output is true with no delay.
- When the **Initial condition of previous input** parameter is set to `0`, and the input is false at t = 0, the output is false with no delay.

Dialog Box and Parameters

Select type

Select between `On delay` or `Off delay` type.

Time delay (s)

Specify the duration of the delay, in seconds. When the **Sample time** parameter is greater than 0, the time delay value must be a multiple of the sample time.

Initial condition of previous input

Specify the initial value of the previous input.

Sample time

Specify the sample time of the block, in seconds. Set to `0` to implement a continuous block.

Inputs and Outputs

The input signal must be a Boolean signal. The output is Boolean.

Characteristics

Direct Feedthrough	Yes
Sample Time	Specified in the **Sample Time** parameter
Scalar Expansion	Yes, of parameters
Dimensionalized	Yes
Zero-Crossing Detection	No

Example

The power_Logic example shows the operation of the On/Off Delay block.

The model sample time is parameterized with the variable Ts (default value Ts = 5e-3). To simulate a continuous On/Off Delay block, specify Ts = 0 in the MATLAB Command Window.

Overmodulation

Add third harmonic or triplen harmonic zero-sequence signal to three-phase signal

Library

Control and Measurements/Pulse & Signal Generators

Description

The Overmodulation block increases the linear region of a three-phase PWM generator by adding a third harmonic or triplen harmonic zero-sequence signal V_0 to the three-phase original reference signal U_{ref}. This zero-sequence signal does not appear in the line-to-line voltages.

A modulation index of up to 1.1547 (exact value = 2/sqrt(3)) can be used without pulse dropping.

The Overmodulation block implements three overmodulation techniques:
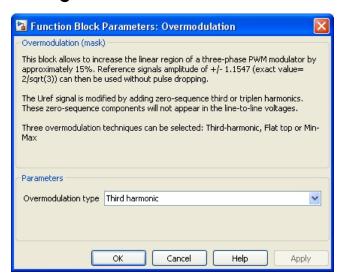
- The Third Harmonic overmodulation technique. In this technique the third-harmonic signal V0 subtracted from the original signal is calculated as

$$V_0 = \frac{|U|}{6} \times \sin\left[3 \cdot (wt + \angle U)\right]$$

- The Flat Top overmodulation technique. In this technique the portion of the three-phase input signal exceeding values +/−1 is computed. The three resulting signals are then summed and removed from the original signal U_{ref}. The resulting modified signal U_{ref}* is therefore a flat-top three-phase signal that contains zero-sequence triplen-harmonics. The block outputs a value between −1 and 1.

- The Min-Max overmodulation technique. In this technique the minimum and maximum values of the three components of input signal U_{ref} are summed and divided by two, and then subtracted from the input signal. The resulting modified signal U_{ref}*

also contains zero-sequence triplen-harmonics. The block outputs a value between −1 and 1.

Dialog Box and Parameters

Overmodulation type

Select the overmodulation technique you want to apply to the Uref signal: `Third harmonic`, `Flat top`, or `Min-Max`.

Inputs and Outputs

Uref

The three-phase reference signal of three-phase PWM generator.

Uref*

The overmodulated three-phase signal of three-phase PWM generator.

Characteristics

Sample Time	Inherited

Scalar Expansion	No
Dimensionalized	Yes

Example

The power_OverModulation example compares the three overmodulation techniques implemented in the Overmodulation block. Choose the overmodulation technique (type 1, 2, or 3 on the first input of the Multiport Switch) and run the simulation. Observe the resulting waveforms in Scope 1.

The model sample time is parameterized with variable Ts (default value of 5e-6). To run a continuous simulation, specify Ts = 0 in the MATLAB Command Window and change the **Simulation type** parameter of the Powergui block to Continuous before starting the simulation.

Parallel RLC Branch

Implement parallel RLC branch

Library

Fundamental Blocks/Elements
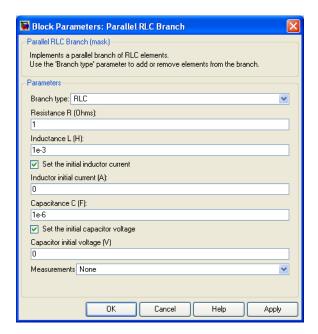
Description

The Parallel RLC Branch block implements a single resistor, inductor, and capacitor or a parallel combination of these. Use the **Branch type** parameter to select elements you want to include in the branch.

Negative values are allowed for resistance, inductance, and capacitance.

Dialog Box and Parameters

Branch type

Select the elements you want to include in the branch. The **R** letter defines the resistor, the **L** letter defines the inductor, and the **C** letter defines the capacitor. Select **Open circuit** to define an open circuit (R=inf, L=inf, C=0). Only existing elements are displayed in the block icon.

Resistance

The branch resistance, in ohms (Ω). The **Resistance** parameter is not visible if the resistor element is not specified in the **Branch type** parameter.

Inductance L

The branch inductance, in henries (H). The **Inductance** parameter is not visible if the inductor element is not specified in the **Branch type** parameter.

Set the initial inductor current

If selected, the initial inductor current is defined by the **Inductor initial current** parameter. If not selected, the software calculates the initial inductor current in order to start the simulation steady-state.

The **Set the initial inductor current** parameter is not visible and have no effect on the block if the inductor element is not specified in the **Branch type** parameter.

Inductor initial current (A)

The initial inductor current used at the start of the simulation. The **Inductor initial current** parameter is not visible and have no effect on the block if the inductor is not modeled and if the **Set the initial inductor current** parameter is not selected.

Capacitance C

The branch capacitance, in farads (F). The **Capacitance** parameter is not visible if the capacitance element is not specified in the **Branch type** parameter.

Set the initial capacitor voltage

If selected, the initial capacitor voltage is defined by the **Capacitor initial voltage** parameter. If not selected, the software calculates the initial capacitor voltage in order to start the simulation in steady-state.

The **Set the initial capacitor voltage** parameter is not visible and have no effect on the block if the capacitor element is not specified in the **Branch type** parameter.

Capacitor initial voltage (V)

The initial capacitor voltage used at the start of the simulation. The **Capacitor initial voltage** parameter is not visible and have no effect on the block if the capacitor is not modeled and if the **Set the initial capacitor voltage** parameter is not selected.

Measurements

Select `Branch voltage` to measure the voltage across the Parallel RLC Branch block terminals.

Select `Branch current` to measure the total current (sum of R, L, C currents) flowing through the Parallel RLC Branch block.

Select `Branch voltage and current` to measure the voltage and the current of the Parallel RLC Branch block.
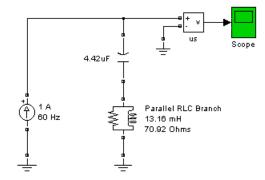
Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurement is identified by a label followed by the block name.

Measurement	Label
Branch voltage	Ub:

Measurement	Label
Branch current	Ib:

Example

The power_paralbranch example is used to obtain the frequency response of an eleventh-harmonic filter (tuned frequency at 660 Hz) connected on a 60 Hz power system:

The network impedance in the Laplace domain is

$$Z(s) = \frac{V(s)}{I(s)} = \frac{RLCs^2 + Ls + R}{LCs^2 + RCs}.$$

To obtain the frequency response of the impedance you have to get the state-space model (A B C D matrices) of the system.
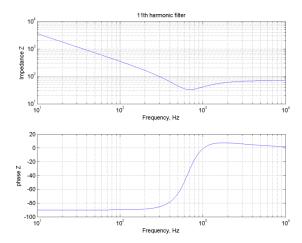
This system is a one input (Is) and one output (Vs) system.

Note If you have Control System Toolbox software installed, you can get the transfer function *Z(s)* from the state-space matrices and the bode function.

```
[A,B,C,D] = power_analyze('power_paralbranch');
freq = logspace(1,4,500);
w = 2*pi*freq;
[Zmag,Zphase] = bode(A,B,C,D,1,w);
```

```
subplot(2,1,1)
loglog(freq,Zmag)
grid
title('11th harmonic filter')
xlabel('Frequency, Hz')
ylabel('Impedance Z')
subplot(2,1,2)
semilogx(freq,Zphase)
xlabel('Frequency, Hz')
ylabel('phase Z')
grid
```

You can also use the Impedance Measurement block and the Powergui block to plot the impedance as a function of frequency.

See Also

Multimeter, Parallel RLC Load, powergui, Series RLC Branch, Series RLC Load

Parallel RLC Load

Implement linear parallel RLC load

Library

Fundamental Blocks/Elements

Description
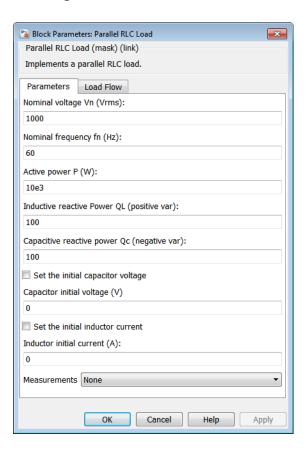
The Parallel RLC Load block implements a linear load as a parallel combination of RLC elements. At the specified frequency, the load exhibits a constant impedance. The active and reactive powers absorbed by the load are proportional to the square of the applied voltage.

Only elements associated with nonzero powers are displayed in the block icon.

Dialog Box and Parameters

Parameters Tab

Nominal voltage Vn

The nominal voltage of the load, in volts RMS (Vrms).

Nominal frequency fn

The nominal frequency, in hertz (Hz).

Active power P

The active power of the load, in watts.

Inductive reactive power QL

The inductive reactive power QL, in vars. Specify a positive value, or 0.

Capacitive reactive power QC

The capacitive reactive power QC, in vars. Specify a positive value, or 0.

Set the initial capacitor voltage

If selected, the initial capacitor voltage is defined by the **Capacitor initial voltage** parameter. If not selected, the software calculates the initial capacitor voltage in order to start the simulation in steady-state.

The **Set the initial capacitor voltage** parameter have no effect on the block if the capacitive reactive power is equal to zero.

Capacitor initial voltage (V)

The initial capacitor voltage used at the start of the simulation. The **Capacitor initial voltage** parameter have no effect on the block if the capacitive reactive power is equal to zero and if the **Set the initial capacitor voltage** parameter is not selected.

Set the initial inductor current

If selected, the initial inductor current is defined by the **Inductor initial current** parameter. If not selected, the software calculates the initial inductor current in order to start the simulation steady-state.

The **Set the initial inductor current** parameter have no effect on the block if the inductive reactive power is equal to zero.

Inductor initial current (A)

The initial inductor current used at the start of the simulation. The **Inductor initial current** parameter have no effect on the block if the inductive reactive power is equal to zero and if the **Set the initial inductor current** parameter is not selected.

Measurements

Select **Branch voltage** to measure the voltage across the Parallel RLC Load block terminals.

Select **Branch current** to measure the current flowing through the Parallel RLC Load block.

Select **Branch voltage and current** to measure the voltage and the current of the Parallel RLC Load block.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurement is identified by a label followed by the block name.

Measurement	Label
Branch voltage	`Ub:`
Branch current	`Ib:`

Load Flow Tab

The Load Flow tool of the powergui block uses the parameters on this tab. These load flow parameters affect only model initialization. They do not affect simulation.

Load type

Specify the load type. The default value is `constant Z`.

If you select `constant Z`, the load impedance is determined from the nominal phase-to-phase voltage Vn, active power P, and reactive power (QL-QC) specified on the **Parameters** tab of the block dialog box. During the load flow solution, the impedance is kept constant. The effective P and Q therefore vary proportionally to the square of the bus voltage computed by the Load Flow tool.

If you select `constant PQ`, the active power P and reactive power Q are kept constant and equal to the values specified on the **Parameters** tab of the block dialog box. When you apply the load flow solution to the model (by clicking **Apply** in the Load Flow tool), the **Nominal phase-to-phase voltage Vn** parameter on the **Parameters** tab is automatically adjusted to the phase-to-phase bus voltage computed by the Load Flow tool.

If you select `constant I`, the load current is kept constant at its nominal value determined from the base voltage specified in the dialog box of the associated Load Flow Bus block and from active power P and reactive power QL and QC specified on the **Parameters** tab of the block dialog box. The effective P and Q therefore vary proportionally to the bus voltage computed by the Load Flow tool. When you apply the load flow solution to the model (by clicking **Apply** in the Load Flow tool), the pu value of the nominal voltage Vn on the **Parameters** tab is automatically adjusted to the square root of the load voltage (in pu) computed by the Load Flow tool.

Examples

The power_paralload example uses a Parallel RLC Load block to implement a load.

See Also
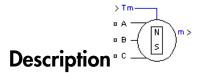
Multimeter, Parallel RLC Branch, Series RLC Branch, Series RLC Load

Permanent Magnet Synchronous Machine

Model the dynamics of a three-phase permanent magnet synchronous machine with sinusoidal or trapezoidal back electromotive force, or the dynamics of a five-phase permanent magnet synchronous machine with sinusoidal back electromotive force

Library

Fundamental Blocks/Machines

Description

The Permanent Magnet Synchronous Machine block operates in either generator or motor mode. The mode of operation is dictated by the sign of the mechanical torque (positive for motor mode, negative for generator mode). The electrical and mechanical parts of the machine are each represented by a second-order state-space model.

The sinusoidal model assumes that the flux established by the permanent magnets in the stator is sinusoidal, which implies that the electromotive forces are sinusoidal.

The trapezoidal model assumes that the winding distribution and flux established by the permanent magnets produce three trapezoidal back EMF waveforms.

The block implements the following equations.

Three-Phase Sinusoidal Model Electrical System

These equations are expressed in the rotor reference frame (qd frame). All quantities in the rotor reference frame are referred to the stator.

$$\frac{d}{dt}i_d = \frac{1}{L_d}v_d - \frac{R}{L_d}i_d + \frac{L_q}{L_d}p\omega_m i_q$$

$$\frac{d}{dt}i_q = \frac{1}{L_q}v_q - \frac{R}{L_q}i_q - \frac{L_d}{L_q}p\omega_m i_d - \frac{\lambda p\omega_m}{L_q}$$

$$T_e = 1.5\,p[\lambda i_q + (L_d - L_q)i_d i_q]$$
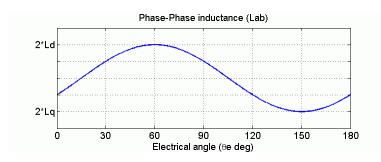
L_q, L_d	q and d axis inductances
R	Resistance of the stator windings
i_q, i_d	q and d axis currents
v_q, v_d	q and d axis voltages
ω_m	Angular velocity of the rotor
λ	Amplitude of the flux induced by the permanent magnets of the rotor in the stator phases
p	Number of pole pairs
T_e	Electromagnetic torque

The L_q and L_d inductances represent the relation between the phase inductance and the rotor position due to the saliency of the rotor. For example, the inductance measured between phase a and b (phase c is left open) is given by:

$$L_{ab} = L_d + L_q + \left(L_q - L_d\right)\cos\left(2\theta_e + \frac{\pi}{3}\right)$$

Θ_e represents the electrical angle.

The next figure shows the variation of the phase to phase inductance in function of the electrical angle of the rotor.

Phase-Phase inductance (Lab)

- For a round rotor, there is no variation in the phase inductance.

$$L_d = L_q = \frac{L_{ab}}{2}$$

- For a salient round rotor, the dq inductances are given by:

$$L_d = \frac{\max(L_{ab})}{2}$$

and

$$L_q = \frac{\min(L_{ab})}{2}$$

Five-Phase Sinusoidal Model Electrical System

These equations are expressed in the rotor reference frame using an extended Park transformation (q1d1 and q2d2 frame). All quantities in the rotor reference frame are referred to the stator.

$$\frac{d}{dt}i_{d1} = \frac{1}{L}v_{d1} - \frac{R}{L}i_{d1} + \frac{L_q}{L}p\omega_m i_{q1}$$

$$\frac{d}{dt}i_{q1} = \frac{1}{L}v_{q1} - \frac{R}{L}i_{q1} - \frac{L_d}{L}p\omega_m i_{d1} - \frac{\lambda p\omega_m}{L}$$

$$\frac{d}{dt}i_{d2} = \frac{1}{L}v_{d2} - \frac{R}{L}i_{d2}$$

$$\frac{d}{dt}i_{q2} = \frac{1}{L}v_{q2} - \frac{R}{L}i_{q2}$$

$$T_e = 2.5p\lambda i_{q1}$$

L	Armature inductance
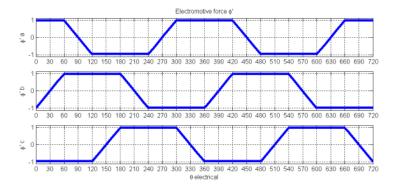
R	Resistance of the stator windings
i_{q1}, i_{d1}	q1 and d1 axis currents
v_{q1}, v_{d1}	q1 and d1 axis voltages
i_{q2}, i_{d2}	q2 and d2 axis currents
v_{q2}, v_{d2}	q2 and d2 axis voltages
ω_m	Angular velocity of the rotor
λ	Amplitude of the flux induced by the permanent magnets of the rotor in the stator phases
p	Number of pole pairs
T_e	Electromagnetic torque

Three-Phase Trapezoidal Model Electrical System

These equations are expressed in the phase reference frame (abc frame). Note that the phase inductance L_s is assumed constant and does not vary with the rotor position.

$$\frac{d}{dt}i_a = \frac{1}{3L_s}\left(2v_{ab} + v_{bc} - 3R_s i_a + \lambda p \omega_m \left(-2\Phi_a' + \Phi_b' + \Phi_c'\right)\right)$$

$$\frac{d}{dt}i_b = \frac{1}{3L_s}\left(-v_{ab} + v_{bc} - 3R_s i_b + \lambda p \omega_m \left(\Phi_a' - 2\Phi_b' + \Phi_c'\right)\right)$$

$$\frac{d}{dt}i_c = -\left(\frac{d}{dt}i_a + \frac{d}{dt}i_b\right)$$

$$T_e = p\lambda\left(\Phi_a' \cdot i_a + \Phi_b' \cdot i_b + \Phi_c' \cdot i_c\right),$$

The electromotive force Φ' is represented by

and

L_s	Inductance of the stator windings
R	Resistance of the stator windings
i_a, i_b, i_c	a, b and c phase currents
Φ_a', Φ_b', Φ_c'	a, b and c phase electromotive forces
v_{ab}, v_{bc}	ab and bc phase to phase voltages
ω_m	Angular velocity of the rotor
λ	Amplitude of the flux induced by the permanent magnets of the rotor in the stator phases
p	Number of pole pairs
T_e	Electromagnetic torque

Mechanical System (for all models)
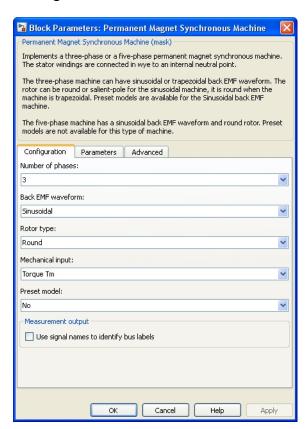
$$\frac{d}{dt}\omega_r = \frac{1}{J}\left(T_e - T_f - F\omega_m - T_m\right)$$

$$\frac{d\theta}{dt} = \omega_m,$$

J	Combined inertia of rotor and load
F	Combined viscous friction of rotor and load

θ	Rotor angular position
T_m	Shaft mechanical torque
T_f	Shaft static friction torque
ω_m	Angular velocity of the rotor (mechanical speed)

Dialog Box and Parameters

Configuration Tab

Number of phases

Select between a three-phase machine model or a five-phase machine model. This parameter is disabled when the **Back EMF waveform** parameter is set to `Trapezoidal`, or when the **Rotor type** parameter is set to `Salient-pole`.

Back EMF waveform

Select between the `Sinusoidal` and the `Trapezoidal` electromotive force. This parameter is disabled when the **Number of phases** parameter is set to `5`.

Rotor type

Select between the `Salient-pole` and the round (cylindrical) rotor. This parameter is disabled when the **Number of phases** parameter is set to `5` or when the **Back EMF waveform** parameter is set to `Trapezoidal`.

Mechanical input
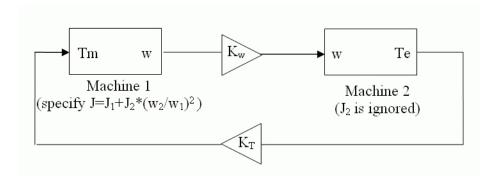
Select the torque applied to the shaft, the rotor speed as a Simulink input of the block, or to represent the machine shaft by a Simscape rotational mechanical port.

Select `Torque Tm` to specify a torque input, in N.m., and change labeling of the block input to `Tm`. The machine speed is determined by the machine Inertia J and by the difference between the applied mechanical torque Tm and the internal electromagnetic torque Te. The sign convention for the mechanical torque is when the speed is positive, a positive torque signal indicates motor mode and a negative signal indicates generator mode.

Select `Speed w` to specify a speed input, in rad/s, and change labeling of the block input to `w`. The machine speed is imposed and the mechanical part of the model (Inertia J) is ignored. Using the speed as the mechanical input allows modeling a mechanical coupling between two machines.

The next figure indicates how to model a stiff shaft interconnection in a motor-generator set when friction torque is ignored in machine 2. The speed output of machine 1 (motor) is connected to the speed input of machine 2 (generator), while machine 2 electromagnetic torque output Te is applied to the mechanical torque input Tm of machine 1. The Kw factor takes into account speed units of both machines (pu or rad/s) and gear box ratio `w2/w1`. The KT factor takes into account torque units of both machines (pu or N.m) and machine ratings. Also, as the inertia J2 is ignored in machine 2, J2 referred to machine 1 speed must be added to machine 1 inertia J1.

1-581

Select `Mechanical rotational port` to add to the block a Simscape mechanical rotational port that allows connection of the machine shaft with other Simscape blocks with mechanical rotational ports. The Simulink input representing the mechanical torque `Tm` or the speed `w` of the machine is then removed from the block.

The next figure indicates how to connect an Ideal Torque Source block from the Simscape library to the machine shaft to represent the machine in motor mode, or in generator mode, when the rotor speed is positive.

Preset Model

Provides a set of predetermined electrical and mechanical parameters for various permanent magnet synchronous motor ratings of torque (N.m), DC bus voltage (V), rated speed (rpm), and continuous stall torque (N.m).

The **Preset Model** parameter is enabled only when the **Number of phases** parameter is set to 3, the **Back EMF waveform** parameter is set to Sinusoidal, and the **Rotor type** parameter is set to Round.

Select one of the preset models to load the corresponding electrical and mechanical parameters in the entries of the dialog box. Select No if you do not want to use a preset model, or if you want to modify some of the parameters of a preset model.

When you select a preset model, the electrical and mechanical parameters in the **Parameters** tab of the dialog box become nonmodifiable (unavailable). To start from a given preset model and then modify machine parameters:

1 Select the preset model that you want to initialize the parameters.

2 Change the **Preset model** parameter value to No. This does not change the machine parameters. It just breaks the connection with the particular preset model.

3 Modify the machine parameters as you want, then click **Apply**.

Use signal names to identify bus labels

When this check box is selected, the measurement output uses the signal names to identify the bus labels. Select this option for applications that require bus signal labels to have only alphanumeric characters.

When this check box is cleared, the measurement output uses the signal definition to identify the bus labels. The labels contain nonalphanumeric characters that are incompatible with some Simulink applications.

Parameters Tab

Stator phase resistance

The stator phase resistance Rs (Ω).

Armature inductance (H)

The armature inductance of the sinusoidal model with round rotor (Ld is equal to Lq). This parameter is visible only when the **Back EMF waveform** parameter is set to Sinusoidal, and the **Rotor type** parameter set to Round.

Inductances [Ld(H) Lq(H)]

The phase to neutral Ld (H) and Lq (H) inductances in the d-axis and q-axis of the sinusoidal model with salient-pole rotor. This parameter is visible only when

the **Back EMF waveform** parameter is set to `Sinusoidal`, and the **Rotor type** parameter set to `Salient-pole`.

Stator phase inductances Ls (H)

The stator-phase-to-neutral inductance Ls (H) of the trapezoidal model. This parameter is visible only when the **Back EMF waveform** parameter is set to `Trapezoidal`.

Specify

Lets you select the machine constant that you want to specify for block parameterization:

- `Flux linkage established by magnets`
- `Voltage Constant`
- `Torque Constant`

Once you select a constant, you can enter its value in the appropriate parameter field, while the other two parameters become inaccessible.

Flux linkage

The constant flux λ (Wb) per pole pairs induced in the stator windings by the magnets.

Voltage constant

The peak line to line voltage per 1000 rpm. This voltage represents the peak open circuit voltage when the machine is driven as a generator at 1000 rpm.

Torque constant

The torque per ampere constant. This constant assumes that the machine is driven by an inverter which provides a perfect synchronization between the current and the Back-EMF.

- Sinusoidal model: A sine wave current is assumed (for more information, see `ac6_example_simplified`).
- Trapezoidal model: A square ware current is assumed (for more information, see `ac7_example_simplified`).

Back EMF flat top area

The width of the flat top for a half period of the electromotive force Φ' (degrees) (only for trapezoidal machine).

Inertia, viscous damping, pole pairs, static friction

The combined machine and load inertia coefficient J (kg.m^2), combined viscous friction coefficient F (N.m.s), pole pairs p, and shaft static friction T_f (N.m).

If the **static friction** parameter value is omitted or not specified, the block considers this value to be 0.

Initial conditions
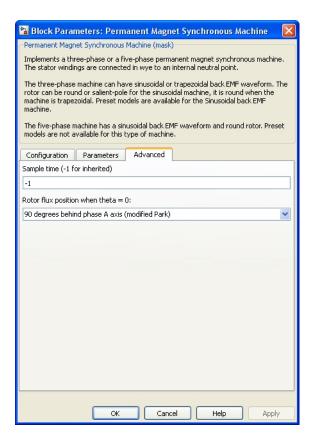
Specifies the mechanical speed (rad/s), mechanical angle Θ_m (degrees), and instantaneous stator current (A):

Three-phase machine [w_m, Θ_m, i_a, i_b]

Five-phase machine [w_m, Θ_m, i_a, i_b, i_c, i_d]

Because the stator is wye-connected and the neutral point is isolated, the current i_c in the three-phase machine is given by $i_c = -i_a-i_b$, and the current i_e in the five-phase machine is given by $i_e = -i_a -i_b -i_c -i_d$.

Advanced Tab
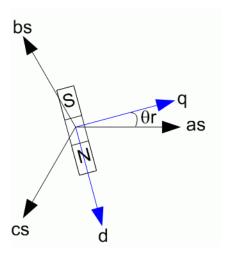
Sample time (−1 for inherited)

Specifies the sample time used by the block. To inherit the sample time specified in the Powergui block, set this parameter to `-1`.

Rotor flux position when theta = 0
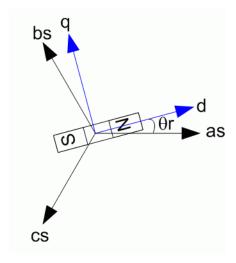
Lets you select the reference position of the rotor flux relative to the phase A axis.

Select `Rotor 90 degrees behind phase A axis when theta = 0 (Modified Park)` to choose the reference position of the rotor represented by:

The modified Park transformation [4] is more convenient for vector control because the maximum phase induction occurs at theta = 0.

Select `Rotor aligned with phase A axis when theta =0 (Original Park)` to choose the reference position of the rotor represented by:

Inputs and Outputs

Tm

The Simulink input is the mechanical torque at the machine shaft. This input is normally positive because the Permanent Magnet Synchronous Machine block is usually used as a motor. If you choose to use the block in generator mode, you can apply a negative torque input.

w

The alternative block input (depending on the value of the **Mechanical input** parameter) is the machine speed, in rad/s.

m
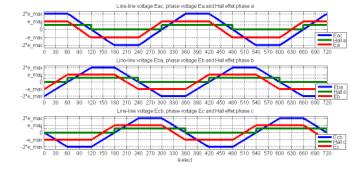
The Simulink output of the block is a vector containing measurement signals. The available signals depend on the model you selected. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Name	Definition	Units	Model
ias	Stator current is_a	A	all
ibs	Stator current is_b	A	all
ics	Stator current is_c	A	all
ids	Stator current is_d	A	5-Phase Sinusoidal
ies	Stator current is_e	A	5-Phase Sinusoidal
iqs	Stator current is_q	A	3-Phase Sinusoidal
ids	Stator current is_d	A	3-Phase Sinusoidal
iqs1	Stator current is_q1	A	5-Phase Sinusoidal
ids1	Stator current is_d1	A	5-Phase Sinusoidal
iqs2	Stator current is_q2	A	5-Phase Sinusoidal
ids2	Stator current is_d2	A	5-Phase Sinusoidal
vqs	Stator voltage Vs_q	V	3-Phase Sinusoidal
vds	Stator voltage Vs_d	V	3-Phase Sinusoidal
vqs1	Stator voltage Vs_q1	V	5-Phase Sinusoidal
vds1	Stator voltage Vs_d1	V	5-Phase Sinusoidal
vqs2	Stator voltage Vs_q2	V	5-Phase Sinusoidal
vds2	Stator voltage Vs_d2	V	5-Phase Sinusoidal

Name	Definition	Units	Model
ea	Phase back EMF e_a	V	3-Phase Trapezoidal
eb	Phase back EMF e_b	V	3-Phase Trapezoidal
ec	Phase back EMF e_c	V	3-Phase Trapezoidal
ha	Hall effect signal h_a[*]	logic 0-1	3-Phase, Sinusoidal and Trapezoidal
hb	Hall effect signal h_b[*]	logic 0-1	3-Phase, Sinusoidal and Trapezoidal
hc	Hall effect signal h_c[*]	logic 0-1	3-Phase, Sinusoidal and Trapezoidal
w	Rotor speed wm	rad/s	all
theta	Rotor angle thetam	rad	all
Te	Electromagnetic torque Te	N.m	all

The Hall effect signal provides a logical indication of the back EMF positioning. This signal is very useful to directly control the power switches. There is a change of state at each zero crossing of the phase to phase voltage. These signals must be decoded before being applied to the switches.

Assumption

The Permanent Magnet Synchronous Machine block assumes a linear magnetic circuit with no saturation of the stator and rotor iron. This assumption can be made because of the large air gap usually found in permanent magnet synchronous machines.

Limitations

When you use Permanent Magnet Synchronous Machine blocks in discrete systems, you might have to use a small parasitic resistive load, connected at the machine terminals, to avoid numerical oscillations. Large sample times require larger loads. The minimum resistive load is proportional to the sample time. Remember that with a 25 µs time step on a 60 Hz system, the minimum load is approximately 2.5% of the machine nominal power. For example, a 200 MVA PM synchronous machine in a power system discretized with a 50 µs sample time requires approximately 5% of resistive load or 10 MW. If the sample time is reduced to 20 µs, a resistive load of 4 MW is sufficient.
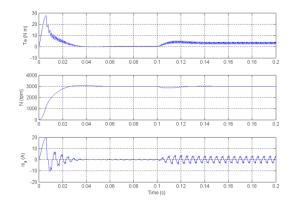
Example

The `power_brushlessDCmotor` example illustrates the use of the Permanent Magnet Synchronous Machine block in motoring mode with a closed-loop control system built entirely with Simulink blocks. The complete system includes a six step inverter block from the SimPowerSystems library. Two control loops are used; the inner loop synchronizes the pulses of the bridge with the electromotive forces, and the outer loop regulates the motor's speed, by varying the DC bus voltage. The mechanical torque applied at the motor's shaft is originally 0 N.m (no load) and steps to its nominal value (3 N.m) at t = 0.1 second.

Set the simulation parameters as follows:
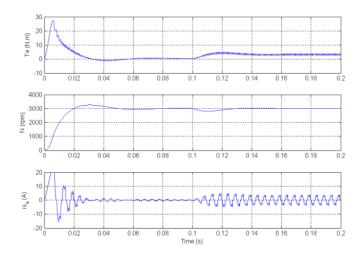
- Type: Fixed-step
- Integrator type: `Runge-Kutta`, `ode4`
- Sample time: 5e-6 (set automatically by the **Model properties**)
- Stop time: `0.2`

Set the **Flux distribution** parameter to `Trapezoidal` and run the simulation to observe the motor's torque, speed, and currents. Change the **Back EMF flat top area parameter** of the trapezoidal model from 120 to 0 and observe the waveform of the electromotive force e_a.

The torque climbs to nearly 28 N.m and stabilizes rapidly to its reference value. The nominal torque is applied at t = 0.1 second and the controller reacts rapidly and increases the DC bus voltage to produce the required electric torque. Observe the saw tooth shape of the currents waveforms. This is caused by the six step controller, which applies a constant voltage value during 120 electrical degrees to the motor. The initial current is high and decreases during the acceleration to the nominal speed. When the nominal torque is applied, the stator current increases to maintain the nominal speed. The saw tooth waveform is also observed in the electromotive torque signal Te. However, the motor's inertia prevents this noise from appearing in the motor's speed waveform.

When the **Back EMF flat top area** parameter of the trapezoidal model is changed from 120 to 0, the model reacts exactly like the sinusoidal model. The electromotive force e_a is purely sinusoidal and the torque ripple is less than the previous case. The sinusoidal model requires a larger current to produce the same torque. That reason is why the trapezoidal machine is used in high torque applications, and the sinusoidal machine in precision applications.

References

[1] Grenier, D., L.-A. Dessaint, O. Akhrif, Y. Bonnassieux, and B. LePioufle. "Experimental Nonlinear Torque Control of a Permanent Magnet Synchronous Motor Using Saliency." *IEEE Transactions on Industrial Electronics*, Vol. 44, No. 5, October 1997, pp.680-687.

[2] Toliyat, H.A. "Analysis and Simulation of Multi-Phase Variable Speed Induction Motor Drives Under Asymmetrical Connections." *Applied Power Electronics Conference and Exposition*, Vol. 2, March 1996, pp. 586-592.

[3] Beaudart, F., F. Labrique, E. Matagne, D. Telteux, and P. Alexandre. "Control under normal and fault tolerant operation of multiphase SMPM synchronous machines with mechanically and magnetically decoupled phases." *International Conference on Power Engineering, Energy and Electrical Drives*, March 2009, pp. 461-466.

[4] Krause, P.C., O. Wasynczuk, and S.D. Sudhoff. *Analysis of Electric Machinery and Drive Systems*. IEEE Press, 2002.

PI Section Line

Implement single-phase transmission line with lumped parameters

Library

Fundamental Blocks/Elements

Description
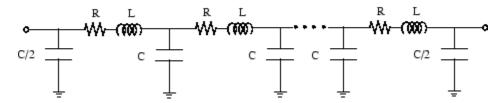
The PI Section Line block implements a single-phase transmission line with parameters lumped in PI sections.

For a transmission line, the resistance, inductance, and capacitance are uniformly distributed along the line. An approximate model of the distributed parameter line is obtained by cascading several identical PI sections, as shown in the following figure.

Unlike the Distributed Parameter Line block, which has an infinite number of states, the PI section linear model has a finite number of states that permit you to compute a linear state-space model. The number of sections to be used depends on the frequency range to be represented.

An approximation of the maximum frequency range represented by the PI line model is given by the following equation:

$$f_{\max} = \frac{N \cdot v}{8 \cdot ltot}$$

where

N	Number of PI sections
v	Propagation speed (km/s) = $1 = \sqrt{lc}$; l in H/km, c in F/km
$ltot$	Line length (km)

For example, for a 100 km aerial line having a propagation speed of 300,000 km/s, the maximum frequency range represented with a single PI section is approximately 375 Hz. For studying interactions between a power system and a control system, this simple model could be sufficient. However for switching surge studies involving high-frequency transients in the kHz range, much shorter PI sections should be used. In fact, you can obtain the most accurate results by using a distributed parameters line model.

Note The `Powergui` block provides a graphical tool for the calculation of the resistance, inductance, and capacitance per unit length based on the line geometry and the conductor characteristics.

Hyperbolic Correction of RLC Elements

Let us assume the following line parameters:

r	Resistance per unit length (Ω/km)
l	Inductance per unit length (H/km)
c	Capacitance per unit length (F/km)
f	Frequency (Hz)
$lsec$	Line section length = $ltot$ / N (km)

For short line sections (approximately $lsec$ <50 km) the RLC elements for each line section are simply given by:

$$R = r \cdot l \sec$$
$$L = l \cdot l \sec$$
$$C = c \cdot l \sec$$

However, for long line sections, the RLC elements given by the above equations must be corrected in order to get an exact line model at a specified frequency. The RLC elements are then computed using hyperbolic functions as explained below.

$$\omega = 2\pi f$$

Per unit length series impedance at frequency f is

$$z = r + j\omega l$$

Per unit length shunt admittance at frequency f is

$$y = j\omega c$$

Characteristic impedance is

$$Z_c = \sqrt{z/y}$$

Propagation constant is

$$\gamma = \sqrt{z \cdot y}$$

$$Z = R + j\omega L = Z_c \cdot \sinh(\gamma \cdot l \sec)$$

$$R = \text{real}(Z)$$

$$L = \text{imag}(Z)/\omega$$

$$Y = \frac{2}{Z_c} \cdot \tanh\left(\gamma \cdot \frac{l \sec}{2}\right)$$

$$C = \text{imag}(Y) / \omega$$

Hyperbolic corrections result in RLC values slightly different from the non corrected values. R and L are decreased while C is increased. These corrections become more important as line section length is increasing. For example, let us consider a 735 kV line with the following positive-sequence and zero-sequence parameters (these are the default parameters of the `Three-Phase PI Section Line` block and `Distributed Parameter Line` block):

Positive sequence	$r = 0.01273$ Ω/km $l = 0.9337 \times 10^{-3}$ H/km $c = 12.74 \times 10^{-9}$ F/km
Zero sequence	$r = 0.3864$ Ω/km $l = 4.1264 \times 10^{-3}$ H/km $c = 7.751 \times 10^{-9}$ F/km

For a 350 km line section, noncorrected RLC positive-sequence values are:

$$R = 0.01273 \times 350 = 4.455 \ \Omega$$

$$L = 0.9337 \times 10^{-3} \times 350 = 0.3268 \ \text{H}$$

$$C = 12.74 \times 10^{-9} \times 350 = 4.459 \times 10^{-6} \ \text{F}$$
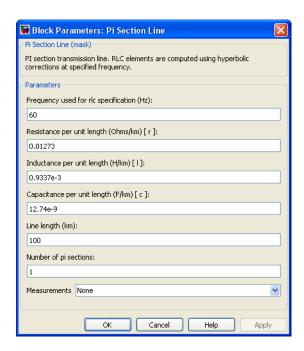
Hyperbolic correction at 60 Hz yields:

$$R = 4.153 \ \Omega$$

$$L = 0.3156 \ \text{H}$$

$$C = 4.538 \times 10^{-6} \ \text{F}$$

For these particular parameters and long line section (350 km), corrections for positive-sequence RLC elements are relatively important (respectively −6.8%, −3.4%, and + 1.8%). For zero-sequence parameters, you can verify that even higher RLC corrections must be applied (respectively −18%, −8.5%, and +4.9%).

The PI Section Line block always uses the hyperbolic correction, regardless of the line section length.

Dialog Box and Parameters

Frequency used for rlc specifications

Frequency f, in hertz (Hz), at which per unit length r, l, c parameters are specified. Hyperbolic correction is applied on RLC elements of each line section using this frequency.

Resistance per unit length

The resistance per unit length of the line, in ohms/km (Ω/km).

Inductance per unit length

The inductance per unit length of the line, in henries/km (H/km). This parameter can not be zero, because it would result in an invalid propagation speed computation.

Capacitance per unit length

The capacitance per unit length of the line, in farads/km (F/km). This parameter can not be zero, because it would result in an invalid propagation speed computation.

Length

The line length in km.

Number of pi sections

The number of PI sections. The minimum value is 1.

Measurements

Select `Input and output voltages` to measure the sending end (input port) and receiving end (output port) voltages of the line model.

Select `Input and output currents` to measure the sending end and receiving end currents of the line model.

Select `All pi-section voltages and currents` to measure voltages and currents at the start and end of each pi-section.
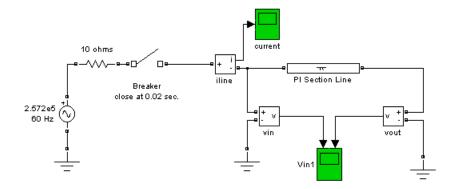
Select `All voltages and currents` to measure the sending end and receiving end voltages and currents of the line model.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurement is identified by a label followed by the block name.
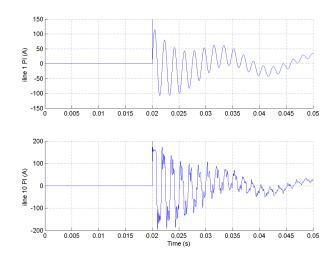
Measurement	Label
Sending end voltage (block input)	`Us:`
Receiving end voltage (block output)	`Ur:`
Sending end current (input current)	`Is:`
Receiving end current (output current)	`Ir:`

Example

The power_piline example shows the line energization voltages and currents of a PI section line.

The results obtained with the line modeled by one PI section of 100 km and 10 PI sections of 10 km are shown.

See Also

Distributed Parameter Line, `Three-Phase PI Section Line`

PLL

Determine frequency and fundamental component of signal phase angle

Library

Control and Measurements/PLL

Description
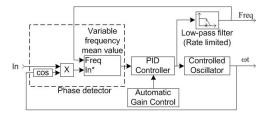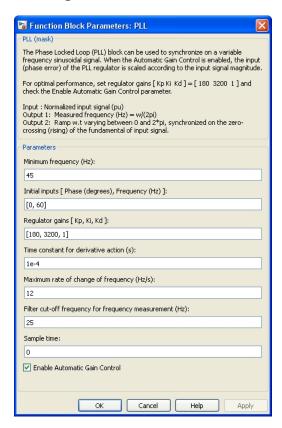
The PLL block models a Phase Lock Loop (PLL) closed-loop control system, which tracks the frequency and phase of a sinusoidal signal by using an internal frequency oscillator. The control system adjusts the internal oscillator frequency to keep the phases difference to 0.

The figure shows the internal diagram of the PLL.

The input signal is mixed with an internal oscillator signal. The DC component of the mixed signal (proportional to the phase difference between these two signals) is extracted with a variable frequency mean value. A Proportional-Integral-Derivative (PID) controller with an optional automatic gain control (AGC) keeps the phase difference to 0 by acting on a controlled oscillator. The PID output, corresponding to the angular velocity, is filtered and converted to the frequency, in hertz, which is used by the mean value.

Dialog Box and Parameters

Minimum frequency (Hz)

Specify the minimum expected frequency of the input signal. This parameter sets the buffer size of the Mean (Variable Frequency) block used inside the block to compute the mean value.

Initial inputs [Phase (degrees), Frequency (Hz)]

Specify the initial phase and frequency of the input signal.

Regulator gains [Kp, Ki, Kd]

Specify the proportional, integral, and derivative gains of the internal PID controller. Use the gains to tune the PLL response time, overshoot, and steady-state error performances.

Time constant for derivative action (s)

Specify the time constant for the first-order filter of the PID derivative block.

Maximum rate of change of frequency (Hz/s)

Specify the maximum positive and negative slope of the signal frequency.

Filter cut-off frequency for frequency measurement (Hz)

Specify the second-order lowpass filter cut-off frequency.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Enable automatic gain control

When this check box is selected, the PLL block optimizes its performances by scaling the PID regulator signal according to the input signal magnitude. Select this option when the input signal is not normalized.

Inputs and Outputs

In

The normalized input signal, in pu.

Freq

The measured frequency, in hertz.

wt

Angle (rad) varying between 0 and 2*pi, synchronized on the zero-crossing (rising) of the fundamental of the input signal.

Characteristics

Sample Time	Specified in the **Sample Time** parameter. Continuous when **Sample Time** = 0.
Scalar Expansion	No
Dimensionalized	No
Zero-Crossing Detection	Yes

Example

The power_PLL example shows the use of the PLL (3ph) and PLL blocks.

The PLL block is fed by a sinusoidal signal of 60 Hz, increasing to 61 Hz from 0.5 s to 1.5 s. Notice that the frequency reaches the new frequency in a short response time.

The PLL (3ph) block is fed by three-phase sinusoidal signals increasing from 60 Hz to 61 Hz between 0.5 and 1.5 seconds. The PLL (3ph) frequency reaches the new frequency faster than the PLL due to the additional phase information.

The model sample time is parameterized with the variable Ts (with a default value of 0). To discretize the PLL block, specify Ts=50e-6 in the MATLAB Command Window.

PLL (3ph)

Determine frequency and fundamental component of three-phase signal phase angle

Library

Control and Measurements/PLL

Description
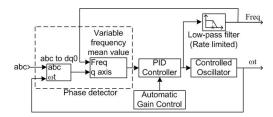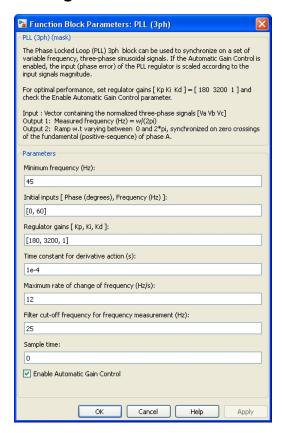
The PLL (3ph) block models a Phase Lock Loop (PLL) closed-loop control system, which tracks the frequency and phase of a sinusoidal three-phase signal by using an internal frequency oscillator. The control system adjusts the internal oscillator frequency to keep the phases difference to 0.

The figure shows the internal diagram of the PLL.

The three-phase input signal is converted to a dq0 rotating frame (Park transform) using the angular speed of an internal oscillator. The quadrature axis of the signal, proportional to the phase difference between the abc signal and the internal oscillator rotating frame, is filtered with a Mean (Variable Frequency) block. A Proportional-Integral-Derivative (PID) controller, with an optional automatic gain control (AGC), keeps the phase difference to 0 by acting on a controlled oscillator. The PID output, corresponding to the angular velocity, is filtered and converted to the frequency, in hertz, which is used by the mean value.

Dialog Box and Parameters

Minimum frequency (Hz)

Specify the minimum expected frequency of the input signal. This parameter sets the buffer size of the Mean (Variable Frequency) block used inside the block to compute the mean value.

Initial inputs [Phase (degrees), Frequency (Hz)]

Specify the initial phase and frequency of the input signal.

Regulator gains [Kp, Ki, Kd]

Specify the proportional, integral, and derivative gains of the internal PID controller. Use the gains to tune the PLL response time, overshoot, and steady-state error performances.

Time constant for derivative action (s)

Specify the time constant for the first-order filter of the PID derivative block.

Maximum rate of change of frequency (Hz/s)

Specify the maximum positive and negative slope of the signal frequency.

Filter cut-off frequency for frequency measurement (Hz)

Specify the second-order lowpass filter cut-off frequency.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Enable automatic gain control

When this check box is selected, the PLL block optimizes its performances by scaling the PID regulator signal according to the input signal magnitude. Select this option when the input signal is not normalized.

Inputs and Outputs

abc

The normalized three-phase signals, in pu.

Freq

The measured frequency, in hertz.

wt

Angle (rad) varying between 0 and 2*pi, synchronized on zero crossings of the fundamental (positive-sequence) of phase A.

Characteristics

Sample Time	Specified in the **Sample Time** parameter. Continuous when **Sample Time** = 0.
Scalar Expansion	No
Dimensionalized	No
Zero-Crossing Detection	Yes

Example

The power_PLL example shows the use of the PLL (3ph) and PLL blocks.

The PLL block is fed by a sinusoidal signal of 60 Hz, increasing to 61 Hz from 0.5 s to 1.5 s. Notice that the frequency reaches the new frequency in a short response time.

The PLL (3ph) block is fed by three-phase sinusoidal signals increasing from 60 Hz to 61 Hz between 0.5 and 1.5 seconds. The PLL (3ph) frequency reaches the new frequency faster than the PLL due to the additional phase information.

The model sample time is parameterized with the variable Ts (with a default value of 0). To discretize the PLL block, specify Ts=50e-6 in the MATLAB Command Window.

PM Synchronous Motor Drive

Implement Permanent Magnet Synchronous Motor (PMSM) vector control drive
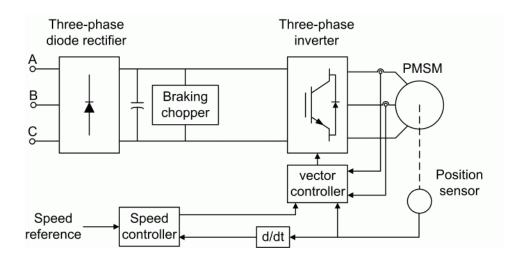
Library

Electric Drives/AC drives

Description
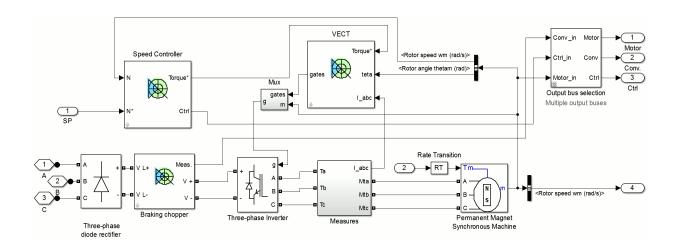
The high-level schematic shown below is built from six main blocks. The PMSM motor, the three-phase inverter, and the three-phase diode rectifier models are provided with the SimPowerSystems library. More details are available in the reference pages for these blocks. The speed controller, the braking chopper, and the vector controller models are specific to the drive library. It is possible to use a simplified version of the drive containing an average-value model of the inverter for faster simulation.

Note In SimPowerSystems software, the PM Synchronous Motor Drive block is commonly called the **AC6** motor drive.

High-Level Schematic
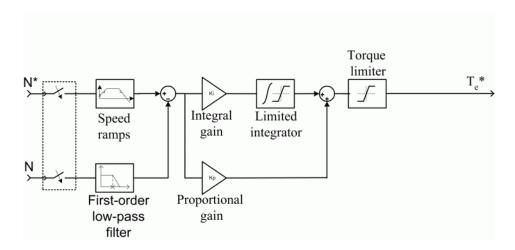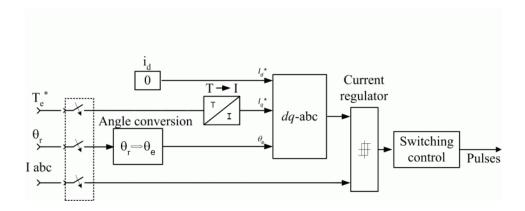
Simulink Schematic

Speed Controller

The speed controller is based on a PI regulator, shown below. The output of this regulator is a torque set point applied to the vector controller block.

Vector Controller

The vector controller contains four main blocks, shown below. These blocks are described below.

The *dq-abc* block performs the conversion of the *dq* current component in the rotor reference frame into *abc* phase variables.

The *current regulator* is a bang-bang current controller with adjustable hysteresis bandwidth.

The *angle conversion* block is used to compute the electrical rotor angle from the mechanical rotor angle.

The *Switching control* block is used to limit the inverter commutation frequency to a maximum value specified by the user.
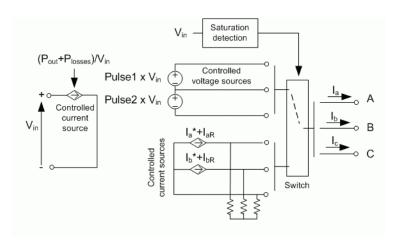
When using the average-value inverter, the *ab* current references are sent to the inverter, as well as switching pulses from a slightly modified *Switching control block*.

Braking Chopper

The braking chopper block contains the DC bus capacitor and the dynamic braking chopper, which is used to absorb the energy produced by a motor deceleration.

Average-Value Inverter

The average-value inverter is shown in the following figure.

It is composed of one controlled current source on the DC side and of two controlled current sources and two controlled voltage sources on the AC side. The DC current source allows the representation of the average DC bus current behavior following the next equation:

$I_{dc} = (P_{out} + P_{losses}) / V_{in}$

with P_{out} being the output power, P_{losses} the losses in the power electronic devices, and V_{in} the DC bus voltage.

On the AC side, the current sources represent the average phase currents fed to the motor. The regulation being fast, the current values are set equal to the current references sent by the current regulator. A small current is injected to compensate for the current drawn by the three-phase load (needed because of the inverter current sources in series with inductive motor).

During loss of current tracking due to insufficient inverter voltage, the currents are fed by two controlled voltage sources. These voltage sources represent the square wave mode and allow good representation of the phase currents during inverter saturation. Each voltage source outputs either Vin or 0, depending on the values of the pulses (1 or 0) sent by the current controller.

Remarks

The model is discrete. Good simulation results have been obtained with a 2 μs time step. To simulate a digital controller device, the control system has two different sampling times:

- Speed controller sampling time
- Vector controller sampling time

The speed controller sampling time has to be a multiple of the vector controller sampling time. The latter sampling time has to be a multiple of the simulation time step. The average-value inverter allows the use of bigger simulation time steps since it does not generate small time constants (due to the RC snubbers) inherent to the detailed converter. For a vector controller sampling time of 75 μs, good simulation results have been obtained for a simulation time step of 75 μs. The simulation time step can, of course, not be higher than the vector controller time step.

The stator current direct component *id** is set to zero inside the vector controller block because the rotor flux is supplied by the permanent magnets.

Dialog Box

Permanent Magnet Synchronous Machine Tab

The **Permanent Magnet Synchronous Machine** tab displays the parameters of the Permanent Magnet Synchronous Machine block of the Fundamental Blocks (powerlib) library.

Output bus mode

>   Select how the output variables are organized. If you select **Multiple output buses**, the block has three separate output buses for motor, converter, and controller variables. If you select **Single output bus**, all variables output on a single bus.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Select between the load torque, the motor speed and the mechanical rotational port as mechanical input. If you select and apply a load torque, the output is the motor speed according to the following differential equation that describes the mechanical system dynamics:

$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

If you select the motor speed as mechanical input, then you get the electromagnetic torque as output, allowing you to represent externally the mechanical system dynamics. The internal mechanical system is not used with this mechanical input selection and the inertia and viscous friction parameters are not displayed.

For the mechanical rotational port, the connection port S counts for the mechanical input and output. It allows a direct connection to the Simscape environment. The mechanical system of the motor is also included in the drive and is based on the same differential equation.

See "Mechanical Coupling of Two Motor Drives".

Converters and DC Bus Tab

Rectifier section

The rectifier section of the Converters and DC bus tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the universal bridge parameters.

Inverter section

The inverter section of the Converters and DC bus tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the universal bridge parameters.

The average-value inverter uses the following parameters.

Source frequency

The frequency of the three-phase voltage source (Hz).

On-state resistance

The on-state resistance of the inverter devices (ohms).

DC Bus Field — Capacitance

The DC bus capacitance (F).

Braking Chopper Section

Resistance

The braking chopper resistance used to avoid bus over-voltage during motor deceleration or when the load torque tends to accelerate the motor (ohms).

Frequency

The braking chopper frequency (Hz).

Activation Voltage

The dynamic braking is activated when the bus voltage reaches the upper limit of the hysteresis band. The following figure illustrates the braking chopper hysteresis logic.

Deactivation Voltage

The dynamic braking is shut down when the bus voltage reaches the lower limit of the hysteresis band. The chopper hysteresis logic is shown in the following figure.

Controller Tab

Regulation Type

This pop-up menu allows you to choose between speed and torque regulation.

Schematic Button

When you press this button, a diagram illustrating the speed and vector controllers schematics appears.

Speed Controller section

Speed cutoff frequency

The speed measurement first-order low-pass filter cutoff frequency (Hz). This parameter is used in speed regulation mode only.

Speed controller sampling time

The speed controller sampling time (s). The sampling time must be a multiple of the simulation time step.

Speed Ramps — Acceleration

The maximum change of speed allowed during motor acceleration (rpm/s). An excessively large positive value can cause DC bus under-voltage. This parameter is used in speed regulation mode only.

Speed Ramps — Deceleration

The maximum change of speed allowed during motor deceleration (rpm/s). An excessively large negative value can cause DC bus overvoltage. This parameter is used in speed regulation mode only.

PI Regulator — Proportional Gain

The speed controller proportional gain. This parameter is used in speed regulation mode only.

PI Regulator — Integral Gain

The speed controller integral gain. This parameter is used in speed regulation mode only.

Torque output limits — Negative

The maximum negative demanded torque applied to the motor by the current controller (N.m).

Torque output limits — Positive

The maximum positive demanded torque applied to the motor by the current controller (N.m).

Vector Controller Section

Sampling Time

The vector controller sampling time (s). The sampling time must be a multiple of the simulation time step.

Current controller hysteresis band

The current hysteresis bandwidth. This value is the total bandwidth distributed symmetrically around the current set point (A). The following figure illustrates a case where the current set point is Is[*] and the current hysteresis bandwidth is set to dx.

This parameter is not used when using the average-value inverter.

> **Note** This bandwidth can be exceeded because a fixed-step simulation is used. A rate transition block is needed to transfer data between different sampling rates. This block causes a delay in the gate signals, so the current may exceed the hysteresis band.

Maximum switching frequency

The maximum inverter switching frequency (Hz). This parameter is not used when using the average-value inverter.

Block Inputs and Outputs

SP

The speed or torque set point. The speed set point can be a step function, but the speed change rate will follow the acceleration / deceleration ramps. If the load torque and the speed have opposite signs, the accelerating torque will be the sum of the electromagnetic and load torques.

Tm or Wm

The mechanical input: load torque (Tm) or motor speed (Wm).

A, B, C

The three phase terminals of the motor drive.

Wm or Te

The mechanical output: motor speed (Wm) or electromagnetic torque (Te).

When the **Output bus mode** parameter is set to **Multiple output buses**, the block has the following three output buses:

Motor

The motor measurement vector. This vector allows you to observe the motor's variables using the Bus Selector block.

Conv

The three-phase converters measurement vector. This vector contains:

- The DC bus voltage
- The rectifier output current
- The inverter input current

Note that all current and voltage values of the bridges can be visualized with the Multimeter block.

Ctrl

The controller measurement vector. This vector contains:

- The torque reference
- The speed error (difference between the speed reference ramp and actual speed)
- The speed reference ramp or torque reference

When the **Output bus mode** parameter is set to **Single output bus**, the block groups the Motor, Conv, and Ctrl outputs into a single bus output.

Model Specifications

The library contains a 3 hp drive parameter set. The specifications of the 3 hp drive are shown in the following table

3 HP Drive Specifications

Drive Input Voltage		
	Amplitude	220 V
	Frequency	60 Hz
Motor Nominal Values		
	Power	3 hp
	Speed	1800
	Voltage	300

Example

The `ac6_example` example illustrates an AC6 motor drive simulation with standard load condition. At time t = 0 s, the speed set point is 300 rpm.

As shown in the following figure, the speed precisely follows the acceleration ramp. At t = 0.5 s, the nominal load torque is applied to the motor. At t = 1 s, the speed set point is changed to 0 rpm. The speed decreases to 0 rpm. At t = 1.5 s., the mechanical load passes from 11 N.m to −11 N.m. Average voltage, current, torque, and speed values are identical for both models. Notice that the higher frequency signal components are not represented with the average-value converter.

AC6 Example Waveforms (Blue: Detailed Converter, Red: Average-Value Converter)

References

[1] Bose, B. K., *Modern Power Electronics and AC Drives*, Prentice-Hall, N.J., 2002.

[2] Krause, P. C., *Analysis of Electric Machinery*, McGraw-Hill, 1986.

Positive-Sequence (PLL-Driven)

Compute positive-sequence component of three-phase signal at fundamental frequency

Library

Control and Measurements/Measurements

Description

The Positive-Sequence (PLL-Driven) block computes the positive-sequence component (magnitude and phase) of the input 3 signal over a running window of one cycle of the fundamental frequency given by input 1. The reference frame required for the computation is given by the input 2. The first two inputs are normally connected to a PLL block.
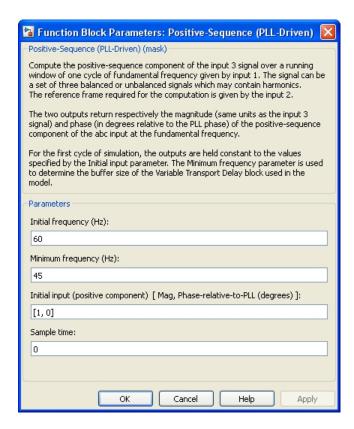
The positive-sequence component of a three-phase signal (V_1 or current I_1) is computed as

$$V_1 = \frac{1}{3}\left(V_a + a \cdot V_b + a^2 \cdot V_c\right)$$

V_a, V_b, V_c = three voltage phasors at the fundamental frequency

$a = e^{j\,2\pi/3} = 1\angle 120°$ complex operator

A Fourier analysis over a sliding window of one cycle of the fundamental frequency (input 1) is first applied to the three input signals. The block evaluates the phasor values at the fundamental. Then the transformation is applied to obtain the positive sequence.

As the block uses a running average window to perform the Fourier analysis, one cycle of simulation must complete before the outputs give the correct magnitude and angle. For example, the block response to a step change of V_1 is a one-cycle ramp. For the first cycle of simulation, the output is held constant to the values specified by the initial input parameters.

Dialog Box and Parameters

Initial frequency (Hz)

Specify the frequency of the first cycle of simulation.

Minimum frequency (Hz)

The minimum frequency value determines the buffer size of the Variable Time Delay block used inside the block to compute the phasors.

Initial input (positive component) [Mag, Phase-relative-to-PLL (degrees)]

Specify the initial positive-sequence magnitude and phase (relative to the PLL phase), in degrees, of the input signals.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Inputs and Outputs

Freq

Fundamental frequency (Hz) required by the computation. This input is normally connected to the Freq output of a PLL block.

wt

Angle of the reference frame (rad/s) required for the computation. This input is normally connected to the wt output of a PLL block.

abc

The vectorized signal of the three [a b c] sinusoidal signals. Typical input signals are voltages or currents measured by Current Measurement or Voltage Measurement blocks.

|u|Magnitude

Outputs the magnitude of the positive-sequence component in the same unit as the input signal.

∠u Phase

Outputs the phase of the positive-sequence component, in degrees, relative to the reference frame wt (input 2).

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	No
Dimensionalized	No

Example

The power_PositiveSequencePLLDriven model computes the positive-sequence component of a three-phase signal containing harmonics. It shows that the block outputs

accurate magnitude and phase even if the fundamental frequency of the input signal varies during the simulation.

The model sample time is parameterized by the Ts variable set to a default value of 50e-6 s. Set Ts to 0 in the command window to simulate the model in continuous mode.

Power

Compute active and reactive powers of voltage-current pair at fundamental frequency

Library

Control and Measurements/Measurements

Description

The Power block computes the active power (P), in watts, and the reactive power (Q), in vars, of a voltage-current pair at fundamental frequency. To perform this computation, the block first determines the fundamental values (magnitude and phase) of the two input signals V & I. The following P and Q are then calculated:
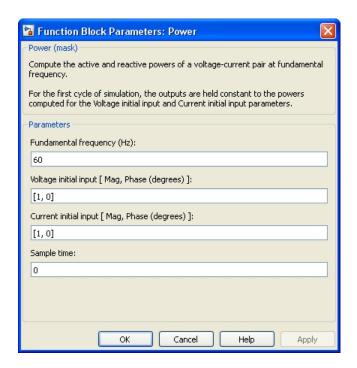
$$P = \frac{|V|}{\sqrt{2}} \times \frac{|I|}{\sqrt{2}} \times \cos(\varphi)$$

$$Q = \frac{|V|}{\sqrt{2}} \times \frac{|I|}{\sqrt{2}} \times \sin(\varphi)$$

$$\varphi = \angle V - \angle I$$

As this block uses a running average window, one cycle of simulation must complete before the outputs give the correct value. For the first cycle of simulation, the outputs are held constant using the values specified by the **Voltage initial input** and **Current initial input** parameters.

Dialog Box and Parameters

Fundamental frequency (Hz)

Specify the fundamental frequency, in hertz, of the input signals.

Voltage initial input [Mag, Phase (degrees)]

Specify the voltage initial magnitude and phase to set a constant output for the first cycle of simulation.

Current initial input [Mag, Phase (degrees)]

Specify the current initial magnitude and phase to set a constant output for the first cycle of simulation.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Inputs and Outputs

V

  The voltage signal.

I

  The current signal.

P

  The active power of voltage-current pair signal, in watts.

Q

  The reactive power of voltage-current pair signal, in vars.

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	Yes, of the parameters
Dimensionalized	Yes

Example

The power_Power model shows the accuracy of the Power block in evaluating the active and reactive powers of a voltage-current set.

The model sample time is parameterized by the Ts variable set to a default value of 50e-6 s. Set Ts to 0 in the command window to simulate the model in continuous mode.

Power (3ph, Instantaneous)

Compute three-phase instantaneous active and reactive powers

Library

Control and Measurements/Measurements

Description
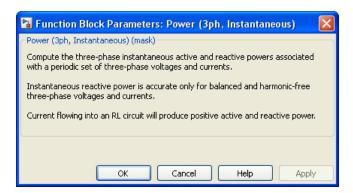
The Power (3ph, Instantaneous) block computes the three-phase instantaneous active power P (in watts) and reactive power Q (in vars) associated with a periodic set of three-phase voltages and currents. These formulas are used to perform the calculations:

$$P = V_a \cdot I_a + V_b \cdot I_b + V_c \cdot I_c$$
$$Q = \frac{1}{\sqrt{3}} \left[(V_b - V_c) \cdot I_a + (V_c - V_a) \cdot I_b + (V_a - V_b) \cdot I_c \right]$$

With these formulas, a current flowing into an RL circuit produces a positive P and a positive Q.

The computed instantaneous reactive power is accurate only for balanced and harmonic-free three-phase voltages and currents.

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Dialog Box and Parameters

The block has no parameters.

Inputs and Outputs

Vabc

　The three-phase voltage signal.

Iabc

　The three-phase current signal.

P

　The three-phase instantaneous active power P, in watts.

Q

　The three-phase instantaneous reactive power Q, in vars.

Example

The power_ThreePhasePower model compares the outputs of the block with the Power (Positive-Sequence) block and the Power (dq0, Instantaneous) block. It shows that the Power (3ph, Instantaneous) block gives accurate results when the voltages and currents are balanced and harmonic free. When the voltage supply becomes unbalanced, the P output exhibits a ripple, and an error appears on the Q output.

The model sample time is parameterized by the Ts variable set to a default value of 50e-6 s. Set Ts to 0 in the command window and change the **Simulation type** parameter of the Powergui block to `Continuous` to simulate the model in continuous mode.

Power (3ph, Phasor)

Compute three-phase active and reactive powers using three-phase voltage and current phasors

Library

Control and Measurements/Measurements

Description
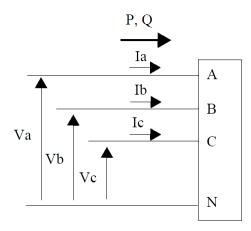
The Power (3ph, Phasor) block outputs total active power P and reactive power Q of a three-phase voltage-current phasor signal pair. P and Q are computed as follows:
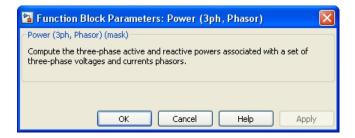
$$P + jQ = \frac{1}{2}\left(Va \times Ia^* + Vb \times Ib^* + Vc \times Ic^*\right)$$

Ia^*, Ib^*, Ic^* are the complex conjugates of Ia, Ib, and Ic.

The figure shows sign conventions:

Dialog Box and Parameters

The block has no parameters.

Inputs and Outputs

Vabc

    The three-phase phasor (three complex signals) voltage signal, in volts peak.

Iabc

    The three-phase phasor (three complex signals) current signal, in amperes peak.

P

    Returns the total active power, in watts.

Q

    Returns the total active power, in vars.

Characteristics

Direct Feedthrough	Yes
Dimensionalized	No

Example

The power_PhasorPowerMeasurements example shows the use of the Power (3ph, Phasor) block.

Power (dq0, Instantaneous)

Compute three-phase instantaneous active and reactive powers

Library

Control and Measurements/Measurements

Description

The Power (dq0, Instantaneous) block computes the three-phase instantaneous active and reactive powers from a periodic set of three-phase voltages and currents expressed in the dq0 reference frame. These formulas perform the calculations:
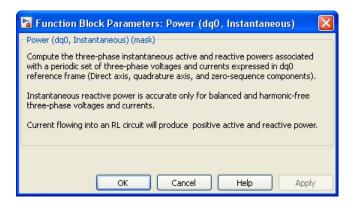
$$P = \frac{3}{2} \times \left(V_d \cdot I_d + V_q \cdot I_q + 2 \cdot V_0 \cdot I_0 \right)$$

$$Q = \frac{3}{2} \times \left(V_q \cdot I_d - V_d \cdot I_q \right)$$

The inputs Vdq0 and Idq0 (direct axis, quadrature axis, and zero-sequence components) of the three-phase voltage and current are normally connected to the outputs of the abc-to-dqo Transformation block.

With these formulas, a current flowing into an RL circuit produces a positive P and a positive Q.

The computed instantaneous reactive power is accurate only for balanced and harmonic-free three-phase voltages and currents.

Dialog Box and Parameters

The block has no parameters.

Inputs and Outputs

Vdq0

The voltage signal, expressed in the dq0 reference frame.

Idq0

The current signal, expressed in the dq0 reference frame.

P

The three-phase instantaneous active power P, in watts.

Q

The three-phase instantaneous reactive power Q, in vars.

Example

The power_ThreePhasePower model compares the outputs of the block with the Power (Positive-Sequence) block and the Power (3ph, Instantaneous) block. It shows that the Power (dq0, Instantaneous) block gives accurate results when the voltages and currents are balanced and harmonic free. When the voltage supply becomes unbalanced, the P output exhibits a ripple, and an error appears on the Q output.

The model sample time is parameterized by the Ts variable set to a default value of 50e-6 s. Set Ts to 0 in the command window and change the **Simulation type** parameter of the Powergui block to `Continuous` to simulate the model in continuous mode.

powergui

Environment block for SimPowerSystems Specialized Technology models

Library

Fundamental Blocks (powerlib)

Description

The powergui block allows you to choose one of these methods to solve your circuit:

- Continuous, which uses a variable-step solver from Simulink
- Ideal switching continuous
- Discretization of the electrical system for a solution at fixed time steps
- Phasor solution
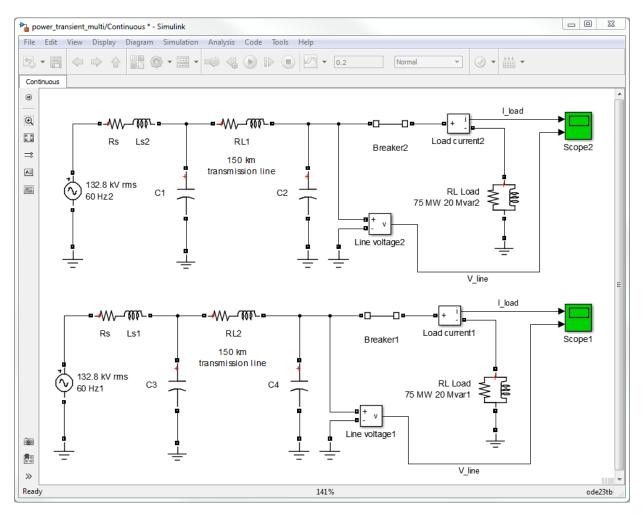
The powergui block also opens tools for steady-state and simulation results analysis and for advanced parameter design.

You need the powergui block to simulate any Simulink model containing SimPowerSystems Specialized Technology blocks. It stores the equivalent Simulink circuit that represents the state-space equations of the model.
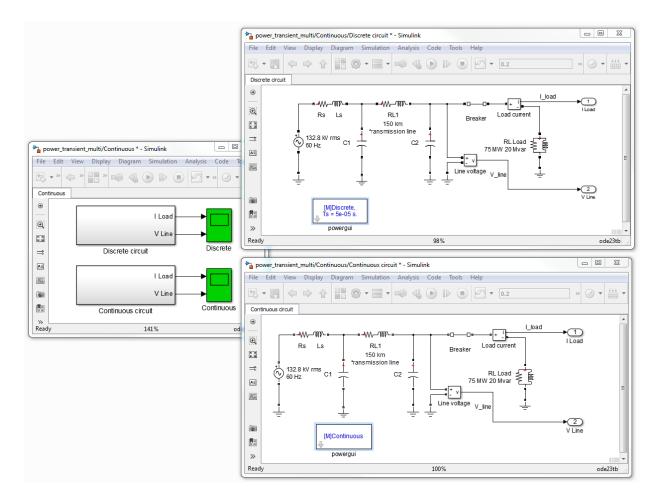
When using one powergui block in a model:

- Place the powergui block in the top-level diagram for optimal performance.
- Make sure that the block uses the name `powergui`.

You can use multiple powergui blocks in a system that contains two or more independent electrical circuits that you want to simulate with different powergui solvers. For example, this system simulates the upper electrical circuit in discrete mode and the bottom circuit in continuous mode. The purpose is to compare simulation performance of the two methods.
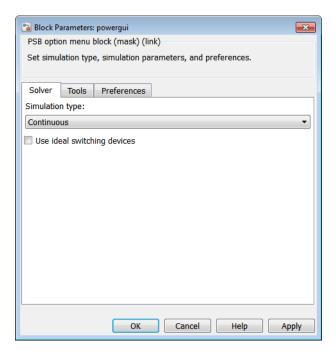
To do so, put each circuit in two different subsystem, and then add a powergui block inside every subsystem. The figure shows this configuration:

When you use more than one powergui block in a model:

- Do not place a powergui block in the top-level diagram.
- Place every independent model in a different subsystem.
- Place a single powergui block in the top level diagram of every subsystem.

Dialog Box and Parameters

- "Solver" on page 1-642
- "Tools" on page 1-646
- "Preferences" on page 1-648

Solver

The configuration of the **Solver** tab depends on the option that you select from the **Simulation type** list.

Simulation type

Select `Continuous` (the default) to perform a continuous solution of the model.

Select `Discrete` to perform a discretization of the model. You specify the sample time in the **Sample time** parameter.

Select `Phasor` to perform phasor simulation of the model, at the frequency specified by the **Phasor frequency** parameter.

Use of ideal switching devices

Select to model the switches and power electronic blocks using ideal or quasi-ideal switches. For more information, see "Using the Ideal Switching Device Method". This parameter is visible only when the **Simulation type** parameter is set to `Continuous`. By default, this option is not selected.

Disable snubbers in switching devices

Select to disable the snubber devices of the power electronic and breaker blocks in your model. This parameter is visible only if **Use ideal switching devices** is selected. By default, this option is not selected.

Disable On resistance in switching devices (Ron=0)

Select to disable the internal resistance of switches and power electronic devices and to force the value to zero ohms. This parameter is visible only if you select **Use ideal switching devices**. By default, this option is not selected.

Disable Forward voltage in switching devices (Vf=0)

Select to disable the internal forward voltage of power electronic devices and to force the value to zero volts. This parameter is visible only if you select **Use ideal switching devices**. By default, this option is not selected.

Display circuit differential equations

Select to display the differential equations of the model in the MATLAB Command Window when the simulation starts. This parameter is visible only if you select **Use ideal switching devices**. For more information, see "Using the Ideal Switching Device Method". By default, this option is not selected.

Solver type

Set to `Tustin/Backward Euler (TBE)` to simulate the electrical model using a combination of Tustin and Backward Euler methods.

Set to `Tustin` to discretize the electrical model using the Tustin method.

Set to `Backward Euler` to discretize the electrical model using the Backward Euler method.

The default and recommended method is the `Tustin/Backward Euler (TBE)` method, as explained in "Simulating Discretized Electrical Systems". This parameter is visible only if you set **Simulation Type** to `Discrete`.

Interpolate

Select to increase simulation speed by enabling the solver to interpolate in discrete models using power electronics. When this option is selected, the solver captures gate transitions of power electronic devices occurring between two sample times, allowing larger sample times (typically 20X) than you use with the standard solvers. For example, simulating a 5 kHz PWM converter with Tustin (no interpolation) or Tustin/Backward Euler normally requires a 1.0 µs sample time (sampling frequency = 200 x PWM frequency) to obtain a good resolution on pulse generation and guarantee accurate results. With interpolation enabled, using a sample time as large as 20 µs executes faster while preserving model accuracy.

When you enable this option:

- Use a continuous pulse generator to guarantee the best accuracy on pulse generation (specify sample time = 0 in pulse-generation blocks).
- In **Simulink Model Configuration Parameters**, select a continuous, variable-step solver (`ode45` or `ode23tb` with default settings). The continuous solver is required by the interpolation solver to compute the gate signals time delays with respect to discrete sample times. The solver uses these pulse delays to interpolate between sample times and produce accurate results.

See the power_buck example model to see how interpolation increases accuracy and simulation speed.

Use time-stamped gate signals

The interpolation method computes model outputs at fixed sample times while taking into account switching events that occur between two sample times. The method receives pulses at fixed time steps and computes the time delays of gate signals arriving within each time step. Computing the time delays enables the method to capture the evolution of states at different switching times.

When **Use time-stamped gate signals** is cleared, the interpolation method computes the time delays of gate signal.

When **Use time-stamped gate signals** is selected, the block does not compute the time delays of gate signals. You then need to directly provide time-stamped gate signals to the switching devices in your model. See the power_buck example for more information on the concept of time-stamped gate signals in SimPowerSystems switching devices.

The **Use time-stamped gate signals** parameter is visible only when you set **Simulation type** to Discrete, set **Solver type** to Tustin, and select the **Interpolate** option. By default, this option is cleared.

Store state-space matrices

Select to increase simulation speed by enabling the solver to store and reuse matrix computation results. This parameter is visible only when you set **Simulation type** to `Discrete`, set **Solver type** to `Tustin`, and select the **Interpolate** option. By default, this option is not selected.

Buffer Size (MBytes)

Specify the buffer size for saving state-space matrix computations. This parameter is visible only when you set **Simulation type** to `Discrete`, set **Solver type** to `Tustin`, and select the **Interpolate** and **Store state-space matrices** options. The default is value is `100` MB.

Sample time (s)
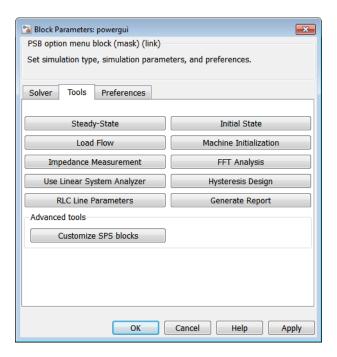
Specify the sample time used to discretize the electrical circuit. This parameter is visible only when the **Simulation type** parameter is set to `Discrete`.

Set the **Sample time** parameter t to a value greater than 0. The powergui block displays the value of the sample time. The default is value is `50e-6` s.

Phasor frequency (Hz)

Specify the frequency for performing the phasor simulation of the model. This parameter is visible only when you set **Simulation type** to `Phasor`. The default is value is `60` Hz.

Tools

Steady-State

> Open the Steady-State Voltages and Currents Tool dialog box to display the steady-state voltages and currents of the model. For more information, see `power_steadystate`.

Initial State

> Open the Initial States Setting Tool dialog box to display and modify initial capacitor voltages and inductor currents of the model. For more information, see `power_initstates`.

Load Flow

> Open the Load Flow Tool dialog box to perform load flow and initialize three-phase networks and machines so that the simulation starts in steady state.

> The Load Flow tool uses the Newton-Raphson method to provide robust and faster convergence solution compared to the Machine Initialization tool.

The Load Flow tool offers most of the functionality of other tools available in the power utility industry. For more information, see `power_loadflow`.

Machine Initialization

Open the Machine Initialization Tool dialog box to initialize three-phase networks containing three-phase machines so that the simulation starts in steady state. The Machine Initialization tool offers simplified load flow features but can still initialize machine initial currents of your models. For more information, see `power_loadflow`.

Impedance Measurement

Open the Impedance vs Frequency Measurement Tool dialog box to display the impedance versus frequency defined by the Impedance Measurement blocks. For more information, see `power_zmeter`.

FFT Analysis

Open the FFT Analysis Tool dialog box to perform Fourier analysis of signals stored in a structure with time format. For more information, see `power_fftscope`.

See "Performing Harmonic Analysis Using the FFT Tool"for an example that uses the FFT Analysis tool .

Use Linear System Analyzer

Open a window to generate the state-space model of your system (if you have Control System Toolbox software installed) and open the Linear System Analyzer interface for time and frequency domain responses. For more information, see `power_ltiview`.

Hysteresis Design Tool

Open a window to design a hysteresis characteristic for the saturable core of the Saturable Transformer block and the Three-Phase Transformer blocks (two- and three-windings). For more information, see `power_hysteresis`.

RLC Line Parameters

Open a window to compute RLC parameters of an overhead transmission line from conductor characteristics and tower geometry. For more information, see `power_lineparam`.

Generate Report

Open the Generate Report Tool dialog box to generate a report of steady-state variables, initial states, and machine load flow for a model. For more information, see `power_report`.

Customize SPS blocks

Open `power_customize` to create custom SimPowerSystems Specialized Technology blocks.

Preferences

The load flow parameters are for model initialization only. They do not have an impact on simulation performance.

Disable SimPowerSystems warnings

When this check box is selected, the SimPowerSystems warnings do not display during model analysis and simulation. By default, this option is not selected.

Display SimPowerSystems compilation messages

Select to enable the command-line echo messages during model analysis. By default, this option is not selected.

Use TLC file when in Accelerator Simulation Mode and for code generation

Select to use TLC state-space S-functions (`sfun_spssw_contc.tlc` and `sfun_spssw_discc.tlc`) in Accelerator mode and for code generation.

Clear this box if you notice a slowdown in performance when using Accelerator mode, compared to previous releases. This slowdown occurs if you have the LCC compiler installed as the default compiler for building external interface (`mex`). By default, this option is not selected.

Start simulation with initial electrical states from

If `blocks` is selected, initial state values defined in blocks are used for the simulation.

If `steady` is selected, force all initial electrical state values to steady-state values.

If `zero` is selected, force all initial electrical state values to zero.

The default is `blocks`.

Load flow frequency (Hz)

Specify the frequency used by the Load Flow tool to compute the normalized Ybus network admittance matrix of the model and to perform the load flow calculations. The default value is `60` Hz.

Base power Pbase (VA)

Specify the base power used by the Load Flow tool to compute the normalized Ybus network admittance matrix in pu/Pbase and bus base voltages of the model, at the frequency specified by the **Load flow frequency** parameter.

To avoid a badly conditioned Ybus matrix, select the base power value in the range of nominal powers and loads of the model. For a transmission network with voltages ranging from 120 kV to 765 kV, a 100 MVA base is usually selected. For a distribution network or for a small plant consisting of generators, motors, and loads having a nominal power in the range of hundreds of kilowatts, a 1 MVA base power is better adapted. The default value is `100e6` VA.

PQ tolerance (pu)

Defines the tolerance between P and Q when the Load flow tool stops to iterate. The default value is `1e−4`.

Max iterations

Defines the maximum number of iterations the Load flow tool iterates until the P and Q powers mismatch at each bus is lower than the **PQ tolerance** parameter value (in pu/Pbase). The power mismatch is defined as the difference between the net power injected into the bus by generators and loads and the power transmitted on all links leaving that bus. For example, if the base power is 100 MVA and **PQ tolerance** is set to `1e-4`, the maximum power mismatch at all buses does not exceed 0.1 MW or 0.1 Mvar. The default value is `50`.

Voltage units

Determine the voltage units (V, kV) used by the Load Flow tool to display voltages. The default is `kV`.

Power units

Determine the power units (W, kW, MW) used by the Load Flow tool to display powers. The default is `MW`.

See Also

power_customize, power_fftscope, power_hysteresis, power_initstates, power_lineparam, power_ltiview, power_loadflow, power_report, power_steadystate, power_zmeter

Introduced before R2006a

Power (Phasor)

Compute active and reactive powers using voltage and current phasors

Library

Control and Measurements/Measurements

Description
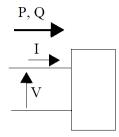
The Power (Phasor) block computes the active power P and reactive power Q of a pair of voltage-current signals. P and Q are computed as follows:
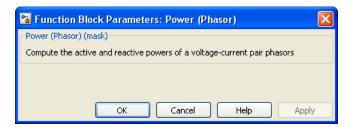
$$P + jQ = \frac{1}{2}\left(V \times I^*\right)$$

I^* = complex conjugate of I.

Sign conventions are defined as

Dialog Box and Parameters

The block has no parameters.

Inputs and Outputs

V

The phasor (complex signal) voltage, in volts peak.

I

The phasor (complex signal) current, in amperes peak.

P

Returns the active power, in watts.

Q

Returns the active power, in vars.

Characteristics

Direct Feedthrough	Yes
Dimensionalized	Yes

Example
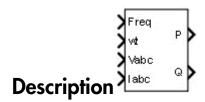
The power_PhasorPowerMeasurements example shows the use of the Power (Phasor) block.

Power (PLL-Driven, Positive-Sequence)

Compute positive-sequence active and reactive powers

Library

Control and Measurements/Measurements

Description

The Power (PLL-Driven, Positive-Sequence) block computes the positive-sequence active power P (in watts) and reactive power Q (in vars) of a periodic set of three-phase voltages and currents. To perform this computation, the block first computes the positive sequence of the input voltages and currents with a running window over one cycle of the fundamental frequency given by input 1. The reference frame required for the computation is given by the input 2. The first two inputs are normally connected to the outputs of a PLL block.

These formulas are then evaluated:
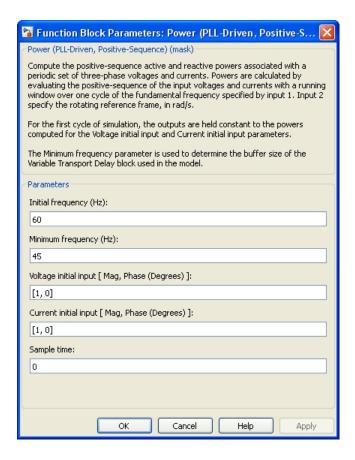
$$P = 3 \times \frac{|V_1|}{\sqrt{2}} \times \frac{|I_1|}{\sqrt{2}} \times \cos(\varphi)$$

$$Q = 3 \times \frac{|V_1|}{\sqrt{2}} \times \frac{|I_1|}{\sqrt{2}} \times \sin(\varphi)$$

$$\varphi = \angle V_1 - \angle I_1$$

V_1 is the positive-sequence component of input Vabc. I_1 is the positive-sequence component of input Iabc.

With these formulas, a current flowing into an RL circuit produces a positive P and a positive Q.

As this block uses a running average window, one cycle of simulation must complete before the outputs give the correct value. For the first cycle of simulation, the output is held constant using the values specified by the **Voltage initial input** and **Current initial input** parameters.

Dialog Box and Parameters

Initial frequency (Hz)

Specify the frequency of the first cycle of simulation.

Minimum frequency (Hz)

Specify the minimum frequency value to determine the buffer size of the Variable Time Delay block used by the block to compute the phasors.

Voltage initial input [Mag, Phase (degrees)]

Specify the initial positive-sequence magnitude and phase (relative to the PLL phase), in degrees, of the voltage signals.

Current initial input [Mag, Phase (degrees)]

Specify the initial positive-sequence magnitude and phase (relative to the PLL phase), in degrees, of the current signals.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Inputs and Outputs

Freq

Fundamental frequency (Hz) required by the computation. This input is normally connected to the output Freq of a PLL block.

wt

Angle of the reference frame (rad/s) required for the computation. This input is normally connected to the output wt of a PLL block.

Vabc

The vectorized signal of the three [a b c] voltage sinusoidal signals. Typical input signals are voltages measured by the Three-Phase V-I Measurement block.

Iabc

The vectorized signal of the three [a b c] current sinusoidal signals. Typical input signals are currents measured by the Three-Phase V-I Measurement block.

P

Positive-sequence active power (watts)

Q

Positive-sequence reactive power (vars)

Characteristics

Sample Time	Specified in the **Sample Time** parameter

	Continuous if **Sample Time** = 0
Scalar Expansion	No
Dimensionalized	No

Example

The power_PowerPLLDrivenPositiveSequence model shows how the block evaluates the positive-sequence active and reactive powers of a voltage source connected to a three-phase load. It shows that the block outputs accurate values for P and Q even if the fundamental frequency of the voltage supply (containing harmonics) varies during the simulation.

The model sample time is parameterized by the Ts variable set to a default value of 50e-6 s. Set Ts to 0 in the command window and change the **Simulation type** parameter of the Powergui block to Continuous to simulate the model in continuous mode.

Power (Positive-Sequence)

Compute positive-sequence active and reactive powers

Library

Control and Measurements/Measurements

Description

The Power (Positive-Sequence) block computes the positive-sequence active power P (in watts) and reactive power Q (in vars) of a periodic set of three-phase voltages and currents. To perform this computation, the block first computes the positive sequence of the input voltages and currents with a running window over one cycle of the specified fundamental frequency. These formulas are then evaluated:
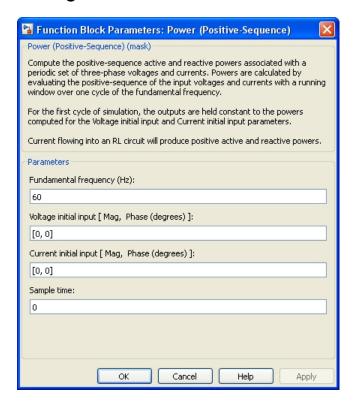
$$P = 3 \times \frac{|V_1|}{\sqrt{2}} \times \frac{|I_1|}{\sqrt{2}} \times \cos(\varphi)$$

$$Q = 3 \times \frac{|V_1|}{\sqrt{2}} \times \frac{|I_1|}{\sqrt{2}} \times \sin(\varphi)$$

$$\varphi = \angle V_1 - \angle I_1$$

V_1 is the positive-sequence component of input Vabc. I_1 is the positive-sequence component of input Iabc.

A current flowing into an RL circuit produces a positive P and a positive Q.

As this block uses a running average window, one cycle of simulation must complete before the outputs give the correct value. For the first cycle of simulation, the output is held constant using the values specified by the **Voltage initial input** and **Current initial input** parameters.

Dialog Box and Parameters

Fundamental frequency (Hz)

Specify the fundamental frequency, in hertz, of the input signals.

Voltage initial input [Mag, Phase (degrees)]

Specify the voltage initial magnitude and phase used by the block to compute the constant output for the first cycle of simulation.

Current initial input [Mag, Phase (degrees)]

Specify the current initial magnitude and phase used by the block to compute the constant output for the first cycle of simulation.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Inputs and Outputs

Vabc

  The three-phase voltage signal.

Iabc

  The three-phase current signal.

P

  The positive-sequence active power, in watts.

Q

  The positive-sequence reactive power, in vars.

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	No
Dimensionalized	No

Example

The power_ThreePhasePower model compares the outputs of the Power (Positive-Sequence) block with the Power (3ph, Instantaneous) and the Power (dq0, Instantaneous) block. The Power (Positive-Sequence) block gives ripple-free accurate results even with the presence of zero and negative sequences in the voltage supply.
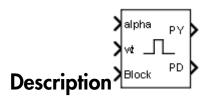
The model sample time is parameterized by the Ts variable set to a default value of 50e-6 s. Set Ts to 0 in the command window and change the **Simulation type** parameter of the Powergui block to Continuous to simulate the model in continuous mode.

Pulse Generator (Thyristor)

Generate pulses for twelve-pulse and six-pulse thyristor converters

Library
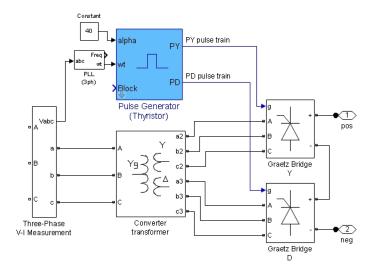
Control and Measurements/Pulse & Signal Generators

Description

The Pulse Generator (Thyristor) block generates two pulse trains. These control a twelve-pulse thyristor converter made of two three-phase full-wave thyristor bridges (also called Graetz bridges). In steady-state condition, each pulse train consists of six equidistant square pulses with 60 degrees shift between them.
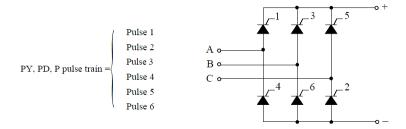
The first set of pulses (PY) is sent to the six-pulse bridge connected to the wye (Y) secondary winding of the Y/Y/Delta converter transformer. The second set of pulses (PD) is sent to the six-pulse bridge connected to the delta secondary winding of the converter transformer. The PD pulses can be set to lead or lag the PY pulses by 30 electrical degrees, depending on the configuration of the delta connection of the converter transformer.

The following figure shows an example of a Pulse Generator (Thyristor) block connected to a twelve-pulse thyristor converter.

The Pulse Generator (Thyristor) block can be programmed to control a six-pulse thyristor converter made of one three-phase full-wave thyristor bridge. In this configuration, the PD pulse train is not generated and the block outputs only the PY pulse train. The pulse train, renamed P, is suitable for a Graetz bridge connected to a converter transformer, with no phase shift between primary and secondary windings.

The pulse ordering in the pulse trains corresponds to the natural order of commutation of a three-phase thyristor bridge, as shown in the following figure.
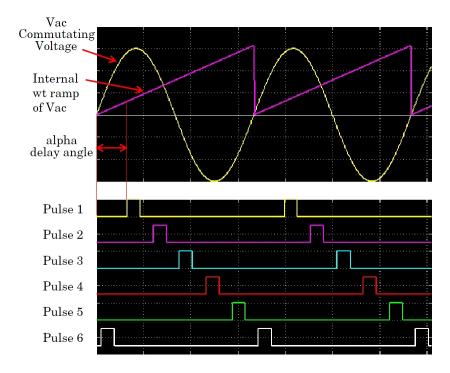
The table below gives the commutating voltages for the thyristors according to the transformer conection. The transformer conection reflects the phase shift between the AC source and the thyristors.

Thyristor to be ignited	1	2	3	4	5	6
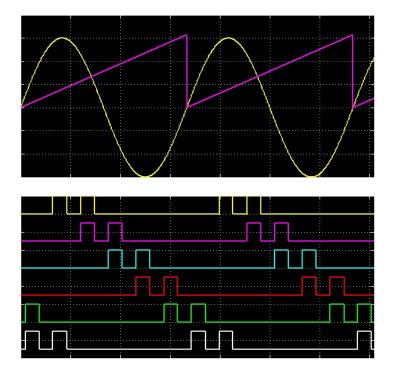
Thyristor to be extinguished	5	6	1	2	3	4
Commutating voltage for a Y-Y conection	Vac	Vbc	Vba	Vca	Vcb	Vab
for a Y-D1 (lagging)	-Vc	Vb	-Va	Vc	-Vb	Va
for a Y-D11 (leading)	Va	-Vc	Vb	-Va	Vc	-Vb

The Pulse Generator (Thyristor) block is controlled by the alpha angle reference signal and by the synchronization signal wt. The wt signal is an angle varying between 0 and 2*pi radians, synchronized on zero crossings of the fundamental (positive-sequence) of phase A of the primary voltage of the converter transformer. The wt signal is normally obtained from a phase locked loop (PLL) system.
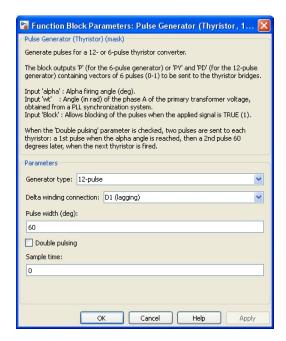
The Pulse Generator (Thyristor) block generates internal wt ramps to control the pulses. The alpha delay angle is expressed in electrical degrees by which the pulse is delayed relative to angle zero of its commutating voltage. The figure shows how the PY pulse train is generated.

The Pulse Generator (Thyristor) block can be configured to work in double-pulsing mode. In this mode two pulses are sent to each thyristor: a first pulse when the alpha angle is reached, and then a second pulse 60 degrees later, when the next thyristor is fired. This figure shows the double pulses in a PY pulse train.

Dialog Box and Parameters

Generator type

Select the type of thyristor converter to control. When set to `6-pulse`, the PD pulse train output is not generated, and the PY output is renamed to P.

Delta winding connection

Specify the type of delta secondary winding connection of the converter transformer. When set to `D1(lagging)`, the PD pulses lag the PY pulses by 30 degrees. When set to `D11(leading)`, the PD pulses lead the PY pulses by 30 degrees.

Pulse width (deg)

Specify the width of the pulses, in degrees.

Double pulsing

When this check box is selected, the Pulse Generator (Thyristor) block implements the double-pulsing technique.

Sample time

Specify the sample time of the block, in seconds. Set to `0` to implement a continuous block.

Inputs and Outputs

`alpha`

> The alpha delay angle signal, in degrees. This input can be connected to a Constant block, or it can be connected to a controller system to control the pulses of the generator.

`wt`

> Angle, in radians, varying between 0 and 2*pi, synchronized on zero crossings of the fundamental (positive-sequence) of phase A of the primary voltage of the converter transformer. The wt signal is normally obtained from a phase locked loop (PLL) system.

`Block`

> When set to true (Boolean 1), blocks the operation of the generator. The pulses are disabled and block the operation of the generator.

`PY, P`

> Outputs the six-pulse signals to be sent to the six-pulse thyristor converter connected to the Y secondary winding of the converter transformer. The output is named `PY` when the **Generator type** parameter is set to 12-pulse, and named PY when the **Generator type** parameter is set to `6-pulse`.

`PD`

> Outputs the six-pulse signals to be sent to the six-pulse thyristor converter connected to the Delta (D) secondary winding of the converter transformer. This output does not exist when the **Generator type** parameter is set to `6-pulse`.

Characteristics

Sample Time	Specified in the **Sample Time** parameter
Scalar Expansion	No
Dimensionalized	No
Zero-Crossing Detection	Yes

Example

The power_PulseGenerator example shows various uses of the pulse generator.

The model sample time is parameterized with the variable Ts (default value Ts = 50e-6). To simulate continuous mode, specify Ts = 0 in the MATLAB Command Window.

PV Array

Implement PV array modules.
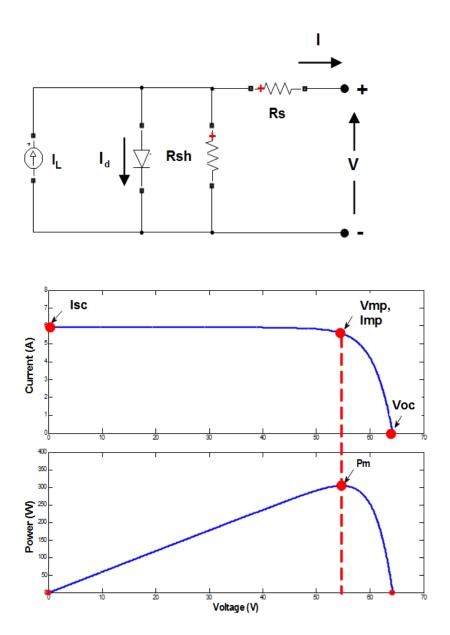
Library

Renewables/Solar

Description

The PV Array block implements an array of photovoltaic (PV) modules. The array is built of strings of modules connected in parallel, each string consisting of modules connected in series. This block allows you to model preset PV modules from the National Renewable Energy Laboratory (NREL) System Advisor Model (Jan. 2014) as well as PV modules that you define.

The PV Array block is a five parameter model using a current source IL (light-generated current), diode (I0 and nI parameters), series resistance Rs, and shunt resistance Rsh to represent the irradiance- and temperature-dependent I-V characteristics of the modules.

The diode I-V characteristics for a single module are defined by the equations

$$I_d = I_0 \left[\exp\left(\frac{V_d}{V_T}\right) - 1 \right]$$

$$V_T = \frac{kT}{q} \times nI \times Ncell$$

where:

I_d = diode current (A)

V_d = diode voltage (V)

I_0 = diode saturation current (A)

nI = diode ideality factor, a number close to 1.0
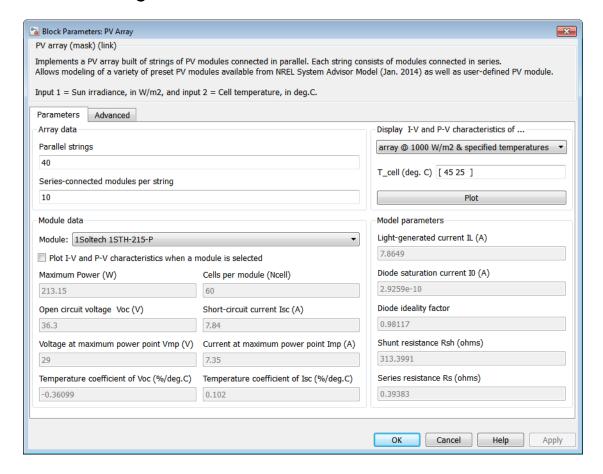
k = Boltzman constant = 1.3806e-23 J.K-1

q = electron charge = 1.6022e-19 C

T = cell temperature (K)

$Ncell$ = number of cells connected in series in a module

Dialog Box and Parameters

- "Parameters" on page 1-669
- "Advanced" on page 1-672

Parameters

Parallel strings

Number of strings of series-connected modules that are connected in parallel. The default value is 40.

Series-connected modules per string

Number of PV modules connected in series in each string. The default value is `10`.

Module

Select `User-defined` or a preset PV module from the NREL System Advisory Model database. Over 10,000 modules are listed from main manufacturers, sorted in alphabetical order. The NREL database includes manufacturer datasheets measured under standard test conditions (STC) (irradiance=1000 W/m^2, temperature=25 degrees C).

When you select a module, this data from the NREL database updates when you apply your changes: Ncell, Voc, Isc, Vmp, Imp maximum power, as well as temperature coefficients of Voc and Isc. The function computes the five corresponding model parameters (IL, I0, nI, Rsh, Rs) using an optimization function and displays them on the right side of the dialog box.

When you select `User-defined`, you can enter your own specifications for the module data (Ncell, Voc, Isc, Vmp, Imp, and temperature coefficients of Voc and Isc). When you apply the changes, the function computes the five model parameters.

The default value is `1Soltech 1STH-215-P`.

Plot I-V and P-V characteristics when a module is selected

Select to plot the I-V and P-V characteristics under standard test conditions of the PV module selected in the **Module** parameter. The plot updates every time you select a different module. Red circles on the plot identify the module Voc, Isc, Vmp, and Imp parameters.

The default value is unselected.

Maximum Power (W)

Power obtained at maximum power point (Vmp, Imp). Pmax is computed as *Pmax = Vmp × Imp*. The default value is `213.15` W.

Cells per module (Ncell)

Number of cells per module. The default value is `60`.

Open circuit voltage Voc (V)

Voltage obtained when array terminals are left open. The default value is `36.3` V.

Short-circuit current Isc (A)

Current obtained when array terminals are short circuited. The default value is `7.84` A.

Voltage at maximum power point Vmp (V)

Voltage at maximum power point. The default value is `29` V.

Current at maximum power point Imp (A)

Current at maximum power point. The default value is `7.35` A.

Temperature coefficient of Voc (%/deg.C)

Defines variation of *Voc* as a function of temperature. The open-circuit voltage at temperature T is obtained as
$Voc_T = Voc\ (1 + beta\_Voc(T–25),$

where *Voc* is the open-circuit voltage at 25 degrees C, *VocT* is the open-circuit voltage at temperature T (in degrees C), *beta_Voc* is the temperature coefficient (in %/degrees C), and T is the temperature in degrees C.

The default value is `-0.36099` %/deg.C.

Temperature coefficient of Isc (%/deg.C)

Defines variation of *Isc* as a function of temperature. The short-circuit current at temperature T is obtained as
$Isc_T = Isc\ (1 + alpha\_Isc(T–25),$

where *Isc* is the short-circuit current at 25 degrees C, *IscT* is the short-circuit current at temperature T (in degrees C), *alpha_Isc* is the temperature coefficient (in %/degrees C) and T is the temperature in degrees C.

The default value is `0.102` %/deg.C.

Display I-V and P-V characteristics of...

To display the I-V and P-V characteristics of one module or of the whole array, for variable irradiance or for variable temperatures, select an option:
```
one module @ 25 deg. C & specified irradiances
array @ 25 deg. C & specified irradiances
array @ 1000 W/m2 & specified temperatures
```

The selected characteristics display when you click **Plot**.

The default value is `array @ 1000 W/m2 & specified temperatures`.

Irradiances (W/m2)

This parameter is available only if **Display I-V and P-V characteristics of** is set to `one module @ 25 deg.C & specified irradiances` or `array @ 25 deg. C & specified irradiances`. Enter a vector of irradiances in W/m^2.

T_cell (deg. C)

This parameter is available only if **Display I-V and P-V characteristics of** is set to `array @ 1000 W/m2 & specified temperatures`. Enter a vector of temperatures in degrees C. The default value is `[45 25]` deg. C.

Light-generated current IL (A)

Current for one module under STC, flowing out of the controllable current source that models the light-generated current. An optimization function determines this parameter to fit the module data. The default value is `7.8649` A.

Diode saturation current I0 (A)

Saturation current of the diode modeling the PV array for one module under STC. An optimization function determines this parameter to fit the module data. The default value is `2.9259e-10` A.

Diode ideality factor

Ideality factor of the diode modeling the PV array. An optimization function determines this parameter to fit the module data. The default value is `0.98117`.

Shunt resistance Rsh (ohms)

Shunt resistance of the model for one module under STC. An optimization function determines this parameter to fit the module data. The default value is `313.3991` Ω.

Series resistance Rs (ohms)

Series resistance of the model for one module under STC. An optimization function determines this parameter to fit the module data. The default value is `0.39383` Ω.

Advanced

Break algebraic loop in internal model

By default this parameter is not selected. You then get an algebraic loop in the internal diode model, both in a continuous model or in a discrete model. If you use the block in a discrete system using large sample times, this algebraic loop is required to get an iterative, accurate solution for the highly nonlinear diode characteristics. For example, the PV array connected to an average model of power electronic converter runs with a sample time as large as `50e-6` sec, and Simulink can solve the algebraic loop.

When the PV array block is connected to a detailed power electronic converter where real switches are simulated, you need to specify a small sample time to get accurate resolution in PWM pulse generation (for example, `1e-6` sec with a 5 kHz PWM inverter). In this case, to speed up simulation, select this parameter to break the algebraic loop.

When the model is discrete, break the algebraic loop by using a one-simulation-step time delay. This approach can cause numerical oscillations if the sample time is too large.

When the model is continuous, break the algebraic loop by using a first-order filter. The **Time constant (s)** parameter then becomes visible.

When the model uses an algebraic loop (i.e., the parameter is not selected), current and voltage measurement filters are used inside the continuous and the discrete model to help solve the algebraic loop. The **Measurement Filter Time constant (s)** parameter then becomes visible.

Time constant (s)

The filter time constant is visible in a continuous model only when **Break algebraic loop in internal model** is selected. The default value is `1e-6` sec.

Measurement Filter Time constant (s)

The measurement filter time constant is visible in both discrete and continuous model when **Break algebraic loop in internal model** is not selected. The default value is `5e-5` sec.

Inputs and Outputs

`Ir`

Connect to this input a Simulink signal representing varying sun irradiance in W/m2.

`T`

Connect to this input a Simulink signal representing varying cell temperature in degrees C.

`m`

Simulink output vector containing five signals. You can select these signals using the Bus Selector block in the Simulink library.

Signal	Signal Name	Definition
1	V_PV	PV array voltage (V)
2	I_PV	PV array current (A)
3	I_diode	diode current (A)
4	Irradiance (W/m2)	Irradiance (W/m2)
5	Temperature (deg C)	Temperature (degrees C)

Related Examples

- 250-kW Grid-Connected PV Array
- 400-kW Grid-Connected PV Farm (Average Model)
- Partial Shading of a PV Module
- Single-Phase, 240 Vrms, 3500 W Transformerless Grid-Connected PV Array

Introduced in R2015a

PWM Generator
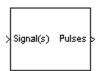
Generate pulses for carrier-based two-level pulse width modulator (PWM) in converter bridge

Library

powerlib_extras/Control Blocks, powerlib_extras/Discrete Control Blocks

---

Note: The Pulse & Signal Generators section of the Control and Measurements library contains the PWM Generator (2-level) block. This is an improved version of the PWM Generator block. The new block features a mechanism that eliminates duplicate continuous and discrete versions of the same block by basing the block configuration on the simulation mode. If your legacy models contain the PWM Generator block, they will continue to work. However, for best performance, use the PWM Generator (2-level) block in your new models.

Description
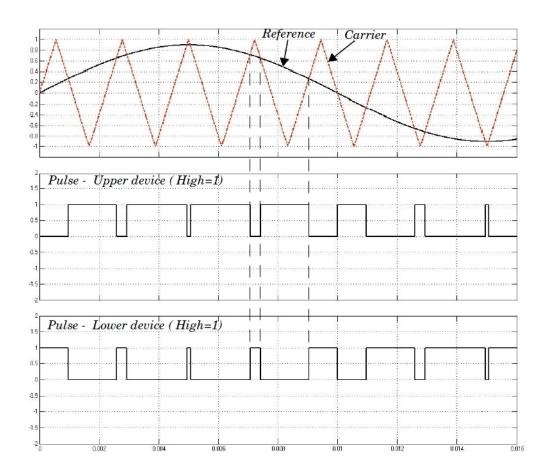
The PWM Generator block generates pulses for carrier-based pulse width modulation (PWM) converters using two-level topology. The block can be used to fire the forced-commutated devices (FETs, GTOs, or IGBTs) of single-phase, two-phase, three-phase, two-level bridges or a combination of two three-phase bridges.

The pulses are generated by comparing a triangular carrier waveform to a reference modulating signal. The modulating signals can be generated by the PWM generator itself, or they can be a vector of external signals connected at the input of the block. One reference signal is needed to generate the pulses for a single- or a two-arm bridge, and three reference signals are needed to generate the pulses for a three-phase, single or double bridge.

The amplitude (modulation), phase, and frequency of the reference signals are set to control the output voltage (on the AC terminals) of the bridge connected to the PWM Generator block.

The two pulses firing the two devices of a given arm bridge are complementary. For example, pulse 4 is low (0) when pulse 3 is high (1). This is illustrated in the next two figures.
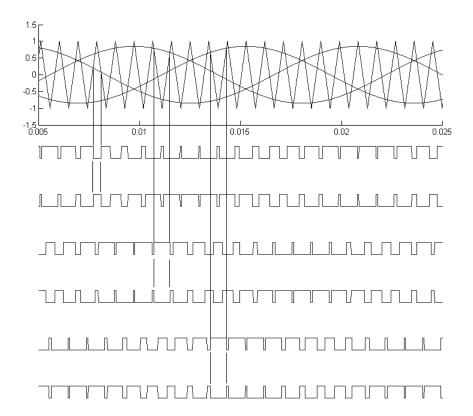
The following figure displays the two pulses generated by the PWM Generator block when it is programmed to control a one-arm bridge.
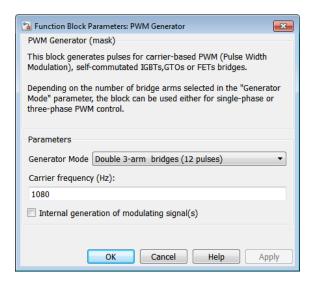
The triangular carrier signal is compared with the sinusoidal modulating signal. When the modulating signal is greater than the carrier pulse 1 is high (1) and pulse 2 is low (0).

For a single-phase two-arm bridge the modulating signal used for arm 2 is the negative of modulating signal used for arm 1 (180 degrees phase shift). For a three-phase six-arm bridge the three modulating signals used for bridge 2 are the negative of the modulating signals applied to bridge 1.

The following figure displays the six pulses generated by the PWM Generator block when it is programmed to control a three-arm bridge.
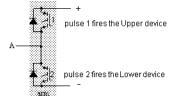
Dialog Box and Parameters
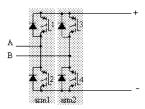
Generator Mode

Specify the number of pulses to generate. The number of pulses is proportional to the number of bridge arms to fire.
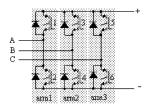
Select `1-arm bridge (2 pulses)` to fire the self-commutated devices of a one-arm bridge. Pulse 1 fires the upper device and pulse 2 fires the lower device.

Select `2-arm bridge (4 pulses)` to fire the self-commutated devices of a two-arm bridge. Four pulses are generated for a two-arm bridge. Pulses 1 and 3 fire the upper devices of the first and second arm. Pulses 2 and 4 fire the lower devices.

Select `3-arm bridge (6 pulses)` to fire the self-commutated devices of a three-arm bridge. Pulses 1, 3, and 5 fire the upper devices of the first, second, and third arms. Pulses 2, 4, and 6 fire the lower devices.

Select `Double 3-arm bridges (12 pulses)` to fire the self-commutated devices of two six-pulse bridges connected in a twelve-pulse bridge configuration. The first six pulses (1 to 6) fire the six devices of the first three-arm bridge and the last six pulses (7 to 12) fire the six devices of the second three-arm bridge.

Carrier frequency

The frequency, in hertz, of the carrier triangular signal.

Internal generation of modulating signal(s)

If selected, the modulating signal is generated by the block. Otherwise, external modulating signals are used for pulse generation. The default is unselected.

Modulation index (0 < m < 1)

The **Modulation index** parameter is visible only if the **Internal generation of modulating signal (s)** parameter is selected.

The amplitude of the internal sinusoidal modulating signal. The **Modulation index** must be greater than 0, and lower than or equal to 1. This parameter is used to control the amplitude of the fundamental component of the output voltage of the controlled bridge. This parameter is only visible when **Internal generation of modulating signal(s)** is selected.

Frequency of output voltage

> The **Frequency of output voltage (Hz)** parameter is visible only if the **Internal generation of modulating signal (s)** parameter is selected. This parameter is only visible when **Internal generation of modulating signal(s)** is selected.

> The frequency, in hertz, of the internal modulating signals. This parameter is used to control the fundamental frequency of the output voltage of the controlled bridge.

Phase of output voltage

> The **Phase of output voltage** parameter is visible only if the **Internal generation of modulating signal (s)** parameter is selected. This parameter is only visible when **Internal generation of modulating signal(s)** is selected.

> The phase, in degrees, of the internal modulating signal. This parameter is used to control the phase of the fundamental component of the output voltage of the controlled bridge.

Inputs and Outputs

`Signal(s)`

> The input is not visible when **Internal generation of modulating signal (s)** is selected.

> The input is the vector of modulating signals when **Internal generation of modulating signal** is not selected. Connect this input to a single-phase sinusoidal signal when the block is used to control a single- or a two-arm bridge, or to a three-phase sinusoidal signal when the PWM Generator block is controlling one or two three-phase bridges.

`Pulses`

> The output contains the two, four, six, or twelve pulse signals used to fire the self-commutated devices (MOSFETs, GTOs, or IGBTs) of single-phase, two-phase, or three-phase bridges or a combination of two three-phase bridges.

See Also

PWM Generator (2-level) | PWM Generator (3-level) | Universal Bridge

Related Examples

- power_1phPWM

- power_3phPWM

PWM Generator (2-Level)

Generate pulses for PWM-controlled 2-level converter

Library
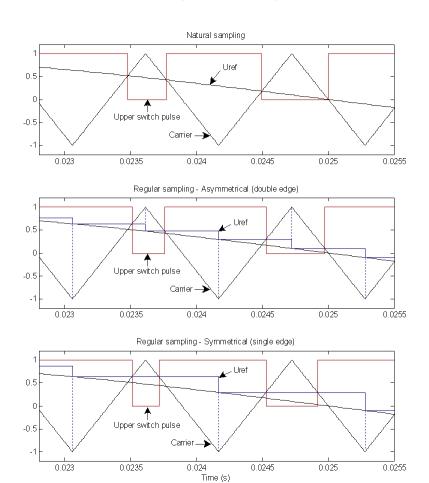
Control and Measurements/Pulse & Signal Generators

Description

The PWM Generator (2-Level) block generates pulses for carrier-based pulse width modulation (PWM) converters using two-level topology. The block can control switching devices (FETs, GTOs, or IGBTs) of three different converter types: single-phase half-bridge (1 arm), single-phase full-bridge (2 arms), or three-phase bridge (3 arms).

The reference signal (Uref input), also called modulating signal, is compared with a symmetrical triangle carrier. When the reference signal is greater than the carrier, the pulse for the upper switching device is high (1), and the pulse for the lower device is low (0).
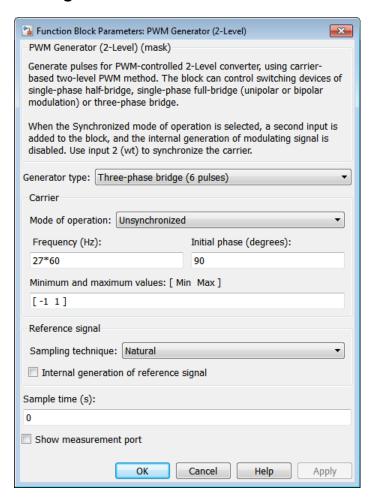
To control a single-phase full-bridge device, you can select unipolar or bipolar PWM modulation. Using the unipolar modulation, each arm is controlled independently. A second reference signal is internally generated by phase-shifting the original reference signal by 180 degrees. Using the bipolar modulation, the state of the lower switching device of the second arm is the same as the state of the upper switch of the first arm, and the state of the upper switch of the second arm is the same as the state of the lower switch of the first arm. The unipolar modulation produces better quality AC waveform, but the bipolar modulation produces very low-varying common-mode voltage.

The figure describes the three techniques to sample the reference signal Uref. The natural sampling technique models the behavior of an analog implementation of a PWM generator. Using the two regular sampling techniques, Uref can be sampled twice at both the valley and the peak of the carrier or only once at the valley of the carrier. The former is referred to as asymmetrical sampling or double-edge technique. The latter is called symmetrical sampling or single-edge technique.

Reference Signal Sampling Techniques

Dialog Box and Parameters

Generator type

> Specify the number of pulses to generate. The number of pulses generated by the block is proportional to the number of bridge arms to fire.
>
> Select `Single-phase half-bridge (2 pulses)` to fire the self-commutated devices of a single-phase half-bridge converter. Pulse 1 fires the upper device, and pulse 2 fires the lower device.

Select `Single-phase full-bridge (4 pulses)` to fire the self-commutated devices of a single-phase full-bridge converter. Four pulses are then generated. Pulses 1 and 3 fire the upper devices of the first and second arm. Pulses 2 and 4 fire the lower devices.

Select `Three-phase bridge (6 pulses)` to fire the self-commutated devices of a three-phase bridge converter. Pulses 1, 3, and 5 fire the upper devices of the first, second, and third arms. Pulses 2, 4, and 6 fire the lower devices.

Carrier: Mode of operation

When set to `Unsynchronized`, the frequency of the unsynchronized carrier signal is determined by the **Frequency** parameter.

When set to `Synchronized`, the carrier signal is synchronized to an external reference signal (input wt) and the carrier frequency is determined by the **Switching ratio** parameter.

Carrier: Frequency (Hz)

Specify the frequency, in hertz, of the triangular carrier signal. This parameter is available only if the **Mode of operation** parameter is set to `Unsynchronized`.

Carrier: Initial phase (degrees)

Specify the carrier initial phase, in degrees. A value of 90 degrees means that the triangle carrier initial position is set to midpoint between its minimum and maximum value and the slope is positive.

This parameter is available only if the **Mode of operation** parameter is set to `Unsynchronized`.

Carrier: Minimum and maximum values

Specify the minimum (valley) and maximum (peak) values of the triangular carrier signal.

Switching ratio (carrier frequency/output frequency)

Specify the frequency (F_c) of the triangular carrier signal.

$$F_c = SwitchingRatio \times OutputVoltageFrequency$$

This parameter is available only if the **Mode of operation** parameter is set to `Synchronized`.

Reference signal: Sampling technique

Specify how the reference signal is sampled: `Natural`, `Asymmetrical regular (double edge)`, or `Symmetrical regular (single edge)`.

If you select a regular sampling technique, the **Sample time** parameter must be an integer submultiple of the sampling period. The sampling period is equal to 1/**Carrier Frequency**/2 for asymmetrical sampling and to 1/**Carrier Frequency** for symmetrical sampling.

Reference signal: Internal generation of reference signal

When selected, the reference signal is generated by the block.

When not selected, external reference signals are used for pulse generation.

This parameter is available only if the **Mode of operation** parameter is set to `Unsynchronized`.

Reference signal: Modulation index

Specify the modulation index to control the amplitude of the fundamental component of the output voltage of the converter. The modulation index must be greater than 0 and lower than or equal to 1. This parameter is available only when the **Internal generation of reference signal** parameter is selected.

Reference signal: Frequency (Hz)

Specify the output voltage frequency used to control the frequency of the fundamental component of the output voltage of the converter. This parameter is available only when the **Internal generation of modulating signal (s)** parameter is selected.

Reference signal: Phase (degrees)

Specify this parameter to control the phase of the fundamental component of the output voltage of the converter. This parameter is available only when the **Internal generation of modulating signal (s)** parameter is selected.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block. If you select a regular sampling technique, the **Sample time** parameter must be an integer submultiple of the sampling period. The sampling period is equal to 1/**Carrier Frequency**/2 for asymmetrical sampling and to 1/**Carrier Frequency** for symmetrical sampling.

Show measurement port

Select this check box to add a Simulinkoutput to the block. The output returns the carrier signal that is used to determine the output pulses and the sampled reference signal.

Inputs and Outputs

Uref

The vectorized reference signal used to generate the output pulses. The input is visible only when the **Internal generation of modulating signal (s)** is not selected. Connect this input to a single-phase sinusoidal signal when the block is used to control a single-phase half- or full-bridge converter, or to a three-phase sinusoidal signal when the PWM Generator block is controlling a three-phase bridge converter. For linear operation of this block, the magnitude of Uref must be between −1 and +1.

wt

The external reference signal used to synchronize the carrier. This Simulink input port is not present when **Carrier: Mode of operation** is set to Unsynchronized.

P

The output contains the two, four, or six pulse signals used to fire the self-commutated devices (MOSFETs, GTOs, or IGBTs) of a one-, two- or three-arm converter.

m

The measurement output that returns the carrier signal used to determine the output pulses and the sampled reference signal. This port is present only when **Show measurement port** is selected.

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	No
Dimensionalized	No

Examples

The power_PWMGenerator2Level model uses a simple circuit to illustrate the operation of the PWM Generator (2-Level). Run the simulation and use the FFT Analysis tool of the

Powergui block to see the harmonics and the THD value of the voltages produced by the three-phase two-level converter.

The model sample time is parameterized by the Ts variable set to a default value of 50e-6 s. Set Ts to 0 in the command window and change the **Simulation type** parameter of the Powergui block to `Continuous` to simulate the model in continuous mode.

The power_BipolarPWMGenerator model shows a comparison between unipolar PWM and bipolar PWM techniques.

PWM Generator (3-Level)

Generate pulses for PWM-controlled three-level converter

Library

Control and Measurements/Pulse & Signal Generators

Description
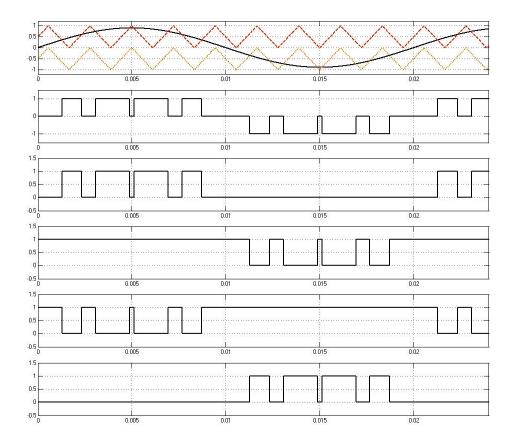
The PWM Generator (3-Level) block generates pulses for carrier-based pulse-width modulation (PWM) converters using three-level topology. The block can control switching devices (FETs, GTOs, or IGBTs) of three different converter types: single-phase half-bridge (one arm), single-phase full-bridge (two arms), or three-phase bridge (three arms).

The reference signal (Uref input), also called the modulating signal, is naturally sampled and compared with two symmetrical level-shifted triangle carriers.

The following figure shows how the pulses are generated for a single-phase, half-bridge three-level converter.

The converter arm can have three states: +1, 0, or −1. When the reference signal is greater than the positive carrier, the state of the arm is +1; when the reference signal is smaller than the negative carrier, the state of the arm is −1.
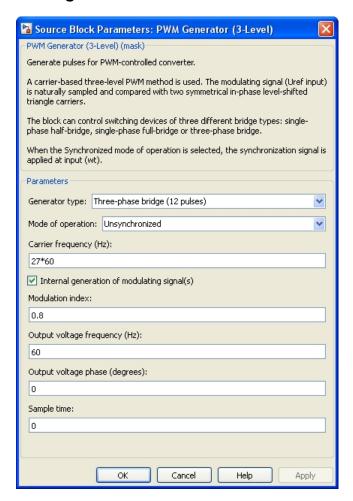
Otherwise, the state is 0. Based on the current state of the arm, the appropriate pulses are generated.

State	Q1	Q2	Q3	Q4
1	1	1	0	0
0	0	1	1	0
−1	0	0	1	1

One reference signal is required to generate the four pulses of an arm. For a single-phase full-bridge converter, a second reference signal is required to generate the four pulses of the second arm. This signal is internally generated by phase-shifting the original reference signal by 180 degrees. For a three-phase bridge, three reference signals are required to generate the 12 pulses.

The reference signal also can be internally generated by the PWM generator. In this case, specify a modulation index, voltage output frequency, and phase.

Dialog Box and Parameters

Generator type

> Specify the number of pulses to generate. The number of pulses generated by the block is proportional to the number of bridge arms to control.

> Select `Single-phase half-bridge (4 pulses)` to fire the self-commutated devices of a single-phase half-bridge converter. Pulses (1, 2) fire the upper devices and pulses (3, 4) fire the lower devices.

Select `Single-phase full-bridge (8 pulses)` to fire the self-commutated devices of a single-phase full-bridge converter. Eight pulses are then generated. Pulses (1, 2) and (5, 6) fire the upper devices of the first and second arms. Pulses (3, 4) and (7, 8) fire the lower devices of the first and second arms.

Select `Three-phase bridge (12 pulses)` to fire the self-commutated devices of a three-phase bridge converter. Pulses (1, 2), (5, 6), and (9, 10) fire the upper devices of the first, second, and third arms. Pulses (3, 4), (7, 8), and (11, 12) fire the lower devices of the three arms.

Mode of operation

When set to `Unsynchronized`, the frequency of the unsynchronized carrier signal is determined by the **Carrier frequency** parameter.

When set to `Synchronized`, the carrier signal is synchronized to an external reference signal (input wt), and the carrier frequency is determined by the **Switching ratio** parameter.

Carrier frequency (Hz)

Specify to determine the frequency, in hertz, of the two triangular carrier signals. The **Carrier frequency** parameter is visible only when the **Mode of operation** parameter is set to `Unsynchronized`.

Switching ratio (carrier frequency/output frequency)

Determines the frequency (F_c) of the two triangular carrier signals.

$$F_c = SwitchingRatio \times OutputVoltageFrequency$$

The **Switching ratio** parameter is visible only when the **Mode of operation** parameter is set to `Synchronized`.

Internal generation of modulating signal (s)

When this check box is selected, the block generates the reference signal.

The parameter is visible only when the **Mode of operation** parameter is set to `Unsynchronized`.

Modulation index

Specify the modulation index to control the amplitude of the fundamental component of the output voltage of the converter. The modulation index must be greater than 0 and lower than or equal to 1. The parameter is visible only when the **Internal generation of modulating signal (s)** check box is selected.

Output voltage frequency (Hz)

Specify the output voltage frequency to control the fundamental component frequency of the output voltage of the converter. The parameter is visible only when the **Internal generation of modulating signal (s)** check box is selected.

Output voltage phase (degrees)

This parameter controls the phase of the fundamental component of the output voltage of the converter. The parameter is visible only when the **Internal generation of modulating signal (s)** check box is selected.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Inputs and Outputs

Uref

The vectorized reference signal used to generate the output pulses. The input is visible only when the **Internal generation of modulating signal (s)** is not selected. Connect this input to:

- A single-phase sinusoidal signal when the block controls a single-phase half- or full-bridge converter
- A three-phase sinusoidal signal when the PWM Generator block controls a three-phase bridge converter

For linear operation of this block, the magnitude of Uref must be between −1 and +1.

P

The output contains the 4, 8, or 12 pulses used to fire the self-commutated devices (MOSFETs, GTOs, or IGBTs) of a one-, two- or three-arm three-level converter.

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	No

Dimensionalized	No

Example

The power_PWMGenerator3Level model uses a simple circuit to show how the PWM Generator (3-Level) operates. Run the simulation and use the FFT Analysis tool of the Powergui block to see the harmonics and the THD value of the voltages produced by the three-phase three-level converter.

The model sample time is parameterized by the Ts variable set to a default value of 2e-6. Set Ts to 0 in the command window and change the **Simulation type** parameter of the Powergui block to Continuous to simulate the model in continuous mode.

PWM Generator (DC-DC)

Generate pulse for PWM-controlled DC-DC converter

Library

Control and Measurements/Pulse & Signal Generators

Description
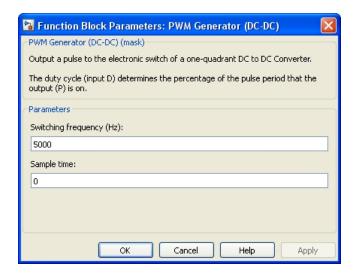
The PWM Generator (DC-DC) block outputs a pulse to fire the MOSFET, GTO, or IGBT switch of a one-quadrant converter (buck or boost). The duty cycle of the generator is specified by the input D. A value between 0 and 1 determines the percentage of the pulse period that the output is on.

Dialog Box and Parameters

Switching frequency (Hz)

Specify the switching frequency Fsw of the generator, in hertz. The switching frequency is the frequency of the internal sawtooth signal used to generate the pulse.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Inputs and Outputs

D

The duty cycle of the generator. Specify a signal with a value between 0 and 1.

P

Outputs the pulse.

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	No
Dimensionalized	No

Example

The power_PWMGeneratorDCDC example shows the operation of the PWM Generator (DC-DC) block. Run the simulation for various duty cycles values and observe the resulting voltage and current on the Scope block.
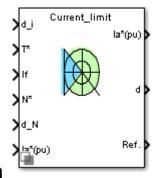
The model sample time is parameterized with variable Ts (default value Ts=500e-9). To run a continuous simulation, specify Ts = 0 in the MATLAB Command Window, and set the **Simulation type** parameter of the Powergui block to Continuous before starting the simulation.

Regulation Switch

Implement torque controller, and switch that selects between torque or speed regulation, for DC motor drives

Library

Electric Drives/Fundamental Drive Blocks
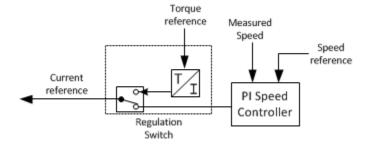
Description

The Regulation Switch block consists of a DC machine (wound-field type) torque controller model and a Simulink Switch model. The latter is used to select the regulation mode, torque, or speed regulation of the DC drive, as shown in the figure.

The torque controller provides the reference DC current for the machine using the equation

$$I^* = \frac{T^*}{K_{T,}}$$

where T^* is the torque reference (N.m) and K_T is the torque constant (N.m/A).

A second reference DC current is obtained from the PI speed controller. Depending on the regulation mode, the switch selects between the two DC current references.

The Regulation Switch block has two operating modes depending on whether a current limiter is used. The operating mode with a current limiter allows the lower limit of the reference current to be reduced proportionally to the machine speed. This mode improves the current regulation particularly at low speeds where the back-EMF is not high enough to generate high reverse currents.

Dialog Box and Parameters

Drive type

Specify the drive type to use:

- `Rectifier based` (default)
- `Chopper based`

Regulation type

Specify the regulation type to use:

- `Speed regulation` (default)
- `Torque regulation`

Number of quadrants

Specify the number of quadrants to use. The default value is `2`.

Mode

Specify the operating mode to use:

- `Without current limiter` (default)
- `With current limiter`

Power (VA)

DC machine nominal power, in volt amperes. The default value is `200*746`.

Voltage (V)

DC machine nominal voltage, in volts. The default value is `440`

Armature resistance Ra (Ohms)

Armature resistance of the DC machine, in ohms. The default value is `0.0597`.

Field-armature mutual inductance Laf (H)

Field-armature mutual inductance of the DC machine, in henry. The default value is `3.320`.

Forward voltage Von (V)

Forward voltage of each thyristor in the bridge converter, in volts. The default value is `1.3`.

Ron (Ohms)

Internal resistance of each thyristor in the bridge converter, in ohms. The default value is `1e-3`.

Current reference limit (pu)

Maximum absolute value (pu) of the armature current reference. The default value is `1.5`.

Controller sample time (s)

The controller sampling time, in seconds. The default value is `20e-6`.

Network sample time (s)

Simulation time step, in seconds. The default value is `1e-6`.

Inputs and Outputs

`d_i`

Armature current reference error (difference between the reference and the actual machine current).

`T*`

Torque reference, in Newton-meter.

`If`

Field current, in amperes.

`N*`

Speed reference, in rpm.

`d_N`

Speed error (difference between the speed reference ramp and the actual speed).

`la*(pu)`

Armature current reference, in per-unit.

`d`

Speed or armature current error.

`Ref`

Speed reference ramp or torque reference.

Examples

The Regulation Switch block is used in the DC1 to DC7 blocks of the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

```
Bridge Firing Unit (AC) | Bridge Firing Unit (DC) | Current Controller
(Brushless DC) | Current Controller (DC) | Direct Torque Controller
| Field-Oriented Controller | Six-Step Generator | Space Vector
Modulator | Speed Controller (AC) | Speed Controller (DC) | Speed
Controller (Scalar Control) | Vector Controller (PMSM)  | Vector
Controller (WFSM)  | Voltage Controller (DC Bus)
```

More About

·   "Electric Drives Library"

Introduced in R2015b

RMS

Compute true root mean square (RMS) value of signal

Library

Control and Measurements/Measurements

Description
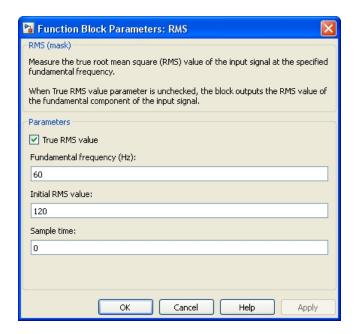
The RMS block computes the true root mean square (RMS) value of the input signal. The true RMS value of the input signal is calculated over a running average window of one cycle of the specified fundamental frequency:

$$
RMS(f(t)) = \sqrt{\frac{1}{T} \int_{t-T}^{t} f(t)^2},
$$

where $f(t)$ is the input signal and T is 1/(fundamental frequency).

As this block uses a running average window, one cycle of simulation must complete before the output gives the correct value. For the first cycle of simulation, the output is held to this specified initial RMS value.

Dialog Box and Parameters

True RMS value

Select this check box to have the block compute the true RMS value of the input signal.

Clear this check box to have the block compute the fundamental value of the input signal, divided by sqrt(2).

Fundamental frequency (Hz)

Specify the fundamental frequency, in hertz, of the input signal.

Initial RMS value

Specify the initial RMS value of the output signal.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	Yes, of the parameters
Dimensionalized	Yes

Example

The power_RMS_THD example shows two applications of the RMS measurement block. One RMS block calculates the true RMS value of a signal with harmonics, and another one calculates the RMS value of the same signal at the fundamental frequency.

The model sample time is parameterized by the Ts variable set to a default value of 50e-6 s. Set Ts to 0 in the command window to simulate the model in continuous mode.

Sample and Hold

Sample first input and hold its value based on value of second input

Library

Control and Measurements/Additional Components

Description
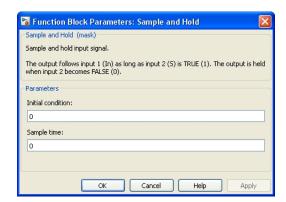
The Sample and Hold block outputs the `In` input signal as long as `S` input signal is true. The block holds the output when the `S` input signal becomes false.

Dialog Box and Parameters

Initial condition

Specify the initial value of the output.

Sample time

Specify the sample time of the block, in seconds. Set to `0` to implement a continuous block.

Inputs and Outputs

In

The signal.

S

The control signal, which must be a Boolean.

Out

The sampled signal.

Characteristics

Direct Feedthrough	Yes
Sample Time	Specified in the **Sample Time** parameter
Scalar Expansion	Yes
Dimensionalized	Yes
Zero-Crossing Detection	No

Example

The power_SampleAndHold example shows the operation of the Sample and Hold block.
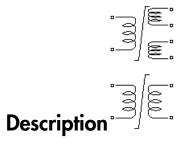
The model sample time is parameterized with the variable Ts (default value Ts = 50e-6). To simulate a continuous Bistable block, specify Ts = 0 in the MATLAB Command Window.

Saturable Transformer
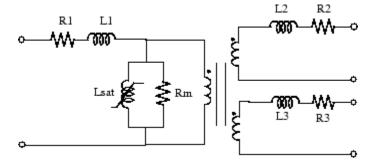
Implement two- or three-winding saturable transformer

Library

Fundamental Blocks/Elements

Description

The Saturable Transformer block model shown consists of three coupled windings wound on the same core.

The model takes into account the winding resistances (R1 R2 R3) and the leakage inductances (L1 L2 L3) as well as the magnetizing characteristics of the core, which is modeled by a resistance Rm simulating the core active losses and a saturable inductance Lsat.
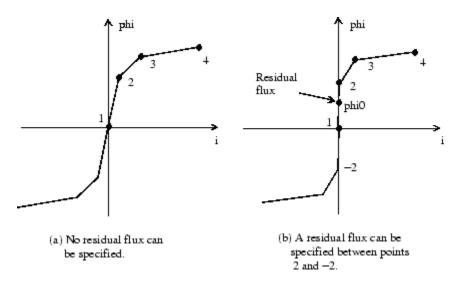
You can choose one of the following two options for the modeling of the nonlinear flux-current characteristic

1 Model saturation without hysteresis. The total iron losses (eddy current + hysteresis) are modeled by a linear resistance, Rm.

2 Model hysteresis and saturation. Specification of the hysteresis is done by means of the **Hysteresis Design Tool** of the Powergui block. The eddy current losses in the core are modeled by a linear resistance, Rm.

Note Modeling the hysteresis requires additional computation load and therefore slows down the simulation. The hysteresis model should be reserved for specific applications where this phenomenon is important.

Saturation Characteristic Without Hysteresis

When the hysteresis is not modeled, the saturation characteristic of the Saturable Transformer block is defined by a piecewise linear relationship between the flux and the magnetization current.

(a) No residual flux can be specified.

(b) A residual flux can be specified between points 2 and −2.

Therefore, if you want to specify a residual flux, phi0, the second point of the saturation characteristic should correspond to a null current, as shown in the figure (b).

The saturation characteristic is entered as (i, phi) pair values in per units, starting with pair (0, 0). The software converts the vector of fluxes Φ_{pu} and the vector of currents I_{pu}

into standard units to be used in the saturation model of the Saturable Transformer block:

$\Phi = \Phi_{\text{pu}}\Phi_{\text{base}}$

$I = I_{\text{pu}}I_{\text{base}},$

where the base flux linkage (Φ_{base}) and base current (I_{base}) are the peak values obtained at nominal voltage power and frequency:

$$I_{\text{base}} = \frac{Pn}{V_1}\sqrt{2}$$

$$\Phi_{\text{base}} = \frac{V_1}{2\pi f_n}\sqrt{2}.$$

The base flux is defined as the peak value of the sinusoidal flux (in webers) when winding 1 is connected to a 1 pu sinusoidal voltage source (nominal voltage). The Φ_{base} value defined above represents the base flux linkage (in volt-seconds). It is related to the base flux by the following equation:
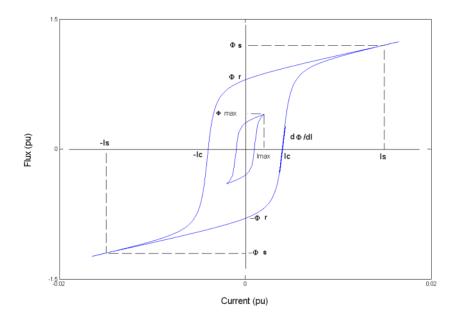
Φ_{base} = Base flux × number of turns of winding 1.

When they are expressed in pu, the flux and the flux linkage have the same value.

Saturation Characteristic with Hysteresis

The magnetizing current I is computed from the flux Φ obtained by integrating voltage across the magnetizing branch. The static model of hysteresis defines the relation between flux and the magnetization current evaluated in DC, when the eddy current losses are not present.

The hysteresis model is based on a semi empirical characteristic, using an arctangent analytical expression $\Phi(I)$ and its inverse $I(\Phi)$ to represent the operating point trajectories. The analytical expression parameters are obtained by curve fitting empirical data defining the major loop and the single-valued saturation characteristic. The **Hysteresis design tool** of the Powergui block is used to fit the hysteresis major loop of a particular core type to basic parameters. These parameters are defined by the remanent flux (Φr), the coercive current (Ic), and the slope ($d\Phi/dI$) at (0, Ic) point as shown in the next figure.
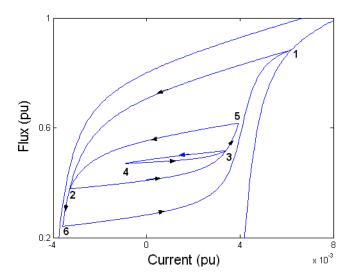
The major loop half cycle is defined by a series of N equidistant points connected by line segments. The value of N is defined in the **Hysteresis design tool** of the Powergui block. Using N = 256 yields a smooth curve and usually gives satisfactory results.

The single-valued saturation characteristic is defined by a set of current-flux pairs defining a saturation curve which should be asymptotic to the air core inductance Ls.

The main characteristics of the hysteresis model are summarized below:

1 A symmetrical variation of the flux produces a symmetrical current variation between -Imax and +Imax, resulting in a symmetrical hysteresis loop whose shape and area depend on the value of Φmax. The major loop is produced when Φmax is equal to the saturation flux (Φs). Beyond that point the characteristic reduces to a single-valued saturation characteristic.

2 In transient conditions, an oscillating magnetizing current produces minor asymmetrical loops, as shown in the next figure, and all points of operation are assumed to be within the major loop. Loops once closed have no more influence on the subsequent evolution.

The trajectory starts from the initial (or residual) flux point, which must lie on the vertical axis inside the major loop. You can specify this initial flux value phi0, or it is automatically adjusted so that the simulation starts in steady state.

The Per Unit Conversion

In order to comply with industry practice, the block allows you to specify the resistance and inductance of the windings in per unit (pu). The values are based on the transformer rated power Pn in VA, nominal frequency fn in Hz, and nominal voltage Vn, in Vrms, of the corresponding winding. For each winding the per unit resistance and inductance are defined as

$$R(\text{p.u.}) = \frac{R(\Omega)}{R_{\text{base}}}$$

$$L(\text{p.u.}) = \frac{L(H)}{L_{\text{base}}}.$$

The base resistance and base inductance used for each winding are

$$R_{\text{base}} = \frac{V_n^2}{Pn}$$

$$L_{\text{base}} = \frac{R_{\text{base}}}{2\pi f_n}.$$

For the magnetization resistance Rm, the pu values are based on the transformer rated power and on the nominal voltage of winding 1.

The default parameters of winding 1 specified in the dialog box section give the following base values:
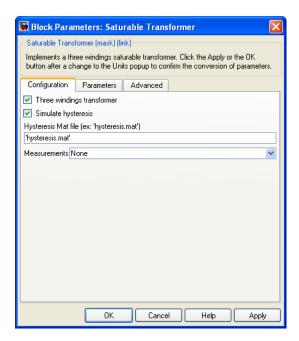
$$R_{\text{base}} = \frac{\left(735 \cdot 10^3 / \sqrt{3}\right)^2}{250 \cdot 10^6} = 720.3\Omega$$

$$L_{\text{base}} = \frac{720.3}{2\pi \cdot 60} = 1.91H.$$

For example, if winding 1 parameters are R1 = 1.44 Ω and L1 = 0.1528 H, the corresponding values to enter in the dialog box are

$$R_1 = \frac{1.44\Omega}{720.3\Omega} = 0.002 \text{ p.u.}$$

$$L_1 = \frac{0.1528H}{1.91H} = 0.08 \text{ p.u.}$$

Dialog Box and Parameters

Configuration Tab

Three windings transformer

>   If selected, specify a saturable transformer with three windings; otherwise it implements a two windings transformer.

Simulate hysteresis

>   Select to model hysteresis saturation characteristic instead of a single-valued saturation curve.

Hysteresis Mat file

>   The **Hysteresis Mat file** parameter is visible only if the **Simulate hysteresis** parameter is selected.

>   Specify a .mat file containing the data to be used for the hysteresis model. When you open the **Hysteresis Design Tool** of the Powergui, the default hysteresis loop and

parameters saved in the `hysteresis.mat` file are displayed. Use the **Load** button of the Hysteresis Design tool to load another `.mat` file. Use the **Save** button of the Hysteresis Design tool to save your model in a new `.mat` file.

Measurements

Select `Winding voltages` to measure the voltage across the winding terminals of the Saturable Transformer block.

Select `Winding currents` to measure the current flowing through the windings of the Saturable Transformer block.

Select `Flux and excitation current (Im + IRm)` to measure the flux linkage, in volt seconds (V.s), and the total excitation current including iron losses modeled by Rm.

Select `Flux and magnetization current (Im)` to measure the flux linkage, in volt seconds (V.s), and the magnetization current, in amperes (A), not including iron losses modeled by Rm.

Select `All measurement (V, I, Flux)` to measure the winding voltages, currents, magnetization currents, and the flux linkage.

Place a Multimeter block in your model to display the selected measurements during the simulation.

In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

Measurement	Label
Winding voltages	`Uw1:, Uw2:, Uw3:`
Winding currents	`Iw1:, Iw2:, Iw3:`
Excitation current	`Iexc:`
Magnetization current	`Imag:`
Flux linkage	`Flux:`

Parameters Tab

Units

>   Specify the units used to enter the parameters of the Saturable Transformer block. Select pu to use per unit. Select SI to use SI units. Changing the **Units** parameter from pu to SI, or from SI to pu, will automatically convert the parameters displayed in the mask of the block. The per unit conversion is based on the transformer rated power Pn in VA, nominal frequency fn in Hz, and nominal voltage Vn, in Vrms, of the windings.

Nominal power and frequency

>   The nominal power rating, Pn, in volt-amperes (VA), and frequency, in hertz (Hz), of the transformer. Note that the nominal parameters have no impact on the transformer model when the **Units** parameter is set to SI.

Winding 1 parameters

>   The nominal voltage in volts RMS, resistance in pu or ohms, and leakage inductance in pu or Henrys for winding 1. Set the winding resistances and inductances to 0to implement an ideal winding.

Winding 2 parameters

The nominal voltage in volts RMS, resistance in pu or ohms, and leakage inductance in pu or Henrys for winding 2. Set the winding resistances and inductances to 0to implement an ideal winding.

Winding 3 parameters

The **Winding 3 parameters** are not available if the **Three windings transformer** parameter is not selected. The nominal voltage in volts RMS, resistance in pu or ohms, and leakage inductance in pu or Henrys for winding 3. Set the winding resistances and inductances to 0 to implement an ideal winding.
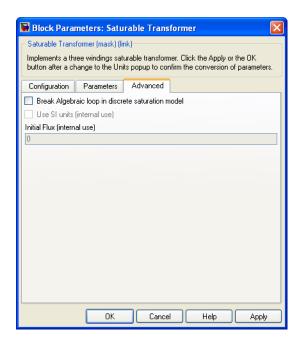
Saturation characteristic

Specify a series of magnetizing current (pu) - flux (pu) pairs starting with (0,0).

Core loss resistance and initial flux

Specify the active power dissipated in the core by entering the equivalent resistance Rm in pu. For example, to specify a 0.2% of active power core loss at nominal voltage, use Rm = 500 pu. You can also specify the initial flux phi0 (pu). This initial flux becomes particularly important when the transformer is energized. If phi0 is not specified, the initial flux is automatically adjusted so that the simulation starts in steady state. When simulating hysteresis, Rm models the eddy current losses only.

Advanced Tab

Break Algebraic loop in discrete saturation model

> When you use the block in a discrete system, you will get an algebraic loop.
> This algebraic loop, which is required in most cases to get an accurate solution,
> tends to slow down the simulation. However, to speed up the simulation, in some
> circumstances, you can disable the algebraic loop by selecting **Break Algebraic
> loop in discrete saturation model**. You should be aware that disabling the
> algebraic loop introduces a one-simulation-step time delay in the model. This can
> cause numerical oscillations if the sample time is too large.

Limitations
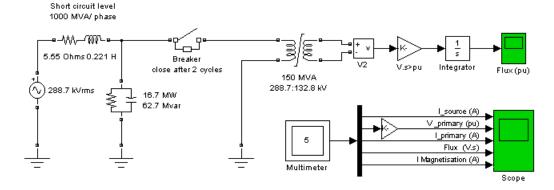
Windings can be left floating (that is, not connected by an impedance to the rest of the
circuit). However, the floating winding is connected internally to the main circuit through
a resistor. This invisible connection does not affect voltage and current measurements.

Example

The power_xfosaturable example illustrates the energization of one phase of a three-phase 450 MVA, 500/230 kV transformer on a 3000 MVA source. The transformer parameters are

Nominal power and frequency	Pn = 150e6 VA	fn = 60 Hz	
Winding 1 parameters (primary)	V1 = 500e3 Vrms/ sqrt(3)	R1 = 0.002 pu	L1 = 0.08 pu
Winding 2 parameters (secondary)	V2 = 230e3 Vrms/ sqrt(3)	R2 = 0.002 pu	L2 = 0.08 pu
Saturation characteristic	[0 0; 0.0 1.2; 1.0 1.52]		
Core loss resistance and initial flux	Rm = 500 pu	phi0 = 0.8 pu	
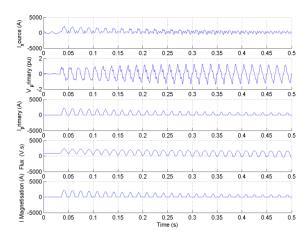
Simulation of this circuit illustrates the saturation effect on the transformer current and voltage.

As the source is resonant at the fourth harmonic, you can observe a high fourth-harmonic content in the secondary voltage. In this circuit, the flux is calculated in two ways:

- By integrating the secondary voltage
- By using the Multimeter block

The simulation results demonstrate these points:

References

[1] Casoria, S., P. Brunelle, and G. Sybille, "Hysteresis Modeling in the MATLAB/Power System Blockset," Electrimacs 2002, École de technologie supérieure, Montreal, 2002.

[2] Frame, J.G., N. Mohan, and Tsu-huei Liu, "Hysteresis modeling in an Electro-Magnetic Transients Program," presented at the IEEE PES winter meeting, New York, January 31 to February 5, 1982.

See Also

Linear Transformer, Multimeter, Mutual Inductance, powergui, Three-Phase Transformer (Two Windings), Three-Phase Transformer (Three Windings)

Sawtooth Generator
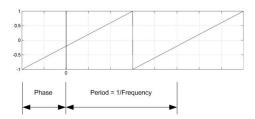
Generate sawtooth waveform at regular intervals

Library

Control and Measurements/Pulse & Signal Generators

Description
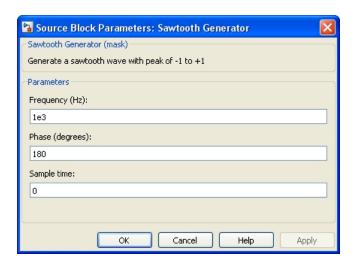
The Sawtooth Generator block generates a sawtooth waveform, with peak amplitude of +/−1, at regular intervals. The figure shows how the **Frequency** and **Phase** block parameters affect the output waveform.

Dialog Box and Parameters

Frequency (Hz)

Specify the frequency of the sawtooth waveform, in hertz.

Phase (degrees)

Specify the delay of the sawtooth waveform, in degrees. When the phase is set to 0, the waveform starts with an amplitude of −1 and a positive slope.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	No
Dimensionalized	No
Zero-Crossing Detection	No

Example

The power_SignalGenerators example shows various uses of the Sawtooth Generator block.

Second-Order Filter

Implement second-order filter

Library

Control and Measurements/Filters

Description

Based on the **Filter type** selected in the block menu, the Second-Order Filter block implements the following transfer function:

Low-pass filter:

$$H(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

High-pass filter:

$$H(s) = \frac{s^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

Band-pass filter:

$$H(s) = \frac{2\zeta\omega_n s}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

Band-stop (notch) filter:

$$H(s) = \frac{s^2 + \omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

s = Laplace operator

ω_n = natural frequency; $\omega_n = 2\pi f_n$
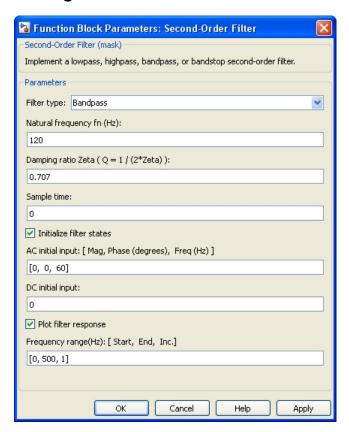
ζ = damping ratio (called Zeta in the block menu)

The key characteristics of the Second-Order Filter block are:

- Input accepts a vectorized input of N signals, implementing N filters. This feature is particularly useful for designing controllers in three-phase systems (N = 3).

- Filter states can be initialized for specified DC and AC inputs.

- It enables you to compute and plot filter response.

Dialog Box and Parameters

Filter type

Specify the type of filter: Lowpass, Highpass, Bandpass, or Bandstop (notch).

Natural frequency fn (Hz)

Specify the natural frequency of the filter, in hertz. This value must be a scalar or a vector.

Damping ratio Zeta (Q = 1/(2*Zeta))

Specify the damping ratio of the filter. The damping ratio is typically a value between 0 and 1.

The damping ratio is related to the filter quality factor Q:

$$Q = \frac{1}{2\zeta}$$

For a bandpass or a bandstop filter, the 3 dB bandwidth is given by

$$BW = \frac{f_n}{Q} = 2\zeta f_n$$

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Initialize filter states

When this check box is selected, filter states are initialized according to the **AC initial input** and **DC initial input** parameters.

AC initial input: [Mag, Phase (degrees), Freq (Hz)]

Specify the magnitude of the initial AC component of the input signal, its phase, in degrees, and its frequency, in hertz.

When the input is vectorized (N signals), specify an N-by-3 matrix, where each row of the matrix corresponds to a particular input.

The **AC initial input** parameter is visible only when the **Initialize filter states** parameter is selected.

DC initial input

Specify the value of the initial DC component of the input signal. When the input signal is vectorized, specify a 1-by-N vector, where each value corresponds to a particular input.

The **DC initial input** parameter is visible only when the **Initialize filter states** parameter is selected.

Plot filter response

When this check box is selected, the filter step response and its Bode diagram (magnitude and phase of transfer function as a function of frequency) are plotted in a figure.

Frequency range (Hz): [Start, End, Inc.]

Specify the frequency range for plotting the filter Bode diagram. Specify a vector containing the starting frequency, the end frequency, and the incremental frequency, in hertz.

The **Frequency range** parameter is visible only when the **Plot filter response** parameter is selected.

Characteristics

Direct Feedthrough	Yes
Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	Yes, of the parameters
States	Two states per filter
Dimensionalized	Yes

Example

The power_SecondOrderFilter example shows the Second-Order Filter block using two **Filter type** parameter settings (Lowpass and Bandstop).

The model sample time is parameterized with variable Ts (default value Ts = 50e-6). To simulate continuous filters, specify Ts = 0 in the MATLAB Command Window before starting the simulation.

Second-Order Filter (Variable-Tuned)

Implement second-order variable-tuned filter

Library

Control and Measurements/Filters

Description

Depending on the **Filter type** selected in the block menu, the Second-Order Filter block implements the following transfer function. The Fn input determines the filter natural frequency $f_n = \omega_n / (2\pi)$ of the filter.

Lowpass filter:

$$H(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

Highpass filter:

$$H(s) = \frac{s^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

Bandpass filter:

$$H(s) = \frac{2\zeta\omega_n s}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

Bandstop (Notch) filter:

$$H(s) = \frac{s^2 + \omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

s = Laplace operator

ω_n = natural frequency; $\omega_n = 2\pi f_n$
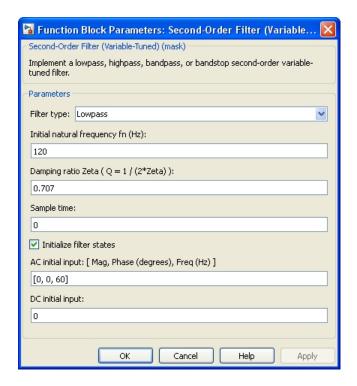
ζ = damping ratio (called Zeta in the block menu)

Dialog Box and Parameters

Filter type

Specify the type of filter: Lowpass, Highpass, Bandpass, or Bandstop (notch).

Initial natural frequency fn (Hz)

The initial natural frequency of the filter, in hertz. This value must be a scalar or a vector.

Damping ratio Zeta (Q = 1/(2*Zeta))

Specify the damping ratio of the filter. The damping ratio is typically a value between 0 and 1.

The damping ratio is related to the filter quality factor Q:

$$Q = \frac{1}{2\zeta}$$

For a bandpass or a bandstop filter, the 3 dB bandwidth is given by

$$BW = \frac{f_n}{Q} = 2\zeta f_n$$

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Initialize filter states

When this check box is selected, filter states are initialized according to the **AC initial input** and **DC initial input** parameters.

AC initial input: [Mag, Phase (degrees), Freq (Hz)]

Specify the magnitude of the initial AC component of the input signal, its phase, in degrees, and its frequency, in hertz.

When the input is vectorized (N signals), specify an N-by-3 matrix, where each row of the matrix corresponds to a particular input.

The **AC initial input** parameter is visible only when the **Initialize filter states** parameter is selected.

DC initial input

Specify the value of the initial DC component of the input signal. When the input signal is vectorized, specify a 1-by-N vector, where each value corresponds to a particular input.

The **DC initial input** parameter is visible only when the **Initialize filter states** parameter is selected.

Inputs and Outputs

The inputs accept vectorized signals of N values, thus implementing N filters. This capability is particularly useful for designing controllers in three-phase systems (N = 3).

Characteristics

Direct Feedthrough	Yes
Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	Yes, of the parameters
States	Two states per filter
Dimensionalized	Yes

Example

The power_SecondOrderFilterTuned example shows various uses of the Second-Order Filter (Variable-Tuned) block with two **Filter type** parameter settings (Lowpass and Bandstop).
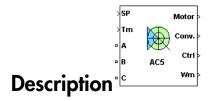
The model sample time is parameterized with variable Ts (default value Ts = 50e-6). To simulate continuous filters, specify Ts = 0 in the MATLAB Command Window before starting the simulation.

Self-Controlled Synchronous Motor Drive

Implement Self-Controlled Synchronous Motor Drive

Library

Electric Drives/AC drives

Description
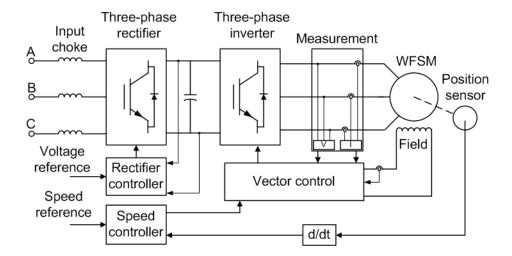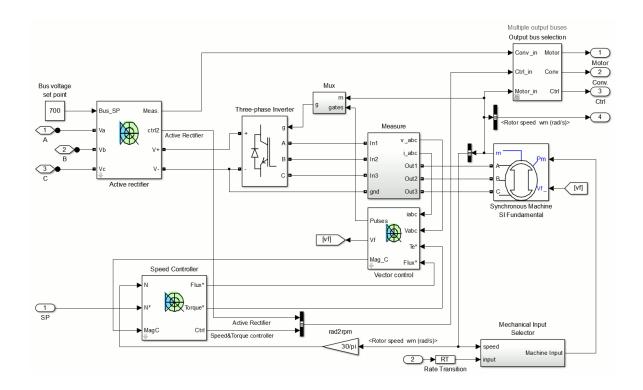
This block models a wound field synchronous motor (WFSM) vector control drive model. The high-level schematic shown below is built from six main blocks. The WFSM motor, the three-phase inverter, and the three-phase rectifier models are provided with the SimPowerSystems library. More details are available in the reference pages for these blocks. The speed controller, the rectifier controller, and the vector control models are specific to the drive library. It is possible to use a simplified version of the drive containing average-value models of the inverter and rectifier for faster simulation.

Note In SimPowerSystems software, the Self-Controlled Synchronous Motor Drive block is commonly called the **AC5** motor drive.

High-Level Schematic
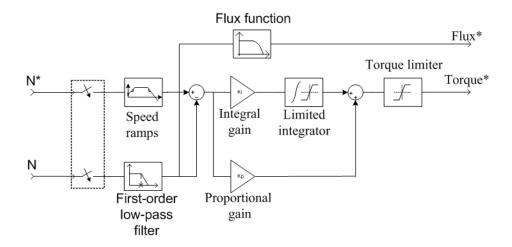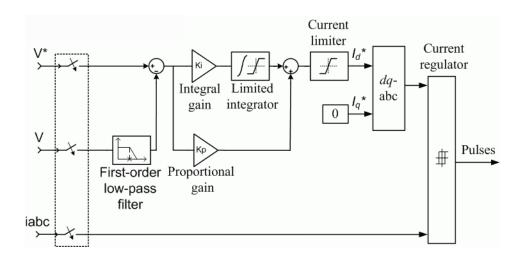
Simulink Schematic

Speed Controller

The speed controller is based on a PI regulator, shown below. The outputs of this regulator are set points for the torque and the flux applied to the vector control block.

Rectifier Controller

The rectifier controller is based on a PI regulator of the DC bus voltage. The output of this regulator is the direct (active) component of the AC line current. The reactive component of the AC line current is set to zero in order to operate at unity power factor.

The *dq-abc* block performs the conversion of the *dq* current components into *abc* phase variables.

The *current regulator* is a bang-bang current controller with adjustable hysteresis bandwidth.

Vector Controller

The vector control contains five main blocks shown in this figure. These blocks are described below.

Vector controller

The *flux estimator* block is used to estimate the motor stator flux ψ_{dqs}^{s}.

The *flux PI controller* is used to regulate the flux in the machine.
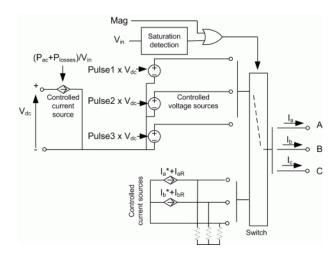
The *dq2abc* block performs the conversion of the *dq* current components into *abc* phase variables.

The *current regulator* is a bang-bang current controller with adjustable hysteresis bandwidth.

The *magnetization control* unit contains the logic used to switch between the magnetization and normal operation mode.

Average-Value Inverter and Rectifier

The average-value inverter/rectifier internal architecture is shown in the following figure.

It is composed of one controlled current source on the DC side and of two controlled current sources and three controlled voltage sources on the AC side. The DC current source allows the representation of the average DC bus current behavior following the next equation:

$I_{dc} = (P_{ac} + P_{losses}) / V_{dc}$

with P_{ac} being the AC side instantaneous power, P_{losses} the losses in the power electronics devices, and V_{dc} the DC bus voltage.

On the AC side, the current sources represent the average phase currents fed to the motor. The regulation being fast, the current values are set equal to the current references sent by the current regulator. A small current is injected to compensate for the current drawn by the three-phase load (needed because of the inverter current sources in series with the inductive motor).

During loss of current tracking due to insufficient inverter voltage, the currents are fed by three controlled voltage sources. These voltage sources represent the square wave mode and allow good representation of the phase currents during inverter saturation. Each voltage source outputs either Vin or 0, depending on the values of the pulses (1 or 0) send by the current controller.

Remarks

The model is discrete. Good simulation results have been obtained with a 2 μs time step. To simulate a digital controller device, the control system has two different sampling times:

- Speed controller sampling time
- Active rectifier controller and vector controller sampling time

The speed controller sampling time has to be a multiple of the vector controller sampling time. The latter sampling time has to be a multiple of the simulation time step. The average-value inverter and rectifier allow the use of bigger simulation time steps since they do not generate small time constants (due to the RC snubbers) inherent to the detailed converters. For a vector controller and active rectifier controller sampling time of 50 μs, good simulation results have been obtained for a simulation time step of 50 μs. This time step can, of course, not be higher than the smallest controller sampling time.

The torque sign convention of the synchronous machine is different from the one of the asynchronous and PM synchronous machines. That is, the synchronous machine is in the motor operation mode when the electric torque is negative and in the generator operation mode when the electric torque is positive.

Dialog Box

Synchronous Machine Tab

The **Synchronous Machine** tab displays the parameters of the Synchronous Machine block of the Fundamental Blocks (powerlib) library.

Output bus mode

Select how the output variables are organized. If you select **Multiple output buses**, the block has three separate output buses for motor, converter, and controller variables. If you select **Single output bus**, all variables output on a single bus.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Select between the load torque, the motor speed and the mechanical rotational port as mechanical input. If you select and apply a load torque, the output is the motor speed according to the following differential equation that describes the mechanical system dynamics:

$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

If you select the motor speed as mechanical input, then you get the electromagnetic torque as output, allowing you to represent externally the mechanical system dynamics. The internal mechanical system is not used with this mechanical input selection and the inertia and viscous friction parameters are not displayed.

For the mechanical rotational port, the connection port S counts for the mechanical input and output. It allows a direct connection to the Simscape environment. The mechanical system of the motor is also included in the drive and is based on the same differential equation.

See "Mechanical Coupling of Two Motor Drives".

Converters and DC bus tab

Rectifier section

The rectifier section of the Converters and DC bus tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the universal bridge parameters.

Inverter section

The inverter section of the Converters and DC bus tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the universal bridge parameters.

The average-value rectifier uses the three following parameters.

Source frequency

The frequency of the three-phase voltage source (Hz).

Source Voltage

The RMS line-to-line voltage of the three-phase voltage source (V).

On-state resistance

The on-state resistance of the rectifier devices (ohms).

The average-value inverter uses the two following parameters:

On-state resistance

The on-state resistance of the inverter devices (ohms).

Forward voltages [Device Vf, Diode Vdf]

Forward voltages, in volts (V), of the forced-commutated devices and of the antiparallel diodes. These values are needed for startup and for square wave mode.

DC Bus Capacitance

The DC bus capacitance value (F).

Input Choke section

Input chokes reduce line current harmonics.
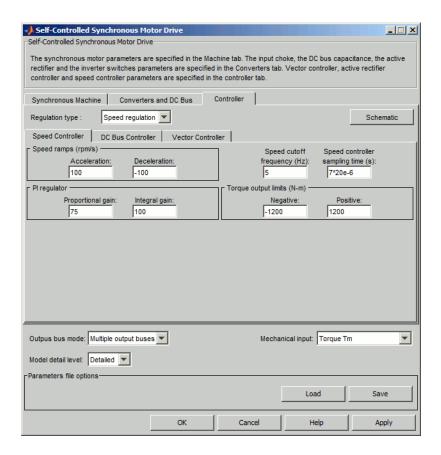
Resistance

The input choke resistance value (ohms).

Inductance

The input choke inductance value (H).

Controller tab

Regulation type

This drop-down menu allows you to choose between speed and torque regulation.

Schematic

When you click this button, a diagram illustrating the speed, rectifier, and vector controllers schematics appears.

Controller — Speed Controller Subtab

Speed cutoff frequency

The speed measurement first-order low-pass filter cutoff frequency (Hz).

Speed controller sampling time

The speed controller sampling time (s). The sampling time must be a multiple of the simulation time step.

Speed ramps — Acceleration

The maximum change of speed allowed during motor acceleration. An excessively large positive value can cause DC bus under-voltage (rpm/s).

Speed ramps — Deceleration

The maximum change of speed allowed during motor deceleration. An excessively large negative value can cause DC bus over-voltage (rpm/s).

PI regulator — Proportional gain

The speed controller proportional gain.

PI regulator — Integral gain

The speed controller integral gain.

Torque output limits — Negative
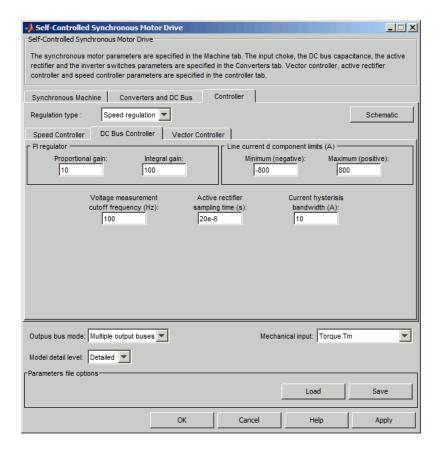
The maximum negative demanded torque applied to the motor by the vector controller (N.m).

Torque output limits — Positive

The maximum positive demanded torque applied to the motor by the vector controller (N.m).

Controller — DC Bus Controller Subtab

PI regulator — Proportional gain

The DC bus voltage controller proportional gain.

PI regulator — Integral gain

The DC bus voltage controller integral gain.

Line current d component limits — Minimum (negative)

The maximum current flowing from the DC bus capacitor towards the AC line (A).

Line current d component limits — Maximum (positive)

The maximum current flowing from the AC line towards the DC bus capacitor (A).

Voltage measurement cutoff frequency

The bus voltage measurement low-pass filter cutoff frequency (Hz).
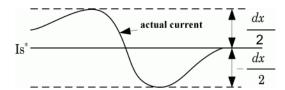
Active rectifier sampling time

The DC bus voltage controller sampling time (s). The sampling time must be a multiple of the simulation time step.

Current hysteresis bandwidth
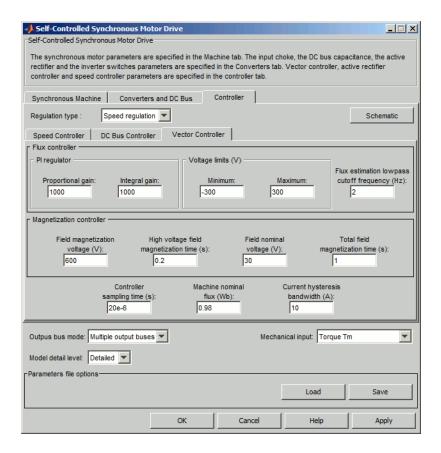
The current hysteresis bandwidth. This value is the total bandwidth distributed symmetrically around the current set point (A). The following figure illustrates a case where the current set point is Is^* and the current hysteresis bandwidth is set to dx.

This parameter is not used when using the average-value inverter.

Note This bandwidth can be exceeded because a fixed-step simulation is used. A rate transition block is needed to transfer data between different sampling rates. This block causes a delay in the gate signals, so the current may exceed the hysteresis band.

Controller — Vector Controller Subtab

Controller sampling time

The vector controller sampling time (s). The sampling time must be a multiple of the simulation time step.

Machine nominal flux

The motor stator nominal flux (Wb).

Current hysteresis bandwidth

The current hysteresis bandwidth (for details, see the **DC Bus Controller** subtab).

Flux Controller Section

PI regulator — Proportional gain

The flux controller proportional gain.

PI regulator — Integral gain

The flux controller integral gain.

Voltage limits — Minimum

The minimum voltage applied to the motor excitation field (V).

Voltage limits — Maximum

The maximum voltage applied to the motor excitation field (V).

Flux estimation lowpass cutoff frequency

The flux estimation first-order filter cutoff frequency (Hz).

Magnetization Controller Section

When you start the self-controlled synchronous motor, the magnetic flux of the motor must be first established before the motor is allowed to produce an electric torque. Since the motor field time constant is high, a field voltage much higher than nominal is applied in order to accelerate the building of the magnetic flux in the synchronous motor. After the period during which the high voltage is applied, the field voltage is lowered down to its nominal value during a second short period that adds to the latter period giving the total magnetization period. This procedure gives a smooth startup of the self-controlled synchronous motor.

Field magnetization voltage

The field magnetization voltage applied in order to establish the stator flux (V).

High voltage field magnetization time

The field magnetization high voltage application time (s).

Field nominal voltage

The field nominal voltage (V).

Total field magnetization time

The total time before the drive is ready to produce a torque (s).

Block Inputs and Outputs

SP

>The speed or torque set point. The speed set point can be a step function, but the speed change rate will follow the acceleration / deceleration ramps. If the load torque and the speed have opposite signs, the accelerating torque will be the sum of the electromagnetic and load torques.

Tm or Wm

>The mechanical input: load torque (Tm) or motor speed (Wm). For the mechanical rotational port (S), this input is deleted.

A, B, C

>The three phase terminals of the motor drive.

Wm, Te or S

>The mechanical output: motor speed (Wm), electromagnetic torque (Te) or mechanical rotational port (S).

When the **Output bus mode** parameter is set to **Multiple output buses**, the block has the following three output buses:

Motor

>The motor measurement vector. This vector allows you to observe the motor's variables using the Bus Selector block.

Conv

>The three-phase converters measurement vector. This vector contains:
>
>- The DC bus voltage
>- The rectifier output current
>- The inverter input current
>
>Note that all current and voltage values of the bridges can be visualized with the Multimeter block.

Ctrl

>The controller measurement vector. This vector contains the values for the active rectifier and for the inverter.
>
>For the active rectifier:
>
>- The active component of the current reference.

- The voltage error (difference between the DC bus voltage reference and actual DC bus voltage)
- The DC bus voltage reference

For the inverter:

- The torque reference
- The flux reference
- The speed error (difference between the speed reference ramp and actual speed)
- The speed reference ramp or torque reference

When the **Output bus mode** parameter is set to **Single output bus**, the block groups the Motor, Conv, and Ctrl outputs into a single bus output.

Model Specifications

The library contains a 200 hp drive parameter set. The specifications of the 200 hp drive are shown in the following table
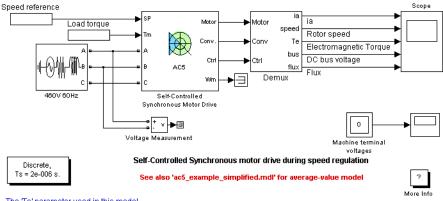
14 HP and 200 HP Drive Specifications

		14 HP Drive	200 HP Drive
Drive Input Voltage			
	Amplitude	460 V	460 V
	Frequency	60 Hz	60 Hz
Motor Nominal Values			
	Power	14 hp	200 hp
	Speed	1800 rpm	1800 rpm
	Voltage	460 V	460 V

.

Example
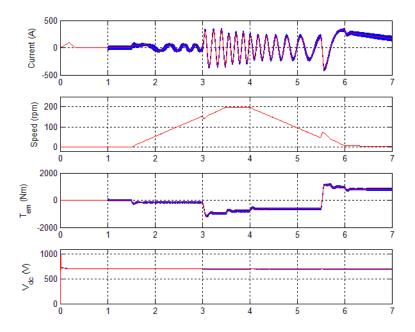
The `ac5_example` example illustrates an AC5 motor drive simulation with standard load condition for the detailed and average-value models. At time t = 1.5 s, the speed set point is 200 rpm.

As shown below, the speed precisely follows the acceleration ramp. At t = 3 s, the nominal load torque is applied to the motor. At t = 4 s, the speed set point is changed to 0 rpm. The speed decreases along the prescribed deceleration ramp to 0 rpm. At t = 5.5 s., the mechanical load passes from −792 N.m to 792 N.m. Notice that the results of the average-value model are similar to those of the detailed model except that the higher frequency signal components are not represented with the average-value converter.

AC5 Example Waveforms (Blue : Detailed Converter, Red : Average-Value Converter)

References

[1] Bose, B. K., *Modern Power Electronics and AC Drives*, Prentice-Hall, N.J., 2002.

[2] Krause, P. C., *Analysis of Electric Machinery*, McGraw-Hill, 1986.

Sequence Analyzer

Compute positive-, negative-, and zero-sequence components of three-phase signal

Library

Control and Measurements/Measurements

Description

The Sequence Analyzer block outputs the magnitude and phase of the positive-, negative-, and zero-sequence components of a set of three balanced or unbalanced signals. Index 1 denotes the positive sequence, index 2 denotes the negative sequence, and index 0 denotes the zero sequence. The signals can optionally contain harmonics. The three sequence components of a three-phase signal (voltages V_1 V_2 V_0 or currents I_1 I_2 I_0) are computed as follows:
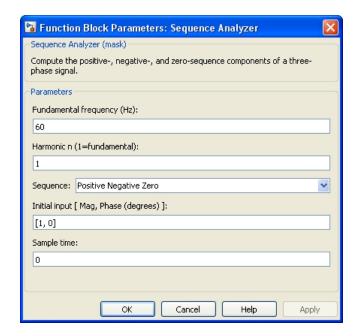
$$V_1 = \frac{1}{3}\left(V_a + a \cdot V_b + a^2 \cdot Vc\right)$$

$$V_2 = \frac{1}{3}\left(V_a + a^2 \cdot V_b + a \cdot Vc\right)$$

$$V_0 = \frac{1}{3}\left(V_a + V_b + Vc\right)$$

V_a, V_b, V_c = three voltage phasors at the specified frequency

$a = e^{j\,2\pi/3} = 1\angle 120°$ complex operator

A Fourier analysis over a sliding window of one cycle of the specified frequency is first applied to the three input signals. It evaluates the phasor values Va, Vb, and Vc at the specified fundamental or harmonic frequency. Then the transformation is applied to obtain the positive sequence, negative sequence, and zero sequence.

As the block uses a running average window to perform the Fourier analysis, one cycle of simulation must complete before the outputs give the correct magnitude and angle. For

example, the block response to a step change of V1 is a one-cycle ramp. For the first cycle of simulation, the output is held constant using the values specified by the initial input parameters.

Dialog Box and Parameters

Fundamental frequency (Hz)

Specify the fundamental frequency, in hertz, of the three-phase input signal.

Harmonic n (1=fundamental)

Specify the harmonic component to evaluate the sequences. Set to 1 to compute the sequences at the fundamental frequency or to the number corresponding to the desired harmonic.

Sequence

Specify the sequence component the block outputs. The options include `Positive`, `Negative`, `Zero`, and `Positive Negative Zero`. Select `Positive Negative Zero` to calculate all the sequences.

Initial input [Mag, Phase (degrees)]

Specify the initial magnitude and phase, in degrees, of the positive-sequence component of the input signal.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Inputs and Outputs

abc

Connects the vectorized signal of the three [a b c] sinusoidal signals to the input.

Iabc

The three-phase current signal.

|u| Magnitude

Outputs the magnitude (peak value) of the specified sequence component(s), in the same units as the abc input signals.

∠u Phase

Outputs the phase, in degrees, of the specified components.

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	No
Dimensionalized	No

Example

The power_SequenceAnalyzer model shows the use of the Sequence Analyzer block to compute the three sequence components of a three-phase sinusoidal voltage. The model sample time

The model sample time is parameterized by the Ts variable set to a default value of 50e-6 s. Set Ts to 0 in the command window to simulate the model in continuous mode.

Sequence Analyzer (Phasor)

Compute sequence components (positive, negative, and zero) of three-phase phasor signal

Library

Control and Measurements/Measurements

Description
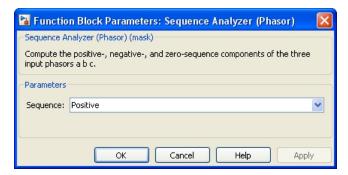
The Sequence Analyzer (Phasor) block computes the three-sequence phasor components (positive sequence u_1, negative sequence u_2, and zero sequence u_0) of a three-phase phasor signal as follows:

$$
\begin{bmatrix} u_1 \\ u_2 \\ u_0 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix}
$$

where α is the complex operator performing a $2\pi/3$ rotation:

$$
a = e^{\frac{j2\pi}{3}}
$$

Dialog Box and Parameters

Sequence

> Select the sequence components: `Positive`, `Negative`, `Zero`, or all three sequences `Positive`, `Negative`, and `Zero`.

Inputs and Outputs

abc

> The three-phase phasor signal [u_a u_b u_c].

mag u

> Returns the magnitude of the selected sequence phasor component.

angle u

> Returns the angle, in degrees, of the selected sequence phasor component.

Characteristics

Direct Feedthrough	Yes
Dimensionalized	No

Example

The power_PhasorMeasurements example shows the use of the Sequence Analyzer (Phasor) block.

Series RLC Branch

Implement series RLC branch
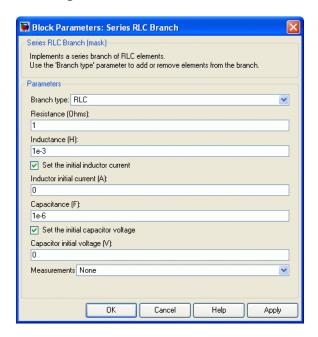
Library

Fundamental Blocks/Elements

Description

The Series RLC Branch block implements a single resistor, inductor, or capacitor, or a series combination of these. Use the **Branch type** parameter to select elements you want to include in the branch.

Negative values are allowed for resistance, inductance, and capacitance.

Dialog Box and Parameters

Branch type

Select the elements you want to include in the branch. The **R** letter defines the resistor, the **L** letter defines the inductor, and the **C** letter defines the capacitor. Select **Open circuit** to define an open circuit (R=0, L=0, C=inf). Only existing elements are displayed in the block icon.

Resistance

The branch resistance, in ohms (Ω). The **Resistance** parameter is not visible if the resistor element is not specified in the **Branch type** parameter.

Inductance L

The branch inductance, in henries (H). The **Inductance** parameter is not visible if the inductor element is not specified in the **Branch type** parameter.

Set the initial inductor current

If selected, the initial inductor current is defined by the **Inductor initial current** parameter. If not selected, the software calculates the initial inductor current in order to start the simulation steady-state.

The **Set the initial inductor current** parameter is not visible and have no effect on the block if the inductor element is not specified in the **Branch type** parameter.

Inductor initial current (A)

The initial inductor current used at the start of the simulation. The **Inductor initial current** parameter is not visible and have no effect on the block if the inductor is not modeled and if the **Set the initial inductor current** parameter is not selected.

Capacitance C

The branch capacitance, in farads (F). The **Capacitance** parameter is not visible if the capacitance element is not specified in the **Branch type** parameter.

Set the initial capacitor voltage

If selected, the initial capacitor voltage is defined by the **Capacitor initial voltage** parameter. If not selected, the software calculates the initial capacitor voltage in order to start the simulation in steady-state.

The **Set the initial capacitor voltage** parameter is not visible and have no effect on the block if the capacitor element is not specified in the **Branch type** parameter.

Capacitor initial voltage (V)

The initial capacitor voltage used at the start of the simulation. The **Capacitor initial voltage** parameter is not visible and have no effect on the block if the capacitor is not modeled and if the **Set the initial capacitor voltage** parameter is not selected.

Measurements

Select `Branch voltage` to measure the voltage across the Series RLC Branch block terminals.

Select `Branch current` to measure the current flowing through the Series RLC Branch block.
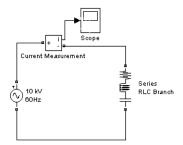
Select `Branch voltage and current` to measure the voltage and the current of the Series RLC Branch block.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurement is identified by a label followed by the block name.

Measurement	Label
Branch voltage	Ub:
Branch current	Ib:

Example

Obtain the frequency response of a fifth-harmonic filter (tuned frequency = 300 Hz) connected on a 60 Hz power system. This example is available in the power_seriesbranch model.

The network impedance in the Laplace domain is

$$Z(s) = \frac{V(s)}{I(s)} = \frac{LCs^2 + RCs + 1}{Cs}.$$

To obtain the frequency response of the impedance you have to get the state-space model (A B C D matrices) of the system.
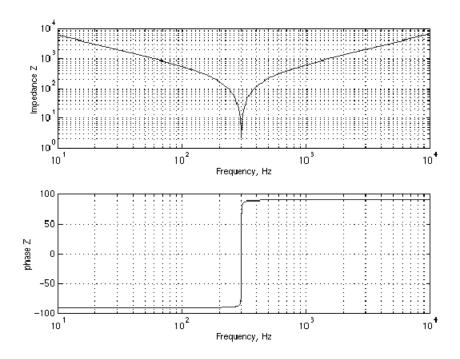
This system is a one-input (Vsource) and one-output (Current Measurement block) system.

Note If you have Control System Toolbox software installed, you can use the `bode` function to get the transfer function *Z(s)* from the state-space matrices as follows:

```
[A,B,C,D] = power_analyze('power_seriesbranch');
freq = logspace(1,4,500);
w = 2*pi*freq;
[Ymag,Yphase] = bode(A,B,C,D,1,w);
% invert Y(s) to get Z(s)
Zmag = 1./Ymag;
Zphase = -Yphase;
subplot(2,1,1)
loglog(freq,Zmag)
grid
```

```
title('5th harmonic filter')
xlabel('Frequency, Hz')
ylabel('Impedance Zmag')
subplot(2,1,2)
semilogx(freq,Zphase)
xlabel('Frequency, Hz')
ylabel('phase Z')
grid
```

You can also use the Impedance Measurement block and the Powergui block to plot
the impedance as a function of frequency. In order to measure the impedance you must
disconnect the voltage source.

See Also

Multimeter, Parallel RLC Branch, Parallel RLC Load, Series RLC Load

Series RLC Load

Implement linear series RLC load

Library

Fundamental Blocks/Elements
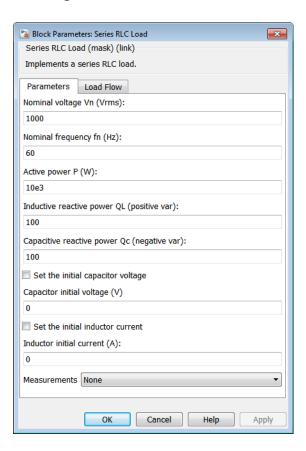
Description

The Series RLC Load block implements a linear load as a series combination of R L C elements. At the specified frequency, the load exhibits a constant impedance. The active and reactive powers absorbed by the load are proportional to the square of the applied voltage. Only elements associated with nonzero powers are displayed in the block icon.

Dialog Box and Parameters

Parameters Tab

Nominal voltage Vn

The nominal voltage of the load, in volts RMS.

Nominal frequency fn

The nominal frequency, in hertz.

Active power P

The active power of the load, in watts.

Inductive reactive power QL

The inductive reactive power QL, in vars. Specify a positive value, or 0.

Capacitive reactive power QC

The capacitive reactive power QC, in vars. Specify a positive value, or 0.

Set the initial capacitor voltage

If selected, the initial capacitor voltage is defined by the **Capacitor initial voltage** parameter. If not selected, the software calculates the initial capacitor voltage in order to start the simulation in steady-state.

The **Set the initial capacitor voltage** parameter have no effect on the block if the capacitive reactive power is equal to zero.

Capacitor initial voltage (V)

The initial capacitor voltage used at the start of the simulation. The **Capacitor initial voltage** parameter have no effect on the block if the capacitive reactive power is equal to zero and if the **Set the initial capacitor voltage** parameter is not selected.

Set the initial inductor current

If selected, the initial inductor current is defined by the **Inductor initial current** parameter. If not selected, the software calculates the initial inductor current in order to start the simulation steady-state.

The **Set the initial inductor current** parameter have no effect on the block if the inductive reactive power is equal to zero.

Inductor initial current (A)

The initial inductor current used at the start of the simulation. The **Inductor initial current** parameter have no effect on the block if the inductive reactive power is equal to zero and if the **Set the initial inductor current** parameter is not selected.

Measurements

Select `Branch voltage` to measure the voltage across the Series RLC Load block terminals.

Select `Branch current` to measure the current flowing through the Series RLC Load block.

Select `Branch voltage and current` to measure the voltage and the current of the Series RLC Load block.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurement is identified by a label followed by the block name:

Measurement	Label
Branch voltage	`Ub:`
Branch current	`Ib:`

Load Flow Tab

The Load Flow tool of the powergui block uses the parameters on this tab. These load flow parameters affect only model initialization. They do not affect simulation.

Load type

Specify the load type. The default value is `constant Z`.

If you select `constant Z`, the load impedance is determined from the nominal phase-to-phase voltage Vn, active power P, and reactive power (QL-QC) specified on the **Parameters** tab of the block dialog box. During the load flow solution, the impedance is kept constant. The effective P and Q therefore vary proportionally to the square of the bus voltage computed by the Load Flow tool.

If you select `constant PQ`, the active power P and reactive power Q are kept constant and equal to the values specified on the **Parameters** tab of the block dialog box. When you apply the load flow solution to the model (by clicking **Apply** in the Load Flow tool), the **Nominal phase-to-phase voltage Vn** parameter on the **Parameters** tab is automatically adjusted to the phase-to-phase bus voltage computed by the Load Flow tool.

If you select `constant I`, the load current is kept constant at its nominal value determined from the base voltage specified in the dialog box of the associated Load Flow Bus block and from active power P and reactive power QL and QC specified on the **Parameters** tab of the block dialog box. The effective P and Q therefore vary proportionally to the bus voltage computed by the Load Flow tool. When you apply the load flow solution to the model (by clicking **Apply** in the Load Flow tool), the pu value of the nominal voltage Vn on the **Parameters** tab is automatically adjusted to the square root of the load voltage (in pu) computed by the Load Flow tool.

Examples

The power_seriesload example uses a Series RLC Load block to implement a simple load.

See Also
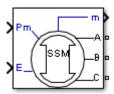
Multimeter, Parallel RLC Branch, Parallel RLC Load, Series RLC Branch

Simplified Synchronous Machine

Model the dynamics of simplified three-phase synchronous machine

Library

Fundamental Blocks/Machines

Description

The Simplified Synchronous Machine block models both the electrical and mechanical characteristics of a simple synchronous machine.

The electrical system for each phase consists of a voltage source in series with an RL impedance, which implements the internal impedance of the machine. The value of R can be zero but the value of L must be positive.

The Simplified Synchronous Machine block implements the mechanical system described by

$$\Delta\omega(t) = \frac{1}{2H}\int_0^t (Tm - Te)\,dt - Kd\Delta\omega(t)$$
$$\omega(t) = \Delta\omega(t) + \omega_0,$$

where
$\Delta\omega$ = Speed variation with respect to speed of operation
H = constant of inertia
Tm = mechanical torque
Te = electromagnetic torque
Kd = damping factor representing the effect of damper windings
$\omega(t)$ = mechanical speed of the rotor
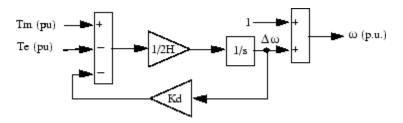
ω_0 = speed of operation (1 p.u.)

Although the parameters can be entered in either SI units or per unit in the dialog box, the internal calculations are done in per unit. The following block diagram illustrates how the mechanical part of the model is implemented. The model computes a deviation with respect to the speed of operation; not the absolute speed itself.

The Kd damping coefficient simulates the effect of damper windings normally used in synchronous machines. When the machine is connected to an infinite network (zero impedance), the variation of machine power angle delta (δ) resulting from a change of mechanical power (P_m) can be approximated by the following second-order transfer function:

$$\frac{\delta}{P_m} = \frac{\omega_s / (2H)}{s^2 + 2\zeta\omega_n s + \omega_n^2},$$

where

δ	Power angle delta: angle of internal voltage E with respect to terminal voltage, in radians
P_m	Mechanical power in pu
ω_n	Frequency of electromechanical oscillations = $\sqrt{\omega_s P_{max} / (2H)}$ in rad/s
ζ	Damping ratio = $\left(K_d / 4\right)\sqrt{2 / \left(\omega_s H P_{max}\right)}$
ω_s	Electrical frequency in rad/s
P_{max}	Maximum power in pu transmitted through reactance X at terminal voltage V_t and internal voltage E. $P_{max} = V_t E/X$, where V_t, E, and X are in pu
H	Inertia constant(s)

K_d	Damping factor (pu_of_torque / pu_of_speed)
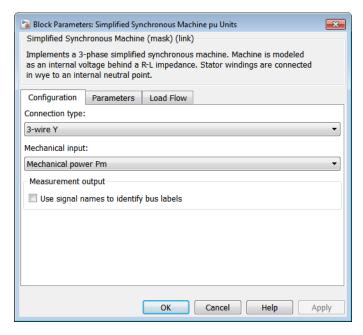
This approximate transfer function, which has been derived by assuming $\sin(\delta) = \delta$, is valid for small power angles ($\delta < 30$ degrees). It follows from the preceding ζ expression that the Kd value required to obtain a given ζ damping ratio:

$$K_d = 4\zeta \sqrt{\omega_s HP_{\max} / 2}.$$

Dialog Box and Parameters

In the Machines library you can choose between the SI units or the pu units Simplified Synchronous Machine blocks to specify the electrical and mechanical parameters of the model. These two blocks simulate exactly the same simplified synchronous machine model; the only difference is how you enter the parameter units.

Configuration Tab

Connection type

Specify the number of wires used in the three-phase Y connection: either three-wire (neutral not accessible) or four-wire (neutral is accessible).
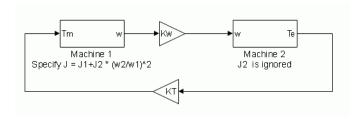
Mechanical input

Select the mechanical power applied to the shaft or the rotor speed as a Simulink input of the block, or to represent the machine shaft by a Simscape rotational mechanical port.

Select **Mechanical power Pm** to specify a mechanical power input, in W or in pu, and change labeling of the block input to Pm. The machine speed is determined by the machine Inertia J (or inertia constant H for the pu machine) and by the difference between the mechanical torque Tm, resulting from the applied mechanical power Pm, and the internal electromagnetic torque Te. The sign convention for the mechanical power is when the speed is positive, a positive mechanical power signal indicates generator mode and a negative signal indicates motor mode.

Select **Speed w** to specify a speed input, in rad/s or in pu, and change labeling of the block input to w. The machine speed is imposed and the mechanical part of the model (inertia constant H) is ignored. Using the speed as the mechanical input allows modeling a mechanical coupling between two machines.

The next figure indicates how to model a stiff shaft interconnection in a motor-generator set when friction torque is ignored in machine 2. The speed output of machine 1 (motor) is connected to the speed input of machine 2 (generator), while machine 2 electromagnetic torque output Te is applied to the mechanical torque input Tm of machine 1. The Kw factor takes into account speed units of both machines (pu or rad/s) and gear box ratio w2/w1. The KT factor takes into account torque units of both machines (pu or N.m) and machine ratings. Also, because the inertia J2 is ignored in machine 2, J2 referred to machine 1 speed must be added to machine 1 inertia J1.

Select **Mechanical rotational port** to add to the block a Simscape mechanical rotational port that allows connection of the machine shaft with other Simscape

blocks having mechanical rotational ports. The Simulink input representing the mechanical power *Pm* or the speed w of the machine is then removed from the block.

The next figure indicates how to connect an Ideal Torque Source block from the Simscape library to the machine shaft to represent the machine in motor mode, or in generator mode, when the rotor speed is positive.

Use signal names to identify bus labels

When this check box is selected, the measurement output uses the signal names to identify the bus labels. Select this option for applications that require bus signal labels to have only alphanumeric characters.

When this check box is cleared, the measurement output uses the signal definition to identify the bus labels. The labels contain nonalphanumeric characters that are incompatible with some Simulink applications.

Parameters Tab

Nominal power, line-to-line voltage, and frequency

The nominal apparent power Pn (VA), frequency fn (Hz), and RMS line-to-line voltage Vn (V). Computes nominal torque and converts SI units to pu.

Inertia, damping factor and pairs of poles

The inertia (J in kg.m^2 or H in seconds) damping factor (Kd) and number of pairs of poles (p). The damping factor must be specified in (pu of torque)/(pu of speed) in both machine dialog boxes (in pu and in SI).

Internal impedance

The resistance R (Ω or pu) and reactance L (H or pu) for each phase.

Initial conditions

The initial speed deviation (% of nominal), rotor angle (degrees), line current magnitudes (A or pu), and phase angles (degrees). These values are automatically computed by the load flow utility of the Powergui block.
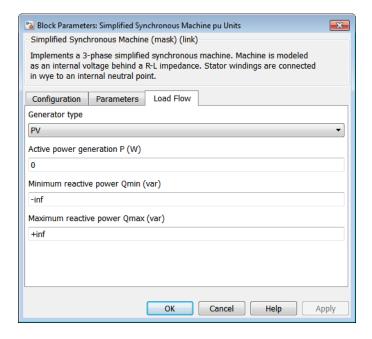
Sample time (−1 for inherited)

Specifies the sample time used by the block. To inherit the sample time specified in the Powergui block, set this parameter to -1.

Load Flow Tab

The load flow parameters define block parameters for use with the Load Flow tool of the Powergui block. These load flow parameters are for model initialization only. They have no impact on the block model or on the simulation performance.

The configuration of the **Load Flow** tab depends on the option selected for the **Generator type** parameter.

Generator type

Specify the generator type of the machine.

Select `swing` to implement a generator controlling magnitude and phase angle of its terminal voltage. The reference voltage magnitude and angle are specified by the **Swing bus or PV bus voltage** and **Swing bus voltage angle** parameters of the Load Flow Bus block connected to the machine terminals.

Select `PV` to implement a generator controlling its output active power P and voltage magnitude V. P is specified by the **Active power generation P** parameter of the block. V is specified by the **Swing bus or PV bus voltage** parameter of the Load Flow Bus block connected to the machine terminals. You can control the minimum and maximum reactive power generated by the block by using the **Minimum reactive power Qmin** and **Maximum reactive power Qmax** parameters.

Select `PQ` to implement a generator controlling its output active power P and reactive power Q. P and Q are specified by the **Active power generation P** and **Reactive power generation Q** parameters of the block, respectively.

Active power generation P

Specify the active power that you want generated by the machine, in watts. When the machine operates in motor mode, you specify a negative value. This parameter is available if you specify **Generator type** as `PV` or `PQ`.

Reactive power generation Q

Specify the reactive power that you want generated by the machine, in vars. A negative value indicates that the reactive power is absorbed by the machine. This parameter is available only if you specify **Generator type** as `PQ`.

Minimum reactive power Qmin

This parameter is available only if you specify **Generator type** as `PV`. Indicates the minimum reactive power that can be generated by the machine while keeping the terminal voltage at its reference value. This reference voltage is specified by the **Swing bus or PV bus voltage** parameter of the Load Flow Bus block connected to the machine terminals. The default value is `-inf`, which means that there is no lower limit on the reactive power output.

Maximum reactive power Qmax

This parameter is available only if you specify **Generator type** as `PV`. Indicates the maximum reactive power that can be generated by the machine while keeping the terminal voltage at its reference value. This reference voltage is specified by the **Swing bus or PV bus voltage** parameter of the Load Flow Bus block connected

to the machine terminals. The default value is `+inf`, which means that there is no upper limit on the reactive power output.

Inputs and Outputs

Pm

The mechanical power supplied to the machine, in watts. The input can be a constant signal or it can be connected to the output of the Hydraulic Turbine and Governor block. The frequency of the internal voltage sources depends on the mechanical speed of the machine.

w

The alternative block input instead of `Pm` (depending on the value of the **Mechanical input** parameter) is the machine speed, in rad/s.

E

The amplitude of the internal voltages of the block. It can be a constant signal or it can be connected to the output of a voltage regulator. If you use the SI units machine, this input must be in volts phase-to-phase RMS. If you use the pu units machine, it must be in pu.

m

The Simulink output of the block is a vector containing measurement signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library. Depending on the type of mask that you use, the units are in SI or in pu.

Name	Definition	Units
ias	Stator current is_a	A or pu
ibs	Stator current is_b	A or pu
ics	Stator current is_c	A or pu
va	Terminal voltage Va	V or pu
vb	Terminal voltage Vb	V or pu
vc	Terminal voltage Vc	V or pu
ea	Internal voltage Ea	V or pu
eb	Internal voltage Eb	V or pu
ec	Internal voltage Ec	V or pu

Name	Definition	Units
theta	Rotor angle theta	rad
w	Rotor speed wm	rad/s
Pe	Electrical power Pe	W

Assumptions

The electrical system of the Simplified Synchronous Machine block consists solely of a voltage source behind a synchronous reactance and resistance. All the other self- and magnetizing inductances of the armature, field, and damping windings are neglected. The effect of damper windings is approximated by the damping factor Kd. The three voltage sources and RL impedance branches are Y-connected (three wires or four wires). The load might or might not be balanced.

Limitations

When you use Simplified Synchronous Machine blocks in discrete systems, you might have to use a small parasitic resistive load, connected at the machine terminals, to avoid numerical oscillations. Large sample times require larger loads. The minimum resistive load is proportional to the sample time. Remember that with a 25 µs time step on a 60 Hz system, the minimum load is approximately 2.5% of the machine nominal power. For example, a 200 MVA simplified synchronous machine in a power system discretized with a 50 µs sample time requires approximately 5% of resistive load or 10 MW. If the sample time is reduced to 20 µs, a resistive load of 4 MW should be sufficient.

Example
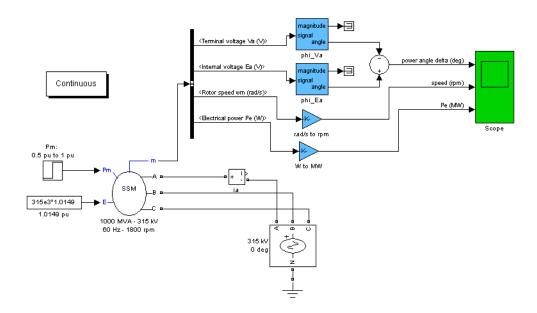
The power_simplealt example uses the Simplified Synchronous Machine block to represent a 1000 MVA, 315 kV, 60 Hz equivalent source connected to an infinite bus (Three-Phase Programmable Voltage Source block). The Simplified Synchronous Machine (SI Units) block is used as a synchronous generator. The internal resistance and reactance are set respectively to 0.02 pu (1.9845 Ω) and 0.2 pu (X = 19.845 Ω; L = 0.0526 H). The inertia of the machine is J = 168,870 kg.m^2, corresponding to an inertia constant H = 3 s. The electrical frequency is ω_s = 2*п*60 = 377 rad/s. The machine has two pairs of poles such that its synchronous speed is 2*п*60/2 = 188.5 rad/s or 1800 rpm.

The **Load Flow** option of the Powergui has been used to initialize the machine to start simulation in steady state with the machine generating 500 MW. The required internal voltage computed by the load flow is 1.0149 pu. Therefore, an internal voltage E = 315e3*1.0149 = 319,690 Vrms phase-to-phase is specified in the Constant block connected to the E input. The maximum power that can be delivered by the machine with a terminal voltage V_t = 1.0 pu and an internal voltage E = 1.0149 pu is $P_{max} = V_t*E/X$ = 1.0149/0.2 = 5.0745 pu.

The damping factor Kd is adjusted to obtain a damping ratio ζ = 0.3. The required Kd value is:

$$K_d = 4\zeta \sqrt{\omega_s HP_{max} / 2} = 64.3$$
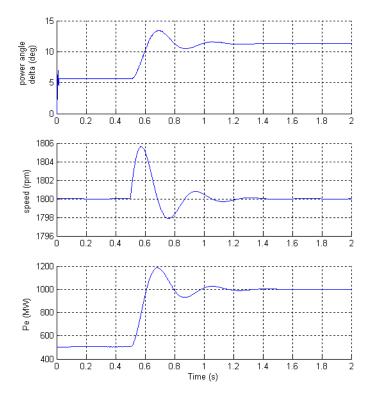
Two Fourier blocks measure the power angle δ. This angle is computed as the difference between the phase angle of phase A internal voltage and the phase angle of phase A terminal voltage.

In this example, a step is performed on the mechanical power applied to the shaft. The machine is initially running in steady state with a mechanical power of 505 MW

(mechanical power required for an output electrical power of 500 MW, considering the resistive losses). At t = 0.5 s the mechanical power is suddenly increased to 1000 MW.

Run the example and observe the electromechanical transient on the Scope block displaying the power angle δ in degrees, the machine speed in rpm, and the electrical power in MW. Simulation results are shown in the following figure.

For an initial electrical power Pe = 500 MW (0.5 pu), the load angle δ is 5.65 degrees, which corresponds to the expected value:

$$Pe = \frac{V_t E \sin\delta}{X} = \frac{1.0 \cdot 1.0149 \cdot \sin(5.65^\circ)}{0.2} = 0.5 \text{ p.u.}$$

As the mechanical power is stepped from 0.5 pu to 1.0 pu, the load angle increases and goes through a series of under damped oscillations (damping ratio ζ = 0.3) before stabilizing to its new value of 11.3 degrees. The frequency of the oscillations is given by:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{\omega_s P_{\max}}{2H}} = 2.84 \text{ Hz.}$$

See Also

Excitation System, Hydraulic Turbine and Governor, powergui, Steam Turbine and Governor, Synchronous Machine
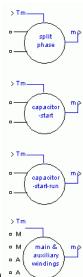
Introduced before R2006a

Single Phase Asynchronous Machine

Model dynamics of single phase asynchronous machine with squirrel-cage rotor

Library

Fundamental Blocks/Machines
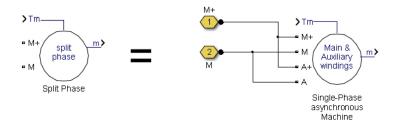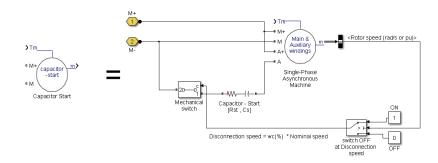
Description

This machine has two windings: main and auxiliary. With the model, you can simulate the split-phase, the capacitor-start, the capacitor-start-capacitor-run, and main & auxiliary windings operation modes.
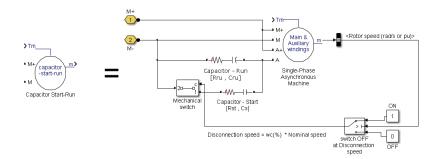
For the split-phase mode, the main and auxiliary windings are internally connected as follows:

For the capacitor-start mode, the main and auxiliary windings are internally connected as follows:

For the capacitor-start-capacitor-run mode, the main and auxiliary windings are internally connected as follows:
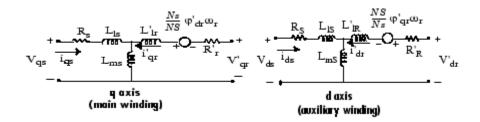
The electrical part of the machine is represented by a fourth-order state-space model and the mechanical part by a second-order system. All electrical variables and parameters

are referred to the stator, indicated by the following prime signs in the machine equations. All stator and rotor quantities are in the stator reference frame (dq frame). The subscripts are defined in the following table.

Subscript	Definition
d	d axis quantity
q	q axis quantity
r	Referred to the main winding rotor quantity
R	Referred to the auxiliary winding rotor quantity
s	Main winding stator quantity
S	Auxiliary winding stator quantity
l	Leakage inductance
m	Magnetizing inductance

Electrical System

q axis
(main winding)

d axis
(auxiliary winding)

$V_{qs} = R_s i_{qs} + d\varphi_{qs}/dt$

$V_{ds} = R_S i_{ds} + d\varphi_{ds}/dt$

$V'_{qr} = R'_r i'_{qr} + d\varphi'_{qr}/dt - (N_s/N_S)\omega_r \varphi'_{dr}$

$V'_{dr} = R'_R i'_{dr} + d\varphi'_{dr}/dt + (N_S/N_s)\omega_r \varphi'_{qr}$

$T_e = p[(N_S/N_s)\varphi'_{qr}i'_{dr} - (N_s/N_S)\varphi'_{dr}i'_{qr}]$

where

$\varphi_{qs} = L_{ss}i_{qs} + L_{ms}i'_{qr}$

$\varphi_{ds} = L_{SS}i_{ds} + L_{mS}i'_{dr}$

$\varphi'_{qr} = L'_r i'_{qr} + L_{ms}i_{qs}$

$\varphi'_{dr} = L'_{RR}i'_{dr} + L_{mS}i_{ds}$

$L_{ss} = L_{ls} + L_{ms}$

$L_{SS} = L_{lS} + L_{mS}$

$L'_{rr} = L'_{lr} + L_{ms}$

$L'_{RR} = L'_{lR} + L_{mS}$

Mechanical System

$$\frac{d}{dt}\omega_m = \frac{T_e - F\omega_m - T_m}{2H}$$

$$\frac{d}{dt}\theta_m = \omega_m.$$

Reference frame

The reference frame fixed in the stator converts voltages and currents to the dq frame.

The following relationships describe the ab-to-dq frame transformations applied to the single phase asynchronous machine.

$$\begin{bmatrix} f_{qs} \\ f_{ds} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} f_{as} \\ f_{bs} \end{bmatrix}$$

$$\begin{bmatrix} f_{qr} \\ f_{dr} \end{bmatrix} = \begin{bmatrix} \cos(\theta r) & -\sin(\theta r)) \\ -\sin(\theta r) & -\cos(\theta r) \end{bmatrix} \begin{bmatrix} f_{ar} \\ f_{br} \end{bmatrix}.$$

The variable f can represent either voltage, currents, or flux linkage.

The single phase asynchronous machine block parameters are defined as follows (all quantities are referred to the stator).

Parameter	Definition
R_s, L_{ls}	Main winding stator resistance and leakage inductance
R_S, L_{lS}	Auxiliary winding stator resistance and leakage inductance
R'_r, L'_{lr}	Main winding rotor resistance and leakage inductance
R'_R, L'_{lR}	Auxiliary winding rotor resistance and leakage inductance. The two values are equal to the main winding rotor resistance and leakage inductances values, respectively.
L_{ms}	Main winding magnetizing inductance
L_{mS}	Auxiliary winding magnetizing inductance
L_{ss}, L'_{rr}	Total main winding stator and rotor inductances
L_{SS}, L'_{RR}	Total auxiliary winding stator and rotor inductances
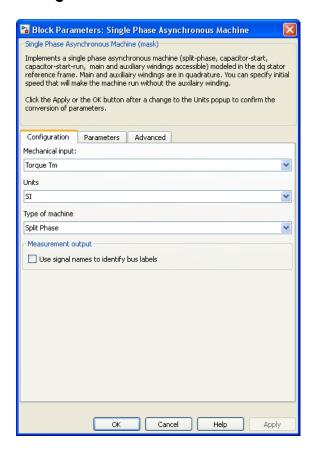
Parameter	Definition
V_{as}, i_{as}	Main winding stator voltage and current
V_{bs}, i_{bs}	Auxiliary winding stator voltage and current
V_{qs}, i_{qs}	q axis stator voltage and current
V'_{qr}, i'_{qr}	q axis rotor voltage and current
V_{ds}, i_{ds}	d axis stator voltage and current
V'_{dr}, i'_{dr}	d axis rotor voltage and current
ϕ_{qs}, ϕ_{ds}	Stator q and d axis fluxes
ϕ'_{qr}, ϕ'_{dr}	Rotor q and d axis fluxes
ω_m	Angular velocity of the rotor
Θ_m	Rotor angular position
p	Number of pole pairs
ω_r	Electrical angular velocity (ω_m x p)
Θ_r	Electrical rotor angular position (Θ_m x p)
T_e	Electromagnetic torque
T_m	Shaft mechanical torque
J	Combined rotor and load inertia coefficient in (kg.m^2). Set to infinite to simulate locked rotor.
F	Combined rotor and load viscous friction coefficient.
H	Combined rotor and load inertia constant in (s). Set to infinite to simulate locked rotor.

Parameter	Definition
N_s	Number of main winding's effective turns.
N_S	Number of auxiliary winding's effective turns.
R_{st}	Capacitor-Start resistance
C_s	Capacitor-Start
R_{run}	Capacitor-Run resistance
C_{run}	Capacitor-Run
N	Ratio of number of auxiliary winding's effective turns and number of main winding's effective turns.

Dialog Box and Parameters

You can choose between two types of units to specify the electrical and mechanical parameters of the model, the per unit dialog box, and the SI dialog box. Both blocks are modeling the same machine. Depending on the dialog box that you use, SimPowerSystems automatically converts the parameters that you specify into per unit parameters. The Simulink model of the Single Phase Asynchronous Machine block uses per unit parameters.

Configuration Tab

Mechanical input
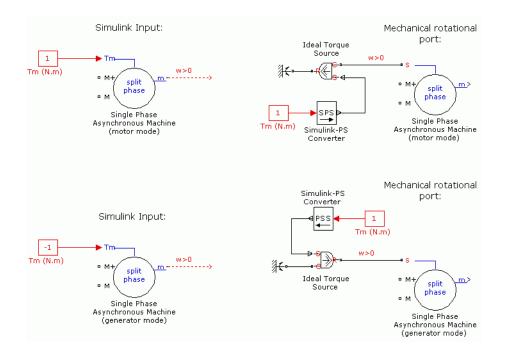
Select the torque applied to the shaft as a Simulink input of the block, or to represent the machine shaft by a Simscape rotational mechanical port.

Select **Torque Tm** to specify a torque input, in N.m or in pu, and change labeling of the block input to Tm. The machine speed is determined by the machine Inertia J (or inertia constant H for the pu machine) and by the difference between the applied mechanical torque Tm and the internal electromagnetic torque Te. The sign convention for the mechanical torque is when the speed is positive, a positive torque signal indicates motor mode and a negative signal indicates generator mode.

Select **Mechanical rotational port** to add to the block a Simscape mechanical rotational port that allows connection of the machine shaft with other Simscape blocks that have mechanical rotational ports. The Simulink input representing the mechanical torque Tm of the machine is then removed from the block.

The next figure indicates how to connect an Ideal Torque Source block from the Simscape library to the machine shaft to represent the machine in motor mode, or in generator mode, when the rotor speed is positive.

Units

Specify the per unit dialog box or the SI dialog box.

Type of machine
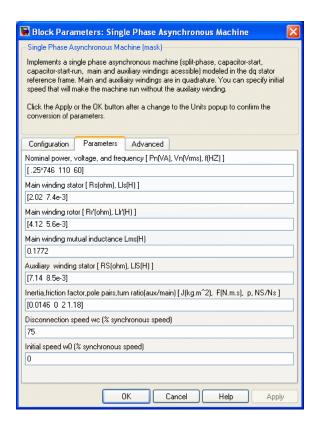
Specify one of the four types of single phase asynchronous machines (the split-phase, the capacitor-start, the capacitor-start-capacitor-run, or the main & auxiliary windings).

Use signal names to identify bus labels

When this check box is selected, the measurement output uses the signal names to identify the bus labels. Select this option for applications that require bus signal labels to have only alphanumeric characters.

When this check box is cleared, the measurement output uses the signal definition to identify the bus labels. The labels contain nonalphanumeric characters that are incompatible with some Simulink applications.

Parameters Tab

Nominal power, voltage, and frequency

The nominal apparent power Pn (VA), RMS Vn (V), and frequency fn (Hz).

Main winding stator

The stator resistance R_s (Ω or pu) and leakage inductance L_{ls} (H or pu).

Main winding rotor

The rotor resistance R_r' (Ω or pu) and leakage inductance L_{lr}' (H or pu), both referred to the stator.

Main winding mutual inductance

The magnetizing inductance L_{ms} (H or pu).

Auxiliary winding stator

The stator resistance R_S (Ω or pu) and leakage inductance L_{lS} (H or pu). Note that the Auxiliary winding rotor parameters are assumed to be equal to the main winding rotor resistance and leakage inductances values. Therefore it is not required to specify them in the dialog box.

Inertia, friction factor, pole pairs, turn ratio (aux/main)

For the **SI units** dialog box: the combined machine and load inertia coefficient J (kg.m^2), the combined viscous friction coefficient F (N.m.s), the number of pole pairs p and ratio of number of auxiliary winding's effective turns, and the number of main winding's effective turns. **pu units** dialog box: the inertia constant H (s), the combined viscous friction coefficient F (pu), and the number of pole pairs p.

Capacitor-Start

The start capacitance C_s (farad or pu) and capacitor series resistance R_{st}(Ω or pu).

Capacitor-Run

The run capacitance Crun (farad or pu) and series resistance Rrun (farad or pu).
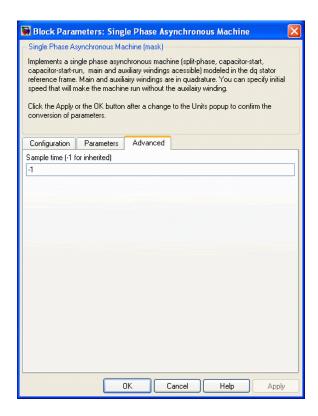
Disconnection speed

Specifies the speed (%) when the auxiliary winding may be disconnected.

Initial speed

Specifies the initial speed (%).

Advanced Tab

Sample time (−1 for inherited)

Specifies the sample time used by the block. To inherit the sample time specified in the Powergui block, set this parameter to `-1`.

Inputs and Outputs

Tm

The Simulink input of the block is the mechanical torque at the machine shaft. When you use the SI parameters mask, the input is a signal in N.m; otherwise it is in pu.

m

The Simulink output of the block is a vector containing measurement signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library. Depending on the type of mask you use, the units are in SI, or in pu.

Name	Definition	Units
iar	Rotor current ir_a	A or pu
ibr	Rotor current ir_b	A or pu
iqr	Rotor current iq	A or pu
idr	Rotor current id	A or pu
phiqr	Rotor flux phir_q	V.s or pu
phidr	Rotor flux phir_d	V.s or pu
ias	Main winding stator current ia	A or pu
ibs	Auxiliary winding stator current ib	A or pu
phiqs	Stator flux phis_q(V.s)	V.s or pu
phids	Stator flux phis_d(V.s)	V.s or pu
vc	Voltage capacitor Vc	V or pu
w	Rotor speed	rad/s
Te	Electromagnetic torque Te	N.m or pu
theta	Rotor angle thetam	rad

Limitations

The Single Phase Asynchronous Machine block does not include a representation of iron losses and saturation.

Example
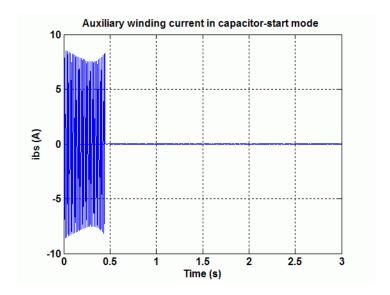
The `power_singlephaseASM` example shows the use of the Single Phase Asynchronous Machine block in two modes of operation.

It consists of a single phase asynchronous machine in an open-loop speed control system. The main and auxiliary windings are fed by a single phase power supply. The motor is started at no-load and a step of 1N.m is applied at 2 seconds.

Capacitor-Start Operation Mode
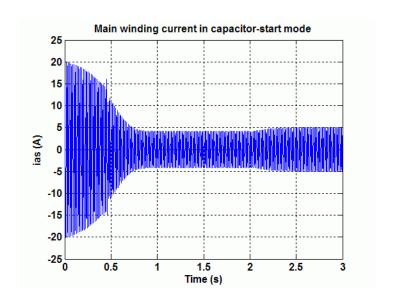
In capacitor-start operation mode the auxiliary winding is tripped when the machine is accelerated to 75% of the rated speed.

The last figure in the series, Electromagnetic Torque in Capacitor-Start Operation Mode, shows the electromagnetic torque developed by the machine. Because there is a step load of 1 N.m, the average torque is 1 N.m. The torque ripple amplitude is about 2.5 N.m, or 150% of the rated load. The torque pulsation affects the operation of the machine.
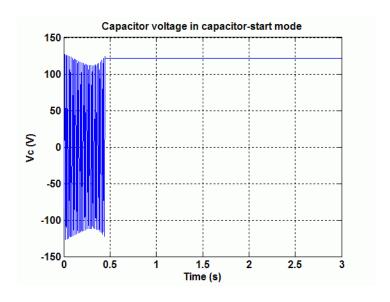
Auxiliary Winding Current in Capacitor-Start Operation Mode
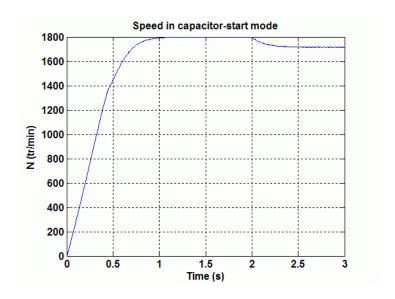
The auxiliary winding current is set to zero when the speed reaches 75% of the rated speed. The voltage across the start-capacitor remains at its maximum value, because current and voltage across a capacitor are in quadrature.
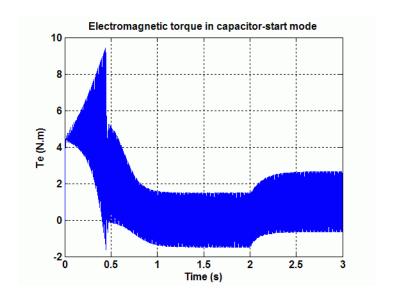
Main Winding Current in Capacitor-Start Operation Mode

Capacitor Voltage in Capacitor-Start Operation Mode

Speed in Capacitor-Start Operation Mode
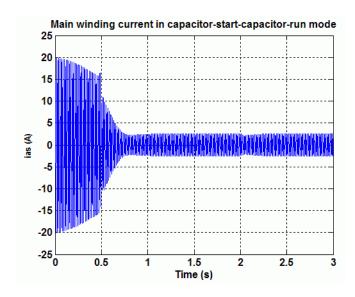
Electromagnetic Torque in Capacitor-Start Operation Mode
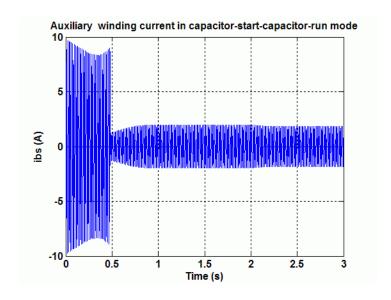
Capacitor-Start-Run Operation Mode

An improvement in the operation mode of the single phase asynchronous machine occurs when the auxiliary winding is still connected in series with a capacitor after starting.
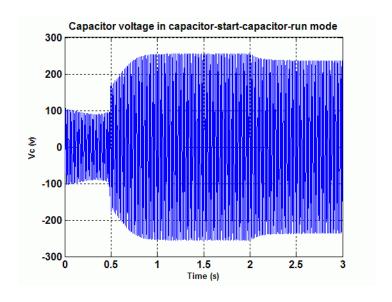
The next figures show the simulation wave forms in the capacitor-start-run operation mode single phase asynchronous machine. The magnitude of the torque ripple at steady state is only about 3% of the load torque. It improves the operation of a single phase asynchronous machine by limiting the shaft's vibrations.
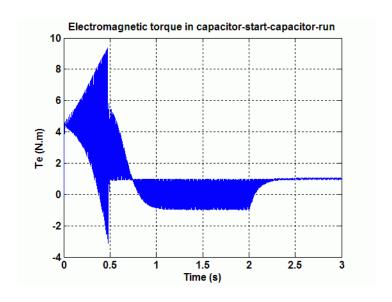
Main Winding Current in Capacitor-Start-Run Operation Mode
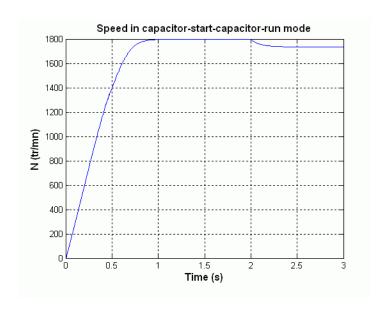
Auxiliary Winding Current in Capacitor-Start-Run Operation Mode

Capacitor Voltage in Capacitor-Start-Run Operation Mode

Electromagnetic Torque in Capacitor-Start-Run Operation Mode

Speed in Capacitor-Start-Run Operation Mode

References
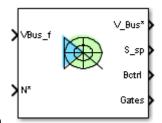
[1] Krause, P.C., O. Wasynczuk, and S.D. Sudhoff, *Analysis of Electric Machinery*, IEEE Press, 1995.

Six-Step Generator

Implement pulse generator for six-step VSI AC motor drive

Library

Electric Drives/Fundamental Drive Blocks
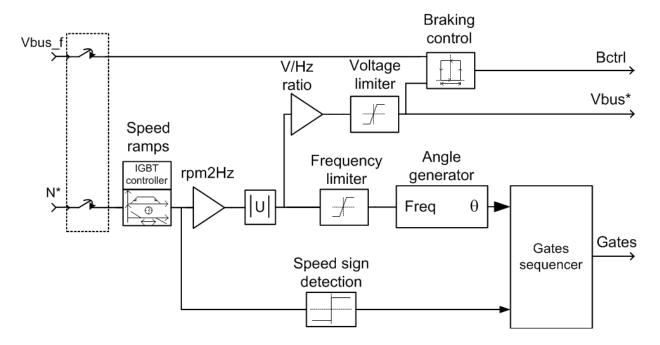
Description
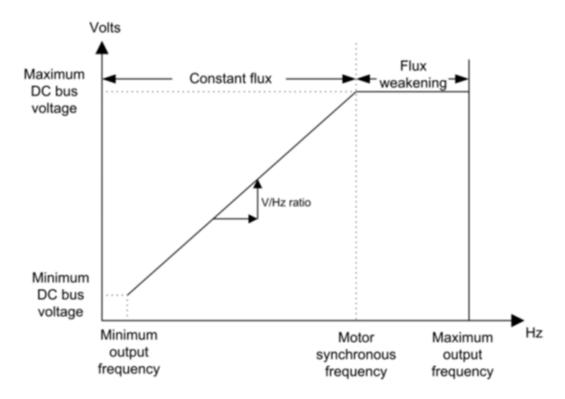
The Six-Step Generator block provides frequency-dependent switching signals for a three-phase inverter in a six-step VSI AC motor drive. The block also outputs the DC bus voltage set point (based on the open loop V/Hz control principle) for a thyristor bridge along with the control signal for the braking chopper. The Six-Step Generator block consists of four main blocks, as shown in the figure.

High-level schematic
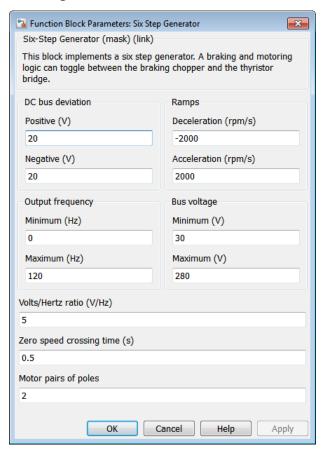
The Braking control block derives the control signal for the braking chopper when the DC bus voltage reaches its maximum limit.

The Volts/Hz ratio block is the stator supply frequency to stator voltage (or DC bus voltage) conversion gain. This gain is kept constant to keep the stator flux constant until the nominal speed is reached. Above nominal speed, this gain is not used, as the stator voltage is maintained constant to its nominal value irrespective of the stator frequency (field weakening operation).

The Angle generator block computes the stator flux position from the stator supply frequency. The Gates sequencer block contains six comparators to produce the six-step switching waveforms. Supplementary logic enables a speed reversal by inverting two phases.

Dialog Box and Parameters
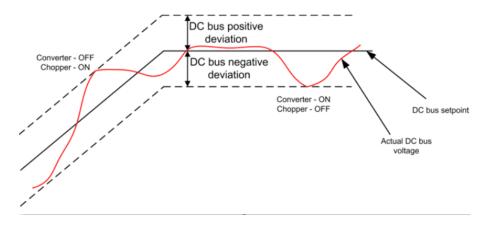
- "DC bus deviation" on page 1-805
- "Output frequency" on page 1-806
- "Ramps" on page 1-806
- "Bus Voltage" on page 1-807
- "Other Parameters" on page 1-807

DC bus deviation

Positive (V)

The maximum deviation of the actual bus voltage over the DC bus set point, in volts.

The default value is 20.

Negative (V)

The maximum deviation, in volts, of the actual bus voltage under the DC bus set point. The default value is 20.

Output frequency

Minimum (Hz)

The six-step generator minimum output frequency, in hertz. The default value is 0.

Maximum (Hz)

The six-step generator maximum output frequency, in hertz. The default value is 120.

Ramps

Deceleration (rpm/s)

The maximum change of speed allowed during motor deceleration, in rpm/s. The default value is -2000.

Acceleration (rpm/s)

The maximum change of speed allowed during motor acceleration, in rpm/s. The default value is 2000.

Bus Voltage

Minimum (V)

The minimum DC bus voltage, in volts. The default value is 30.

Maximum (V)

The maximum DC bus voltage, in volts. The default value is 280.

Other Parameters

Volts/Hertz ratio (V/Hz)

The constant ratio between the stator line-to-line RMS voltage and frequency. The default value is 5.

Zero speed crossing time (s)

The delay at zero speed, in seconds, to eliminate the motor air gap residual flux. The default value is 0.5.

Motor pairs of poles

The number of pole pairs of the AC machine. The default value is 2.

Inputs and Outputs

VBus_f

The measured DC bus voltage.

N*

The machine speed reference.

V_Bus*

The DC bus voltage set point for the thyristor bridge.

S_sp

The adjusted speed reference based on the **Deceleration** and **Acceleration** parameters.

Bctrl

Control signal (0 or 1) for the Braking Chopper.

Gates

The gate signals (pulses) for the three-phase inverter.

Examples

The Six-Step Generator block is used in the AC1 block of the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

```
Bridge Firing Unit (AC) | Bridge Firing Unit (DC) | Current Controller
(Brushless DC) | Current Controller (DC) | Direct Torque Controller |
Field-Oriented Controller | Regulation Switch | Space Vector Modulator
| Speed Controller (AC) | Speed Controller (DC) | Speed Controller
(Scalar Control) | Vector Controller (PMSM) | Vector Controller
(WFSM) | Voltage Controller (DC Bus)
```

More About

- "Electric Drives Library"
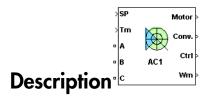
Introduced in R2015b

Six-Step VSI Induction Motor Drive

Implement six-step inverter fed Induction Motor Drive

Library

Electric Drives/AC drives

Description
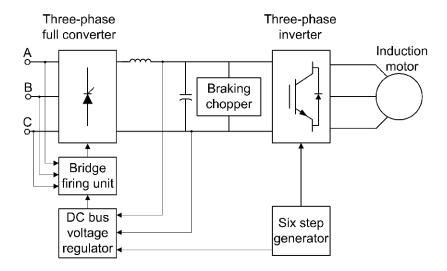
The high-level schematic shown below is built from seven main blocks. The induction motor, the three-phase inverter, the three-phase thyristor rectifier, and the bridge firing unit are provided with the SimPowerSystems library. More details are available in the reference pages for these blocks. The three other blocks are specific to the Electric Drives library. These blocks are the DC bus voltage regulator, the six-step generator, and the DC bus voltage filter.

Note In SimPowerSystems software, the Six-Step VSI Induction Motor Drive block is commonly called the **AC1** motor drive.

High-Level Schematic

Simulink Schematic

Bridge Firing Unit
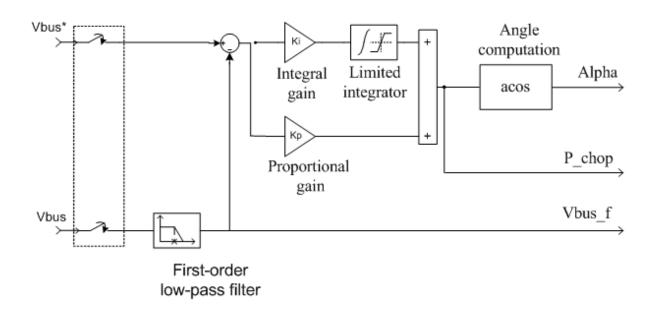
The bridge firing unit is used to convert the firing angle, provided by the DC bus voltage regulator, into pulses applied to the thyristor gates. The bridge firing unit block contains notch filters applied to the voltage measurement to remove harmonics. The discrete synchronized six-pulse generator block is used to generate the pulses.

DC Bus Voltage Regulator and Braking Chopper
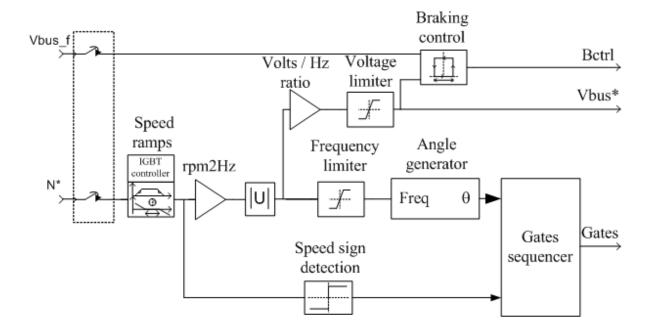
The DC bus voltage regulator is based on a PI controller and a hysteresis chopper logic. When the bus voltage decreases, the PI controller reduces the firing angle. When the bus voltage increases, the PI controller increases the firing angle. The chopper logic is based on hysteresis control. If the voltage reaches the upper hysteresis limit, the DC voltage controller toggles to braking mode and the chopper is activated, whereas the

thyristor bridge is shut off. In chopper mode, the proportional action remains active but the integral gain is set to zero because the chopper dynamics are very high and the integral gain is useless. When the bus voltage reaches the hysteresis lower limit, the braking chopper is shut down and the thyristor bridge is reactivated. The following figure illustrates the DC bus PI regulator.

Six-Step Generator

The six-step generator illustrated in the following figure contains six comparators to produce the six-step switching waveforms. Some supplementary logic enables a speed reversal by inverting two phases.
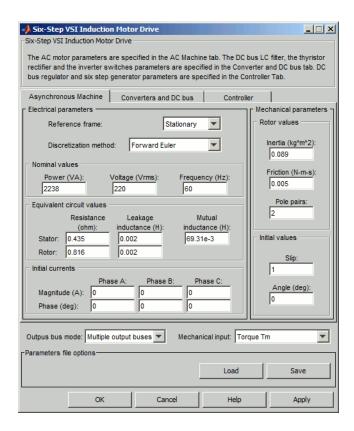
Remarks

In the AC1 motor drive, the motor speed is not regulated in closed loop. Instead, the speed set point is used only to determine the motor voltage and frequency applied by the six-step inverter in order to maintain the (V/F) ratio (or the motor flux) constant from 0 to the nominal speed. Above nominal speed, the motor operates in the flux weakening mode; that is, the voltage is maintained constant at its nominal value while the frequency is increased proportionally to the speed set point.

When reversing speed, a short delay is required at the zero speed crossing so that air gap flux decays to zero.

Dialog Box

Asynchronous Machine Tab

The **Asynchronous Machine** tab displays the parameters of the Asynchronous Machine block of the Fundamental Blocks (powerlib) library.

Output bus mode

> Select how the output variables are organized. If you select **Multiple output buses**, the block has three separate output buses for motor, converter, and controller variables. If you select **Single output bus**, all variables output on a single bus.

Mechanical input

Select between the load torque, the motor speed and the mechanical rotational port as mechanical input. If you select and apply a load torque, the output is the motor speed according to the following differential equation that describes the mechanical system dynamics:

$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

If you select the motor speed as mechanical input, then you get the electromagnetic torque as output, allowing you to represent externally the mechanical system dynamics. The internal mechanical system is not used with this mechanical input selection and the inertia and viscous friction parameters are not displayed.

For the mechanical rotational port, the connection port S counts for the mechanical input and output. It allows a direct connection to the Simscape environment. The mechanical system of the motor is also included in the drive and is based on the same differential equation.

See "Mechanical Coupling of Two Motor Drives".

Converters and DC Bus Tab

Rectifier section

The rectifier section of the Converters and DC bus tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the universal bridge parameters.

Inverter section

The inverter section of the Converters and DC bus tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the universal bridge parameters.

DC Bus Filter — Inductance

The low-pass DC bus filter inductance (H).

DC Bus Filter — Capacitance

The low-pass DC bus filter capacitance (F).

Braking Chopper section
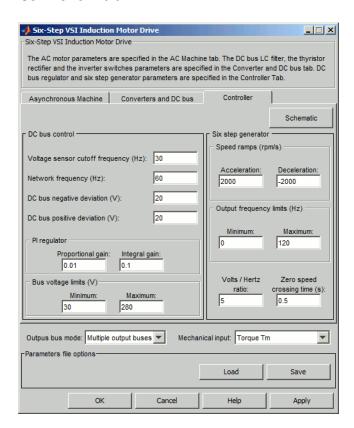
Resistance

The braking chopper resistance used to avoid bus over-voltage during motor deceleration or when the load torque tends to accelerate the motor (Ω).

Frequency

The braking chopper frequency (Hz).

Controller Tab

Schematic Button

> When you press this button, a diagram illustrating the speed and current controllers schematics appears.

DC Bus Control section

Voltage Sensor Cutoff Frequency
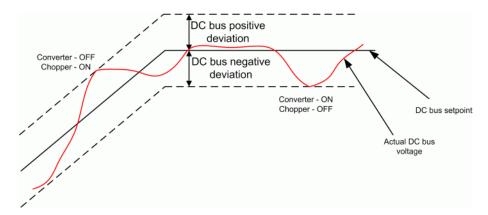
> The DC bus voltage measurement first-order filter cutoff frequency (Hz).

DC Bus Negative Deviation

> The maximum deviation of the actual bus voltage under the DC bus set point. Refer to the figure shown in the DC Bus Positive Deviation parameter section.

DC Bus Positive Deviation

> The maximum deviation of the actual bus voltage over the DC bus set point.

Proportional Gain

> The proportional gain of the DC bus PI controller.

Integral Gain

> The integral gain of the DC bus PI controller.

Voltage limits — Minimum

> The minimum DC bus voltage (V).

Voltage limits — Maximum

> The maximum DC bus voltage (V).

Six-Step Generator section

Volts / Hertz Ratio

The proportionality constant between the stator line-to-line RMS voltage and frequency (V / Hz).

Zero Speed Crossing Time

The delay at zero speed to eliminate the motor air gap residual flux (s).

Speed Ramps — Acceleration

The maximum change of speed allowed during motor acceleration. An excessively large positive value can cause DC bus under-voltage and undesirable harmonics on the line side voltages (rpm/s).

Speed Ramps — Deceleration
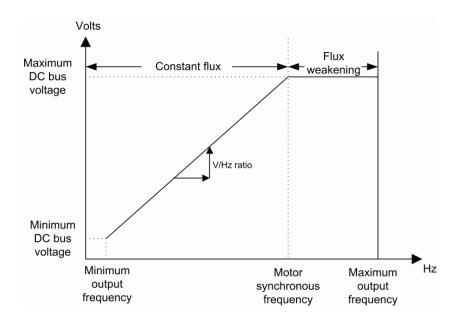
The maximum change of speed allowed during motor deceleration. An excessively large negative value can cause DC bus over-voltage (rpm/s).

Frequency Limits — Minimum

The six-step generator minimum output frequency (Hz).

Frequency Limits — Maximum

The six-step generator maximum output frequency (Hz).

Graphical Representation of the Six-Step Generator Limits

Block Inputs and Outputs

SP

> The speed or torque set point. The speed set point can be a step function, but the speed change rate will follow the acceleration / deceleration ramps. If the load torque and the speed have opposite signs, the accelerating torque will be the sum of the electromagnetic and load torques.

Tm or Wm

> The mechanical input: load torque (Tm) or motor speed (Wm). For the mechanical rotational port (S), this input is deleted.

A, B, C

> The three phase terminals of the motor drive.

Wm, Te or S

> The mechanical output: motor speed (Wm), electromagnetic torque (Te) or mechanical rotational port (S).

When the **Output bus mode** parameter is set to **Multiple output buses**, the block has the following three output buses:

Motor

> The motor measurement vector. This vector allows you to observe the motor's variables using the Bus Selector block.

Conv

> The three-phase converters measurement vector. This vector contains:

- The rectifier output voltage
- The inverter output voltage
- The rectifier input current
- The inverter output current

> Note that all current and voltage values of the bridges can be visualized with the Multimeter block.

Ctrl

> The controller measurement vector. This vector contains:

- The firing angle computed by the current controller
- The speed error (difference between the speed reference ramp and actual speed)
- The speed reference ramp

When the **Output bus mode** parameter is set to **Single output bus**, the block groups the Motor, Conv, and Ctrl outputs into a single bus output.

Model Specifications

The library contains a 3 hp and a 500 hp drive parameter set. The specifications of these two drives are shown in the following table.
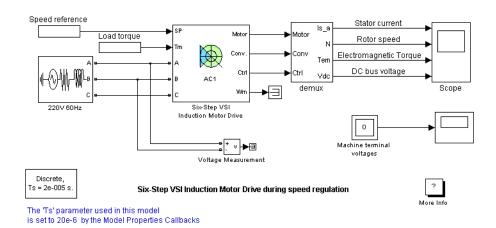
3 HP and 500 HP Drive Specifications

		3 HP Drive	500 HP Drive
Drive Input Voltage			
	Amplitude	220 V	2300 V

		3 HP Drive	500 HP Drive
Drive Input Voltage			
Motor Nominal Values	Frequency	60 Hz	60 Hz
	Power	3 hp	500 hp
	Speed	1705 rpm	1773 rpm
	Voltage	220 V	2300 V
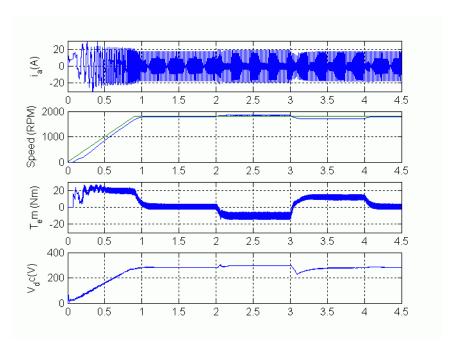
Example

The `ac1_example` example illustrates a typical operation of the AC1 motor drive. A speed reference step from zero to 1800 rpm is applied at t = 0.

As shown in the following figure, the speed set point doesn't go instantaneously to 1800 rpm but follows the acceleration ramp (2000 rpm/s). The motor reaches steady state at t = 1.3 s. At t = 2 s, an accelerating torque is applied on the motor's shaft. You can observe a speed increase. Because the rotor speed is higher than the synchronous speed, the motor is working in the generator mode. The braking energy is transferred to the DC link and the bus voltage tends to increase. However, the over-voltage activates the braking chopper, which causes the voltage to decrease. In this example, the braking resistance is not big enough to avoid a voltage increase but the bus is maintained within

tolerable limits. At t = 3 s, the torque applied to the motor's shaft steps from −11 N.m to +11 N.m. You can observe a DC voltage and speed drop at this point. The DC bus controller switches from braking to motoring mode. At t = 4 s, the load torque is removed completely.

References
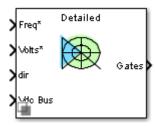
[1] Bose, B. K., *Modern Power Electronics and AC Drives*, Prentice-Hall, N.J., 2002.

[2] Harunur, M. R., *Power Electronics*, Prentice-Hall, 1988.

Space Vector Modulator

Implement space vector modulator for PWM VSI AC motor drive

Library

Electric Drives/Fundamental Drive Blocks
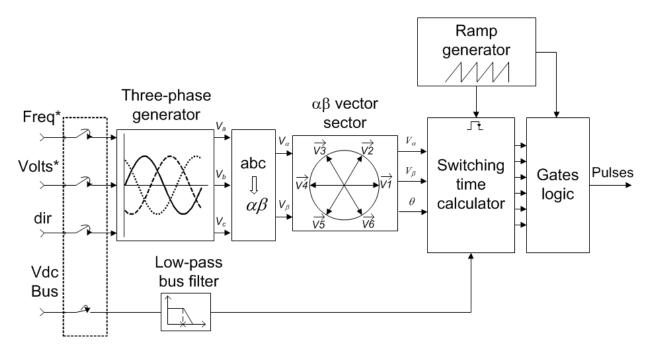
Description

The Space Vector Modulator block generates pulses for either a detailed or average-value three-phase inverter following the space vector pulse-width modulation strategy.
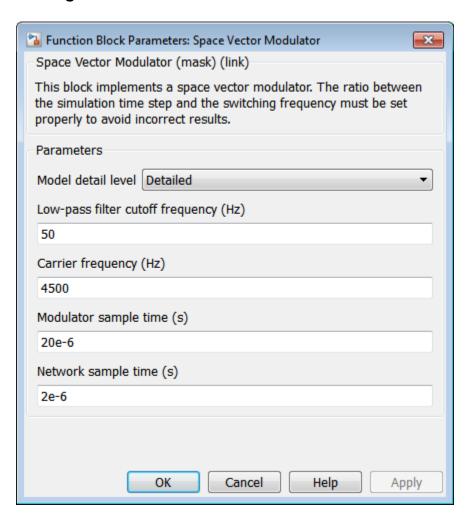
The Space Vector Modulator block consists of seven main blocks.

- The three-phase generator produces three sine waves with variable frequency and amplitude. The three signals are out of phase with each other by 120 degrees. The inverter-requested frequency and voltage are two of the block inputs.

- The low-pass bus filter removes fast transients from the DC bus voltage measurement. This filtered voltage computes the voltage vector applied to the motor.

- The alpha-beta transformation converts variables from the three-phase system to the two-phase αß system.

- The αß vector sector finds the sector of the αß plane in which the voltage vector lies. The αß plane is divided into six different sectors spaced by 60 degrees.

- The ramp generator produces a unitary ramp at the PWM switching frequency. This ramp is a time base for the switching sequence.

- The switching time calculator calculates the timing of the voltage vector applied to the motor. The block input is the sector in which the voltage vector lies.

- The gates logic receives the timing sequence from the switching-time calculator and the ramp from the ramp generator. This block compares the ramp and the gate timing signals to activate the inverter switches as needed.

When using an average-value inverter, the gates logic block is disabled and the inverter leg PWM duty cycles are issued by the switching time calculator. In this mode, the Space Vector Modulator block outputs the duty cycles of the various pulses but not the pulses themselves. These duty cycle signals are expected by the average-value Three-Phase Inverter block when used in space vector modulation mode.

Dialog Box and Parameters

Model detail level

Specify the model detail level to use:

- `Detailed` (default)
- `Average`

Low-pass filter cutoff frequency (Hz)

The cutoff frequency, in hertz, of the first-order filter applied to the DC bus voltage measurement. The default value is `50`.

Carrier frequency (Hz)

The inverter switching frequency, in hertz. The default value is `4500`.

Modulator sample time (s)

The Space Vector Modulator sampling time, in seconds. The sampling time must be a multiple of the simulation time step. The default value is `20e-6`.

Network sample time (s)

The simulation time step, in seconds. The default value is `2e-6`.

Inputs and Outputs

`Freq*`

The output frequency set point of the inverter.

`Volts*`

The maximum AC output voltage set point of the inverter.

`dir`

Motor speed sign (-1 for negative speed, 1 for positive, or 0).

`Vdc Bus`

DC Bus voltage.

`Gates`

The switching signals for the three-phase inverter. This output is visible only when the **Model detail level** parameter is set to `Detailed`.

`Duty`

A vector containing the duty cycles of the three inverter arms. This output is visible only when the **Model detail level** parameter is set to `Average`.

Examples

The Space Vector Modulator block is used in the AC2 block of the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

`Bridge Firing Unit (AC)` | `Bridge Firing Unit (DC)` | `Current Controller (Brushless DC)` | `Current Controller (DC)` | `Direct Torque Controller` | `Field-Oriented Controller` | `Regulation Switch` | `Six-Step Generator` | `Space Vector Modulator` | `Speed Controller (AC)` | `Speed Controller (DC)` | `Speed Controller (Scalar Control)` | `Vector Controller (PMSM)` | `Vector Controller (WFSM)` | `Voltage Controller (DC Bus)`

More About

- "Electric Drives Library"
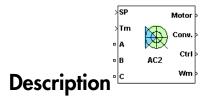
Introduced in R2015b

Space Vector PWM VSI Induction Motor Drive

Implement space vector PWM VSI induction motor drive
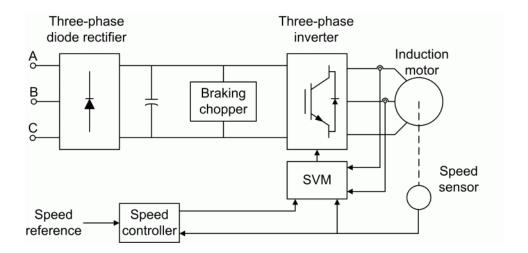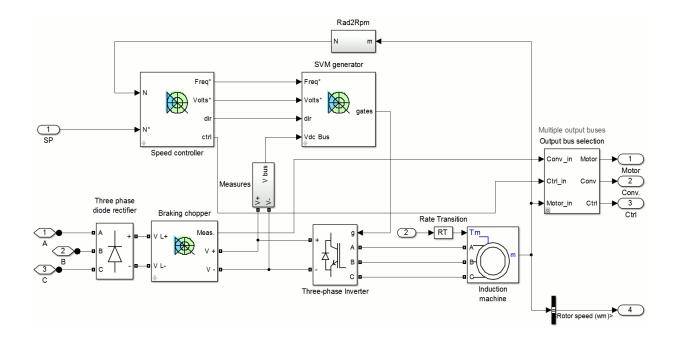
Library

Electric Drives/AC drives

Description

The high-level schematic shown below is built from six main blocks. The induction motor, the three-phase inverter, and the three-phase diode rectifier models are provided with the SimPowerSystems library. More details are available in the reference pages for these blocks. The speed controller, the braking chopper, and the space vector modulator models are specific to the drive library. It is possible to use a simplified version of the drive containing an average-value model of the inverter for faster simulation.

Note In SimPowerSystems software, the Space Vector PWM VSI Induction Motor Drive block is commonly called the **AC2** motor drive.

High-Level Schematic

Simulink Schematic

Speed Controller
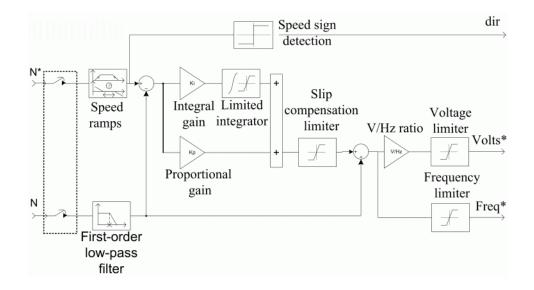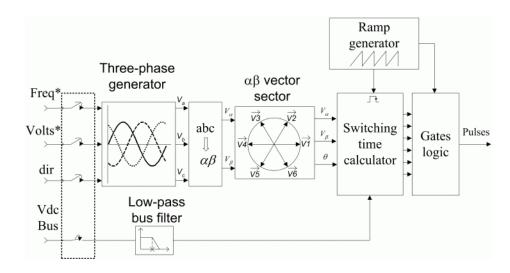
The speed controller is based on a PI regulator that controls the motor slip. As shown in the following figure, the slip value computed by the PI regulator is added to the motor speed in order to produce the demanded inverter frequency. The latter frequency is also used to generate the demanded inverter voltage in order to maintain the motor V/F ratio constant.

Space Vector Modulator

The space vector modulator (SVM) contains seven blocks, shown in the following figure. These blocks are described below.

The *three-phase generator* is used to produce three sine waves with variable frequency and amplitude. The three signals are out of phase with each other by 120 degrees. The inverter demanded frequency and voltage are two of the block inputs.

The *low-pass bus filter* is used to remove fast transients from the DC bus voltage measurement. This measure is used to compute the voltage vector applied to the motor.

The *alpha beta transformation* converts variables from the three-phase system to the two-phase αβ system.

The αβ *vector sector* is used to find the sector of the αβ plane in which the voltage vector lies. The αβ plane is divided into six different sectors spaced by 60 degrees.

The *ramp generator* is used to produce a unitary ramp at the PWM switching frequency. This ramp is used as a time base for the switching sequence.
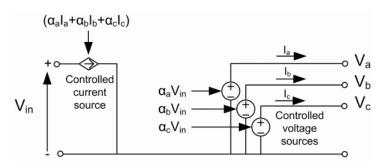
The *switching time calculator* is used to calculate the timing of the voltage vector applied to the motor. The block input is the sector in which the voltage vector lies.

The *gates logic* receives the timing sequence from the *switching time calculator* and the ramp from the *ramp generator*. This block compares the ramp and the gate timing signals to activate the inverter switches at the proper time.

When using the average-value inverter, the *gates logic* block is disabled and the inverter leg PWM duty cycles are issued by the *switching time calculator* to control the average-value inverter.

Average-Value Inverter

The average-value inverter is shown in the following figure.

It is composed of one controlled current source on the DC side and three controlled voltage sources on the AC side. The DC current source allows the representation of the average DC bus current behavior, following the next equation:

$I\mathrm{dc} = a_a I_a + a_b I_b + a_c I_c$

with a_a, a_b, a_c being the PWM duty cycles of the inverter legs A, B, and C respectively, and I_a, I_b, I_c the corresponding three-phase currents. The three AC voltage sources represent the average voltage values of the three-phase inverter voltages V_a, V_b, V_c, following the next equation:

$V_a = a_a V_\mathrm{in}$
$V_b = a_b V_\mathrm{in}$
$V_c = a_c V_\mathrm{in}$,

with V_in being the input DC bus voltage value.

Braking Chopper

The braking chopper block contains the DC bus capacitor and the dynamic braking chopper, which is used to absorb the energy produced by a motor deceleration.

Remarks

The model is discrete. Good simulation results have been obtained with a 2 μs time step. In order to simulate a digital controller device, the control system has two different sampling times:

- The speed controller sampling time
- The SVM controller sampling time

The speed controller sampling time has to be a multiple of the SVM sampling time. The latter sampling time has to be a multiple of the simulation time step.

The simulation step size must be chosen in accordance with the inverter's switching frequency. A rule of thumb is to choose a simulation step size 100 times smaller than the switching period. If the simulation step size is set too high, the simulation results can be erroneous. The average-value inverter allows the use of bigger simulation time steps
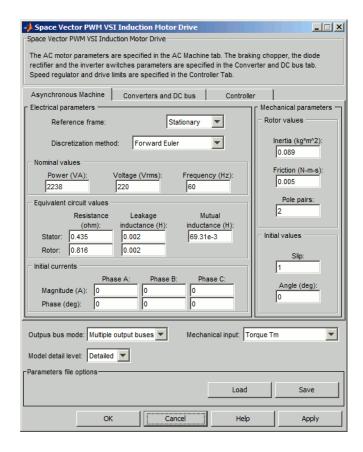
since it does not generate small time constants (due to the RC snubbers) inherent to the detailed converter. For a controller sampling time of 20 μs, good simulation results have been obtained for a simulation time step of 20 μs. This time step can, of course, not be higher than the controller time step.

In the AC2 motor drive, the motor speed is regulated by controlling the motor slip. The motor current or torque is not regulated, however, so the speed response tends to be sluggish at low speed because of torque ripple.

When reversing speed, a short delay is required at the zero speed crossing so that air gap flux decays to zero.

Dialog Box

Asynchronous Machine Tab

The **Asynchronous Machine** tab displays the parameters of the Asynchronous Machine block of the Fundamental Blocks (powerlib) library.

Output bus mode

Select how the output variables are organized. If you select **Multiple output buses**, the block has three separate output buses for motor, converter, and controller variables. If you select **Single output bus**, all variables output on a single bus.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Select between the load torque, the motor speed and the mechanical rotational port as mechanical input. If you select and apply a load torque, the output is the motor speed according to the following differential equation that describes the mechanical system dynamics:

$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

For the mechanical rotational port, the connection port S counts for the mechanical input and output. It allows a direct connection to the Simscape environment. The mechanical system of the motor is also included in the drive and is based on the same differential equation.

If you select the motor speed as mechanical input, then you get the electromagnetic torque as output, allowing you to represent externally the mechanical system dynamics. The internal mechanical system is not used with this mechanical input selection and the inertia and viscous friction parameters are not displayed.

For the mechanical rotational port, the connection port S counts for the mechanical input and output. It allows a direct connection to the Simscape environment. The mechanical system of the motor is also included in the drive and is based on the same differential equation.

See "Mechanical Coupling of Two Motor Drives".

Converters and DC Bus Tab

Rectifier section

The rectifier section of the Converters and DC bus tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the universal bridge parameters.

Inverter section

The inverter section of the Converters and DC bus tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the universal bridge parameters. This parameter is not used when using the average-value inverter.

Braking Chopper section

Capacitance

The DC bus capacitance (F).

Resistance
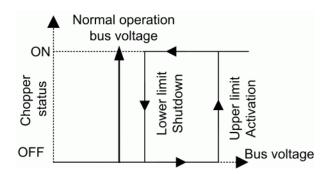
The braking chopper resistance used to avoid bus over-voltage during motor deceleration or when the load torque tends to accelerate the motor (Ω).

Frequency
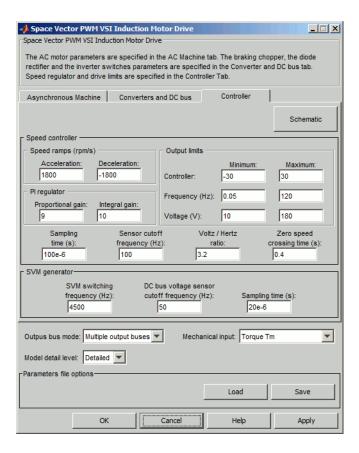
The braking chopper frequency (Hz).

Activation and Shutdown Voltage

The dynamic braking is activated when the bus voltage reaches the upper limit of the hysteresis band. The dynamic braking is shut down when the bus voltage reaches the lower limit of the hysteresis band. The following figure illustrates the braking hysteresis logic.

Controller Tab

Schematic Button

When you press this button, a diagram illustrating the speed and current controllers schematics appears.

Speed Controller section

Speed Ramps — Acceleration

The maximum change of speed allowed during motor acceleration. An excessively large positive value can cause DC bus under-voltage (rpm/s).

Speed Ramps — Deceleration

The maximum change of speed allowed during motor deceleration. An excessively large negative value can cause DC bus over-voltage (rpm/s).

Proportional Gain

The speed controller proportional gain.

Integral Gain

The speed controller integral gain.

Output Negative Saturation

The maximum negative slip compensation computed by the slip regulator (Hz).

Output Positive Saturation

The maximum positive slip compensation computed by the slip regulator (Hz).

Minimum Frequency

The minimum demanded inverter frequency applied to the motor (Hz).

Maximum Frequency

The maximum demanded inverter frequency applied to the motor (Hz).

Minimum Output Voltage

The minimum demanded inverter output voltage (V). If this parameter is set to zero, the zero speed cannot be reached under several load conditions.

Maximum Output Voltage

The maximum demanded inverter output voltage (V). This parameter must be set in accordance with the motor rating. If this parameter is set too high, you will observe over-modulation in the current and voltage waveforms.

Volts / Hertz Ratio

The proportionality constant between the stator line-to-line RMS voltage and frequency (V / Hz).

Zero Speed Crossing Time

The delay at zero speed to eliminate the motor air gap residual flux (s).

Speed Sensor Cutoff Frequency

The speed measurement first-order low-pass filter cutoff frequency (Hz).

Sampling Time

The speed controller sampling time(s). The sampling time must be a multiple of the simulation time step.

SVM Generator section

Switching Frequency

The inverter switching frequency (Hz).

Voltage Sensor Cutoff Frequency

The cutoff frequency of the first-order low-pass filter applied to the DC bus voltage measurement.(Hz).

Sampling Time

The SVM generator sampling time (s). The sampling time must be a multiple of the simulation time step.

Block Inputs and Outputs

SP

The speed or torque set point. The speed set point can be a step function, but the speed change rate will follow the acceleration / deceleration ramps. If the load torque and the speed have opposite signs, the accelerating torque will be the sum of the electromagnetic and load torques.

Tm or Wm

The mechanical input: load torque (Tm) or motor speed (Wm). For the mechanical rotational port (S), this input is deleted.

A, B, C

The three phase terminals of the motor drive.

Wm, Te or S

The mechanical output: motor speed (Wm), electromagnetic torque (Te) or mechanical rotational port (S).

When the **Output bus mode** parameter is set to **Multiple output buses**, the block has the following three output buses:

Motor

The motor measurement vector. This vector allows you to observe the motor's variables using the Bus Selector block.

Conv

The three-phase converters measurement vector. This vector contains:

- The DC bus voltage
- The rectifier output current
- The inverter input current

Note that all current and voltage values of the bridges can be visualized with the Multimeter block.

Ctrl

The controller measurement vector. This vector contains:

- The slip compensation
- The speed error (difference between the speed reference ramp and actual speed)
- The speed reference ramp

When the **Output bus mode** parameter is set to **Single output bus**, the block groups the Motor, Conv, and Ctrl outputs into a single bus output.

Model Specifications

The library contains a 3 hp and a 200 hp drive parameter set. The specifications of these two drives are shown in the following table.

3 HP and 200 HP Drive Specifications
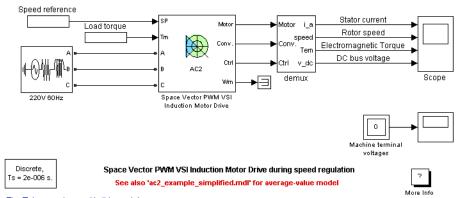
		3 HP Drive	**200 HP Drive**
Drive Input Voltage			
	Amplitude	220 V	575 V
	Frequency	60 Hz	60 Hz
Motor Nominal Values			
	Power	3 hp	200 hp
	Speed	1705 rpm	1785 rpm
	Voltage	220 V	575 V
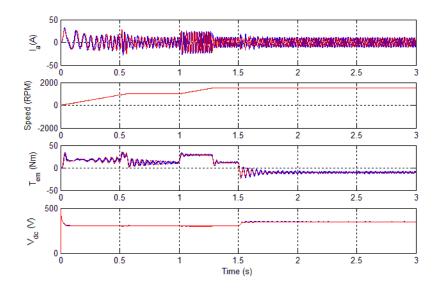
Example

The ac2_example example illustrates an AC2 induction motor drive simulation with standard load conditions. At time t = 0 s, the speed set point is 1000 rpm.

As shown in the following figure, the speed precisely follows the acceleration ramp. At t = 0.5 s, the nominal load torque is applied to the motor. At t = 1 s, the speed set point is changed to 1500 rpm. The speed increases to 1500 rpm. At t = 1.5 s, the mechanical load passes from 11 N.m to −11 N.m. The figure illustrates the results obtained respectively with the detailed and the average-value inverter. Average voltage, current, torque, and speed values are identical for both models. The higher frequency signal components are not represented with the average-value converter.

AC2 Example Waveforms (Blue : Detailed Converter, Red : Average-Value Converter)
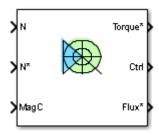
References

[1] Bose, B. K., *Modern Power Electronics and AC Drives*, Prentice-Hall, N.J., 2002.

[2] Grelet, G., and G. Clerc, *Actionneurs électriques, Éditions*, Eyrolles, Paris, 1997.

[3] Krause, P. C, *Analysis of Electric Machinery*, McGraw-Hill, 1986.

Speed Controller (AC)

Implement speed controller model for vector controlled AC motor drives
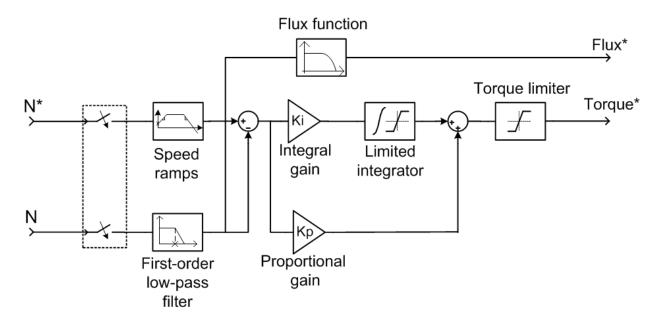
Library

Electric Drives/Fundamental Drive Blocks

Description
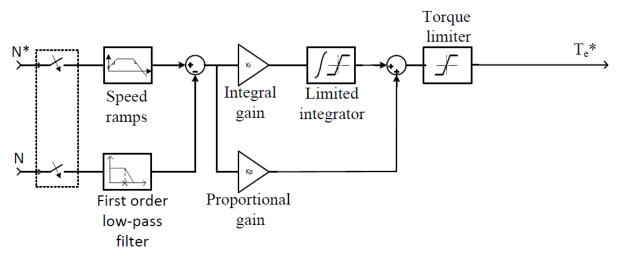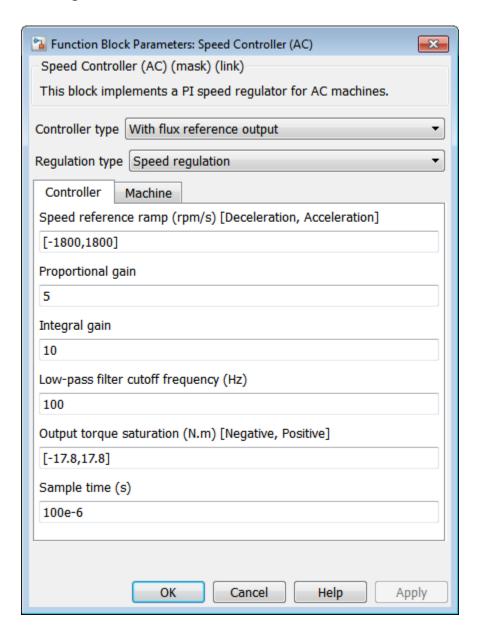
The Speed Controller (AC) block represents a PI speed regulator model for AC machines used in vector-controlled drives. It has two operating instances: the first with both torque and flux references outputs and the second with torque reference output only. The models of the first and second instances are shown in the figures.

Dialog Box and Parameters

Controller Tab

Controller type

Specify the type of controller to use:

- `With flux reference output` (default)
- `Without flux reference output`

Regulation type

Specify the type of regulation to use:

- `Speed regulation` (default)
- `Tourqe regulation`

Speed reference ramp (rpm/s) [Deceleration, Acceleration]

The maximum rate of change of the speed reference, in rpm/s, to keep the machine's currents within rated values. This parameter is required and enabled only if the **Regulation type** parameter is set to `Speed regulation`. The default value is `[-1800,1800]`.

The default value is `[-1800,1800]`.

Proportional gain

The PI controller's proportional gain. This parameter is required and available only if the **Regulation type** parameter is set to `Speed regulation`. The default value is `5`.

Integral gain

The PI controller's integral gain. This parameter is required and available only if the **Regulation type** parameter is set to `Speed regulation`. The default value is `10`.

Low-pass filter cutoff frequency (Hz)

The speed measurement first-order filter cutoff frequency, in hertz. This parameter is required and available only if the **Regulation type** parameter is set to `Speed regulation`. The default value is `100`.

Output torque saturation (N.m) [Negative, Positive]

The minimum (negative) and maximum (positive) torque reference output limits, in newton-meter. The default value is `[-17.8,17.8]`.

The default value is [-17.8,17.8].

Sample time (s)

The speed-controller sampling time, in seconds. The sampling time must be a multiple of the simulation time step. The default value is 100e-6.

Machine Tab

Nominal frequency (Hz)

The nominal frequency of the machine, in hertz. This parameter is required and available only if the **Speed controller type** parameter is set to With flux reference output. The default value is 60.

Pairs of poles

The number of pole pairs. This parameter is required and available only if the **Speed controller type** parameter is set to With flux reference output. The default value is 2.

The default value is 2.

Nominal flux (Wb)

The nominal flux for the machine, in weber. This parameter is required and available only if the **Speed controller type** parameter is set to With flux reference output. The default value is 0.3.

Inputs and Outputs

N

The speed of the machine, in rpm.

N*

The speed reference of the machine, in rpm. When the **Regulation type** parameter is set to Torque regulation, this input refers to the torque reference of the machine.

MagC

A binary signal indicating if the machine is magnetized enough to be started (1) or not (0). This signal is typically provided by another controller that has the capacity to establish the magnetization level of the machine, for example, the Field-Oriented Controller.

This input is available only if the **Speed controller type** parameter is set to `With flux reference output`.

Torque*

The torque reference, in newton-meter.

Ctrl

A bus containing these measurements:

- `Torque reference` — In newton-meter.
- `Flux reference (Wb)` — This signal is available only when the **Speed controller type** parameter is set to `With flux reference output`.
- `Error` — When the **Regulation type** parameter is set to `Speed regulation`, this signal is the speed error (difference between the reference and actual speed). Otherwise, it is zero.
- `Reference` — The speed reference, in rpm. When the **Regulation type** parameter is set to `Torque regulation`, this measurement refers to the torque reference, in newton-meter.

Flux*

The flux reference, in weber. This output is available only when the **Speed controller type** parameter is set to `With flux reference output`.

Examples

The Speed Controller (AC) block is used in the AC3, AC4, AC5, AC6, and AC7 blocks from the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

Bridge Firing Unit (AC) | Bridge Firing Unit (DC) | Current Controller (Brushless DC) | Current Controller (DC) | Direct Torque Controller | Field-Oriented Controller | Regulation Switch | Six-Step Generator | Space Vector Modulator | Speed Controller (DC) | Speed Controller

```
(Scalar Control) | Vector Controller (PMSM)  | Vector Controller
(WFSM)  | Voltage Controller (DC Bus)
```

More About

- "Electric Drives Library"

Introduced in R2015b
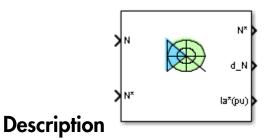
Speed Controller (DC)
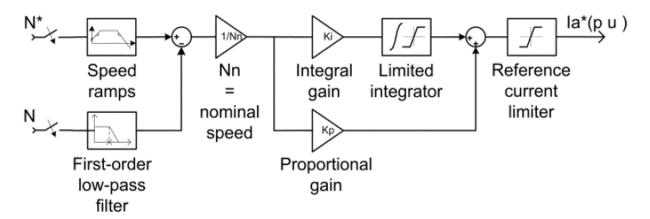
Implement a speed controller model for DC motor drives

Library

Electric Drives/Fundamental Drive Blocks

Description

The Speed Controller (DC) block represents a PI speed regulator model for DC machines. The model is shown in the figure.
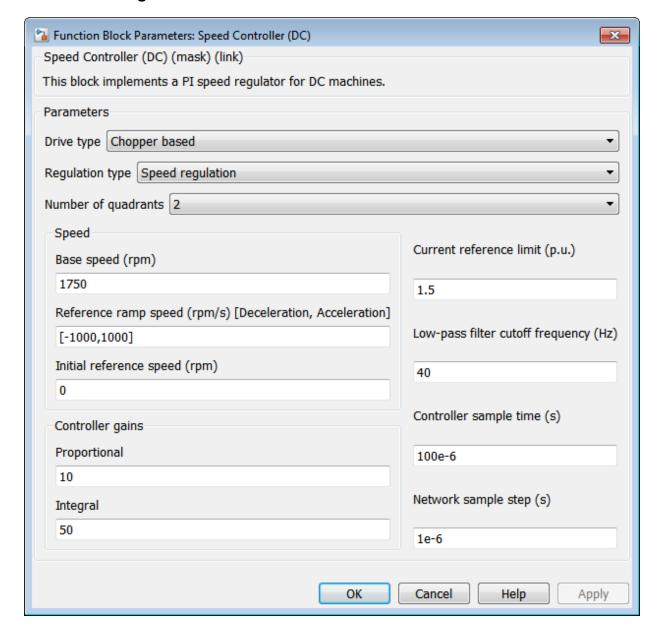
The controller outputs the armature current reference, in pu. This current reference is typically used by a current controller to obtain the electromagnetic torque needed to reach the desired speed.

The controller takes the speed reference and the rotor speed of the DC machine as inputs. The speed reference change rate follows the acceleration and deceleration ramps you define in order to avoid sudden reference changes that could cause armature over-current and destabilize the system. To avoid negative speeds, the speed reference has a lower limit of 0 rpm.

The speed measurement is filtered by a first-order low-pass filter. The current reference output is limited between symmetrical lower and upper limits that you define.

Dialog Box and Parameters

Function Block Parameters: Speed Controller (DC)

Speed Controller (DC) (mask) (link)

This block implements a PI speed regulator for DC machines.

Parameters

Drive type | Chopper based

Regulation type | Speed regulation

Number of quadrants | 2

Speed

Base speed (rpm)

1750

Reference ramp speed (rpm/s) [Deceleration, Acceleration]

[-1000,1000]

Initial reference speed (rpm)

0

Controller gains

Proportional

10

Integral

50

Current reference limit (p.u.)

1.5

Low-pass filter cutoff frequency (Hz)

40

Controller sample time (s)

100e-6

Network sample step (s)

1e-6

OK   Cancel   Help   Apply

Drive type

Specify the drive type to use:

- `Chopper based` (default)
- `Rectifier based`

Regulation type

Specify the regulation type to use:

- `Speed regulation` (default)
- `Torque regulation`

Number of quadrants

Specify the number of quadrants to use. The default value is `2`.

Base speed (rpm)

Base speed of the DC machine, in rpm, typically equivalent to the nominal operating speed. The default value is `1750`.

Reference ramp speed (rpm/s) [Deceleration, Acceleration]

The maximum rate of change of the speed reference to maintain the machine's currents within rated values. The default value is `[-1000,1000]`.

Initial reference speed (rpm)

Initial speed reference of the DC machine, in rpm. The default value is `0`.

Proportional

The PI controller's proportional gain. The default value is `10`.

Integral

The PI controller's integral gain. The default value is `50`.

Current reference limit (pu)

The maximum magnitude of the output current reference, in per-unit. The default value is `1.5`.

Low-pass filter cutoff frequency (Hz)

The speed measurement first-order filter cutoff frequency, in hertz. The default value is `40`.

Controller sample time (s)

The speed controller sampling time, in seconds. The sampling time must be a multiple of the simulation time step. The default value is `100e-6`.

Network sample time (s)

The time step used for the simulation, in seconds. The default value is `1e-6`.

Inputs and Outputs

N

The speed of the machine, in rpm.

N*

The speed reference of the machine, in rpm.

d_N

Speed error (difference between the speed reference ramp and the actual speed).

la*(pu)

Armature current reference, in per-unit.

Examples

The Speed Controller (DC) block is used in the DC1, DC2, DC3, DC4, DC5, DC6, and DC7 blocks of the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

```
Bridge Firing Unit (AC) | Bridge Firing Unit (DC) | Current Controller
(Brushless DC) | Current Controller (DC) | Direct Torque Controller
| Field-Oriented Controller | Regulation Switch | Six-Step Generator
| Space Vector Modulator | Speed Controller (AC) | Speed Controller
(Scalar Control) | Vector Controller (PMSM) | Vector Controller
(WFSM) | Voltage Controller (DC Bus)
```

More About

- "Electric Drives Library"

Introduced in R2015b
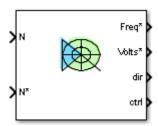
Speed Controller (Scalar Control)

Implement speed-controller model for scalar controlled AC drives
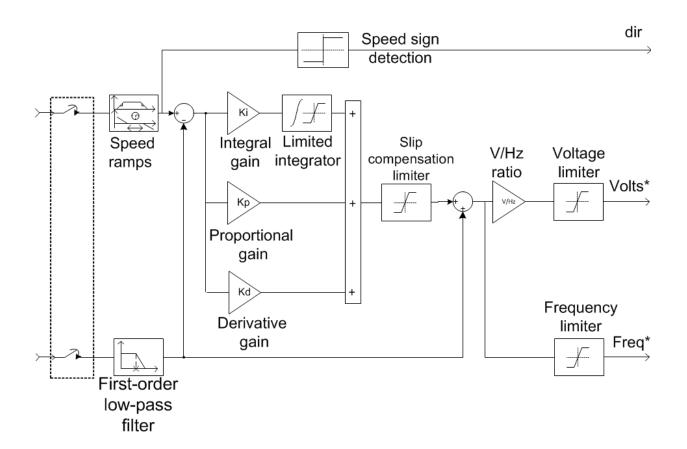
Library

Electric Drives/Fundamental Drive Blocks

Description
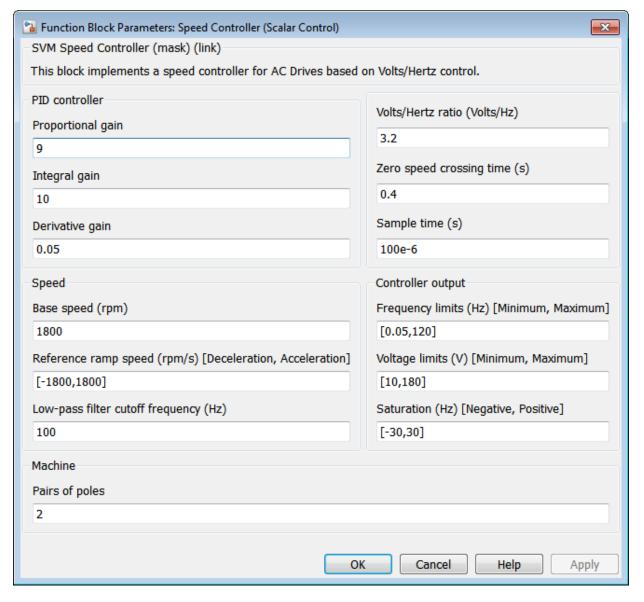
The Speed Controller (Scalar Control) block models a PID speed-regulator model for AC machines used in scalar-controlled (Volts/Hertz) drives. The output of the PID regulator is the machine slip, which is added to the machine speed to obtain the reference frequency of the inverter. To keep the machine Volts/Hertz ratio constant, the reference frequency also generates the reference voltage of the inverter.

Dialog Box and Parameters

Function Block Parameters: Speed Controller (Scalar Control)

SVM Speed Controller (mask) (link)

This block implements a speed controller for AC Drives based on Volts/Hertz control.

PID controller

Proportional gain

`9`

Integral gain

`10`

Derivative gain

`0.05`

Volts/Hertz ratio (Volts/Hz)

`3.2`

Zero speed crossing time (s)

`0.4`

Sample time (s)

`100e-6`

Speed

Base speed (rpm)

`1800`

Reference ramp speed (rpm/s) [Deceleration, Acceleration]

`[-1800,1800]`

Low-pass filter cutoff frequency (Hz)

`100`

Controller output

Frequency limits (Hz) [Minimum, Maximum]

`[0.05,120]`

Voltage limits (V) [Minimum, Maximum]

`[10,180]`

Saturation (Hz) [Negative, Positive]

`[-30,30]`

Machine

Pairs of poles

`2`

OK   Cancel   Help   Apply

Proportional gain

The PID controller's proportional gain. The default value is `9`.

Integral gain

The PID controller's integral gain. The default value is `10`.

Derivative gain

The PID controller's derivative gain. The default value is `0.05`.

Base speed (rpm)

Base speed of the AC machine, in rpm, typically equivalent to the nominal operating speed. The default value is `1800`.

Reference ramp speed (rpm/s) [Deceleration, Acceleration]

The maximum rate of change of the speed reference to keep the machine's currents within rated values. The default value is `[-1800,1800]`.

Low-pass filter cutoff frequency (Hz)

The speed measurement first-order filter cutoff frequency, in hertz. The default value is `100`.

Pairs of poles

The number of pole pairs. The default value is `2`.

Volts/Hertz ratio (Volts/Hz)

The proportionality constant between the stator line-to-line RMS voltage and frequency, in volts/hertz. The default value is `3.2`.

Zero speed crossing time (s)

The delay at zero speed, in seconds, to eliminate the machine air gap residual flux. The default value is `0.4`.

Sample time (s)

The speed-controller sampling time, in seconds. The sampling time must be a multiple of the simulation time step. The default value is `100e-6`.

Frequency limits (Hz) [Minimum, Maximum]

The minimum and maximum reference frequency limits, in hertz. The default value is `[0.05,120]`.

Voltage limits (V) [Minimum, Maximum]

The minimum and maximum reference voltage limits, in volts. The default value is `[10,180]`.

Saturation (Hz) [Negative, Positive]

The PI controller maximum negative and positive output, in hertz. The default value is [-30,30].

Inputs and Outputs

N

The speed of the machine, in rpm.

N*

The speed reference of the machine, in rpm.

Freq*

The reference frequency of the inverter.

Volts*

The reference voltage of the inverter.

dir

Motor speed sign (-1 for negative speed, 1 for positive speed, or 0).

ctrl

A bus containing these measurements:

- Voltage reference — In volts.
- Frequency reference — In hertz.
- Error — The speed error (difference between the reference and actual speed).
- Speed reference — In rpm.

Examples

The Speed Controller (Scalar Control) block is used in the AC2 block of the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

Bridge Firing Unit (AC) | Bridge Firing Unit (DC) | Current Controller
(Brushless DC) | Current Controller (DC) | Direct Torque Controller
| Field-Oriented Controller | Regulation Switch | Six-Step Generator
| Space Vector Modulator | Speed Controller (AC) | Speed Controller
(DC) | Vector Controller (PMSM) | Vector Controller (WFSM) | Voltage
Controller (DC Bus)

More About

·   "Electric Drives Library"
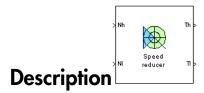
Introduced in R2015b

Speed Reducer

Implement speed reducer
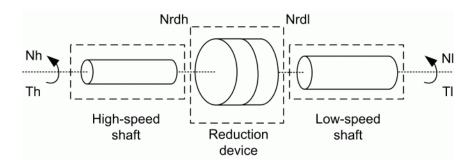
Library

Electric Drives/Shafts and Speed Reducers

Description
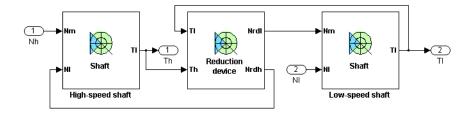
The high-level schematic shown below is built from three main blocks: a high-speed shaft, a reduction device, and a low-speed shaft. More details on the shaft model are included in the Mechanical Shaft reference pages.

High-Level Schematic

Simulink Schematic

The next figure shows the Simulink schematic of the speed reducer model.

Reduction Device

The reduction device dynamics are governed by the following equation:

$$J_{\text{rdh}}\ddot{\theta}_{\text{rdh}} = T_h - \frac{T_l}{\eta i},$$

where J_{rdh} is the inertia of the reduction device with respect to the high-speed side, $\ddot{\theta}_{\text{rdh}}$ is the acceleration of the high-speed side of the reduction device, T_h is the torque transmitted by the high-speed shaft to the input of the reduction device, T_l is the torque transmitted by the low-speed shaft from the output of the reduction device, η is the efficiency of the reduction device, and i is the reduction ratio ($i \geq 1$).
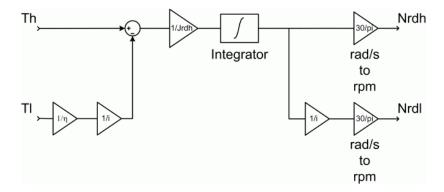
For reduction devices composed of gears, the efficiency varies according to the type of gears, the number of stages (thus the reduction ratio), the lubricant, etc. For small reduction ratios, the efficiency can climb up to 95%. For higher reduction ratios, the efficiency can be as low as 75%. However, most commercial speed reducers now have high efficiencies of 90% to 95%.

The output speed N_{rdl} (the speed of the driving side of the low-speed shaft) of the reduction device is given by the following equation:
$N_{\text{rdl}} = N_{\text{rdh}} / i,$

where N_{rdh} is the input speed of the reduction device (the speed of the loaded side of the high-speed shaft).

The following figure shows the reduction device schematic.

Remarks
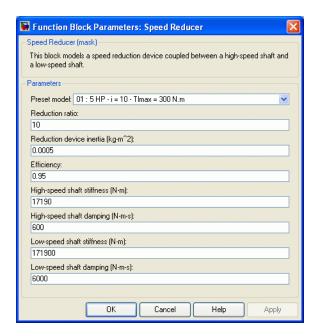
The stiffness of the shafts must be high enough to avoid large angular deflections that could cause misalignment inside the bearings and damage.

Keep in mind that the low-speed shaft will have a higher stiffness and a higher damping factor than the high-speed shaft, the torque on the low-speed shaft being a lot bigger. For proper simulation results, the damping factor of both shafts must be high enough to avoid undesired transient speed and torque oscillations.

Too high stiffness and damping factor values or too low gearbox inertias can cause simulation errors.

The model is discrete. Good simulation results have been obtained with a 1 µs time step.

Dialog Box

Preset Model

This pop-up menu allows you to choose preset model parameters.

Reduction Ratio

The reduction ratio of the speed reducer ($i \geq 1$).

Reduction Device Inertia

The inertia of the reduction device with respect to the high-speed side (kg.m2).

Efficiency

The efficiency of the reduction device.

High-Speed Shaft Stiffness

The stiffness of the high-speed shaft (N.m).

High-Speed Shaft Damping

The internal damping of the high-speed shaft (N.m.s).

Low-Speed Shaft Stiffness

The stiffness of the low-speed shaft (N.m).

Low-Speed Shaft Damping

The internal damping of the low-speed shaft (N.m.s).

Block Inputs and Outputs

Inputs

The block has two inputs: Nh and Nl.

The first input, Nh, is the speed (rpm) of the driving end of the high-speed shaft.

The second input, Nl, is the speed (rpm) of the loaded end of the low-speed shaft.

Outputs

The block has two outputs: Th and Tl.

The Th output is the torque transmitted by the high-speed shaft to the reduction device.

The Tl output is the torque transmitted by the low-speed shaft to the load.

Model Specifications

The library contains four preset models. The specifications of these speed reducer models are shown in the following table.
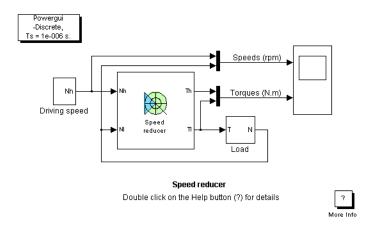
Preset Speed Reducer Models

	1st	2nd	3rd	4th
Power (hp)	5	5	200	200
Reduction ratio	10	100	10	100
Max. output torque (N.m)	300	3000	12200	122000

The high-speed and low-speed shafts of the preset models have been designed in order to present 0.1 degrees of angular deflection at maximum torque.

Example

The `reducer_example` example illustrates the speed reducer model.

Speed reducer
Double click on the Help button (?) for details

The speed reducer is driven by a variable-speed source and is connected to a load. The load has an inertia of 30 kg.m2 and a viscous friction term of 0.5 N.m.s.

The speed reducer has a reduction ratio of 10, and the inertia of the reduction device with respect to the high-speed side is 0.0005 kg.m2. The reduction ratio being quite low, the efficiency is high and worth 0.95.
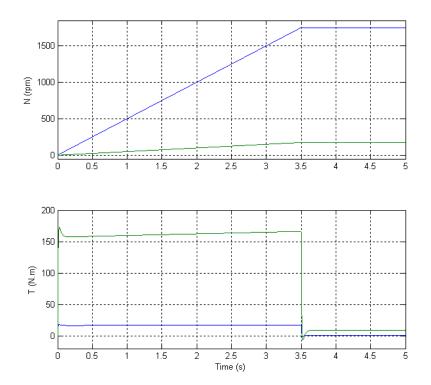
The high-speed shaft has a stiffness of 17190 N.m and an internal damping factor of 600 N.m.s. This shaft is designed to have 0.1 degree of angular deflection for a 30 N.m load torque. The low-speed shaft, having a higher torque to transmit, has a stiffness of 171900 N.m and an internal damping factor of 6000 N.m.s. This shaft is designed to have 0.1 degree of angular deflection for a 300 N.m load torque.

At t = 0 s, the driving speed starts climbing to 1750 rpm with a 500 rpm/s acceleration ramp. This causes the transmitted torque of the high-speed shaft to jump to about 18 N.m. Because of the reduction device, the torque transmitted to the load by the low-speed shaft is a lot bigger and is worth about 170 N.m.

During the accelerating phase, both torques keep increasing in order to compensate the viscous friction of the load. Notice that the load accelerates with a ramp of +50 rpm/s because of the reduction ratio of the gearbox.

At t = 3.5 s, the driving speed settles at 1750 rpm. Since no more accelerating torque is needed, the input and output torques decrease and stabilize respectively to 0.965 N.m and 9.16 N.m at t = 4 s. The load speed is now equal to 175 rpm.

The following figure shows the speed reducer input and output speeds and torques.

References
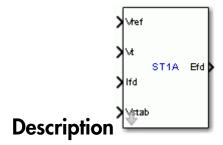
[1] Norton, Robert L., *Machine Design*, Prentice Hall, 1998.

[2] Nise, Norman S., *Control Systems Engineering*, Addison-Wesley Publishing Company, 1995.

ST1A Excitation System

Implements IEEE type ST1A excitation system model

Library

Fundamental Blocks/Machines/Excitation Systems (sps_avr)

Description
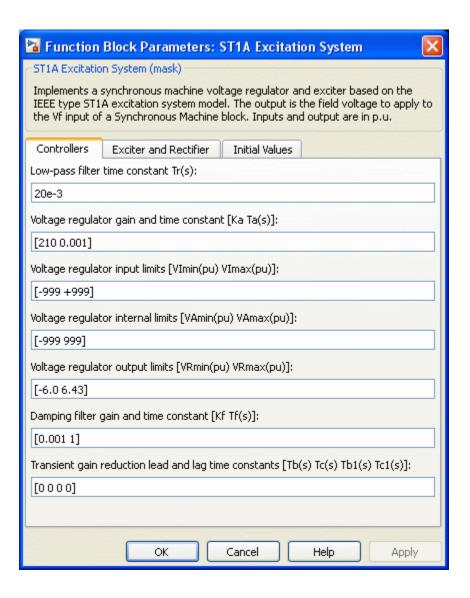
This block models an excitation system where the supply of power to the controlled bridge rectifier is provided by the generator terminals through a transformer to lower the voltage to an appropriate level. The voltage regulator gain and excitation system time constants are represented by Ka and Ta, respectively.

This block is an adaptation of the ST1A excitation system of the IEEE 421 standard, copyright IEEE 2005, all rights reserved.

Dialog Box and Parameters

Controllers Tab

Low-pass filter time constant

The time constant Tr of the first-order system representing the stator terminal voltage transducer.

Voltage regulator gain and time constant

The gain Ka and time constant Ta of the first-order system representing the main regulator.

Voltage regulator input limits

The voltage regulator input limits VImin and VImax, in p.u.

Voltage regulator internal limits

The voltage regulator internal limits VAmin and VAmax, in p.u.

Voltage regulator output limits

The voltage regulator output limits VRmin and VRmax, in p.u.

Damping filter gain and time constant

The gain Kf and time constant Tf of the first-order system representing the derivative feedback.

Transient gain reduction lead and lag time constants

The time constants Tb, Tc, Tb1, and Tc1 of the second-order system representing the lead-lag compensator.

Exciter and Rectifier Tab

Exciter output current limiter gain KLR

The exciter output current limiter gain.
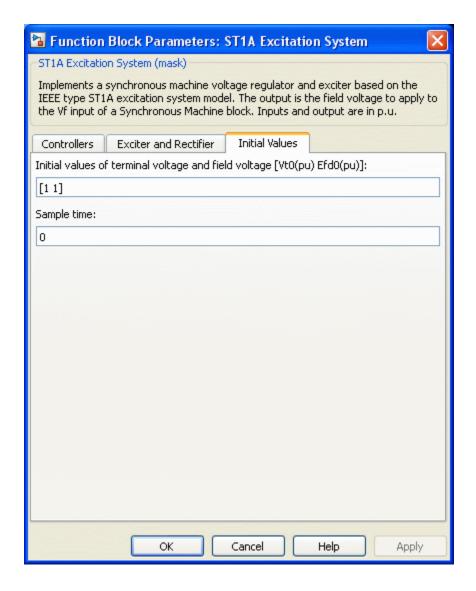
Exciter output current limit reference ILR

The exciter output current limit reference.

Rectifier loading factor Kc

The rectifier loading factor proportional to commutating reactance.

Initial Values Tab

Initial values of terminal voltage and field voltage

The initial values of terminal voltage Vt0 and field voltage Efd0, both in p.u. Initial terminal voltage is normally set to 1 pu. The Vt0 and Efd0 values can be determined using the Powergui Load Flow tool.

Sample time

Specify a value greater than zero to discretize the block at the given sample time. Set to -1 to inherit the simulation type and sample time parameters of the Powergui block.

Ports

Vref

The reference value of the stator terminal voltage, in p.u.

Vt

The measured value in p.u. of the stator terminal voltage of the controlled Synchronous Machine block.

Ifd

The measured value in p.u. of the stator field current of the controlled Synchronous Machine block.

Vstab

Connect this input to a power system stabilizer to provide additional stabilization of power system oscillations. When you do not use this option, connect to a Simulink ground block. The input is in p.u.

Efd

The field voltage to apply to the `Vf` input of the controlled Synchronous Machine block. The output is in p.u.

Example

The `power_machines` example contains a Configurable Subsystem block that allows you to select between seven types of excitation systems to control the terminal voltage of the Synchronous Machine block. This configurable block refers to the `power_machines_lib` example library that contains seven pretuned excitation system blocks that fit simulation requirements for this example.

Right-click the EXCITATION configurable block, then select **ST1A** from the **Block Choice** menu to control the Synchronous Machine block using the ST1A Excitation System block.

References

[1] "IEEE Recommended Practice for Excitation System Models for Power System Stability Studies." *IEEE Standard*, Vol. 421, No. 5, 2005 (Revision of IEEE 521.5-1992).

ST2A Excitation System

Implements IEEE type ST2A excitation system model

Library

Fundamental Blocks/Machines/Excitation Systems (sps_avr)

Description
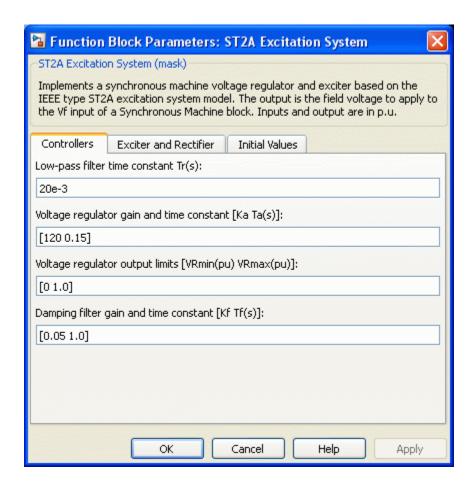
This block models a compound source rectifier excitation system. It utilizes both terminal voltage, Vt, and terminal current, It, to form a model of the exciter power source.

This block is an adaptation of the ST2A excitation system of the IEEE 421 standard, copyright IEEE 2005, all rights reserved.

Dialog Box and Parameters

Controllers Tab

Low-pass filter time constant

> The time constant Tr of the first-order system representing the stator terminal voltage transducer.

Voltage regulator gain and time constant

The gain Ka and time constant Ta of the first-order system representing the main regulator.

Voltage regulator output limits

The voltage regulator output limits VRmin and VRmax, in p.u.

Damping filter gain and time constant

The gain Kf and time constant Tf of the first-order system representing the derivative feedback.

Exciter and Rectifier Tab

Exciter gain and time constant

The gain Ke and time constant Te of the first-order system representing the exciter.

Current circuit gain coefficient KI

The current circuit gain coefficient.

Potential circuit gain coefficient Kp

The potential circuit gain coefficient.
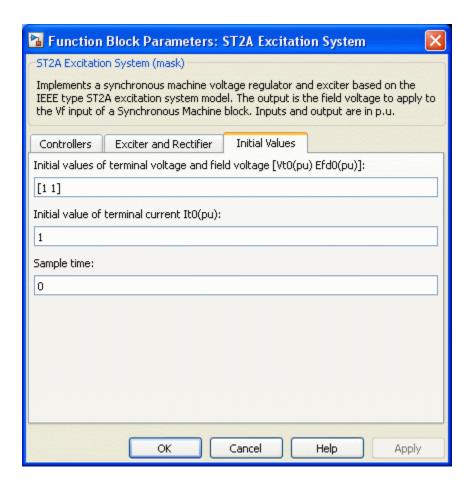
Direct axis synchronous machine reactance

Enter the value of the Xd reactance of the controlled Synchronous Machine block.

Rectifier loading factor Kc

The rectifier loading factor, proportional to commutating reactance.

Initial Values Tab

Initial values of terminal voltage and field voltage

> The initial values of terminal voltage Vt0 and field voltage Efd0, both in p.u. Initial terminal voltage is normally set to 1 pu. The Vt0 and Efd0 values can be determined using the Powergui Load Flow tool.

Initial value of terminal current

> The initial value of terminal current It0, in p.u. This value can be determined using the Powergui Load Flow tool.

Sample time

Specify a value greater than zero to discretize the block at the given sample time. Set to -1 to inherit the simulation type and sample time parameters of the Powergui block.

Ports

Vref

The reference value of the stator terminal voltage, in p.u.

Vt

The measured value in p.u. of the stator terminal voltage of the controlled Synchronous Machine block.

It

It The measured value in p.u. of the stator terminal current of the controlled Synchronous Machine block.

Ifd

The measured value in p.u. of the stator field current of the controlled Synchronous Machine block.

Vstab

Connect this input to a power system stabilizer to provide additional stabilization of power system oscillations. When you do not use this option, connect to a Simulink ground block. The input is in p.u.

Efd

The field voltage to apply to the `Vf` input of the controlled Synchronous Machine block. The output is in p.u.

Example

The `power_machines` example contains a Configurable Subsystem block that allows you to select between seven types of excitation systems to control the terminal voltage of the Synchronous Machine block. This configurable block refers to the `power_machines_lib` example library that contains seven pretuned excitation system blocks that fit simulation requirements for this example.

Right-click the EXCITATION configurable block, then select **ST2A** from the **Block Choice** menu to control the Synchronous Machine block using the ST2A Excitation System block.

References

[1] "IEEE Recommended Practice for Excitation System Models for Power System Stability Studies." *IEEE Standard*, Vol. 421, No. 5, 2005 (Revision of IEEE 521.5-1992).

Stair Generator

Generate signal changing at specified transition times

Library

Control and Measurements/Pulse & Signal Generators

Description
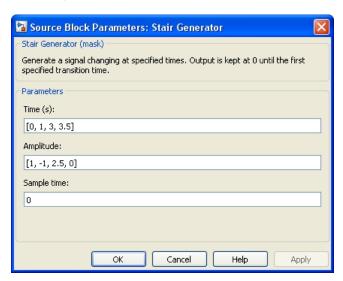
The Stair Generator block generates a signal changing at specified transition times. Use the Stair Generator block to generate a logical signal to control the opening and closing of the Breaker block and the Ideal Switch block. You can also use the Stair Generator block to generate a signal whose amplitude changes by steps at specified transition times.

Dialog Box and Parameters

Source Block Parameters: Stair Generator

Stair Generator (mask)

Generate a signal changing at specified times. Output is kept at 0 until the first specified transition time.

Parameters

Time (s):

[0, 1, 3, 3.5]

Amplitude:

[1, -1, 2.5, 0]

Sample time:

0

OK   Cancel   Help   Apply

Time (s)

Specify the transition times, in seconds, when the output changes to the values specified in the **Amplitude** parameter. The output is kept to zero until the simulation reaches the first transition time.

Amplitude

Specify the amplitude sequence of the output signal. The amplitude is kept constant between the transition times specified in the **Time (s)** parameter. The amplitude of the output is kept to 0 until the simulation reaches the first transition time.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	No
Dimensionalized	No
Zero-Crossing Detection	No

Example

The power_SignalGenerators example shows the use of the Stair Generator block.

Static Synchronous Compensator (Phasor Type)

Implement phasor model of three-phase static synchronous compensator

Library

FACTS/Power-Electronics Based FACTS

Description
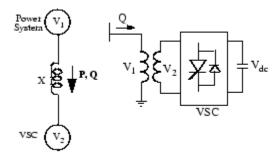
The Static Synchronous Compensator (STATCOM) is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids [1]. The STATCOM regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the STATCOM generates reactive power (STATCOM capacitive). When system voltage is high, it absorbs reactive power (STATCOM inductive).

The variation of reactive power is performed by means of a Voltage-Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage V2 from a DC voltage source. The principle of operation of the STATCOM is explained on the figure below showing the active and reactive power transfer between a source V1 and a source V2. In this figure, V1 represents the system voltage to be controlled and V2 is the voltage generated by the VSC.

$P = (V_1 V_2)\sin\delta / X$, $Q = V_1(V_1 - V_2\cos\delta) / X$

Symbol	Meaning
V_1	Line to line voltage of source 1
V_2	Line to line voltage of source 2
X	Reactance of interconnection transformer and filters
δ	Phase angle of V_1 with respect to V_2

Operating Principle of the STATCOM

In steady state operation, the voltage V2 generated by the VSC is in phase with V1 (δ=0), so that only reactive power is flowing (P=0). If V2 is lower than V1, Q is flowing from V1 to V2 (STATCOM is absorbing reactive power). On the reverse, if V2 is higher than V1, Q is flowing from V2 to V1 (STATCOM is generating reactive power). The amount of reactive power is given by
$Q = (V_1(V_1 - V_2)) / X$.
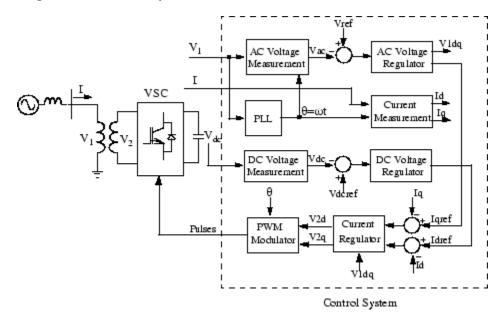
A capacitor connected on the DC side of the VSC acts as a DC voltage source. In steady state the voltage V2 has to be phase shifted slightly behind V1 in order to compensate for transformer and VSC losses and to keep the capacitor charged. Two VSC technologies can be used for the VSC:

·   VSC using GTO-based square-wave inverters and special interconnection transformers. Typically four three-level inverters are used to build a 48-step voltage waveform. Special interconnection transformers are used to neutralize harmonics contained in the square waves generated by individual inverters. In this type of VSC, the fundamental component of voltage V2 is proportional to the voltage Vdc. Therefore Vdc has to be varied for controlling the reactive power.

- VSC using IGBT-based PWM inverters. This type of inverter uses Pulse-Width Modulation (PWM) technique to synthesize a sinusoidal waveform from a DC voltage source with a typical chopping frequency of a few kilohertz. Harmonic voltages are cancelled by connecting filters at the AC side of the VSC. This type of VSC uses a fixed DC voltage Vdc. Voltage V2 is varied by changing the modulation index of the PWM modulator.

The STATCOM (Phasor Type) block models an IGBT-based STATCOM (fixed DC voltage). However, as details of the inverter and harmonics are not represented, it can be also used to model a GTO-based STATCOM in transient stability studies. A detailed model of a GTO-based STATCOM is provided in the FACTS example library (`power_statcom_gto48p` example).

The figure below shows a single-line diagram of the STATCOM and a simplified block diagram of its control system.

Single-line Diagram of a STATCOM and Its Control System Block Diagram

The control system consists of:

- A phase-locked loop (PLL) which synchronizes on the positive-sequence component of the three-phase primary voltage V1. The output of the PLL (angle $\Theta = \omega t$) is used

to compute the direct-axis and quadrature-axis components of the AC three-phase voltage and currents (labeled as Vd, Vq or Id, Iq on the diagram).

- Measurement systems measuring the d and q components of AC positive-sequence voltage and currents to be controlled as well as the DC voltage Vdc.

- An outer regulation loop consisting of an AC voltage regulator and a DC voltage regulator. The output of the AC voltage regulator is the reference current Iqref for the current regulator (Iq = current in quadrature with voltage which controls reactive power flow). The output of the DC voltage regulator is the reference current Idref for the current regulator (Id = current in phase with voltage which controls active power flow).

- An inner current regulation loop consisting of a current regulator. The current regulator controls the magnitude and phase of the voltage generated by the PWM converter (V2d V2q) from the Idref and Iqref reference currents produced respectively by the DC voltage regulator and the AC voltage regulator (in voltage control mode). The current regulator is assisted by a feed forward type regulator which predicts the V2 voltage output (V2d V2q) from the V1 measurement (V1d V1q) and the transformer leakage reactance.
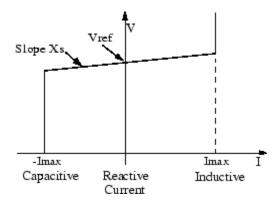
The STACOM block is a phasor model which does not include detailed representations of the power electronics. You must use it with the phasor simulation method, activated with the Powergui block. It can be used in three-phase power systems together with synchronous generators, motors, dynamic loads and other FACTS and Renewable Energy systems to perform transient stability studies and observe impact of the STATCOM on electromechanical oscillations and transmission capacity at fundamental frequency.

STATCOM V-I Characteristic

The STATCOM can be operated in two different modes:

- In voltage regulation mode (the voltage is regulated within limits as explained below)
- In var control mode (the STATCOM reactive power output is kept constant)

When the STATCOM is operated in voltage regulation mode, it implements the following V-I characteristic.

STATCOM V-I characteristic

As long as the reactive current stays within the minimum and minimum current values (-Imax, Imax) imposed by the converter rating, the voltage is regulated at the reference voltage Vref. However, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in the figure. In the voltage regulation mode, the V-I characteristic is described by the following equation:

$V = V_{ref} + Xs\ I$

where

V	Positive sequence voltage (pu)
I	Reactive current (pu/Pnom) (I > 0 indicates an inductive current)
Xs	Slope or droop reactance (pu/Pnom)
Pnom	Three-phase nominal power of the converter specified in the block dialog box

STATCOM vs SVC
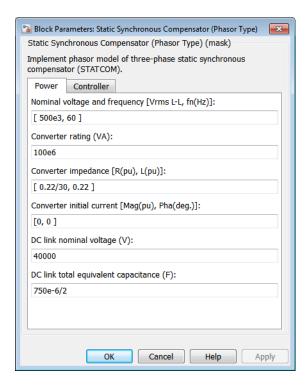
The STATCOM performs the same function as the SVC. However at voltages lower than the normal voltage regulation range, the STATCOM can generate more reactive power than the SVC. This is due to the fact that the maximum capacitive power generated by a SVC is proportional to the square of the system voltage (constant susceptance) while the maximum capacitive power generated by a STATCOM decreases linearly with voltage (constant current). This ability to provide more capacitive reactive power during

a fault is one important advantage of the STATCOM over the SVC. In addition, the STATCOM will normally exhibits a faster response than the SVC because with the VSC, the STATCOM has no delay associated with the thyristor firing (in the order of 4 ms for a SVC).

Dialog Box and Parameters

The STATCOM parameters are grouped in two categories: `Power data` and `Control parameters`. Use the **Display** listbox to select which group of parameters you want to visualize.

Power Tab

Nominal voltage and frequency

The nominal line-to-line voltage in Vrms and the nominal system frequency in hertz.

Converter rating

The nominal power of the converter in VA.

Converter impedance

The positive-sequence resistance and inductance of the converter, in pu based on the nominal power and voltage ratings. R and L represent the resistance and leakage inductance of the coupling transformer and the resistance and inductance of the series filtering inductors connected at the VSC output.

Converter initial current

The initial value of the positive-sequence current phasor (Magnitude in pu and Phase in degrees). If you know the initial value of the current corresponding to the STATCOM operating point you may specify it in order to start simulation in steady state. If you don't know this value, you can leave [0 0]. The system will reach steady-state after a short transient.

DC link nominal voltage

The nominal voltage of the DC link in volts.

DC link total equivalent capacitance
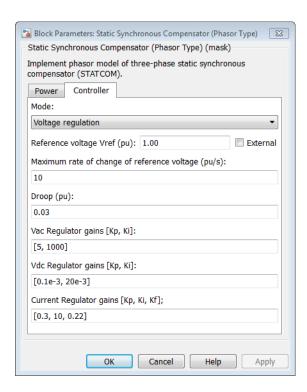
The total capacitance of the DC link in farads. This capacitance value is related to the STATCOM rating and to the DC link nominal voltage. The energy stored in the capacitance (in joules) divided by the STATCOM rating (in VA) is a time duration which is usually a fraction of a cycle at nominal frequency. For example, for the default parameters, (C=375 μF, Vdc=40 000 V, Snom=100 MVA) this ratio $\left(C \cdot V_{\mathrm{dc}}^2 \, / \, 2 \right) / S_{\mathrm{nom}}$ is 3.0 ms, which represents 0.18 cycle for a 60 Hz frequency. If you change the default values of the nominal power rating and DC voltage, you should change the capacitance value accordingly.

Controller Tab

Mode

> Specifies the STATCOM mode of operation. Select either `Voltage regulation` or `Var Control`.

Reference voltage Vref

> This parameter is not visible when the **Mode of operation** parameter is set to `Var Control`.
>
> Reference voltage, in pu, used by the voltage regulator.
>
> When **External** is selected, a Simulink input named Vref appears on the block, allowing you to control the reference voltage from an external signal (in pu). The **Reference grid voltage** parameter is therefore unavailable.

Maximum rate of change of reference voltage

This parameter is not visible when the **Mode of operation** parameter is set to `Var Control`.

Maximum rate of change of the reference voltage, in pu/s, when an external reference voltage is used.

Droop (pu):

This parameter is not visible when the **Mode of operation** parameter is set to `Var Control`.

Droop reactance, in pu/converter rating Snom, defining the slope of the V-I characteristic.

Vac Regulator Gains: [Kp Ki]

This parameter is not visible when the **Mode of operation** parameter is set to `Var Control`.

Gains of the AC voltage PI regulator. Specify proportional gain Kp in (pu of I)/(pu of V), and integral gain Ki, in (pu of I)/(pu of V)/s, where V is the AC voltage error and I is the output of the voltage regulator.

Reactive power setpoint Qref

This parameter is not visible when the **Mode of operation** parameter is set to `Voltage Control`.

Reference reactive power, in pu, when the STATCOM is in `Var Control`.

Maximum rate of change of reactive power setpoint Qref

This parameter is not visible when the **Mode of operation** parameter is set to `Voltage Control`.

Maximum rate of change of the reference reactive power, in pu/s.

Vdc Regulator Gains: [Kp Ki]

Gains of the DC voltage PI regulator which controls the voltage across the DC bus capacitor. Specify proportional gain Kp in (pu of I)/Vdc, and integral gain Ki, in (pu of I)/Vdc/s, where Vdc is the DC voltage error and I is the output of the voltage regulator.

Current Regulators Gains: [Kp Ki Kf]

Gains of the inner current regulation loop.

Specify proportional gain Kp in (pu of V)/(pu of I), integral gain Ki, in (pu of V)/(pu of I)/s, and feed forward gain Kf in (pu of V)/(pu of I), where V is the output V2d or V2q of the current regulator and I is the Id or Iq current error.

For optimal performance, the feed forward gain should be set to the converter reactance (in pu) given by parameter L in the **Converter impedance [R L]** parameters.

Inputs and Outputs

A B C

The three terminals of the STATCOM.

Trip

Apply a simulink logical signal (0 or 1) to this input. When this input is high the STATCOM is disconnected and its control system is disabled. Use this input to implement a simplified version of the protection system.

Vref

Simulink input of the external reference voltage signal.

This input is visible only the **External control of reference voltage Vref** parameter is checked.

m

Simulink output vector containing 16 STATCOM internal signals. These signals are either voltage and current phasors (complex signals) or control signals. They can be individually accessed by using the Bus Selector block. They are, in order:

Signal	Signal Group	Signal Names	Definition
1-3	Power Vabc (cmplx)	Va_prim (pu) Vb_prim (pu) Vc_prim (pu)	Phasor voltages (phase to ground) Va, Vb, Vc at the STATCOM primary terminals (pu)
4-6	Power Iabc (cmplx)	Ia_prim (pu) Ib_prim (pu) Ic_prim (pu)	Phasor currents Ia, Ib, Ic flowing into the STATCOM (pu)
7	Power	Vdc (V)	DC voltage (V)
8	Control	Vm (pu)	Positive-sequence value of the measured voltage (pu)
9	Control	Vref (pu)	Reference voltage (pu)
10	Control	Qm (pu)	STATCOM reactive power. A positive value indicates inductive operation.

Signal	Signal Group	Signal Names	Definition
11	Control	Qref (pu)	Reference reactive power (pu)
12	Control	Id (pu)	Direct-axis component of current (active current) flowing into STATCOM (pu). A positive value indicates active power flowing into STATCOM.
13	Control	Iq (pu)	Quadrature-axis component of current (reactive current) flowing into STATCOM (pu). A positive value indicates capacitive operation.
14	Control	Idref (pu)	Reference value of direct-axis component of current flowing into STATCOM (pu)
15	Control	Iqref (pu)	Reference value of quadrature-axis component of current flowing into STATCOM (pu)
16	Control	modindex	The modulation index m of the PWM modulator. A positive number 0<m<1. m=1 corresponds to the maximum voltage V2 which can be generated by the VSC without overmodulation.

Example

See the power_statcom example which illustrates the steady-state and dynamic performance of a STATCOM regulating voltage on a 500 kV, 60 Hz, system. The example also compares the performance of the STACOM with an SVC having the same rating.

References

[1] N. G. Hingorani, L. Gyugyi, "Understanding FACTS; Concepts and Technology of Flexible AC Transmission Systems," *IEEE Press book*, 2000.

See Also

Static Var Compensator (Phasor Type), Unified Power Flow Controller (Phasor Type)

Static Synchronous Series Compensator (Phasor Type)

Implement phasor model of three-phase static synchronous series compensator

Library

FACTS/Power-Electronics Based FACTS

Description
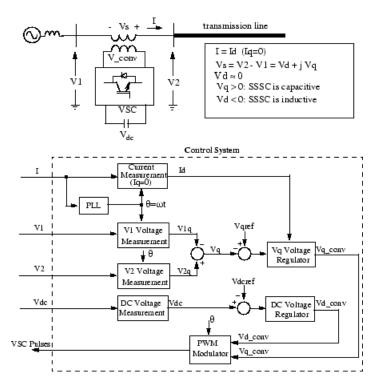
The Static Synchronous Series Compensator (SSSC) is a series device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve power oscillation damping on power grids [1]. The SSSC injects a voltage Vs in series with the transmission line where it is connected.

Single-line Diagram of a SSSC and Its Control System Block Diagram

As the SSSC does not use any active power source, the injected voltage must stay in quadrature with line current. By varying the magnitude Vq of the injected voltage in quadrature with current, the SSSC performs the function of a variable reactance compensator, either capacitive or inductive.

The variation of injected voltage is performed by means of a Voltage-Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage V_conv from a DC voltage source.

A capacitor connected on the DC side of the VSC acts as a DC voltage source. A small active power is drawn from the line to keep the capacitor charged and to provide transformer and VSC losses, so that the injected voltage Vs is practically 90 degrees out of phase with current I. In the control system block diagram Vd_conv and Vq_conv designate the components of converter voltage V_conv which are respectively in phase and in quadrature with current. Two VSC technologies can be used for the VSC:

- VSC using GTO-based square-wave inverters and special interconnection transformers. Typically four three-level inverters are used to build a 48-step voltage waveform. Special interconnection transformers are used to neutralize harmonics contained in the square waves generated by individual inverters. In this type of VSC, the fundamental component of voltage V_conv is proportional to the voltage Vdc. Therefore Vdc has to varied for controlling the injected voltage.

- VSC using IGBT-based PWM inverters. This type of inverter uses Pulse-Width Modulation (PWM) technique to synthesize a sinusoidal waveform from a DC voltage with a typical chopping frequency of a few kilohertz. Harmonics are cancelled by connecting filters at the AC side of the VSC. This type of VSC uses a fixed DC voltage Vdc. Voltage V_conv is varied by changing the modulation index of the PWM modulator.

The SSSC (Phasor Type) block models an IGBT-based SSSC (fixed DC voltage). However, as details of the inverter and harmonics are not represented, it can be also used to model a GTO-based SSSC in transient stability studies.

The control system consists of:
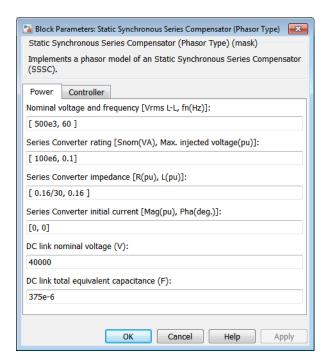
- A phase-locked loop (PLL) which synchronizes on the positive-sequence component of the current I. The output of the PLL (angle $\Theta = \omega t$) is used to compute the direct-axis and quadrature-axis components of the AC three-phase voltages and currents (labeled as Vd, Vq or Id, Iq on the diagram).

- Measurement systems measuring the q components of AC positive-sequence of voltages V1 and V2 (V1q and V2q) as well as the DC voltage Vdc.

- AC and DC voltage regulators which compute the two components of the converter voltage (Vd_conv and Vq_conv) required to obtain the desired DC voltage (Vdcref) and the injected voltage (Vqref). The Vq voltage regulator is assisted by a feed forward type regulator which predicts the V_conv voltage from the Id current measurement.

The SSSC block is a phasor model which does not include detailed representations of the power electronics. You must use it with the phasor simulation method, activated with the Powergui block. It can be used in three-phase power systems together with synchronous generators, motors, dynamic loads and other FACTS and Renewable Energy systems to perform transient stability studies and observe impact of the SSSC on electromechanical oscillations and transmission capacity at fundamental frequency.

Dialog Box and Parameters

The SSSC parameters are grouped in two categories: `Power data` and `Control parameters`. Use the **Display** listbox to select which group of parameters you want to visualize.

Power Tab

Nominal voltage and frequency

The nominal line-to-line voltage in Vrms and the nominal system frequency in hertz.

Series Converter rating

The nominal rating of the series converter in VA and the maximum value of the injected voltage V_conv on the VSC side of the transformer (see single line diagram), in pu of nominal phase-to-ground voltage.

Series Converter impedance

The positive-sequence resistance and inductance of the converter, in pu based on the nominal converter rating and nominal voltage. R and L represent the resistance and leakage inductance of the coupling transformer plus the resistance and inductance of the series filtering inductors connected at the VSC output.

Series Converter initial current

The initial value of the positive-sequence current phasor (Magnitude in pu and Phase in degrees). If you know the initial value of the current corresponding to the SSSC operating point you may specify it in order to start simulation in steady state. If you don't know this value, you can leave [0 0]. The system will reach steady-state after a short transient.

DC link nominal voltage

The nominal voltage of the DC link in volts.

DC link total equivalent capacitance
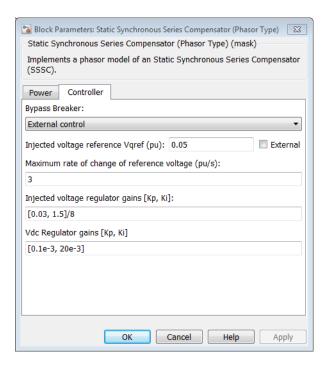
The total capacitance of the DC link in farads. This capacitance value is related to the SSSC converter rating and to the DC link nominal voltage. The energy stored in the capacitance (in joules) divided by the converter rating (in VA) is a time duration which is usually a fraction of a cycle at nominal frequency. For example, for the default parameters, (C=375 µF, Vdc=40 000 V, Snom=100 MVA) this ratio is 3.0 ms, which represents 0.18 cycle for a 60 Hz frequency. If you change the default values of the nominal power rating and DC voltage, you should change the capacitance value accordingly.

Controller Tab

Bypass Breaker

Specifies the status of the bypass breaker connected inside the block across terminals A1, B1, C1 and A2, B2, C2. Select either `External Control`, `Open` or `Closed`. If the bypass breaker is in external control, a Simulink input named Bypass appears on the block, allowing to control the status of the bypass breaker from an external signal (0 or 1).

Injected voltage reference Vqref

Specify the quadrature-axis component of the voltage injected on the VSC side of the series transformer, in pu. When **External** is selected, a Simulink input named Vqef appears on the block, allowing you to control the reference voltage from an external signal (in pu). The **Injected voltage reference Vqref** parameter is therefore unavailable.

Maximum rate of change for Vqref

Maximum rate of change of the Vqref voltage, in pu/s.

Injected voltage regulator gains: [Kp Ki]

Gains of the PI regulator which controls the injected voltage. Specify proportional gain Kp in (pu of Vq_conv)/(pu of V), and integral gain Ki, in (pu of Vq_conv)/(pu of V)/s, where V is the Vq voltage error and Vq_conv is the quadrature-axis component of the voltage generated by the VSC.

The feed forward gain is computed from the **Series converter impedance [R L]** parameters.

Vdc regulator gains: [Kp Ki]

Gains of the DC voltage PI regulator which controls the voltage across the DC bus capacitor. Specify proportional gain Kp in (pu of Vd_conv)/Vdc, and integral gain Ki, in (pu of Vd_conv)/Vdc/s, where Vdc is the DC voltage error and Vd_conv is the direct-axis component of the voltage generated by the converter.

Inputs and Outputs

A1 B1 C1

The three input terminals of the SSSC.

A2 B2 C2

The three output terminals of the SSSC.

Bypass

This input is visible only when the **Bypass Breaker** parameter is set to `External Control`.

Apply a simulink logical signal (0 or 1) to this input. When this input is high the bypass breaker is closed.

Vqref

This input is visible only when the **External control of injected voltage Vqref** parameter is checked.

Apply a simulink signal specifying the reference voltage, in pu.

m

Simulink output vector containing 17 SSSC internal signals. These signals are either voltage and current phasors (complex signals) or control signals. They can be individually accessed by using the Bus Selector block. They are, in order:

1-907

Signal	Signal Group	Signal Names	Definition
1-3	Power Vabc1 (cmplx)	Va1 (pu) Vb1 (pu) Vc1 (pu)	Phasor voltages (phase to ground) Va, Vb, Vc at the SSSC input terminals A1, B1, C1 (pu)
4	Power	Vdc (V)	DC voltage (V)
5-7	Power Vabc2 (cmplx)	Va2 (pu) Vb2 (pu) Vc2 (pu)	Phasor voltages (phase to ground) Va, Vb, Vc at the SSSC output terminals A2, B2, C2 (pu)
8-10	Power Vabc_Inj (cmplx)	Va_Inj (pu) Vb_Inj (pu) Vc_Inj (pu)	Phasors of injected voltages Vs= V2-V1 (pu)
11-13	Power Iabc (cmplx)	Ia (pu) Ib (pu) Ic (pu)	Phasor currents Ia, Ib, Ic flowing out of terminals A2, B2, C2 (pu)
14	Control	Vqref (pu)	Reference value of quadrature-axis injected voltage (pu)
15	Control	Vqinj (pu)	Measured injected voltage in quadrature-axis (pu)
16	Control	Id(pu)	Measured current (pu)
17	Control	modindex	The modulation index m of the PWM modulator. A positive number $0<m<1$. $m=1$ corresponds to the maximum voltage V_conv which can be generated by the series converter without overmodulation.

Example

See the power_sssc example which illustrates the use of a SSSC for damping power oscillations on a 500 kV, 60 Hz, system.

References

[1] N. G. Hingorani, L. Gyugyi, "Understanding FACTS; Concepts and Technology of Flexible AC Transmission Systems," *IEEE Press book*, 2000

See Also

Unified Power Flow Controller (Phasor Type)

Static Var Compensator (Phasor Type)

Implement phasor model of three-phase static var compensator

Library

FACTS/Power-Electronics Based FACTS
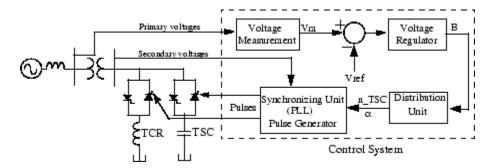
Description

The Static Var Compensator (SVC) is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids [1]. The SVC regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive). The variation of reactive power is performed by switching three-phase capacitor banks and inductor banks connected on the secondary side of a coupling transformer. Each capacitor bank is switched on and off by three thyristor switches (Thyristor Switched Capacitor or TSC). Reactors are either switched on-off (Thyristor Switched Reactor or TSR) or phase-controlled (Thyristor Controlled Reactor or TCR).

The figure below shows a single-line diagram of a static var compensator and a simplified block diagram of its control system.

Single-line Diagram of an SVC and Its Control System Block Diagram

The control system consists of

- A measurement system measuring the positive-sequence voltage to be controlled. A Fourier-based measurement system using a one-cycle running average is used.

- A voltage regulator that uses the voltage error (difference between the measured voltage Vm and the reference voltage Vref) to determine the SVC susceptance B needed to keep the system voltage constant

- A distribution unit that determines the TSCs (and eventually TSRs) that must be switched in and out, and computes the firing angle α of TCRs

- A synchronizing system using a phase-locked loop (PLL) synchronized on the secondary voltages and a pulse generator that send appropriate pulses to the thyristors

The SVC (Phasor Type) block is a phasor model, and you must use it with the phasor simulation method, activated with the Powergui block. It can be used in three-phase power systems together with synchronous generators, motors, and dynamic loads to perform transient stability studies and observe impact of the SVC on electromechanical oscillations and transmission capacity. This model does not include detailed representations of the power electronics, the measurement system, or the synchronization system. These systems are approximated rather by simple transfer functions that yield a correct representation at the system's fundamental frequency.
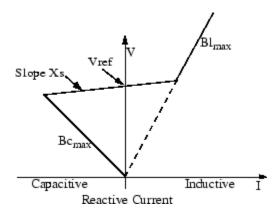
A detailed model of a SVC using three TSCs and one TCR is provided in the `power_svc_1tcr3tsc` example.

SVC V-I Characteristic

The SVC can be operated in two different modes:

- In voltage regulation mode (the voltage is regulated within limits as explained below)
- In var control mode (the SVC susceptance is kept constant)

When the SVC is operated in voltage regulation mode, it implements the following V-I characteristic.

SVC V-I characteristic

As long as the SVC susceptance B stays within the maximum and minimum susceptance values imposed by the total reactive power of capacitor banks (Bc_{max}) and reactor banks (Bl_{max}), the voltage is regulated at the reference voltage Vref. However, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in the figure. The V-I characteristic is described by the following three equations:

$$V = \begin{cases} V_{\text{ref}} + Xs \cdot I & \text{if SVC is in regulation range } \left(-Bc_{max} < B < Bl_{max}\right) \\ -\dfrac{I}{Bc_{max}} & \text{if SVC is fully capacitive } \left(B = Bc_{max}\right) \\ \dfrac{I}{Bl_{max}} & \text{if SVC is fully inductive } \left(B = Bl_{max}\right), \end{cases}$$

where

V	Positive sequence voltage (pu)
I	Reactive current (pu/Pbase) (I > 0 indicates an inductive current)

Xs	Slope or droop reactance (pu/Pbase)
Bcmax	Maximum capacitive susceptance (pu/Pbase) with all TSCs in service, no TSR or TCR
Blmax	Maximum inductive susceptance (pu/Pbase) with all TSRs in service or TCRs at full conduction, no TSC
Pbase	Three-phase base power specified in the block dialog box

SVC Dynamic Response

When the SVC is operating in voltage regulation mode, its response speed to a change of system voltage depends on the voltage regulator gains (proportional gain Kp and integral gain Ki), the droop reactance Xs, and the system strength (short-circuit level).

For an integral-type voltage regulator (Kp = 0), if the voltage measurement time constant Tm and the average time delay Td due to valve firing are neglected, the closed-loop system consisting of the SVC and the power system can be approximated by a first-order system having the following closed-loop time constant:

$T_c = 1 / (Ki(Xs + Xn))$

where
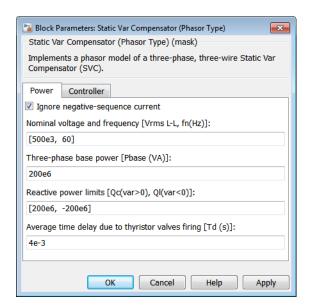
T_c	Closed loop time constant
Ki	Proportional gain of the voltage regulator (pu_B/pu_V/s)
Xs	Slope reactance pu/Pbase
Xn	Equivalent power system reactance (pu/Pbase)

This equation demonstrates that you obtain a faster response speed when the regulator gain is increased or when the system short-circuit level decreases (higher Xn values). If you take into account the time delays due to voltage measurement system and valve firing, you obtain an oscillatory response and, eventually, an instability with too weak a system or too large a regulator gain.

Dialog Box and Parameters

The SVC parameters are grouped in two categories: `Power Data` and `Control Parameters`. Use the **Display** listbox to select which group of parameters you want to visualize.

Power Tab

Ignore negative-sequence current

> The SVC is modeled by a three-wire system using two current sources. The SVC does not generate any zero-sequence current, but it can generate negative-sequence currents during unbalanced system operation. The negative-sequence susceptance of the SVC is assumed to be identical to its positive-sequence value, as determined by the B value computed by the voltage regulator.

> Check this box to ignore negative-sequence current.

Nominal voltage and frequency

> The nominal line-to-line voltage in Vrms and the nominal system frequency in hertz.

Three-phase base power

> Three-phase base power, in VA, used to specify the following parameters in pu: droop reactance Xs, gains Kp and Ki of the voltage PI regulator, and reference susceptance Bref. This base power is also used to normalize the output B susceptance signal.
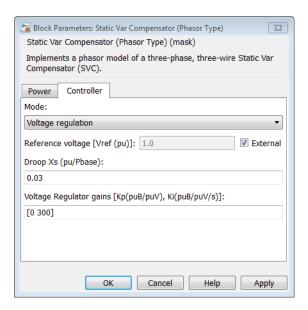
Reactive power limits

> The maximum SVC reactive powers at 1 pu voltage, in vars. Enter a positive value for the capacitive reactive power Qc (vars generated by the SVC) and a negative value for the inductive reactive power Ql (vars absorbed by the SVC).

Average time delay due to thyristor valves firing

Average time delay simulating the non instantaneous variation of thyristor fundamental current when the distribution unit sends a switching order to the pulse generator. Because pulses have to be synchronized with thyristor commutation voltages, this delay normally varies between 0 and 1/2 cycle. The suggested average value is 4 ms.

Controller Tab

Mode

Specifies the SVC mode of operation. Select either `Voltage regulation` or `Var control (Fixed susceptance Bref)`.

Reference voltage Vref

This parameter is not visible when the **Mode of operation** parameter is set to `Var Control`.

Reference voltage, in pu, used by the voltage regulator. When **External** is selected, a Simulink input named Vref appears on the block, allowing you to control the reference voltage from an external signal (in pu). The **Reference grid voltage** parameter is therefore unavailable.

Droop Xs

This parameter is not visible when the **Mode of operation** parameter is set to `Var Control`.

Droop reactance, in pu/Pbase, defining the slope of the V-I characteristic.

Voltage regulator gains

This parameter is not visible when the **Mode of operation** parameter is set to `Var Control`.

Proportional gain, in (pu of B)/(pu of V), and integral gain, in pu_B/pu_V/s, of the voltage regulator.

Susceptance Bref

This parameter is not visible when the **Mode of operation** parameter is set to `Voltage regulation`.

Reference susceptance, in pu/Pbase, when the SVC is operating in var control mode.

Inputs and Outputs

A B C

The three terminals of the SVC.

Vref

Simulink input of the reference voltage signal.

This input is visible only when the **External control of reference voltage Vref** parameter is checked.

m
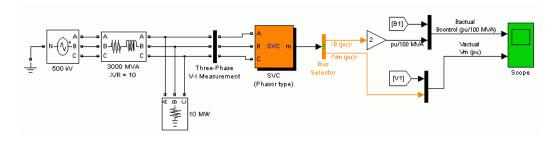
Simulink output vector containing six SVC internal signals. These signals are either voltage and current phasors (complex signals) or control signals. They can be individually accessed by using the Bus Selector block. They are, in order:

Signal	Signal Group	Signal Names	Definition
1-3	Power Iabc (cmplx)	Ia(pu) Ib(pu) Ic(pu)	Phasor currents Ia, Ib, Ic flowing into the SVC (pu)

Signal	Signal Group	Signal Names	Definition
4	Control	Vm (pu)	Positive-sequence value of measured voltage (pu)
5	Control	B (pu)	SVC susceptance output of the voltage regulator (pu). A positive value indicates that the SVC is capacitive.
6	Control	Q (pu)	SVC reactive power output (pu). A positive value indicates inductive operation.

Example

The power_svc example illustrates the steady-state and dynamic performance of a +200 Mvar/- 100 Mvar SVC regulating voltage on a 500 kV, 60 Hz, system.
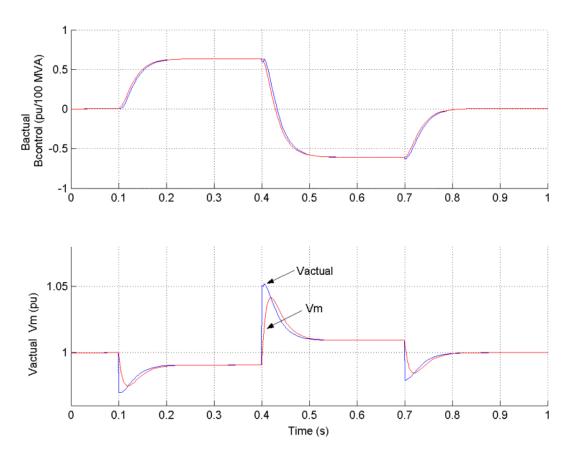
Open the SVC block menu and look at its parameters. The SVC is set to `Voltage regulation` mode with a reference voltage Vref = 1.0 pu. The voltage droop reactance is 0.03 pu/200 MVA, so that the voltage varies from 0.97 pu to 1.015 pu when the SVC current goes from fully capacitive to fully inductive. Double-click the blue block to display the SVC V-I characteristic.

The Three-Phase Programmable Voltage Source is used to vary the system voltage and observe the SVC performance. Initially the source is generating its nominal voltage (500 kV). Then, voltage is successively decreased (0.97 pu at t = 0.1 s), increased (1.03 pu at t = 0.4 s) and finally returned to nominal voltage (1 pu at t = 0.7 s).

Start the simulation and observe the SVC dynamic response to voltage steps on the Scope. Waveforms are reproduced on the figure below. Trace 1 shows the actual positive-sequence susceptance B1 and control signal output B of the voltage regulator. Trace

2 shows the actual system positive-sequence voltage V1 and output Vm of the SVC measurement system.
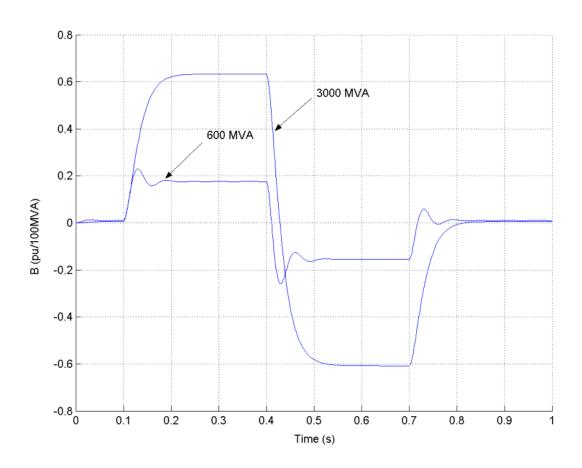
The SVC response speed depends on the voltage regulator integral gain Ki (proportional gain Kp is set to zero), system strength (reactance Xn), and droop (reactance Xs).

As mentioned above, neglecting the voltage measurement time constant Tm and the average time delay Td due to valve firing, the system can be approximated by a first-order system having a closed-loop time constant:
$T_c = 1 / (Ki(Xs + Xn))$

With given system parameters (Ki = 300; Xn = 0.0667 pu/200 MVA; Xs = 0.03 pu/200 MVA), the closed-loop time constant is Tc = 0.0345 s.

If you increase the regulator gain or decrease the system strength, Tm and Td are no longer negligible, and you instead observe an oscillatory response and eventually instability. The figure below compares the SVC susceptance (B output of the voltage regulator) for two different short-circuit levels: 3000 VA and 600 MVA.

References

[1] N. G. Hingorani, L. Gyugyi, "Understanding FACTS; Concepts and Technology of Flexible AC Transmission Systems," *IEEE Press book*, 2000

See Also

Static Synchronous Compensator (Phasor Type)

Steam Turbine and Governor
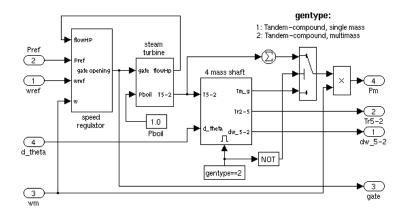
Model the dynamics of speed governing system, steam turbine, and multimass shaft

Library

Fundamental Blocks/Machines

Description
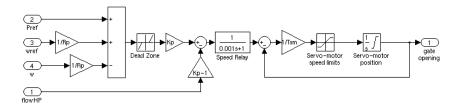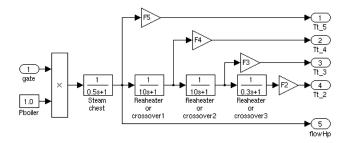
The Steam Turbine and Governor block implements a complete tandem-compound steam prime mover, including a speed governing system, a four-stage steam turbine, and a shaft with up to four masses.

The speed governing system consists of a proportional regulator, a speed relay, and a servomotor controlling the gate opening. It is similar to one of the models proposed in [1].
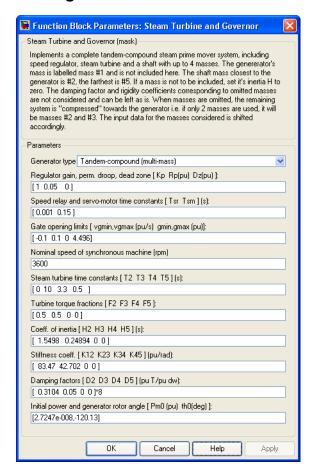
The steam turbine has four stages, each modeled by a first-order transfer function. The first stage represents the steam chest while the three other stages represent either reheaters or crossover piping. The boiler is not modeled and boiler pressure is constant at 1.0 pu. Fractions F2 to F5 are used to distribute the turbine power to the various shaft stages:

The shaft models a four-mass system, which is coupled to the mass in the Synchronous Machine model for a total of five masses. The machine's mass is labeled mass #1. The mass in the Steam Turbine and Governor block, which is closest to the machine's mass, is mass #2, while the mass farthest from the machine is mass #5. The shaft is characterized by mass inertias H, damping factors D, and rigidity coefficients K. If you choose to simulate a single-mass shaft, the entire four-mass shaft subsystem in the Steam Turbine and Governor block is disabled and all the torque from the turbine is added together and applied to the machine's mass:

Dialog Box and Parameters

Generator type

Specifies rotor type: single mass or multimass tandem-compound. If you choose a single-mass system, the multimass shaft subsystem in the Steam Turbine and Governor block is disabled and the turbine's output torques are summed together and applied to the single mass in the Synchronous Machine block.

Regulator gain, permanent droop, dead zone

The gain Kp, permanent droop Rp (pu), and dead-zone width Dz (pu). Set gain to 3 if you want to use the steam flow feedback loop. Otherwise, set gain to 1.

Speed relay and servo-motor time constants

The speed relay and gate servomotor time constants Tsr (s) and Tsm (s).

Gate opening limits

The minimum and maximum gate opening speed vgmin and vgmax (both in pu/s), and minimum and maximum gate opening gmin and gmax (both in pu).

Nominal speed of synchronous machine

The synchronous speed of the generator driven by the steam turbine (rpm).

Steam turbine time constants

The turbine time constants T2 to T5 (s). Numbered consistently with turbine torque fractions and mass numbers; i.e., T5 is the time constant of the first turbine stage, which models the steam chest.

Turbine torque fractions

The turbine torque fractions F2 to F5. Must total 1, otherwise an error message appears. Fraction numbers correspond to mass numbers; i.e., F2 is the fraction of torque to be applied to mass #2 of the multimass shaft.

Coefficient of inertia; Stiffness coefficient; Damping factors

Only visible if generator type is `multimass`. Coefficients of inertia H2 to H5 (s), stiffness coefficients K12 to K45 (pu/rad), and damping factors D2 to D5 (pu torque / pu speed deviation) are associated with the masses of the multimass shaft. K12 corresponds to the rigidity coefficient between masses #1 and #2, and so on.

Note If you do not want to simulate all four masses in the multimass shaft, simply set the inertia of unwanted masses to 0. The rigidity coefficient and damping factor corresponding to omitted masses are not considered. When masses are not simulated, the remaining system is "compressed" toward the generator; i.e., if only two masses are used (excluding the generator), they are masses #2 and #3. The input data for the masses considered are shifted accordingly. In any case, inertias must be consistent with torque fractions. You cannot set an inertia to 0 and set the corresponding torque fraction to a nonzero value. However, you can set a torque fraction to 0 and set the corresponding mass inertia to a nonzero value.

Initial power and generator rotor angle

If the shaft is multimass, enter the initial mechanical power Pm0 (pu) and initial generator angle Θe0 (degrees). If the shaft is single mass, enter only initial mechanical power.

Initial mechanical power is automatically updated by the load flow utility of the Powergui block. Initial angle is also computed by the load flow utility and is written in the associated Synchronous Machine block dialog box.

Inputs and Outputs

wref

The speed reference, in pu. It is normally connected to a Constant block with the value set to 1.0 pu.

Pref

The electrical power reference, in pu. It is set to a constant value corresponding to the initial active power drawn from the Synchronous Machine block connected to the Steam Turbine and Governor block.

wm

The generator's speed, in pu. This is one of the signals in the last output of the Synchronous Machine model (internal variables).

d_theta

The generator's power angle deviation. It is also one of the signals in the last output of the Synchronous Machine model (internal variables).

dw_5-2

Output a vector containing the speed deviations, in pu, of masses 5, 4, 3, and 2.

Tr5-2

Output a vector containing the torques, in pu, transmitted by masses 5, 4, 3, and 2.

gate

Gate opening in pu.

Pm

The mechanical power, in pu, that you connect to the first input of a Synchronous Machine block.

Example
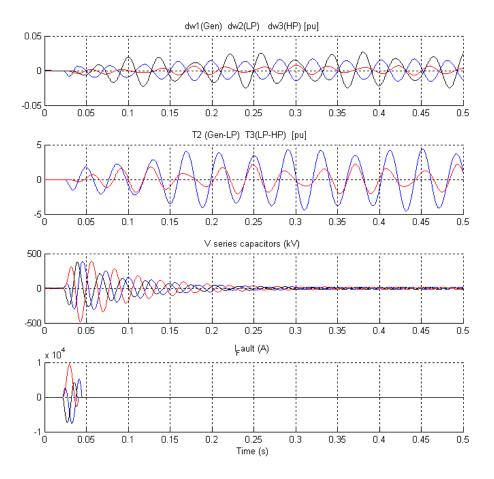
The power_thermal example illustrates the use of the Steam Turbine and Governor block. This system is an IEEE benchmark used to study subsynchronous resonance and particularly torque amplification after a fault on a series-compensated power system [2]. It consists in a single generator connected to an infinite bus via two transmission lines, one of which is series compensated. The subsynchronous mode introduced by the compensation capacitor after a fault has been applied and cleared excites the oscillatory torsional modes of the multimass shaft and the torque amplification phenomenon can be observed. Open the Simulink diagram by typing `power_thermal` at the command line.

This system is slightly different from the one presented in [2]. Since we are using the Synchronous Machine mass as the first mass, we cannot model the exciter's mass as is done in [2]. Therefore, our system has only three masses, representing the generator's rotor (mass #1) and the turbine's low and high pressure stages (masses #2 and #3, respectively).

In order to start the simulation in steady state, you must first initialize the synchronous machine and steam turbine by using the **Machine Initialization** tool of the Powergui. Set the generator as a `PV generator` with zero active power to simulate an initially unloaded generator.

This test is performed without regulators. The machine's excitation voltage is also set to a constant value (1.00406 pu), which is computed by the load flow.

Run the simulation. Once the simulation is completed, observe the mass speed deviations, torques, series capacitor voltages and fault currents.

The peak values of all these signals correspond within 3% to those given in Table 5, case 1A, of [2]. The torque amplification is clearly observed on all masses of the shaft system. The high-pressure turbine (mass #3) transmits a peak torque exceeding 2 pu to the low-pressure turbine (mass #2), while the low-pressure turbine transmits a peak torque exceeding 4 pu to the generator's rotor (mass #1).

References

[1] IEEE committee report, "Dynamic models for steam and hydro turbines in power system studies," *IEEE Transactions on Power Apparatus and Systems*, Vol.PAS-92, No.6, 1973, pp.1904-1915.

[2] IEEE Subsynchronous resonance working group, "Second benchmark model for computer simulation of subsynchronous resonance," *IEEE Transactions on Power Apparatus and Systems*, Vol.PAS-104, No.5, 1985, pp.1057-1066.

See Also
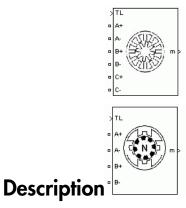
Excitation System, Hydraulic Turbine and Governor, powergui, Synchronous Machine

Stepper Motor

Implement stepper motor model

Library

Fundamental Blocks/Machines

Description
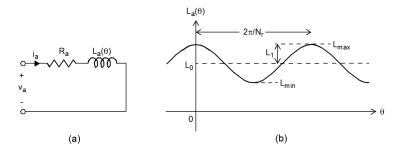
The Stepper Motor (STM) block implements a generic model that represents two most popular families of stepper motors:

- Variable-reluctance stepper motors
- Permanent-magnet or hybrid stepper motors

The Stepper Motor model consists of electrical and mechanical sections. The electrical section is represented by an equivalent circuit, configuration of which depends on the motor type. The equivalent circuits have been built with the supposition that the magnetic circuit is linear (no saturation) and the mutual inductance between phases is negligible. The mechanical section is represented by a state-space model based on inertia moment and viscous friction coefficient.

For a variable-reluctance stepper motor, the equivalent circuit for one phase is shown in the following figure.

(a)   (b)

In this model, R_a and $L_a(\theta)$ represent respectively the resistance and the inductance of phase A winding. The winding inductance varies as a function of the rotor position:
$L_a(\theta) = L_0 + L_1\cos(N_r\theta)$,

where L_0 is the average inductance, L_1 is the maximum inductance variation and N_r is the rotor teeth number.
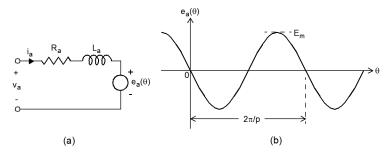
Note that at the reference position ($\theta = 0$), the rotor tooth is fully aligned with A-axis pole so that the A-phase winding inductance is then maximum.

The total electromagnetic torque produced by the motor is the sum of the torques produced by the motor phases:

$$T_e = \sum_{x=1}^{m} 0.5i_x^2 \frac{dL_x}{d\theta},$$

where m is the phase number, i_x is the winding current in phase x and L_x is the inductance function of phase x winding.

For a permanent-magnet (PM) or hybrid stepper motor, the equivalent circuit for one phase is shown in the following figure.

(a)   (b)

In this model, R_a and L_a represent respectively the resistance and inductance of A-phase winding. Due to the large value of the air gap introduced by the magnets, the winding inductance of the permanent-magnet or hybrid stepper motor can be considered to be independent of the rotor position. The voltage source $e_a(\theta)$ represents the motor back EMF (electromotive force) which is a sinusoidal function of the rotor position:

$$e_a(\theta) = -p\psi_m \sin(p\theta)\frac{d\theta}{dt},$$
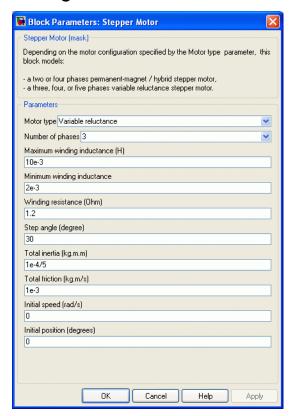
where p is the number of pole pairs and ψ_m is the motor maximum magnetic flux.

Note that at the reference position ($\theta = 0$), the North pole on the rotor is fully aligned with A-axis pole so that the A-phase back EMF is then zero.

The electromagnetic torque produced by a two-phase PM or hybrid stepper motor is equal to the sum of the torque resulting from the interaction of the phase currents and magnetic fluxes created by the magnets and the detent torque, which results from the saliency of the rotor:

$T_e = -p\psi_m i_a \sin(p\theta) - p\psi_m i_b \sin(p\theta - \pi/2) - T_{\mathrm{dm}}\sin(2p\theta).$

Dialog Box and Parameters

Motor type

Select `Variable reluctance` to implement a variable-reluctance stepper motor.

Number of phases

You can select 3, 4 or 5 phases.

Maximum winding inductance

The maximum inductance L_{max} (Henry) of each phase winding.

Minimum winding inductance

The minimum inductance L_{min} (Henry) of each phase winding.

Winding resistance

The resistance R_a (ohm) of each phase winding.

Step angle

The step angle (degrees) of the rotor movement.

Total inertia

The total inertia momentum J (kg.m^2) of the motor and the load.
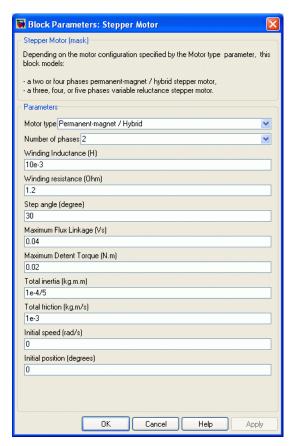
Total friction

The total viscous friction coefficient B (N.m.s) of the motor and the load.

Initial speed

The initial rotation speed ω_0 (rad/s).

Initial position

The initial rotor position Θ_0 (degrees).

Motor type

Select `Permanent-magnet/Hybrid` to implement a permanent-magnet or hybrid stepper motor.

Number of phases

You can select 2 or 4 phases.

Winding inductance

The inductance L_a (Henry) of each phase winding.

Winding resistance

The resistance R_a (ohm) of each phase winding.

Step angle

The step angle (degrees) of the rotor movement.

Maximum flux linkage

The maximum flux linkage ψ_m (V.s) produced by the magnets.

Maximum detent torque

The maximum detent torque T_{dm} (N.m) resulting from the saliency of the rotor.

Total inertia

The total inertia momentum J (kg.m^2) of the motor and the load.

Total friction

The total viscous friction coefficient B (N.m.s) of the motor and the load.

Initial speed

The initial rotation speed ω_0 (rad/s).

Initial position

The initial rotor position Θ_0 (degrees).

Inputs and Outputs

TL

The mechanical load torque (in N.m). TL is positive in motor operation and negative in generator operation.

m

The Simulink output of the block is a vector containing 5 signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Signal	Definition	Units	Symbol
1	Phase voltage	V	V_{ph}
2	Phase current	A	I_{ph}
3	Electromagnetic torque	N.m	T_e
4	Rotor speed	rad/s	w
5	Rotor position	rad	Theta

How to Get Stepper Motor Parameters

The parameters used in the stepper model are usually obtained from the manufacturer data sheets. In the case where the parameters are not available, they can be determined from experimental measurements.

Variable-Reluctance Stepper Motor Parameters

The parameters provided by manufacturer data sheets are usually: number of phases, holding torque, step angle, voltage per phase, current per phase, winding resistance (R_a), maximum inductance (L_{max}), average inductance (L_0), and rotor inertia (J).

Permanent-Magnet/Hybrid Stepper Motor Parameters

The parameters provided by manufacturer data sheets are usually: number of phases, holding torque, step angle, voltage per phase, current per phase, winding resistance (R_a), winding inductance (L_a), and rotor inertia (J).

The maximum detent torque (T_{dm}) is not always specified. This parameter can be assumed to be equal to 1-10% of the maximum holding torque.
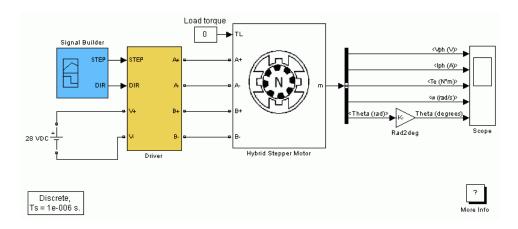
The maximum flux linkage (ψ_m) is not always specified. This parameter can be obtained experimentally by driving the motor to a constant speed N (rpm) and by measuring the maximum open-circuit winding voltage E_m (V).

The parameter ψ_m is then computed by the following relation:

$\psi_m = (30/p\pi)(E_m/N)$,

where p is the number of pole pairs given by $p = 360 / (2m \cdot step)$. Here m = phase number, $step$ = step angle in degrees.
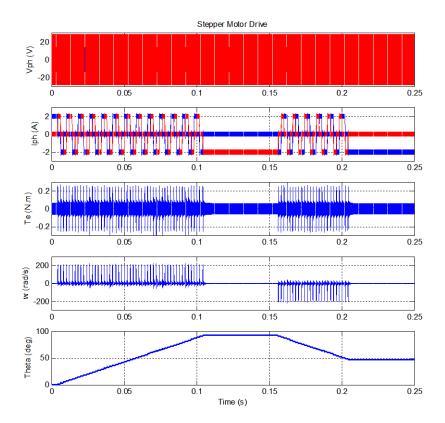
Example

The `power_steppermotor` example illustrates the operation of a stepper motor drive using a two-phase hybrid stepper motor model.
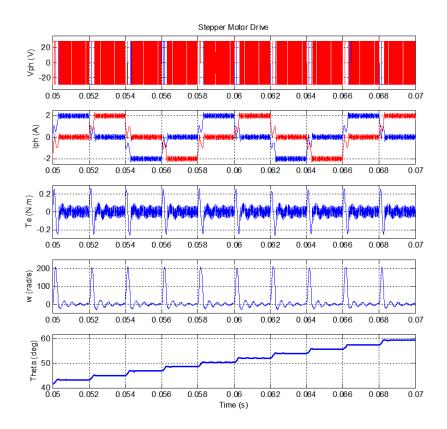
The motor phases are fed by two H-bridge MOSFET PWM converters connected to a 28 V DC voltage source. The motor phase currents are independently controlled by two hysteresis-based controllers which generate the MOSFET drive signals by comparing the measured currents with their references. Square-wave current references are generated using the current amplitude and the step frequency parameters specified in the dialog window. The movement of the stepper drive is controlled by the STEP and DIR signals received from external sources.

The following waveforms are obtained from a simulation of 0.25 sec operation of the stepper motor drive during which the stepper rotates during 0.1 sec in the positive direction, stops for 0.05 sec, rotates in the reverse direction for 0.05 sec and stops.

Detailed waveforms are shown in the following figure.

Stepper Motor Drive

References

[1] T. Kenjo, A. Sugawara, *Stepping Motors and Their Microprocessor Controls*, 2nd Edition, Oxford University Press, Oxford, 2003.

[2] P. Acarnley, *Stepping Motors - A guide to theory and practice*, 4th Edition, The Institution of Electrical Engineers, London, 2002.

Supercapacitor
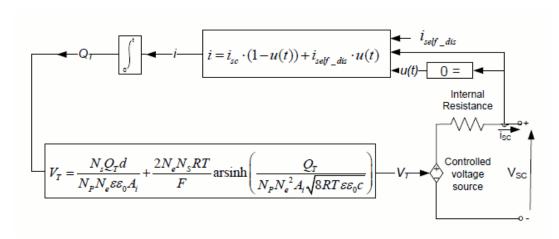
Implement generic supercapacitor model

Library

Electric Drives/Extra Sources

Description

The Supercapacitor block implements a generic model parameterized to represent most popular types of supercapacitors. The figure shows the equivalent circuit of the supercapacitor:

The supercapacitor output voltage is expressed using a Stern equation as:

$$V_{SC} = \frac{N_s Q_T d}{N_p N_e \varepsilon \varepsilon_0 A_i} + \frac{2 N_e N_s RT}{F} \sinh^{-1}\left(\frac{Q_T}{N_p N_e{}^2 A_i \sqrt{8RT \varepsilon \varepsilon_0 c}} \right) - R_{SC} \cdot i_{SC}$$

with

$$Q_T = \int i_{SC}\, dt$$
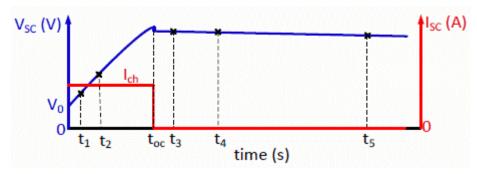
To represent the self-discharge phenomenon, the supercapacitor electric charge is modified as follows (when $i_{SC} = 0$):

$$Q_T = \int i_{self\_dis}\, dt$$

where

$$i_{self\_dis} = \begin{cases} \dfrac{C_T \alpha_1}{1 + s R_{SC} C_T} & \text{if} \quad t - t_{oc} \le t_3 \\[2ex] \dfrac{C_T \alpha_2}{1 + s R_{SC} C_T} & \text{if} \quad t_3 \prec t - t_{oc} \le t_4 \\[2ex] \dfrac{C_T \alpha_3}{1 + s R_{SC} C_T} & \text{if} \quad t - t_{oc} \succ t_4 \end{cases}$$

The constants $\alpha 1$, $\alpha 2$, and $\alpha 3$ are the rates of change of the supercapacitor voltage during time intervals (*toc*, *t3*), (*t3*, *t4*), and (*t4*, *t5*) respectively, as shown in the figure:
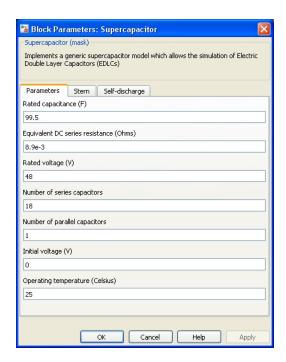
Variable	Description
A_i	Interfacial area between electrodes and electrolyte (m2)
c	Molar concentration (mol m −3) equal to c = 1/(8NAr3)
F	Faraday constant

Variable	Description
i_{sc}	Supercapacitor current (A)
Vsc	Supercapacitor voltage (V)
C_T	Total capacitance (F)
R_{sc}	Total resistance (ohms)
N_e	Number of layers of electrodes
NA	Avogadro constant
Np	Number of parallel supercapacitors
Ns	Number of series supercapacitors
QT	Electric charge (C)
R	Ideal gas constant
d	Molecular radius
T	Operating temperature (K)
ε	Permittivity of material
ε0	Permittivity of free space

Dialog Box and Parameters

Parameters Tab

Rated capacitance (F)

> Specify the nominal capacitance of the supercapacitor, in farad.

Equivalent DC series resistance (Ohms)

> Specify the internal resistance of the supercapacitor, in ohms.

Rated voltage (V)

> Specify the rated voltage of the supercapacitor, in volts. Typical rated voltage is equal to 2.7 V.

Number of series capacitors

> Specify the number of series capacitors to be represented.

Number of parallel capacitors

Specify the number of parallel capacitors to be represented.

Initial voltage (V)
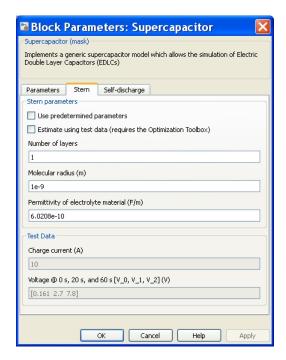
Specify the initial voltage of the supercapacitor, in volts.

Operating temperature (celsius)

Specify the operating temperature of the supercapacitor. The nominal temperature is 25° C.

Stern Tab

Use predetermined parameters

When this check box is selected, loads predetermined parameters of the Stern model into the mask of the block. These parameter values have been determined from experimental tests, and they can be used as default values to represent a common

supercapacitor. Experimental validation of the model has shown a maximum error of 2% for charge and discharge when using the predetermined parameters.

When this check box is selected, the **Number of layers**, **Molecular radius (m)**, **Permittivity of electrolyte material (F/m)**, and **Estimate using test data** parameters appear dimmed.

Estimate using test data

When this check box is selected, you provide test data required for the estimation of the Stern model parameters. This parameter is available only if the Optimization Toolbox™ of MATLAB is installed.

When this check box is selected, the **Charge current (A)** and **Voltage @ 0 s, 20 s, and 60 s [V_0, V_2, V_3] (V)** parameters are enabled. The **Use predetermined parameters**, **Number of layers**, **Molecular radius (m)**, and **Permittivity of electrolyte material (F/m)** parameters appear dimmed.

Number of layers

Specify the number of layers related to the Stern model.

Molecular of radius (m)

Specify the molecular radius related to the Stern model, in meters.

Permittivity of electrolyte material (F/m)

Specify the permittivity of the electrolyte material, in farad/meter.
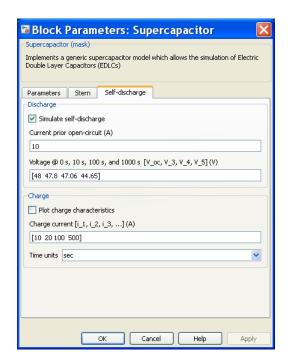
Charge current (A)

Specify the charge current during a constant current charge test, in amperes.

Voltage @ 0 s, 20 s, and 60 s [V_0, V_2, V_3] (V)

Specify the supercapacitor voltage, in volts, at 0 s, 20 s, and 60 s, when the supercapacitor is charged with a constant current equal to the value provided in the **Charge current (A)** parameter.

Self-discharge Tab

Simulate self-discharge

When this check box is selected, you provide test data required for modeling the self-discharge phenomenon.

Current prior open-circuit (A)

Specify the current prior to an open-circuit event, in amperes.

Voltage @ 0 s, 10 s, 100 s, and 1000 s [V_oc, V_3, V_4, V_5] (V)

Specify the supercapacitor voltage, in volts, at 0 s, 10 s, 100 s, and at 1000 s, when the supercapacitor is open-circuit. The corresponding current prior to open-circuit is given in the **Current prior open-circuit (A)** parameter.

Plot charge characteristics

When this check box is selected, the block plots a figure containing the charge curves at the specified charge currents and time units.

Charge current [i_1, i_2, i_3, ...] (A)

Specify the charge currents, in amperes, used to plot the charge characteristics.

Time units

Specify the time units (seconds, minutes, hours) used to plot the charge characteristics.

Inputs and Outputs

m

Outputs a vector containing measurement signals. You can demultiplex these signals using the `Bus Selector` block.

Signal	Definition	Units	Symbol
1	The supercapacitor current	A	`Current`
2	The supercapacitor voltage	V	`Voltage`
3	The state of charge (SOC), between 0 and 100	%	`SOC`

The SOC for a fully charged supercapacitor is 100% and for an empty supercapacitor is 0%. The SOC is calculated as:

$$SOC = \frac{Qinit - \int_0^t i(\tau)\, d\tau}{Q_T} \times 100$$

Model Assumptions

- Internal resistance is assumed constant during the charge and the discharge cycles.
- The model does not take into account temperature effect on the electrolyte material.
- No aging effect is taken into account.
- Charge redistribution is the same for all values of voltage.
- The block does not model cell balancing.
- Current through the supercapacitor is assumed to be continuous.

Example

The parallel_battery_SC_boost_converter example shows a simple hybridization of a supercapacitor with a battery. The supercapacitor is connected to a buck/boost converter and the battery is connected to a boost converter. The DC bus voltage is equal to 42V. The converters are doing power management. The battery power is limited by a rate limiter block, therefore the transient power is supplied to the DC bus by the supercapacitor.

References

[1] Oldham, K. B. "A Gouy-Chapman-Stern model of the double layer at a (metal)/(ionic liquid) interface." *J. Electroanalytical Chem*. Vol. 613, No. 2, 2008, pp. 131–38.

[2] Xu, N., and J. Riley. "Nonlinear analysis of a classical system: The double-layer capacitor." *Electrochemistry Communications*. Vol. 13, No. 10, 2011, pp. 1077–81.

SVPWM Generator (2-Level)

Generate pulses for SVPWM-controlled two-level converter
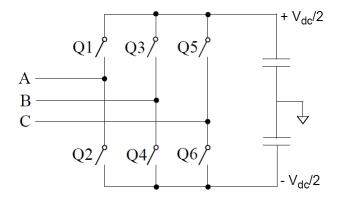
Library

Control and Measurements/Pulse & Signal Generators

Description
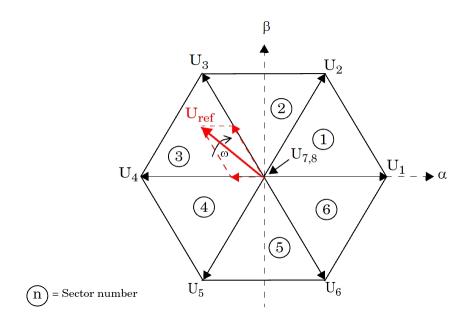
The SVPWM Generator (2-Level) block generates pulses for three-phase two-level DC/AC converters using the space-vector pulse width modulation (SVPWM) technique.

The converter switches are represented by the following equivalent circuit:

As shown in the following figure, the objective of the SVPWM technique is to approximate the reference voltage vector (U_{ref}) instantaneously by combining the switching states corresponding to the basic space vectors.

$\left(\!\!\begin{array}{c} n \end{array}\!\!\right)$ = Sector number

More precisely, for every PWM period, the reference vector U_{ref} is averaged by using its two adjacent space vectors (U_3 and U_4 in the figure) for a certain duration of time and a null vector (U_7 or U_8) for the rest of the period.
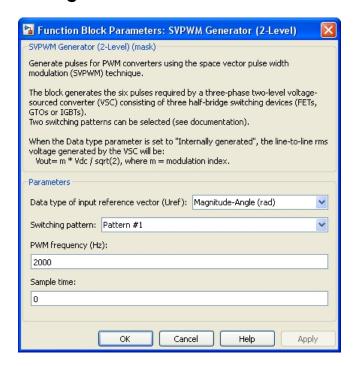
Vector	Q1	Q3	Q5
U_1	1	0	0
U_2	1	1	0
U_3	0	1	0
U_4	0	1	1
U_5	0	0	1
U_6	1	0	1
U_7	0	0	0
U_8	1	1	1

The block implements two symmetrical switching patterns[1]:

Pattern #1: With this pattern, known as Software-Determined, each PWM channel switches twice per every PWM period.

Pattern #2: With this pattern, known as Hardware-Determined, one PWM channel remains constant for the entire PWM period. Consequently, the number of switching times for this pattern is less than pattern #1. As a result, switching losses are reduced with Pattern #2.

Dialog Box and Parameters

Data type of input reference vector (Uref)

Specify the type of reference vector.

When set to Magnitude-Angle (rad), the U_{ref} vector is specified by the following inputs:

$|U|$ Magnitude of Uref (value between 0 and 1)

When set to `alpha-beta components`, the U_{ref} vector is specified by the Uα and Uß inputs.

When set to `Internally generated`, the U_{ref} is no longer an input to the block. It is internally generated in order to control the converter output voltage as specified in the output voltage parameter.

Switching pattern

When set to `Pattern #1`, every device of the converter switches twice per every PWM period.

When set to `Pattern #2`, the status of one of the three arms stays constant (no switching) for the entire PWM period.

PWM frequency (Hz)

Specify the PWM frequency that determines the PWM period.

$PWMperiod = 1 / PWMFrequency$

Output voltage: [Mag (0<m<1), Phase (degrees), Freq (Hz)]

Specify the magnitude, phase, and frequency of the output voltage of the two level converter controlled by the block. The magnitude of the fundamental component of the converter line-to-line output voltage is defined as

$$V_{LLrms} = m \times \frac{V_{dc}}{\sqrt{2}}$$

This parameter is visible only when the **Data type of input reference vector Uref** parameter is set to `Internally generated`.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Inputs and Outputs

Uref

When the **Data type of input reference vector Uref** parameter is set to `Magnitude-Angle (rad)`, the two block inputs are the magnitude and the phase, in radians, of the rotating reference vector U_{ref}.

When the **Data type of input reference vector Uref** parameter is set to `alpha-beta components`, the two block inputs are the alpha-beta components of U_{ref}.

The output contains the six pulse signals to fire the self-commutated devices (Q1 to Q6) of a converter device.

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	No
Dimensionalized	No

Example

The power_SVPWMGenerator2Level model uses two simple circuits to show how the SVPWM Generator (2-Level) works and to compare the two switching pattern options. Run the simulation and open the FFT Analysis tool of the Powergui block to see the harmonics and the THD value of the voltages produced by the two converters.

The model sample time is parameterized by the Ts variable set to a default value of 2e-6 s. Set Ts to 0 in the command window and change the **Simulation type** parameter of the Powergui block to `Continuous` to simulate the model in continuous mode.

References

[1] Yu, Z., *Application Report SPRA524, Space-Vector PWM with TMS320C24x Using H/W & S/W Determined Switching Patterns*, Texas Instruments, 1999.

Surge Arrester

Implement metal-oxide surge arrester

Library

Fundamental Blocks/Elements

Description
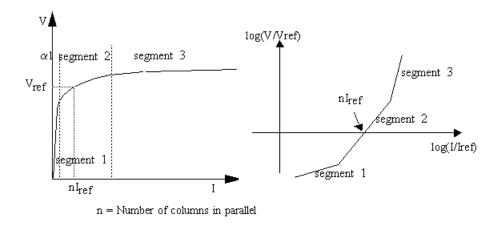
The Surge Arrester block implements a highly nonlinear resistor used to protect power equipment against overvoltages. For applications requiring high power dissipation, several columns of metal-oxide discs are connected in parallel inside the same porcelain housing. The nonlinear V-I characteristic of each column of the surge arrester is modeled by a combination of three exponential functions of the form
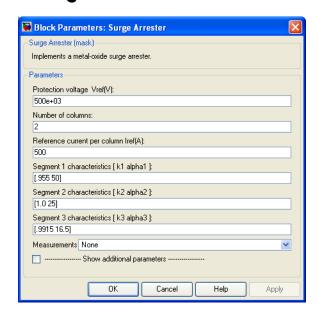
$$\frac{V}{V_{\text{ref}}} = k_i \left(\frac{I}{I_{\text{ref}}} \right)^{1/\alpha_i}.$$

The protection voltage obtained with a single column is specified at a reference current (usually 500 A or 1 kA). Default parameters k and α given in the dialog box fit the average V-I characteristic provided by the main metal-oxide arrester manufacturers and they do not change with the protection voltage. The required protection voltage is obtained by adding discs of zinc oxide in series in each column.

This V-I characteristic is graphically represented as follows (on a linear scale and on a logarithmic scale).

n = Number of columns in parallel

Dialog Box and Parameters

Protection voltage Vref

The protection voltage of the Surge Arrester block, in volts (V).

Number of columns

The number of metal-oxide disc columns. The minimum is one.

Reference current per column Iref

The reference current of one column used to specify the protection voltage, in amperes (A).

Segment 1 characteristics

The k and α parameters of segment 1.

Segment 2 characteristics

The k and α parameters of segment 2.

Segment 3 characteristics

The k and α characteristics of segment 3.

Measurements

Select `Branch voltage` to measure the voltage across the Surge Arrester block terminals.

Select `Branch current` to measure the current flowing through the Surge Arrester block.

Select `Branch voltage and current` to measure the surge arrester voltage and current.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurement is identified by a label followed by the block name.

Measurement	Label
Branch voltage	Ub:
Branch current	Ib:

Limitations

The Surge Arrester block is modeled as a current source driven by the voltage appearing across its terminals. Therefore, it cannot be connected in series with an inductor or another current source. As the Surge Arrester block is highly nonlinear, a stiff integrator algorithm must be used to simulate the circuit. `de23t` with default parameters usually

gives the best simulation speed. For continuous simulation, in order to avoid an algebraic loop, the voltage applied to the nonlinear resistance is filtered by a first-order filter with a time constant of 0.01 microseconds. This very fast time constant does not significantly affect the result accuracy.

When you use the Surge Arrester block in a discrete system, you will get an algebraic loop. This algebraic loop, which is required in most cases to get an accurate solution, tends to slow down the simulation. However, to speed up the simulation, in some circumstances, you can disable the algebraic loop by selecting **Show additional parameters** and then **Break algebraic loop in discrete model**. You should be aware that disabling the algebraic loop introduces a one-simulation-step time delay in the model. This can cause numerical oscillations if the sample time is too large.

Example

The power_surgnetwork example illustrates the use of metal-oxide varistors (MOV) on a 735 kV series-compensated network. Only one phase of the network is represented. The capacitor connected in series with the line is protected by a 30 column arrester. At t = 0.03 seconds, a fault is applied at the load terminals. The current increases in the series capacitor and produces an overvoltage that is limited by the Surge Arrester block. Then the fault is cleared at t = 0.1 seconds.

At fault application, the resulting overvoltage makes the MOV conduct.

See Also
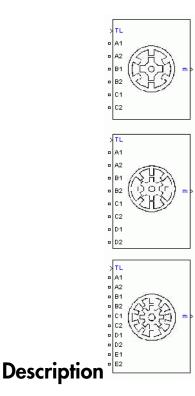
Multimeter

Switched Reluctance Motor
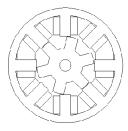
Model the dynamics of switched reluctance motor

Library

Fundamental Blocks/Machines

Description
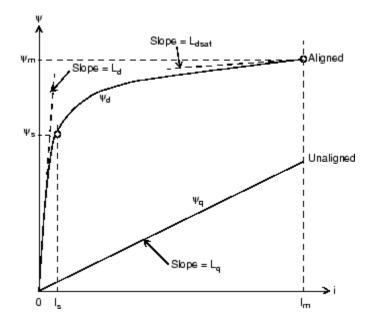
The Switched Reluctance Motor (SRM) block represents three most common switched reluctance motors: three-phase 6/4 SRM, four-phase 8/6 SRM, five-phase 10/8 SRM, as shown in the following figure.
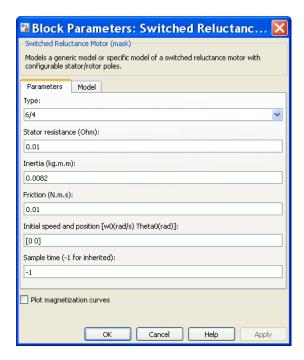
The electric part of the motor is represented by a nonlinear model based on the magnetization characteristic composed of several magnetizing curves and on the torque characteristic computed from the magnetization curves. The mechanic part is represented by a state-space model based on inertia moment and viscous friction coefficient.

To be versatile, two models are implemented for the SRM block: specific and generic models. In the specific SRM model, the magnetization characteristic of the motor is provided in a lookup table. The values are obtained by experimental measurement or calculated by finite-element analysis. In the generic model, the magnetization characteristic is calculated using nonlinear functions and readily available parameters.

Dialog Box and Parameters

Parameters Tab

Type

Specifies a three-phase 6/4 motor, four-phase 8/6 motor, or a five-phase 10/8 motor.

Set to `6/4 (60 kw preset model)`, to `8/6 (75 kw preset model)`, or to `10/8 (10 kw preset model)` to use a predetermined specific model of a switched reluctance motor. When you use these presets, you do not need to specify the parameters in the **Model** tab.

Stator resistance

The resistance Rs (Ω) of each stator phase winding.

Inertia

The inertia momentum J (kg.m^2).

Friction

The friction coefficient B (N.m.s).
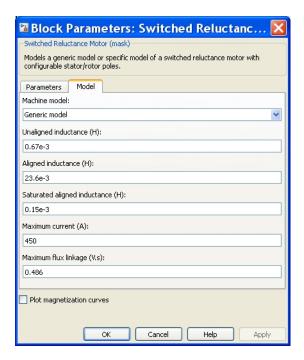
Initial speed and position

The initial rotation speed w0 (rad/s) and initial rotor position Theta0 (rad).

Sample time (−1 for inherited)

Specifies the sample time used by the block. To inherit the sample time specified in the Powergui block, set this parameter to -1.

Model Tab: Generic Model

Machine model

Select `Generic model` or `Specific model`. The **Model** tab is modified accordingly.

Unaligned inductance

The stator inductance when the rotor is in unaligned position L_q (H).

Aligned inductance

The unsaturated stator inductance when the rotor is in aligned position L_d (H).

Saturated aligned inductance

The saturated stator inductance when the rotor is in aligned position L_{dsat} (H).

Maximum current

The stator maximum current I_m (A).

Maximum flux linkage
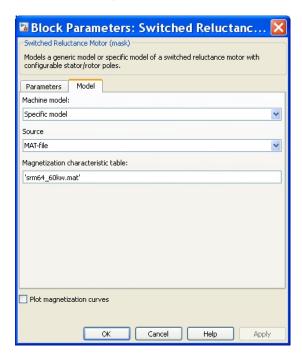
The maximum flux linkage ψ_m (Wb or V.s) corresponding to I_m.

Plot magnetization curves

If selected, the mask plots the magnetization curves corresponding to the lookup table provided. The magnetization curves represent the machine flux linkage versus the stator current with the rotor position as a parameter.

Model Tab: Specific Model

Machine model

Select `Generic model` or `Specific model`. The **Model** tab is modified accordingly.

Source

Select `Dialog` to specify the magnetization characteristic directly in the mask of the block. Select `Mat file` to specify the magnetization characteristic from data in a MAT file.

Magnetization characteristic table

When the **Source** parameter is set to `Dialog`, enter the 2-D lookup table containing the flux linkage as a function of stator current and rotor position.

When the **Source** parameter is set to `MAT-file`, enter the name of the MAT-file that contains the 2-D lookup table flux linkage table, the rotor angle vector, and the stator current vector. The MAT-file must contain these three variable names: FTBL, RotorAngles, and StatorCurrents.

Rotor angle vector

The rotor position Θ (deg) for which the flux linkage is specified. The **Rotor angle vector** parameter is visible only when the **Source** parameter is set to `Dialog`.

Stator current vector

The stator current I_s (A) for which the flux linkage is specified. The **stator current vector** parameter is visible only when the **Source** parameter is set to `Dialog`.

Plot magnetization curves

If selected, the mask plots the magnetization curves corresponding to the lookup table provided. The magnetization curves represent the machine flux linkage versus the stator current with the rotor position as a parameter.

Inputs and Outputs

TL

The block input is the mechanical load torque (in N.m). TL is positive in motor operation and negative in generator operation.

m

The block output m is a vector containing several signals. You can demultiplex these signals by using the Bus Selector block from Simulink library.
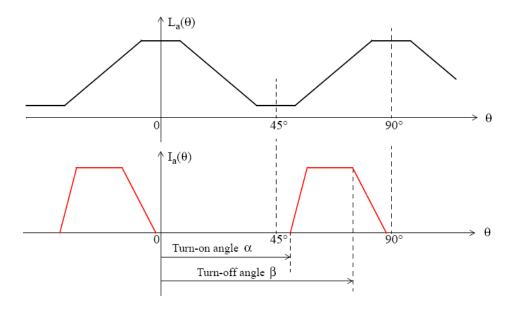
Signal	Definition	Units
V	Stator voltages	V

Signal	Definition	Units
flux	Flux linkage	V.s
I	Stator currents	A
Te	Electromagnetic torque	N.m
w	Rotor speed	rad/s
teta	Rotor position	rad

Example

The `power_SwitchedReluctanceMotor` example illustrates the simulation of the Switched Reluctance Motor.

To develop positive torque, the currents in the phases of a SRM must be to the rotor position. The following figure shows the ideal waveforms (Phase A inductance and current) in a 6/4 SRM. Turn-on and turn-off angles refer to the rotor position where the converter's power switch is turned on and turned off, respectively.

References

[1] T.J.E. Miller, *Switched Reluctance Motors and Their Control*, Clarendon Press, Oxford, 1993.

[2] R. Krishnan, *Switched Reluctance Motor Drives*, CRC Press, 2001.

[3] D.A. Torrey, X.M. Niu, E.J. Unkauf, "Analytical modelling of variable-reluctance machine magnetisation characteristics," IEE Proceedings - Electric Power Applications, Vol. 142, No. 1, January 1995, pp. 14-22.

[4] H. Le-Huy, P. Brunelle, "Design and Implementation of a Switched Reluctance Motor Generic Model for Simulink SimPowerSystems," Electrimacs2005 Conference.

Synchronized 6-Pulse Generator
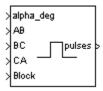
Implement synchronized pulse generator to fire thyristors of six-pulse converter

Library

powerlib_extras/Control Blocks, powerlib_extras/Discrete Control Blocks
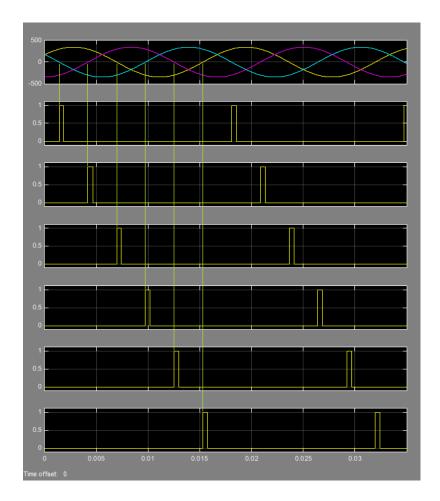
Note: The Pulse & Signal Generators section of the Control and Measurements library contains the Pulse Generator (Thyristor, 6-Pulse) block. This is an improved version of the Synchronized 6-Pulse Generator block. The new block features a mechanism that eliminates duplicate continuous and discrete versions of the same block by basing the block configuration on the simulation mode. If your legacy models contain the Synchronized 6-Pulse Generator block, they will continue to work. However, for best performance, use the Pulse Generator (Thyristor, 6-Pulse) block in your new models.

Description
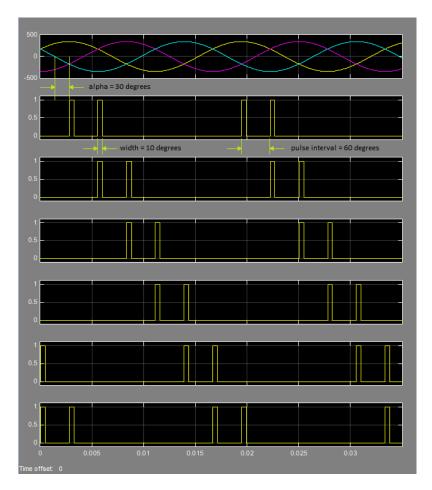
The Synchronized 6-Pulse Generator block can be used to fire the six thyristors of a six-pulse converter. The output of the block is a vector of six pulses individually synchronized on the six thyristor voltages. The pulses are generated alpha degrees after the increasing zero crossings of the thyristor commutation voltages.

The figures below display the synchronization of the six pulses for an alpha angle of 0 degrees. The pulses are generated exactly at the zero crossings of the three line-to-line synchronization voltages.

The Synchronized 6-Pulse Generator block can be configured to work in double-pulsing mode. In this mode two pulses are sent to each thyristor: a first pulse when the alpha angle is reached, then a second pulse 60 degrees later, when the next thyristor is fired.

The figures below display the synchronization of the six pulses for an alpha angle of 30 degrees and with double-pulsing mode. Notice that the pulses are generated 30 degrees after the zero crossings of the line-to-line.
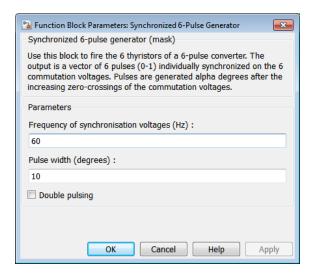
The pulse ordering at the output of the block corresponds to the natural order of commutation of a three-phase thyristor bridge. When you connect the Synchronized 6-Pulse Generator block to the pulses input of the Universal Bridge block (with the thyristors as the power electronic device), the pulses are sent to the thyristors in the following order:

When you build your own three-phase thyristor bridge with single thyristor blocks, you need to connect the pulse signals of the Synchronized 6-Pulse Generator block to the gate inputs of the corresponding thyristors.

Dialog Box and Parameters

Frequency of synchronization voltages

> The frequency, in hertz, of the synchronization voltages. It usually corresponds to the frequency of the network.

Pulse width

> The width of the pulses, in degrees.

Double pulsing

> If selected, the generator sends to each thyristor a first pulse when the alpha angle is reached, and then a second pulse 60 degrees later when the next thyristor in the sequence is fired.

Inputs and Outputs

alpha_deg

Input 1 is the alpha firing signal, in degrees. This input can be connected to a Constant block, or it can be connected to a controller system to control the pulses of the generator.

AB, BC, CA

Inputs 2, 3, and 4 are the phase-to-phase synchronization voltages Vab, Vbc, and Vca. The synchronization voltages should be in phase with the three phase-phase voltages at the converter AC terminals. Synchronization voltages are normally derived at the primary windings of the converter transformer. If the converter is connected to the delta winding of a Wye/Delta transformer, the synchronization voltages should be the phase-to-ground voltages of the primary windings.

Freq

Available only with the discrete version of the Synchronized 6-Pulse Generator. This input should be connected to a Constant block containing the fundamental frequency, in hertz, or to a PLL tracking the frequency of the system.

block
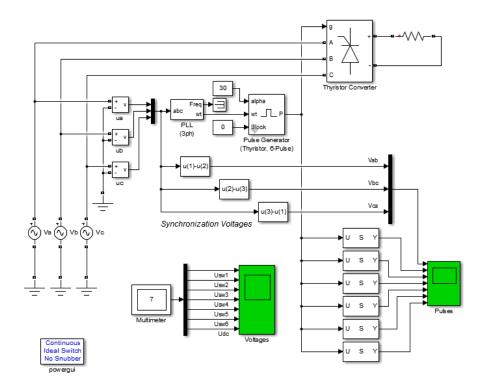
Input 5 allows you to block the operation of the generator. The pulses are disabled when the applied signal is greater than zero.

pulses

The output contains the six pulse signals.

Example
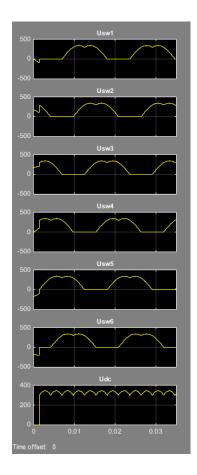
The power_sixpulses example uses a Pulse Generator (Thyristor, 6-Pulse) block (the improved version of the Synchronized 6-Pulse Generator block) to fire the thyristors of a six-pulse thyristor bridge. The bridge is fed by a three-phase voltage source (200 V peak line-to-ground or 245 V RMS line-to-line) and it is connected to a resistive load.

A first simulation is performed with an alpha angle of 0 degrees. Open the Constant block connected at input 1 of the Pulse Generator (Thyristor) block and set its value to 0. Start the simulation. The average voltage is

$$V_{dc} = \frac{3\sqrt{2}}{\pi} E = \frac{3\sqrt{2}}{\pi} 245 = 331 \text{ volts.}$$
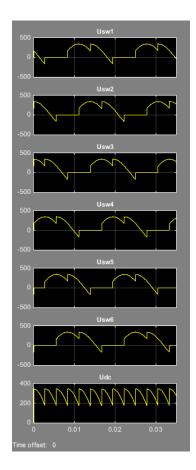
The six thyristor voltages are displayed in the next figure. The resulting DC voltage at the output of the rectifier is also displayed (average value of 331 V).

Now change the value of the alpha angle to 30 degrees and start the simulation. Notice that the waveforms of the thyristor voltages look different from the previous case. The thyristors start conducting 30 degrees after their commutation voltage becomes positive and the resulting DC voltage at the output of the rectifier is lower. Its average value is now

$$V_{dc} = \frac{3\sqrt{2}}{\pi} E \cos \alpha = \frac{3\sqrt{2}}{\pi} 245 \cos(30°) = 286 \text{ volts.}$$

The thyristor voltages and DC voltage for alpha = 30 degrees are

The figures show that the mean value of the DC voltage can be controlled by the alpha angle applied to the Pulse Generator (Thyristor, 6-Pulse) block.

See Also

Pulse Generator (Thyristor) | Synchronized 12-Pulse Generator

Related Examples

- power_hvdc

Synchronized 12-Pulse Generator

Implement synchronized pulse generator to fire thyristors of twelve-pulse converter

Library

powerlib_extras/Control Blocks, powerlib_extras/Discrete Control Blocks

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Note: The Pulse & Signal Generators section of the Control and Measurements library contains the Pulse Generator (Thyristor, 12-Pulse) block. This is an improved version of the Synchronized 12-Pulse Generator block. The new block features a mechanism that eliminates duplicate continuous and discrete versions of the same block by basing the block configuration on the simulation mode. If your legacy models contain the Synchronized 12-Pulse Generator block, they will continue to work. However, for best performance, use the Pulse Generator (Thyristor, 12-Pulse) block in your new models.

Description
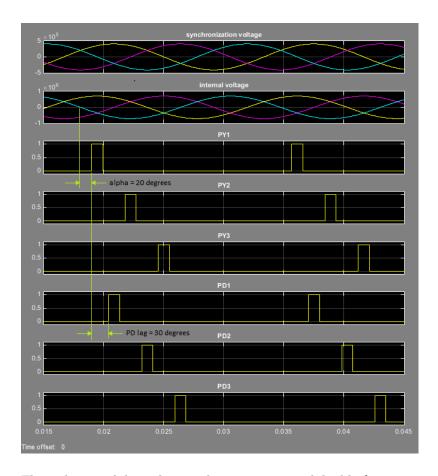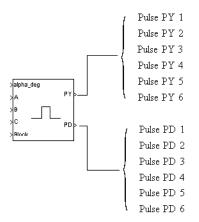
The Synchronized 12-Pulse Generator block generates two vectors of six pulses synchronized on the twelve thyristor commutation voltages. The first set of pulses, denoted PY, is sent to the six-pulse bridge connected to the wye (Y) secondary winding of the Y/Y/Delta converter transformer. The second set of pulses, denoted PD, is sent to the six-pulse bridge connected to the delta secondary winding of the converter transformer.
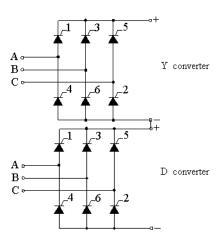
The synchronization voltages provided to the generator are the three phase-to-ground voltages Va, Vb, Vc measured on the primary side (Y) of the Y/Y/Delta converter transformer. The PY pulses are generated alpha degrees after the zero crossing of the phase-to-phase voltages generated from the synchronization voltages. The PD pulses can be set to lead or lag the PY pulses by 30 degrees.

The following figure shows the synchronization and internal phase-to-phase voltages plus the first three pulses of the PY and PD output vectors. In this example the PY pulses are generated 20 degrees (alpha angle) after the zero crossing of the phase-to-phase voltages and the PD pulses lag the PY pulses by 30 degrees.
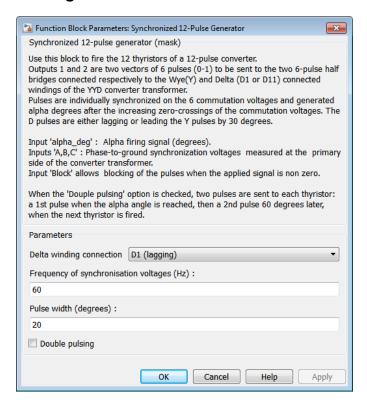
The ordering of the pulses in the two outputs of the block corresponds to the natural order of commutation of a three-phase thyristor bridge. When you connect the Synchronized 12-Pulse Generator block outputs to the pulse inputs of the Universal Bridge blocks (with the thyristor device), the pulses are sent to the thyristors in the following way:

Dialog Box and Parameters

Delta winding connection

If set to `D1 (lagging)`, the PD pulses lag the PY pulses by 30 degrees. If set to `D11 (leading)`, the PD pulses lead the PY pulses by 30 degrees.

Frequency of synchronization voltages

The frequency, in hertz, of the synchronization voltages. It usually corresponds to the frequency of the network.

Pulse width

The width of the pulses, in degrees.

Double pulsing

If selected, the generator sends to each thyristor a first pulse when the alpha angle is reached, and then a second pulse 60 degrees later when the next thyristor in the

sequence is fired. The double pulsing is applied separately on the two vectors of pulses.

Inputs and Outputs

alpha_deg

> Input 1 is the alpha firing signal, in degrees. This input can be connected to a Constant block, or it can be connected to a controller system to control the pulses of the generator.

A, B, C

> Inputs 2, 3, and 4 are the phase-to-ground synchronization voltages Va, Vb, and Vc. The synchronization voltages should be measured at the primary side of the converter transformer.

Freq

> Available only with the discrete version of the Synchronized 6-Pulse Generatorblock. This input should be connected to a Constant block containing the fundamental frequency, in hertz, or to a PLL tracking the frequency of the system.

block

> Input 5 allows you to block the operation of the generator. The pulses are disabled when the applied signal is greater than zero.

PY

> Output 1 contains the six-pulse signals to be sent to the six-pulse thyristor converter connected to the Y secondary winding of the converter transformer.

PD

> Output 2 contains the six-pulse signals to be sent to the six-pulse thyristor converter connected to the Delta (D) secondary winding of the converter transformer.
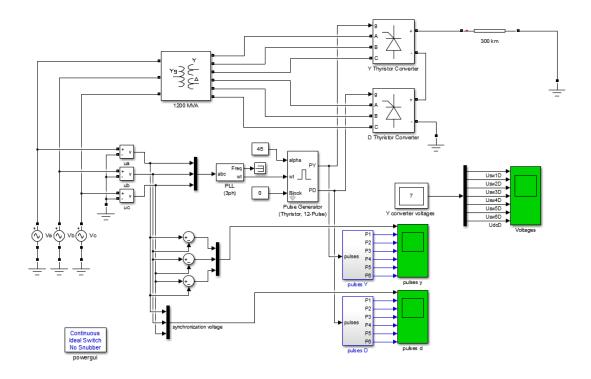
Example

In the power_twelvepulses example a Pulse Generator (Thyristor) block (the improved version of the Synchronized 12-Pulse Generator block) is used to fire the thyristors of a twelve-pulse thyristor bridge built with two six-pulse bridges. The bridge is fed by a three-winding three-phase transformer (500 kV / 200 kV / 200 kV). The Y-connected
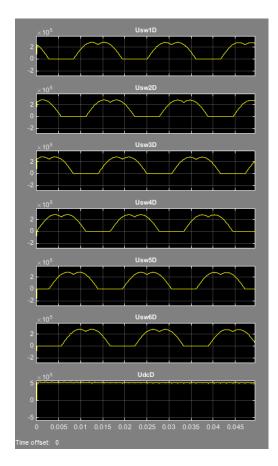
secondary feeds the first six-pulse bridge. The Delta secondary feeds the second bridge. The transformer is assumed to be ideal (no leakage reactances, no resistance). The expected DC voltage obtained for alpha = 0 is

$$V_{dc} = 2\frac{3\sqrt{2}}{\pi} 200 \text{ kV} = 540 \text{ kV}.$$

The two bridge rectifiers are connected in series and a 300 km DC line is connected to the rectifier.

A first simulation is performed with an alpha angle of 0 degrees. Open the Constant block connected at input 1 of the Pulse Generator (Thyristor, 12-Pulse) block and set its value to 0. Start the simulation. The voltages of the thyristors of the D Thyristor Converter block are displayed in the next figure. The resulting DC voltage at the input terminal of the transmission line is also displayed (average value = 540 kV).

Compare the DC voltage generated by the Generator (Thyristor, 12–Pulse) block with the DC voltage you obtained with the Generator (Thyristor, 6–Pulse) block. Notice that the ripple in the DC voltage waveform is lower. The rectifier voltage contains the harmonics 12*k (k = 1,2,...).

See Also
Pulse Generator (Thyristor) | Synchronized 6-Pulse Generator

Related Examples
- power_hvdc12pulse
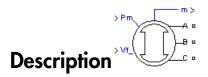
Synchronous Machine

Model the dynamics of three-phase round-rotor or salient-pole synchronous machine

Library

Fundamental Blocks/Machines

Description
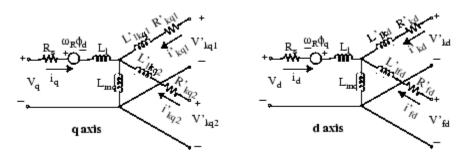
The Synchronous Machine block operates in generator or motor modes. The operating mode is dictated by the sign of the mechanical power (positive for generator mode, negative for motor mode). The electrical part of the machine is represented by a sixth-order state-space model and the mechanical part is the same as in the Simplified Synchronous Machine block.

The model takes into account the dynamics of the stator, field, and damper windings. The equivalent circuit of the model is represented in the rotor reference frame (qd frame). All rotor parameters and electrical quantities are viewed from the stator. They are identified by primed variables. The subscripts used are defined as follows:

- *d,q*: d and q axis quantity
- *R,s*: Rotor and stator quantity
- *l,m*: Leakage and magnetizing inductance
- *f,k*: Field and damper winding quantity

The electrical model of the machine is

q axis

d axis

with the following equations.

$$V_d = R_s i_d + \frac{d}{dt}\varphi_d - \omega_R \varphi_q \qquad \varphi_d = L_d i_d + L_{md}\left(i'_{fd} + i'_{kd}\right)$$

$$V_q = R_s i_q + \frac{d}{dt}\varphi_q + \omega_R \varphi_d \qquad \varphi_q = L_q i_q + L_{mq} i'_{kq}$$

$$V'_{fd} = R'_{fd} i'_{fd} + \frac{d}{dt}\varphi'_{fd} \qquad \varphi'_{fd} = L'_{fd} i'_{fd} + L_{md}\left(i_d + i'_{kd}\right)$$

$$V'_{kd} = R'_{kd} i'_{kd} + \frac{d}{dt}\varphi'_{kd} \qquad \varphi'_{kd} = L'_{kd} i'_{kd} + L_{md}\left(i_d + i'_{fd}\right)$$

$$V'_{kq1} = R'_{kq1} i'_{kq1} + \frac{d}{dt}\varphi'_{kq1} \qquad \varphi'_{kq1} = L'_{kq1} i'_{kq1} + L_{mq} i_q$$

$$V'_{kq2} = R'_{kq2} i'_{kq2} + \frac{d}{dt}\varphi'_{kq2} \qquad \varphi'_{kq2} = L'_{kq2} i'_{kq2} + L_{mq} i_q$$

This model assumes currents flowing into the stator windings. The measured stator currents returned by the Synchronous Machine block (Ia, Ib, Ic, Id, Iq) are the currents flowing out of the machine.

Base Values, Transformation Ratio, and Rotor Parameters Referred to the Stator

The Synchronous Machine SI Fundamental block and the Synchronous Machine pu Fundamental block allow you to specify the fundamental parameters of a synchronous machine. You enter field and damper windings parameters (resistances, leakage inductances, and mutual inductances) in SI (Ω, H) or in pu. When you enter parameters in SI, the RL parameters of field and damper windings are not the actual field RL values of the machine but the RL values referred to the stator.

You can compute base values for stator and rotor windings when the parameters are specified in pu. You can also compute the Stator/Field transformation ratio and the field parameters referred to the stator from the actual field parameters (windings RL values, nominal field voltage, and nominal field current).

Stator Base Values

The stator base values are:

$$V_{sbase} = \frac{V_n \sqrt{2}}{\sqrt{3}}$$ = base stator voltage = peak nominal line-to-neutral voltage (V)

$$I_{sbase} = \frac{P_n \sqrt{2}}{V_n \sqrt{3}}$$ = base stator current (A)

$$Z_{sbase} = \frac{V_{sbase}}{I_{sbase}} = \frac{V_n^{\,2}}{P_n}$$ = base stator impedance (Ω)

$$\omega_{base} = 2\pi f_n$$ = base angular frequency (rad/s)

$$L_{sbase} = \frac{Z_{sbase}}{\omega_{base}}$$ = base stator inductance (H)

with
P_n = three-phase nominal power (VA)
V_n = nominal line-to-line voltage (Vrms)
f_n = nominal frequency (Hz)
i_{fn} = nominal field current producing nominal stator voltage at no load (A)

The stator parameters to specify in the Synchronous Machine SI Fundamental block are:
R_s = stator resistance per phase (Ω)
L_l = stator leakage inductance (H)
L_{md} = direct-axis magnetizing inductance viewed from stator (H)
L_{mq} = quadrature-axis magnetizing inductance viewed from stator (H)
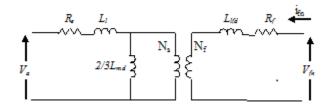
The stator parameters to enter in the Synchronous Machine pu Fundamental block are:

$$R_{s\_pu} = \frac{R_s}{Z_{sbase}} = \text{stator resistance per phase (pu)}$$

$$L_{l\_pu} = \frac{L_l}{L_{sbase}} = \text{stator leakage inductance (pu)}$$

$$L_{md\_pu} = \frac{L_{md}}{L_{sbase}} = \text{direct-axis magnetizing inductance (pu)}$$

$$L_{mq\_pu} = \frac{L_{mq}}{L_{sbase}} = \text{quadrature-axis magnetizing inductance (pu)}$$

Stator/Field Transformation Ratio

The following figure shows one phase of the stator winding coupled with the field winding.

N_s and N_f are, respectively, the equivalent number of sinusoidally distributed turns of the stator winding and of the field winding.
R_s , L_l = stator resistance and leakage inductance.
R_f , L_{lfd} = field resistance and leakage inductance.

When the three stator windings are energized with a three-phase positive-sequence voltage and field winding is open, the stator magnetizing inductance is L_{md}. However, when only one phase is energized and field winding is open, the magnetizing inductance is 2/3 L_{md} as shown in the figure.

At no load, when the field winding is rotating at nominal speed and bears the nominal field DC current i_{fn}, the amplitude of AC voltage (peak value) induced on one phase of stator is V_{sbase}.

The maximum mutual inductance between one stator winding and the field winding is obtained when the two windings are aligned. It is given by:

$$L_{sfd} = \frac{2}{3} L_{md} \frac{N_f}{N_s} = \frac{V_{sbase}}{i_{fn} \, \omega_{base}}$$

from which we deduce the transformation ratio:

$$\frac{N_s}{N_f} = \frac{2}{3} L_{md} \frac{i_{fn} \, \omega_{base}}{V_{sbase}}$$

The transformation ratio can be also expressed as:

$$\frac{N_s}{N_f} = \frac{2}{3} \frac{I_{fbase}}{I_{sbase}}$$

where I_{fbase} is the base field current, which is computed as explained below.

Field Base Values

$$I_{fbase} = i_{fn} L_{md\_pu} \quad = \text{base field current (A)}$$

$$V_{fbase} = \frac{P_n}{I_{fbase}} \quad = \text{base field voltage (V)}$$

$$Z_{fbase} = \frac{V_{fbase}}{I_{fbase}} \quad = \text{base field impedance (Ω)}$$

$$L_{fbase} = \frac{Z_{fbase}}{\omega_{base}} \quad = \text{base field inductance (H)}$$

The actual field parameters are:
R_f = field resistance (Ω)
L_{lfd} = field leakage inductance (H)

The field parameters to enter in the Synchronous Machine pu Fundamental block menu are:

$$R_{f\_pu} = \frac{R_f}{Z_{fbase}} = \text{field resistance (pu)}$$

$$L_{lfd\_pu} = \frac{Ll_{fd}}{L_{fbase}} = \text{field leakage inductance (pu)}$$

Field Voltage, Current and RL Values Referred to the Stator

The field parameters to enter in the Synchronous Machine SI Fundamental block are the field resistance and leakage inductance referred to the stator (R_f', L_{lfd}').

If the nominal field current i_{fn} is known, the transformation ratio N_s/N_f is calculated using the same equation as for the stator/field transformation ratio.

According to Krause [1], the field voltage and current referred to the stator (V_f', I_f') are deduced from actual V_f, I_f values as follows:

$$V_f' = \frac{N_s}{N_f} V_f$$

$$I_f' = \frac{2}{3} \frac{N_f}{N_s} I_f$$

When the actual field resistance R_f and leakage inductances L_{lfd} (seen from the rotor) are known, the values referred to the stator are:

$$R_f' = \frac{3}{2} R_f \left(\frac{N_s}{N_f} \right)^2$$

$$L_{lfd}' = \frac{3}{2} L_{lfd} \left(\frac{N_s}{N_f} \right)^2$$

1-985

When the nominal field current is not known, and if the pu values of field resistance and leakage inductances are known (R_{f_pu}, L_{lfd_pu}), the corresponding SI values referred to the stator are computed as follows:

$$R_f' = R_{f\_pu} \times Z_{sbase}$$

$$L_{lfd}' = L_{lfd\_pu} \times L_{sbase}$$

The same conversions are used for RL parameters of damper windings.

Field Voltage and Current for SI Fundamental Synchronous Machine

When you specify the nominal field current, the signal applied to the Vf input corresponds to the actual field voltage, as in real life. The field current returned by the measurement output also correspond to the actual field current If.

Nominal field voltage producing nominal stator voltage at no load is given by:

$$V_{fn} = R_f \times i_{fn}$$

When you do not specify the nominal field current, the signal applied to the Vf input corresponds to the actual field voltage referred to the stator. In this case, the nominal field voltage referred to the stator producing nominal stator voltage at no load is:

$$V_{fn}' = \frac{R_{f\_pu}}{L_{md\_pu}} V_{sbase} = \frac{R_f'}{L_{md}\,\omega_{base}} V_{sbase}$$

The field current returned by the measurement output is the field current referred to the stator. The nominal field current referred to the stator is:

$$I_{fn}' = \frac{I_{sbase}}{L_{md\_pu}} = \frac{I_{sbase}}{I_{fbase}} i_{fn}$$

Field Voltage and Current for PU Fundamental Synchronous Machine
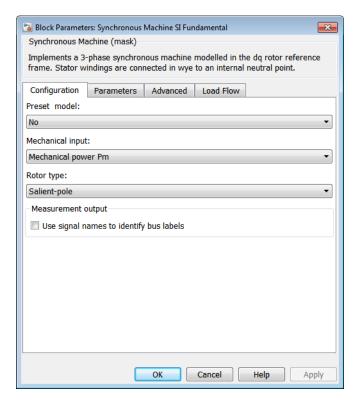
The voltage applied at the Vf input of the Synchronous Machine pu Fundamental block is normalized with respect to nominal field voltage so that a 1pu input produces a 1 pu

stator voltage at no load. The If current returned by the measurement output of the block is also normalized with respect to nominal field current so that a 1pu input produces If = 1pu.

Dialog Box and Parameters

In the Fundamental Blocks (powerlib) library you can choose between three Synchronous Machine blocks to specify the parameters of the model. They simulate exactly the same synchronous machine model; the only difference is the way that you enter the parameter units in the **Parameters** tab.

Configuration Tab

Preset model

Provides a set of predetermined electrical and mechanical parameters for various synchronous machine ratings of power (kVA), phase-to-phase voltage (V), frequency (Hz), and rated speed (rpm).

Select one of the preset models to load the corresponding electrical and mechanical parameters in the entries of the dialog box. Select No if you do not want to use a preset model, or if you want to modify some of the parameters of a preset model, as described below.

When you select a preset model, the electrical and mechanical parameters in the **Parameters** tab of the dialog box become nonmodifiable (unavailable). To start from a given preset model and then modify machine parameters, do the following:

1 Select the preset model that you want to initialize the parameters.

2 Change the **Preset model** parameter value to No. This action does not change the machine parameters. By doing so, you just break the connection with the particular preset model.

3 Modify the machine parameters as you want, then click **Apply**.

Mechanical input

Allows you to select the mechanical power applied to the shaft or the rotor speed as a Simulink input of the block, or to represent the machine shaft by a Simscape rotational mechanical port.

Select **Mechanical power Pm** to specify a mechanical power input, in W or in pu, and change labeling of the block input to Pm. The machine speed is determined by the machine Inertia J (or inertia constant H for the pu machine) and by the difference between the mechanical torque Tm, resulting from the applied mechanical power Pm, and the internal electromagnetic torque Te. The sign convention for the mechanical power is when the speed is positive, a positive mechanical power signal indicates generator mode and a negative signal indicates motor mode.

Select **Speed w** to specify a speed input, in rad/s or in pu, and change labeling of the block input to w. The machine speed is imposed and the mechanical part of the model (inertia constant H) is ignored. Using the speed as the mechanical input allows modeling a mechanical coupling between two machines.

The next figure indicates how to model a stiff shaft interconnection in a motor-generator set, where both machines are synchronous machines.
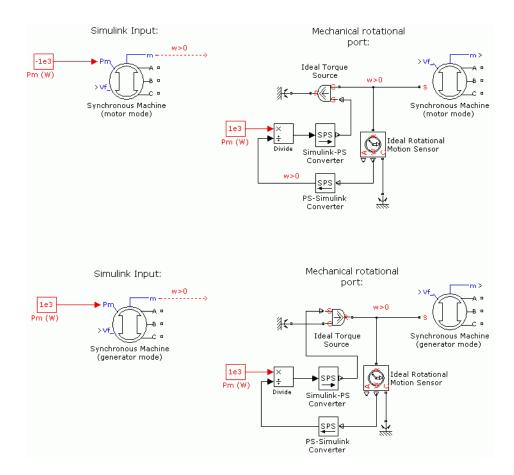
The speed output of machine 1 (motor) is connected to the speed input of machine 2 (generator). In this figure friction torque is ignored in machine 2. Therefore, its

electromagnetic torque output Te corresponds to the mechanical torque Tm applied to the shaft of machine 1. The corresponding mechanical input power of machine 1 is computed as Pm = Tm*w.The Kw factor takes into account speed units of both machines (pu or rad/s) and gear box ratio w2/w1. The KT factor takes into account torque units of both machines (pu or N.m) and machine ratings. Also, as the inertia J2 is ignored in machine 2, J2 referred to machine 1 speed must be added to machine 1 inertia J1.

Select **Mechanical rotational port** to add to the block a Simscape mechanical rotational port that allows connection of the machine shaft with another machine shaft or with other Simscape blocks having mechanical rotational ports. The Simulink input representing the mechanical power `Pm` or the speed `w` of the machine is then removed from the block.

The next figure indicates how to connect an Ideal Torque Source block from the Simscape library to the machine shaft to represent the machine in motor mode, or in generator mode, when the rotor speed is positive.
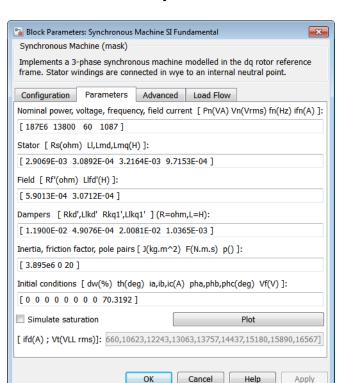
Rotor type

Specify rotor type: `Salient-pole` or `Round` (cylindrical). This choice affects the number of rotor circuits in the q-axis (damper windings).

Use signal names to identify bus labels

When this check box is selected, the measurement output uses the signal names to identify the bus labels. Select this option for applications that require bus signal labels to have only alphanumeric characters.

When this check box is cleared, the measurement output uses the signal definition to identify the bus labels. The labels contain nonalphanumeric characters that are incompatible with some Simulink applications.

Parameters Tab for Synchronous Machine SI Fundamental

Nominal power, voltage, frequency, field current

The total three-phase apparent power Pn (VA), RMS line-to-line voltage Vn (V), frequency fn (Hz), and field current ifn (A).

The nominal field current is the current that produces nominal terminal voltage under no-load conditions. This model was developed with all quantities viewed from the stator, as explained in Krause [1]. The nominal field current makes it possible to compute the transformation ratio of the machine, which allows you to apply the field voltage viewed from the rotor, as in real life. It also allows the field current, which is a variable in the output vector of the model, to be viewed from the rotor.

If the value of the nominal field current is not known, you must enter 0 or leave it blank. Since the transformation ratio cannot be determined in this case, you have

to apply the field voltage as viewed from the stator. The field current in the output vector is also viewed from the stator.

Stator

The resistance Rs (Ω), leakage inductance Lls (H), and d-axis and q-axis magnetizing inductances Lmd (H) and Lmq (H).

Field

The field resistance Rf' (Ω) and leakage inductance Llfd' (H), both referred to the stator.

Dampers

The d-axis resistance Rkd' (Ω) and leakage inductance Llkd' (H), the q-axis resistance Rkq1' (Ω) and leakage inductance Llkq1' (H), and (only if round rotor) the q-axis resistance Rkq2' (Ω) and leakage inductance Llkq2' (H). All of these values are referred to the stator.

Inertia, friction factor, pole pairs

The inertia coefficient J (kg.m^2), friction factor F (N.m.s), and the number of pole pairs p. The friction torque Tf is proportional to the rotor speed ω (Tf = F.ω. Tf is expressed in N.m, F in N.m.s, and ω in rad/s).

Initial conditions

The initial speed deviation Δω (% of nominal speed), electrical angle of the rotor Θe (degrees), line current magnitudes ia, ib, ic (A) and phase angles pha, phb, phc (degrees), and the initial field voltage Vf (V). You can compute these values automatically by using the Load Flow tool or the Machine Initialization tool of the Powergui block.

You can specify the initial field voltage in one of two ways. If you know the nominal field current (first line, last parameter), in the dialog box, enter the initial field voltage in volts DC referred to the rotor. Otherwise, enter a zero as the nominal field current, and specify the initial field voltage in volts DC referred to the stator. You can determine the nominal field voltage viewed from the stator by selecting the **Display Vfd which produces a nominal Vt** check box on the **Advanced** tab.

Simulate saturation

Specifies whether magnetic saturation of the rotor and stator iron is to be simulated or not.

[ifd; Vt]
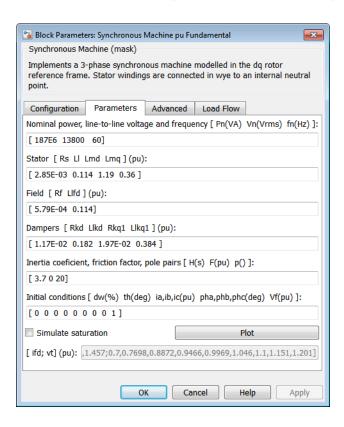
The no-load saturation curve parameters. Magnetic saturation of the stator and rotor iron is modeled by a piecewise linear relationship specifying points on the no-load

saturation curve. The first row of this matrix contains the values of field currents. The second row contains values of corresponding terminal voltages. The first point (first column of the matrix) must be different from [0,0]. This point corresponds to the point where the effect of saturation begins.

You must select the **Simulate saturation** check box to simulate saturation. Selecting this check box allows you to enter the matrix of parameters for simulating the saturation. If you do not want to model saturation in your simulation, do not select the **Simulate saturation** check box. In this case, the relationship between the ifd and Vt obtained is linear (no saturation).

Click **Plot** to view the no-load saturation curve.

Parameters Tab for Synchronous Machine pu Fundamental

Nominal power, line-to-line voltage, and frequency

Total three-phase apparent power (VA), RMS line-to-line voltage (V), frequency (Hz), and field current (A).

This line is identical to the first line of the fundamental parameters in SI dialog box, except that you do not specify a nominal field current. This value is not required here because we do not need the transformation ratio. Since rotor quantities are viewed from the stator, they are converted to pu using the stator base quantities derived from the preceding three nominal parameters.

Stator; Field; Dampers

Contain exactly the same parameters as in the previous dialog box, but they are expressed here in pu instead of SI units.
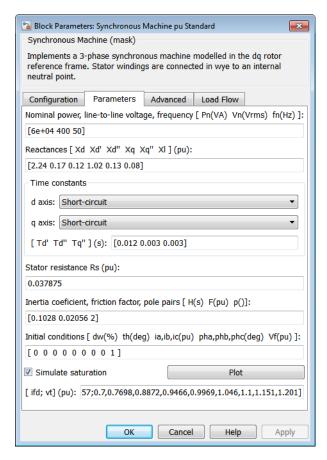
Inertia coefficient, friction factor, pole pairs

The inertia constant H (s), where H is the ratio of energy stored in the rotor at nominal speed over the nominal power of the machine, the friction factor F (pu torque/pu speed), and the number of pole pairs p. The friction torque Tf is proportional to the rotor speed ω (Tf=F.ω, where all quantities are expressed in pu).

Initial conditions; Simulate saturation; Saturation parameters

The same initial conditions and saturation parameters as in the SI units dialog box, but all values are expressed in pu instead of SI units. For saturation, the nominal field current and nominal RMS line-to-line voltage are the base values for the field current and terminal voltage, respectively.

Parameters Tab for Synchronous Machine pu Standard

Nominal power, line-to-line voltage, and frequency

The same parameters as in the pu Fundamental dialog box.

Reactances

The d-axis synchronous reactance Xd, transient reactance Xd', and subtransient reactance Xd", the q-axis synchronous reactance Xq, transient reactance Xq' (only if round rotor), and subtransient reactance Xq", and finally the leakage reactance Xl (all in pu).

d-axis time constants; q-axis time constant(s)

Specify the time constants you supply for each axis: either open-circuit or short-circuit.

Time constants

The d-axis and q-axis time constants (all in s). These values must be consistent with choices made on the two previous lines: d-axis transient open-circuit (Tdo') or short-circuit (Td') time constant, d-axis subtransient open-circuit (Tdo") or short-circuit (Td") time constant, q-axis transient open-circuit (Tqo') or short-circuit (Tq') time constant (only if round rotor), q-axis subtransient open-circuit (Tqo") or short-circuit (Tq") time constant.
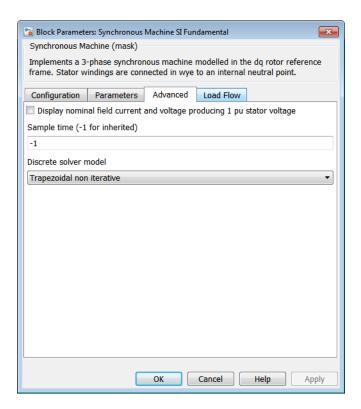
Stator resistance

The stator resistance Rs (pu).

Inertia coefficient, friction factor, pole pairs; Initial conditions; Simulate saturation; Saturation parameters

The same parameters as in the pu Fundamental dialog box.
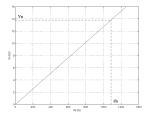
Advanced Tab

Display nominal field current and voltage producing 1 pu stator voltage
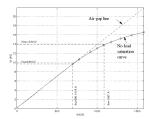
Select to determine the nominal field current and voltage viewed from the stator. This parameter is visible only for the Synchronous Machine SI Fundamental block.

As an example, without saturation, a typical curve might be as in the following figure. ifn is 1087 A and Vn is 13800 V RMS line-to-line, which is also 11268 V peak line-to-neutral.

Saturation is modeled as a piecewise linear saturation curve by using two look-up tables implementing variations of Lmd and Lmq magnetizing inductances.

The next figure illustrates the good fit graphically (the diamonds are the actual points entered in the dialog box).

In this particular case, the following values are used:

ifn	1087 A
ifd	[695.64, 774.7, 917.5, 1001.6, 1082.2, 1175.9, 1293.6, 1430.2, 1583.7] A
Vt	[9660, 10623, 12243, 13063, 13757, 14437, 15180, 15890, 16567] V

Sample time (−1 for inherited)

Specifies the sample time used by the block. To inherit the sample time specified in the Powergui block, set this parameter to `-1`.

Discrete solver model
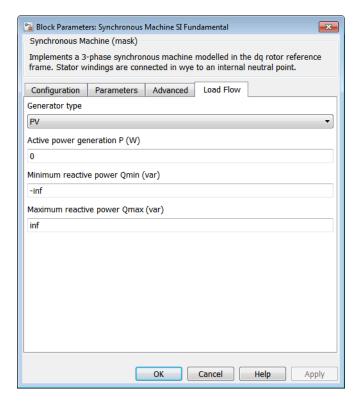
Specifies the integration method used by the block when the **Solver type** parameter of the Powergui block is set to `Discrete`. The choices are: `Trapezoidal non iterative`, `Trapezoidal iterative (alg. loop)`, and `Forward Euler`.

For more info on what method to use in your application, see Simulating Discretized Electrical Systems.

Load Flow Tab

The load flow parameters are used to define block parameters for use with the Load Flow tool of the Powergui block. These load flow parameters are used for model initialization only. They have no impact on the block model and on the simulation performance.

The configuration of the **Load Flow** tab depends on the option selected for the **Generator type** parameter.

Generator type

> Specify the generator type of the machine.

> Select `swing` to implement a generator controlling magnitude and phase angle of its terminal voltage. The reference voltage magnitude and angle are specified by the **Swing bus or PV bus voltage** and **Swing bus voltage angle** parameters of the Load Flow Bus block connected to the machine terminals.

Select PV to implement a generator controlling its output active power P and voltage magnitude V. P is specified by the **Active power generation P** parameter of the block. V is specified by the **Swing bus or PV bus voltage** parameter of the Load Flow Bus block connected to the machine terminals. You can control the minimum and maximum reactive power generated by the block by using the **Minimum reactive power Qmin** and **Maximum reactive power Qmax** parameters.

Select PQ to implement a generator controlling its output active power P and reactive power Q. P and Q are specified by the **Active power generation P** and **Reactive power generation Q** parameters of the block, respectively.

Active power generation P

Specify the active power that you want generated by the machine, in watts. When the machine operates in motor mode, you specify a negative value. This parameter is available if you specify **Generator type** as PV or PQ.

Reactive power generation Q

Specify the reactive power that you want generated by the machine, in vars. A negative value indicates that the reactive power is absorbed by the machine. This parameter is available only if you specify **Generator type** as PQ.

Minimum reactive power Qmin

This parameter is available only if you specify **Generator type** as PV. Indicates the minimum reactive power that can be generated by the machine while keeping the terminal voltage at its reference value. This reference voltage is specified by the **Swing bus or PV bus voltage** parameter of the Load Flow Bus block connected to the machine terminals. The default value is -inf, which means that there is no lower limit on the reactive power output.

Maximum reactive power Qmax

This parameter is available only if you specify **Generator type** as PV. Indicates the maximum reactive power that can be generated by the machine while keeping the terminal voltage at its reference value. This reference voltage is specified by the **Swing bus or PV bus voltage** parameter of the Load Flow Bus block connected to the machine terminals. The default value is inf, which means that there is no upper limit on the reactive power output.

Inputs and Outputs

The units of inputs and outputs vary according to which dialog box you use to enter the block parameters. If the fundamental parameters in SI units is used, the inputs and

outputs are in SI units (except for dw in the vector of internal variables, which is always in pu, and angle Θ, which is always in rad). Otherwise, the inputs and outputs are in pu.

Pm

> The first Simulink input is the mechanical power at the machine's shaft, in Watts or pu. In generating mode, this input can be a positive constant or function or the output of a prime mover block (see the Hydraulic Turbine and Governor or Steam Turbine and Governor blocks). In motoring mode, this input is usually a negative constant or function.

w

> The alternative block input instead of Pm (depending on the value of the **Mechanical input** parameter) is the machine speed, in rad/s.

Vf

> The second Simulink input of the block is the field voltage. This voltage can be supplied by a voltage regulator in generator mode (see the Excitation System block). It is usually a constant in motor mode.

> If you use the model in SI fundamental units, the field voltage Vf must be entered in volts DC if nominal field current Ifn is specified, or in volts referred to stator if Ifn is not specified. To obtain the Vfd producing nominal voltage, select the **Display nominal field current and voltage producing 1 pu stator voltage** check box in the **Advanced** tab. If you use the model in pu Standard or in pu Fundamental units, Vf must be entered in pu (1 pu of field voltage producing 1 pu of terminal voltage at no load).

m

> The Simulink output of the block is a vector containing measurement signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library. Depending on the type of mask that you use, the units are in SI or in pu.

Name	Definition	Units
ias	Stator current is_a	A or pu
ibs	Stator current is_b	A or pu
ics	Stator current is_c	A or pu
iq	Stator current iq	A or pu
id	Stator current id	A or pu

Name	Definition	Units
ifd	Field current ifd	A or pu
ikq	Damper winding current ikq1	A or pu
Ikq2	Damper winding current ikq2	A or pu
ikd	Damper winding current ikd	A or pu
phimq	Mutual flux phimq	V.s or pu
phimd	Mutual flux phimd	V.s or pu
vq	Stator voltage vq	V or pu
vd	Stator voltage vd	V or pu
lmq	Lmq saturated inductance	H or pu
lmd	Lmd saturated inductance	H or pu
dtheta	Rotor angle deviation d_theta	rad
w	Rotor speed wm	rad/s
Pe	Electrical power Pe	VA or pu
dw	Rotor speed deviation dw	rad/s
theta	Rotor mechanical angle theta	Degree
Te	Electromagnetic torque Te	N.m or pu
delta	Load angle delta	rad
Pe0	Output active power Peo	VA or pu
Qe0	Output reactive power Qeo	VAR or pu

Limitations

In Discrete systems, when you use Synchronous Machine blocks discretized with the trapezoidal non iterative solver or the forward Euler solver, you might have to use a small parasitic resistive load, connected at the machine terminals, to avoid numerical oscillations. Large sample times require larger loads. The minimum resistive load is proportional to the sample time. As a rule of thumb, remember that with a 25 µs time step on a 60 Hz system, the minimum load is approximately 2.5% of the machine nominal power. For example, a 200 MVA synchronous machine in a power system discretized with a 50 µs sample time requires approximately 5% of resistive load or 10 MW. If the sample time is reduced to 20 µs, a resistive load of 4 MW should be sufficient.

However, if you discretize the Synchronous Machine block using the trapezoidal iterative (alg. loop) solver, you can use a negligible parasitic load (below 0.1% of nominal power) while preserving numerical stability. This iterative model producing an algebraic loop results in slower simulation speed.

Example 1

The power_SM_Fundamental example shows the use of the Synchronous Machine SI Fundamental block and the Synchronous Machine pu Fundamental block to model a 555 MVA, 24 kV, 60 Hz, 3600 rpm synchronous generator. It shows how to specify SI and pu parameters. It also explains how to compute field and damper rotor winding parameters that are referred to the stator. In addition to the field winding, the round rotor of this machine has three damper windings: one damper in the direct axis and two dampers in the quadrature axis.

Three circuits simulate the same synchronous machine:

- Circuit 1: Fundamental parameters are specified in SI. The nominal field current is specified (ifn = 1300 A).
- Circuit 2: Fundamental parameters are specified in SI. The nominal field current is not specified (ifn = 0).
- Circuit 3: Fundamental parameters are specified in pu.

Machine parameters are taken from an example in Kundur [3].

Look at the **Model Properties/PreLoad Fcn** callback section of the model to see machine specifications as well as the computation of stator and field bases, RL rotor parameters referred to the stator, transformation ratio, and nominal field voltage and current.

The machines initially operate in steady state at virtually no load (load = 0. 1 % of nominal power) with constant field voltage and mechanical power. A phase-to-phase 6-cycle fault is applied at t = 0.1 sec. The Scope shows the comparison between line-to-line AB voltage, phase A stator current, and field current of the three machines.

To simulate the discrete model, select **Discrete** simulation type in the **Configuration parameters** of the Powergui block. The model is discretized with a sample time Ts = 50 µs. To obtain a stable model with such a small load (0. 1 % of nominal power), select the **Trapezoidal iterative (alg. Loop)** discrete solver in the **Advanced** tab of each Synchronous Machine block.

Example 2

The power_syncmachine example illustrates the use of the Synchronous Machine block in motor mode. The simulated system consists of an industrial grade synchronous motor (150 HP (112 kVA), 762 V) connected to a network with a 10 MVA short-circuit level. The machine is initialized for an output electrical power of −50 kW (negative value for motor mode), corresponding to a mechanical power of −48.9 kW. The corresponding values of mechanical power and field voltage are specified by the Pm Step block and in the Vf Constant block. The Pm Step block applies a sudden increase of mechanical power from −48.9 kW to −60 kW at time t = 0.1 s.

Run the simulation.

After the load has increased from 48.9 kW to 60 kW at t = 0.1 s, the machine speed oscillates before stabilizing to 1800 rpm. The load angle (angle between terminal voltage and internal voltage) increases from −21 degrees to −53 degrees.

References

[1] Krause, P.C., *Analysis of Electric Machinery*, McGraw-Hill, 1986, Section 12.5.

[2] Kamwa, I., et al., "Experience with Computer-Aided Graphical Analysis of Sudden-Short-Circuit Oscillograms of Large Synchronous Machines," *IEEE Transactions on Energy Conversion*, Vol. 10, No. 3, September 1995.

[3] Kundur, P., *Power System Stability and Control*, McGraw-Hill, 1994.

See Also

Excitation System, Hydraulic Turbine and Governor, powergui, Simplified Synchronous Machine, Steam Turbine and Governor

THD

Compute total harmonic distortion (THD) of signal

Library

Control and Measurements/Measurements

Description

The THD block computes the total harmonic distortion (THD) of a periodic distorted signal. The signal can be a measured voltage or current.

The THD is defined as the root mean square (RMS) value of the total harmonics of the signal, divided by the RMS value of its fundamental signal. For example, for currents, the THD is defined as
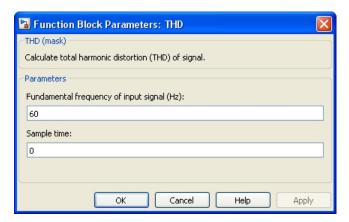
$$\text{total harmonic distortion (THD)} = \frac{I_H}{I_F}$$

$$I_H = \sqrt{I_2^2 + I_3^2 + \ldots + I_n^2} \quad I_n : \text{RMS value of the harmonic n}$$

$$I_F : \text{RMS value of the fundamental current}$$

The THD has a null value for a pure sinusoidal voltage or current.

Dialog Box and Parameters

Fundamental frequency of input signal (Hz)

Specify the frequency, in hertz, of the fundamental signal.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	Yes, of the parameters
Dimensionalized	Yes

Example

The power_RMS_THD model uses a THD block to compute the THD of a 60 Hz signal with second harmonic and a DC bias.
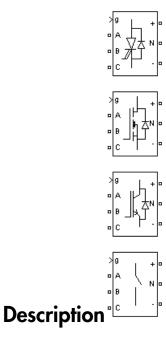
The model sample time is parameterized by the Ts variable set to a default value of 50e-6 s. Set Ts to 0 in the command window to simulate the model in continuous mode.

Three-Level Bridge
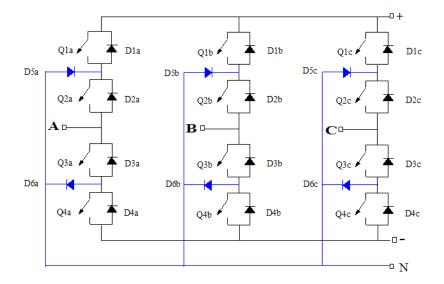
Implement three-level neutral point clamped (NPC) power converter with selectable topologies and power switching devices

Library

Fundamental Blocks/Power Electronics

Description
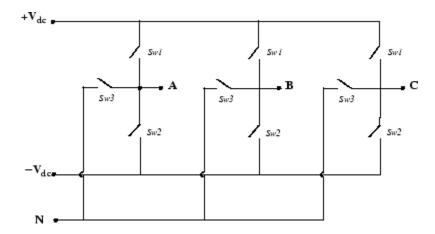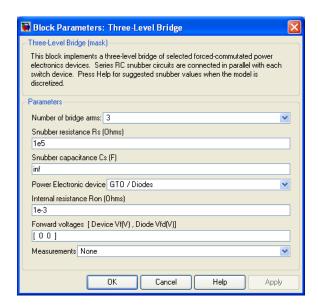
The Three-Level Bridge block implements a three-level power converter that consists of one, two, or three arms of power switching devices. Each arm consists of four switching devices along with their antiparallel diodes and two neutral clamping diodes as shown in the figure below.

The type of power switching device (IGBT, GTO, MOSFET, or ideal switch) and the number of arms (one, two, or three) are selectable from the dialog box. When the ideal switch is used as the switching device, the Three-Level Bridge block implements an ideal switch bridge having a three-level topology as shown in the following figure.

Dialog Box and Parameters

Number of bridge arms

Determine the bridge topology: one, two, or three arms.

Snubber resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to `inf` to eliminate the snubbers from the model.

Snubber capacitance Cs

The snubber capacitance, in farads (F). Set the **Snubber capacitance Cs** parameter to `0` to eliminate the snubbers, or to `inf` to get a resistive snubber.

When you are you using a continuous solver you can completely eliminate snubbers, if you select **Enable use of ideal switching devices** in the Configure parameters section of the Powergui block dialog box. To disable snubbers in all power electronic devices select **Disable snubbers in switching devices**.

When your system is discretized, you can simulate power electronic devices with virtually no snubbers by specifying purely resistive snubbers with a very large resistance, thus producing negligible leakage currents. The bridge operates

satisfactorily with purely resistive snubbers if you select the Tustin/Backward Euler (TBE) discretization method (default solver in the Configure parameters section of the Powergui block dialog box).

If you are using the Tustin solver you need to specify Rs and Cs snubber values to avoid numerical oscillations when the firing pulses are blocked (bridge operating as a rectifier). In this condition, you must use appropriate values of Rs and Cs. You can use the following formulas to compute approximate values of Rs and Cs:

$$Rs > 2\frac{Ts}{Cs}$$

$$Cs < \frac{Pn}{1000(2\pi f)Vn^2},$$

where
Pn = nominal power of single- or three-phase converter (VA)
Vn = nominal line-to-line AC voltage (Vrms)
f = fundamental frequency (Hz)
Ts = sample time (s)

These *Rs* and *Cs* values are derived from the following two criteria:

- The snubber leakage current at fundamental frequency is less than 0.1% of nominal current when power electronic devices are not conducting.
- The RC time constant of snubbers is higher than two times the sample time Ts.

Note that the Rs and Cs values that guarantee numerical stability of the discretized bridge can be different from actual values used in the physical circuit.

Power electronic device

Select the type of power electronic device to use in the bridge.

Internal resistance Ron

Internal resistance of the selected devices and diodes, in ohms (Ω).

Forward voltages [Device Vf, Diode Vfd]

The forward voltage of the selected devices (for GTO or IGBT only) and of the antiparallel and clamping diodes, in volts.

Measurements

Select `All Device currents` to measure the current flowing through all the components (switching devices and diodes). If the snubber devices are defined, the measured currents are those flowing through the power electronic devices only.

Select `Phase-to-neutral and DC voltages` to measure the terminal voltages (AC and DC) of the Three-Level Bridge block.

Select `All voltages and currents` to measure all voltages and currents defined for the Three-Level Bridge block.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurement** list box of the Multimeter block, the measurement is identified by a label followed by the block name.

Measurement	Label (for GTO, IGBT, MOSFET Devices)
Device currents	`IQ1a, IQ2a, IQ3a, IQ4a,`
	`IQ1b, IQ2b, IQ3b, IQ4b,`
	`IQ1c, IQ2c, IQ3c, IQ4c,`
	`ID1a, ID2a, ID3a, ID4a, ID5a, ID6a,`
	`ID1b, ID2b, ID3b, ID4b, ID5b, ID6b,`
	`ID1c, ID2c, ID3c, ID4c, ID5c, ID6c`
Terminal voltages	`Uan:`, `Ubn:`, `Ucn:`, `Udc+:`, `Udc-:`

Measurement	Label (for Ideal Switch Device)
Device currents	`Isw1a, Isw2a, Isw3a, Isw1b, Isw2b, Isw3b, Isw1c, Isw2c, Isw3c`
Terminal voltages	`Uan:`, `Ubn:`, `Ucn:`, `Udc+:`, `Udc-:`

Inputs and Outputs

The input g is a vectorized gating signal containing pulses to control the power electronic devices of the bridge. The length of the input vector depends on the number of arm you specified for the bridge topology.

Topology	Pulse Vector of Input g
One arm	[Q1a,Q2a,Q3a,Q4a]
Two arms	[Q1a,Q2a,Q3a,Q4a,Q1b,Q2b,Q3b,Q4b]
Three arms	[Q1a,Q2a,Q3a,Q4a,Q1b,Q2b,Q3b,Q4b,Q1c,Q2c,Q3c,Q4c]
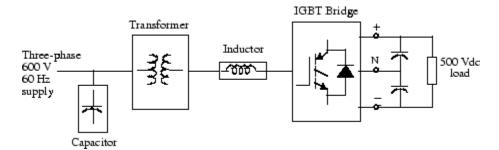
Note In the case of the ideal switch converter, the Q1 pulse is sent to Sw1, the Q4 pulse to Sw2, and a logical AND operation is performed on the Q2 and Q3 pulses and the result sent to Sw3.

Assumptions and Limitations
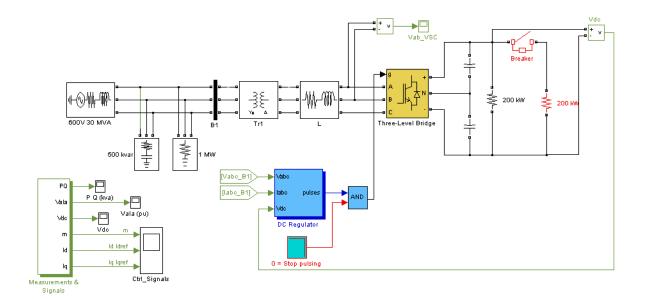
Turn-on and turn-off times (Fall time, Tail time) of power switching devices are not modeled in the Three-Level Bridge block.

Example

The power_3levelVSC example illustrates the use of the Three-Level Bridge block in an AC-DC converter consisting of a three-phase IGBT-based voltage sourced converter (VSC). The converter is pulse-width modulated (PWM) to produce a 500 V DC voltage (+/- 250 V). In this example, the converter chopping frequency is 1620 Hz and the power system frequency is 60 Hz.

The VSC is controlled in a closed loop by two PI regulators in order to maintain a DC voltage of 500 V at the load while maintaining a unity input power factor for the AC supply.

The initial conditions for a steady-state simulation are generated by running an initial simulation to steady state for an integer number of cycles of 60 Hz. The final states (both SimPowerSystems and Simulink controller states) are saved in a vector called `xInitial`. This vector, as well as the sample times (`Ts_Power` and `Ts_Control`) are saved in the `power_3levelVSC_xinit.mat` file.

When you open this model, the initial condition vector `xInitial` and the sample times saved in the MAT file are automatically loaded in the workspace. Start the simulation. The monitored signals start in steady state.

Observe the following signals:
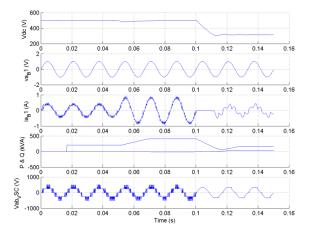
- The DC voltage (Vdc Scope block)
- The primary voltage and current of phase A of the AC supply (VaIa Scope block)
- The device currents of leg A of the IGBT bridge (Ia_Devices Scope block inside the Measurements & Signals subsystem)
- The line-to-line terminal voltage of the VSC (Vab_VSC Scope block)

At 50 ms, a 200 kW load is switched in. You can see that the dynamic response of the DC regulator to the sudden load variation from 200 kW to 400 kW is satisfactory. The
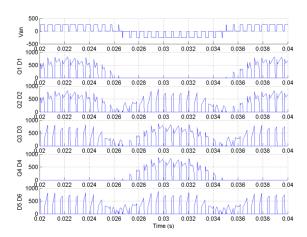
DC voltage reverts to 500 V within 2 cycles and the unity power factor on the AC side is maintained.

At 100 ms, a *stop-pulsing* signal is activated and the pulses normally sent to the converter are blocked. You can see that the DC voltage drops to 315 V. A drastic change in the primary current waveform can also be observed. When the pulses are blocked, the Three-Level Bridge block operation becomes similar to a three-phase diode bridge.

The following two figures summarize the results of the simulation. The first figure shows the operation of the AC-DC converter during the load variation and when the pulses are blocked.

The second figure shows the current flowing in the various devices of the IGBT bridge when the converter is feeding 500 Vdc to a 200-kW load.

See Also
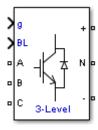
Multimeter

Three-Level NPC Converter

Implement three-phase, three-level Neutral-Point Clamped (NPC) power converter

Library

Fundamental Blocks/Power Electronics

Description
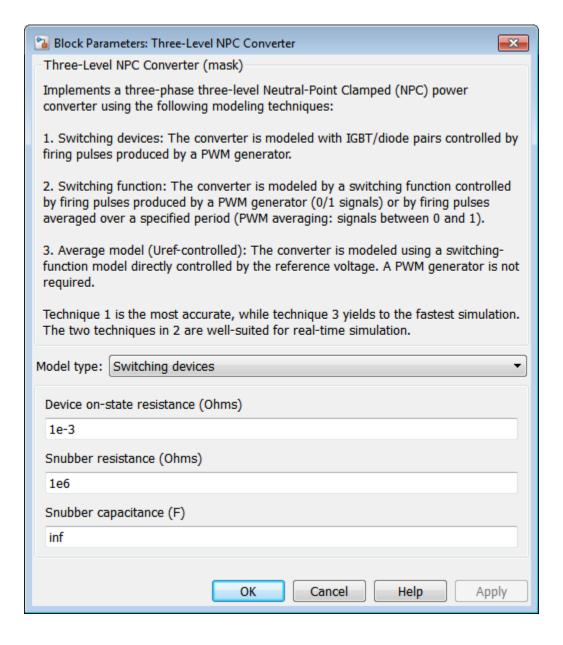
The Three-Level NPC Converter block implements a three-phase, three-level neutral-point clamped power converter. You can choose from three model types:

- **Switching devices** — The converter is modeled with IGBT/diode pairs controlled by firing pulses produced by a PWM generator. This model provides the most accurate simulation results.

- **Switching function** — The converter is modeled by a switching-function model. The switches are replaced with two voltage sources and two diodes on the AC side and with two current sources on the DC side.

  The converter is controlled by firing pulses produced by a PWM generator (0/1 signals) or by firing pulses averaged over a specified period (PWM averaging: signals between 0 and 1). Both modes of operation produce harmonics normally generated by a PWM-controlled converter and also correctly simulate rectifying operation as well as blanking time. This model type is well-suited for real-time simulation.

- **Average model (Uref-controlled)** — The converter is modeled using a switching-function model directly controlled by the reference voltage signals (Uref). A PWM generator is not required. This model provides the fastest simulations.

Dialog Box and Parameters

Parameters

Model type

Specify the model type to use:

- `Switching devices` (default)
- `Switching function`
- `Average model (Uref-controlled)`

Device on-state resistance (Ohms)

Internal resistance of the switching devices, in ohms. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `1e-3`.

Snubber resistance Rs (Ohms)

The snubber resistance, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `1e6`.

Snubber capacitance (F)

The snubber capacitance, in farads. Set the snubber capacitance to `0` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `inf`.

Diode on-state resistance (Ohms)

Internal resistance of the diodes, in ohms. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `1e-3`.

Diode snubber resistance (Ohms)

The snubber resistance, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `1e6`.

Diode snubber capacitance (F)

The snubber capacitance in farads. Set the snubber capacitance to `0` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `inf`.

Diode forward voltage (V)

Forward voltage, in volts, across the diode when it is conducting. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `1e-3`.

Current source snubber resistance (Ohms)

The snubber resistance across the two current sources, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `inf`.

Inputs and Outputs

g

A vectorized gating signal to control the converter. The gating signal contains 12 firing pulses. The first four pulses control the Q1a to Q4a switching devices (phase A of the converter), pulses five to eight control the Q1b to Q4b switching devices (phase B of the converter), and the last four pulses control the Q1c to Q4c switching devices (phase C of the converter). This port is visible only when you set the **Model type** parameter to `Switching devices` or `Switching function`.

Uref

A vectorized signal to control the converter. The signal contains three reference voltages (one for each phase). This port is visible only when you set the **Model type** parameter to `Average model (Uref-controlled)`.

BL

You can block all firing pulses to the converter by applying a signal value of 1 at the BL input.

Examples

See the Power Converters Modeling Techniques example for a comparison of the three converter modeling techniques.
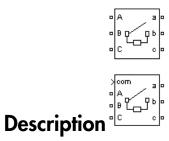
Introduced in R2015b

Three-Phase Breaker

Implement three-phase circuit breaker opening at current zero crossing

Library

Fundamental Blocks/Elements

Description
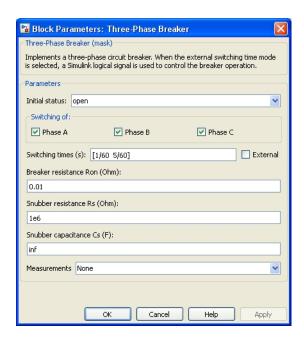
The Three-Phase Breaker block implements a three-phase circuit breaker where the opening and closing times can be controlled either from an external Simulink signal (external control mode), or from an internal control timer (internal control mode).

The Three-Phase Breaker block uses three Breaker blocks connected between the inputs and the outputs of the block. You can use this block in series with the three-phase element you want to switch. The arc extinction process of the Three-Phase Fault block is the same as for the Breaker block. See the Breaker block reference pages for details on the modeling of the single-phase breakers.

If the Three-Phase Breaker block is set in external control mode, a control input appears in the block icon. The control signal connected to this input must be either 0 or 1, 0 to open the breakers, 1 to close them. If the Three-Phase Breaker block is set in internal control mode, the switching times are specified in the dialog box of the block. The three individual breakers are controlled with the same signal.

Series Rs-Cs snubber circuit are included in the model. They can be optionally connected to the three individual breakers. If the Three-Phase Breaker block happens to be in series with an inductive circuit, an open circuit or a current source, you must use the snubbers.

Dialog Box and Parameters

Initial status

The initial status of the breakers. The initial status is the same for the three breakers. Depending on the initial status, the icon shows a closed contact or an open contact.

Switching of: Phase A

If selected, the switching of phase A is activated. If not selected, the breaker of phase A stays in its initial status specified in the **Initial status** parameter.

Switching of: Phase B

If selected, the switching of phase B is activated. If not selected, the breaker of phase B stays in its initial status specified in the **Initial status** parameter.

Switching of: Phase C

If selected, the switching of phase C is activated. If not selected, the breaker of phase C stays in its initial status specified in the **Initial status** parameter.

Switching times (s)

> The **Switching times (s)** parameter is available only if the **External** check box is not selected.

> Specify the vector of switching times when using the Three-Phase Breaker block in internal control mode. At each transition time the selected breakers opens or closes depending to their initial state.

External

> If selected, adds a fourth input port to the Three-Phase Breaker block for an external control of the switching times of the breakers. The switching times are defined by a Simulink signal (`0-1 sequence`).

Breakers resistance Ron

> The internal breaker resistances, in ohms (Ω). The **Breaker resistance Ron** parameter cannot be set to 0.

Snubbers resistance Rs

> The snubber resistances, in ohms (Ω). Set the **Snubber resistance Rs** parameter to `inf` to eliminate the snubbers from the model.

Snubbers capacitance Cs

> The snubber capacitances, in farads (F). Set the **Snubber capacitance Cs** parameter to `0` to eliminate the snubbers, or to `inf` to get resistive snubbers.

Measurements

> Select `Breaker voltages` to measure the voltage across the three internal breaker terminals.

> Select `Breaker currents` to measure the current flowing through the three internal breakers. If the snubber devices are connected, the measured currents are the ones flowing through the breakers contacts only.

> Select `Breaker voltages and currents` to measure the breaker voltages and the breaker currents.

> Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurements is identified by a label followed by the block name and the phase:

Measurement	Label
Breaker voltages	Ub <block_name> /Breaker A:

Measurement	Label
	Ub <block_name> /Breaker B:
	Ub <block_name> /Breaker C:
Breaker currents	Ib <block_name> /Breaker A:
	Ib <block_name> /Breaker B:
	Ib <block_name> /Breaker C:

Inputs and Outputs

If the Three-Phase Breaker block is set in external control mode, a Simulink input is added to the block to control the opening and closing of the three internal breakers.

Example

See the power_3phlinereclose and power_3phseriescomp examples for circuits using the Three-Phase Breaker block.

See Also

Breaker, Three-Phase Fault

Three-Phase Dynamic Load

Implement three-phase dynamic load with active power and reactive power as function of voltage or controlled from external input

Library

Fundamental Blocks/Elements

Description

The Three-Phase Dynamic Load block implements a three-phase, three-wire dynamic load whose active power P and reactive power Q vary as function of positive-sequence voltage. Negative- and zero-sequence currents are not simulated. The three load currents are therefore balanced, even under unbalanced load voltage conditions.

The load impedance is kept constant if the terminal voltage V of the load is lower than a specified value Vmin. When the terminal voltage is greater than the Vmin value, the active power P and reactive power Q of the load vary as follows:

$$P(s) = P_0 \left(\frac{V}{V_0} \right)^{n_p} \frac{1+T_{p1}s}{1+T_{p2}s}$$

$$Q(s) = Q_0 \left(\frac{V}{V_0} \right)^{n_q} \frac{1+T_{q1}s}{1+T_{q2}s},$$
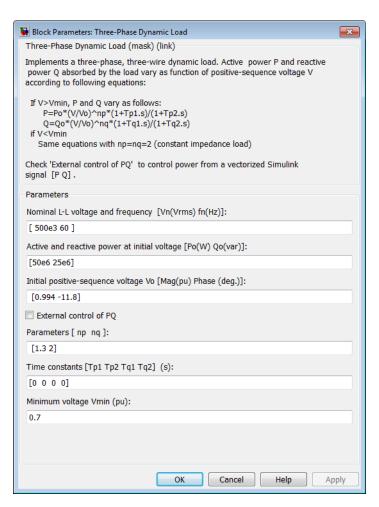
where

- V_0 is the initial positive sequence voltage.
- P_0 and Q_o are the initial active and reactive powers at the initial voltage V_o.
- V is the positive-sequence voltage.
- n_p and n_q are exponents (usually between 1 and 3) controlling the nature of the load.

- T_{p1} and T_{p2} are time constants controlling the dynamics of the active power P.

- T_{q1} and T_{q2} are time constants controlling the dynamics of the reactive power Q.

For a constant current load, for example, you set n_p to 1 and n_q to 1, and for constant impedance load you set n_p to 2 and n_q to 2.

Dialog Box and Parameters

Block Parameters: Three-Phase Dynamic Load

Three-Phase Dynamic Load (mask) (link)

Implements a three-phase, three-wire dynamic load. Active power P and reactive power Q absorbed by the load vary as function of positive-sequence voltage V according to following equations:

If V>Vmin, P and Q vary as follows:
   P=Po*(V/Vo)^np*(1+Tp1.s)/(1+Tp2.s)
   Q=Qo*(V/Vo)^nq*(1+Tq1.s)/(1+Tq2.s)
if V<Vmin
   Same equations with np=nq=2 (constant impedance load)

Check 'External control of PQ' to control power from a vectorized Simulink signal [P Q] .

Parameters

Nominal L-L voltage and frequency [Vn(Vrms) fn(Hz)]:

[500e3 60]

Active and reactive power at initial voltage [Po(W) Qo(var)]:

[50e6 25e6]

Initial positive-sequence voltage Vo [Mag(pu) Phase (deg.)]:

[0.994 -11.8]

☐ External control of PQ

Parameters [np nq]:

[1.3 2]

Time constants [Tp1 Tp2 Tq1 Tq2] (s):

[0 0 0 0]

Minimum voltage Vmin (pu):

0.7

OK   Cancel   Help   Apply

Nominal L-L voltage and frequency

Specifies the nominal phase-to-phase voltage, in volts RMS, and nominal frequency, in hertz, of the load.

Active and reactive power at initial voltage

Specifies the initial active power Po, in watts, and initial reactive power Qo, in vars, at the initial voltage Vo.

When you use the Machine Initialization tool of Powergui to initialize the dynamic load and start simulation in steady state, these parameters are automatically updated according to P and Q set points specified for the load.

If you use the Load Flow tool of Powergui to initialize the dynamic load, these parameters represent the P and Q reference powers used by the load flow.

Initial positive-sequence voltage Vo

Specifies the magnitude and phase of the initial positive-sequence voltage of the load.

When you use the Load Flow tool or the Machine Initialization tool of Powergui to initialize the dynamic load and start simulation in steady state, these two parameters are automatically updated according to values computed by the load flow.

External control of PQ

If selected, the active power and reactive power of the load are defined by an external Simulink vector of two signals.

Parameters [np nq]

Specifies the **np** and **nq** parameters that define the nature of the load.

Time constants [Tp1 Tp2 Tq1 Tq2]

Specifies the time constants controlling the dynamics of the active power and the reactive power.

Minimum voltage Vmin

Specifies the minimum voltage at which the load dynamics commences. The load impedance is constant below this value.
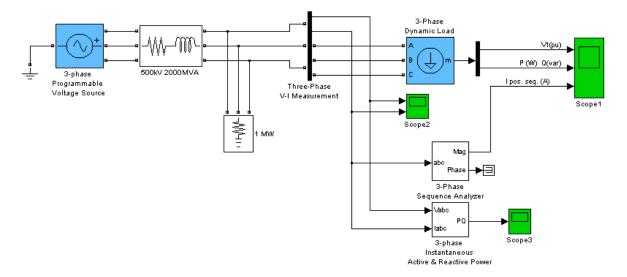
Inputs and Outputs

If **External control of PQ** is selected, a Simulink input, labeled PQ, appears. This input is used to control the active and reactive powers of the load from a vector of two signals [P, Q].

The m output is a vector containing the following three signals: positive-sequence voltage (pu); active power P (W); and reactive power Q (vars).

Example

The power_dynamicload model uses a Three-Phase Dynamic Load block connected on a 500 kV, 60 Hz power network. The network is simulated by its Thevenin equivalent (voltage source behind a R-L impedance corresponding to a three-phase short-circuit level of 2000 MVA). The source internal voltage is modulated in order to simulate voltage variation during a power swing. As the dynamic load is a nonlinear model simulated by current sources, it cannot be connected to an inductive network (R-L in series). Therefore, a small resistive load (1 MW) has been added in parallel with the dynamic load.

In order to start the simulation in steady state, you must specify the correct initial positive-sequence voltage Vo (magnitude and phase) corresponding to the desired Po and Qo values. You use the load flow utility to find this voltage and initialize the dynamic load. Open the Powergui and select **Machine Initialization**. Specify the desired active power and reactive powers for the dynamic load (50 MW, 25 Mvar):
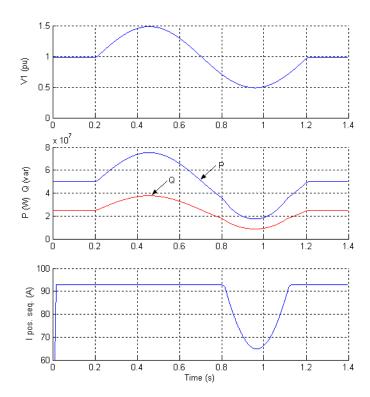
Active Power = 50e6; Reactive Power = 25e6

Then press the **Compute and Apply** button. Once the load flow has been solved the three phase-to-phase voltages of the dynamic load (0.9844 pu) as well as its line currents are displayed. The phase angle of the phase-to-neutral load voltage Uan is also displayed (−1.41 degrees). This angle corresponds to the angle of the positive-sequence voltage. If you now open the Three-Phase Dynamic Load dialog box, notice that the values of Po, Qo, and Vo have been updated.

Start the simulation and observe load voltage, P&Q powers, and current on Scope1. Observe that simulation starts in steady state. At t = 0.2 s, when voltage modulation is initiated, P and Q start to increase (trace 2), but, as np and nq are set to 1, the load current (trace 3) stays constant. When voltage falls below 0.7 pu the load behaves as a constant impedance. Therefore load current follows this voltage variation.

Observe on Scope2 variations of instantaneous voltages and currents. Also, notice that computed P and Q displayed on Scope3 are the same as P and Q internal signals returned by the Dynamic Load measurement output.

The signals displayed on the Scope1 block are shown below.
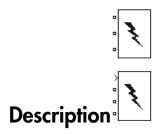
Three-Phase Fault

Implement programmable phase-to-phase and phase-to-ground fault breaker system

Library

Fundamental Blocks/Elements

Description
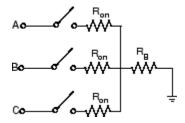
The Three-Phase Fault block implements a three-phase circuit breaker where the opening and closing times can be controlled either from an external Simulink signal (external control mode), or from an internal control timer (internal control mode).

The Three-Phase Fault block uses three Breaker blocks that can be individually switched on and off to program phase-to-phase faults, phase-to-ground faults, or a combination of phase-to-phase and ground faults. The arc extinction process of the Three-Phase Fault block is the same as for the Breaker block. See the `Breaker` block for details on the modeling of the single-phase breakers.
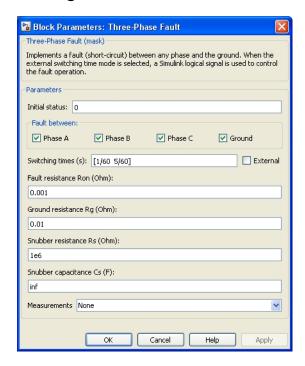
The ground resistance Rg is automatically set to 10^6 ohms when the ground fault option is not programmed. For example, to program a fault between the phases A and B you need to select the **Phase A** and **Phase B** block parameters only. To program a fault

between the phase A and the ground, you need to select the **Phase A** and **Ground** parameters and specify a small value for the ground resistance.

If the Three-Phase Fault block is set in external control mode, a control input appears in the block icon. The control signal connected to the fourth input must be either 0 or 1, 0 to open the breakers, 1 to close them. If the Three-Phase Fault block is set in internal control mode, the switching times and status are specified in the dialog box of the block.

Series Rs-Cs snubber circuits are included in the model. They can be optionally connected to the fault breakers. If the Three-Phase Fault block is in series with an inductive circuit, an open circuit or a current source, you must use the snubbers.

Dialog Box and Parameters

Initial status

> The initial status of the fault breaker is usually 0 (open). However, you can start the simulation in steady state with the fault initially applied on the system.

Phase A

If selected, the fault switching of phase A is activated. If not selected, the breaker of phase A stays in the status specified in the **Initial status** parameter.

Phase B

If selected, the fault switching of phase B is activated. If not selected, the breaker of phase B stays in the status specified in the **Initial status** parameter.

Phase C

If selected, the fault switching of phase C is activated. If not selected, the breaker of phase C stays in the status specified in the **Initial status** parameter.

Ground

If selected, the fault switching to the ground is activated. A fault to the ground can be programed for the activated phases. For example, if the **Phase C** and **Ground** parameters are selected, a fault to the ground is applied to the phase C. The ground resistance is set internally to 1e6 ohms when the **Ground** parameter is not selected.

Switching times (s)

Specify the vector of switching times when using the Three-Phase Breaker block in internal control mode. At each transition time the selected fault breakers opens or closes depending to the initial status. The **Switching times (s)** parameter is not available if the **External** parameter is selected.

External

If selected, adds a fourth input port to the Three-Phase Fault block for an external control of the switching times of the fault breakers. The switching times are defined by a Simulink signal (0 or 1) connected to the fourth input port of the block.

Fault resistances Ron

The internal resistance, in ohms (Ω), of the phase fault breakers. The **Fault resistances Ron** parameter cannot be set to 0.

Ground resistance Rg

The **Ground resistance Rg** parameter is available only if the **Ground** parameter is selected. The ground resistance, in ohms (Ω). The **Ground resistance Rg** parameter cannot be set to 0.

Snubbers resistance Rs

The snubber resistances, in ohms (Ω). Set the **Snubbers resistance Rs** parameter to inf to eliminate the snubbers from the model.

Snubbers capacitance Cs

The snubber capacitances, in farads (F). Set the **Snubbers capacitance Cs** parameter to `0` to eliminate the snubbers, or to `inf` to get resistive snubbers.

Measurements

Select `Fault voltages` to measure the voltage across the three internal fault breaker terminals.

Select `Fault currents` to measure the current flowing through the three internal breakers. If the snubber devices are connected, the measured currents are the ones flowing through the breakers contacts only.

Select `Fault voltages and currents` to measure the breaker voltages and the breaker currents.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name and the phase:

Measurement	Label
Fault voltages	Ub <block name> /Fault A:,
	Ub <block name> /Fault B:,
	Ub <block name> /Fault C:,
Fault currents	Ib <block name> /Fault A:,
	Ib <block name> /Fault B:,
	Ib <block name> /Fault C:,

Inputs and Outputs

The three fault breakers are connected in wye between terminals A, B and C and the internal ground resistor. If the Three-Phase Fault block is set to external control mode, a Simulink input is added to the block to control the opening and closing of the three internal breakers.

Example

See the power_3phseriescomp example for a circuit using the Three-Phase Fault block.

See Also
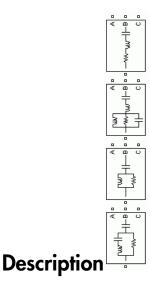
`Breaker`, `Multimeter`, and `Three-Phase Breaker`

Three-Phase Harmonic Filter

Implement four types of three-phase harmonic filters using RLC components

Library

Fundamental Blocks/Elements

Description

Three-phase harmonic filters are shunt elements that are used in power systems for decreasing voltage distortion and for power factor correction. Nonlinear elements such as power electronic converters generate harmonic currents or harmonic voltages, which are injected into power system. The resulting distorted currents flowing through system impedance produce harmonic voltage distortion. Harmonic filters reduce distortion by diverting harmonic currents in low impedance paths. Harmonic filters are designed to be capacitive at fundamental frequency, so that they are also used for producing reactive power required by converters and for power factor correction.
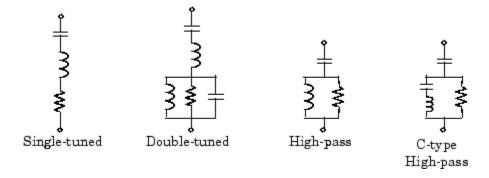
In order to achieve an acceptable distortion, several banks of filters of different types are usually connected in parallel. The most commonly used filter types are

- Band-pass filters, which are used to filter lowest order harmonics such as 5th, 7th, 11th, 13th, etc. Band-pass filters can be tuned at a single frequency (single-tuned filter) or at two frequencies (double-tuned filter).

- High-pass filters, which are used to filter high-order harmonics and cover a wide range of frequencies. A special type of high-pass filter, the C-type high-pass filter, is used to provide reactive power and avoid parallel resonances. It also allows filtering low order harmonics (such as 3rd), while keeping zero losses at fundamental frequency.
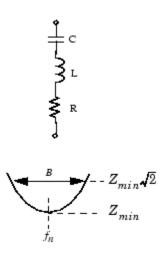
The Three-Phase Harmonic Filter is built of RLC elements. The resistance, inductance, and capacitance values are determined from the filter type and from the following parameters:

- Reactive power at nominal voltage
- Tuning frequencies
- Quality factor. The quality factor is a measure of the sharpness of the tuning frequency. It is determined by the resistance value.

The four types of filters that can be modeled with the Three-Phase Harmonic Filter block are shown below:

Single-tuned   Double-tuned   High-pass   C-type
High-pass

The simplest filter type is the single-tuned filter. The following figure gives the definition of the quality factor Q and practical formulae for computing the reactive power Q_C and losses (active power P). The quality factor Q of the filter is the quality factor of the reactance at the tuning frequency $Q = (nX_L)/R$. The quality factor determines the bandwidth B, which is a measure of the sharpness of the tuning frequency as shown in the figure.

Tuned harmonic order	$n = f_n/f_1 = $ $\sqrt{X_C / X_L}$		f_1 = fundamental frequency
Quality factor	$Q = nX_L/R = X_C/(nR)$		$\omega = 2\pi f_1$ = angular frequency
Bandwidth	$B = f_n/Q$	where	f_n = tuning frequency
Reactive power at f_1	$Q_C = (V^2/X_C)\, n^2/(n^2 - 1)$		n = harmonic order = (f_n/f_1)
Active power at f_1 (losses)	$P \approx (Q_C/Q)\, n/(n^2 - 1)$		V = nominal line-line voltage
			X_L = inductor reactance at fundamental frequency = $L\omega$
			X_C = capacitor reactance at fundamental frequency = $1/(C\omega)$

The double-tuned filter performs the same function as two single-tuned filters although it has certain advantages: its losses are much lower and the impedance magnitude at the frequency of the parallel resonance that arises between the two tuning frequencies is lower.

The double-tuned filter consists of a series LC circuit and a parallel RLC circuit. If f_1 and f_2 are the two tuning frequencies, both the series circuit and the parallel circuit are tuned to approximately the mean geometric frequency $f_m = \sqrt{f_1 f_2}$.

The quality factor Q of the double-tuned filter is defined as the quality factor of the parallel L, R elements at the mean frequency f_m: $Q = R / (L \cdot 2\pi f_m)$.
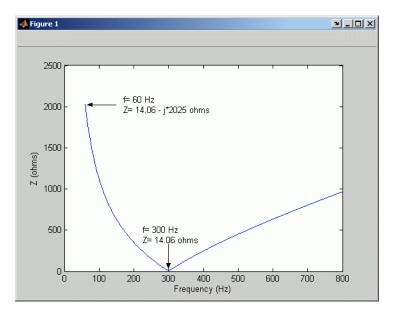
The high-pass filter is a single-tuned filter where the L and R elements are connected in parallel instead of series. This connection results in a wide-band filter having an impedance at high frequencies limited by the resistance R.

The quality factor of the high-pass filter is the quality factor of the parallel RL circuit at the tuning frequency: $Q = R / (L \cdot 2\pi f_n)$.
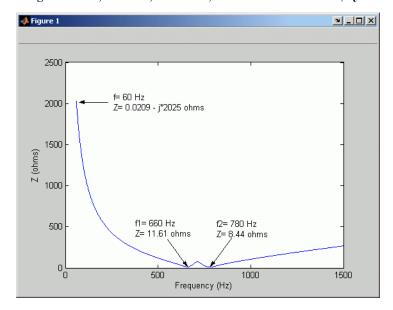
The C-type high-pass filter is a variation of the high-pass filter, where the inductance L is replaced with a series LC circuit tuned at the fundamental frequency. At fundamental frequency, the resistance is, therefore, bypassed by the resonant LC circuit and losses are null.

The quality factor of the C-type filter is still given by the ratio: $Q = R / (L \cdot 2\pi f_n)$.
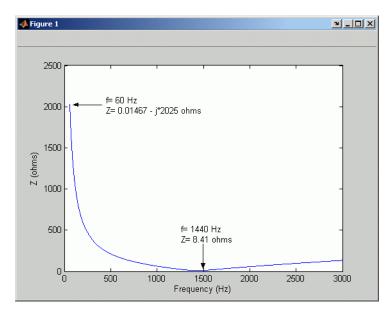
The following figures give R, L, C values and typical impedance versus frequency curves obtained for the four types of filters applied on a 60 Hz network. Each filter is rated 315 kV, 49 Mvar.
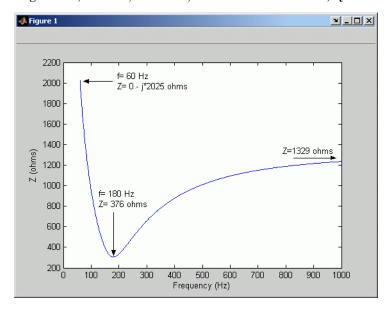
Single-Tuned, 315 kV, 49 Mvar, 5th Harmonic Filter; Q = 30

Double-Tuned, 315 kV, 49 Mvar, 11th and 13th Harmonics Filter; Q = 16
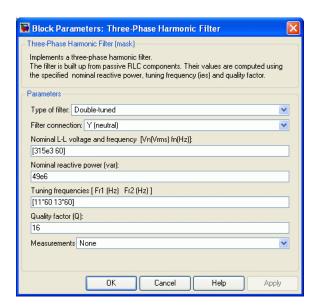
High-Pass, 315 kV, 49 Mvar, 24th Harmonic Filter; Q = 10

C-Type High-Pass, 315 kV, 49 Mvar, 3rdHharmonic Filter; Q = 1.75

Dialog Box and Parameters

Type of filter

Select one of the four filter types: Single-tuned, Double-tuned, High-pass or C-type high-pass.

Filter connection

Select the connection of the three filter branches.

Y(grounded)	Neutral is grounded.
Y(floating)	Neutral is not accessible.
Y(neutral)	Neutral is made accessible through a fourth connector.
Delta	Three phases connected in delta.

Nominal L-L voltage and frequency

The nominal phase-to-phase voltage of the filter, in volts RMS (Vrms) and the nominal frequency, in hertz (Hz).

Nominal reactive power

The three-phase capacitive reactive power Q_C, in vars. Specify a positive value.

Tuning frequency or Tuning frequencies

The tuning frequency of the single frequency filter (single-tuned, high-pass or C-type high-pass), or the two frequencies of the double-tuned filter, in hertz (Hz).

Quality factor (Q)

The quality factor Q of the filter defined as explained in the above Description section. Dimensionless positive number.

Measurements

Select **Branch voltages** to measure the three voltages across each phase of the Three-Phase Harmonic Filter block terminals. For a Y connection, these voltages are the phase-to-ground or phase-to-neutral voltages. For a delta connection, these voltages are the phase-to-phase voltages.

Select **Branch currents** to measure the three currents flowing through each phase of the filter. For a delta connection, these currents are the currents flowing in each branch of the delta.

Select **Branch voltages and currents** to measure the three voltages and the three currents of the Three-Phase Harmonic Filter block.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

Measurement		Label
Branch voltages	Y(grounded): Uag, Ubg, Ucg	Uag: , Ubg: , Ucg:
	Y(floating): Uan, Ubn, Ucn	Uan: , Ubn: , Ucn:
	Y(neutral): Uan, Ubn, Ucn	Uan: , Ubn: , Ucn:
	Delta: Uab, Ubc, Uca	Uab: , Ubc: , Uca:
Branch currents	Y(grounded): Ia, Ib, Ic	Iag: , Ibg: , Icg:
	Y(floating): Ia, Ib, Ic	Ian: , Ibn: , Icn:
	Y(neutral): Ia, Ib, Ic	Ian: , Ibn: , Icn:
	Delta: Iab, Ibc, Ica	Iab: , Ibc: , Ica:

Example

The power_harmonicfilter example illustrates the use of the Three-Phase Harmonic Filter block to filter harmonic currents generated by a 12-pulse, 1000 MW, AC/DC converter in a 500 kV, 60 Hz system. The filter set is made of the following four components providing a total of 600 Mvar:
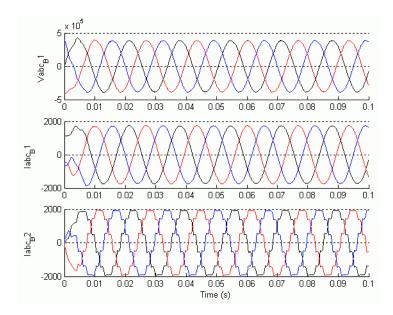
- One 150 Mvar C-type high-pass filter tuned to the 3rd harmonic (F1)
- One 150 Mvar double-tuned filter tuned to the 11/13th (F2)
- One 150 Mvar high-pass filter tuned to the 24th (F3)
- One 150 Mvar capacitor bank

Time-domain simulation

Run the simulation with an alpha firing angle of 19 degrees. You should get a DC voltage level of 500 kV. Now, look inside Scope1. Compare the currents flowing into Bus B1 (Iabc_B1, axis 2) with those flowing into Bus B2 (Iabc_B2, axis 3). You can see that the harmonic filters almost eliminate the harmonics generated by the converter. If you use
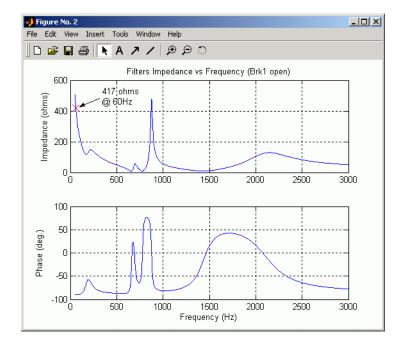
the FFT tool of the Powergui, you will find that the harmonic filters reduce the THD of the current injected in the system from 9% to 0.7%.

Frequency-Domain Response

You will now plot the impedance vs. frequency of the harmonic filters:

1   Disconnect the filters from the AC bus. To do so, double-click on the breaker Brk1, select **open** for initial status of breakers, and click **OK**.

2   Open the Powergui and select **Impedance vs Frequency Measurement**.

3   Click the **Display/Save** button. The software computes and displays the filter's frequency response.

4   Double-click the block Show filters impedance vs frequency. A second figure appears, showing the precomputed filters frequency response. The impedance data of the two figures should be identical to the one shown below.

If you zoom the figure (using the **Tool** menu), you should find an impedance of 417 ohms capacitive (−90deg.) at 60 Hz. This value confirms that the total reactive power of the filters at 60 Hz is:

$$Q_c = \frac{V^2}{X_c} = \frac{(500 \cdot 10^3)^2}{417} = 600 \text{ Mvar.}$$

Three-Phase Mutual Inductance Z1-Z0

Implement three-phase impedance with mutual coupling among phases

Library

Fundamental Blocks/Elements

Description
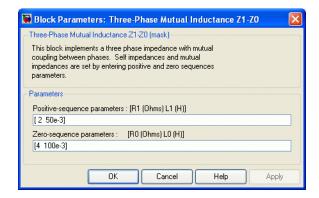
The Three-Phase Mutual Inductance Z1-Z0 block implements a three-phase balanced inductive and resistive impedance with mutual coupling between phases. This block performs the same function as the three-winding Mutual Inductance block. For three-phase balanced power systems, it provides a more convenient way of entering system parameters in terms of positive- and zero-sequence resistances and inductances than the self- and mutual resistances and inductances.

Dialog Box and Parameters

Positive-sequence parameters
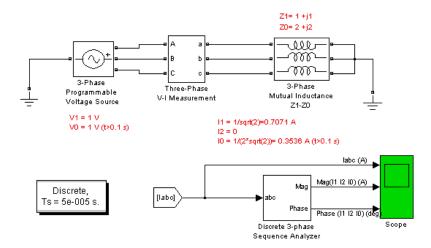
The positive-sequence resistance R1, in ohms (Ω), and the positive-sequence inductance L1, in henries (H).

Zero-sequence parameters
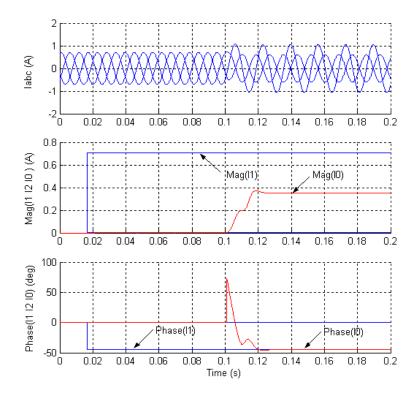
The zero-sequence resistance R0, in ohms (Ω), and the zero-sequence inductance L0, in henries (H).

Example

The power_3phmutseq10 example illustrates the use of the Three-Phase Mutual Inductance Z1-Z0 block to build a three-phase inductive source with different values for the positive-sequence impedance Z1 and the zero-sequence impedance Z0. The programmed impedance values are Z1 = 1+j1 Ω and Z0 = 2+j2 Ω. The Three-Phase Programmable Voltage Source block is used to generate a 1-volt, 0-degree, positive-sequence internal voltage. At t = 0.1 s, a 1- volt, 0-degree, zero-sequence voltage is added to the positive-sequence voltage. The three source terminals are short-circuited to ground and the resulting positive-, negative-, and zero-sequence currents are measured using the Discrete 3-Phase Sequence Analyzer block.

The current waveforms and their sequence components (magnitude and phase) are displayed on the Scope block. The resulting waveforms are shown on the following figure.

The polar impedance values are $Z_1 = \sqrt{2}\angle45°\,\Omega$ and $Z_0 = 2\sqrt{2}\angle45°\,\Omega$.

Therefore, the positive- and zero-sequence currents displayed on the scope are

$$I_1 = \frac{V_1}{Z_1} = \frac{1}{\sqrt{2}\angle45°} = 0.7071A\angle-45°$$

$$I_0 = \frac{V_0}{Z_0} = \frac{1}{2\sqrt{2}\angle45°} = 0.3536A\angle-45°$$

The transients observed on the magnitude and the phase angle of the zero-sequence current when the zero-sequence voltage is added (at t = 0.1 s) are due to the Fourier measurement technique used by the Discrete 3-Phase Sequence Analyzer block. As the Fourier analysis uses a running average window of one cycle, it takes one cycle for the magnitude and phase to stabilize.

See Also

Mutual Inductance

Three-Phase OLTC Phase Shifting Transformer Delta-Hexagonal (Phasor Type)

Implement phasor model of three-phase OLTC phase-shifting transformer using delta hexagonal connection

Library

FACTS/Transformers

Description
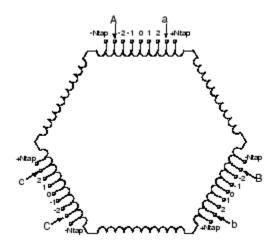
This block is used to model a phase-shifting transformer using on-load tap changers (OLTC) for introducing a phase shift between three-phase voltages at two buses in a transmission system. Controlling phase-shift on a transmission system will affect primarily flow of active power. Although the phase-shifting transformer does not provide as much flexibility and speed as power-electronics based FACTS, it can be considered as a basic power flow controller. This is why it has been included in the facts library. The dynamic performance of the phase-shifting transformer can be enhanced by using a thyristor-based tap changer instead of a mechanical tap changer. As this model is a phasor model which does not implement the details of current transfer from one tap to the next tap, you can use it to model a thyristor-based phase-shifter. You can also use this block together with the Three-phase OLTC Regulating Transformer (Phasor Type) block for building phasor models of more complex transformer-based FACTS topologies.

The delta hexagonal connection consists of three pairs of windings interconnected in a hexagonal configuration as shown on the figure below.

Delta-Hexagonal Phase-Shifting Transformer Connections

$$\psi = 2 \times \arctan(-k / \sqrt{3})$$

Symbol	Range
ψ = phase shift of abc output voltages with respect to ABC input voltages	$-60° \leq \psi \leq +60°$
N = tap position	$-N_{tap} \leq N \leq +N_{tap}$
k = relative tap position = N/N_{tap}	$-1 \leq k \leq +1$

Each phase consists of two coupled windings drawn in parallel on the figure: one tapped winding with two OLTCs and one winding without taps. All windings have the same number of turns. The two OLTCs vary phase shift by moving transformer input terminals (A, B, C) and outputs terminals (a, b, c) symmetrically with respect to center tap 0. This delta hexagonal connection has the advantage of keeping a 1:1voltage ratio while the phase shift is varied.
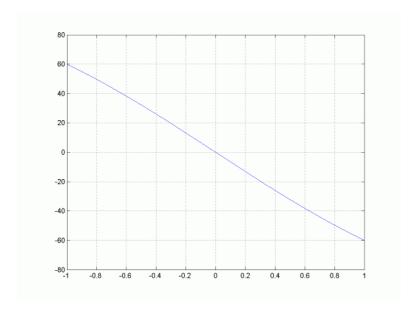
When the two OLTCs move taps from the center position (0) to the winding end (position Ntap), the phase shift between inputs (ABC) and outputs (abc) varies from 0 to 60 degrees. When ABC are at position −Ntap and abc are at position +Ntap, the output voltages abc are lagging input voltages ABC by 60 degrees. On the other end, when ABC are at position +Ntap and abc are at position −Ntap, the output voltages abc are leading

1-1051

input voltages ABC by 60 degrees. For intermediate positions the phase shift ψ is given by the equation on the figure. This equation assumes that all tap are evenly spaced.

For example, if each half tapped winding consists of 10 taps (total of 21 taps/ winding including center tap 0) and if ABC and abc terminals are respectively at tap −7 and tap +7, then, k=7/10 =0.7

Therefore, abc voltages are lagging ABC voltages by 44 degrees.

The phase angle varies almost linearly as function of tap position as shown on the figure below.
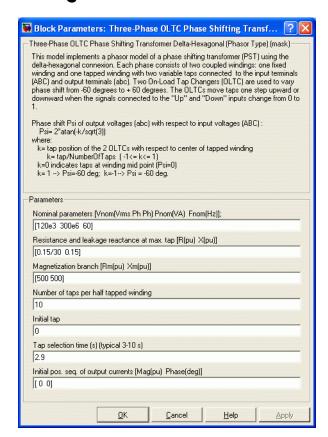
Variation of phase shift as function of tap position

You control tap positions, and therefore phase shift, by sending pulses to one of the two block inputs labeled Up and Down. Applying a pulse to the Up (or Down) input will move the tap position upward (or downward) when the signal is changing from 0 to 1.

Mechanical tap changers are relatively slow devices. The time required to move from one tap position to the next one is usually comprised between 3 and 10 seconds. You specify this mechanical time delay in the block menu.

> **Note** OLTCs use additional switches and resistors (or inductors) to transfer current from the outgoing tap to the ongoing tap without interrupting load current. During the transfer, taps are temporarily short circuited through resistors or inductors. The transfer time (typically from 40 ms to 60 ms) is fast as compared to the tap selection process (3s to 10 s). As this block implements a phasor model for study of transient stability of power systems in the range of seconds to minutes, the tap transfer process is not modelled and an instantaneous tap transfer is assumed. A detailed delta-hexagonal phase-shifting transformer model is provided in the `power_PSTdeltahex` example.

Dialog Box and Parameters

Nominal parameters [Vnom Pnom Fnom]

The nominal line to line voltage, in volts rms, the three-phase nominal power, in VA and the nominal frequency, in hertz.

Resistance and leakage reactance at max. tap [R X]

The transformer short circuit impedance due to winding resistances and leakage reactances, at maximum phase shift (input and output taps at −Ntap and +Ntap positions). Specify resistance and reactance, in pu.

The transformer positive-sequence impedance Z_1, in pu, and zero-sequence Z_0, in pu, vary with relative tap position k as follows:

$$Z_1 = (R + jX)\frac{|k|(-3k^2 + 2|k| + 9)}{2(k^2 + 3)}$$

$$Z_0 = k^2 \frac{R_m jX_m}{R_m + jX_m},$$

where: R, X are the transformer resistance and reactance defined in the parameter **Resistance and leakage reactance at max. tap** (k=1 or k=−1) and **R**m, **X**m **are the transformer magnetizing** resistance and reactance defined in the **Magnetizing branch** parameter described below.

Note that these impedances keep the same value for positive and negative values of k. For k=0, impedances are zero because the transformer input terminals are short-circuited with output terminals.

Magnetizing branch [Rm Xm]

The resistance, in pu, and the reactance, in pu of the parallel R_m, X_m branch modelling respectively iron losses and reactive magnetizing currents. Saturation is not modelled.

Number of taps per half winding (Ntap)

The number of taps per half winding. The total number of taps per winding, including center tap 0, is therefore 2*Ntap+1.

Initial tap

Specify an integer (Tapinit) corresponding the initial tap position of output terminals abc. The initial tap position of input terminals ABC is therefore –Tapinit.

Tap selection time

The mechanical time delay, in seconds, required for the OLTCs to move the taps by one position. Typical values are in the 3s-10s range.

Initial pos. seq. output currents [Mag Phase]

The initial value of the positive-sequence current phasor (Magnitude in pu and Phase in degrees) flowing out of terminals abc. If you know the initial value of currents you may specify it in order to start simulation in steady state. If you don't know these values, you can leave [0 0]. The system will reach steady-state after a short transient.

Inputs and Outputs

A B C

The three transformer input terminals

a b c

The three transformer output terminals

Up

Simulink input for controlling tap position. Applying a pulse to this input will initiate upward tap changing when the pulse is changing from 0 to 1.

Down

Simulink input for controlling tap position. Applying a pulse to this input will initiate downward tap changing when the pulse is changing from 0 to 1.

m

Simulink output vector containing 17 internal signals. These signals are either complex signals (voltage phasors, current phasors or impedances) or control signals. They can be individually accessed by using the Bus Selector block. They are, in order:

Signal	Signal Group	Signal Names	Definition
1-3	VABC (cmplx)	VA (pu) VB (pu) VC (pu)	Phasor voltages (phase to ground) at the transformer input terminals A, B, C (pu)
4-6	Vabc (cmplx)	Va (pu) Vb (pu) Vc (pu)	Phasor voltages (phase to ground) at the transformer output terminals a, b, c (pu)
7-9	IABC (cmplx)	IA (pu) IB (pu) IC (pu)	Phasor currents flowing into the input terminals A, B, C

Signal	Signal Group	Signal Names	Definition
10-12	Iabc (cmplx)	Ia (pu) Ib (pu) Ic (pu)	Phasor currents flowing out of the output terminals a, b, c
13-14	Z (cmplx)	Z1 (pu) Z0 (pu)	Positive- and zero-sequence complex impedances (R+jX)
15	Psi (degrees)	Psi (degrees)	Phase shift of abc output voltages with respect to ABC input voltages
16	Tap	Tap	Tap position
17	Ready	Ready	Logical signal generated by the tap changer controller. The Ready signal becomes (1) after the tap selection has been completed, thus enabling a new tap change. The Up and Down pulses to the OLTC are blocked as long as the Ready signal is (0).

Example

See the `power_PSTdeltahex` example, which illustrates the use of the Three-Phase OLTC Phase Shifting Transformer Delta-Hexagonal (Phasor Type) block to control power transfer between two equivalent sources in a 120 kV transmission. The phasor model is compared with a detailed model of phase shifting transformer. Look under the masked blocks to see how both models are implemented. The detailed model uses switches and three Multi-Winding Transformer blocks, whereas the phasor model uses current sources.

See Also

Three-Phase OLTC Regulating Transformer (Phasor Type)

Three-Phase OLTC Regulating Transformer (Phasor Type)

Implement phasor model of three-phase OLTC regulating transformer

Library

FACTS/Transformers

Description
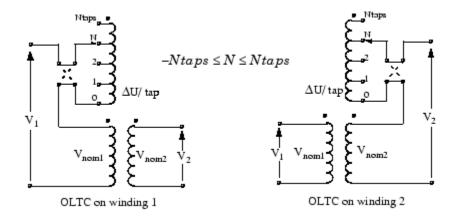
This block is used to model a three-phase two-winding transformer or autotransformer using a on-load tap changer (OLTC) for regulating voltage on a transmission or distribution system. Controlling voltage on a transmission system will affect primarily flow of reactive power, which, in turn, will affect the power transfer limits. Although the regulating transformer does not provide as much flexibility and speed as power-electronics based FACTS, it can be considered as a basic power flow controller. This is why it has been included in the facts library. The dynamic performance of the regulating transformer can be enhanced by using a thyristor-based tap changer instead of a mechanical tap changer. As this model is a phasor model which does not implement the details of current commutation from one tap to the next tap, you can use it to model a thyristor-based tap changer and implement your own control system by selecting **External control of OLTC** in the block menu. You can also use this block together with the Three-phase OLTC Phase-Shifting Transformer Delta-Hexagonal (Phasor Type) block for building phasor models of more complex transformer-based FACTS topologies.

The figure below shows one phase of the three-phase regulating transformer. Each phase consists of main windings 1 and 2 and of a tapped regulation winding.

One Phase of the Regulating Transformer

$-N_{\text{taps}} \leq N \leq +N_{\text{taps}}$. The voltage ratios on the two windings are:

Winding 1	Winding 2
$\dfrac{V_2}{V_1} = \dfrac{1}{(1 + N \cdot \Delta U)} \times \dfrac{V_{\text{nom2}}}{V_{\text{nom1}}}$	$\dfrac{V_2}{V_1} = (1 + N \cdot \Delta U) \times \dfrac{V_{\text{nom2}}}{V_{\text{nom1}}}$

Voltage regulation is performed by varying the transformer ratio V2/V1 by means of the OLTC. The OLTC can be connected either on winding 1 (left diagram) or on winding 2 (right diagram). The OLTC can select any tap from position 0 (no voltage correction) to maximum tap (position Ntap) yielding maximum voltage correction. The OLTC is also equipped with a reversing switch which allows connecting the regulation winding either in additive or subtractive polarity. The factor multiplying Vnom2/Vnom1 is the voltage correction factor. It is given by:
$1/(1 + N \Delta U)$ for OLTC on winding 1
$1 + N \Delta U$ for OLTC on winding 2

where
N = tap position
ΔU = voltage per tap in pu of nominal voltage of winding 1 or winding 2.

Negative values of N correspond to the reversing switch position shown in dashed lines (regulation winding in subtractive polarity). The transformer resistance and leakage reactance also vary with the tap position.

Mechanical tap changers are relatively slow devices. The time required to move from one tap position to the next one is usually comprised between 3 and 10 seconds. You specify this mechanical time delay in the block menu.

Note OLTCs use additional switches and resistors (or inductors) to transfer current from the outgoing tap to the ongoing tap without interrupting load current. During the transfer, taps are temporarily short circuited through resistors or inductors. The transfer time (typically from 40 ms to 60 ms) is fast as compared to the tap selection process (3s to 10 s). As this block implements a phasor model for study of transient stability of power systems in the range of seconds to minutes, the tap transfer process is not modelled and an instantaneous tap transfer is assumed. A detailed regulating transformer model is provided in the `power_OLTCregtransformer` example.

Automatic voltage control

The regulating transformer is usually associated with a control system which regulates voltage at the transformer terminals (side 1 or side 2) or at a remote bus. Such a control system is provided in the Three-Phase OLTC Regulating Transformer (Phasor Type) block. You must then connect at the Vm input of the block a Simulink signal, which is usually the magnitude of the positive-sequence voltage (in pu) to be controlled, but it can be any signal.The control system will adjust automatically the tap position until the measured voltage Vm is equal to the reference voltage Vref specified in the block menu.

The voltage regulator is a hysteresis type regulator. Each time a tap change is required, the regulator sends a pulse either to the Up or Down input of the Tap Changer Controller. Look under the block mask to see how these control blocks are built. The regulator will ask for a tap change if
$|V_m - V_{\mathrm{ref}}| > \mathrm{DeadBand}/2$

during a time $t >$ Delay, where V_{ref}, DeadBand, and Delay are parameters of the voltage regulator.
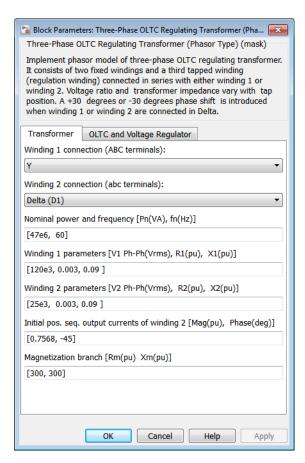
External control of OLTC

If you want to implement your own control system or manually control the tap position, you select **External control of OLTC**. The Vm input will then be replaced by two inputs labeled Up and Down. Applying a pulse to the Up or Down input will move the tap position upward or downward when the signal is changing from 0 to 1.

Dialog Box and Parameters

The transformer and OLTC parameters are grouped in two categories: `Transformer parameters` and `OLTC and Voltage Regulator parameters`. Use the **Show** listbox to select which group of parameters you want to visualize.

Transformer Tab

Winding 1 connection (ABC terminals)

>   The connection of the three windings 1. Select either, `Y` (ungrounded wye), `Yg` (wye grounded), `Delta(D1)` (Delta connection introducing a −30 degrees phase-

shift) or `Delta(D11)` (Delta connection introducing a +30 degrees phase-shift). See the Three-Phase Transformer (Two-Windings) block documentation for an explanation of the phase shifts introduced by D1and D11 connections. The zero-sequence impedance will vary according to the connection. Zero-sequence impedance is computed assuming that the three-phase transformer bank is built with three single-phase, two-winding units.

Winding 2 connection (abc terminals)

The connection of the three windings 2. Select either, `Y` (ungrounded wye), `Yg` (wye grounded), `Delta(D1)` (Delta connection introducing a −30 degrees phase-shift) or `Delta(D11)` (Delta connection introducing a +30 degrees phase-shift). The zero-sequence impedance will vary according to the connection.

Nominal Power and frequency

The three-phase nominal power, in VA and the nominal frequency, in hertz.

Winding 1 parameters

The nominal line to line voltage of winding 1, in volts rms, winding resistance, in pu, and leakage reactance, in pu.

Winding 2 parameters

The nominal line to line voltage of winding 2, in volts rms, winding resistance in pu, and leakage reactance, in pu.
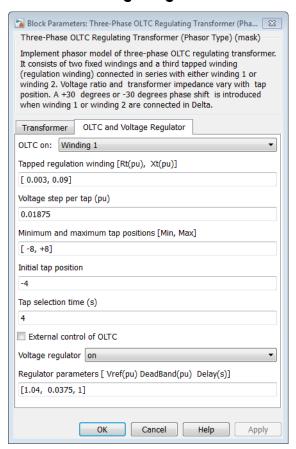
Initial pos. seq. output currents of winding 2

The initial value of the positive-sequence current phasor (Magnitude in pu and Phase in degrees) flowing out of winding 2. The currents flowing into winding 1 will be computed accordingly. If you know the initial value of currents you may specify it in order to start simulation in steady state. If you don't know these values, you can leave [0 0]. The system will reach steady-state after a short transient.

Magnetizing branch

The resistance, in pu and the reactance, in pu, of the parallel Rm, Xm branch modelling respectively iron losses and reactive magnetizing currents. Saturation is not modelled.

OLTC and Voltage Regulator Tab

OLTC on

>   Select either `Winding 1` or `Winding 2`.

Tapped regulation winding

>   The resistance and the leakage reactance of the tapped winding depend on the tap position. Enter the resistance, in pu, and the leakage reactance, in pu, corresponding to the maximum tap position.

Voltage step per tap

>   The voltage step per tap, in pu of the nominal voltage of winding 1 or winding 2.

Minimum and maximum tap positions

You normally specify a negative integer corresponding to maximum tap position with the regulation winding connected in subtractive polarity, followed by a positive integer corresponding to maximum tap position with the regulation winding connected in additive polarity. These two integers specify the number of taps and their absolute values are usually the same. However, if you want to limit tap excursion, you may specify two different values.

Initial tap position

Specify an integer N corresponding to initial tap position with $MinTap \leq N \leq MaxTap$.

Tap selection time

The mechanical time delay, in seconds, required for the OLTC to move the taps by one position. Typical values are in the 3s-10s range.

External control of OLTC

The OLTC is usually controlled by the voltage regulator. Check this parameter if you want to implement your own control system or manually control the tap position. The Vm input will then be replaced by two inputs labeled Up and Down. Applying a pulse to the Up or Down input will move the tap position upward or downward when the signal is changing from 0 to 1.

Voltage regulator

This parameter is not visible when the **External control of OLTC** parameter is checked.

Select on for enabling the voltage regulator. If you select off the OLTC is frozen at the position specified by the **Initial tap position** parameter.

Regulator parameters

This parameter is not visible when the **External control of OLTC** parameter is checked.

Specify the reference voltage Vref, in pu, the dead band of the hysteresis regulator, in pu, and the time delay, in seconds, during which the voltage error must exceed half the dead band for the OLTC to move tap position upward or downward. The dead band is normally adjusted at two times the voltage step specified in the **Voltage step DeltaU per tap** parameter.

Inputs and Outputs

A B C

The three input terminals connected windings 1.

`a b c`

The three output terminals connected to windings 2.

`Vm`

This input is visible only when the **External control of OLTC** parameter is not checked.

Connect to this input the measured voltage to be controlled by the voltage regulator. This signal is usually the magnitude, in pu, of the positive-sequence voltage measured at the transformer terminals (side 1 or side 2) or at a remote bus.

`Up`

This input is visible only when the **External control of OLTC** parameter is checked.

Simulink input for controlling tap position. Applying a pulse to this input will initiate upward tap changing when the pulse is changing from 0 to 1.

`Down`

This input is visible only when the **External control of OLTC** parameter is checked.

Simulink input for controlling tap position. Applying a pulse to this input will initiate downward tap changing when the pulse is changing from 0 to 1.

`m`

Simulink output vector containing 16 internal signals. These signals are either complex signals (voltage phasors, current phasors or impedances) or control signals. They can be individually accessed by using the Bus Selector block. They are, in order:

Signal	Signal Group	Signal Names	Definition
1-3	VABC (cmplx)	VA (pu) VB (pu) VC (pu)	Phasor voltages (phase to ground) at the transformer input terminals A, B, C (pu)
4-6	Vabc (cmplx)	Va (pu) Vb (pu) Vc (pu)	Phasor voltages (phase to ground) at the transformer output terminals a, b, c (pu)
7-9	IABC (cmplx)	IA (pu) IB (pu) IC (pu)	Phasor currents flowing into the input terminals A, B, C

Signal	Signal Group	Signal Names	Definition
10-12	Iabc (cmplx)	Ia (pu) Ib (pu) Ic (pu)	Phasor currents flowing out of the output terminals a, b, c
13-14	Z (cmplx)	Z1 (pu) Z0 (pu)	Positive- and zero-sequence complex impedances (R+jX)
15	Tap	Tap	Tap position
16	Ready	Ready	Logical signal generated by the tap changer controller. This signal is used to enable voltage controller action. The Ready signal becomes (1) after the tap selection has been completed, thus enabling a new tap change. The Up and Down pulses to the OLTC are blocked as long as the Ready signal is (0).

Example

See the `power_OLTCregtransformer` example, which illustrates the use of the Three-Phase OLTC Regulator Transformer (Phasor Type) block to regulate voltage on a 25 kV distribution feeder. The phasor model is compared with a detailed model of regulating transformer. Look under the masked blocks to see how both models are implemented. The detailed model uses switches and three Multi-Winding Transformer blocks, whereas the phasor model uses current sources.

See Also

Three-Phase OLTC Phase Shifting Transformer Delta-Hexagonal (Phasor Type)

Three-Phase Parallel RLC Branch
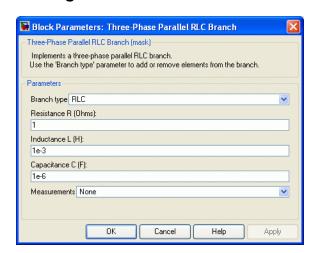
Implement three-phase parallel RLC branch

Library

Fundamental Blocks/Elements

Description

The Three-Phase Parallel RLC Branch block implements three balanced branches consisting each of a resistor, an inductor, a capacitor, or a parallel combination of these. Use the **Branch type** parameter to select elements you want to include in each branch.

Negative values are allowed for resistance, inductance, and capacitance.

Dialog Box and Parameters

Branch type

Select the elements you want to include in the branch. The **R** letter defines the resistor, the **L** letter defines the inductor, and the **C** letter defines the capacitor. Select **Open circuit** to define an open circuit (R=inf, L=inf, C=0). Only existing elements are displayed in the block icon.

Resistance R

The branch resistances, in ohms (Ω).

Inductance L

The branch inductances, in henries (H).

Capacitance C

The branch capacitances, in farads (F).

Measurements

Select `Branch voltages` to measure the three voltages across the Three-Phase Parallel RLC Branch block terminals.

Select `Branch currents` to measure the three total currents (sum of R, L, C currents) flowing through the Three-Phase Parallel RLC Branch block.

Select `Branch voltages and currents` to measure the three voltages and the three currents of the Three-Phase Parallel RLC Branch block.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

Measurement	Label
Branch voltages of phases A, B, and C	Ua: , Ub: , Uc:
Branch currents of phases A, B, and C	Ia: , Ib: , Ic:

See Also

Multimeter, Three-Phase Parallel RLC Load, Three-Phase Series RLC Branch, Three-Phase Series RLC Load

Three-Phase Parallel RLC Load

Implement three-phase parallel RLC load with selectable connection

Library

Fundamental Blocks/Elements

Description
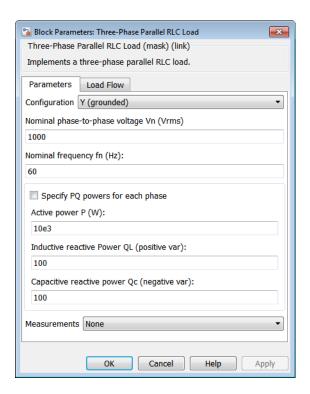
The Three-Phase Parallel RLC Load block implements a three-phase balanced load as a parallel combination of RLC elements. At the specified frequency, the load exhibits a constant impedance. The active and reactive powers absorbed by the load are proportional to the square of the applied voltage.

Only elements associated with nonzero powers are displayed in the block icon.

Dialog Box and Parameters

Parameters Tab

Configuration

The connection of the three phases. Select one of the following four connections:

Y(grounded)	Neutral is grounded.
Y(floating)	Neutral is not accessible.
Y(neutral)	Neutral is made accessible through a fourth connector.
Delta	Three phases connected in delta

The block icon is updated according to the load connection.

Nominal phase-to-phase voltage Vn

The nominal phase-to-phase voltage of the load, in volts RMS (Vrms).

Nominal frequency fn

The nominal frequency, in hertz (Hz).

Specify PQ powers for each phase

Select to specify active powers, inductive reactive powers, and capacitive reactive powers for each phase of the load.

Active power P (W)

The three-phase active power of the load, in watts. This parameter is visible only when **Specify PQ powers for each phase** is cleared.

Inductive reactive power QL (positive var)

The three-phase inductive reactive power QL, in vars. Specify a positive value or 0. This parameter is visible only when **Specify PQ powers for each phase** is cleared.

Capacitive reactive power QC (negative var)

The three-phase capacitive reactive power QC, in vars. Specify a positive value or 0. This parameter is visible only when **Specify PQ powers for each phase** is cleared.

Active powers [Pa Pb Pc] (W):

The three-phase active power of the load, in watts. Specify three positive values. You can specify different powers for each phase, including 0. This parameter is visible only when you select **Specify PQ powers for each phase**.

Inductive reactive powers [QLa QLb QLc] (positive var):

The three-phase inductive reactive power QL, in vars. Specify three positive values. You can specify different powers for each phase, including 0. This parameter is visible only when you select **Specify PQ powers for each phase**.

Capacitive reactive powers [QCa QCb QCc] (negative var):

The three-phase capacitive reactive power QC, in vars. Specify three positive values. You can specify different powers for each phase, including 0. This parameter is visible only when you select **Specify PQ powers for each phase**.

Measurements

Select `Branch voltages` to measure the three voltages across each phase of the Three-Phase Parallel RLC Load block terminals. For a Y connection, these voltages are the phase-to-ground or phase-to-neutral voltages. For a delta connection, these voltages are the phase-to-phase voltages.

Select `Branch currents` to measure the three total currents (sum of R, L, C currents) flowing through each phase of the Three-Phase Parallel RLC Load block. For a delta connection, these currents are the currents flowing in each branch of the delta.

Select **Branch voltages and currents** to measure the three voltages and the three currents of the Three-Phase Parallel RLC Load block.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

Measurement		Label
Branch voltages	Y(grounded): Uag, Ubg, Ucg	Uag: , Ubg: , Ucg:
	Y(floating): Uan, Ubn, Ucn	Uan: , Ubn: , Ucn:
	Y(neutral): Uan, Ubn, Ucn	Uan: , Ubn: , Ucn:
	Delta: Uab, Ubc, Uca	Uab: , Ubc: , Uca:
Branch currents	Y(grounded): Ia, Ib, Ic	Iag: , Ibg: , Icg:
	Y(floating): Ia, Ib, Ic	Ian: , Ibn: , Icn:
	Y(neutral): Ia, Ib, Ic	Ian: , Ibn: , Icn:
	Delta: Iab, Ibc, Ica	Iab: , Ibc: , Ica:

Load Flow Tab

The parameters on this tab are used by the Load Flow tool of the Powergui block. These load flow parameters are used for model initialization only, they have no impact on the block model and on the simulation performance.

Load type

Specify the load type.

If you select `constant Z`, the load impedance is determined from the nominal phase-to-phase voltage Vn, active power P, and reactive power (QL-QC) specified on the **Parameters** tab of the block dialog box. During the load flow solution, the impedance is kept constant. The effective P and Q are therefore varying proportionally to the square of the bus voltage computed by the Load Flow tool.

If you select `constant PQ`, the active power P and reactive power Q are kept constant and equal to the values specified on the **Parameters** tab of the block dialog box. When you apply the load flow solution to the model (by clicking the **Apply** button of the Load Flow tool), the **Nominal phase-to-phase voltage Vn** parameter on the **Parameters** tab is automatically adjusted to the phase-to-phase bus voltage computed by the Load Flow tool.

If you select `constant I`, the load current is kept constant at its nominal value determined from base voltage specified in the dialog box of the associated Load

Flow Bus block and from active power P and reactive power QL and QC specified on the **Parameters** tab of the block dialog box. The effective P and Q are therefore varying proportionally to the bus voltage computed by the Load Flow tool. When you apply the load flow solution to the model (by clicking the **Apply** button of the Load Flow tool), the p.u. value of the nominal voltage Vn on the **Parameters** tab is automatically adjusted to the square root of the load voltage (in pu) computed by the Load Flow tool.

See Also

Multimeter, Three-Phase Dynamic Load, Three-Phase Parallel RLC Branch, Three-Phase Series RLC Branch, Three-Phase Series RLC Load

Three-Phase PI Section Line

Implement three-phase transmission line section with lumped parameters
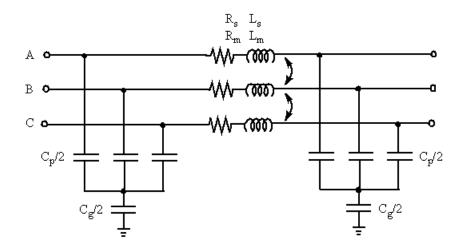
Library

Fundamental Blocks/Elements

Description

The Three-Phase PI Section Line block implements a balanced three-phase transmission line model with parameters lumped in a PI section.

Contrary to the Distributed Parameter Line model where the resistance, inductance, and capacitance are uniformly distributed along the line, the Three-Phase PI Section Line block lumps the line parameters in a single PI section as shown in the figure below.

The line parameters R, L, and C are specified as positive- and zero-sequence parameters that take into account the inductive and capacitive couplings between the three phase

conductors, as well as the ground parameters. This method of specifying line parameters assumes that the three phases are balanced.

The self and mutual resistances (*Rs*, *Rm*), self and mutual inductances (*Ls*, *Lm*) of the three coupled inductors, as well as phase capacitances *Cp* and ground capacitances *Cg*, are deduced from the positive- and zero-sequence RLC parameters as follows.

Let us assume the following line parameters:

r_1, r_0	Positive- and zero-sequence resistances per unit length (Ω/km)
l_1, l_0	Positive- and zero-sequence inductances per unit length (H/km)
c_1, c_0	Positive- and zero-sequence capacitances per unit length (F/km)
f	Frequency (Hz)
lsec	Line section length (km)

The total positive- and zero-sequence RLC parameters including hyperbolic corrections are first evaluated:

$$R_1 = r_1 \cdot l\sec \cdot k_{r1}$$
$$L_1 = l_1 \cdot l\sec \cdot k_{l1}$$
$$C_1 = c_1 \cdot l\sec \cdot k_{c1}$$
$$R_0 = r_0 \cdot l\sec \cdot k_{r0}$$
$$L_0 = l_0 \cdot l\sec \cdot k_{l0}$$
$$C_0 = c_0 \cdot l\sec \cdot k_{c0}$$

where

k_{r1}, k_{l1}, k_{c1}, k_{r0}, k_{l0}, k_{c0} — positive-sequence and zero-sequence hyperbolic correction factors

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Note See the PI Section Line block reference page for an explanation on how to compute RLC parameters taking into account hyperbolic corrections.
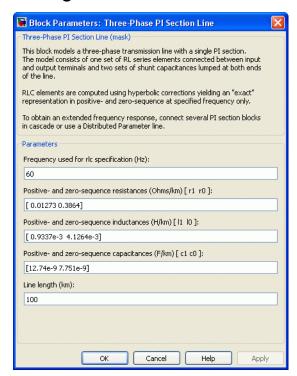
The Powergui block provides a graphical tool for the calculation of resistance, inductance, and capacitance per unit length based on the line geometry and the conductor characteristics. See the `power_lineparam` reference page to learn how to use this tool.

For a short line section (approximately *lsec* < 50 km), these correction factors are negligible (close to unity). However, for long lines, these hyperbolic corrections must be taken into account in order to get an exact line model at the specified frequency.

The RLC line section parameters are then computed as follows:

$$Rs = (2R_1 + R_0)/3$$
$$Ls = (2L_1 + L_0)/3$$
$$R_m = (R_0 - R_1)/3$$
$$L_m = (L_0 - L_1)/3$$
$$C_p = C_1$$
$$C_g = 3C_1C_0/(C_1 - C_0)$$

Dialog Box and Parameters

Frequency used for rlc specification

The frequency used for specification of per unit length rlc line parameters, in hertz (Hz). This is usually the nominal system frequency (50 Hz or 60 Hz).

Positive- and zero-sequence resistances

The positive- and zero-sequence resistances in ohms/kilometer (Ω/km).

Positive- and zero-sequence inductances

The positive- and zero-sequence inductances in henries/kilometer (H/km). The zero-sequence inductance can not be zero, because it would result in an invalid propagation speed computation.

Positive- and zero-sequence capacitances

The positive- and zero-sequence capacitances in farads/kilometer (F/km). The zero-sequence capacitance can not be zero, because it would result in an invalid propagation speed computation.

Line section length

    The line section length in kilometers (km).

Example

The power_triphaseline example illustrates voltage transients at the receiving end of a 200 km line when only phase A is energized. Voltages obtained with two line models are compared: 1) the Distributed Parameters Line block and 2) a PI line model using two Three-Phase PI Section Line blocks.

See Also

Distributed Parameter Line, PI Section Line

Three-Phase Programmable Generator

Generate three-phase signal with programmable time variation of amplitude, phase, frequency, and harmonics

Library

Control and Measurements/Pulse & Signal Generators

Description
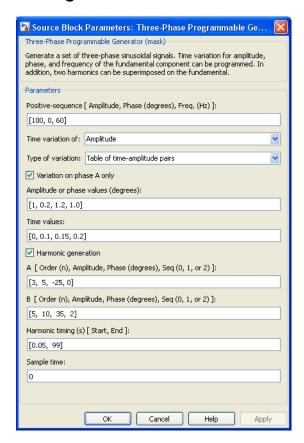
Use the Three-Phase Programmable Generator block to generate a three-phase sinusoidal signal with time-varying parameters. This vectorized signal usually represents a set of three-phase voltages or currents. You can program the time variation for the amplitude, phase, or frequency of the fundamental component of the signal. In addition, you can program two harmonics and superimpose them on the fundamental signal.

Dialog Box and Parameters

Positive-sequence [Amplitude, Phase (degrees), Freq (Hz)]

Specify the amplitude (in volts, amperes, or pu), the phase (in degrees), and the frequency (in hertz) of the positive-sequence component of the three-phase signal.

Time variation of

Specify whether you want to program the time variation of the amplitude, phase, or frequency. If you do not want to program a generator time variation, select None.

The time variation applies to the three phases of the source except when the **Type of variation** parameter is set to Table of amplitude-pairs. In that case, you can apply a variation to phase A only.

Type of variation

Specify the type of variation to apply to the amplitude, phase, or frequency specified by the **Time variation of** parameter. Options include `Step`, `Ramp`, `Modulation` (for sinusoidal modulation), and `Table of amplitude-pairs` (a series of step changes of amplitude or phase at specific times).

Step magnitude

This parameter is visible only when the **Type of Variation** parameter is set to `Step`.

Specify the amplitude of the step change of the magnitude of a positive-sequence amplitude (in volts, amperes, or pu), phase (in degrees), or frequency (in hertz).

Rate of change (value/s)

This parameter is visible only when the **Type of Variation** parameter is set to `Ramp`.

Specify the rate of change of amplitude (in volts/second, amperes/second, or pu/second), phase (in degrees/second), or frequency (in hertz/second).

Amplitude of the modulation

This parameter is visible only when the **Type of Variation** parameter is set to `Modulation`.

Specify the amplitude of the modulation for the amplitude, frequency, or phase, as specified in the **Time variation of** parameter.

Frequency of the modulation (Hz)

This parameter is visible only when the **Type of Variation** parameter is set to `Modulation`.

Specify the frequency of the modulation for the amplitude, phase, or frequency, as specified in the **Time variation of** parameter.

Variation timing (s) [Start, End]

This parameter is visible only when the **Type of Variation** parameter is set to `Step`, `Ramp`, or `Modulation`.

Specify the time, in seconds, when the programmed time variation takes effect and stops.

Variation on phase A only

This parameter is visible only when the **Type of Variation** parameter is set to `Table of time-amplitude pairs`.

When this check box is selected, the time variation specified by the **Amplitude** or **phase values** and **Time values** parameters is applied on phase A only.

Amplitude or phase values (degrees)

This parameter is visible only when the **Type of Variation** parameter is set to `Table of time-amplitude pairs`.

Use this parameter to specify the amplitude or phase values of phase A when **Variation on phase A only** is selected. Otherwise, use it to specify the positive sequence amplitudes or phase values (in degrees) corresponding to times specified in the **Time values** parameter.

Time values

This parameter is visible only when the **Type of Variation** parameter is set to `Table of time-amplitude pairs`.

Specify the times, in seconds, when the amplitude or phase will change, according to the values specified in the **Amplitude or phase values** parameter.

Harmonic generation

Select this check box to enable programming of two harmonics that can be superimposed on the fundamental voltage of the source.

A: [Order (n), Amplitude, Phase (degrees), Seq(0, 1 or 2)]

This parameter is visible only when the **Harmonic generation** check box is selected.

Specify the order, amplitude, phase, and the type of sequence (1 = positive-sequence; 2 = negative-sequence; 0 = zero-sequence) of the first harmonic to superimpose on the fundamental signal.

Specify 1 for the harmonic order and 1 for the sequence to produce a positive-sequence amplitude change without imbalance and without harmonics.

Specify 1 for the harmonic order and 0 or 2 for the sequence to produce a signal imbalance without harmonics.

B: [Order (n), Amplitude, Phase (degrees), Seq(0, 1 or 2)]

This parameter is visible only when the Harmonic generation check box is selected. Specify the order, amplitude, phase, and the type of sequence (1 = positive-sequence;

2 = negative-sequence; 0 = zero-sequence) of the second harmonic to superimpose on the fundamental signal.

Harmonic timing (s) [Start, End]

This parameter is visible only when the **Harmonic generation** check box is selected.

Specify the time, in seconds, when the harmonic generation is superimposed on the fundamental signal and the time when it stops.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Inputs and Outputs

abc

Returns the vectorized signal of phases a, b, and c.

m

Simulink output vector containing eight internal signals.

Signal	Signal Names	Definition
1-3	Mag_abc	Magnitudes of the fundamental component of a, b, c signals
4-6	Phase_abc (deg)	Phases of the fundamental component of a, b, c signals (degrees)
7	Freq (Hz)	Frequency of the fundamental component of a, b, c signals (hertz)
8	wt (rad)	Instantaneous angle of the rotating vector of the positive-sequence component (radians)

Characteristics

Sample Time	• Specified in the **Sample Time** parameter
	• Continuous if **Sample Time** = 0

Scalar Expansion	No
Dimensionalized	No

Example

The power_ThreePhaseProgrammableGenerator model shows two applications of the Three-Phase Programmable Generator block.

In the top model, a sinusoidal modulation of amplitude is programmed from 0.1 s to 0.6 s. Then a positive-sequence signal sag is produced from 0.7 s to 0.9 s by adding a positive-sequence harmonic of order 1 with a 180-degree phase-shift.

In the bottom model, a frequency ramp is programmed from 0.1 s to 0.6 s, and then two harmonics (2nd and 5th) are added from 0.7 s to 0.9 s. The magnitude, phase, and frequency of positive-sequence component are measured using a PLL and a Positive-Sequence (PLL-Driven) block. Variations of measured quantities are compared with specified values available at the measurement output (m).

The model sample time is parameterized with variable Ts (default value Ts=50e-6). To simulate the continuous Three-Phase Programmable Generator block, specify Ts = 0 in the MATLAB Command Window before starting the simulation.

See Also

`Three-Phase Programmable Voltage Source`, `Three-Phase Sine Generator`

Three-Phase Programmable Voltage Source

Implement three-phase voltage source with programmable time variation of amplitude, phase, frequency, and harmonics
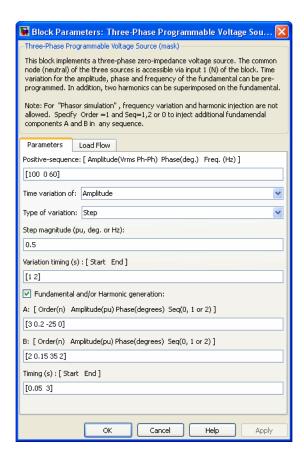
Library

Fundamental Blocks/Electrical Sources

Description

Use this block to generate a three-phase sinusoidal voltage with time-varying parameters. You can program the time variation for the amplitude, phase, or frequency of the fundamental component of the source. In addition, two harmonics can be programmed and superimposed on the fundamental signal.

Dialog Box and Parameters

Parameters Tab

Positive-sequence

The amplitude in volts RMS phase-to-phase, the phase in degrees, and the frequency in hertz of the positive-sequence component of the three voltages.

Time variation of

Specify the parameter for which you want to program the time variation. Select None if you do not want to program the time variation of the source parameters. Select

`Amplitude` if you want to program the time variation of the amplitude. Select `Phase` if you want to program the time variation of the phase. Select `Frequency` if you want to program the time variation of the frequency.

The time variation applies to the three phases of the source except when the **Type of variation** parameter is set to `Table of amplitude-pairs`. In that case you can apply a variation to phase A only.

Type of variation

Specify the type of variation that is applied to the parameter specified by the **Time variation of** parameter. Select `Step` to program a step variation. Select `Ramp` to program a ramp variation. Select `Modulation` to program a modulated variation. Select `Table of amplitude-pairs` to program a series of step changes of amplitudes at specific times.

The `Table of amplitude-pairs` option is available only when the **Time variation of** parameter is set to `Amplitude`.

Step magnitude

This parameter is visible only if the **Type of variation** parameter is set to `Step`.

Specify the amplitude of the step change. The variation of amplitude is specified in pu of the positive-sequence amplitude.

Rate of change

This parameter is visible only if the **Type of variation** parameter is set to `Ramp`.

Specify the rate of change, in volt/seconds. The rate of change of voltage is specified in (pu of the positive-sequence voltage)/second.

Amplitude of the modulation

This parameter is only visible if the **Type of variation** parameter is set to `Modulation`.

Specify the amplitude of the modulation for the source parameter that is specified in the **Time variation of** parameter. When the varying quantity is the voltage amplitude, the amplitude of the modulation is specified in pu of the positive-sequence amplitude.

Frequency of the modulation

This parameter is only visible if the **Type of variation** parameter is set to `Modulation`.

Specify the frequency of the modulation for the source parameter specified in the **Time variation of** parameter.

Variation timing(s)

Specify the time, in seconds, when the programmed time variation takes effect and the time when it stops.

Fundamental and/or Harmonic generation

If selected, two harmonics can be programmed to be superimposed on the fundamental voltage of the source.

A: [Order Amplitude Phase Seq]

This parameter is only visible if the **Fundamental and/or Harmonic generation** check box is selected.

Specify the order, amplitude, phase, and the type of sequence (1 = positive-sequence; 2 = negative-sequence; 0 = zero-sequence) of the first harmonic to be superimposed on the fundamental signal. The voltage of the harmonic is specified in pu of the positive-sequence voltage.

Specify 1 for the harmonic order and 0 or 2 for the sequence to produce a voltage imbalance without harmonics.

B: [Order Amplitude Phase Seq]

This parameter is only visible if the **Fundamental and/or Harmonic generation** check box is selected.

Specify the order, amplitude, phase, and the type of sequence (0 = zero sequence, 1 = positive sequence, 2 = negative sequence) of the second harmonic to be superimposed on the fundamental signal. The voltage of the harmonic is specified in pu of the positive-sequence voltage.

Specify 1 for the harmonic order and 0 or 2 for the sequence to produce a voltage unbalance without harmonics.

Variation Timing(s)
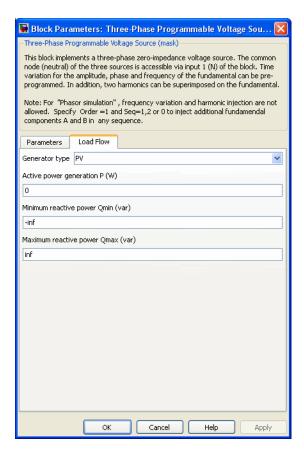
This parameter is visible only if the **Fundamental and/or Harmonic generation** check box is selected.

Specify the time, in seconds, when the harmonic generation is superimposed on the fundamental signal and the time when it stops.

Load Flow Tab

The load flow parameters are used to define block parameters for use with the Load Flow tool of the Powergui block. These load flow parameters are used for model initialization only. They have no impact on the block model and on the simulation's performance.

The configuration of the **Load Flow** tab depends on the option selected for the **Generator type** parameter.

Generator type

Specify the generator type of the voltage source.

Select `swing` to implement a generator controlling magnitude and phase angle of its terminal voltage. The reference voltage magnitude and angle are specified by the **Swing bus or PV bus voltage** and **Swing bus voltage angle** parameters of the Load Flow Bus block connected to the voltage source terminals.

Select `PV` to implement a generator controlling its output active power P and voltage magnitude V. P is specified by the **Active power generation P** parameter of the block. V is specified by the **Swing bus or PV bus voltage** parameter of the Load Flow Bus block connected to the voltage source terminals. You can control the minimum and maximum reactive power generated by the block by using the **Minimum reactive power Qmin** and **Maximum reactive power Qmax** parameters.

Select `PQ` to implement a generator controlling its output active power P and reactive power Q. P and Q are specified by the **Active power generation P** and **Reactive power generation Q** parameters of the block, respectively.

Active power generation P

Specify the active power that you want generated by the source, in watts. This parameter is available if you specify **Generator type** as `PV` or `PQ`.

Reactive power generation Q

Specify the reactive power that you want generated by the source, in vars. This parameter is available only if you specify **Generator type** as `PQ`.

Minimum reactive power Qmin

This parameter is available only if you specify **Generator type** as `PV`. Indicates the minimum reactive power that can be generated by the source while keeping the terminal voltage at its reference value. This reference voltage is specified in the **Swing bus or PV bus voltage** parameter of the Load Flow Bus block connected to the source terminals. The default value is `-inf`, which means that there is no lower limit on the reactive power output.

Maximum reactive power Qmax

This parameter is available only if you specify **Generator type** as `PV`. Indicates the maximum reactive power that can be generated by the source while keeping the terminal voltage at its reference value. This reference voltage is specified in the **Swing bus or PV bus voltage** parameter of the Load Flow Bus block connected to the source terminals. The default value is `inf`, which means that there is no upper limit on the reactive power output.

Example

The power_3phsignalseq circuit illustrates the use of the Three-Phase Programmable Voltage Source block to produce a step variation of the positive-sequence voltage and to inject harmonics into the circuit.

A 25 kV, 100 MVA short-circuit level, equivalent network feeds a 5 MW, 2 Mvar capacitive load. The internal voltage of the source is controlled by the Discrete 3-phase Programmable Voltage Source block.

A positive sequence of 1.0 pu, 0 degrees is specified for the fundamental signal. At t = 0.05 s a step of 0.5 pu is applied to the positive-sequence voltage magnitude, then at t = 0.1 s, 0.08 pu of fifth harmonic in negative sequence is added to the 1.5 pu voltage.

The three-phase voltage and current are measured at the output of the source impedance. Two Discrete Sequence Analyzer blocks are used to measure the positive-sequence fundamental component and the negative-sequence fifth harmonic of the three-phase voltage.

See Also

Three-Phase Source

Three-Phase Sequence Analyzer

Measure positive-, negative-, and zero-sequence components of three-phase signal

Library

powerlib_extras/Measurements, powerlib_extras/Discrete Measurements

---

Note: The Measurements section of the Control and Measurements library contains the Sequence Analyzer block. This is an improved version of the Three-Phase Sequence Analyzer block. The new block features a mechanism that eliminates duplicate continuous and discrete versions of the same block by basing the block configuration on the simulation mode. If your legacy models contain the Three-Phase Sequence Analyzer block, they will continue to work. However, for best performance, use the Sequence Analyzer block in your new models.

Description

The Three-Phase Sequence Analyzer block outputs the magnitude and phase of the positive- (denoted by the index 1), negative- (index 2), and zero-sequence (index 0) components of a set of three balanced or unbalanced signals. The signals can contain harmonics or not. The three sequence components of a three-phase signal (voltages V1 V2 V0 or currents I1 I2 I0) are computed as follows:

$V_1 = (V_a + aV_b + a^2V_c)/3$

$V_2 = (V_a + a^2V_b + aV_c)/3$

$V_0 = (V_a + V_b + V_c)/3$

where
V_a, V_b, V_c = three voltage phasors at specified frequency
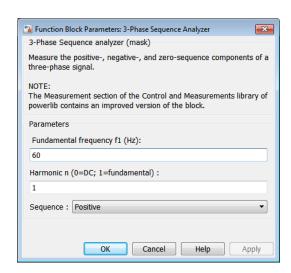
$a = e^{j2\pi}/3 = 1\angle120°$ complex operator.

A Fourier analysis over a sliding window of one cycle of the specified frequency is first applied to the three input signals. It evaluates the phasor values V_a, V_b, and V_c at the specified fundamental or harmonic frequency. Then the transformation is applied to obtain the positive sequence, negative sequence, and zero sequence.

The Three-Phase Sequence Analyzer block is not sensitive to harmonics or imbalances. However, as this block uses a running average window to perform the Fourier analysis, one cycle of simulation has to be completed before the outputs give the correct magnitude and angle. For example, its response to a step change of V_1 is a one-cycle ramp.

The discrete version of this block allows you to specify the initial magnitude and phase of the output signal. For the first cycle of simulation the outputs are held to the values specified by the initial input parameter.

You can modify any parameter during the simulation in order to obtain the different sequence and harmonic components of the input signals.

Dialog Box and Parameters

Fundamental frequency f1

The fundamental frequency, in hertz, of the three-phase input signal.

Harmonic n

Specify the harmonic component from which you want to evaluate the sequences. For DC, enter `0`. For fundamental, enter `1`.

Sequence

Specify which sequence component the block outputs. Select `Positive` to calculate the positive sequence, select `Negative` to calculate the negative sequence, select `0` to compute the zero sequence of the fundamental or specified harmonic of the three-phase input signal. Select `Positive Negative Zero` to get all the sequences.

Inputs and Outputs

abc

Connect to the input the vectorized signal of the three [a b c] sinusoidal signals.

Mag

The first output gives the magnitude (peak value) of the specified sequence component, in the same units as the `abc` input signals.

Phase
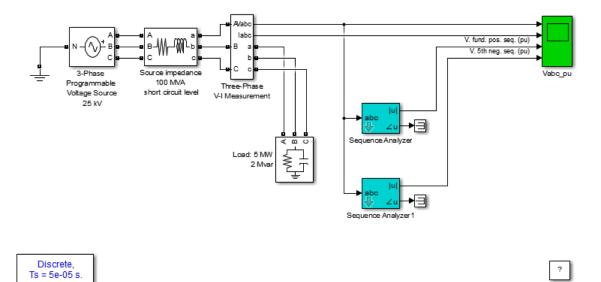
The second output gives the phase in degrees of the specified component(s).

Example

The power_3phsignalseq example illustrates the use of the Sequence Analyzer block (the improved version of the Three-Phase Sequence Analyzer block) to measure the fundamental and harmonic components of a three-phase voltage. A 25kV, 100 MVA short-circuit level, equivalent network feeds a 5 MW, 2 Mvar capacitive load. The internal voltage of the source is controlled by the Programmable Voltage Source block.

A positive sequence of 1.0 pu, 0 degrees is specified for the fundamental signal. At t = 0.05 s a step of 0.5 pu is applied on the positive-sequence voltage magnitude, then at t = 0.1 s, 0.08 pu of fifth harmonic in negative sequence is added to the 1.5 pu voltage.

Two Sequence Analyzer blocks are used to measure the positive-sequence fundamental component and the negative-sequence fifth harmonic of the three-phase voltage.

As the Sequence Analyzer blocks use Fourier analysis, their response time is delayed by one cycle of the fundamental frequency.

See Also

Sequence Analyzer

Three-Phase Series RLC Branch
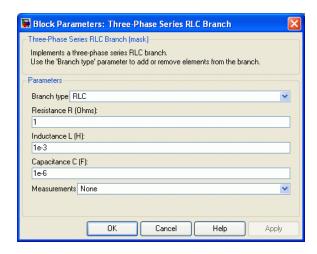
Implement three-phase series RLC branch

Library

Fundamental Blocks/Elements

Description

The Three-Phase Series RLC Branch block implements three balanced branches consisting each of a resistor, an inductor, or a capacitor or a series combination of these. Use the **Branch type** parameter to select elements you want to include in each branch.

Negative values are allowed for resistance, inductance, and capacitance.

Dialog Box and Parameters

Branch Type

Select the elements you want to include in the branch. The **R** letter defines the resistor, the **L** letter defines the inductor, and the **C** letter defines the capacitor. Select **Open circuit** to define an open circuit (R=0, L=0, C=inf). Only existing elements are displayed in the block icon.

Resistance R

The branch resistances, in ohms (Ω).

Inductance L

The branch inductances, in henries (H).

Capacitance C

The branch capacitances, in farads (F).

Measurements

Select `Branch voltages` to measure the three voltages across the Three-Phase Series RLC Branch block terminals.

Select `Branch currents` to measure the three currents flowing through the Three-Phase Series RLC Branch block.

Select `Branch voltages and currents` to measure the three voltages and the three currents of the Three-Phase Series RLC Branch block.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

Measurement	Label
Branch voltages of phases A, B, and C	Ua: , Ub: , Uc:
Branch currents of phases A, B, and C	Ia: , Ib: , Ic:

See Also

Multimeter, Three-Phase Parallel RLC Branch,Three-Phase Parallel RLC Load, Three-Phase Series RLC Load

Three-Phase Series RLC Load

Implement three-phase series RLC load with selectable connection

Library

Fundamental Blocks/Elements

Description
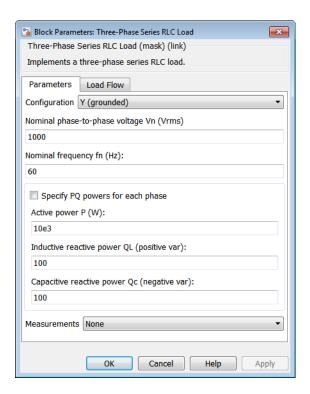
The Three-Phase Series RLC Load block implements a three-phase balanced load as a series combination of RLC elements. At the specified frequency, the load exhibits a constant impedance. The active and reactive powers absorbed by the load are proportional to the square of the applied voltage.

Only elements associated with nonzero powers are displayed in the block icon.

Dialog Box and Parameters

Parameters Tab

Configuration

The connection of the three phases. Select one of the following four connections:

`Y(grounded)`	Neutral is grounded.
`Y(floating)`	Neutral is not accessible.
`Y(neutral)`	Neutral is made accessible through a fourth connector.
`Delta`	Three phases connected in delta

The block icon is updated according to the load connection.

Nominal phase-to-phase voltage Vn

The nominal phase-to-phase voltage of the load, in volts RMS (Vrms).

Nominal frequency fn

The nominal frequency, in hertz (Hz).

Specify PQ powers for each phase

Select to specify active powers, inductive reactive powers, and capacitive reactive powers for each phase of the load.

Active power P (W)

The three-phase active power of the load, in watts. This parameter is visible only when **Specify PQ powers for each phase** is cleared.

Inductive reactive power QL (positive var)

The three-phase inductive reactive power QL, in vars. Specify a positive value or 0. This parameter is visible only when **Specify PQ powers for each phase** is cleared.

Capacitive reactive power QC (negative var)

The three-phase capacitive reactive power QC, in vars. Specify a positive value or 0. This parameter is visible only when **Specify PQ powers for each phase** is cleared.

Active powers [Pa Pb Pc] (W):

The three-phase active power of the load, in watts. Specify three positive values. You can specify different powers for each phase, including 0. This parameter is visible only when you select **Specify PQ powers for each phase**.

Inductive reactive powers [QLa QLb QLc] (positive var):

The three-phase inductive reactive power QL, in vars. Specify three positive values. You can specify different powers for each phase, including 0. This parameter is visible only when you select **Specify PQ powers for each phase**.

Capacitive reactive powers [QCa QCb QCc] (negative var):

The three-phase capacitive reactive power QC, in vars. Specify three positive values. You can specify different powers for each phase, including 0. This parameter is visible only when you select **Specify PQ powers for each phase**.

Measurements

Select `Branch voltages` to measure the three voltages across each phase of the Three-Phase Series RLC Load block terminals. For a Y connection, these voltages are the phase-to-ground or phase-to-neutral voltages. For a delta connection, these voltages are the phase-to-phase voltages.

Select `Branch currents` to measure the three total currents (sum of R, L, C currents) flowing through each phase of the Three-Phase Series RLC Load block. For a delta connection, these currents are the currents flowing in each branch of the delta.

Select `Branch voltages and currents` to measure the three voltages and the three currents of the Three-Phase Series RLC Load block.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

Measurement		Label
Branch voltages	Y(grounded): Uag, Ubg, Ucg	`Uag: , Ubg: , Ucg:`
	Y(floating): Uan, Ubn, Ucn	`Uan: , Ubn: , Ucn:`
	Y(neutral): Uan, Ubn, Ucn	`Uan: , Ubn: , Ucn:`
	Delta: Uab, Ubc, Uca	`Uab: , Ubc: , Uca:`
Branch currents	Y(grounded): Ia, Ib, Ic	`Iag: , Ibg: , Icg:`
	Y(floating): Ia, Ib, Ic	`Ian: , Ibn: , Icn:`
	Y(neutral): Ia, Ib, Ic	`Ian: , Ibn: , Icn:`
	Delta: Iab, Ibc, Ica	`Iab: , Ibc: , Ica:`

Load Flow Tab

The parameters on this tab are used by the Load Flow tool of the Powergui block. These load flow parameters are used for model initialization only, they have no impact on the block model and on the simulation performance.

Load type

Specify the load type.

If you select `constant Z`, the load impedance is determined from the nominal phase-to-phase voltage Vn, active power P, and reactive power (QL-QC) specified on the **Parameters** tab of the block dialog box. During the load flow solution, the impedance is kept constant. The effective P and Q are therefore varying proportionally to the square of the bus voltage computed by the Load Flow tool.

If you select `constant PQ`, the active power P and reactive power Q are kept constant and equal to the values specified on the **Parameters** tab of the block dialog box. When you apply the load flow solution to the model (by clicking the **Apply** button of the Load Flow tool), the **Nominal phase-to-phase voltage Vn** parameter on the **Parameters** tab is automatically adjusted to the phase-to-phase bus voltage computed by the Load Flow tool.

If you select `constant I`, the load current is kept constant at its nominal value determined from base voltage specified in the dialog box of the associated Load

Flow Bus block and from active power P and reactive power QL and QC specified on the **Parameters** tab of the block dialog box. The effective P and Q are therefore varying proportionally to the bus voltage computed by the Load Flow tool. When you apply the load flow solution to the model (by clicking the **Apply** button of the Load Flow tool), the p.u. value of the nominal voltage Vn on the **Parameters** tab is automatically adjusted to the square root of the load voltage (in pu) computed by the Load Flow tool.

See Also

Multimeter, Three-Phase Dynamic Load, Three-Phase Parallel RLC Branch, Three-Phase Parallel RLC Load, Three-Phase Series RLC Branch

Three-Phase Sine Generator

Generate three-phase balanced signal, amplitude, phase, and frequency controlled by block inputs

Library

Control and Measurements/Pulse & Signal Generators

Description
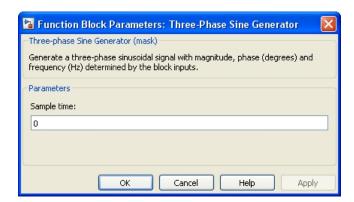
Use the Three-Phase Sine Generator block to generate a three-phase balanced sinusoidal signal (positive-sequence). This vectorized signal usually represents a set of three-phase voltages or currents. Three inputs let you control the amplitude, phase, and frequency of the three-phase output signal.

Dialog Box and Parameters

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Inputs and Outputs

`mag u`

Specify the amplitude of the three-phase output signal.

`angle u`

Specify the angle, in degrees, of the three-phase output signal.

`Freq`

Specify the frequency, in hertz, of the three-phase output signal.

`abc`

Returns the three-phase signal.

`wt`

Angle (rad) varying between 0 and 2*pi, synchronized on zero crossings of the fundamental (positive-sequence) of phase A.

Characteristics

Sample Time	• Specified in the **Sample Time** parameter
	• Continuous if **Sample Time** = 0
Scalar Expansion	No
Dimensionalized	No

Example

The power_ThreePhaseSineGenerator model shows the use of the Three-Phase Sine Generator block.

The initial three-phase signal is set to 1 pu, 60 Hz, 90 deg. The following variations are applied on amplitude and frequency while phase stays constant:

- From 0.1 s to 0.4 s, frequency is ramped from 60 Hz to 63 Hz.

- From 0.2 s to 0.4 s, amplitude is sinusoidally modulated with an amplitude of 0.4 pu and a frequency of 5 Hz.

Measured amplitude and frequency are compared with specified values.

The model sample time is parameterized with variable Ts (default value Ts = 50e-6). To simulate the continuous Three-Phase Programmable Generator block, specify Ts = 0 in the command window.

See Also

`Three-Phase Programmable Voltage Source`, `Three-Phase Programmable Generator`

Three-Phase Source

Implement three-phase source with internal R-L impedance

Library

Fundamental Blocks/Electrical Sources

Description
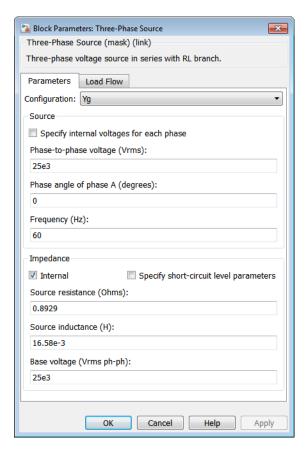
The Three-Phase Source block implements a balanced three-phase voltage source with an internal R-L impedance. The three voltage sources are connected in Y with a neutral connection that can be internally grounded or made accessible. You can specify the source internal resistance and inductance either directly by entering R and L values or indirectly by specifying the source inductive short-circuit level and X/R ratio.

Dialog Box and Parameters

Parameters Tab

Configuration

> The internal connection of the three internal voltage sources. The block icon is updated according to the source connection.

> Select one of these connections:

Y	The three voltage sources are connected in Y to an internal floating neutral.

Yn	The three voltage sources are connected in Y to a neutral connection which is made accessible through a fourth terminal.
Yg	The three voltage sources are connected in Y to an internally grounded neutral.

Specify internal voltages for each phase

Select to specify internal voltage for each phase.

Phase-to-phase rms voltage

The internal phase-to-phase voltage in volts rms. This parameter is available only if **Specify internal voltages for each phase** is not selected.

Phase angle of phase A

The phase angle of the internal voltage generated by phase A, in degrees. The three voltages are generated in a positive sequence. Thus, phase B and phase C internal voltages lag phase A by 120 degrees and 240 degrees, respectively. This parameter is available only if **Specify internal voltages for each phase** is not selected.

Line-to-neutral voltages [Va Vb Vc]

The internal line-to neutral voltage of phase A, B, and C, in volts rms. This parameter is available only if **Specify internal voltages for each phase** is selected.

Phase angle of line-to-neutral voltages [phia phib phic]

The phase angles of the internal voltages generated by phase A, B, and C, in degrees. This parameter is available only if **Specify internal voltages for each phase** is selected.

Frequency

The source frequency in hertz (Hz).

Internal

When this check box is selected, the block implements an internal RL inductance. When the check box is cleared, the internal inductance is not modeled.

Specify short-circuit level parameters

Select to specify internal impedance using the inductive short-circuit level and X/R ratio. This parameter is available only if **Internal** is selected.

3-phase short-circuit level at base voltage

The three-phase inductive short-circuit power, in volts-amperes (VA), at specified base voltage, used to compute the internal inductance L. This parameter is available only if **Internal** and **Specify short-circuit level parameters** are selected.

The internal inductance L (in H) is computed from the inductive three-phase short-circuit power Psc (in VA), base voltage Vbase (in Vrms phase-to-phase), and source frequency f (in Hz) as follows:

$$L = \frac{V_{base}^2}{Psc} \cdot \frac{1}{2\pi f}.$$

Base voltage

The phase-to-phase base voltage, in volts RMS, used to specify the three-phase short-circuit level. The base voltage is usually the nominal source voltage. This parameter is available only if **Internal** and **Specify short-circuit level parameters** are selected.

X/R ratio

The X/R ratio at nominal source frequency or quality factor of the internal source impedance. This parameter is available only if **Internal** and **Specify short-circuit level parameters** are selected.

The internal resistance R (in Ω) is computed from the source reactance X (in Ω) at specified frequency, and X/R ratio as follows:

$$R = \frac{X}{(X/R)} = \frac{2\pi fL}{X/R}.$$

Source resistance

This parameter is available only if **Internal** is selected and **Specify short-circuit level parameters** is not selected.

The source internal resistance in ohms (Ω).

Source inductance

This parameter is available only if **Internal** is selected and **Specify short-circuit level parameters** is not selected.

The source internal inductance in henries (H).

Load Flow Tab

The parameters on this tab are used by the Load Flow tool of the powergui block. These load flow parameters are used for model initialization only, they have no impact on the block model and on the simulation performance.

The configuration of the **Load Flow** tab depends on the option selected for the **Generator type** parameter.

Generator type

Specify the generator type of the voltage source.

Select `swing` to implement a generator controlling magnitude and phase angle of its terminal voltage. The reference voltage magnitude and angle are specified by the **Swing bus or PV bus voltage** and **Swing bus voltage angle** parameters of the Load Flow Bus block connected to the voltage source terminals.

Select `PV` to implement a generator controlling its output active power P and voltage magnitude V. P is specified by the **Active power generation P** parameter of the block. V is specified by the **Swing bus or PV bus voltage** parameter of the Load Flow Bus block connected to the voltage source terminals. You can control the minimum and maximum reactive power generated by the block by using the **Minimum reactive power Qmin** and **Maximum reactive power Qmax** parameters.

Select `PQ` to implement a generator controlling its output active power P and reactive power Q. P and Q are specified by the **Active power generation P** and **Reactive power generation Q** parameters of the block, respectively.

Active power generation P

Specify the desired active power generated by the source, in watts. This parameter is available if you specify **Generator type** as `PV` or `PQ`, and if the **Specify internal voltages for each phase** parameter is selected.

Reactive power generation Q

Specify the desired reactive power generated by the source, in vars. This parameter is available only if you specify **Generator type** as `PQ`.

Active power generation [Pa Pb Pc]

Specify the desired active power generated by each phase of the source, in watts. This parameter is available only if you specify **Generator type** as `PV` or `PQ`, and if **Specify internal voltages for each phase** is selected.

Reactive power generation [Qa Qb Qc]

Specify the desired reactive power generated by each phase of the source, in vars. This parameter is available only if you specify **Generator type** as PQ, and if **Specify internal voltages for each phase** is selected.

Minimum reactive power Qmin or [Qamin,Qbmin Qcmin]

This parameter is available only if you specify **Generator type** as PV. Indicates the minimum reactive power that can be generated by the source while keeping the terminal voltage at its reference value. This reference voltage is specified by the **Swing bus or PV bus voltage** parameter of the Load Flow Bus block connected to the source terminals. The default value is -inf, which means that there is no lower limit on the reactive power output.

Maximum reactive power Qmax or [Qamax,Qbmax Qcmax]

This parameter is available only if you specify **Generator type** as PV. Indicates the maximum reactive power that can be generated by the source while keeping the terminal voltage at its reference value. This reference voltage is specified by the **Swing bus or PV bus voltage** parameter of the Load Flow Bus block connected to the source terminals. The default value is inf, which means that there is no upper limit on the reactive power output.

Examples

See the power_3phseriescomp example, which uses a Three-Phase Source block to model a portion of a 735 kV system with a simplified R-L source. The source impedance is specified by using the three-phase short-circuit level (30,000 MVA) and X/R ratio (X/R = 10).

See Also
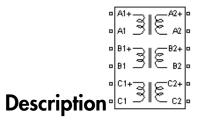
Three-Phase Programmable Voltage Source

Three-Phase Transformer 12 Terminals

Implement three single-phase, two-winding transformers where all terminals are accessible

Library

Fundamental Blocks/Elements

Description
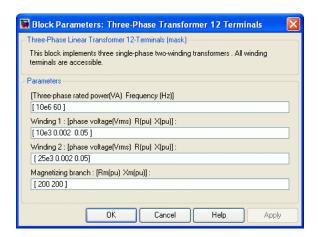
The Three-Phase Transformer 12 Terminals block implements three single-phase, two-winding linear transformers where all the twelve winding connectors are accessible. The block can be used in place of the Three-Phase Transformer (Two Windings) block to implement a three-phase transformer when primary and secondary are not necessarily connected in Y or Delta.

Dialog Box and Parameters

[Three-phase rated power Frequency]

The total nominal power of the three phases, in volt-amperes (VA), and the nominal frequency, in hertz (Hz).

Winding 1: [phase voltage R X]

The nominal voltage of the three primary windings (labeled 1) in volts RMS (Vrms), the winding resistances, in pu, and the winding leakage reactances, in pu.

Winding 2: [phase voltage R X]

The nominal voltage of the three secondary windings (labeled 2) in volts RMS (Vrms), the winding resistances, in pu, and the winding leakage reactances, in pu.

Magnetizing branch: [Rm Xm]

The resistance and reactance simulating the core active and reactive losses, both in pu. For example, to specify 0.2% of active and reactive core losses, at nominal voltage, use Rm = 500 pu and Lm = 500 pu. Lm can be set to `inf` (no reactive core losses), but Rm must have a finite value.

Note Refer to the Linear Transformer for explanations on the per unit system.

Example

See power_3phPWM for an example of use of the Three-Phase Transformer 12 Terminals block in a three-phase double-bridge voltage-sourced converter.

See Also
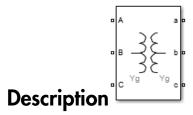
Linear Transformer, Three-Phase Transformer (Two Windings)

Three-Phase Transformer (Two Windings)

Implement three-phase transformer with configurable winding connections

Library

Fundamental Blocks/Elements

Description

This block implements a three-phase transformer using three single-phase transformers. For a detailed description of the electrical model of a single-phase transformer, see the Linear Transformer block.

When activated, the saturation characteristic is the same as the one described for the Saturable Transformer block. If the fluxes are not specified, the initial values are automatically adjusted so that the simulation starts in steady state.

The leakage inductance and resistance of each winding are given in pu based on the transformer nominal power Pn and on the nominal voltage of the winding (V1 or V2). For a description of per units, refer to the Linear Transformer and to the Saturable Transformer.

The two windings of the transformer can be connected as follows:

- Y
- Y with accessible neutral
- Grounded Y
- Delta (D1), delta lagging Y by 30 degrees
- Delta (D11), delta leading Y by 30 degrees

If you select the Y connection with accessible neutral for winding 1, an input port labeled N is added to the block. If you ask for an accessible neutral on winding 2, an extra output port labeled n is generated.
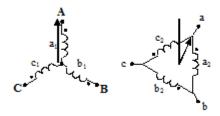
The D1 and D11 notations refer to the clock convention that assumes that the reference Y voltage phasor is at noon (12) on a clock display. D1 and D11 refer respectively to 1:00 p.m. (delta voltages lagging Y voltages by 30 degrees) and 11:00 a.m. (delta voltages leading Y voltages by 30 degrees).

Standard Notation for Winding Connections

The conventional notation for a two-winding three-phase transformer uses two letters followed by a number. The first letter (Y or D) indicates a high-voltage wye or delta winding connection. The second letter (y or d) indicates a low-voltage wye or delta winding connection. The number, an integer between 0 and 12, indicates the position of the low-voltage positive-sequence voltage phasor on a clock display when the high-voltage positive-sequence voltage phasor is at 12:00.

The following three figures are examples of standard winding connections. The dots indicate polarity marks, and arrows indicate the position of phase A-to-neutral voltage phasors on high-voltage and low-voltage windings. The phasors are assumed to rotate in a counterclockwise direction so that rising numbers indicate increasing phase lag.

- Yd1: The low-voltage winding (d) is lagging high-voltage winding (Y) by 30 degrees. The **Winding 2 connection** parameter is set to **D1**.

- Dy11: The low-voltage winding (y) is leading high-voltage winding (D) by 30 degrees. The **Winding 1 connection** parameter is set to **D1**.

- Dy1: The low-voltage winding (y) is lagging high-voltage winding (D) by 30 degrees. The **Winding 1 connection** parameter is set to **D11**.

You can represent many other connections with phase shifts between 0 and 360 degrees (by steps of 30 degrees) by combining the +30- or –30-degree phase shift provided by the D1 and D11 block parameter settings and, in some cases, an additional +/–120-degree phase shift obtained by connecting the output terminals of delta winding to the appropriate phases of the network.

The table explains how to set up the Three-Phase Transformer block to obtain common connections.

Clock Position	Phase Shift (degrees)	Connection	Winding 1 Connection	Winding 2 Connection	Terminals of Delta Winding to Connect to Network ABC Phases
0	0	Yy0	Y	Y	—
		Dd0	D1	D1	abc
1	–30	Yd1	Y	D1	abc

Clock Position	Phase Shift (degrees)	Connection	Winding 1 Connection	Winding 2 Connection	Terminals of Delta Winding to Connect to Network ABC Phases
		Dy1	D11	Y	abc
2	−60	Dd2	D11	D1	abc
5	−150	Yd5	Y	D1	bca
		Dy5	D11	Y	cab
7	+150	Yd7	Y	D11	cab
		Dy7	D1	Y	bca
10	+60	Dd10	D1	D11	abc
11	+30	Yd11	Y	D11	abc
		Dy11	D1	Y	abc

For example, to obtain the Yd5 connection, set the **Winding 1 connection** parameter to **Y** and the **Winding 2 connection** parameter to **D1**, and connect the network phases to the winding 2 as follows:

For more details on conventional transformer winding notations, see International Standard IEC 60076-1 [1].

Dialog Box and Parameters

Configuration Tab

Winding 1 connection (ABC terminals)

    The winding connections for winding 1.

Winding 2 connection (abc terminals)

    The winding connections for winding 2.

Type

Select `Three single-phase transformers` to implement a three-phase transformer using three single-phase transformer models. You can use this core type to represent very large power transformers found in utility grids (hundreds of MW).

Select `Three-limb core (core type)` to implement a three-limb core three-phase transformer. In most applications, three-phase transformers use a three-limb core (core-type transformer). This type of core produces accurate results during an asymmetrical fault for both linear and nonlinear models (including saturation). During asymmetrical voltage conditions, the zero-sequence flux of a core-type transformer returns outside the core, through an air gap, structural steel, and a tank. Thus, the natural zero-sequence inductance L0 (without delta winding) of such a core-type transformer is usually very low (typically 0.5 pu < L0 < 2 pu) compared with a three-phase transformer using three single-phase units (L0 > 100 pu). This low L0 value affects voltages, currents, and flux unbalances during linear and saturated operation.

Select `Five-limb core (shell type)` to implement a five-limb core three-phase transformer. On rare occasions, very large transformers are built with a five-leg core (three phase legs and two external legs). This core configuration, also known as shell type, is chosen mainly to reduce the height of the transformer and make transportation easier. During unbalanced voltage conditions, as opposed to the three-limb transformer, the zero-sequence flux of the five-limb transformer stays inside the steel core and returns through the two external limbs. The natural zero-sequence inductance (without delta) is therefore very high (L0 > 100 pu). Except for small current unbalances due to core asymmetry, the behavior of the five-limb shell-type transformer is similar to that of a three-phase transformer built with three single-phase units.

Simulate saturation

If selected, implements a saturable three-phase transformer.

If you want to simulate the transformer in the phasor mode of the Powergui block, you must clear this parameter.

Simulate hysteresis

Select to model a saturation characteristic including hysteresis instead of a single-valued saturation curve. This parameter is visible only if the **Saturable core** parameter is selected.

If you want to simulate the transformer in the phasor mode of the Powergui block, you must clear this parameter.

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Hysteresis Mat file

This parameter is visible only if the **Simulate hysteresis** parameter is selected.

Specify a .mat file containing the data for use in the hysteresis model. When you open the **Hysteresis Design Tool** of the Powergui block, the default hysteresis loop and parameters saved in the hysteresis.mat file are displayed. Use the **Load** button of the Hysteresis Design tool to load another .mat file. Use the **Save** button of the Hysteresis Design tool to save your model in a new .mat file.

Specify initial fluxes

If selected, the initial fluxes are defined by the **Initial fluxes** parameter on the **Parameters** tab. The **Specify initial fluxes** parameter is visible only if the **Saturable core** parameter is selected.

When the **Specify initial fluxes** parameter is not selected upon simulation, SimPowerSystems software automatically computes the initial fluxes to start the simulation in steady state. The computed values are saved in the **Initial Fluxes** parameter and will overwrite any previous values.

Measurements

Select Winding voltages to measure the voltage across the winding terminals.

Select Winding currents to measure the current flowing through the windings.

Select Fluxes and excitation currents (Im + IRm) to measure the flux linkage, in volt seconds (V.s), and the total excitation current including iron losses modeled by Rm.

Select Fluxes and magnetization currents (Im) to measure the flux linkage, in volt seconds (V.s), and the magnetization current, in amperes (A), not including iron losses modeled by Rm.

Select All measurements (V, I, Flux) to measure the winding voltages, currents, magnetization currents, and the flux linkages.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

If the **Winding 1 connection (ABC terminals)** parameter is set to Y, Yn, or Yg, the labels are as follows.

Measurement	Label
Winding 1 voltages	Uan_w1:, Ubn_w1:, Ucn_w1:
	or
	Uag_w1:, Ubg_w1:, Ucg_w1:
Winding 1 currents	Ian_w1:, Ibn_w1:, Icn_w1:
	or
	Iag_w1:, Ibg_w1:, Icg_w1:
Fluxes	Flux_A:, Flux_B:, Flux_C:
Magnetization currents	Imag_A:, Imag_B:, Imag_C:
Excitation currents	Iexc_A:, Iexc_B:, Iexc_C:

The same labels apply for winding 2, except that 1 is replaced by 2 in the labels.

If the **Winding 1 connection (ABC terminals)** parameter is set to Delta (D11) or Delta (D1), the labels are as follows.

Measurement	Label
Winding 1 voltages	Uab_w1:, Ubc_w1:, Uca_w1:
Winding 1 currents	Iab_w1:, Ibc_w1:, Ica_w1:
Flux linkages	Flux_A:, Flux_B:, Flux_C:
Magnetization currents	Imag_A:, Imag_B:, Imag_C:
Excitation currents	Iexc_A:, Iexc_B:, Iexc_C:

Parameters Tab

Units

Specify the units used to enter the parameters of this block. Select pu to use per unit. Select SI to use SI units. Changing the **Units** parameter from pu to SI, or from SI to pu, automatically converts the parameters displayed in the mask of the block. The per unit conversion is based on the transformer rated power Pn in VA, nominal frequency fn in Hz, and nominal voltage Vn, in Vrms, of the windings.

Nominal power and frequency

The nominal power rating, in volt-amperes (VA), and nominal frequency, in hertz (Hz), of the transformer. The nominal parameters have no impact on the transformer model when the **Units** parameter is set to SI.

Winding 1 parameters

The phase-to-phase nominal voltage in volts RMS, resistance, and leakage inductance in pu for winding 1.

Winding 2 parameters

The phase-to-phase nominal voltage in volts RMS, resistance, and leakage inductance in pu for winding 2.

Magnetization resistance Rm

The magnetization resistance Rm, in pu.

Magnetization inductance Lm

The magnetization inductance Lm, in pu, for a nonsaturable core. The **Magnetization inductance Lm** parameter is not accessible if the **Saturable core** parameter on the **Configuration** tab is selected.

Inductance L0 of zero-sequence flux path return

The Inductance L0 of zero-sequence flux path return, in pu, for the three-limb core transformer type.

This parameter is visible only if the **Type** parameter is set to Three-limb core (core type).

Saturation characteristic

This parameter is available only if the **Saturable core** parameter on the **Configuration** tab is selected.

The saturation characteristic for the saturable core. Specify a series of current/ flux pairs (in pu) starting with the pair (0,0).

Initial fluxes

Specify initial fluxes for each phase of the transformer. This parameter is available only if the **Specify initial fluxes** and **Saturable core** parameters on the **Configuration** tab are selected.

When the **Specify initial fluxes** parameter is not selected upon simulation, SimPowerSystems software automatically computes the initial fluxes to start the simulation in steady state. The computed values are saved in the **Initial Fluxes** parameter and overwrite any previous values.

Advanced Tab

Break Algebraic loop in discrete saturation model

> When you use the block in a discrete system, you get an algebraic loop. This algebraic loop, which is required in most cases to get an accurate solution, tends to slow down the simulation. To speed up the simulation, in some circumstances, you can disable the algebraic loop by selecting **Break Algebraic loop in discrete saturation model**. Be aware that disabling the algebraic loop introduces a one-simulation-step

time delay in the model. This action can cause numerical oscillations if the sample time is too large.

Example

The power_transfo3ph circuit uses the Three-Phase Transformer block where the saturable core is simulated. Both windings are connected in a Y grounded configuration. The neutral points of the two windings are internally connected to the ground.

The 500 kV/ 230 kV saturable transformer is energized on the 500 kV system. Remanent fluxes of 0.8 pu, −0.4 pu, and 0.4 pu have been specified respectively for phases A, B, and C. Run the simulation and observe inrush currents due to core saturation. See also the power_xfonotation model that shows four types of three-phase Yd and Dy transformer connections.

References

[1] IEC. *International Standard IEC 60076-1, Power Transformer - Part 1: General*, Edition 2.1, 2000–04. "Annex D: Three-phase transformer connections." 2000.

See Also
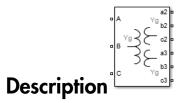
Linear Transformer, Multimeter, Saturable Transformer, Three-Phase Transformer (Three Windings), Three-Phase Transformer Inductance Matrix Type (Two Windings)

Three-Phase Transformer (Three Windings)

Implement three-phase transformer with configurable winding connections

Library

Fundamental Blocks/Elements

Description

This block implements a three-phase transformer by using three single-phase transformers with three windings. For a detailed description of the electrical model of a single-phase transformer, see the Linear Transformer block.

When activated, the saturation characteristic is the same as the one described for the Saturable Transformer block. If the fluxes are not specified, the initial values are automatically adjusted so that the simulation starts in steady state.

The leakage inductances and resistance of each winding are given in pu based on the transformer nominal power Pn and on the nominal voltage of the winding (V1, V2, or V3). For an explanation of per units, refer to the Linear Transformer and to the Saturable Transformer.

The three windings of the transformer can be connected in the following manner:

- Y
- Y with accessible neutral (for windings 1 and 3 only)
- Grounded Y
- Delta (D1), delta lagging Y by 30 degrees
- Delta (D11), delta leading Y by 30 degrees

An input port labeled N is added to the block if you select the Y connection with accessible neutral for winding 1. If you ask for an accessible neutral on winding 3, an extra outport port labeled n3 is generated.

The D1 and D11 notations refer to the following clock convention. It assumes that the reference Y voltage phasor is at noon (12) on a clock display. D1 and D11 refer respectively to 1 PM (delta voltages lagging Y voltages by 30 degrees) and 11 AM (delta voltages leading Y voltages by 30 degrees).

Standard Notation for Winding Connections

The conventional notation for a two-winding three-phase transformer uses two letters followed by a number. The first letter (Y or D) indicates a high-voltage wye or delta winding connection. The second letter (y or d) indicates a low-voltage wye or delta winding connection. The number, an integer between 0 and 12, indicates the position of the low-voltage positive-sequence voltage phasor on a clock display when the high-voltage positive-sequence voltage phasor is at 12:00.

The following three figures are examples of standard winding connections. The dots indicate polarity marks, and arrows indicate the position of phase A-to-neutral voltage phasors on high-voltage and low-voltage windings. The phasors are assumed to rotate in a counterclockwise direction so that rising numbers indicate increasing phase lag.

- Yd1: The low-voltage winding (d) is lagging high-voltage winding (Y) by 30 degrees. The **Winding 2 connection** parameter is set to **D1**.

- Dy11: The low-voltage winding (y) is leading high-voltage winding (D) by 30 degrees. The **Winding 1 connection** parameter is set to **D1**.

- Dy1: The low-voltage winding (y) is lagging high-voltage winding (D) by 30 degrees. The **Winding 1 connection** parameter is set to **D11**.
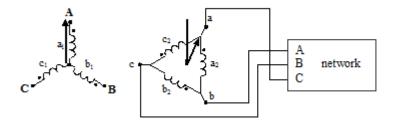

You can represent many other connections with phase shifts between 0 and 360 degrees (by steps of 30 degrees) by combining the +30- or −30-degree phase shift provided by the D1 and D11 block parameter settings and, in some cases, an additional +/−120-degree phase shift obtained by connecting the output terminals of delta winding to the appropriate phases of the network.

The table explains how to set up the Three-Phase Transformer block to obtain common connections.

Clock Position	Phase Shift (degrees)	Connection	Winding 1 Connection	Winding 2 Connection	Terminals of Delta Winding to Connect to Network ABC Phases
0	0	Yy0	Y	Y	—
		Dd0	D1	D1	abc
1	−30	Yd1	Y	D1	abc

Clock Position	Phase Shift (degrees)	Connection	Winding 1 Connection	Winding 2 Connection	Terminals of Delta Winding to Connect to Network ABC Phases
		Dy1	D11	Y	abc
2	−60	Dd2	D11	D1	abc
5	−150	Yd5	Y	D1	bca
		Dy5	D11	Y	cab
7	+150	Yd7	Y	D11	cab
		Dy7	D1	Y	bca
10	+60	Dd10	D1	D11	abc
11	+30	Yd11	Y	D11	abc
		Dy11	D1	Y	abc

For example, to obtain the Yd5 connection, set the **Winding 1 connection** parameter to **Y** and the **Winding 2 connection** parameter to **D1**, and connect the network phases to the winding 2 as follows:

For more details on conventional transformer winding notations, see International Standard IEC 60076-1 [1].

Dialog Box and Parameters

Configuration Tab

Winding 1 connection (ABC terminals)
> The winding connection for winding 1.

Winding 2 connection (abc-2 terminals)
> The winding connection for winding 2.

Winding 3 connection (abc-3 terminals)

The winding connection for winding 3.

Type

Select `Three single-phase transformers` to implement a three-phase transformer using three single-phase transformer models. You can use this core type to represent very large power transformers found in utility grids (hundreds of MW).

Select `Three-limb core (core type)` to implement a three-limb core three-phase transformer. In most applications, three-phase transformers use a three-limb core (core-type transformer). This type of core produces accurate results during an asymmetrical fault for both linear and nonlinear models (including saturation). During asymmetrical voltage conditions, the zero-sequence flux of a core-type transformer returns outside the core, through an air gap, structural steel, and a tank. Thus, the natural zero-sequence inductance L0 (without delta winding) of such a core-type transformer is usually very low (typically 0.5 pu < L0 < 2 pu) compared with a three-phase transformer using three single-phase units (L0 > 100 pu). This low L0 value affects voltages, currents, and flux unbalances during linear and saturated operation.

Select `Five-limb core (shell type)` to implement a five-limb core three-phase transformer. On rare occasions, very large transformers are built with a five-leg core (three phase legs and two external legs). This core configuration, also known as shell type, is chosen mainly to reduce the height of the transformer and make transportation easier. During unbalanced voltage conditions, as opposed to the three-limb transformer, the zero-sequence flux of the five-limb transformer stays inside the steel core and returns through the two external limbs. The natural zero-sequence inductance (without delta) is therefore very high (L0 > 100 pu). Except for small current unbalances due to core asymmetry, the behavior of the five-limb shell-type transformer is similar to that of a three-phase transformer built with three single-phase units.

Simulate saturation

If selected, implements a saturable three-phase transformer. See also the **Saturation characteristic** parameter on the Parameters tab.

Simulate hysteresis

Select to model a saturation characteristic including hysteresis instead of a single-valued saturation curve. This parameter is visible only if the **Saturable core** parameter is selected.

Hysteresis Mat file

This parameter is visible only if the **Simulate hysteresis** parameter is selected.

Specify a `.mat` file containing the data to be used for the hysteresis model. When you open the **Hysteresis Design Tool** of the Powergui, the default hysteresis loop and parameters saved in the `hysteresis.mat` file are displayed. Use the **Load** button of the Hysteresis Design tool to load another `.mat` file. Use the **Save** button of the Hysteresis Design tool to save your model in a new `.mat` file.

Specify initial fluxes

If selected, the initial fluxes are defined by the **Initial fluxes** parameter on the Parameters tab. The **Specify initial fluxes** parameter is visible only if the **Saturable core** parameter is selected.

When the **Specify initial fluxes** parameter is not selected upon simulation, SimPowerSystems software automatically computes the initial fluxes to start the simulation in steady state. The computed values are saved in the **Initial Fluxes** parameter and will overwrite any previous values.

Measurements

Select `Winding voltages` to measure the voltage across the winding terminals of the Three-Phase Transformer block.

Select `Winding currents` to measure the current flowing through the windings of the Three-Phase Transformer block.

Select `Fluxes and excitation currents (Im + IRm)` to measure the flux linkage, in volt seconds (V.s), and the total excitation current including iron losses modeled by Rm.

Select `Fluxes and magnetization currents (Im)` to measure the flux linkage, in volt seconds (V.s), and the magnetization current, in amperes (A), not including iron losses modeled by Rm.

Select `All measurements (V, I, Flux)` to measure the winding voltages, currents, magnetization currents, and the flux linkages.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

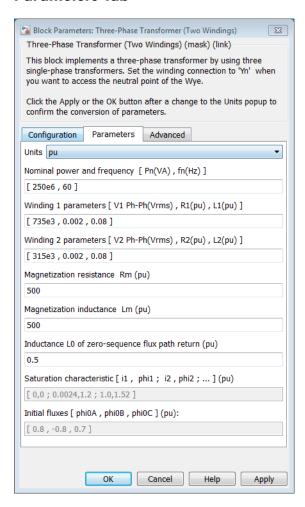If the **Winding 1 connection (ABC terminals)** parameter is set to Y, Yn, or Yg, the labels are as follows.

Measurement	Label
Winding 1 voltages	Uan_w1:, Ubn_w1:, Ucn_w1:
	or
	Uag_w1:, Ubg_w1:, Ucg_w1:
Winding 1 currents	Ian_w1:, Ibn_w1:, Icn_w1:
	or
	Iag_w1:, Ibg_w1:, Icg_w1:
Flux linkages	Flux_A:, Flux_B:, Flux_C:
Magnetization currents	Imag_A:, Imag_B:, Imag_C:
Excitation currents	Iexc_A:, Iexc_B:, Iexc_C:

The same labels apply for winding 2 and winding 3, except that the 1 is replaced by 2 or by 3 in the labels.

If the **Winding 1 connection (ABC terminals)** parameter is set to Delta (D11) or Delta (D1), the labels are as follows.

Measurement	Label
Winding 1 voltages	Uab_w1:, Ubc_w1:, Uca_w1:
Winding 1 currents	Iab_w1:, Ibc_w1:, Ica_w1:
Flux linkages	Flux_A:, Flux_B:, Flux_C:
Magnetization currents	Imag_A:, Imag_B:, Imag_C:
Excitation currents	Iexc_A:, Iexc_B:, Iexc_C:

Parameters Tab

Units

> Specify the units used to enter the parameters of the Three Phase Transformer block. Select pu to use per unit. Select SI to use SI units. Changing the **Units** parameter from pu to SI, or from SI to pu, will automatically convert the parameters displayed in the mask of the block. The per unit conversion is based on the transformer rated power Pn in VA, nominal frequency fn in Hz, and nominal voltage Vn, in Vrms, of the windings.

Nominal power and frequency

> The nominal power rating, in volt-amperes (VA), and nominal frequency, in hertz (Hz), of the transformer. Note that the nominal parameters have no impact on the transformer model when the **Units** parameter is set to SI.

Winding 1 parameters

The phase-to-phase nominal voltage in volts RMS, resistance, and leakage inductance in pu for winding 1.

Winding 2 parameters

The phase-to-phase nominal voltage in volts RMS, resistance, and leakage inductance in pu for winding 2.

Winding 3 parameters

The phase-to-phase nominal voltage in volts RMS, resistance, and leakage inductance in pu for winding 3.

Magnetization resistance Rm

The magnetization resistance Rm, in pu.

Magnetization inductance Lm

The magnetization inductance Lm, in pu, for a nonsaturable core. The **Magnetization inductance Lm** parameter is not accessible if the **Saturable core** parameter is selected.

Inductance L0 of zero-sequence flux path return

The Inductance L0 of zero-sequence flux path return, in pu, for the three-limb core transformer type.

This parameter is visible only if the **Type** parameter is set to `Three-limb core (core type)`.

Saturation characteristic

This parameter is accessible only if the **Saturable core** parameter is selected.

The saturation characteristic for the saturable core. Specify a series of current/ flux pairs (in pu) starting with the pair (0,0).

Initial fluxes

Specifies initial fluxes for each phase of the transformer. This parameter is visible only if the **Specify initial fluxes** and **Saturable core** parameters are selected on the Configuration tab.

When the **Specify initial fluxes** parameter is not selected upon simulation, SimPowerSystems software automatically computes the initial fluxes to start the simulation in steady state. The computed values are saved in the **Initial Fluxes** parameter and will overwrite any previous values.

Advanced Tab

Break Algebraic loop in discrete saturation model

> When you use the block in a discrete system, you will get an algebraic loop. This algebraic loop, which is required in most cases to get an accurate solution, tends to slow down the simulation. However, to speed up the simulation, in some circumstances, you can disable the algebraic loop by selecting **Break Algebraic loop in discrete saturation model**. You should be aware that disabling the algebraic loop introduces a one-simulation-step time delay in the model. This can cause numerical oscillations if the sample time is too large.

Example

The power_transfo3wdn circuit uses two Three-Phase Transformer blocks. Two Multimeter blocks are used to measure the phase A voltage (or AB for delta connections) of each winding

See Also
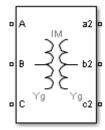
Linear Transformer, Multimeter, Saturable Transformer, Three-Phase Transformer (Two Windings), Three-Phase Transformer Inductance Matrix Type (Three Windings)

Three-Phase Transformer Inductance Matrix Type (Two Windings)

Implement three-phase two-winding transformer with configurable winding connections and core geometry

Library

Fundamental Blocks/Elements

Description
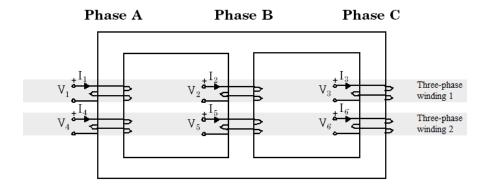
The Three-Phase Transformer Inductance Matrix Type (Two Windings) block is a three-phase transformer with a three-limb core and two windings per phase. Unlike the `Three-Phase Transformer (Two Windings)` block, which is modeled by three separate single-phase transformers, this block takes into account the couplings between windings of different phases. The transformer core and windings are shown in the following illustration.

The phase windings of the transformer are numbered as follows:

- 1 and 4 on phase A
- 2 and 5 on phase B
- 3 and 6 on phase C

This core geometry implies that phase winding 1 is coupled to all other phase windings (2 to 6), whereas in Three-Phase Transformer (Two Windings) block (a three-phase transformer using three independent cores) winding 1 is coupled only with winding 4.

Note The phase winding numbers 1 and 2 should not be confused with the numbers used to identify the three-phase windings of the transformer. Three-phase winding 1 consists of phase windings 1,2,3, and three-phase winding 2 consists of phase windings 4,5,6.

Transformer Model

The Three-Phase Transformer Inductance Matrix Type (Two Windings) block implements the following matrix relationship:

$$
\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_6 \end{bmatrix} = \begin{bmatrix} R_1 & 0 & \dots & 0 \\ 0 & R_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & R_6 \end{bmatrix} \cdot \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_6 \end{bmatrix} + \begin{bmatrix} L_{11} & L_{12} & \dots & L_{16} \\ L_{21} & L_{22} & \dots & L_{26} \\ \vdots & \vdots & \ddots & \vdots \\ L_{61} & L_{62} & \dots & L_{66} \end{bmatrix} \cdot \frac{d}{dt} \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_6 \end{bmatrix}.
$$

R_1 to R_6 represent the winding resistances. The self inductance terms L_{ii} and the mutual inductance terms L_{ij} are computed from the voltage ratios, the inductive component of the no load excitation currents and the short-circuit reactances at nominal frequency. Two sets of values in positive-sequence and in zero-sequence allow calculation of the 6 diagonal terms and 15 off-diagonal terms of the symmetrical inductance matrix.

When the parameter **Core type** is set to `Three single-phase cores`, the model uses two independent circuits with (3x3) R and L matrices. In this condition, the positive-sequence and zero-sequence parameters are identical and you need only to specify positive-sequence values.

The self and mutual terms of the (6x6) L matrix are obtained from excitation currents (one three-phase winding is excited and the other three-phase winding is left open) and from positive- and zero-sequence short-circuit reactances $X1_{12}$ and $X0_{12}$ measured with three-phase winding 1 excited and three-phase winding 2 short-circuited.

Assuming the following positive-sequence parameters:

$Q1_1$= Three-phase reactive power absorbed by winding 1 at no load when winding 1 is excited by a positive-sequence voltage $Vnom_1$ with winding 2 open

$Q1_2$= Three-phase reactive power absorbed by winding 2 at no load when winding 2 is excited by a positive-sequence voltage $Vnom_2$ with winding 1 open

$X1_{12}$= Positive-sequence short-circuit reactance seen from winding 1 when winding 2 is short-circuited

$Vnom_1$, $Vnom_2$= Nominal line-line voltages of windings 1 and 2

The positive-sequence self and mutual reactances are given by:

$$X_1(1,1) = \frac{V_{\mathrm{nom}_1}^2}{Q1_1}$$

$$X_1(2,2) = \frac{V_{\mathrm{nom}_2}^2}{Q1_2}$$

$$X_1(1,2) = X_1(2,1) = \sqrt{X_1(2,2) \cdot (X_1(1,1) - X1_{12})}.$$

The zero-sequence self reactances $X_0(1,1)$, $X_0(2,2)$ and mutual reactance $X_0(1,2) = X_0(2,1)$ are also computed using similar equations.

Extension from the following two (2x2) reactance matrices in positive-sequence and in zero-sequence

$$\begin{bmatrix} X_1(1,1) & X_1(1,2) \\ X_1(2,1) & X_1(2,2) \end{bmatrix} \quad \begin{bmatrix} X_0(1,1) & X_0(1,2) \\ X_0(2,1) & X_0(2,2) \end{bmatrix}$$

to a (6x6) matrix, is performed by replacing each of the four $[X_1 \ X_0]$ pairs by a (3x3) submatrix of the form:

$$\begin{bmatrix} X_s & X_m & X_m \\ X_m & X_s & X_m \\ X_m & X_m & X_s \end{bmatrix}$$

where the self and mutual terms are given by:
$X_s = (X_0 + 2X_1)/3$
$X_m = (X_0 - X_1)/3$

In order to model the core losses (active power P1 and P0 in positive- and zero-sequences), additional shunt resistances are also connected to terminals of one of the three-phase windings. If winding 1 is selected, the resistances are computed as:

$$R1_1 = \frac{V_{\text{nom}_1}^2}{P1_1} \quad R0_1 = \frac{V_{\text{nom}_1}^2}{P0_1}.$$
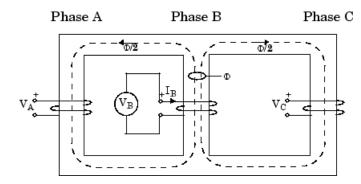
The block takes into account the connection type you select, and the icon of the block is automatically updated. An input port labeled N is added to the block if you select the Y connection with accessible neutral for winding 1. If you ask for an accessible neutral on winding 2, an extra outport port labeled n2 is generated.

Excitation Current in Zero Sequence

Often, the zero-sequence excitation current of a transformer with a 3-limb core is not provided by the manufacturer. In such a case a reasonable value can be guessed as explained below.

The following figure shows a three-limb core with a single three-phase winding. Only phase B is excited and voltage is measured on phase A and phase C. The flux Φ produced

by phase B shares equally between phase A and phase C so that Φ/2 is flowing in limb A and in limb C. Therefore, in this particular case, if leakage inductance of winding B would be zero, voltage induced on phases A an C would be $-k.V_B=-V_B/2$. In fact, because of the leakage inductance of the three windings, the average value of induced voltage ratio k when windings A, B and C are successively excited must be slightly lower than 0.5.

Assume:

Z_s = average value of the three self impedances
Z_m =average value of mutual impedance between phases
Z_1 = positive-sequence impedance of three-phase winding
Z_0 = zero-sequence impedance of three-phase winding
I_1 = positive-sequence excitation current
I_0 = zero-sequence excitation current

$$V_B = Z_s I_B$$
$$V_A = Z_m I_B = -V_B/2$$
$$V_C = Z_m I_B = -V_B/2$$
$$Z_s = \frac{2Z_1 + Z_0}{3}$$
$$Z_m = \frac{Z_0 - Z_1}{3}$$
$$V_A = V_C = \frac{Z_m}{Z_s} V_B = -\frac{\dfrac{Z_1}{Z_0} - 1}{2\dfrac{Z_1}{Z_0} + 1} V_B = -\frac{\dfrac{I_0}{I_1} - 1}{2\dfrac{I_0}{I_1} + 1} V_B = -kV_B,$$

where k= ratio of induced voltage (with k slightly lower than 0.5)

Therefore, the I_0/I_1 ratio can be deduced from k:

$$\frac{I_0}{I_1} = \frac{1+k}{1-2k}.$$

Obviously k cannot be exactly 0.5 because this would lead to an infinite zero-sequence current. Also, when the three windings are excited with a zero-sequence voltage, the flux path should return through the air and tank surrounding the iron core. The high reluctance of the zero-sequence flux path results in a high zero-sequence current.

Let us assume I_1= 0.5%. A reasonable value for I_0 could be 100%. Therefore I_0/I_1=200. According to the equation for I_0/I_1 given above, one can deduce the value of k. *k=(200-1)/ (2*200+1)= 199/401= 0.496.*

Zero-sequence losses should be also higher than the positive-sequence losses because of the additional eddy current losses in the tank.

Finally, it should be mentioned that neither the value of the zero-sequence excitation current nor the value of the zero-sequence losses are critical if the transformer has a winding connected in Delta because this winding acts as a short circuit for zero-sequence.

Winding Connections

The three-phase windings of the transformer can be connected in the following manner:

- Y
- Y with accessible neutral
- Grounded Y
- Delta (D1), delta lagging Y by 30 degrees
- Delta (D11), delta leading Y by 30 degrees

Note The D1 and D11 notations refer to the following clock convention. It assumes that the reference Y voltage phasor is at noon (12) on a clock display. D1 and D11 refer respectively to 1 PM (delta voltages lagging Y voltages by 30 degrees) and 11 AM (delta voltages leading Y voltages by 30 degrees).

Dialog Box and Parameters

Configuration Tab

Core type

Select the core geometry: `Three single-phase cores` or `Three-limb or five-limb core`. If you select the first option, only the positive-sequence parameters are used to compute the inductance matrix. If you select the second option, both the positive- and zero-sequence parameters are used.

Winding 1 connection

The winding connection for three-phase winding 1.

Winding 2 connection

The winding connection for three-phase winding 2.

Connect windings 1 and 2 in autotransformer

Check to connect the three-phase windings 1 and 2 in autotransformer (three-phase windings 1 and 2 in series with additive voltage).

If the first voltage specified in the **Nominal line-line voltages** parameter is higher than the second voltage, the low voltage tap is connected on the right side (a2,b2,c2 terminals). Otherwise, the low voltage tap is connected on the left side (A,B,C terminals).

In autotransformer mode you must specify the same winding connections for the three-phase windings 1 and 2. If you select Yn connection for both winding 1 and winding 2, the common neutral N connector is displayed on the left side.

The following figure illustrates winding connections for one phase of an autotransformer when the three-phase windings are both connected in Yg.

If V1 > V2:

If V2 > V1:

Windings W1,W2,W3 correspond to the following phase winding numbers:

- Phase A: W1=1, W2=4
- Phase B: W1=2, W2=5
- Phase C: W1=3, W2=6

Measurements

Select `Winding voltages` to measure the voltage across the winding terminals of the Three-Phase Transformer block.

Select `Winding currents` to measure the current flowing through the windings of the Three-Phase Transformer block.

Select `All measurements` to measure the winding voltages and currents.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

If the **Winding 1 connection** parameter is set to Y, Yn, or Yg, the labels are as follows.

Measurement	Label
Winding 1 voltages	Uan_w1:, Ubn_w1:, Ucn_w1:
	or
	Uag_w1:, Ubg_w1:, Ucg_w1:
Winding 1 currents	Ian_w1:, Ibn_w1:, Icn_w1:
	or
	Iag_w1:, Ibg_w1:, Icg_w1:

If the **Winding 1 connection** parameter is set to Delta (D11) or Delta (D1), the labels are as follows.

Measurement	Label
Winding 1 voltages	Uab_w1:, Ubc_w1:, Uca_w1:
Winding 1 currents	Iab_w1:, Ibc_w1:, Ica_w1:

The same labels apply for three-phase winding 2, except that 1 is replaced by 2 in the labels.

Parameters Tab

Nominal power and frequency

The nominal power rating, in volt-amperes (VA), and nominal frequency, in hertz (Hz), of the transformer.

Nominal line-line voltages [V1 V2]

The phase-to-phase nominal voltages of windings 1 and 2 in volts RMS.

Winding resistances [R1 R2]

The resistances in pu for windings 1 and 2.

Positive-sequence no-load excitation current

The no-load excitation current in percent of the nominal current when positive-sequence nominal voltage is applied at any three-phase winding terminals (ABC or abc2).

Positive-sequence no-load losses

The core losses plus winding losses at no-load, in watts (W), when positive-sequence nominal voltage is applied at any three-phase winding terminals (ABC or abc2).

Positive-sequence short-circuit reactance

The positive-sequence short-circuit reactances X12 in pu. X12 is the reactance measured from winding 1 when winding 2 is short-circuited.

When the **Connect windings 1 and 2 in autotransformer** parameter is selected, the short-circuit reactances is labeled XHL. H and L indicate respectively the high voltage winding (either winding 1 or winding 2) and the low voltage winding (either winding 1 or winding 2).

Zero-sequence no-load excitation current with Delta windings opened

The no-load excitation current in percent of the nominal current when zero-sequence nominal voltage is applied at any three-phase winding terminals (ABC or abc2) connected in Yg or Yn.

Note: If your transformer contains delta-connected windings (D1 or D11), the zero-sequence current flowing into the Yg or Yn winding connected to the zero-sequence voltage source does not represent the net excitation current because zero-sequence currents are also flowing in the delta winding. Therefore, you must specify the no-load zero-sequence circulation current obtained with the delta windings open.

If you want to measure this excitation current, you must temporarily change the delta windings connections from D1 or D11 to Y, Yg, or Yn, and connect the excited winding in Yg or Yn to provide a return path for the source zero-sequence currents.

Zero-sequence no-load losses with Delta windings opened

The core losses plus winding losses at no-load, in watts (W), when zero-sequence nominal voltage is applied at any group of winding terminals (ABC or abc2) connected in Yg or Yn. The Delta winding must be temporarily open to measure these losses.

Note: If your transformer contains delta-connected windings (D1 or D11), the zero-sequence current flowing into the Yg or Yn winding connected to the zero-sequence

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voltage source does not represent the net excitation current because zero-sequence currents are also flowing in the delta winding. Therefore, you must specify the no-load zero-sequence circulation current obtained with the delta windings open.

Zero-sequence short-circuit reactance

The zero-sequence short-circuit reactance X12 in pu. X12 is the reactance measured from winding 1 when winding 2 is short-circuited.

When the **Connect windings 1 and 2 in autotransformer** parameter is selected, the short-circuit reactances is labeled XHL. H and L indicate respectively the high voltage winding (either winding 1 or winding 2) and the low voltage winding (either winding 1 or winding 2).

Limitations

This transformer model does not include saturation. If you need modeling saturation, connect the primary winding of a saturable Three-Phase Transformer (Two Windings) in parallel with the primary winding of your model. Use the same connection (Yg, D1 or D11) and same winding resistance for the two windings connected in parallel. Specify the Y or Yg connection for the secondary winding and leave it open. Specify appropriate voltage, power ratings, and saturation characteristics that you want. The saturation characteristic is obtained when the transformer is excited by a positive-sequence voltage.
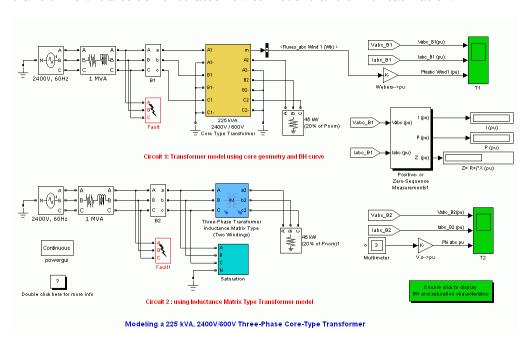
If you are modeling a transformer with three single-phase cores or a five-limb core, this model produces acceptable saturation currents because flux stays trapped inside the iron core.

For a three-limb core, this saturation model still produces acceptable results, even if zero-sequence flux circulates outside of the core and returns through the air and the transformer tank surrounding the iron core. As the zero-sequence flux circulates in the air, the magnetic circuit is mainly linear and its reluctance is high (high magnetizing currents). These high zero-sequence currents (100% and more of nominal current) required to magnetize the air path are already taken into account in the linear model. Connecting a saturable transformer outside the three-limb linear model with a flux-current characteristic obtained in positive sequence will produce currents required for magnetization of the iron core. This model will give acceptable results whether the three-limb transformer has a delta or not.

The following example shows how to model saturation in an inductance matrix type two-winding transformer.

Example

The power_Transfo3phCoreType example model uses the Three-Phase Transformer Inductance Matrix Type (Two Windings) block to model a two-winding core type transformer. It also demonstrates how to model transformer saturation.

Modeling a 225 kVA, 2400V/600V Three-Phase Core-Type Transformer
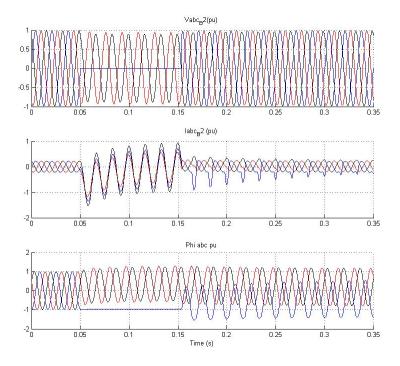
The model shows two identical circuits with a three-phase transformer rated 225 kVA, 2400 V/600V, 60Hz, connected to a 1 MVA, 2400 V power network. A 45 kW resistive load (20 % of transformer nominal power) is connected on the 600 V side. Each phase of the transformer consists of two windings, both connected in wye with a grounded neutral.

The transformers in circuit 1 and circuit 2 use two different models:

- Circuit 1 uses a physical model (yellow block) where the core geometry and the B-H characteristic of the iron used to build the core are the basic parameters used for modeling the magnetic properties of the transformer.

- Circuit 2 uses the Three-Phase Transformer Inductance Matrix Type (Two Windings) block (blue block) for modeling the linear part of the model. Saturation is modeled in the Saturation subsystem (cyan block) by three single-phase saturable transformers connected on the primary side of the linear transformer model.

The example compares performance of both circuits when a single-phase to ground fault is applied on the high voltage terminals of the transformers. Voltages, currents, and fluxes obtained with the Inductance Matrix Type transformer are reproduced below.

See Also
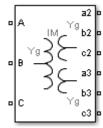
Linear Transformer, Multimeter, Three-Phase Transformer (Two Windings), Three-Phase Transformer (Three Windings), Three-Phase Transformer Inductance Matrix Type (Three Windings)

Three-Phase Transformer Inductance Matrix Type (Three Windings)

Implement three-phase three-winding transformer with configurable winding connections and core geometry

Library

Fundamental Blocks/Elements

Description
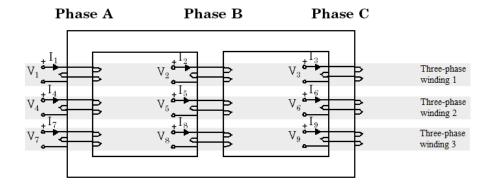
The Three-Phase Transformer Inductance Matrix Type (Three Windings) block is a three-phase transformer with a three-limb core and three windings per phase. Unlike the `Three-Phase Transformer (Three Windings)` block, which is modeled by three separate single-phase transformers, this block takes into account the couplings between windings of different phases. The transformer core and windings are shown in the following illustration.

The phase windings of the transformer are numbered as follows:

- 1 , 4, 7 on phase A
- 2, 5, 8 on phase B
- 3, 6, 9 on phase C

This core geometry implies that phase winding 1 is coupled to all other phase windings (2 to 9), whereas in Three-Phase Transformer (Three Windings) block (a three-phase transformer using three independent cores) winding 1 is coupled only with windings 4 and 7.

Note The phase winding numbers 1, 2, and 3 should not be confused with the numbers used to identify the three-phase windings of the transformer. Three-phase winding 1 consists of phase windings 1,2,3, three-phase winding 2 consists of phase windings 4,5,6, and three-phase winding 3 consists of phase windings 7,8,9.

Transformer Model

The Three-Phase Transformer Inductance Matrix Type (Three-Windings) block implements the following matrix relationship:

$$
\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_9 \end{bmatrix} = \begin{bmatrix} R_1 & 0 & \dots & 0 \\ 0 & R_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & R_9 \end{bmatrix} \cdot \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_9 \end{bmatrix} + \begin{bmatrix} L_{11} & L_{12} & \dots & L_{19} \\ L_{21} & L_{22} & \dots & L_{29} \\ \vdots & \vdots & \ddots & \vdots \\ L_{91} & L_{92} & \dots & L_{99} \end{bmatrix} \cdot \frac{d}{dt} \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_9 \end{bmatrix}.
$$

R_1 to R_9 represent the winding resistances. The self inductance terms L_{ii} and the mutual inductance terms L_{ij} are computed from the voltage ratios, the inductive component of the no load excitation currents and the short-circuit reactances at nominal frequency. Two sets of values in positive-sequence and in zero-sequence allow calculation of the 9 diagonal terms and 36 off-diagonal terms of the symmetrical inductance matrix.

When the parameter **Core type** is set to `Three single-phase cores`, the model uses three independent circuits with (3x3) R and L matrices. In this condition, the positive-sequence and zero-sequence parameters are identical and you need only specifying positive-sequence values.

The self and mutual terms of the (9x9) L matrix are obtained from excitation currents (one three-phase winding is excited and the other two three-phase windings are left open) and from short-circuit reactances.

The following short-circuit reactances are specified in the mask parameters:

$X_{1_{12}}$, $X_{0_{12}}$ — positive- and zero-sequence reactances measured with three-phase winding 1 excited and three-phase winding 2 short-circuited

$X_{1_{13}}$, $X_{0_{13}}$ — positive- and zero-sequence reactances measured with three-phase winding 1 excited and three-phase winding 3 short-circuited

$X_{1_{23}}$, $X_{0_{23}}$ — positive- and zero-sequence reactances measured with three-phase winding 2 excited and three-phase winding 3 short-circuited

Assuming the following positive-sequence parameters for three-phase windings i and j (where i=1,2,or 3 and j=1,2,or 3):

Q_{1i}= Three-phase reactive power absorbed by winding i at no load when winding i is excited by a positive-sequence voltage $Vnom_i$ with winding j open

Q_{1j}= Three-phase reactive power absorbed by winding j at no load when winding j is excited by a positive-sequence voltage $Vnom_j$ with winding i open

X_{1ij} = positive-sequence short-circuit reactance seen from winding i when winding j is short-circuited

Vnom$_i$, *Vnom*$_j$= nominal line-line voltages of windings i and j

The positive-sequence self and mutual reactances are given by:

$$X_1(i,i) = \frac{V^2_{nom_i}}{Q1_i}$$

$$X_1(j,j) = \frac{V^2_{nom_j}}{Q1_j}$$

$$X_1(i,j) = X_1(j,i) = \sqrt{X_1(j,j) \cdot (X_1(i,i) - X1_{ij})}.$$

The zero-sequence self reactances $X_0(i,i)$, $X_0(j,j)$ and mutual reactance $X_0(i,j) = X_0(j,i)$ are also computed using similar equations.

Extension from the following two (3x3) reactance matrices in positive-sequence and in zero-sequence

$$\begin{bmatrix} X_1(1,1) & X_1(1,2) & X_1(1,3) \\ X_1(2,1) & X_1(2,2) & X_1(2,3) \\ X_1(3,1) & X_1(3,2) & X_1(3,3) \end{bmatrix}$$
$$\begin{bmatrix} X_0(1,1) & X_0(1,2) & X_0(1,3) \\ X_0(2,1) & X_0(2,2) & X_0(2,3) \\ X_0(3,1) & X_0(3,2) & X_0(3,3) \end{bmatrix}$$

to a (9x9) matrix, is performed by replacing each of the nine $[X_1\ X_0]$ pairs by a (3x3) submatrix of the form:

$$\begin{bmatrix} X_s & X_m & X_m \\ X_m & X_s & X_m \\ X_m & X_m & X_s \end{bmatrix}$$

where the self and mutual terms are given by:

$X_s = (X_0 + 2X_1)/3$
$X_m = (X_0 - X_1)/3$

In order to model the core losses (active power P1 and P0 in positive- and zero-sequences), additional shunt resistances are also connected to terminals of one of the three-phase winding. If winding i is selected, the resistances are computed as:
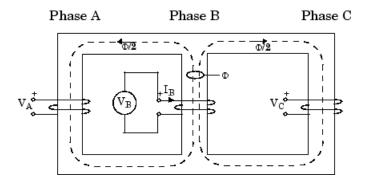
$$R1_i = \frac{V^2_{\text{nom}_i}}{P1_i} \quad R0_i = \frac{V^2_{\text{nom}_i}}{P0_i}.$$

The block takes into account the connection type you select, and the icon of the block is automatically updated. An input port labeled N is added to the block if you select the Y connection with accessible neutral for winding 1. If you ask for an accessible neutral on three-phase winding 2 or 3, an extra outport port labeled n2 or n3 is generated.

Excitation Current in Zero Sequence

Often, the zero-sequence excitation current of a transformer with a 3-limb core is not provided by the manufacturer. In such a case a reasonable value can be guessed as explained below.

The following figure shows a three-limb core with a single three-phase winding. Only phase B is excited and voltage is measured on phase A and phase C. The flux Φ produced by phase B shares equally between phase A and phase C so that $\Phi/2$ is flowing in limb A and in limb C. Therefore, in this particular case, if leakage inductance of winding B would be zero, voltage induced on phases A an C would be $-k.V_B=-V_B/2$. In fact, because of the leakage inductance of the three windings, the average value of induced voltage ratio k when windings A, B and C are successively excited must be slightly lower than 0.5

Assume:

Z_s = average value of the three self impedances
Z_m =average value of mutual impedance between phases
Z_1 = positive-sequence impedance of three-phase winding
Z_0 = zero-sequence impedance of three-phase winding
I_1 = positive-sequence excitation current
I_0 = zero-sequence excitation current

$$V_B = Z_s I_B$$
$$V_A = Z_m I_B = -V_B / 2$$
$$V_C = Z_m I_B = -V_B / 2$$
$$Z_s = \frac{2Z_1 + Z_0}{3}$$
$$Z_m = \frac{Z_0 - Z_1}{3}$$
$$V_A = V_C = \frac{Z_m}{Z_s} V_B = -\frac{\dfrac{Z_1}{Z_0} - 1}{2\dfrac{Z_1}{Z_0} + 1} V_B = -\frac{\dfrac{I_0}{I_1} - 1}{2\dfrac{I_0}{I_1} + 1} V_B = -kV_B,$$

where k= ratio of induced voltage (with k slightly lower than 0.5)

Therefore, the I_0/I_1 ratio can be deduced from k:

$$\frac{I_0}{I_1} = \frac{1 + k}{1 - 2k}.$$

Obviously k cannot be exactly 0.5 because this would lead to an infinite zero-sequence current. Also, when the three windings are excited with a zero-sequence voltage the flux path should return through the air and tank surrounding the iron core. The high reluctance of the zero-sequence flux path results in a high zero-sequence current.

Let us assume I_1= 0.5%. A reasonable value for I_0 could be 100%. Therefore I_0/I_1=200. According to the equation for I_0/I_1 given above, one can deduce the value of k. *k=(200−1)/ (2*200+1)= 199/401= 0.496.*

Zero-sequence losses should be also higher than the positive-sequence losses because of the additional eddy current losses in the tank.

Finally, it should be mentioned that neither the value of the zero-sequence excitation current nor the value of the zero-sequence losses are critical if the transformer has a winding connected in Delta because this winding acts as a short circuit for zero-sequence.

Winding Connections

The three-phase windings can be configured in the following manner:

- Y
- Y with accessible neutral
- Grounded Y
- Delta (D1), delta lagging Y by 30 degrees
- Delta (D11), delta leading Y by 30 degrees

Note The D1 and D11 notations refer to the following clock convention. It assumes that the reference Y voltage phasor is at noon (12) on a clock display. D1 and D11 refer respectively to 1 PM (delta voltages lagging Y voltages by 30 degrees) and 11 AM (delta voltages leading Y voltages by 30 degrees).

Dialog Box and Parameters

Configuration Tab

Core type

> Select the core geometry: `Three single-phase cores` or `Three-limb or five-limb core`. If you select the first option only the positive-sequence parameters are used to compute the inductance matrix. If you select the second option, both the positive- and zero-sequence parameters are used.

Winding 1 connection

The winding connection for three-phase winding 1.

Winding 2 connection

The winding connection for three-phase winding 2.

Winding 3 connection

The winding connection for three-phase winding 3.

Connect windings 1 and 2 in autotransformer

Check to connect the three-phase windings 1 and 2 in autotransformer (three-phase windings 1 and 2 in series with additive voltage).

If the first voltage specified in the **Nominal line-line voltages** parameter is higher than the second voltage, the low voltage tap is connected on the right side (a2,b2,c2 terminals). Otherwise, the low voltage tap is connected on the left side (A,B,C terminals).

In autotransformer mode you must specify the same winding connections for the three-phase windings 1 and 2. If you select Yn connection for both winding 1 and winding 2, the common neutral N connector is displayed on the left side.

The following figure illustrates winding connections for one phase of an autotransformer when the three-phase windings are connected respectively in Yg,Yg, and Delta..

If V1 > V2:

If V2 > V1:

Windings W1,W2,W3 correspond to the following phase winding numbers:

- Phase A: W1=1, W2=4, W3=7
- Phase B: W1=2, W2=5, W3=8
- Phase C: W1=3, W2=6, W3=9

Measurements

Select `Winding voltages` to measure the voltage across the winding terminals of the Three-Phase Transformer block.

Select `Winding currents` to measure the current flowing through the windings of the Three-Phase Transformer block.

Select `All measurements` to measure the winding voltages and currents.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

If the **Winding 1 connection** parameter is set to Y, Yn, or Yg, the labels are as follows.

Measurement	Label
Winding 1 voltages	Uan_w1:, Ubn_w1:, Ucn_w1:

Measurement	Label
Winding 1 currents	or Uag_w1:, Ubg_w1:, Ucg_w1: Ian_w1:, Ibn_w1:, Icn_w1: or Iag_w1:, Ibg_w1:, Icg_w1:

If the **Winding 1 connection** parameter is set to `Delta (D11)` or `Delta (D1)`, the labels are as follows.

Measurement	Label
Winding 1 voltages	Uab_w1:, Ubc_w1:, Uca_w1:
Winding 1 currents	Iab_w1:, Ibc_w1:, Ica_w1:

The same labels apply for three-phase windings 2 and 3, except that 1 is replaced by 2 or 3 in the labels.

Parameters Tab

Nominal power and frequency

The nominal power rating, in volt-amperes (VA), and nominal frequency, in hertz (Hz), of the transformer.

Nominal line-line voltages [V1 V2 V3]

The phase-to-phase nominal voltages of windings 1, 2, 3 in volts RMS.

Winding resistances [R1 R2 R3]

The resistances in pu for windings 1, 2, and 3.

Positive-sequence no-load excitation current

The no-load excitation current in percent of the nominal current when positive-sequence nominal voltage is applied at any three-phase winding terminals (ABC, abc2, or abc3).

Positive-sequence no-load losses

The core losses plus winding losses at no-load, in watts (W), when positive-sequence nominal voltage is applied at any three-phase winding terminals (ABC, abc2, or abc3).

Positive-sequence short-circuit reactances

The positive-sequence short-circuit reactances X12, X23, and X13 in pu. Xij is the reactance measured from winding i when winding j is short-circuited.

When the **Connect windings 1 and 2 in autotransformer** parameter is selected, the short-circuit reactances are labeled XHL, XHT, and XLT. H, L, and T indicate the following terminals: H=high voltage winding (either winding 1 or winding 2), L=low voltage winding (either winding 1 or winding 2), and T=tertiary (winding 3).

Zero-sequence no-load excitation current with Delta windings opened

The no-load excitation current in percent of the nominal current when zero-sequence nominal voltage is applied at any three-phase winding terminals (ABC, abc2, or abc3) connected in Yg or Yn.

Note: If your transformer contains delta-connected windings (D1 or D11), the zero-sequence current flowing into the Yg or Yn winding connected to the zero-sequence voltage source does not represent the net excitation current because zero-sequence currents are also flowing in the delta winding. Therefore, you must specify the no-load zero-sequence circulation current obtained with the delta windings open.

If you want to measure this excitation current, you must temporarily change the delta windings connections from D1 or D11 to Y, Yg, or Yn, and connect the excited winding in Yg or Yn to provide a return path for the source zero-sequence currents.

Zero-sequence no-load losses with Delta windings opened

The core losses plus winding losses at no-load, in watts (W), when zero-sequence nominal voltage is applied at any three-phase winding terminals (ABC, abc2, or abc3) connected in Yg or Yn. The Delta windings must be temporarily open to measure these losses.

Note: Note: If your transformer contains delta-connected windings (D1 or D11), the zero-sequence current flowing into the Yg or Yn winding connected to the zero-sequence voltage source does not represent the net excitation current because zero-sequence currents are also flowing in the delta winding. Therefore, you must specify the no-load zero-sequence circulation current obtained with the delta windings open.

Zero-sequence short-circuit reactances

The zero-sequence short-circuit reactances X12, X23, and X13 in pu. Xij is the reactance measured from winding i when winding j is short-circuited. If the **Zero-sequence X12 measured with winding 3 Delta connected** check box is not selected, X12 represents the short-circuit reactance when winding 3 is not connected in Delta.

When the **Connect windings 1 and 2 in autotransformer** check box is selected, the short-circuit reactances are labeled XHL, XHT, and XLT. H, L, and T indicate the following terminals: H=high voltage winding (either winding 1 or winding 2), L=low voltage winding (either winding 1 or winding 2), and T=tertiary (winding 3).

Zero-sequence X12 measured with winding 3 Delta connected

Select this check box if the available zero-sequence short circuit tests are obtained with tertiary winding (winding 3) connected in Delta.

Limitations

This transformer model does not include saturation. If you need modeling saturation, connect the primary winding of a saturable Three-Phase Transformer (Two Windings) in parallel with the primary winding of your model. Use the same connection (Yg, D1 or D11) and same winding resistance for the two windings connected in parallel. Specify the Y or Yg connection for the secondary winding and leave it open. Specify appropriate voltage, power ratings, and the saturation characteristics that you want. The saturation characteristic is obtained when the transformer is excited by a positive-sequence voltage.

If you are modeling a transformer with three single-phase cores or a five-limb core, this model will produce acceptable saturation currents because flux stays trapped inside the iron core.

For a three-limb core, the saturation model also gives acceptable results even if zero-sequence flux circulates outside of the core and returns through the air and the

transformer tank surrounding the iron core. As the zero-sequence flux circulates in the air, the magnetic circuit is mainly linear and its reluctance is high (high magnetizing currents). These high zero-sequence currents (100% and more of nominal current) required to magnetize the air path are already taken into account in the linear model. Connecting a saturable transformer outside the three-limb linear model with a flux-current characteristic obtained in positive sequence will produce currents required for magnetization of the iron core. This model will give acceptable results whether the three-limb transformer has a delta or not.

See the power_Transfo3phCoreType example showing how saturation is modeled in an inductance matrix type two-winding transformer.

See Also

Linear Transformer, Multimeter, Three-Phase Transformer (Two Windings), Three-Phase Transformer (Three Windings), Three-Phase Transformer Inductance Matrix Type (Two Windings)

Three-Phase V-I Measurement

Measure three-phase currents and voltages in circuit

Library

Fundamental Blocks/Measurements

Description

The Three-Phase V-I Measurement block is used to measure instantaneous three-phase voltages and currents in a circuit. When connected in series with three-phase elements, it returns the three phase-to-ground or phase-to-phase peak voltages and currents.

The block can output the voltages and currents in per unit (pu) values or in volts and amperes.

If you choose to measure phase-to-ground voltages in per unit, the block converts the measured voltages based on peak value of nominal phase-to-ground voltage:

$$V_{\text{abc}}\left(pu\right) = \frac{V_{\text{phase to ground}}\left(V\right)}{V_{\text{base}}\left(V\right)}$$

where

$$V_{\text{base}} = \frac{V_{\text{nom}}\left(Vrms\right)}{\sqrt{3}} \cdot \sqrt{2}$$

If you choose to measure phase-to-phase voltages in per unit, the block converts the measured voltages based on peak value of nominal phase-to-phase voltage:

$$V_{\text{abc}}(pu) = \frac{V_{\text{phase to phase}}(V)}{V_{\text{base}}(V)}$$

where

$$V_{\text{base}} = V_{\text{nom}}(Vrms) \cdot \sqrt{2}$$

If you choose to measure currents in per unit, the block converts the measured currents based on the peak value of the nominal current:

$$I_{\text{abc}}(pu) = \frac{I_{\text{abc}}(A)}{I_{\text{base}}(A)}$$
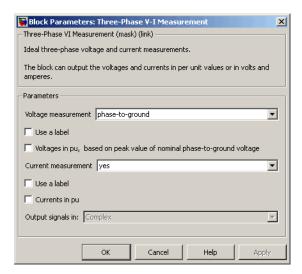
where

$$I\text{base} = \frac{P_{\text{base}}}{V_{\text{nom}}} * \frac{\text{sqrt}(2)}{\text{sqrt}(3)}$$

V_{nom} and P_{base} are specified in the Three-Phase V-I Measurement block dialog box.

The steady-state voltage and current phasors measured by the Three-Phase V-I Measurement block can be obtained from the Powergui block by selecting **Steady-State Voltages and Current**s. The phasor magnitudes displayed in the Powergui stay in peak or RMS values even if the output signals are converted to pu.

Dialog Box and Parameters

Voltage measurement

Select `no` if you do not want to measure three-phase voltage. Select `phase-to-ground` if you want to measure the phase-to-ground voltages. Select `phase-to-phase` if you want to measure the phase-to-phase voltages.

Use a label

If selected, the voltage measurements are sent to a labeled signal. Use a From block to read the voltages. The Goto tag of the From block must correspond to the label specified by the **Signal label** parameter. If not selected, the voltage measurements are available via the Vabc output of the block.

Signal label

Specifies a label tag for the voltage measurements.

Voltages in pu, based on peak value of nominal phase-to-ground voltage

If selected, the measured phase-to-ground voltages are converted in pu.

Note For new models, this parameter is not visible in the dialog box if the **Voltage measurement** parameter is set to `phase-to-phase` or `no`. However, this parameter is visible and selected for a model saved from a previous release with the **Voltage measurement** parameter set to `phase-to-phase` and the **Voltages in pu** option

selected. In such a case, you can choose to keep this parameter as is for compatibility purposes. You can also choose to unselect this parameter and select the **Voltages in pu, based on peak value of nominal phase-to-phase voltage** parameter. You then need to take into account the impact of this new per unit conversion in your model

Voltages in pu, based on peak value of nominal phase-to-phase voltage

If selected, the measured phase-to-phase voltages are converted in pu. This parameter is not visible in the dialog box if **Voltage measurement** parameter is set to `phase-to-ground` or `no`.

Nominal voltage used for pu measurement (Vrms phase-phase)

The nominal voltage, in volts RMS, used to convert the measured voltages in pu. This parameter is not visible in the dialog box if **Voltage measurement** parameter is set to `no`.

Current measurement

Select `yes` if you want to measure the three-phase currents that flow through the block.

Use a label

If selected, the current measurements are sent to a labeled signal. Use a From block to read the currents. The Goto tag of the From block must correspond to the label specified by the **Signal label** parameter. If not selected, the current measurements are available via the Iabc output of the block.

Signal label

Specifies a label tag for the current measurements.

Currents in pu

If selected, the three-phase currents are measured in pu. Otherwise they are measured in amperes.

Base power (VA 3 phase)

The three-phase base power, in volt-ampere (VA), used to convert the measured currents in pu. The **Base power (VA 3 phase)** parameter is not visible in the dialog box if `Currents in pu` is not selected.

Output signal

Specifies the format of the measured signals when the block is used in a phasor simulation. The **Output signal** parameter is disabled when the block is not used in a

phasor simulation. The phasor simulation is activated by a Powergui block placed in the model.

Set to `Complex` to output the measured voltages and currents as complex values. The outputs are complex signals.

Set to `Real-Imag` to output the real and imaginary parts of the measured voltages and currents.

Set to `Magnitude-Angle` to output the magnitudes and angles of the measured voltages and currents.

Set to `Magnitude` to output the magnitudes of the measured voltages and currents. The output is a scalar value.

Inputs and Outputs

`Vabc`

The three measured phase-to-ground or phase-to-phase voltages. The Vabc output disappears when the **Use a label** parameter is selected or when the **Voltage measurement** menu is set to `no`.

`Iabc`

The three measured line currents. The Iabc output disappears when the **Use a label** parameter is selected or when the **Current measurement** menu is set to `no`.

Example

See the power_3phseriescomp example (blocks B1, B2, and B3) for a typical application using the Three-Phase V-I Measurement block.
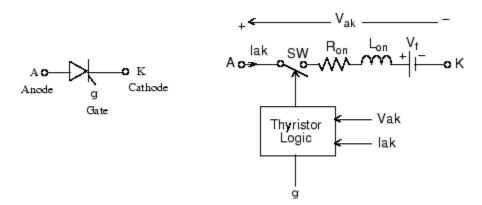
Thyristor

Implement thyristor model

Library

Fundamental Blocks/Power Electronics

Description
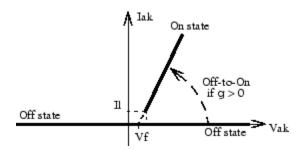
The thyristor is a semiconductor device that can be turned on via a gate signal. The thyristor model is simulated as a resistor Ron, an inductor Lon, and a DC voltage source representing the forward voltage Vf, connected in series with a switch. The switch is controlled by a logical signal depending on the voltage Vak, the current Iak, and the gate signal g.

The Thyristor block also contains a series Rs-Cs snubber circuit that can be connected in parallel with the thyristor device.

The static VI characteristic of this model is shown below.

The thyristor device turns on when the anode-cathode V_{ak} voltage is greater than Vf and a positive pulse signal is applied at the gate input (g > 0). The pulse height must be greater than 0 and last long enough to allow the thyristor anode current to become larger than the latching current *Il*.
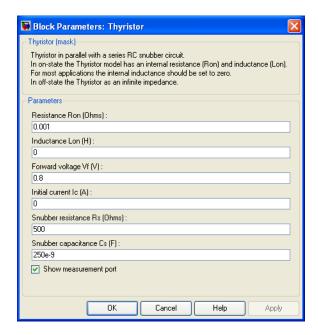
The thyristor device turns off when the current flowing in the device becomes 0 (Iak = 0) and a negative voltage appears across the anode and cathode for at least a period of time equal to the turnoff time Tq. If the voltage across the device becomes positive within a period of time less than Tq, the device turns on automatically even if the gate signal is low (g = 0) and the anode current is less than the latching current. Furthermore, if during turn-on, the device current amplitude stays below the latching current level specified in the dialog box, the device turns off after the gate signal level becomes low (g = 0).

The turnoff time Tq represents the carrier recovery time: it is the time interval between the instant the anode current has decreased to 0 and the instant when the thyristor is capable of withstanding positive voltage Vak without turning on again.

Dialog Box and Parameters

Thyristor Model and Detailed Thyristor Model

In order to optimize simulation speed, two models of thyristors are available: the thyristor model and the detailed thyristor model. For the thyristor model, the latching current *Il* and recovery time *Tq* are assumed to be 0.

Resistance Ron

The thyristor internal resistance Ron, in ohms (Ω). The **Resistance Ron** parameter cannot be set to 0 when the **Inductance Lon** parameter is set to 0.

Inductance Lon

The thyristor internal inductance Lon, in henries (H). The **Inductance Lon** parameter is normally set to 0 except when the **Resistance Ron** parameter is set to 0.

Forward voltage Vf

The forward voltage of the thyristor, in volts (V).

Initial current Ic

When the **Inductance Lon** parameter is greater than 0, you can specify an initial current flowing in the thyristor. It is usually set to 0 in order to start the simulation with the thyristor blocked.

You can specify an **Initial current Ic** value corresponding to a particular state of the circuit. In such a case all states of the linear circuit must be set accordingly. Initializing all states of a power electronic converter is a complex task. Therefore, this option is useful only with simple circuits.

Snubber resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to `inf` to eliminate the snubber from the model.

Snubber capacitance Cs

The snubber capacitance in farads (F). Set the **Snubber capacitance Cs** parameter to `0` to eliminate the snubber, or to `inf` to get a resistive snubber.

Show measurement port
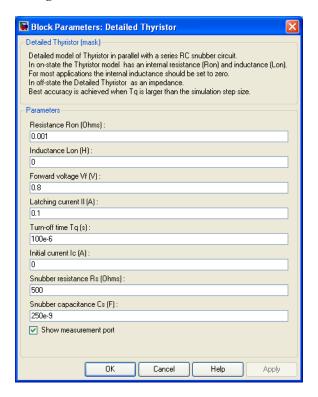
If selected, add a Simulink output to the block returning the thyristor current and voltage.

Latching current Il

The latching current of the detailed thyristor model, in amperes (A).

Turn-off time Tq

The turnoff time Tq of the detailed thyristor model, in amperes (A).

Inputs and Outputs

g

Simulink signal to control the gate of the Thyristor.

m

The Simulink output of the block is a vector containing two signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Signal	Definition	Units
1	Thyristor current	A
2	Thyristor voltage	V

Assumptions and Limitations

The Thyristor block implements a macro model of the real thyristor. It does not take into account either the geometry of the device or complex physical processes that model the behavior of the device [1, 2]. The forward breakover voltage and the critical value of the derivative of the reapplied anode-cathode voltage are not considered by the model.

Depending on the value of the inductance Lon, the Thyristor block is modeled either as a current source (Lon > 0) or as a variable topology circuit (Lon = 0). The Thyristor block cannot be connected in series with an inductor, a current source, or an open circuit, unless its snubber circuit is in use.
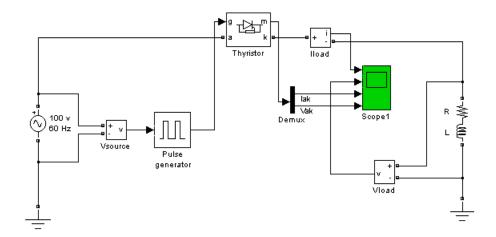
Use the Powergui block to specify either continuous simulation or discretization of your electrical circuit containing Thyristor blocks. When using a continuous model, the `ode23tb` solver with a relative tolerance of 1e-4 is recommended for best accuracy and simulation speed.

The inductance Lon is forced to 0 if you choose to discretize your circuit.
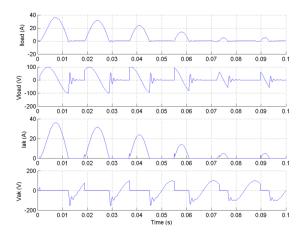
Example

In the power_thyristor example a single-pulse thyristor rectifier is used to feed an RL load. The gate pulses are obtained from a pulse generator synchronized on the source voltage. The following parameters are used:

R		1 Ω
L		10 mH
Thyristor block:	Ron	0.001 Ω
	Lon	0 H
	Vf	0.8 V
	Rs	20 Ω
	Cs	4e-6 F

The firing angle is varied by a pulse generator synchronized on the voltage source. Run the simulation and observe the load current and load voltage, as well as the thyristor current and voltage.

References

[1] Rajagopalan, V., *Computer-Aided Analysis of Power Electronic Systems*, Marcel Dekker, Inc., New York, 1987.

[2] Mohan, N., T.M. Undeland, and W.P. Robbins, *Power Electronics: Converters, Applications, and Design*, John Wiley & Sons, Inc., New York, 1995.

See Also
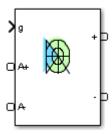
Diode, Universal Bridge

Thyristor Converter

Implements single or three-phase thyristor converter for DC motor drives

Library

Electric Drives/Fundamental Drive Blocks

Description

The Thyristor Converter block represents a standard two-leg (single-phase) or three-leg (three-phase) thyristor bridge model (detailed mode). It has two operating modes to represent a detailed or average-value converter.

Detailed mode

In detailed mode, this block is an instance of the Universal Bridge model configured as a single- (two arms) or three-phase (three arms) thyristor bridge converter. For more details, see Universal Bridge. For four-quadrant operation, two thyristor bridge converters can be connected in antiparallel through circulating current inductors.

Average mode
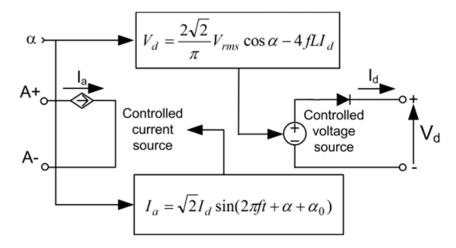
In average mode, the Thyristor Converter block implements an average-value thyristor bridge model for two- or four-quadrant DC drives. The average-value model can be one of these types:

- Single-phase, two-quadrant DC drive

- Single phase, four-quadrant DC drive
- Three phases, two-quadrant DC drive
- Three-phase, four-quadrant DC drive

Single-Phase, Two-Quadrant DC Drive

The converter is composed of one controlled current source on the AC side and one controlled voltage source on the DC side, as shown in the figure.

The AC current source allows the representation of the fundamental single-phase current (Ia) given by

$$I_\alpha = \sqrt{2} I_d \sin(2\pi f t + \alpha + \alpha_0),$$
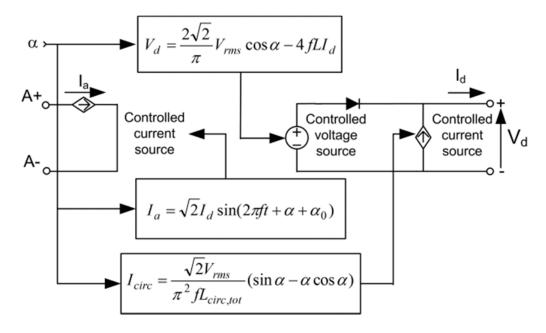
with α being the firing angle value, α_0 the phase angle of the AC side, f the AC frequency, and Id the rectified output current value. The DC voltage source represents the average voltage value of the rectified voltage waveform given by

$$V_d = \frac{2\sqrt{2}}{\pi} V_{rms} \cos\alpha - 4fLI_d,$$

with V_{rms} being the input RMS voltage value and L being the source inductance value.

Single-Phase, Four-Quadrant DC Drive

This model is similar to the single-phase, two-quadrant DC drive model, except that another controlled current source is required on the DC side, as shown in the figure.
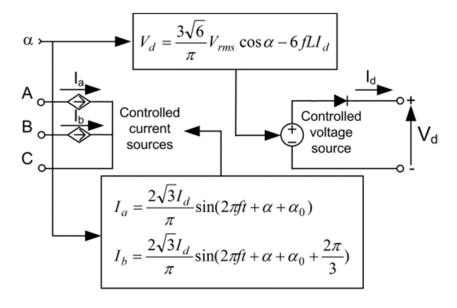
The additional controlled current source represents the circulation current due to the instantaneous voltage difference between both converter outputs of the dual converter. The circulation current is given by

$$I_{circ} = \frac{\sqrt{2}}{\pi^2 f L_{circ,tot}} V_{rms}(\sin\alpha - \alpha\cos\alpha),$$

with $L_{circ,tot}$ being the total circulation inductance of the circulation current loop.

Three-Phase, Two-Quadrant DC Drive

This model is composed of two controlled current sources on the AC side and one controlled voltage source on the DC side, as shown in the figure.
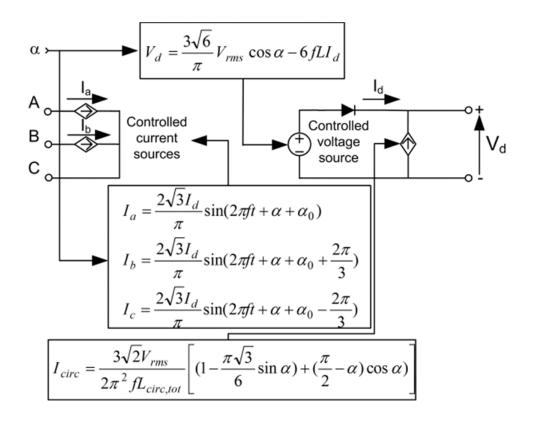
The AC current sources allow the representation of the fundamental three-phase current behaviors. The average voltage value of the rectified voltage waveform is given by
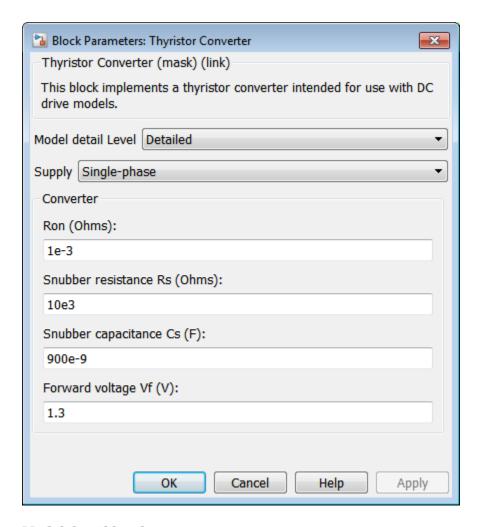
$$V_d = \frac{3\sqrt{6}}{\pi} V_{rms} \cos\alpha - 6fLI_d.$$

Three-Phase, Four-Quadrant DC Drive

In this model, an additional current source is required on the DC side to represent the circulation current in the dual-converter, as shown in the figure.

$$V_d = \frac{3\sqrt{6}}{\pi} V_{rms} \cos \alpha - 6 fLI_d$$

$$I_a = \frac{2\sqrt{3}I_d}{\pi} \sin(2\pi ft + \alpha + \alpha_0)$$

$$I_b = \frac{2\sqrt{3}I_d}{\pi} \sin(2\pi ft + \alpha + \alpha_0 + \frac{2\pi}{3})$$

$$I_c = \frac{2\sqrt{3}I_d}{\pi} \sin(2\pi ft + \alpha + \alpha_0 - \frac{2\pi}{3})$$

$$I_{circ} = \frac{3\sqrt{2}V_{rms}}{2\pi^2 fL_{circ,tot}} \left[(1 - \frac{\pi\sqrt{3}}{6} \sin \alpha) + (\frac{\pi}{2} - \alpha) \cos \alpha \right]$$

Dialog Box and Parameters

Model detail level

Specify the model detail level to use:

- Detailed (default)
- Average

Supply

Specify the number of phases to use:

- `Single-phase` (default)
- `Three-phase`

Number of quadrants

Specify the number of quadrants to use. This parameter is visible only when the Model detail level parameter is set to Average. The default value is `2`.

Ron (Ohms)

Internal resistance of the selected device, in ohms. The default value is `1e-3`.

Snubber resistance Rs (Ohms)

The snubber resistance, in ohms. Set the **Snubber resistance Rs** parameter to `inf` to eliminate the snubbers from the model. The default value is `10e-3`.

Snubber capacitance Cs (F)

The snubber capacitance, in farads. Set the **Snubber capacitance Cs** parameter to `0` to eliminate the snubbers, or to `inf` to get a resistive snubber. The default value is `900e-9`.

Forward voltage Vf (V)

The forward voltage of the thyristors, in volts. The default value is `1.3`.

Line RMS voltage (V)

RMS voltage, in volts, of the supply connected to the A+ or A− (or A, B, C for a three-phase supply) terminals of the drive. This parameter is visible only when the **Model detail level** parameter is set to `Average`. The default value is `460`.

Line frequency (Hz)

Frequency, in hertz, of the supply connected to the A+ or A− (or A, B, C for a three-phase supply) terminals of the drive. This parameter is visible only when the **Model detail level** parameter is set to `Average`. The default value is `60`.

Phase (deg)

Phase angle, in degrees, of the supply connected to the A+ or A− (or A, B, C for a three-phase supply) terminals of the drive. This parameter is visible only when the **Model detail level** parameter is set to `Average`. The default value is `0`.

Source inductance (H)

Source inductance, in henry, of the supply connected to the A+ or A− (or A, B, C for a three-phase supply) terminals of the drive. This parameter is visible only when the

Model detail level parameter is set to `Average` and the **Number of quadrants** parameter is set to `2`. The default value is `0.1e-3`.

Circulation current inductance (H):

The inductance of the circulating current inductors, in henry. This parameter is visible only when the **Model detail level** parameter is set to `Average` and the **Number of quadrants** parameter is set to `4`. The default value is `0`.

Nominal power (W)

Motor nominal power, in watts. This parameter is visible only when the **Model detail level** parameter is set to `Average`. The default value is `5*746`.

Fraction of nominal power dissipated in input resistances

Fraction of nominal power to be dissipated in input resistances. These input resistors are needed due to the converter current sources in series with an inductive motor. This parameter is visible only when the **Model detail level** parameter is set to `Average`. The default value is `0.025`.

Inputs and Outputs

`g`

The gate input for the controlled switch devices. Pulses are sent to upper and lower switches of inverter legs A+ or A– (or A, B, and C for a three-phase converter). This input is visible only when the **Model detail level** parameter is set to `Detailed`.

`A+`

The single-phase terminals on the AC side. The applied voltage must be adequate for the motor size. This input is visible only when the **Supply type** parameter is set to `Single-phase`.

`A-`

The single-phase terminals on the AC side. The applied voltage must be adequate for the motor size. This input is visible only when the **Supply type** parameter is set to `Single-phase`.

`A, B, C`

The three-phase terminals on the AC side. The applied voltage must be adequate for the motor size. This input is visible only when the **Supply type** parameter is set to `Three-phase`.

`Alpha`

Converter firing angle. This input is visible only when the **Model detail level** parameter is set to Average.

+

The positive terminal on the DC side.

-

The negative terminal on the DC side.

Examples

The Thyristor Converter block is used in the DC1, DC2, DC3, and DC4 blocks of the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also
Chopper | Circulating Current Inductors | Inverter (Five-Phase) | Inverter (Three-Phase)

More About
· "Electric Drives Library"

Introduced in R2015b

Timer

Generate signal changing at specified transition times

Library

powerlib_extras/Control Blocks, powerlib_extras/Discrete Control Blocks
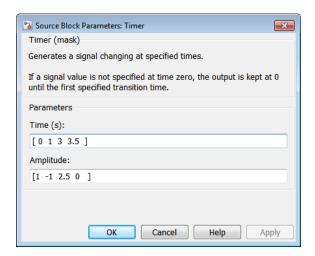
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Note: The Pulse & Signal Generators section of the Control and Measurements library contains the Stair Generator block. This is an improved version of the Timer block. The new block features a mechanism that eliminates duplicate continuous and discrete versions of the same block by basing the block configuration on the simulation mode. If your legacy models contain the Timer block, they will continue to work. However, for best performance, use the Stair Generator block in your new models.

Description

The Timer block generates a signal changing at specified transition times. Use this block to generate a logical signal (0 or 1 amplitudes) and control the opening and closing times of power switches like the Breaker block and the Ideal Switch block. You can also use this block to generate a signal whose amplitude changes by steps at specified transition times.

Dialog Box and Parameters

Time(s)

The transition times, in seconds, when the output of the block changes its value as defined by the **Amplitude** parameter. The **Time(s)** parameter must be a vector of the same length as the vector defined in the **Amplitude** parameter. The definition of the time 0 is optional. If a signal is not specified at time 0, the output is kept at zero until the first transition time specified in the **Amplitude** vector.

Amplitude

The vector of amplitudes of signal to be generated by the Timer block. The amplitude is kept constant between transition times defined in the **Time(s)** vector.

Inputs and Outputs

The output is a signal changing by steps at specified transition times.

See Also
```
Stair Generator
```

Total Harmonic Distortion

Measure total harmonic distortion (THD) of signal

Library

powerlib_extras/Measurements

A discrete version of this block is available in the powerlib_extras/Discrete Measurements library.

Note: The Measurements section of the Control and Measurements library contains the THD block. This is an improved version of the Total Harmonic Distortion block. The new block features a mechanism that eliminates duplicate continuous and discrete versions of the same block by basing the block configuration on the simulation mode. If your legacy models contain the Total Harmonic Distortion block, they will continue to work. However, for best performance, use the THD block in your new models.

Description

The Total Harmonic Distortion block measures the total harmonic distortion (THD) of a periodic distorted signal. The signal can be a measured voltage or current.

The THD is defined as the root mean square (RMS) value of the total harmonics of the signal, divided by the RMS value of its fundamental signal. For example, for currents, the THD is defined as
total harmonic distortion (THD) = I_H/I_F,

where

$$I_H = \sqrt{I_2^2 + I_3^2 + \ldots + I_n^2},$$
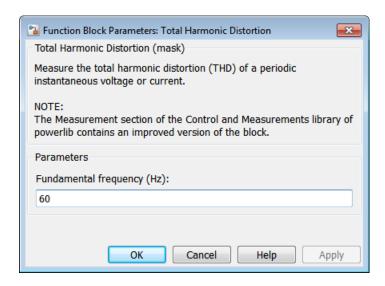
where
I_n = RMS value of the harmonic n
I_F = RMS value of the fundamental current.

The THD has a null value for a pure sinusoidal voltage or current.

Dialog Box and Parameters

Fundamental frequency

The frequency, in hertz, of the fundamental signal.

Inputs and Outputs

`signal`

Connect this input to the voltage or current you want to measure the total harmonic distortion.

`THD`

The output returns the THD of the input signal.

See Also

THD

Triangle Generator
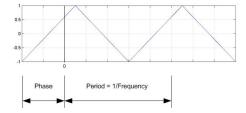
Generate symmetrical triangle waveform at regular intervals
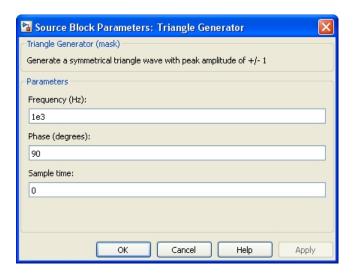
Library

Control and Measurements/Pulse & Signal Generators

Description

The Triangle Generator block generates a symmetrical triangle waveform, with peak amplitude of +/−1. The figure shows how the **Frequency** and **Phase** block parameters affect the output waveform.

Dialog Box and Parameters

Frequency (Hz)

Specify the frequency of the triangle waveform, in hertz.

Phase (degrees)

Specify the delay of the triangle waveform, in degrees. When the phase is set to 0, the waveform starts with an amplitude of −1 and a positive slope.

Sample time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block.

Characteristics

Sample Time	Specified in the **Sample Time** parameter Continuous if **Sample Time** = 0
Scalar Expansion	No
Dimensionalized	No
Zero-Crossing Detection	No

Example
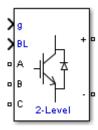
The power_SignalGenerators example shows various uses of the Triangle Generator block.

Two-Level Converter

Implement three-phase two-level power converter

Library

Fundamental Blocks/Power Electronics

Description
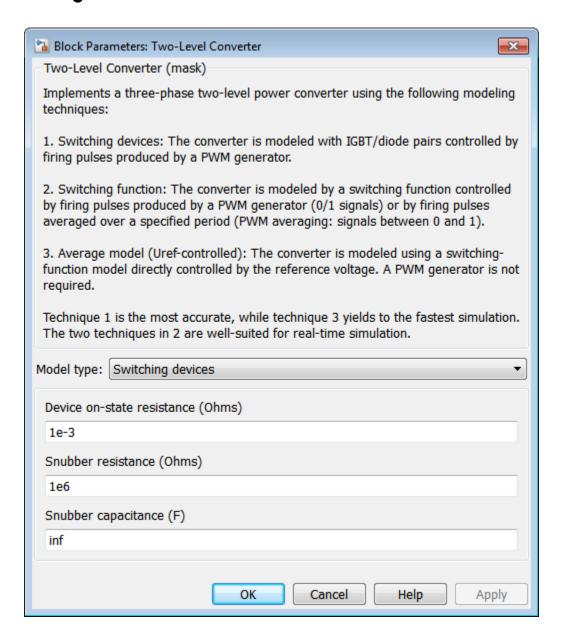
The Two-Level Converter block implements a three-phase, two-level power converter. You can choose from three model types:

- **Switching devices** — The converter is modeled with IGBT/diode pairs controlled by firing pulses produced by a PWM generator. This model provides the most accurate simulation results.

- **Switching function** — The converter is modeled by a switching-function model. The switches are replaced with two voltage sources and two diodes on the AC side and with two current sources on the DC side.

  The converter is controlled by firing pulses produced by a PWM generator (0/1 signals) or by firing pulses averaged over a specified period (PWM averaging: signals between 0 and 1). Both modes of operation produce harmonics normally generated by a PWM-controlled converter and also correctly simulate rectifying operation as well as blanking time. This model type is well-suited for real-time simulation.

- **Average model (Uref-controlled)** — The converter is modeled using a switching-function model directly controlled by the reference voltage signals (Uref). A PWM generator is not required. This model provides the fastest simulations.

Dialog Box and Parameters

Block Parameters: Two-Level Converter

Two-Level Converter (mask)

Implements a three-phase two-level power converter using the following modeling techniques:

1. Switching devices: The converter is modeled with IGBT/diode pairs controlled by firing pulses produced by a PWM generator.

2. Switching function: The converter is modeled by a switching function controlled by firing pulses produced by a PWM generator (0/1 signals) or by firing pulses averaged over a specified period (PWM averaging: signals between 0 and 1).

3. Average model (Uref-controlled): The converter is modeled using a switching-function model directly controlled by the reference voltage. A PWM generator is not required.

Technique 1 is the most accurate, while technique 3 yields to the fastest simulation. The two techniques in 2 are well-suited for real-time simulation.

Model type: | Switching devices

Device on-state resistance (Ohms)

1e-3

Snubber resistance (Ohms)

1e6

Snubber capacitance (F)

inf

OK   Cancel   Help   Apply

Parameters

Model type

Select one of these values:

- `Switching devices` (default)
- `Switching function`
- `Average model (Uref-controlled)`

Device on-state resistance (Ohms)

Internal resistance of the switching devices, in ohms. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `1e-3`.

Snubber resistance (Ohms)

The snubber resistance, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `1e6`.

Snubber capacitance (F)

The snubber capacitance, in farads. Set the snubber capacitance to `0` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `inf`.

Diode on-state resistance (Ohms)

Internal resistance of the diodes, in ohms. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `1e-3`.

Diode snubber resistance (Ohms)

The snubber resistance, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `1e6`.

Diode snubber capacitance (F)

The snubber capacitance in farads. Set the snubber capacitance to `0` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `inf`.

Diode forward voltage (V)

Forward voltage, in volts, across the diode when it is conducting. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `1e-3`.

Current source snubber resistance (Ohms)

The snubber resistance across the two current sources, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (Uref-controlled)`. The default value is `inf`.

Inputs and Outputs

g

A vectorized gating signal to control the converter. The gating signal contains six firing pulses. The first two pulses control the Q1 and Q2 switching devices (phase A of the converter), pulses three and four control the Q3 and Q4 switching devices (phase B of the converter), and the last two pulses control the Q5 and Q6 switching devices (phase C of the converter). This port is visible only when you set the **Model type** parameter to `Switching devices` or `Switching function`.

Uref

A vectorized signal to control the converter. The signal contains three reference voltages (one for each phase). This port is visible only when you set the **Model type** parameter to `Average model (Uref-controlled)`.

BL

You can block all firing pulses to the converter by applying a signal value of 1 at the BL input.

Examples

See the Power Converters Modeling Techniques example for a comparison of the three converter modeling techniques.
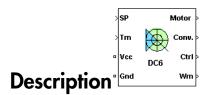
Introduced in R2015b

Two-Quadrant Chopper DC Drive

Implement two-quadrant chopper (buck-boost converter topology) DC drive
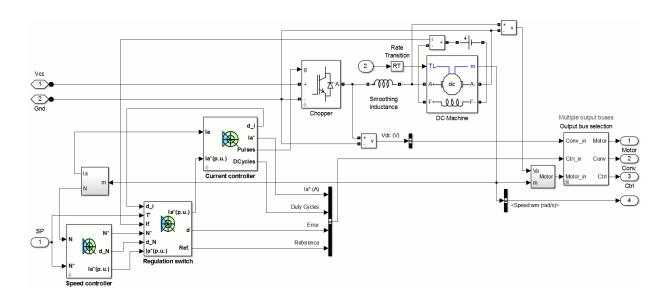
Library

Electric Drives/DC drives

Description

The high-level schematic shown below is built from four main blocks. The DC motor and the IGBT/Diode devices (within the Universal Bridge block) are provided with the SimPowerSystems library. More details are available in the reference pages for these blocks. The two other blocks are specific to the Electric Drives library. These blocks are the speed controller and the current controller. They allow speed or torque regulation. A "regulation switch" block allows you to toggle from one type of regulation to the other. During torque regulation the speed controller is disabled.

Note In SimPowerSystems software, the Two-Quadrant Chopper DC Drive block is commonly called the DC6 motor drive.

High-Level Schematic

Simulink Schematic

Speed Controller

The speed regulator shown below uses a PI controller. The controller outputs the armature current reference (in pu) used by the current controller to obtain the electromagnetic torque needed to reach the desired speed. During torque regulation, the speed controller is disabled.

The controller takes the speed reference (in rpm) and the rotor speed of the DC machine as inputs. The speed reference change rate will follow user-defined acceleration and deceleration ramps in order to avoid sudden reference changes that could cause armature over-current and destabilize the system. In order to avoid negative speeds that could induce conduction of the free-wheeling diode, the speed reference has a lower limit of 0 rpm.

The speed measurement is filtered by a first-order low-pass filter.

The current reference output is limited between symmetrical lower and upper limits defined by the user. Meanwhile, at low speeds, when the back-EMF of the motor is not high enough to generate big reverse currents, the lower limit is reduced proportionally to the speed. This improves current regulation.
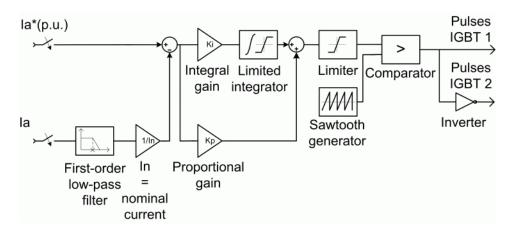
Current Controller

The armature current regulator shown below is based on a second PI controller. The regulator controls the armature current by computing the appropriate duty ratios of the fixed frequency pulses of the two IGBT devices (Pulse Width Modulation). This generates the average armature voltage needed to obtain the desired armature current and thus

the desired electromagnetic torque. For proper system behavior, the two IGBT devices have opposite instantaneous pulse values.
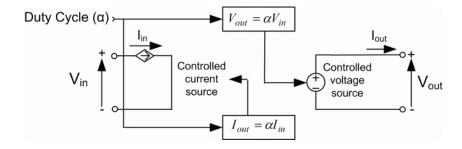
The controller takes the current reference (in pu) and the armature current flowing through the motor as inputs. The current reference is either provided by the speed controller during speed regulation or computed from the torque reference provided by the user during torque regulation. This is managed by the "regulation switch" block. The armature current input is filtered by a first-order low-pass filter.

The pulse width modulation is obtained by comparison of the PI output and a fixed frequency sawtooth carrier signal (see the figure called Pulse Width Modulation (PWM)).

Average-Value Two-Quadrant Chopper

The average-value converter is shown in the following figure.

It is composed of one controlled current source on the DC source side and one controlled voltage source on the motor side. The current source allows the representation of the average input current value following the next equation:

$I_{in} = aI_{out}$,

with a being the firing angle value and I_{out} the armature current value. The voltage source on the motor side represents the average voltage value following the next equation:

$V_{out} = aV_{in}$,

with V_{in} being the input voltage.

Remarks

The machine is separately excited with a constant DC field voltage source. There is thus no field voltage control. By default, the field current is set to its steady-state value when a simulation is started.
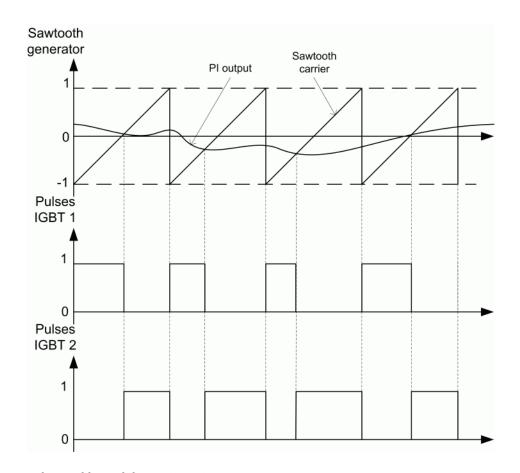
The armature voltage is provided by an IGBT buck-boost converter controlled by two PI regulators. The converter is fed by a constant DC voltage source. Armature current oscillations are reduced by a smoothing inductance connected in series with the armature circuit.

The model is discrete. Good simulation results have been obtained with a 1 μs time step. In order to simulate a digital controller device, the control system has two different sampling times:

- The speed controller sampling time
- The current controller sampling time

The speed controller sampling time has to be a multiple of the current sampling time. The latter sampling time has to be a multiple of the simulation time step.

Pulse Width Modulation (PWM)

Dialog Box

DC Machine Tab

The **DC Machine** tab displays the parameters of the DC Machine block of the Fundamental Blocks (powerlib) library.

Output bus mode

Select how the output variables are organized. If you select **Multiple output buses**, the block has three separate output buses for motor, converter, and controller variables. If you select **Single output bus**, all variables output on a single bus.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Select between the load torque, the motor speed and the mechanical rotational port as mechanical input. If you select and apply a load torque, the output is the motor speed according to the following differential equation that describes the mechanical system dynamics:

$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

If you select the motor speed as mechanical input, then you get the electromagnetic torque as output, allowing you to represent externally the mechanical system dynamics. The internal mechanical system is not used with this mechanical input selection and the inertia and viscous friction parameters are not displayed.

For the mechanical rotational port, the connection port S counts for the mechanical input and output. It allows a direct connection to the Simscape environment. The mechanical system of the motor is also included in the drive and is based on the same differential equation.

See "Mechanical Coupling of Two Motor Drives".

Converter Tab

IGBT/Diode Devices Section

The IGBT/Diode section of the Converter tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the Universal Bridge block parameters.

Smoothing Inductance

The smoothing inductance value (H).

Field DC Source

The DC motor field voltage value (V).

Controller Tab

Schematic Button

When you press this button, a diagram illustrating the speed and current controllers schematics appears.

Regulation Type

This pop-up menu allows you to choose between speed and torque regulation.

Controller — Speed Controller Subtab

Nominal Speed

The nominal speed value of the DC motor (rpm). This value is used to convert motor speed from rpm to pu (per unit).

Initial Speed Reference

The initial speed reference value (rpm). This value allows the user to start a simulation with a speed reference other than 0 rpm.

Low-Pass Filter Cutoff Frequency

Cutoff frequency of the low-pass filter used to filter the motor speed measurement (Hz).

Sampling Time

The speed controller sampling time (s). This sampling time has to be a multiple of the current controller sampling time and of the simulation time step.

Proportional Gain

The proportional gain of the PI speed controller.

Integral Gain

The integral gain of the PI speed controller.

Acceleration

The maximum change of speed allowed during motor acceleration (rpm/s). Too great a value can cause armature over-current.

Deceleration

The maximum change of speed allowed during motor deceleration (rpm/s). Too great a value can cause armature over-current.

Controller — Current Controller Subtab

Low-Pass Filter Cutoff Frequency

Cutoff frequency of the low-pass filter used to filter the armature current measurement (Hz).

Reference Limit

Symmetrical current reference (pu) limit around 0 pu. 1.5 pu is a common value. Keep in mind that the lower limit is automatically reduced for low speeds (see speed controller description).

PWM Switching Frequency

The switching frequency of the two IGBT devices (Hz).

Sampling Time

The current controller sampling time (s). This sampling time has to be a submultiple of the speed controller sampling time and a multiple of the simulation time step.

Power and Voltage nominal values

The DC motor nominal power (W) and voltage (V) values. These values are used to convert armature current from amperes to pu (per unit).

Proportional Gain

The proportional gain of the PI current controller.

Integral Gain

The integral gain of the PI current controller.

Block Inputs and Outputs

SP

The speed or torque set point. The speed set point can be a step function, but the speed change rate will follow the acceleration / deceleration ramps. If the load torque and the speed have opposite signs, the accelerating torque will be the sum of the electromagnetic and load torques.

Tm or Wm

The mechanical input: load torque (Tm) or motor speed (Wm). For the mechanical rotational port (S), this input is deleted.

Vcc, Gnd

The DC voltage source electric connections. The voltage must be adequate for the motor size.

Wm, Te or S

The mechanical output: motor speed (Wm), electromagnetic torque (Te) or mechanical rotational port (S).

When the **Output bus mode** parameter is set to **Multiple output buses**, the block has the following three output buses:

Motor

The motor measurement vector. This vector is composed of two elements:

- The armature voltage

- The DC motor measurement vector (containing the speed, armature current, field current, and electromagnetic torque values). Note that the speed signal is converted from rad/s to rpm before output.

Conv

The IGBT/Diode device measurement vector. This vector includes the converter output voltage. The output current is not included since it is equal to the DC motor armature current. Note that all current and voltage values of the converter can be visualized with the mulimeter block.

Ctrl

The controller measurement vector. This vector contains:

- The armature current reference
- The duty cycle of the PWM pulses
- The speed or torque error (difference between the speed reference ramp and actual speed or between the torque reference and actual torque)
- The speed reference ramp or torque reference

When the **Output bus mode** parameter is set to **Single output bus**, the block groups the Motor, Conv, and Ctrl outputs into a single bus output.

Model Specifications

The library contains a 5 hp and a 200 hp drive parameter set. The specifications of these two drives are shown in the following table.

5 HP and 200 HP Drive Specifications

		5 HP Drive	200 HP Drive
Drive Input Voltage			
	Amplitude	280 V	550 V
Motor Nominal Values			
	Power	5 hp	200 hp
	Speed	1750 rpm	1750 rpm
	Voltage	240 V	500 V

Example

The `dc6_example` example illustrates the two-quadrant chopper drive used with the 200 hp drive parameter set during speed regulation. A 5 hp parameter set is also available in the library.

The buck-boost converter is fed by a 630 V DC bus obtained by rectification of a 460 V AC 60 Hz voltage source. In order to limit the DC bus voltage during dynamic braking mode, a braking chopper has been added between the diode rectifier and the DC6 block. The IGBT switching frequency is 5 kHz.

The speed reference is set at 400 rpm at t = 0 s. Initial load torque is 814 N.m.

Observe that the motor speed follows the reference ramp accurately (+250 rpm/s) and reaches steady state around t = 2 s. The armature current follows the current reference very well, with fast response time and small ripples. Notice that the current ripple frequency is 5 kHz.

At t = 2.1 s, the load torque passes from 814 N.m to 100 N.m. The motor speed recovers fast and is back at 400 rpm at t = 2.75 s. The current reference lowers to about 40 A to generate a smaller electromagnetic torque, the load torque being reduced. As observed before, the armature current follows its reference perfectly.
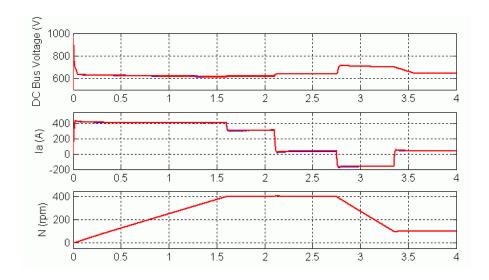
At t = 2.75 s, the speed reference jumps down to 100 rpm. In order for the motor to decelerate following the negative speed ramp, the armature current reverses down to

−160 A to generate a braking electromagnetic torque (dynamic braking mode). This causes the DC bus voltage to increase. The braking chopper limits the voltage value.

At t = 3.4 s, the motor speed reaches 100 rpm and the current reverses back to 40 A.
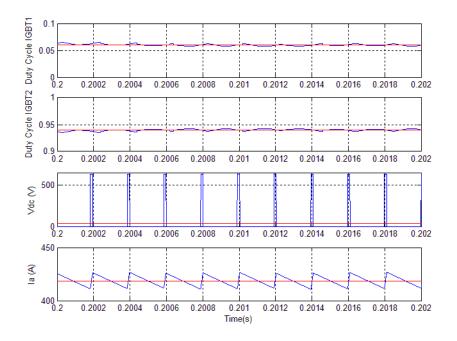
At t = 4 s, the speed stabilizes around its reference.

The following figure shows the DC bus voltage, armature current, and speed waveforms.

DC6 Example — DC Bus Voltage, Current, and Speed Waveforms (Blue: Detailed Converter, Red: Average-Value Converter)

The next figure shows the duty cycles of the chopper pulses and the corresponding armature voltage and current waveforms during a time interval of 2 ms.

DC6 Example — Duty Cycles, Armature Voltage, and Current Waveforms (Blue: Detailed Converter, Red: Average-Value Converter)

References

[1] Boldea, Ion, and S.A. Nasar, *Electric Drives*, CRC Press LLC, 1999.
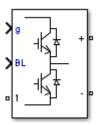
[2] Séguier, Guy, *Electronique de puissance*, Dunod, 1999.

Two-Quadrant DC/DC Converter

Implement two-quadrant DC/DC power converter

Library

Fundamental Blocks/Power Electronics

Description
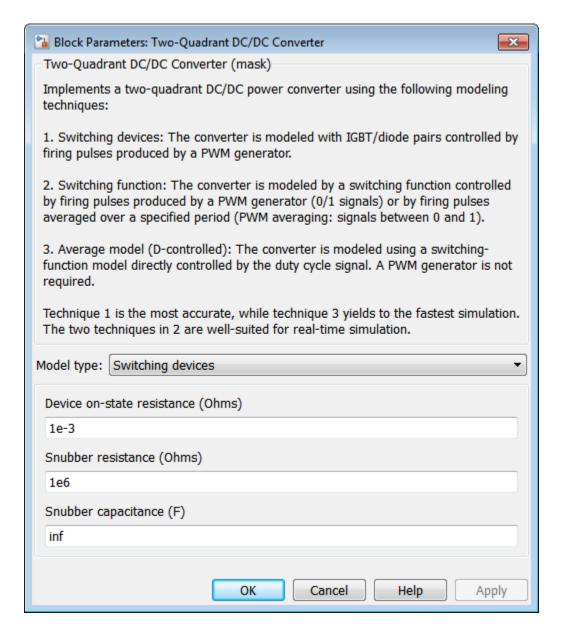
The Two-Quadrant DC/DC Converter block implements a two-quadrant DC/DC power converter. You can choose from three model types :

- **Switching devices** — The converter is modeled with IGBT/diode pairs controlled by firing pulses produced by a PWM generator. This model provides the most accurate simulation results.

- **Switching function** — The converter is modeled by a switching-function model. The switches are replaced with two voltage sources and two diodes on the AC side and with two current sources on the DC side.

  The converter is controlled by firing pulses produced by a PWM generator (0/1 signals) or by firing pulses averaged over a specified period (PWM averaging: signals between 0 and 1). Both modes of operation produce harmonics normally generated by a PWM-controlled converter and also correctly simulate rectifying operation as well as blanking time. This model type is well-suited for real-time simulation.

- **Average model (D-controlled)** — The converter is modeled using a switching-function model directly controlled by the duty cycle signal ($0 < D < 1$). A PWM generator is not required. This model provides the fastest simulations.

Dialog Box and Parameters

Parameters

Model type

Specify the model type to use:

- `Switching devices` (default)
- `Switching function`
- `Average model (D-controlled)`

Device on-state resistance (Ohms)

Internal resistance of the switching devices, in ohms. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `1e-3`.

Snubber resistance (Ohms)

The snubber resistance, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `1e6`.

Snubber capacitance (F)

The snubber capacitance, in farads. Set the snubber capacitance to `0` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `inf`.

Forward voltages [Device Vf (V), Diode Vfd (V)]

The forward voltage of the switching device and of the diode, in volts. This parameter is available only when you set the **Model type** parameter to `Switching devices`. The default value is `[0,0]`.

Diode on-state resistance (Ohms)

Internal resistance of the diodes, in ohms. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (D-controlled)`. The default value is `1e-3`.

Diode snubber resistance (Ohms)

The snubber resistance, in ohms. Set the snubber resistance to `inf` to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to `Switching function` or `Average model (D-controlled)`. The default value is `1e6`.

Diode snubber capacitance (F)

The snubber capacitance in farads. Set the snubber capacitance to 0 to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to Switching function or Average model (D-controlled). The default value is inf.

Diode forward voltage (V)

Forward voltage, in volts, across the diode when it is conducting. This parameter is available only when you set the **Model type** parameter to Switching function or Average model (D-controlled). The default value is 1e-3.

Current source snubber resistance (Ohms)

The snubber resistance in ohms across the two current sources. Set the snubber resistance to inf to eliminate the snubbers. This parameter is available only when you set the **Model type** parameter to Switching function or Average model (D-controlled). The default value is inf.

Inputs and Outputs

g

A vectorized gating signal to control the converter. The gating signal contains two firing pulses. The first pulse controls Q1 and the second pulse controls Q2. This port is visible only when you set the **Model type** parameter to Switching devices or Switching function.

D

The duty cycle signal is a value between 0 and 1 used to control the converter. This port is visible only when you set the **Model type** parameter to Average model (D-controlled).

BL

You can block all firing pulses to the converter by applying a signal value of 1 at the BL input.

Examples

See the Power Converters Modeling Techniques example for a comparison of the three converter modeling techniques.
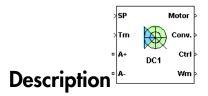
Introduced in R2015b

Two-Quadrant Single-Phase Rectifier DC Drive

Implement two-quadrant single-phase rectifier DC drive
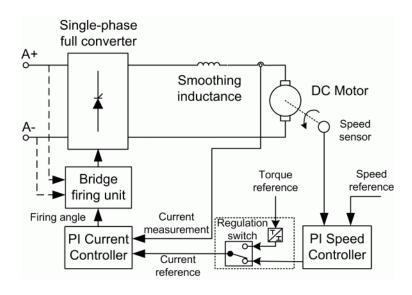
Library

Electric Drives/DC drives

Description
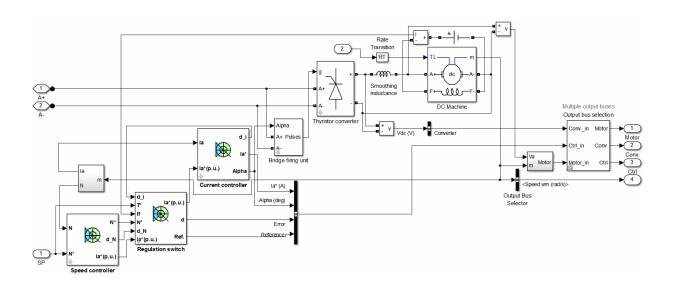
The high-level schematic shown below is built from five main blocks. The DC motor, the single-phase full converter, and the bridge firing unit are provided with the SimPowerSystems library. More details are available in the reference pages for these blocks. The two other blocks are specific to the Electric Drives library. These blocks are the speed controller and the current controller. They allow speed or torque regulation. A "regulation switch" block allows you to toggle from one type of regulation to the other. During torque regulation the speed controller is disabled. It is possible to use a simplified version of the drive containing an average-value model of the single-phase converter and allowing faster simulation.

Note In SimPowerSystems software, the Two-Quadrant Single-Phase Rectifier DC Drive block is commonly called the DC1 motor drive.

High-Level Schematic

Simulink Schematic

Speed Controller
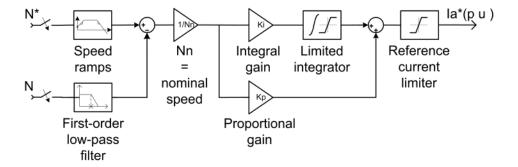
The speed regulator in the following figure uses a PI controller. The controller outputs the armature current reference (in pu) used by the current controller in order to obtain the electromagnetic torque needed to reach the desired speed. During torque regulation, the speed controller is disabled.

The controller takes the speed reference (in rpm) and the rotor speed of the DC machine as inputs. The speed reference change rate will follow user-defined acceleration and deceleration ramps in order to avoid sudden reference changes that could cause armature over-current and destabilize the system. The speed measurement is filtered by a first-order low-pass filter.

The current reference output is limited between 0 pu and an upper limit defined by the user.

Current Controller

The armature current regulator in the following figure is based on a second PI controller. The regulator controls the armature current by computing the appropriate thyristor firing angle. This generates the rectifier output voltage needed to obtain the desired armature current and thus the desired electromagnetic torque.

The controller takes the current reference (in pu) and the armature current flowing through the motor as inputs. The current reference is either provided by the speed controller during speed regulation or computed from the torque reference provided by the user during torque regulation. This is managed by the "regulation switch" block.

The armature current input is filtered by a first-order low-pass filter. An arccosine function is used to linearize the control system during continuous conduction. To compensate nonlinearities appearing during discontinuous conduction, a feedforward term is added to the firing angle. This improves the system's response time. The firing angle can vary between 0 and 180 degrees. You can limit the lower and upper limits to intermediate values.

Average-Value Single-Phase Rectifier

The average-value converter is shown in the following figure.

It is composed of one controlled current source on the AC side and one controlled voltage source on the DC side. The AC current source allows the representation of the fundamental single-phase current behavior following the next equation:

$$I_a = \sqrt{2}I_d \sin\left(2\pi ft + \alpha + \alpha_0\right),$$

with a being the firing angle value, α_0 the phase angle of the AC side, f the AC frequency and I_d the rectified output current value. The DC voltage source represents the average voltage value of the rectified voltage waveform following the next equation:

$$V_d = \frac{2\sqrt{2}}{\pi} V_{\text{rms}} \cos\alpha - 4fLI_d,$$

with V_{rms} being the input RMS voltage value and L being the source inductance value.

Bridge Firing Unit

The bridge firing unit converts the firing angle, provided by the current controller, to four pulses applied to the thyristor gates. The bridge firing unit block contains a band-pass filter on voltage measurement to remove voltage harmonics. The discrete synchronized pulse generator block generates the pulses. Its architecture is based on the Discrete Synchronized 6-Pulse Generator block. Refer to the Synchronized 6-Pulse Generator for more information on this block. When using the average-value converter the bridge firing unit simply outputs the firing angle value needed by the converter.

Remarks

The machine is separately excited with a constant DC field voltage source. There is thus no field voltage control. By default, the field current is set to its steady-state value when a simulation is started.

The armature voltage is provided by a single-phase rectifier controlled by two PI regulators. Armature current oscillations are reduced by a smoothing inductance connected in series with the armature circuit.

The average-value converter represents the average behavior of a single-phase rectifier for continuous armature current. This model is thus not suitable for simulating DC drives under discontinuous armature current conditions.The converter outputs a continuous voltage value equal to the average-value of the real-life rectified voltage. The armature voltage, armature current and electromagnetic torque ripples are thus not represented. The input currents have the frequency and amplitude of the fundamental current component of the real-life input currents.

The model is discrete. Good simulation results have been obtained with a 25 µs time step. The control system (speed and current controllers) samples data following a user-defined sample time in order to simulate a digital controller device. Keep in mind that this sampling time has to be a multiple of the simulation time step.

The average-value converter allows the use of bigger simulation time steps since it does not generate small time constants (due to the RC snubbers) inherent to the detailed converter. For a controller sampling time of 100 µs good simulation results have been obtained for a simulation time step of 100 µs. This time step can of course not be higher than the controller time step.

Dialog Box

DC Machine Tab

The **DC Machine** tab displays the parameters of the DC Machine block of the Fundamental Blocks (powerlib) library.

Output bus mode

Select how the output variables are organized. If you select **Multiple output buses**, the block has three separate output buses for motor, converter, and controller variables. If you select **Single output bus**, all variables output on a single bus.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Select between the load torque, the motor speed and the mechanical rotational port as mechanical input. If you select and apply a load torque, the output is the motor speed according to the following differential equation that describes the mechanical system dynamics:

$$T_e = J \frac{d}{dt} \omega_r + F \omega_r + T_m$$

This mechanical system is included in the motor model.

If you select the motor speed as mechanical input, then you get the electromagnetic torque as output, allowing you to represent externally the mechanical system dynamics. The internal mechanical system is not used with this mechanical input selection and the inertia and viscous friction parameters are not displayed.

For the mechanical rotational port, the connection port S counts for the mechanical input and output. It allows a direct connection to the Simscape environment. The mechanical system of the motor is also included in the drive and is based on the same differential equation.

See "Mechanical Coupling of Two Motor Drives".

Converter Tab

Rectifier section

The Rectifier section of the Converter tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the Universal Bridge block parameters.

Smoothing Inductance

The smoothing inductance value (H).

Field DC Source

The DC motor field voltage value (V).

RMS Voltage

RMS voltage of the single-phase voltage source connected to the A+,A- terminals of the drive (V). This parameter is not used when using the detailed rectifier.

Frequency

Frequency of the single-phase voltage source connected to the A+,A- terminals of the drive (Hz). This parameter is not used when using the detailed rectifier.

Source Inductance

Source inductance of the single-phase voltage source connected to the A+,A- terminals of the drive (H). This parameter is not used when using the detailed rectifier.

Phase Angle

Phase angle of the single-phase voltage source connected to the A+,A- terminals of the drive (deg.). This parameter is not used when using the detailed rectifier.

Controller Tab

Schematic Button

When you press this button, a diagram illustrating the speed and current controllers schematics appears.

Regulation Type

This pop-up menu allows you to choose between speed and torque regulation.

Sampling Time

The controller (speed and current) sampling time (s). The sampling time has to be a multiple of the simulation time step.

Controller — Speed Controller Subtab

Nominal Speed

The nominal speed value of the DC motor (rpm). This value is used to convert motor speed from rpm to pu (per unit).

Initial Speed Reference

The initial speed reference value (rpm). This value allows the user to start a simulation with a speed reference other than 0 rpm.

Low-Pass Filter Cutoff Frequency

Cutoff frequency of the low-pass filter used to filter the motor speed measurement (Hz).

Proportional Gain

The proportional gain of the PI speed controller.

Integral Gain

The integral gain of the PI speed controller.

Acceleration

The maximum change of speed allowed during motor acceleration (rpm/s). Too great a value can cause armature over-current.

Deceleration

The maximum change of speed allowed during motor deceleration (rpm/s). Too great a value can cause armature over-current.

Controller — Current Controller Subtab

Power and Voltage nominal values

The DC motor nominal power (W) and voltage (V) values. These values are used to convert armature current values from amperes to pu (per unit).

Proportional Gain

The proportional gain of the PI current controller.

Integral Gain

The integral gain of the PI current controller.

Low-Pass Filter Cutoff Frequency

Cutoff frequency of the low-pass filter used to filter the armature current measurement (Hz).

Reference Limit

Maximum current reference value (pu). 1.5 pu is a common value.

Controller — Bridge Firing Unit Subtab

Alpha Min

Minimum firing angle value (deg.). 20 degrees is a common value.

Alpha Max

Maximum firing angle value (deg.). 160 degrees is a common value.

Frequency of Synchronization Voltages

Frequency of the synchronization voltages used by the discrete synchronized pulse generator block (Hz). This frequency is equal to the line frequency of the single-phase power line. This parameter is not used when using the average-value converter.

Pulse Width

The width of the pulses applied to the four thyristor gates (deg.). This parameter is not used when using the average-value converter.

Block Inputs and Outputs

SP

The speed or torque set point. The speed set point can be a step function, but the speed change rate will follow the acceleration / deceleration ramps. If the load torque and the speed have opposite signs, the accelerating torque will be the sum of the electromagnetic and load torques.

Tm or Wm

The mechanical input: load torque (Tm) or motor speed (Wm). For the mechanical rotational port (S), this input is deleted.

A+, A-

The single-phase electric connections. The applied voltage must be adequate for the motor size.

Wm, Te or S

The mechanical output: motor speed (Wm), electromagnetic torque (Te) or mechanical rotational port (S).

When the **Output bus mode** parameter is set to **Multiple output buses**, the block has the following three output buses:

Motor

The motor measurement vector. This vector is composed of two elements:

- The armature voltage
- The DC motor measurement vector (containing the speed, armature current, field current, and electromagnetic torque values). Note that the speed signal is converted from rad/s to rpm before output.

Conv

The single-phase converter measurement vector. It includes the converter output voltage. The output current is not included since it is equal to the DC motor armature current.

Note that all current and voltage values of the bridges can be visualized with the Multimeter block.

Ctrl

The controller measurement vector. This vector contains:

- The armature current reference
- The firing angle computed by the current controller
- The speed or torque error (difference between the speed reference ramp and actual speed or between the torque reference and actual torque)
- The speed reference ramp or torque reference

When the **Output bus mode** parameter is set to **Single output bus**, the block groups the Motor, Conv, and Ctrl outputs into a single bus output.

Model Specifications

The library contains a 5 hp drive parameter set. The specifications of the 5 hp drive are shown in the following table.

5 HP Drive Specifications

Drive Input Voltage		
	Amplitude	320 V
	Frequency	50 Hz
Motor Nominal Values		
	Power	5 hp
	Speed	1750 rpm
	Voltage	240 V

Example

The dc1_example example illustrates the single-phase rectifier drive used with the 5 hp drive parameter set during speed regulation.

Two-Quadrant Single-Phase Rectifier 5 HP DC Drive

See also 'dc1_example_simplified.mdl' for average-value model

The 'Ts' parameter used in this model
is set to 25e-6s by the Model Properties Callbacks

The rectifier is fed by a 220 V AC 50 Hz voltage source followed by a linear transformer to boost the voltage to a sufficient value.
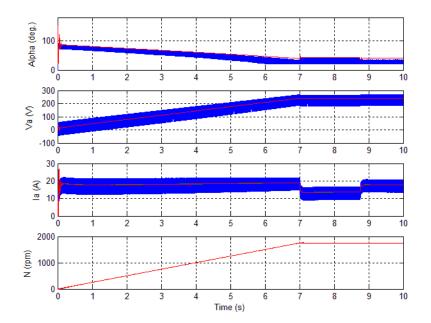
The speed reference is set at 1750 rpm at t = 0 s. Initial load torque is 15 N.m.

Observe that the motor speed follows the reference ramp accurately (+250 rpm/s) and reaches steady state around t = 8.5 s.

The armature current follows the current reference very well, and the firing angle stays below 90 degrees, the converter being in rectifier mode (first quadrant operating mode). The lower limit of the firing angle has been set to 20 degrees.

At t = 8.75 s, the load torque passes from 15 N.m to 20 N.m. The motor speed recovers fast and is back at 1750 rpm at t = 10 s. The current reference rises to about 17.5 A to generate a higher electromagnetic torque to maintain the needed speed. As observed before, the armature current follows its reference perfectly.

The following figure illustrates the results obtained respectively with the detailed and the average-value converters. Average voltage, current, torque and speed values are identical for both models. The average firing angle values however are slightly different. Notice that the higher frequency signal components are not represented with the average-value converter.

DC1 Example Waveforms (Blue: Detailed Converter, Red: Average-Value Converter)
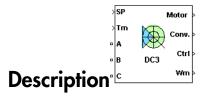
References

[1] Sen, P.C., *Thyristor DC Drives*, J.Wiley and Sons, 1981.

[2] Nondahl, Thomas A., *Microprocessor Control of Motor Drives and Power Converters*, *tutorial course*, IEEE Industry Application Society, October 1993, pp. 7.1-7.26.

Two-Quadrant Three-Phase Rectifier DC Drive

Implement two-quadrant three-phase rectifier DC drive
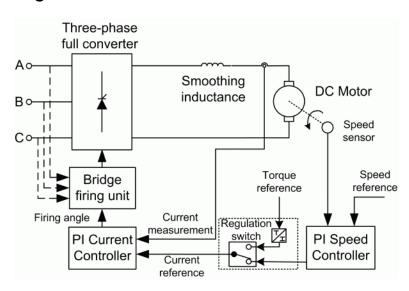
Library

Electric Drives/DC drives

Description
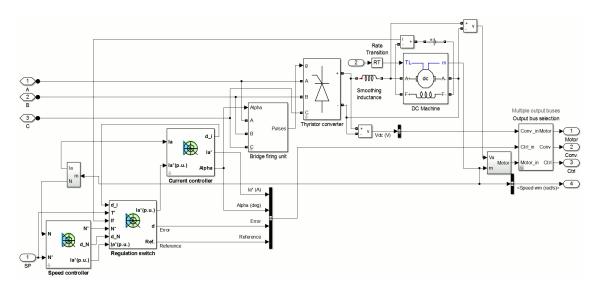
The high-level schematic shown below is built from five main blocks. The DC motor, the three-phase full converter, and the bridge firing unit are provided with the SimPowerSystems library. More details are available in the reference pages for these blocks. The two other blocks are specific to the Electric Drives library. These blocks are the speed controller and the current controller. They allow speed or torque regulation. A "regulation switch" block allows you to toggle from one type of regulation to the other. During torque regulation the speed controller is disabled. It is possible to use a simplified version of the drive containing an average-value model of the three-phase converter and allowing faster simulation.

Note In SimPowerSystems software, the Two-Quadrant Three-Phase Rectifier DC Drive block is commonly called the **DC3** motor drive.

High-Level Schematic

Simulink Schematic

Speed Controller

The speed regulator shown below uses a PI controller. The controller outputs the armature current reference (in pu) used by the current controller in order to obtain the electromagnetic torque needed to reach the desired speed. During torque regulation, the speed controller is disabled.

The controller takes the speed reference (in rpm) and the rotor speed of the DC machine as inputs. The speed reference change rate will follow user-defined acceleration and deceleration ramps in order to avoid sudden reference changes that could cause armature over-current and destabilize the system. The speed measurement is filtered by a first-order low-pass filter.

The current reference output is limited between 0 pu and an upper limit defined by the user.

Current Controller

The armature current regulator shown below is based on a second PI controller. The regulator controls the armature current by computing the appropriate thyristor firing angle. This generates the rectifier output voltage needed to obtain the desired armature current and thus the desired electromagnetic torque.

The controller takes the current reference (in pu) and the armature current flowing through the motor as inputs. The current reference is either provided by the speed controller during speed regulation or computed from the torque reference provided by the user during torque regulation. This is managed by the "regulation switch" block.

The armature current input is filtered by a first-order low-pass filter. An arccosine function is used to linearize the control system during continuous conduction. To compensate nonlinearities appearing during discontinuous conduction, a feedforward term is added to the firing angle. This improves the system's response time. The firing angle can vary between 0 and 180 degrees. You can limit the lower and upper limits to intermediate values.

Average-Value Three-phase Rectifier

The simplified converter is shown in the following figure.

It is composed of two controlled current sources on the AC side and one controlled voltage source on the DC side. The AC current sources allow the representation of the fundamental three-phase current behaviors following the next equations:

$$I_a = \frac{2\sqrt{3}}{\pi} I_d \sin\left(2\pi ft + \alpha + \alpha_0\right)$$

$$I_b = \frac{2\sqrt{3}}{\pi} I_d \sin\left(2\pi ft + \alpha + \alpha_0 + \frac{2\pi}{3}\right),$$

with α being the firing angle value, α_0 the phase angle of phase A, f the AC frequency and I_d the rectified output current value. The DC voltage source represents the average voltage value of the rectified voltage waveform following the next equation:

$$V_d = \frac{3\sqrt{6}}{\pi} V_{\mathrm{rms}} \cos\alpha - 6fLI_d,$$

with V_{rms} being the input phase-to-phase RMS voltage value and L being the source inductance value.

Bridge Firing Unit

The bridge firing unit converts the firing angle, provided by the current controller, to six pulses applied to the thyristor gates. The bridge firing unit block contains a

band-pass filter on voltage measurement to remove voltage harmonics. The Discrete Synchronized 6-Pulse Generator block generates the pulses. Refer to the Synchronized 6-Pulse Generator for more information on this block. When using the average-value converter the bridge firing unit simply outputs the firing angle value needed by the converter.

Remarks

The machine is separately excited with a constant DC field voltage source. There is thus no field voltage control. By default, the field current is set to its steady-state value when a simulation is started.

The armature voltage is provided by a three-phase rectifier controlled by two PI regulators. Armature current oscillations are reduced by a smoothing inductance connected in series with the armature circuit.

The average-value converter represents the average behavior of a three-phase rectifier for continuous armature current. This model is thus not suitable for simulating DC drives under discontinuous armature current conditions. The converter outputs a continuous voltage value equal to the average-value of the real-life rectified voltage. The armature voltage, armature current and electromagnetic torque ripples are thus not represented. The input currents have the frequency and amplitude of the fundamental current component of the real-life input currents.

The model is discrete. Good simulation results have been obtained with a 20 μs time step. The control system (speed and current controllers) samples data following a user-defined sample time in order to simulate a digital controller device. Keep in mind that this sampling time has to be a multiple of the simulation time step.

The average-value converter allows the use of bigger simulation time steps since it does not generate small time constants (due to the RC snubbers) inherent to the detailed converter. For a controller sampling time of 100 μs good simulation results have been obtained for a simulation time step of 100 μs. This time step can of course not be higher than the controller time step.

Dialog Box

DC Machine Tab

The **DC Machine** tab displays the parameters of the DC Machine block of the Fundamental Blocks (powerlib) library.

Output bus mode

Select how the output variables are organized. If you select **Multiple output buses**, the block has three separate output buses for motor, converter, and controller variables. If you select **Single output bus**, all variables output on a single bus.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Select between the load torque, the motor speed and the mechanical rotational port as mechanical input. If you select and apply a load torque, the output is the motor speed according to the following differential equation that describes the mechanical system dynamics:

$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

If you select the motor speed as mechanical input, then you get the electromagnetic torque as output, allowing you to represent externally the mechanical system dynamics. The internal mechanical system is not used with this mechanical input selection and the inertia and viscous friction parameters are not displayed.

For the mechanical rotational port, the connection port S counts for the mechanical input and output. It allows a direct connection to the Simscape environment. The mechanical system of the motor is also included in the drive and is based on the same differential equation.

See "Mechanical Coupling of Two Motor Drives".

Converter Tab

Rectifier section

The Rectifier section of the Converter tab displays the parameters of the Universal Bridge block of the Fundamental Blocks (powerlib) library. Refer to the Universal Bridge for more information on the thyristor converter parameters.

Smoothing Inductance

The smoothing inductance value (H).

Field DC Source

The DC motor field voltage value (V).

Phase-to-Phase RMS Voltage

Phase-to-phase rms voltage of the three-phase voltage source connected to the A,B,C terminals of the drive (V). This parameter is not used when using the detailed rectifier.

Frequency

Frequency of the three-phase voltage source connected to the A,B,C terminals of the drive (Hz). This parameter is not used when using the detailed rectifier.

Source Inductance

Source inductance of the three-phase voltage source connected to the A,B,C terminals of the drive (H). This parameter is not used when using the detailed rectifier.

Phase Angle of Phase A

Phase angle of phase A of the three-phase voltage source connected to the A,B,C terminals of the drive (deg). This parameter is not used when using the detailed rectifier.

Controller Tab

Schematic Button

When you press this button, a diagram illustrating the speed and current controllers schematics appears.

Regulation Type

This pop-up menu allows you to choose between speed and torque regulation.

Sampling Time

The controller (speed and current) sampling time (s). The sampling time has to be a multiple of the simulation time step.

Controller — Speed Controller Subtab

Nominal Speed

The nominal speed value of the DC motor (rpm). This value is used to convert motor speed from rpm to pu (per unit).

Initial Speed Reference

The initial speed reference value (rpm). This value allows the user to start a simulation with a speed reference other than 0 rpm.

Low-Pass Filter Cutoff Frequency

Cutoff frequency of the low-pass filter used to filter the motor speed measurement (Hz).

Proportional Gain

The proportional gain of the PI speed controller.

Integral Gain

The integral gain of the PI speed controller.

Acceleration

The maximum change of speed allowed during motor acceleration (rpm/s). Too great a value can cause armature over-current.

Deceleration

The maximum change of speed allowed during motor deceleration (rpm/s). Too great a value can cause armature over-current.

Controller — Current Controller Subtab

Power and Voltage nominal values

The DC motor nominal power (W) and voltage (V) values. These values are used to convert armature current from amperes to pu (per unit).

Proportional Gain

The proportional gain of the PI current controller.

Integral Gain

The integral gain of the PI current controller.

Low-Pass Filter Cutoff Frequency

Cutoff frequency of the low-pass filter used to filter the armature current measurement (Hz).

Reference Limit

Maximum current reference value (pu). 1.5 pu is a common value.

Controller — Bridge Firing Unit Subtab

Alpha Min

Minimum firing angle value (deg.). 20 degrees is a common value.

Alpha Max

Maximum firing angle value (deg.). 160 degrees is a common value.

Frequency of synchronization voltages

Frequency of the synchronization voltages used by the discrete synchronized 6-pulse generator block (Hz). This frequency is equal to the line frequency of the three-phase power line. This parameter is not used when using the average-value converter.

Pulse Width

The width of the pulses applied to the six thyristor gates (deg.). This parameter is not used when using the average-value converter.

Block Inputs and Outputs

SP

The speed or torque set point. The speed set point can be a step function, but the speed change rate will follow the acceleration / deceleration ramps. If the load torque and the speed have opposite signs, the accelerating torque will be the sum of the electromagnetic and load torques.

Tm or Wm

The mechanical input: load torque (Tm) or motor speed (Wm). For the mechanical rotational port (S), this input is deleted.

A, B, C

The three-phase electric connections. The voltage must be adequate for the motor size.

Wm, Te or S

The mechanical output: motor speed (Wm), electromagnetic torque (Te) or mechanical rotational port (S).

When the **Output bus mode** parameter is set to **Multiple output buses**, the block has the following three output buses:

Motor

The motor measurement vector. This vector is composed of two elements:

- The armature voltage
- The DC motor measurement vector (containing the speed, armature current, field current, and electromagnetic torque values). Note that the speed signal is converted from rad/s to rpm before output.

Conv

The three-phase converter measurement vector. It includes the converter output voltage. The output current is not included since it is equal to the DC motor armature current. Note that all current and voltage values of the detailed rectifier bridge can be visualized with the mulimeter block

Ctrl

The controller measurement vector. This vector contains:

- The armature current reference
- The firing angle computed by the current controller
- The speed or torque error (difference between the speed reference ramp and actual speed or between the torque reference and actual torque)
- The speed reference ramp or torque reference

When the **Output bus mode** parameter is set to **Single output bus**, the block groups the Motor, Conv, and Ctrl outputs into a single bus output.

Model Specifications

The library contains a 5 hp and a 200 hp drive parameter set. The specifications of these two drives are shown in the following table.

5 HP and 200 HP Drive Specifications

		5 HP Drive	200 HP Drive
Drive Input Voltage			
	Amplitude	220 V	460 V
	Frequency	50 Hz	60 Hz
Motor Nominal Values			
	Power	5 hp	200 hp
	Speed	1750 rpm	1750 rpm
	Voltage	240 V	500 V

Example

The dc3_example example illustrates the three-phase rectifier drive used with the 200 hp drive parameter set during torque regulation. A 5 hp parameter set is also available in the library.

Two-Quadrant Three-Phase Rectifier 200 HP DC Drive

See also 'dc3_example_simplified.mdl' for average-value model

The rectifier is fed by a 460 V AC 60 Hz voltage source.

The motor is coupled to a linear load, which means that the mechanical torque of the load is proportional to the speed.

The initial torque reference is set to 0 N.m and the armature current is null. No electromagnetic torque is produced, and the motor stays still.

At t = 0.05 s, the torque reference jumps to 800 N.m. This causes the armature current to rise to about 305 A. Notice that the armature current follows the reference quite accurately, with fast response time and small overshooting. The 15 mH smoothing inductance keeps the current oscillations quite small. Observe also that the average firing angle value stays below 90 degrees, the converter being in rectifier mode.
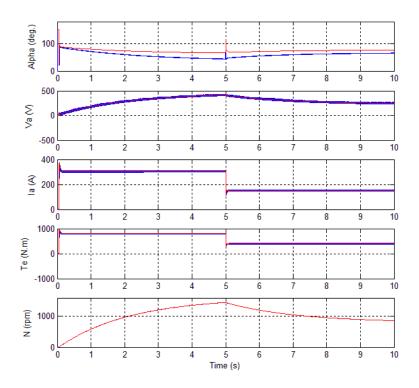
The electromagnetic torque produced by the armature current flow causes the motor to accelerate. The speed rises and starts to stabilize around t = 5 s at about 1450 rpm, the sum of the load and viscous friction torques beginning to equalize the electromagnetic torque.

At t = 5 s, the torque reference is set to 400 N.m and the armature current jumps down to about 155 A. This causes the load torque to decelerate the motor.

At t = 10 s speed starts to stabilize around 850 rpm.

The following figure illustrates the results obtained respectively with the detailed and average-value converters. Average voltage, current, torque and speed values are identical

for both models. The average firing angle values however are slightly different. Notice that the higher frequency signal components are not represented with the simplified converter.

DC3 Example Waveforms (Blue : Detailed Converter, Red : Average-Value Converter)
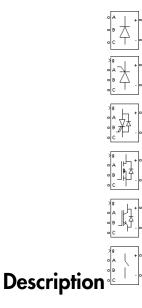
References

[1] Sen, P.C., *Thyristor DC Drives*, J.Wiley and Sons, 1981.

[2] Nondahl, Thomas A., *Microprocessor Control of Motor Drives and Power Converters*, *tutorial course*, IEEE Industry Application Society, October 1993, pp. 7.1-7.26.

Universal Bridge

Implement universal power converter with selectable topologies and power electronic devices

Library

Fundamental Blocks/Power Electronics

Description
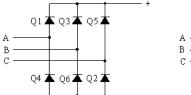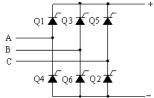
The Universal Bridge block implements a universal three-phase power converter that consists of up to six power switches connected in a bridge configuration. The type of power switch and converter configuration are selectable from the dialog box.

The Universal Bridge block allows simulation of converters using both naturally commutated (or line-commutated) power electronic devices (diodes or thyristors) and forced-commutated devices (GTO, IGBT, MOSFET).
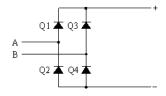
The Universal Bridge block is the basic block for building two-level voltage-sourced converters (VSC).
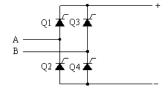
The device numbering is different if the power electronic devices are naturally commutated or forced-commutated. For a naturally commutated three-phase converter (diode and thyristor), numbering follows the natural order of commutation:
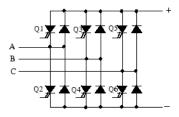
For the case of a two-phase diode or thyristor bridge, and for any other bridge configuration, the order of commutation is the following:
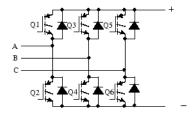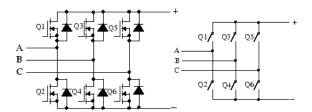
GTO-Diode bridge:
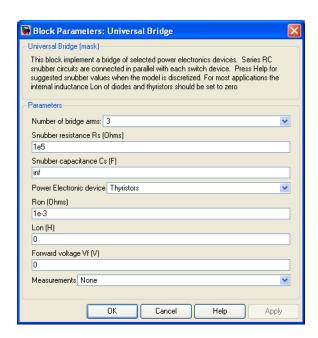
IGBT-Diode bridge:

MOSFET-Diode and Ideal Switch bridges:

Dialog Box and Parameters

Number of bridge arms

> Set to **1** or **2** to get a single-phase converter (two or four switching devices). Set to **3** to get a three-phase converter connected in Graetz bridge configuration (six switching devices).

Snubber resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to `inf` to eliminate the snubbers from the model.

Snubber capacitance Cs

The snubber capacitance, in farads (F). Set the **Snubber capacitance Cs** parameter to `0` to eliminate the snubbers, or to `inf` to get a resistive snubber.

When you are you using a continuous solver, you can completely eliminate snubbers by selecting **Enable use of ideal switching devices** in the Configure parameters section of the Powergui block dialog box. To disable snubbers in all power electronic devices, select **Disable snubbers in switching devices**.

When your system is discretized, you can simulate power electronic devices with virtually no snubbers by specifying purely resistive snubbers with a very large resistance, thus producing negligible leakage currents. The bridge operates satisfactorily with purely resistive snubbers when you select the Tustin/Backward Euler (TBE) discretization method (default solver in the Configure parameters section of the Powergui block dialog box).

If you are using the Tustin solver, you need to specify Rs and Cs snubber values to avoid numerical oscillations with diode and thyristors bridges. For forced-commutated devices (GTO, IGBT, or MOSFET), the bridge operates satisfactorily with purely resistive snubbers as long as firing pulses are sent to switching devices.

If firing pulses to forced-commutated devices are blocked, only antiparallel diodes operate, and the bridge operates as a diode rectifier. In this condition appropriate values of Rs and Cs must also be used.

When the system is discretized using the Tustin solver, use the following formulas to compute approximate values of Rs and Cs:

$$Rs > 2\frac{T_s}{Cs}$$

$$Cs < \frac{P_n}{1000(2\pi f)V_n^2},$$

where
P_n = nominal power of single or three phase converter (VA)
V_n = nominal line-to-line AC voltage (V_{rms})

f = fundamental frequency (Hz)
T_s = sample time (s)

These Rs and Cs values are derived from the following two criteria:

- The snubber leakage current at fundamental frequency is less than 0.1% of nominal current when power electronic devices are not conducting.

- The RC time constant of snubbers is higher than two times the sample time Ts.

These Rs and Cs values that guarantee numerical stability of the discretized bridge can be different from actual values used in a physical circuit.

Power electronic device

Select the type of power electronic device to use in the bridge.

When you select `Switching-function based VSC`, a switching-function voltage source converter type equivalent model is used, where switches are replaced by two voltage sources on the AC side and a current source on the DC side. This model uses the same firing pulses as for other power electronic devices and it correctly represents harmonics normally generated by the bridge.

When you select `Average-model based VSC`, an average-model type of voltage source converter is used to represent the power-electronic switches. Unlike the other power electronic devices, this model uses the reference signals (uref) representing the average voltages generated at the ABC terminals of the bridge. This model does not represent harmonics. It can be used with larger sample times while preserving the average voltage dynamics.

See power_sfavg for an example comparing these two models to an Universal Bridge block using IGBT/Diode device.

Ron

Internal resistance of the selected device, in ohms (Ω).

Lon

Internal inductance, in henries (H), for the diode or the thyristor device. When the bridge is discretized, the Lon parameter must be set to zero.

Forward voltage Vf

This parameter is available only when the selected **Power electronic device** is `Diodes` or `Thyristors`.

Forward voltage, in volts (V), across the device when it is conducting.

Forward voltages [Device Vf, Diode Vfd]

This parameter is available when the selected **Power electronic device** is `GTO/Diodes` or `IGBT/Diodes`.

Forward voltages, in volts (V), of the forced-commutated devices (GTO, MOSFET, or IGBT) and of the antiparallel diodes.

[Tf (s) Tt (s)]

Fall time Tf and tail time Tt, in seconds (s), for the GTO or the IGBT devices.

Measurements

Select `Device voltages` to measure the voltages across the six power electronic device terminals.

Select `Device currents` to measure the currents flowing through the six power electronic devices. If antiparallel diodes are used, the measured current is the total current in the forced-commutated device (GTO, MOSFET, or IGBT) and in the antiparallel diode. A positive current therefore indicates a current flowing in the forced-commutated device and a negative current indicates a current flowing in the diode. If snubber devices are defined, the measured currents are the ones flowing through the power electronic devices only.

Select `UAB UBC UCA UDC voltages` to measure the terminal voltages (AC and DC) of the Universal Bridge block.

Select `All voltages and currents` to measure all voltages and currents defined for the Universal Bridge block.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** menu of the Multimeter block, the measurement is identified by a label followed by the block name.

Measurement	Label
Device voltages	`Usw1:, Usw2:,Usw3:,Usw4:,Usw5:,Usw6:`
Branch current	`Isw1:, Isw2:, Isw3:, Isw4:, Isw5:, Isw6:`
Terminal voltages	`Uab:, Ubc:, Uca:, Udc:`

Inputs and Outputs

g
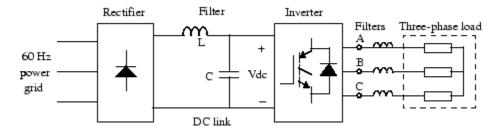
The gate input for the controlled switch devices. The pulse ordering in the vector of the gate signals corresponds to the switch number indicated in the six circuits shown in the Description section. For the diode and thyristor bridges, the pulse ordering corresponds to the natural order of commutation. For all other forced-commutated switches, pulses are sent to upper and lower switches of phases A, B, and C.

Topology	Pulse Vector of Input g
one arm	[Q1,Q2]
two arms	[Q1,Q2,Q3,Q4]
three arms	[Q1,Q2,Q3,Q4,Q5,Q6]
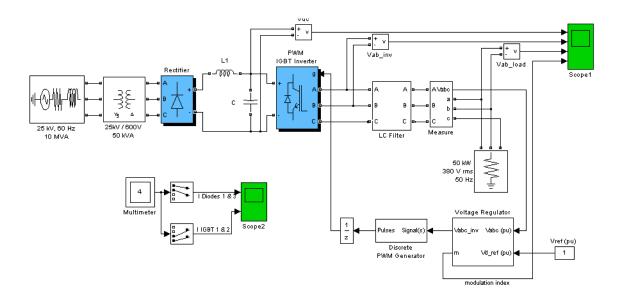
Example

The power_bridges example illustrates the use of two Universal Bridge blocks in an ac/dc/ac converter consisting of a rectifier feeding an IGBT inverter through a DC link. The inverter is pulse-width modulated (PWM) to produce a three-phase 50 Hz sinusoidal voltage to the load. In this example the inverter chopping frequency is 2000 Hz.

The IGBT inverter is controlled with a PI regulator in order to maintain a 1 pu voltage (380 Vrms, 50 Hz) at the load terminals.
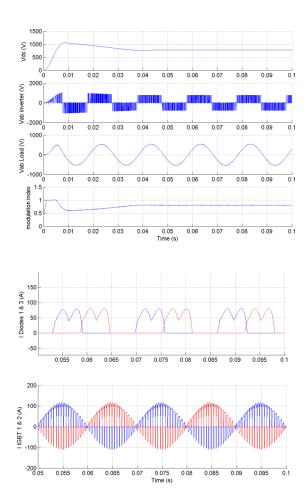
A Multimeter block is used to observe commutation of currents between diodes 1 and 3 in the diode bridge and between IGBT/Diodes switches 1 and 2 in the IGBT bridge.

Start simulation. After a transient period of approximately 40 ms, the system reaches a steady state. Observe voltage waveforms at DC bus, inverter output, and load on Scope1. The harmonics generated by the inverter around multiples of 2 kHz are filtered by the LC filter. As expected the peak value of the load voltage is 537 V (380 V RMS).

In steady state the mean value of the modulation index is m = 0.8, and the mean value of the DC voltage is 778 V. The fundamental component of 50 Hz voltage buried in the chopped inverter voltage is therefore

Vab = 778 V * 0.612 * 0.80 = 381 V RMS

Observe diode currents on trace 1 of Scope2, showing commutation from diode 1 to diode 3. Also observe on trace 2 currents in switches 1 and 2 of the IGBT/Diode bridge (upper and lower switches connected to phase A). These two currents are complementary. A positive current indicates a current flowing in the IGBT, whereas a negative current indicates a current flowing in the antiparallel diode.

See Also

Diode, GTO, Ideal Switch, IGBT, MOSFET, Multimeter,Three-Level Bridge, Thyristor

Unified Power Flow Controller (Phasor Type)

Implement phasor model of three-phase unified power flow controller

Library

FACTS/Power-Electronics Based FACTS
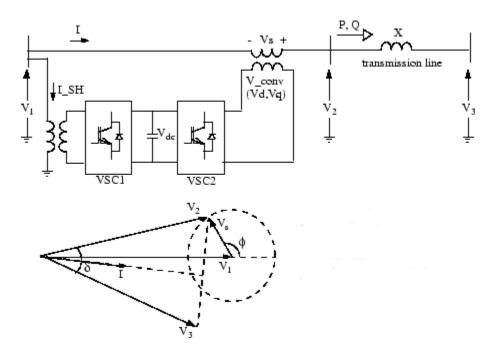
Description
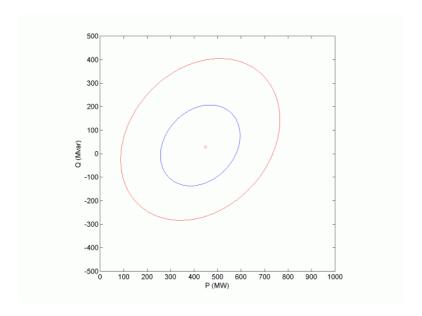
The Unified Power Flow Controller (UPFC) is the most versatile member of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow on power grids [1]. The UPFC uses a combination of a shunt controller (STATCOM) and a series controller (SSSC) interconnected through a common DC bus as shown on the figure below.

Single-line Diagram of a UPFC and Phasor Diagram of Voltages and Currents

$$P = \frac{V_2 V_3 \sin\delta}{X}, \; Q = \frac{V_2(V_2 - V_3 \cos\delta)}{X}$$

This FACTS topology provides much more flexibility than the SSSC for controlling the line active and reactive power because active power can now be transferred from the shunt converter to the series converter, through the DC bus. Contrary to the SSSC where the injected voltage Vs is constrained to stay in quadrature with line current I, the injected voltage Vs can now have any angle with respect to line current. If the magnitude of injected voltage Vs is kept constant and if its phase angle φ with respect to V1 is varied from 0 to 360 degrees, the locus described by the end of vector V2 (V2=V1+Vs) is a circle as shown on the phasor diagram. As φ is varying, the phase shift δ between voltages V2 and V3 at the two line ends also varies. It follows that both the active power P and the reactive power Q transmitted at one line end can be controlled. The UPFC controllable region in the P-Q plane is the area enclosed an by an ellipse as shown on the figure below.

Controllable Region for a 100 MVA UPFC connected on 500 kV, 200 km line

This figure was obtained with a 100 MVA UPFC controlling active and reactive power at one end of a 500 kV, 200 km transmission line. The following parameters have been used:

- Line: length = 200km; reactance = 0.35 Ω /km

- System voltage: 500 kV infinite sources V1 and V3; V1=1.0 pu, 0 degree; V3= 1.0 pu, −7.22 degrees

- Series and shunt converter rating: 100 MVA

- Series converter: nominal injected voltage = 10% of nominal line-to-ground voltage (28.9 kV); impedance (transformer leakage reactance and filters) = 0.15 pu

With V3 lagging V1 by 7.22 degrees, the natural power flow without compensation is 450 MW or 50% of the line surge impedance loading (SIL=900 MW). With an injected voltage Vs = 0.1 pu any operating point inside the larger ellipse can be obtained and active power can be varied by approximately +/- 300 MW.

In addition to allow control of the line active and reactive power, the UPFC provides an additional degree of freedom. Its shunt converter operating as a STATCOM controls voltage V1 by absorbing or generating reactive power.

Both the series and shunt converters use a Voltage-Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSCs use forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage from a DC voltage source. The common capacitor connected on the DC side of the VSCs acts as a DC voltage source. Two VSC technologies can be used for the VSCs:
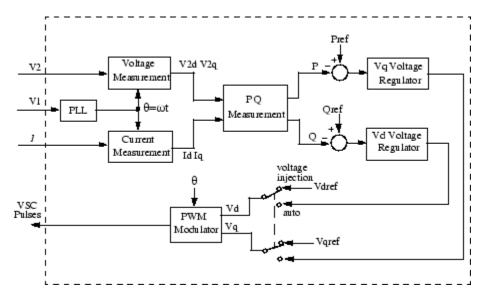
- VSC using GTO-based square-wave inverters and special interconnection transformers. Typically four three-level inverters are used to build a 48-step voltage waveform. Special interconnection transformers are used to neutralize harmonics contained in the square waves generated by individual inverters. In this type of VSC, the fundamental component of voltage is proportional to the voltage Vdc. Therefore Vdc has to varied for controlling the injected voltage.

- VSC using IGBT-based PWM inverters. This type of inverter uses Pulse-Width Modulation (PWM) technique to synthesize a sinusoidal waveform from a DC voltage with a typical chopping frequency of a few kilohertz. Harmonics are cancelled by connecting filters at the AC side of the VSC. This type of VSC uses a fixed DC voltage Vdc. Voltage is varied by changing the modulation index of the PWM modulator.

The UPFC (Phasor Type) block models an IGBT-based UPFC. However, as details of the inverter and harmonics are not represented, it can be also used to model a GTO-based UPFC in transient stability studies.

Control System

The shunt converter operates as a STATCOM. For a description of its control system, refer to the Static Synchronous Compensator (Phasor Type). In summary, the shunt converter controls the AC voltage at its terminals and the voltage of the DC bus. It uses a dual voltage regulation loop: an inner current control loop and an outer loop regulating AC and DC voltages.

Control of the series branch is different from the SSSC. In a SSSC the two degrees of freedom of the series converter are used to control the DC voltage and the reactive power. In case of a UPFC the two degrees of freedom are used to control the active power and the reactive power. A simplified block diagram of the series converter is shown below.

Simplified Block Diagram of the Series Converter Control System

The series converter can operate either in power flow control (automatic mode) or in manual voltage injection mode. In power control mode, the measured active power and reactive power are compared with reference values to produce P and Q errors. The P error and the Q error are used by two PI regulators to compute respectively the Vq and Vd components of voltage to be synthesized by the VSC. (Vq in quadrature with V1controls active power and Vd in phase with V1 controls reactive power). In manual voltage injection mode, regulators are not used. The reference values of injected voltage Vdref and Vqref are used to synthesize the converter voltage.
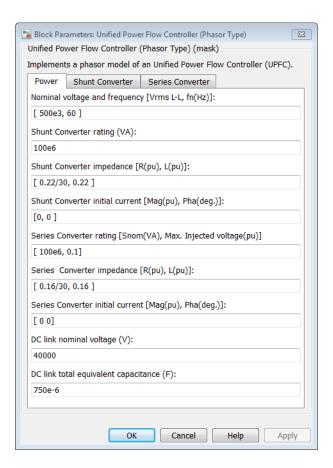
The UPFC block is a phasor model which does not include detailed representation of the power electronics. You must use it with the phasor simulation method, activated with the Powergui block. It can be used in three-phase power systems together with synchronous generators, motors, dynamic loads and other FACTS and Renewable Energy systems to perform transient stability studies and observe impact of the UPFC on electromechanical oscillations and transmission capacity at fundamental frequency.

Dialog Box and Parameters

The UPFC parameters are grouped in three categories: `Power data`, `Control parameters (shunt converter)`, and `Control parameters (series`

converter). Use the **Display** listbox to select which group of parameters you want to visualize.

Power Tab

Nominal voltage and frequency

The nominal line-to-line voltage in Vrms and the nominal system frequency in hertz.

Shunt Converter rating

The nominal rating of the shunt converter in VA.

Shunt Converter impedance

The positive-sequence resistance R and inductance L of the shunt converter, in pu based on the nominal converter rating and nominal voltage. R and L represent the resistance and leakage inductance of the shunt transformer plus the resistance and inductance of the series filtering inductors connected at the VSC output.

Shunt Converter initial current

The initial value of the positive-sequence current phasor (Magnitude in pu and Phase in degrees). If you know the initial value of the shunt current corresponding to the UPFC operating point you may specify it in order to start simulation in steady state. If you don't know this value, you can leave [0 0]. The system will reach steady-state after a short transient.

Series Converter rating

The ratings of the series converter in VA and the maximum value of the injected voltage V_conv on the VSC side of the transformer (see single line diagram), in pu of nominal phase-to-ground voltage.

Series Converter impedance

The positive-sequence resistance and inductance of the converter, in pu, based on the converter rated power and voltage. R and L represent the resistance and leakage inductance of the series transformer plus the resistance and inductance of the series filtering inductors connected at the VSC output.

Series Converter initial current

The initial value of the positive-sequence current phasor (Magnitude in pu and Phase in degrees). If you know the initial value of the series current corresponding to the UPFC operating point you may specify it in order to start simulation in steady state. If you don't know this value, you can leave [0 0]. The system will reach steady-state after a short transient.

DC link nominal voltage

The nominal voltage of the DC link in volts.

DC link total equivalent capacitance

The total capacitance of the DC link in farads. This capacitance value is related to the UPFC converter ratings and to the DC link nominal voltage. The energy stored in the capacitance (in joules) divided by the converter rated power (in VA) is a time duration which is usually a fraction of a cycle at nominal frequency. For example, for the default parameters, (C=750 µF, Vdc=40 000 V, Snom=100 MVA) this ratio

$1/2 \cdot C \cdot V_{dc}^2 / S_{nom}$ is 6.0 ms, which represents 0.36 cycle for a 60 Hz frequency. If you change the default values of the nominal power rating and DC voltage, you should change the capacitance value accordingly.

Shunt Converter Tab

Mode

Specifies the shunt converter mode of operation. Select either `Voltage regulation` or `Var Control`.

Reference voltage Vref

This parameter is not visible when the **Mode** parameter is set to `Var Control`.

Reference voltage, in pu, used by the voltage regulator. When **External** is selected, a Simulink input named Vref appears on the block, allowing you to control the reference voltage from an external signal (in pu). The **Reference voltage Vref** parameter is therefore unavailable.

Maximum rate of change of reference voltage

This parameter is not visible when the **Mode** parameter is set to `Var Control`.

Maximum rate of change of the reference voltage, in pu/s, when an external reference voltage is used.

Droop

This parameter is not visible when the **Mode** parameter is set to `Var Control`.

Droop reactance, in pu/shunt converter rating Snom, defining the slope of the V-I characteristic.

Vac Regulator Gains: [Kp Ki]

This parameter is not visible when the **Mode** parameter is set to `Var Control`.

Gains of the AC voltage PI regulator. Specify proportional gain Kp in (pu of I)/(pu of V), and integral gain Ki, in (pu of I)/(pu of V)/s, where V is the AC voltage error and I is the output of the voltage regulator.

Reactive power setpoint Qref

This parameter is not visible when the **Mode** parameter is set to `Voltage Control`.

Reference reactive power, in pu, when the shunt converter is in `Var Control`.

Maximum rate of change of reactive power setpoint Qref

This parameter is not visible when the **Mode** parameter is set to `Voltage Control`.

Maximum rate of change of the reference reactive power, in pu/s.

Vdc Regulator gains: [Kp Ki]

Gains of the DC voltage PI regulator which controls the voltage across the DC bus capacitor. Specify proportional gain Kp in (pu of I)/Vdc, and integral gain Ki, in (pu of I)/Vdc/s, where Vdc is the DC voltage error and I is the output of the voltage regulator.

Current Regulators gains: [Kp Ki]

Gains of the inner current regulation loop.

Specify proportional gain Kp in (pu of V)/(pu of I), integral gain Ki, in (pu of V)/(pu of I)/s, where V is the output of the d or q current regulator and I is the Id or Iq current error.

The current regulator is assisted by a feed forward regulator. The feed forward gain in (pu of V)/(pu of I) is the shunt converter reactance (in pu) given by parameter L in the **Shunt converter impedance [R L]** parameters.

Series Converter Tab

Bypass Breaker

Specifies the status of the bypass breaker connected inside the block across terminals A1, B1, C1 and A2, B2, C2. Select either `External Control`, `Open` or `Closed`. If the bypass breaker is in external control, a Simulink input named Bypass appears on the block, allowing to control the status of the bypass breaker from an external signal (0 or 1).

Mode

Specifies the series converter mode of operation. Select either `Power flow control` or `Manual voltage injection`.

Reference powers

This parameter is not visible when the **Mode** parameter is set to `Manual voltage injection`.

Specify references values, in pu. When **External** is selected, a Simulink input named PQref appears on the block, allowing you to control the active and reactive powers from an external signal (in pu). The **Reference powers** parameter is therefore unavailable.

Maximum rate of change of reference powers

This parameter is not visible when the **Mode** parameter is set to `Manual voltage injection`.

Specify maximum rate of change of Pref and Qref, in pu/s.

Power Regulator gains: [Kp Ki]

This parameter is not visible when the **Mode** parameter is set to `Manual voltage injection`.

Gains of the PI regulators which control the line active power and reactive power. Specify proportional gain Kp in (pu of Vdq)/(pu of PQ), and integral gain Ki, in (pu of Vdq)/(pu of PQ)/s, where Vdq is the Vd or Vq injected voltage and PQ is the P or Q voltage error.

Reference voltages

This parameter is not visible when the **Mode** parameter is set to `Power flow control`.

Specify the direct-axis and quadrature-axis components of the voltage injected on the VSC side of the series transformer, in pu. When **External** is selected, a Simulink input named Vdqref appears on the block, allowing you to control the injected voltage from an external signal (in pu). The **Reference voltages** parameter is therefore unavailable.

Maximum rate of change for references voltages

This parameter is not visible when the **Mode** parameter is set to `Power flow control`.

Specify maximum rate of change of the Vdref and Vqref voltages, in pu/s.

Inputs and Outputs

`A1 B1 C1`

The three input terminals of the UPFC.

`A2 B2 C2`

The three output terminals of the UPFC.

`Trip`

Apply a simulink logical signal (0 or 1) to this input. When this input is high the shunt converter is disconnected and the series converter is bypassed. In addition, when the trip signal is high the shunt and series control systems are disabled. Use this input to implement a simplified version of the protection system.

`Bypass`

This input is visible only when the **Bypass Breaker** parameter is set to `External Control`.

Apply a simulink logical signal (0 or 1) to this input. When this input is high the bypass breaker is closed.

Vdqref

This input is visible only when the **External control of injected voltage Vdref _Vqref** parameter is checked.

Apply a simulink vectorized signal specifying the reference voltages Vdref and Vqref, in pu.

PQref

This input is visible only when the **External control of power references Pref _Qref** parameter is checked.

Apply a simulink vectorized signal specifying the reference powers Pref and Qref, in pu.

m

Simulink output vector containing 34 UPFC internal signals. These signals are either voltage and current phasors (complex signals) or control signals. They can be individually accessed by using the Bus Selector block. They are, in order:

Signal	Signal Group	Signal Names	Definition
1-3	Power Vabc1 (cmplx)	Va1 (pu) Vb1 (pu) Vc1 (pu)	Phasor voltages (phase to ground) Va, Vb, Vc at the UPFC input terminals A1, B1, C1 (pu)
4-6	Power Iabc_SH (cmplx)	Ia_SH (pu) Ib_SH (pu) Ic_SH (pu)	Phasor currents Ia, Ib, Ic flowing into the shunt converter (pu)
7	Power	Vdc (V)	DC voltage (V)
8-10	Power Vabc2 (cmplx)	Va2 (pu) Vb2 (pu) Vc2 (pu)	Phasor voltages (phase to ground) Va, Vb, Vc at the UPFC output terminals A2, B2, C2 (pu)
11-13	Power Vabc_Inj (cmplx)	Va_Inj (pu) Vb_Inj (pu) Vc_Inj (pu)	Phasors of injected voltages Vs=V2-V1 (pu)
14_16	Power Iabc_SE (cmplx)	Ia_SE (pu) Ib_SE (pu)	Phasor currents Ia, Ib, Ic flowing in the series

Signal	Signal Group	Signal Names	Definition
		Ic_SE (pu)	transformer from ABC1 to ABC2 (pu)
17	Control (Shunt)	Vm (pu)	Positive-sequence value of the measured voltage (pu)
18	Control (Shunt)	Vref (pu)	Reference voltage (pu)
19	Control (Shunt)	Qm (pu)	Shunt converter reactive power. A positive value indicates inductive operation.
20	Control (Shunt)	Qref (pu)	Reference reactive power (pu)
21	Control (Shunt)	Id (pu)	Direct-axis component of current (active current) flowing into the shunt converter (pu). A positive value indicates active power flowing into shunt converter.
22	Control (Shunt)	Iq (pu)	Quadrature-axis component of current (reactive current) flowing into the shunt converter (pu). A positive value indicates capacitive operation.
23	Control (Shunt)	Idref (pu)	Reference value of direct-axis component of current flowing into shunt converter (pu)
24	Control (Shunt)	Iqref (pu)	Reference value of quadrature-axis component of current flowing into shunt converter (pu)

Signal	Signal Group	Signal Names	Definition
25	Control (Shunt)	modindex	The modulation index m of the shunt converter PWM modulator. A positive number 0<m<1. m=1 corresponds to the maximum voltage which can be generated by the VSC without overmodulation.
26	Control (Series)	P (pu)	Measured active power flowing out of terminals A2, B2, C2 (pu)
27	Control (Series)	Q (pu)	Measured reactive power flowing out of terminals A2, B2, C2 (pu)
28	Control (Series)	Pref (pu)	Reference active power (pu)
29	Control (Series)	Qref (pu)	Reference reactive power (pu)
30	Control (Series)	Vd_conv (pu)	Direct-axis injected voltage on VSC side of series transformer (pu)
31	Control (Series)	Vq_conv (pu)	Quadrature-axis injected voltage on VSC side of series transformer (pu)
32	Control (Series)	Vdref (pu)	Reference value of direct-axis injected voltage (pu)
33	Control (Series)	Vqref (pu)	Reference value of quadrature-axis injected voltage (pu)

Signal	Signal Group	Signal Names	Definition
34	Control (Series)	modindex	The modulation index m of the series converter PWM modulator. A positive number 0<m<1. m=1 corresponds to the maximum voltage V_conv which can be generated by the series converter without overmodulation.

Example

See the power_upfc example, which illustrates the use of a UPFC controlling power on a 500 kV, 60 Hz, system.

References

[1] N. G. Hingorani, L. Gyugyi, "Understanding FACTS; Concepts and Technology of Flexible AC Transmission Systems," IEEE Press book, 2000

See Also
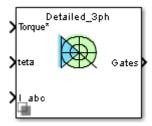
Static Synchronous Compensator (Phasor Type), Static Synchronous Series Compensator (Phasor Type)

Vector Controller (PMSM)

Implement vector controller model for permanent magnet synchronous machines (PMSM)

Library

Electric Drives/Fundamental Drive Blocks
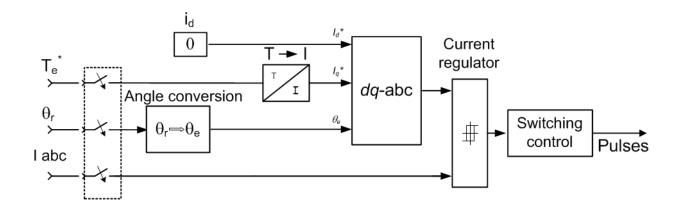
Description
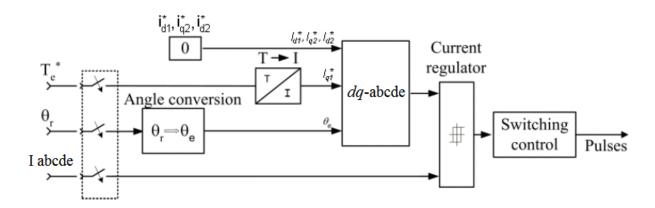
The Vector Controller (PMSM) block is similar to the Field-Oriented Controller block for induction machines, as it offers DC-machine-like performance for sinusoidal permanent magnet machines. The machine torque can be controlled irrespective of the stator flux.

The PMSM vector-controller model is for use with a three-phase or three-phase permanent magnet synchronous machine. It has two operating modes to represent a detailed or an average-value controller.

Detailed mode

In detailed mode, the Vector Controller (PMSM) block contains four main blocks, shown for a three-phase and five-phase PMSM, respectively.
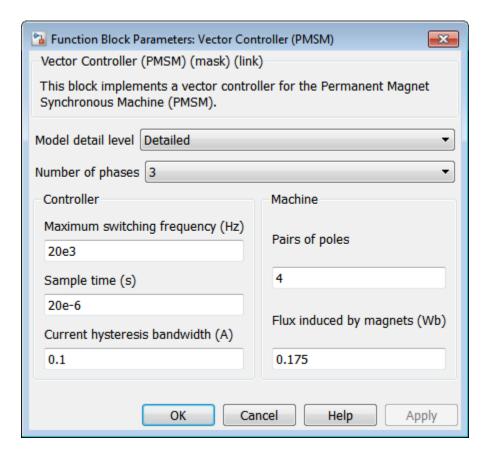
- The dq-abc and dq-abcde blocks perform the conversion of the dq current components in the rotor reference frame into abc- and abcde-phase variables respectively.

- The current regulator is a bang-bang current controller with adjustable hysteresis bandwidth.

- The angle conversion block computes the electrical rotor angle from the mechanical rotor angle.

- The Switching control block limits the inverter commutation frequency to a maximum value that you specify.

Average mode

In average mode, the high-frequency switching actions of the power switches are not represented in the Vector Controller (PMSM) block.

Average mode is similar to detailed mode except that there is no switching control block and the pulses generated by the current regulator are three-level signals (-1, 0, 1). The three-level signals indicate whether the average-value inverter applies a negative, zero, or positive DC bus voltage (Vdc) to the machine during inverter saturation. In detailed mode, the Vector Controller (PMSM) model outputs the actual pulses for the inverter switches.

Dialog Box and Parameters

Model detail level

Specify the model detail level to use:

- `Detailed` (default)
- `Average`

Number of phases

Select between a three-phase and five-phase PMSM. The default value is `3`.

Maximum switching frequency (Hz)
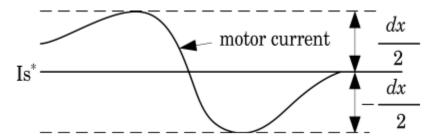
The maximum inverter switching frequency, in hertz. This parameter is available only when the **Model detail level** parameter is set to `Detailed`. The default value is `20e3`.

Sample time (s)

The vector-controller sampling time, in seconds. The sampling time must be a multiple of the simulation time step. The default value is `20e-6`.

Current hysteresis bandwidth (A)

The current regulator hysteresis bandwidth, in amperes. This parameter is available only when the **Model detail level** parameter is set to `Detailed`. The default value is `0.1`. This value is the total hysteresis bandwidth distributed symmetrically around the current set point. The figure shows a case where the current set point is `Is*` and the current regulator hysteresis bandwidth is set to `dx`.

Pairs of poles

The number of pole pairs. The default value is `4`.

Flux induced by magnets (Wb)

The constant flux, in webers, per pole pairs induced in the stator windings by the magnets. The default value is `0.175`.

Inputs and Outputs

`Torque`

The torque reference, typically provided by a speed controller.

`teta`

The rotor flux angle.

`I_abc`

The three line currents of the three-phase PMSM. This input is visible only when the **Number of phases** parameter is set to 3.

I_abcde

The five line currents of the five-phase PMSM. This input is visible only when the **Number of phases** parameter is set to 5.

Sig*

A vector containing measurement signals:

- iabc* — The three reference currents, available when the **Number of phases** parameter is set to 3.
- iabcde*— The five reference currents, available when the **Number of phases** parameter is set to 5.
- Pulses* — Two three-level signals when a three-phase PMSM is used (four three-level signals when a five-phase PMSM is used). The three-level signals, -1, 0, or 1, indicate whether the average-value inverter applies a negative, zero, or positive DC bus voltage (Vdc) to the machine.

This output is visible only when the **Model detail level** parameter is set to Average.

Gates

The pulses for the six inverter switches. This output is visible only when the **Model detail level** parameter is set to Detailed.

Examples

The Vector Controller (PMSM) block is used in the AC6 block of the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also
Bridge Firing Unit (AC) | Bridge Firing Unit (DC) | Current Controller (Brushless DC) | Current Controller (DC) | Direct Torque Controller

| Field-Oriented Controller | Regulation Switch | Six-Step Generator | Space Vector Modulator | Speed Controller (AC) | Speed Controller (DC) | Speed Controller (Scalar Control) | Vector Controller (WFSM) | Voltage Controller (DC Bus)

More About

- "Electric Drives Library"
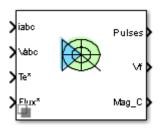
Introduced in R2015b

Vector Controller (WFSM)

Implement vector controller model for a wound-field synchronous machine (WFSM)

Library

Electric Drives/Fundamental Drive Blocks
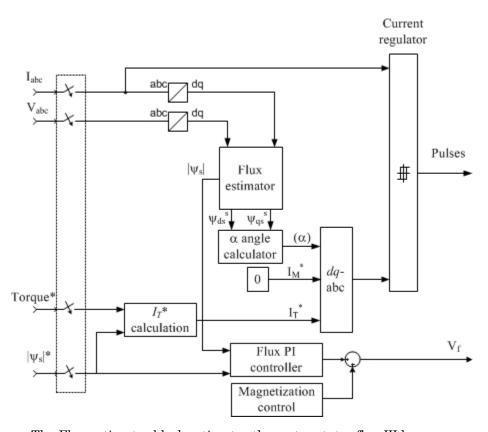
Description

The WFSM vector controller offers fast transient response and DC-machine-like performance to a WFSM drive as the stator flux and developed torque are independently controlled.

The WFSM vector controller model has two operating modes, detailed and average, for a detailed or average-value inverter, respectively.

Detailed mode

In detailed mode, the Vector Controller (WFSM) block contains five main blocks.
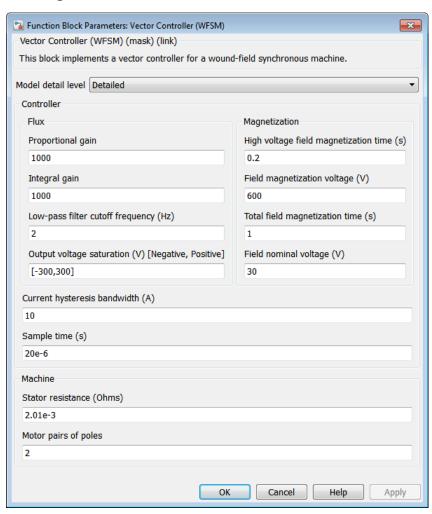
- The Flux estimator block estimates the motor stator flux Ψ_{dqs}^s.
- The Flux PI controller regulates the flux in the machine.
- The dq-abc block performs the conversion of the dq current components into abc-phase variables.
- The current regulator is a bang-bang current controller with adjustable hysteresis bandwidth.
- The magnetization control unit contains the logic used to switch between the magnetization and normal operation mode.

Average mode

In average mode, the high-frequency switching actions of the power switches are not represented.

Average mode is similar to detailed mode except that the pulses generated by the current regulator are three-level signals (-1, 0, 1). These signals indicate whether the average-value inverter applies a negative, zero, or positive DC bus voltage (Vdc) to the machine during inverter saturation. In detailed mode, the Vector Controller (WFSM) block outputs the actual pulses for the inverter switches.

Dialog Box and Parameters

Model detail level

Specify the model detail level to use:

- `Detailed` (default)
- `Average`

Proportional gain

The flux controller proportional gain. The default value is `1000`.

Integral gain

The flux controller integral gain. The default value is `1000`.

Low-pass filter cutoff frequency (Hz)

The flux estimation first-order filter cutoff frequency, in hertz. The default value is `2`.

Output voltage saturation (V) [Negative, Positive]

The minimum and maximum voltage applied to the motor excitation field, in volts. The default value is `[-300,300]`.

High voltage field magnetization time (s)

The field magnetization high- voltage application time, in seconds. The default value is `0.2`.

Field magnetization voltage (V)

The field magnetization voltage applied to establish the stator flux, in volts. The default value is `600`.

Total field magnetization time (s)

The total time before the drive is ready to produce a torque, in seconds. The default value is `1`.
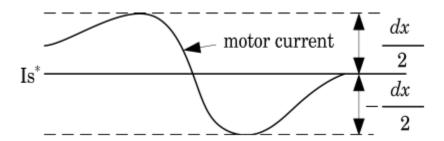
Field nominal voltage (V)

The field nominal voltage, in volts. The default value is `30`.

Current hysteresis bandwidth (A)

The current regulator hysteresis bandwidth, in amperes. This value is the total hysteresis bandwidth distributed symmetrically around the current set point. The figure shows a case where the current set point is Is* and the current regulator hysteresis bandwidth is set to *dx*.

The default value is `10`.

Sample time (s)

> The vector-controller sampling time, in seconds. The sampling time must be a multiple of the simulation time step. The default value is `20e-6`.

Stator resistance (Ohms)

> The stator phase resistance Rs, in ohms, of the motor. The default value is `2.01e-3`.

Motor pairs of poles

> The number of pole pairs. The default value is `2`.

Inputs and Outputs

`iabc`

> The three line currents of the WFSM.

`Vabc`

> The three-phase voltage of the WFSM.

`Te*`

> The torque reference, typically provided by a speed controller.

`Flux*`

> The flux reference, typically provided by a speed controller.

`Pulses`

> The pulses for the six inverter switches. This output is visible only when the **Model detail level** parameter is set to `Detailed`.

`Vf`

> Field voltage for the WFSM.

`Mag_C`

This binary signal indicates if the machine is magnetized (1) enough to be started or not (0).

Sig*

A vector containing measurement signals:

- Iabc — The three line currents.
- iabc* — The three reference currents.
- pulses* — Two three-level signals (-1, 0, 1) indicating whether the average-value inverter applies a negative, zero, or positive DC bus voltage (Vdc) to the machine.
- Mag_c — Binary signal that indicates if the machine is magnetized enough to be started (1) or not (0).

This output is visible only when the **Model detail level** parameter is set to Average.

Examples

The Vector Controller (WFSM) block is used in the AC5 block of the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

Bridge Firing Unit (AC) | Bridge Firing Unit (DC) | Current Controller (Brushless DC) | Current Controller (DC) | Direct Torque Controller | Field-Oriented Controller | Regulation Switch | Six-Step Generator | Space Vector Modulator | Speed Controller (AC) | Speed Controller (DC) | Speed Controller (Scalar Control) | Vector Controller (PMSM) | Voltage Controller (DC Bus)

More About

- "Electric Drives Library"
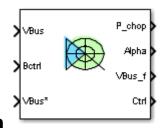
Introduced in R2015b

Voltage Controller (DC Bus)

Implement DC bus voltage controller for thyristor bridge rectifier

Library

Electric Drives/Fundamental Drive Blocks
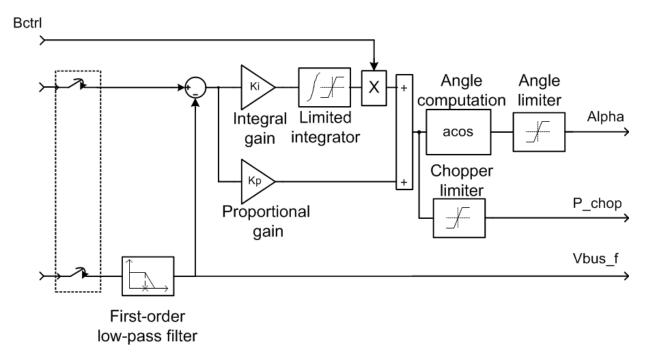
Description
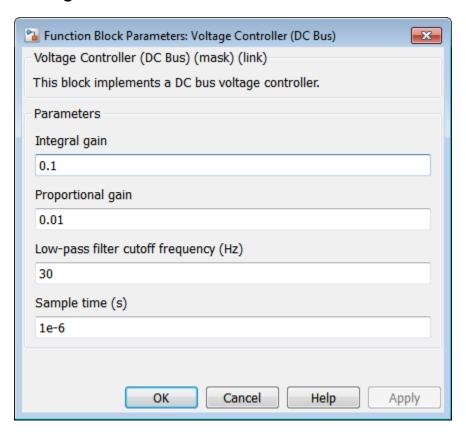
The Voltage Controller (DC Bus) block represents a PI DC bus voltage regulator model for a thyristor bridge rectifier.

The controller outputs the thyristor bridge firing angle (Alpha). This firing angle is typically used by a thyristor bridge firing unit to generate the gate signals needed to reach the desired DC bus voltage.

When the bridge rectifier reaches its operating limit and the DC bus voltage becomes too high, the controller outputs the duty cycle (P_chop) for a braking chopper. The latter ensures that the DC bus voltage is kept within its upper and lower limits. During this operating mode, the braking chopper control signal (Bctrl) cancels out the integral gain of the PI controller. The integral gain is not needed due to the high dynamics of the braking chopper.

Dialog Box and Parameters

Integral gain

The PI controller's integral gain. The default value is `0.1`.

Proportional gain

The PI controller's proportional gain. The default value is `0.01`.

Low-pass filter cutoff frequency (Hz)

The DC bus voltage measurement first-order filter cutoff frequency, in hertz. The default value is `30`.

Sample time (s)

The time step used for the simulation, in seconds. The default value is `1e-6`.

Inputs and Outputs

VBus

> The DC bus voltage set point for the thyristor bridge.

Bctrl

> The braking chopper control signal (0 or 1).

VBus*

> The measured DC bus voltage.

P_chop

> The duty cycle of the braking chopper.

Alpha

> The thyristor bridge rectifier firing angle.

VBus_f

> The measured DC bus voltage filtered.

Ctrl

> A vector containing the following measurement signals:
>
> - `Alpha (deg)` — The thyristor bridge firing angle.
> - `Voltage Error (V)` — Difference between the DC bus voltage reference and the actual DC bus voltage (filtered).

Examples

The Voltage Controller (DC Bus) block is used in the AC1 block of the Electric Drives library.

References

[1] Bose, B. K. *Modern Power Electronics and AC Drives*, NJ: Prentice-Hall, 2002.

See Also

`Bridge Firing Unit (AC)` | `Bridge Firing Unit (DC)` | `Current Controller (Brushless DC)` | `Current Controller (DC)` | `Direct Torque Controller`

| Field-Oriented Controller | Regulation Switch | Six Step Generator | Space Vector Modulator | Speed Controller (DC) | Speed Controller (Scalar Control) | Speed-Controller (AC) | Vector Controller (PMSM) | Vector Controller (WFSM) | Voltage Controller (DC Bus)

More About

- "Electric Drives Library"

Introduced in R2015b

Voltage-Current Simscape Interface

Ideal coupling between SimPowerSystems and Simscape electrical circuits

Library

Fundamental Blocks/Interface Elements

Description

The Voltage-Current Simscape Interface block connects SimPowerSystems circuits with electrical elements from the Simscape Foundation library. This block preserves current through the block and voltage across the block, conserving electrical power.

- On the SimPowerSystems side, the electrical connector ports +sps and -sps act like a controlled voltage source, feeding voltage from the Simscape side to the connected SimPowerSystems elements, while maintaining the current through the block.

- On the Simscape side, the electrical connector ports +ssc and -ssc act like a controlled current source, feeding current from the SimPowerSystems side to the connected Simscape elements, while maintaining the voltage across the block.

The following figure gives an overview of the interface.
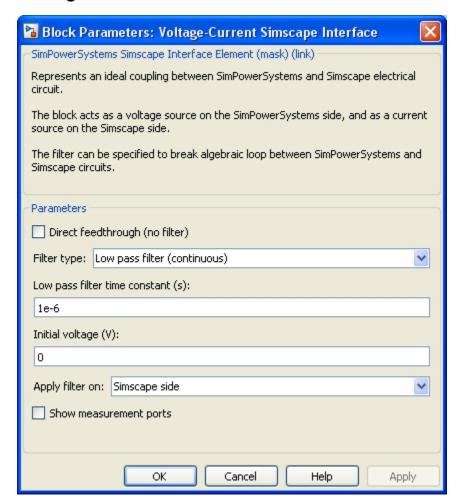
The block measures the voltage between the +ssc and -ssc ports and propagates it to the +sps and -sps ports, preserving the polarity. The block also measures the current flowing from the +sps to the -sps port and propagates it from the -ssc to the +ssc port.

You can specify a filter to break the algebraic loop between SimPowerSystems and Simscape ports. You can specify the filter as a first order continuous transfer function or as a discrete unit delay block. You can apply it on the SimPowerSystems side, to the measured voltage, or on the Simscape side, to the measured current. Depending on the measured signal where the filter is applied, the other signal is always a direct feedthrough.

If you do not specify a filter, direct feedthrough is applied on both measured signals. However, this configuration results in an algebraic loop containing the Voltage Sensor, Controlled Voltage Source, Current Measurement, and Controlled Current Source blocks, which might cause numerical issues.

Dialog Box and Parameters

Direct feedthrough (no filter)

> If selected, direct feedthrough is applied between SimPowerSystems and Simscape ports on both sides.

Filter type

> Set this parameter to Low pass filter (continuous) to implement a first order continuous transfer function filter between SimPowerSystems and Simscape ports.

Set this parameter to `Unit delay (discrete)` to implement a discrete unit delay filter between SimPowerSystems and Simscape ports.

Set this parameter to `First-order input filtering` to implement a first order continuous transfer function filter with first-order filtering of the Simulink-PS Converter block that provides one derivative. You can apply this filter only on the SimPowerSystems side.

Set this parameter to `Second-order input filtering` to implement a first order continuous transfer function filter with second-order filtering of the Simulink-PS Converter block that provides derivatives one and two. You can apply this filter only on the SimPowerSystems side.

The **Filter type** parameter is not visible when the **Direct feedthrough (no filter)** check box is selected.

Low pass filter constant (s)

Specify the low pass filter time constant of the filter, in seconds. This parameter is visible only when the **Filter type** parameter is set to `Low pass filter (continuous)`, to `First-order input filtering`, or to `Second-order input filtering`.

Sample time of unit delay (s)

Specify the sample time of the unit delay filter, in seconds. This parameter is visible only when the **Filter type** parameter is set to `Unit delay (discrete)`.

Initial voltage (V)

Specify the initial voltage value of the measured SimPowerSystems voltage.

This parameter is visible only when you apply the filter on the SimPowerSystems side.

Initial current (A)

Specify the initial current value of the measured Simscape current.

This parameter is visible only when you apply the filter on the Simscape side.

Apply filter on

Set this parameter to `SimPowerSystems side` to apply the filter on the measured SimPowerSystems voltage.

Set this parameter to `Simscape side` to apply the filter on the measured Simscape current.

The **Apply filter on** parameter is not visible when the **Direct feedthrough (no filter)** check box is selected, to `First-order input filtering`, or to `Second-order input filtering`.

Show measurement port

If selected, adds a Simulink output to the block that returns the SimPowerSystems current and voltage and to the Simscape current and voltages in a bus signal.

Limitations

When simulating SimPowerSystems models along with Simscape blocks, select the Simulink solver carefully.

Use the `ode23tb` solver for solving SimPowerSystems circuits containing switches or nonlinear element. If you use other stiff solvers, SimPowerSystems software gives you the following warning:

```
Warning: You have required continuous-time simulation of a system containing
switches or nonlinear elements. The ode23tb variable-step stiff solver with
relative tolerance set to 1e-4 is recommended in order to get best accuracy
and simulationperformance. For some highly nonlinear models it may be
necessary to set the "Solver reset method" parameter to "Robust".
See "Improving Simulation Performance" chapter in SimPowerSystems documentation
for additional information on how to select an appropriate integration method.
```

However, if you use the `ode23tb` solver for solving models containing Simscape blocks, Simscape software gives you the following warning:

```
Warning: The solver chosen is not recommended if the model is stiff, which is
typical for models containing Simscape components. These solvers are typically
preferred for Simscape models:ode23t, ode15s or ode14x (fixed-step). To disable
this diagnostic,change the explicit solver diagnostic setting on the Simscape
panel of the model Configuration Parameters.
```

Although the Simscape warning can be disabled, as described in the warning message, the SimPowerSystems warning cannot be disabled with regular configuration parameters. To disable the SimPowerSystems warning when you chose a solver other than `ode23tb`, select the Powergui block in your model, then, at the MATLAB Command line, type:

```
set_param(gcb,'FunctionMessages','on')
```

Example

See the power_SSCmodeling example for an example of interfacing SimPowerSystems and Simscape models using the Current-Voltage Simscape Interface block.

See Also

`Current-Voltage Simscape Interface`, `Current-Voltage Simscape Interface (gnd)`, `Voltage-Current Simscape Interface (gnd)`

Voltage-Current Simscape Interface (gnd)

Ideal coupling between SimPowerSystems and Simscape electrical circuits

Library

Fundamental Blocks/Interface Elements

Description

The Voltage-Current Simscape Interface (gnd) block connects SimPowerSystems circuits with electrical elements from the Simscape Foundation library. This block preserves current through the block and voltage across the block, conserving electrical power.

- On the SimPowerSystems side, the electrical connector port sps acts like a controlled voltage source referred to the ground, feeding voltage from the Simscape side to the connected SimPowerSystems elements.

- On the Simscape side, the electrical connector port ssc acts like a controlled current source referred to the ground, feeding current from the SimPowerSystems side to the connected Simscape elements.

The following figure gives an overview of the interface.

The block measures the voltage between the `ssc` port and the Simscape electrical reference and propagates it to the `sps` port, preserving the polarity with respect to the SimPowerSystems electrical reference. The block also measures the current entering the `sps` port and propagates it to the `ssc` port.

You can specify a filter to break the algebraic loop between SimPowerSystems and Simscape ports. You can specify the filter as a first order continuous transfer function or as a discrete unit delay block. You can apply it on the SimPowerSystems side, to the measured voltage, or on the Simscape side, to the measured current. Depending on the measured signal where the filter is applied, the other signal is always a direct feedthrough.

If you do not specify a filter, direct feedthrough is applied on both measured signals. However, this configuration results in an algebraic loop containing the Voltage Measurement, Controlled Voltage Source, Current Sensor, and Controlled Current Source blocks, which might cause numerical issues.

Dialog Box and Parameters

Direct feedthrough (no filter)

If selected, direct feedthrough is applied between SimPowerSystems and Simscape ports on both sides.

Filter type

Set this parameter to `Low pass filter (continuous)` to implement a first order continuous transfer function filter between SimPowerSystems and Simscape ports.

Set this parameter to `Unit delay (discrete)` to implement a discrete unit delay filter between SimPowerSystems and Simscape ports.

Set this parameter to `First-order input filtering` to implement a first order continuous transfer function filter with first-order filtering of the Simulink-PS Converter block that provides one derivative. You can apply this filter only on the SimPowerSystems side.

Set this parameter to `Second-order input filtering` to implement a first order continuous transfer function filter with second-order filtering of the Simulink-PS Converter block that provides derivatives one and two. You can apply this filter only on the SimPowerSystems side.

The **Filter type** parameter is not visible when the **Direct feedthrough (no filter)** check box is selected.

Low pass filter constant (s)

Specify the low pass filter time constant of the filter, in seconds. This parameter is visible only when the **Filter type** parameter is set to `Low pass filter (continuous)`, to `First-order input filtering`, or to `Second-order input filtering`.

Sample time of unit delay (s)

Specify the sample time of the unit delay filter, in seconds. This parameter is visible only when the **Filter type** parameter is set to `Unit delay (discrete)`.

Initial voltage (V)

Specify the initial voltage value of the measured SimPowerSystems voltage.

This parameter is visible only when you apply the filter on the SimPowerSystems side.

Initial current (A)

Specify the initial current value of the measured Simscape current.

This parameter is visible only when you apply the filter on the Simscape side.

Apply filter on

Set this parameter to `SimPowerSystems side` to apply the filter on the measured SimPowerSystems voltage.

Set this parameter to `Simscape side` to apply the filter on the measured Simscape current.

The **Apply filter on** parameter is not visible when the **Direct feedthrough (no filter)** check box is selected, when the **Filter type** is set to `First-order input filtering`, or when the **Filter type** is set to `Second-order input filtering`.

Show measurement port

If selected, adds a Simulink output to the block that returns the SimPowerSystems current and voltage and to the Simscape current and voltages in a bus signal.

Limitations

When simulating SimPowerSystems models along with Simscape blocks, select the Simulink solver carefully.

Use the `ode23tb` solver for solving SimPowerSystems circuits containing switches or nonlinear element. If you use other stiff solvers, SimPowerSystems software gives you the following warning:

```
Warning: You have required continuous-time simulation of a system containing
switches or nonlinear elements. The ode23tb variable-step stiff solver with
relative tolerance set to 1e-4 is recommended in order to get best accuracy
and simulationperformance. For some highly nonlinear models it may be
necessary to set the "Solver reset method" parameter to "Robust".
See "Improving Simulation Performance" chapter in SimPowerSystems documentation
for additional information on how to select an appropriate integration method.
```

However, if you use the `ode23tb` solver for solving models containing Simscape blocks, Simscape software gives you the following warning:

```
Warning: The solver chosen is not recommended if the model is stiff, which is
typical for models containing Simscape components. These solvers are typically
preferred for Simscape models:ode23t, ode15s or ode14x (fixed-step). To disable
this diagnostic,change the explicit solver diagnostic setting on the Simscape
panel of the model Configuration Parameters.
```

Although the Simscape warning can be disabled, as described in the warning message, the SimPowerSystems warning cannot be disabled with regular configuration parameters. To disable the SimPowerSystems warning when you chose a solver other than `ode23tb`, select the Powergui block in your model, then, at the MATLAB Command line, type:

```
set_param(gcb,'FunctionMessages','on')
```

Example

See the power_SSCmodeling example for an example of interfacing SimPowerSystems and Simscape models using the Current-Voltage Simscape Interface block.

See Also

`Current-Voltage Simscape Interface`, `Current-Voltage Simscape Interface (gnd)`, `Voltage-Current Simscape Interface`

Voltage Measurement

Measure voltage in circuit

Library

Fundamental Blocks/Measurements
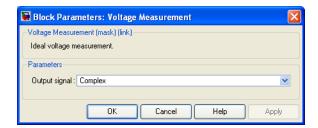
Description

The Voltage Measurement block measures the instantaneous voltage between two electric nodes. The output provides a Simulink signal that can be used by other Simulink blocks.

Dialog Box and Parameters

Output signal

Specifies the format of the output signal when the block is used in a phasor simulation. The **Output signal** parameter is disabled when the block is not used in a phasor simulation. The phasor simulation is activated by a Powergui block placed in the model.

Set to `Complex` to output the measured current as a complex value. The output is a complex signal.

Set to `Real-Imag` to output the real and imaginary parts of the measured current. The output is a vector of two elements.

Set to `Magnitude-Angle` to output the magnitude and angle of the measured current. The output is a vector of two elements.

Set to `Magnitude` to output the magnitude of the measured current. The output is a scalar value.

See Also
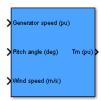
Current Measurement, powergui, Three-Phase V-I Measurement

Wind Turbine

Implement model of variable pitch wind turbine

Library

Renewables/Wind Generation

Description

The model is based on the steady-state power characteristics of the turbine. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine. The output power of the turbine is given by the following equation.

$$P_m = c_p(\lambda, \beta) \frac{\rho A}{2} v_{\text{wind}}^3,$$

where

P_m	Mechanical output power of the turbine (W)
c_p	Performance coefficient of the turbine
ρ	Air density (kg/m^3)
A	Turbine swept area (m^2)
v_{wind}	Wind speed (m/s)
λ	Tip speed ratio of the rotor blade tip speed to wind speed

| β | Blade pitch angle (deg) |

Equation 1-1 can be normalized. In the per unit (pu) system we have:

$$P_{m\_pu} = k_p c_{p\_pu} v_{wind\_pu}^3,$$

where

P_{m_pu}	Power in pu of nominal power for particular values of ρ and *A*
c_{p_pu}	Performance coefficient in pu of the maximum value of c_p
v_{wind_pu}	Wind speed in pu of the base wind speed. The base wind speed is the mean value of the expected wind speed in m/s.
k_p	Power gain for c_{p_pu}=1 pu and v_{wind_pu}=1 pu, k_p is less than or equal to 1
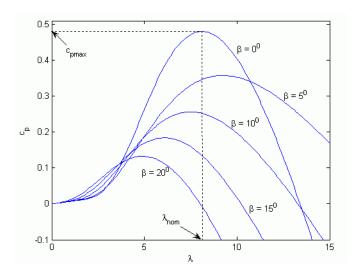
A generic equation is used to model $c_p(\lambda,\beta)$. This equation, based on the modeling turbine characteristics of [1], is:

$$c_p(\lambda,\beta) = c_1 \left(c_2 / \lambda_i - c_3\beta - c_4 \right) e^{-c_5/\lambda_i} + c_6\lambda,$$
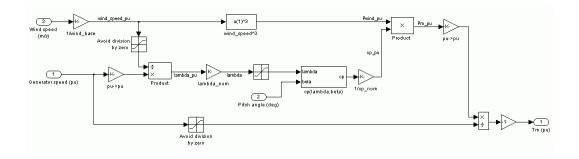
with

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}.$$
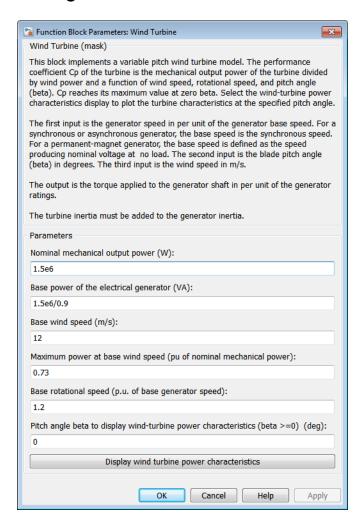
The coefficients c_1 to c_6 are: $c_1 = 0.5176$, $c_2 = 116$, $c_3 = 0.4$, $c_4 = 5$, $c_5 = 21$ and $c_6 = 0.0068$. The c_p-λ characteristics, for different values of the pitch angle β, are illustrated below. The maximum value of c_p ($c_{pmax} = 0.48$) is achieved for β = 0 degree and for λ = 8.1. This particular value of λ is defined as the nominal value ($\lambda_{\_nom}$).

The Simulink model of the turbine is illustrated in the following figure. The three inputs are the generator speed (ωr_pu) in pu of the nominal speed of the generator, the pitch angle in degrees and the wind speed in m/s. The tip speed ratio λ in pu of $\lambda_{\_nom}$ is obtained by the division of the rational speed in pu of the base rotational speed (defined below) and the wind speed in pu of the base wind speed. The output is the torque applied to the generator shaft.

Dialog Box and Parameters

Nominal mechanical output power

The nominal output power in watts (W).

Base power of the electrical generator

The nominal power of the electrical generator coupled to the wind turbine, in VA. This parameter is used to compute the output torque in pu of the nominal torque of the generator.

Base wind speed

The base value of the wind speed, in m/s, used in the per unit system. The base wind speed is the mean value of the expected wind speed. This base wind speed produces a mechanical power which is usually lower than the turbine nominal power.

Maximum power at base wind speed

The maximum power at base wind speed in pu of the nominal mechanical power. This parameter is the power gain k_p already defined.

Base rotational speed

The rotational speed at maximum power for the base wind speed. The base rotational speed is in pu of the base generator speed. For a synchronous or asynchronous generator, the base speed is the synchronous speed. For a permanent-magnet generator, the base speed is defined as the speed producing nominal voltage at no load.

Pitch angle beta to display wind turbine power characteristics

The pitch angle beta, in degrees, used to display the power characteristics. Beta must be greater than or equal to zero.

Display wind turbine power characteristics

Click to plot the turbine power characteristics for different wind speeds and for the specified pitch angle beta.

Inputs and Outputs

`Generator speed (pu)`

Simulink input of the generator speed in pu based on the nominal speed of the generator.

`Pitch angle (deg)`

Simulink input of the pitch angle.

`Wind speed (m/s)`
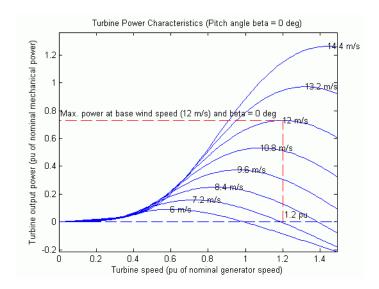
Simulink input of the wind speed in m/s.

`Tm (pu)`

Simulink output of the mechanical torque of the wind turbine, in pu of the nominal generator torque. The nominal torque of the generator is based on the nominal generator power and speed.

Example

The mechanical power P_m as a function of generator speed, for different wind speeds and for blade pitch angle ß = 0 degree, is illustrated below. This figure is obtained with the default parameters (base wind speed = 12 m/s, maximum power at base wind speed = 0.73 pu (k_p = 0.73) and base rotational speed = 1.2 pu).

References

[1] Siegfried Heier, "Grid Integration of Wind Energy Conversion Systems," John Wiley & Sons Ltd, 1998, ISBN 0-471-97143-X

See Also

Wind Turbine Induction Generator (Phasor Type) Wind Turbine Doubly-Fed Induction Generator (Phasor Type)

Wind Turbine Doubly-Fed Induction Generator (Phasor Type)

Implement phasor model of variable speed doubly-fed induction generator driven by wind turbine
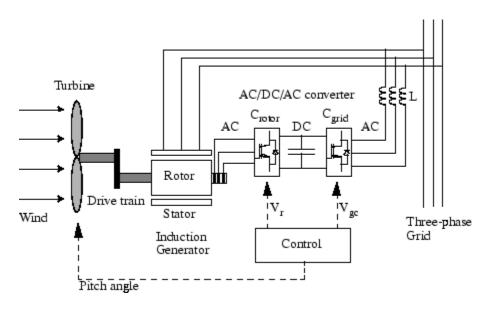
Library

Renewables/Wind Generation

Description

The wind turbine and the doubly-fed induction generator (WTDFIG) are shown in the figure called The Wind Turbine and the Doubly-Fed Induction Generator System. The AC/DC/AC converter is divided into two components: the rotor-side converter (C_{rotor}) and the grid-side converter (C_{grid}). C_{rotor} and C_{grid} are Voltage-Sourced Converters that use forced-commutated power electronic devices (IGBTs) to synthesize an AC voltage from a DC voltage source. A capacitor connected on the DC side acts as the DC voltage source. A coupling inductor L is used to connect C_{grid} to the grid. The three-phase rotor winding is connected to C_{rotor} by slip rings and brushes and the three-phase stator winding is directly connected to the grid. The power captured by the wind turbine is converted into electrical power by the induction generator and it is transmitted to the grid by the stator and the rotor windings. The control system generates the pitch angle command and the voltage command signals V_r and V_{gc} for C_{rotor} and C_{grid} respectively in order to control the power of the wind turbine, the DC bus voltage and the reactive power or the voltage at the grid terminals.

The Wind Turbine and the Doubly-Fed Induction Generator System

Operating Principle of the Wind Turbine Doubly-Fed Induction Generator

The power flow, illustrated in the figure called The Power Flow, is used to describe the operating principle. In this figure the followings parameters are used:

P_m	Mechanical power captured by the wind turbine and transmitted to the rotor
P_s	Stator electrical power output
P_r	Rotor electrical power output
P_{gc}	C_{grid} electrical power output
Q_s	Stator reactive power output
Q_r	Rotor reactive power output
Q_{gc}	C_{grid} reactive power output
T_m	Mechanical torque applied to rotor
T_{em}	Electromagnetic torque applied to the rotor by the generator
ω_r	Rotational speed of rotor

ω_s	Rotational speed of the magnetic flux in the air-gap of the generator, this speed is named synchronous speed. It is proportional to the frequency of the grid voltage and to the number of generator poles.
J	Combined rotor and wind turbine inertia coefficient

The mechanical power and the stator electric power output are computed as follows:

$P_m = T_m \omega_r$

$P_s = T_{em} \omega_s.$

For a lossless generator the mechanical equation is:
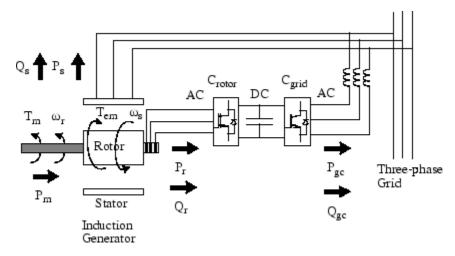
$$J \frac{d\omega_r}{dt} = T_m - T_{em}.$$

In steady-state at fixed speed for a lossless generator $T_m = T_{em}$ and $P_m = P_s + P_r$.

It follows that:

$$P_r = P_m - P_s = T_m \omega_r - T_{em} \omega_s = -T_m \frac{\omega_s - \omega_r}{\omega_s} \omega_s = -sT_m \omega_s = -sP_s,$$

where s is defined as the slip of the generator: $s = (\omega_s - \omega_r)/\omega_s$.

The Power Flow

Generally the absolute value of slip is much lower than 1 and, consequently, P_r is only a fraction of P_s. Since T_m is positive for power generation and since ω_s is positive and constant for a constant frequency grid voltage, the sign of P_r is a function of the slip sign. P_r is positive for negative slip (speed greater than synchronous speed) and it is negative for positive slip (speed lower than synchronous speed). For super-synchronous speed operation, P_r is transmitted to DC bus capacitor and tends to rise the DC voltage. For sub-synchronous speed operation, P_r is taken out of DC bus capacitor and tends to decrease the DC voltage. C_{grid} is used to generate or absorb the power P_{gc} in order to keep the DC voltage constant. In steady-state for a lossless AC/DC/AC converter P_{gc} is equal to P_r and the speed of the wind turbine is determined by the power P_r absorbed or generated by C_{rotor}. The power control will be explained below.

The phase-sequence of the AC voltage generated by C_{rotor} is positive for sub-synchronous speed and negative for super-synchronous speed. The frequency of this voltage is equal to the product of the grid frequency and the absolute value of the slip.

C_{rotor} and C_{grid} have the capability of generating or absorbing reactive power and could be used to control the reactive power or the voltage at the grid terminals.
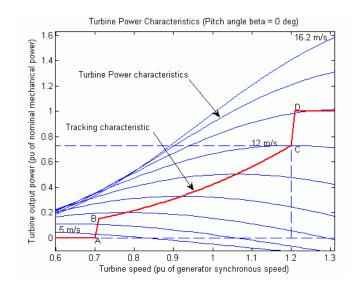
C_rotor Control System

The rotor-side converter is used to control the wind turbine output power and the voltage (or reactive power) measured at the grid terminals.

Power Control
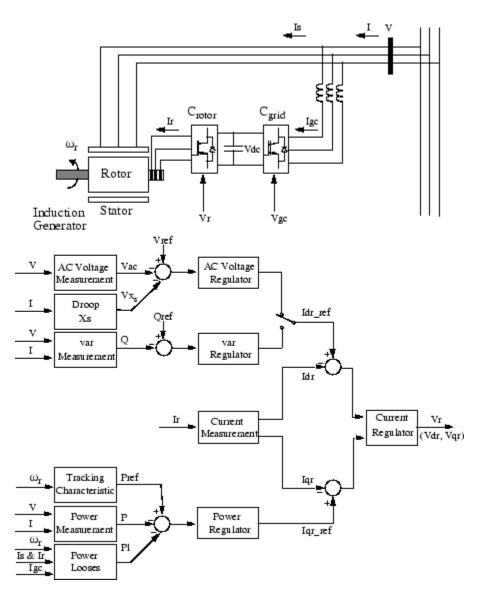
The power is controlled in order to follow a pre-defined power-speed characteristic, named tracking characteristic. An example of such a characteristic is illustrated in the figure called Turbine Characteristics and Tracking Characteristic, by the ABCD curve superimposed to the mechanical power characteristics of the turbine obtained at different wind speeds. The actual speed of the turbine ω_r is measured and the corresponding mechanical power of the tracking characteristic is used as the reference power for the power control loop. The tracking characteristic is defined by four points: A, B, C and D. From zero speed to speed of point A the reference power is zero. Between point A and point B the tracking characteristic is a straight line, the speed of point B must be greater than the speed of point A. Between point B and point C the tracking characteristic is the locus of the maximum power of the turbine (maxima of the turbine power vs turbine speed curves). The tracking characteristic is a straight line from point C and point D. The power at point D is one per unit (1 pu) and the speed of the point D must be greater than

the speed of point C. Beyond point D the reference power is a constant equal to one per unit (1 pu).

Turbine Characteristics and Tracking Characteristic

The generic power control loop is illustrated in the figure called Rotor-Side Converter Control System. The actual electrical output power, measured at the grid terminals of the wind turbine, is added to the total power losses (mechanical and electrical) and is compared with the reference power obtained from the tracking characteristic. A Proportional-Integral (PI) regulator is used to reduce the power error to zero. The output of this regulator is the reference rotor current Iqr_ref that must be injected in the rotor by converter C_{rotor}. This is the current component that produce the electromagnetic torque T_{em}. The actual Iqr component of positive-sequence current is compared to Iqr_ref and the error is reduced to zero by a current regulator (PI). The output of this current controller is the voltage Vqr generated by C_{rotor}. The current regulator is assisted by feed forward terms which predict Vqr.
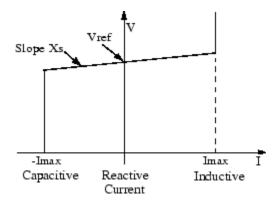
Rotor-Side Converter Control System

Voltage Control and Reactive Power Control

The voltage or the reactive power at grid terminals is controlled by the reactive current flowing in the converter C_{rotor}. The generic control loop is illustrated in the figure called Rotor-Side Converter Control System.

When the wind turbine is operated in voltage regulation mode, it implements the following V-I characteristic.

Wind Turbine V-I Characteristic

As long as the reactive current stays within the maximum current values (-Imax, Imax) imposed by the converter rating, the voltage is regulated at the reference voltage Vref. However, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in the figure called Wind Turbine V-I Characteristic. In the voltage regulation mode, the V-I characteristic is described by the following equation:

$V = V_{ref} + X_s I$

where

V	Positive sequence voltage (pu)
I	Reactive current (pu/Pnom) (I > 0 indicates an inductive current)
X_s	Slope or droop reactance (pu/Pnom)
Pnom	Three-phase nominal power of the converter specified in the block dialog box

When the wind turbine is operated in var regulation mode the reactive power at grid terminals is kept constant by a var regulator.

The output of the voltage regulator or the var regulator is the reference d-axis current Idr_ref that must be injected in the rotor by converter C_{rotor}. The same current regulator as for the power control is used to regulate the actual Idr component of positive-sequence current to its reference value. The output of this regulator is the d-axis voltage Vdr generated by C_{rotor}. The current regulator is assisted by feed forward terms which predict Vdr.

Vdr and Vqr are respectively the d-axis and q-axis of the voltage Vr.

Note:

- for C_{rotor} control system and measurements the d-axis of the d-q rotating reference frame is locked on the generator mutual flux by a PLL which is assumed to be ideal in this phasor model.

- the magnitude of the reference rotor current Ir_ref is equal to $\sqrt{I_{dr\_ref}^2 + I_{qr\_ref}^2}$. The maximum value of this current is limited to 1 pu. When Idr_ref and Iqr_ref are such that the magnitude is higher than 1 pu the Iqr_ref component is reduced in order to bring back the magnitude to 1 pu.

C_grid Control System

The converter C_{grid} is used to regulate the voltage of the DC bus capacitor. In addition, this model allows using C_{grid} converter to generate or absorb reactive power.
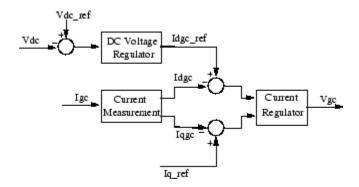
The control system, illustrated in the figure called Grid-Side Converter Control System, consists of:

- Measurement systems measuring the d and q components of AC positive-sequence currents to be controlled as well as the DC voltage Vdc.

- An outer regulation loop consisting of a DC voltage regulator. The output of the DC voltage regulator is the reference current Idgc_ref for the current regulator (Idgc = current in phase with grid voltage which controls active power flow).

- An inner current regulation loop consisting of a current regulator. The current regulator controls the magnitude and phase of the voltage generated by converter C_{grid} (Vgc) from the Idgc_ref produced by the DC voltage regulator and specified Iq_ref reference. The current regulator is assisted by feed forward terms which predict the C_{grid} output voltage.

The magnitude of the reference grid converter current Igc_ref is equal to

$$\sqrt{I_{dgc\_\text{ref}}^2 + I_{qr\_\text{ref}}^2}$$
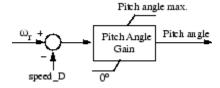
. The maximum value of this current is limited to a value defined by the converter maximum power at nominal voltage. When Idgc_ref and Iq_ref are such that the magnitude is higher than this maximum value the Iq_ref component is reduced in order to bring back the magnitude to its maximum value.

Grid-Side Converter Control System

Pitch Angle Control System

The pitch angle is kept constant at zero degree until the speed reaches point D speed of the tracking characteristic. Beyond point D the pitch angle is proportional to the speed deviation from point D speed. The control system is illustrated in the following figure.

Pitch Control System

Turbine Model

The turbine model uses the Wind Turbine bloc of the Renewables/Wind Generation library. See documentation of this model for more details.

Induction Generator
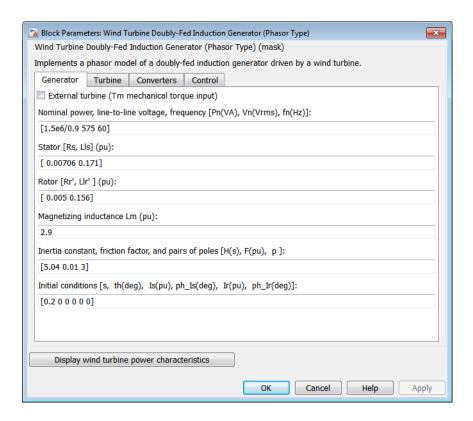
The doubly-fed induction generator phasor model is the same as the wound rotor asynchronous machine (see the Machines library) with the following two points of difference:

1 Only the positive-sequence is taken into account, the negative-sequence has been eliminated.

2 A trip input has been added. When this input is high the induction generator is disconnected from the grid and from C_{rotor}.

Dialog Box and Parameters

The WTDFIG parameters are grouped in four categories: Generator data, Converters data, Turbine data, and Control parameters. Use the Display listbox to select which group of parameters you want to visualize.

Generator Tab

External turbine (Tm mechanical torque input)

> When you select this parameter, the **Turbine** tab is not visible, and a Simulink input named Tm appears on the block, allowing to use an external signal for the generator input mechanical torque. This external torque must be in pu based on the nominal electric power and synchronous speed. For example, the external torque may come from a user defined turbine model. Following the convention used in the induction machine, the torque must be negative for power generation.

Nominal power, line-to-line voltage and frequency

> The nominal power in VA, the nominal line-to-line voltage in Vrms and the nominal system frequency in hertz.

Stator

The stator resistance Rs and leakage inductance Lls in pu based on the generator rating.

Rotor

The rotor resistance Rr' and leakage inductance Llr', both referred to the stator, in pu based on the generator rating.

Magnetizing inductance

The magnetizing inductance Lm in pu based on the generator rating.

Inertia constant, friction factor and pairs of poles

Combined generator and turbine inertia constant H in seconds, combined viscous friction factor F in pu based on the generator rating and number of pole pairs p.

You may need to use your own turbine model, in order for example, to implement different power characteristics or to implement the shaft stiffness. Your model must then output the mechanical torque applied to the generator shaft. If the inertia and the friction factor of the turbine are implemented inside the turbine model you specify only the generator inertia constant H and the generator friction factor F.

Initial conditions

The initial slip s, electrical angle Θ in degrees, stator phasor current magnitude in pu, stator phasor current phase angle in degrees, rotor phasor current magnitude in pu and rotor phasor current phase angle in degrees.

Display wind turbine power characteristics

Click to plot the turbine power characteristics at zero degree of pitch angle for different wind speeds. The tracking characteristic is also displayed on the same figure.

Turbine Tab

Electric Power-Speed characteristic

This parameter is visible only when the **External mechanical torque** parameter is checked. It is used to specify a series of speed-power pairs for the tracking characteristic. The speed is in pu based on synchronous speed and the power is in pu based on nominal generator power.

Nominal wind turbine mechanical output power

This parameter is not visible when the **External mechanical torque** parameter is checked.

The nominal turbine mechanical output power in watts.

Tracking characteristic speeds

This parameter is not visible when the **External mechanical torque** parameter is checked.

Specify the speeds of point A to point D of the tracking characteristic in pu of the synchronous speed. speed_B must be greater than speed_A and speed_D must be greater than speed_C.

Power at point C

This parameter is not visible when the **External mechanical torque** parameter is checked.

Specify the power of point C of the tracking characteristic in pu of the **Nominal wind turbine mechanical output power.**

Wind speed at point C

This parameter is not visible when the **External mechanical torque** parameter is checked.

Specify wind speed in m/s for point C. The power at point C is the maximum turbine output power for the specified wind speed.

Pitch angle controller gain [Kp]

This parameter is not visible when the **External mechanical torque** parameter is checked.

Proportional gain Kp of the pitch controller. Specify Kp in degrees/(speed deviation pu). The speed deviation is the difference between actual speed and speed of point D in pu of synchronous speed.

Maximum pitch angle

This parameter is not visible when the **External mechanical torque** parameter is checked.

The maximum pitch angle in degrees.

Maximum rate of change of pitch angle

This parameter is not visible when the **External mechanical torque** parameter is checked.

The maximum rate of change of the pitch angle in degrees/s.

Converters Tab

Converter maximum power

The maximum power of both C_{grid} and C_{rotor} in pu of the nominal power. This parameter is used to compute the maximum current at 1 pu of voltage for C_{grid}. The maximum current for C_{rotor} is 1 pu.

Grid-side coupling inductor

The coupling inductance L and its resistance R in pu based on the generator rating.

Coupling inductor initial currents

The coupling inductor initial phasor current in positive-sequence. Enter magnitude IL in pu and phase ph_IL in degrees. If you know the initial value of the current corresponding to the WTDFIG operating point you may specify it in order to start simulation in steady state. If you don't know this value, you can leave [0 0]. The system will reach steady-state after a short transient.

Nominal DC bus voltage

The nominal DC bus voltage in volts.

DC bus capacitor

The total capacitance of the DC link in farads. This capacitance value is related to the WTDFIG rating and to the DC link nominal voltage. The energy stored in the capacitance (in joules) divided by the WTDFIG rating (in VA) is a time duration which is usually a fraction of a cycle at nominal frequency. For example, for the default parameters, (C=10000 μF, Vdc=1200 V, Pn=1.67 MVA) this ratio

$1/2 \cdot C \cdot V_{dc}^2 / P_n$ is 4.3 ms, which represents 0.26 cycle for a 60 Hz frequency. If you change the default values of the nominal power rating and DC voltage, you should change the capacitance value accordingly.

Control Tab

Mode

Specifies the **WTDFIG** mode of operation. Select either `Voltage regulation` or `Var regulation`.

Reference grid voltage Vref

This parameter is not visible when the **Mode** parameter is set to `Var regulation`.

Reference voltage, in pu, used by the voltage regulator. When **External** is selected, a Simulink input named Vref appears on the block, allowing you to control the

reference voltage from an external signal (in pu). The **Reference grid voltage** parameter is therefore unavailable.

Generated reactive power Qref

This parameter is not visible when the **Mode** parameter is set to `Voltage regulation`.

Reference generated reactive power at grid terminals, in pu, used by the var regulator. When **External** is selected, a Simulink input named Qref appears on the block, allowing you to control the reference reactive power from an external signal (in pu). The **Generated reactive power Qref** parameter is therefore unavailable

Grid-side converter generated reactive current reference (Iq_ref)

Reference grid-side converter reactive current, in pu, used by the current regulator. Specify a positive value of Iq_ref for generated reactive power. When **External** is selected, a Simulink input named Iq_ref appears on the block, allowing you to control the grid-side converter reactive current from an external signal (in pu). The **Grid-side converter generated reactive current reference** parameter is therefore unavailable.

Grid voltage regulator gains [Kp Ki]

This parameter is not visible when the **Mode** parameter is set to `Var regulation`.

Gains of the AC voltage regulator. Specify proportional gain Kp in (pu of I)/(pu of V), and integral gain Ki, in (pu of I)/(pu of V)/s, where V is the AC voltage error and I is the output of the voltage regulator.

Droop Xs

This parameter is not visible when the **Mode** parameter is set to `Var regulation`.

Droop reactance, in pu/nominal power, defining the slope of the V-I characteristic.

Reactive power regulator gains [Kp Ki]

This parameter is not visible when the **Mode** parameter is set to `Voltage regulation`.

Gains of the var regulator. Specify proportional gain Kp in (pu of I)/(pu of Q), and integral gain Ki, in (pu of I)/(pu of Q)/s, where Q is the reactive power error and I is the output of the var regulator.

Power regulator gains [Kp Ki]

Gains of the power regulator. Specify proportional gain Kp in (pu of I)/(pu of P), and integral gain Ki, in (pu of I)/(pu of P)/s, where P is the power error and I is the output of the power regulator.

DC bus voltage regulator gains [Kp Ki]

Gains of the DC voltage regulator which controls the voltage across the DC bus capacitor. Specify proportional gain Kp in (pu of I)/(Vdc), and integral gain Ki, in (pu of I)/(Vdc)/s, where Vdc is the DC voltage error and I is the output of the voltage regulator.

Grid-side converter current regulator gains [Kp Ki]

Gains of the grid-side converter current regulator.

Specify proportional gain Kp in (pu of V)/(pu of I) and integral gain Ki, in (pu of V)/(pu of I)/s, where V is the output Vgc of the current regulator and I is the current error.

Rotor-side converter current regulator gains [Kp Ki]

Gains of the rotor-side converter current regulator.

Specify proportional gain Kp in (pu of V)/(pu of I) and integral gain Ki, in (pu of V)/(pu of I)/s, where V is the output Vr of the current regulator and I is the current error.

Maximum rate of change of reference grid voltage

This parameter is not visible when the **Mode** parameter is set to `Var regulation`.

Maximum rate of change of the reference voltage, in pu/s, when an external reference voltage is used.

Maximum rate of change of reference reactive power

This parameter is not visible when the **Mode** parameter is set to `Voltage regulation`.

Maximum rate of change of the reference reactive power, in pu/s, when an external reference reactive power is used.

Maximum rate of change of reference power

Maximum rate of change of the reference power in pu/s.

Maximum rate of change of converters reference current

Maximum rate of change of the reference current in pu/s for both the rotor-side and the grid-side converters.

Inputs and Outputs

A B C

The three terminals of the WTDFIG.

Trip

Apply a simulink logical signal (0 or 1) to this input. When this input is high the WTDFIG is disconnected and its control system is disabled. Use this input to implement a simplified version of the protection system.

Wind (m/s)

This input is not visible when the **External mechanical torque** parameter is checked.

Simulink input of the wind speed in m/s.

Tm

This input is visible only when the **External mechanical torque** parameter is checked.

Simulink input of the mechanical torque. Tm must be negative for power generation. Use this input when using an external turbine model.

Vref

This input is visible only when the **Mode of operation** parameter is set to Voltage regulation and the **External grid voltage reference** parameter is checked.

Simulink input of the external reference voltage signal.

Qref

This input is visible only when the **Mode of operation** parameter is set to Var regulation and the **External generated reactive power reference** parameter is checked.

Simulink input of the external reference generated reactive power signal at grid terminals.

Iq_ref

This input is visible only when the **External reactive current Iq_ref for grid-side converter** parameter is checked.

Simulink input of the external reference grid-side converter reactive current signal.

m

Simulink output vector containing 29 WTDFIG internal signals. These signals can be individually accessed by using the Bus Selector block. They are, in order:

Signal	Signal Group	Signal Names	Definition
1-3	Iabc (cmplx) (pu)	Ia (pu) Ib (pu) Ic (pu)	Phasor currents Ia, Ib, Ic flowing into the WTDFIG terminals in pu based on the generator rating.
4-6	Vabc (cmplx) (pu)	Va (pu) Vb (pu) Vc (pu)	Phasor voltages (phase to ground) Va, Vb, Vc at the WTDFIG terminals in pu based on the generator rating.
7-8	Vdq_stator (pu)	Vd_stator (pu) Vq_stator (pu)	Direct-axis and quadrature-axis component of stator voltage in pu based on the generator rating. Vd_stator and Vq_stator are respectively the real and imaginary parts of the positive-sequence stator phasor voltage.
9-11	Iabc_stator (cmplx) (pu)	Ia_stator (pu) Ib_stator (pu) Ic_stator (pu)	Phasor currents Ia, Ib, Ic flowing into the stator in pu based on the generator rating.
12-13	Idq_stator (pu)	Id_stator (pu) Iq_stator (pu)	Direct-axis and quadrature-axis component of stator current in pu based on the generator rating. Id_stator and Iq_stator are respectively the real and imaginary parts of the positive-sequence stator phasor current.
14-15	Vdq_rotor (pu)	Vd_rotor (pu) Vq_rotor (pu)	Direct-axis and quadrature-axis component of rotor voltage in pu based on the generator rating. Vd_rotor and Vq_rotor are respectively the real and imaginary parts of the positive-sequence rotor phasor voltage.

Signal	Signal Group	Signal Names	Definition
16-17	Idq_rotor (pu)	Id_rotor (pu) Iq_rotor (pu)	Direct-axis and quadrature-axis component of currents flowing into the rotor in pu based on the generator rating. Id_rotor and Iq_rotor are respectively the real and imaginary parts of the positive-sequence rotor phasor current.
18		wr (pu)	Generator rotor speed (pu)
19		Tm (pu)	Mechanical torque applied to the generator (pu)
20		Te (pu)	Electromagnetic torque in pu based on the generator rating.
21-22	Vdq_grid_conv (pu)	Vd_grid_conv (pu) Vq_grid_conv (pu)	Direct-axis and quadrature-axis component of grid-side converter voltage in pu based on the generator rating. Vd_grid_conv and Vq_grid_conv are respectively the real and imaginary parts of the grid-side converter phasor voltage.
23-25	Iabc_grid_conv (cmplx) (pu)	Ia_grid_conv (pu) Ib_grid_conv (pu) Ic_grid_conv (pu)	Phasor currents Ia, Ib, Ic flowing into the grid-side converter in pu based on the generator rating.
26		P (pu)	WTDFIG output power. A positive value indicates power generation.
27		Q (pu)	WTDFIG output reactive power. A positive value indicates reactive power generation.
28		Vdc (V)	DC voltage (V).
29		Pitch_angle (deg)	Blade pitch angle in degrees.

Example

See the power_wind_dfig example, which illustrates the steady-state and dynamic performance of the WTDFIG in a 9 MW Wind Farm connected on a 25 kV, 60 Hz, system.

References

[1] R. Pena, J.C. Clare, G.M. Asher, "Doubly fed induction generator using back-to-back PWM converters and its application to variable-speed wind-energy generation," IEEE Proc.-Electr. Power Appl., Vol. 143, No. 3, May 1996

[2] Vladislav Akhmatov, "Variable-Speed Wind Turbines with Doubly-Fed Induction Generators, Part I: Modelling in Dynamic Simulation Tools," Wind Engineering Volume 26, No. 2, 2002

[3] Nicholas W. Miller, Juan J. Sanchez-Gasca, William W. Price, Robert W. Delmerico, "DYNAMIC MODELING OF GE 1.5 AND 3.6 MW WIND TURBINE-GENERATORS FOR STABILITY SIMULATIONS," GE Power Systems Energy Consulting, IEEE WTG Modeling Panel, Session July 2003

See Also

Wind Turbine, Wind Turbine Induction Generator (Phasor Type)

Wind Turbine Induction Generator (Phasor Type)

Implement phasor model of squirrel-cage induction generator driven by variable pitch wind turbine

Library

Renewables/Wind Generation

Description
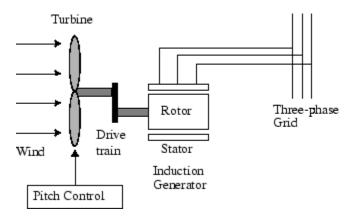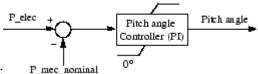
The wind turbine and the induction generator (WTIG) are shown below. The stator winding is connected directly to the grid and the rotor is driven by the wind turbine. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding. The pitch angle is controlled in order to limit the generator output power to its nominal value for high wind speeds. In order to generate power the induction generator speed must be slightly above the synchronous speed. But the speed variation is typically so small that the WTIG is considered to be a fixed-speed wind generator. The reactive power absorbed by the induction generator is provided by the grid or by some devices like capacitor banks, SVC, STATCOM or synchronous condenser.

Pitch Angle Control System

The wind turbine model uses the `Wind Turbine` block of the Renewables/Wind Generation library. See documentation of this block for details.

A Proportional-Integral (PI) controller is used to control the blade pitch angle in order to limit the electric output power to the nominal mechanical power. The pitch angle is kept constant at zero degree when the measured electric output power is under its nominal value. When it increases above its nominal value the PI controller increases the pitch angle to bring back the measured power to its nominal value. The control system is illustrated in the figure below:
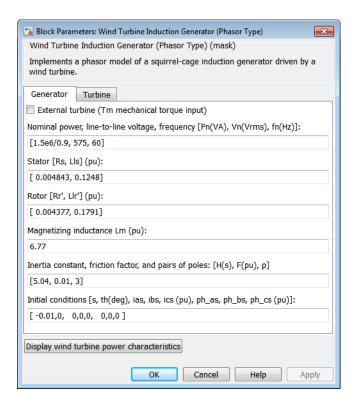
Dialog Box and Parameters

The WTIG parameters are grouped in two categories: Generator `data` and Turbine data». Use the Display listbox to select which group of parameters you want to visualize.

Generator Tab

External turbine (Tm mechanical torque input)

> When this parameter is selected, the **Turbine** tab is not visible in the mask dialog box, and a Simulink input named Tm appears on the block, allowing to use an external signal for the generator input mechanical torque. This external torque must be in pu based on the nominal electric power and synchronous speed of the generator. For example, the external torque may come from a user defined turbine model. By convention for the induction machine, the torque must be negative for power generation.

Nominal power, line-to-line voltage and frequency

> The nominal power in VA, the nominal line-to-line voltage in Vrms and the nominal system frequency in hertz.

Stator [Rs, Lls]

The stator resistance Rs and leakage inductance Lls in pu based on the generator ratings.

Rotor [Rr', Llr']

The rotor resistance Rr' and leakage inductance Llr', both referred to the stator, in pu based on the generator ratings.

Magnetizing inductance Lm

The magnetizing inductance Lm in pu based on the generator ratings.

Inertia constant, friction factor and pairs of poles

Combined generator and turbine inertia constant H in seconds, combined viscous friction factor F in pu based on the generator ratings and number of pole pairs p.

You may need to use your own turbine model, in order for example, to implement different power characteristics or to implement the shaft stiffness. Your model must then output the mechanical torque applied to the generator shaft. If the inertia and the friction factor of the turbine are implemented inside the turbine model you specify only the generator inertia constant H and the generator friction factor F.

Initial conditions

The initial slip s, electrical angle Θ in degrees, stator current magnitude in pu and phase angle in degrees.

Display wind turbine power characteristics

Click to plot the turbine power characteristics at the specified pitch angle for different wind speeds.

Turbine Tab

This tab is not visible when the **External turbine (Tm mechanical torque input)** parameter is selected.

Refer to the Wind Turbine for a detailed documentation.

Nominal wind turbine mechanical output power

This parameter is not visible when the **External mechanical torque** parameter is checked.

The nominal turbine mechanical output power in watts.

Base wind speed

This parameter is not visible when the **External mechanical torque** parameter is checked.

The base value of the wind speed, in m/s, used in the per unit system. The base wind speed is the mean value of the expected wind speed. This base wind speed produces a mechanical power which is usually lower than the turbine nominal power.

Maximum power at base wind speed

This parameter is not visible when the **External mechanical torque** parameter is checked.

The maximum power at base wind speed in pu of the nominal mechanical power.

Base rotational speed

This parameter is not visible when the **External mechanical torque** parameter is checked.

The rotational speed at maximum power for the base wind speed. The base rotational speed is in pu of the base generator speed.

Pitch angle controller gain [Kp Ki]

This parameter is not visible when the **External mechanical torque** parameter is checked.

Proportional and Integral gains Kp and Ki of the pitch controller. Specify Kp in degrees/(power deviation pu) and Ki in degrees/(power deviation pu)/s. The power deviation is the difference between actual electrical output power and the nominal mechanical power in pu of the generator nominal power.

Maximum pitch angle (deg)

This parameter is not visible when the **External mechanical torque** parameter is checked.

The maximum pitch angle in degrees.

Maximum rate of change of pitch angle

This parameter is not visible when the **External mechanical torque** parameter is checked.

The maximum rate of change of the pitch angle in degrees/s.

Inputs and Outputs

A B C

The three terminals of the WTIG.

Trip

Apply a simulink logical signal (0 or 1) to this input. When this input is high the WTIG is disconnected. Use this input to implement a simplified version of the protection system.

Wind (m/s)

This input is not visible when the **External mechanical torque** parameter is checked.

Simulink input of the wind speed in m/s.

Tm

This input is visible only when the **External mechanical torque** parameter is checked.

Simulink input of the mechanical torque. Tm must be negative for power generation. Use this input when using an external turbine model.

m

Simulink output vector containing 8 WTIG internal signals. These signals can be individually accessed by using the Bus Selector block. They are, in order:

Signal	Signal Names	Definition
1	Vabc (cmplx) (pu)	Phasor voltages (phase to ground) Va, Vb, Vc at the WTIG terminals in pu based on the generator ratings.
2	Iabc (cmplx) (pu)	Phasor currents Ia, Ib, Ic flowing into the WTIG terminals in pu based on the generator ratings.
3	P (pu)	WTIG output power in pu based on the generator ratings. A positive value indicates power generation.
4	Q (pu)	WTIG output reactive power in pu based on the generator ratings. A positive value indicates reactive power generation.
5	wr (pu)	Generator rotor speed (pu)
6	Tm (pu)	Mechanical torque applied to the generator in pu based on the generator ratings.

Signal	Signal Names	Definition
7	Te (pu)	Electromagnetic torque in pu based on the generator ratings.
8	Pitch_angle (deg)	Blade pitch angle in degrees.

Example

See the power_wind_ig example, which illustrates the steady-state and dynamic performance of the WTIG. Three WTIG blocks are used to simulate a 9 MW wind farm connected in a 25 kV, 60 Hz, system. Voltage regulation is performing by a 3 Mvar STATCOM.

References

[1] Siegfried Heier, "Grid Integration of Wind Energy Conversion Systems," John Wiley & Sons Ltd, 1998, ISBN 0-471-97143-X

See Also

Wind Turbine, Wind Turbine Doubly-Fed Induction Generator (Phasor Type)

Zigzag Phase-Shifting Transformer

Implement zigzag phase-shifting transformer with configurable secondary winding connection

Library

Fundamental Blocks/Elements

Description

The Zigzag Phase-Shifting Transformer block implements a three-phase transformer with a primary winding connected in a zigzag configuration and a configurable secondary winding. The model uses three single-phase, three- winding transformers. The primary winding connects the windings 1 and 2 of the single-phase transformers in a zigzag configuration. The secondary winding uses the windings 3 of the single phase transformers, and they can be connected in one of the following ways:

- Y
- Y with accessible neutral
- Grounded Y
- Delta (D1), delta lagging Y by 30 degrees
- Delta (D11), delta leading Y by 30 degrees

> **Note** The D1 and D11 notations refer to the following clock convention. It assumes that the reference Y voltage phasor is at noon (12) on a clock display. D1 and D11 refer respectively to 1 PM (lagging Y by 30 degrees) and 11 AM (leading Y by 30 degrees).

If the secondary winding is connected in Y, the secondary phase voltages are leading or lagging the primary voltages by the Phi phase angle specified in the parameters of the block. If the secondary winding is connected in delta (D11), an additional phase shift of
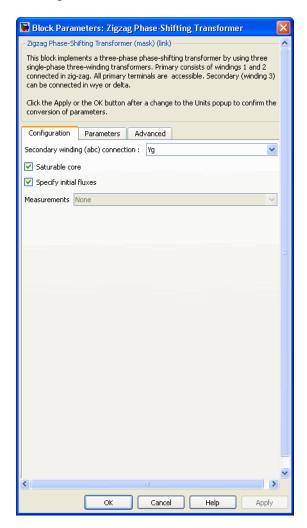
+30 degrees is added to the phase angle. If the secondary winding is connected in delta (D1), a phase shift of −30 degrees is added to the phase angle.

The block takes into account the connection type you have selected and the icon of the block is automatically updated. An output port labeled N is added to the block if you select the Y connection with accessible neutral for the secondary winding.

The saturation characteristic, when activated, is the same as the one described for the Saturable Transformer block.

Dialog Box and Parameters

Configuration Tab

Secondary winding (abc) connection

The winding connection for the secondary winding.

Saturable core

If selected, implements a saturable core.

Specify initial fluxes

If selected, the initial fluxes are defined by the **Initial fluxes** parameter on the Parameters tab. The **Specify initial fluxes** parameter is available only if the **Saturable core** parameter is selected.

When the **Specify initial fluxes** parameter is not selected upon simulation, SimPowerSystems software automatically computes the initial fluxes to start the simulation in steady state. The computed values are saved in the **Initial Fluxes** parameter and will overwrite any previous values.

Measurements

Select `Winding voltages` to measure the voltage across the winding terminals of the Three-Phase Transformer block.

Select `Winding currents` to measure the current flowing through the windings of the Three-Phase Transformer block.

Select `Fluxes and excitation currents (Im + IRm)` to measure the flux linkage, in volt-seconds (V.s), and the total excitation current including iron losses modeled by Rm.

Select `Fluxes and magnetization currents (Im)` to measure the flux linkage, in volt-seconds (V.s), and the magnetization current, in amperes (A), not including iron losses modeled by Rm.

Select `All measurements (V, I, Flux)` to measure the winding voltages, currents, magnetization currents, and the flux linkages.

Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

The labels used in the Multimeter are as follows.

Measurement	Label
Winding voltages of primary (zigzag)	`Uprim_A:, Uprim_B:, Uprim_C:`
Winding currents of primary (zigzag)	`Iprim_A:, Iprim_B:, Iprim_C:`
Winding voltages of secondary (Y, Yn, or Yg)	`Usec_A:, Usec_B:, Usec_C:`

Measurement	Label
Winding voltages of secondary (delta)	Usec_AB:, Usec_BC:, Usec_CA:
Winding currents of secondary (Y, Yn, or Yg)	Isec_A:, Isec_B:, Isec_C:
Winding currents of secondary (delta)	Isec_AB:, Isec_BC:, Isec_CA:
Fluxes (windings 1 of zigzag)	Flux_A:, Flux_B:, Flux_C:
Excitation currents (windings 1 of zigzag)	Iexc_A:, Iexc_B:, Iexc_C:
Magnetization currents (windings 1 of zigzag)	Imag_A:, Imag_B:, Imag_C:

Parameters Tab

Units

Specify the units used to enter the parameters of the Zigzag Phase-Shifting Transformer block. Select pu to use per unit. Select SI to use SI units. Changing the **Units** parameter from pu to SI, or from SI to pu, will automatically convert the parameters displayed in the mask of the block. The per unit conversion is based on the transformer rated power Pn in VA, nominal frequency fn in Hz, and nominal voltage Vn, in Vrms, of the windings.

Nominal power and frequency

The nominal power rating, in volt-amperes (VA), and nominal frequency, in hertz (Hz), of the transformer. Note that the nominal parameters have no impact on the transformer model when the **Units** parameter is set to SI.

Primary (zigzag) nominal voltage Vp

The phase-to-phase nominal voltage in volts RMS, for the primary winding of the transformer.

Secondary nom. voltage phase shift

The phase-to-phase nominal voltage, in volts RMS, and the phase shift, in degrees, for the secondary winding of the transformer.

Winding 1 zig-zag [R1 L1]

The resistance and leakage inductance of the windings 1 of the single-phase transformers used to implement the primary winding of the Zigzag Phase-Shifting Transformer.

Winding 2 zig-zag [R2 L2]

The resistance and leakage inductance of the windings 2 of the single-phase transformers used to implement the primary winding of the Zigzag Phase-Shifting Transformer.

Winding 3 secondary [R3 L3]

The resistance and leakage inductance of the windings 3 of the single-phase transformers used to implement the secondary winding of the Zigzag Phase-Shifting Transformer.

Magnetizing branch [Rm Lm]

The **Magnetizing branch** parameter is not accessible if the **Saturable core** check box is selected.

The magnetization resistance Rm and inductance Lm, in pu, when the saturation is not simulated.

Magnetization resistance Rm

This parameter is accessible only if the **Saturable core** parameter on the Configuration tab is selected.

The magnetization resistance Rm, in pu, when the saturation is simulated.

Saturation characteristic

This parameter is accessible only if the **Saturable core** parameter on the Configuration tab is selected.

The saturation characteristic for the saturable core. Specify a series of current/ flux pairs (in pu) starting with the pair (0,0).

Initial fluxes
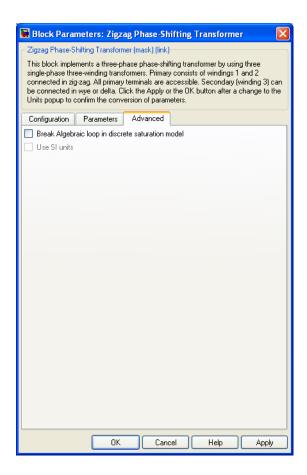
Specify initial fluxes for each phase of the transformer. This parameter is accessible only if the **Specify initial fluxes** parameter on the Configuration tab is selected.

When the **Specify initial fluxes** parameter is not selected upon simulation, SimPowerSystems software automatically computes the initial fluxes to start the simulation in steady state. The computed values are saved in the **Initial Fluxes** parameter and will overwrite any previous values.

Advanced Tab

Break Algebraic loop in discrete saturation model

> When you use the block in a discrete system, you will get an algebraic loop. This algebraic loop, which is required in most cases to get an accurate solution, tends to slow down the simulation. However, to speed up the simulation, in some circumstances, you can disable the algebraic loop by selecting **Break Algebraic loop in discrete saturation model**. You should be aware that disabling the algebraic loop introduces a one-simulation-step time delay in the model. This can cause numerical oscillations if the sample time is too large.

Example

See the help text of the power_48pulsegtoconverter example.

In this model, a 48-pulse GTO converter is built with four Three-Level Bridge blocks and four Zigzag Phase-Shifting Transformer blocks. Harmonic neutralization is obtained by use of appropriate phase shifts introduced by the Zigzag connections (+7.5/−7.5 degrees) and of secondary winding connections (Y or Delta).

See Also

Multimeter, Three-Phase Transformer (Three Windings)

2

Function Reference

This table indicates the tasks performed by the commands described in this chapter.

power_analyze	Analyze electric circuit
power_AsynchronousMachineParams	Estimate electrical parameters of double cage asynchronous machine based on standard manufacturer specifications
power_cableparam	Compute RLC parameters of radial copper cables with single screen, based on conductor and insulator characteristics
power_customize	Prepare a SimPowerSystems Specialized Technology block for customization
power_fftscope	Fourier analysis of simulation data signals
power_flicker	Perform statistical analysis of instantaneous flicker level signal
power_hysteresis	View and edit hysteresis characteristic for saturable core of Saturable Transformer blocks
power_init	Set initial state values of model built with Simulink and SimPowerSystems software
power_initstates	Compute and modify initial values of voltages and currents of model
power_lineparam	Compute RLC parameters of overhead transmission line from its conductor characteristics and tower geometry
power_loadflow	Perform positive-sequence load flow or unbalanced load flow. Initialize models containing three-phase machines and dynamic load blocks

power_ltiview	Create state-space object of model for use with the Linear System Analyzer tool
power_new	Create new SimPowerSystems model populated by required and commonly used blocks
power_PMSynchronousMachineParams	Convert manufacturer specifications to mask parameters of Permanent Magnet Synchronous Machine block
power_report	Generate report of steady state variables, initial states, and machine load flow for model
power_statespace	Compute state-space model of linear electrical circuit
power_steadystate	Compute steady-state values of voltages and currents of model
power_zmeter	Compute impedance versus frequency of Impedance Measurement blocks of model

power_analyze

Analyze electric circuit

Syntax

```
sps = power_analyze('sys','structure')
[A,B,C,D,x0,states,inputs,outputs,uss,xss,yss,frequencies,Hlin] =...
power_analyze('sys')
sps = power_analyze('sys','sort')
sps = power_analyze('sys','ss')
sps = power_analyze('sys','net')
SW = power_analyze('sys','getSwitchStatus')
sps = power_analyze('sys','setSwitchStatus',SW)
```

Description

The `power_analyze` command computes the equivalent state-space model of the specified electrical model built with SimPowerSystems software. It evaluates the *A, B, C, D* standard matrices of the state-space system described by the equations

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

where the state vector *x* represents the inductor currents and capacitor voltages, the input vector u represents the voltage and current sources, and the output vector y represents the voltage and current measurements of the model.

Nonlinear elements, such as the switch devices, motors and machines, are simulated by current sources driven by the voltages across the nonlinear element terminals. The nonlinear elements produces additional current source inputs to the *u* vector, and additional voltage measurements outputs to the *y* vector.

The Simulink blocks of the model, as well as internal Simulink models of the SimPowerSystems nonlinear elements are not represented in the state-space matrices.

State-Space Matrices

The *A, B, C, D* matrices are computed for the particular circuit topology where all the switch devices, if any, are considered to be open status (that is, with infinite impedance).

power_analyze also computes the Aswitch, Bswitch, Cswitch, and Dswitch matrices for the circuit topology that take into account the initial state (open/closed) of the Breaker and Ideal Switch blocks present in the model. The initial state of power electronic devices (Diodes, Thyristors, and so on) is considered to be open, unless a nonzero initial current value is specified in the mask of the device when Lon parameter is different from zero.

For a circuit that contains no switches, the Aswitch, Bswitch, Cswitch, and Dswitch matrices have exactly the same values as the *A, B, C, D* matrices.

States

In SimPowerSystems software, each state variable name begins with a prefix Uc_ for capacitor voltages or Il_ for inductor currents, followed by the name of the block in which the element (C or L) is found.

A string is added to this prefix for blocks containing more than one inductance or capacitor. For example, the Linear Transformer block is represented with four state variables, one for each of the three leakage inductances, defined with the prefixes Il_winding_*x*:, where *x* is the winding number of the transformer, and one state for the magnetization inductance defined with the prefix Il_Lm:.

Inputs

Each input state variable name begins with a prefix U_ for voltage sources or I_ for current sources, followed by the name of the source block. A string can be added to the prefix for blocks containing more than one source. For example, the Synchronous Machine block produces two current inputs with prefixes I_A: and I_B: (phase A and phase B machine currents).

Outputs

Each output state variable name begins with a prefix U_ for voltage outputs or I_ for current outputs, followed by the name of the block that produces the output. A string can be added to the prefix for blocks containing more than one output. For example,

the Synchronous Machine block produces two voltage outputs with prefixes `U_AB:` and `U_BC:` (two machine phase-to-phase voltages).

Sign Conventions

The following conventions are used for inputs:

- Source current flowing in the arrow direction is positive.
- Positive source voltage is indicated by a + sign on the icon.

The sign conventions used for voltages and currents of state variables and measurement outputs are described in "Measuring Voltages and Currents" in the *SimPowerSystems User's Guide*. See also "Sign Conventions for Voltages and Currents" on page 2-131 for current directions and voltage polarities.

Output Arguments: Structure

`sps = power_analyze('sys','`**`structure`**`')` creates a structure array `sps` with fields and values describing the model `sys`.

The fields of the structure array are defined in the following order.

Field	Description
circuit	Name of the model
states	char array of state variable names
inputs	char array of system input names
outputs	char array of system output names
A	nstates-by-nstates state-space A matrix
B	nstates-by-ninput state-space B matrix
C	noutput-by-nstates state-space C matrix
D	noutput-by-ninput state-space D matrix
x0	nstates-by-1 vector of initial conditions of the state variables listed in states
xss	nstates-by-nfreq steady-state values of states. A set of values is computed for every frequency specified in the frequencies vector.

Field	Description
uss	`ninput`-by-`nfreq` steady-state values of `inputs`. A set of values is computed for every frequency specified in the `frequencies` vector.
yss	`noutput`-by-`nfreq` steady-state values of `outputs`. A set of values is computed for every frequency specified in the `frequencies` vector.
frequencies	1-by-`nfreq` vector of input source frequencies ordered by increasing values
DependentStates	`char` array of dependent state variable names. The dependent states are not included in the state-space equations.
x0DependentStates	Vector of initial conditions of dependent states
xssDependentStates	`nstates`-by-`nfreq` steady-state values of dependent states
Adiscrete	Discrete state-space A matrix. Returns an empty value when the Powergui is in continuous or in phasor mode.
Bdiscrete	Discrete state-space B matrix. Returns an empty value when the Powergui is in continuous or in phasor mode.
Cdiscrete	Discrete state-space C matrix. Returns an empty value when the Powergui is in continuous or in phasor mode.
Ddiscrete	Discrete state-space D matrix. Returns an empty value when the Powergui is in continuous or in phasor mode.
x0discrete	Vector of discrete initial conditions. Returns an empty value when the Powergui is in continuous or in phasor mode.
SampleTime	Sample time value used to compute discrete state-space matrices
Aswitch	A matrix taking into account the initial status of switch devices
Bswitch	B matrix taking into account the initial status of switch devices
Cswitch	C matrix taking into account the initial status of switch devices
Dswitch	D matrix taking into account the initial status of switch devices

Field	Description
xOswitch	Vector of initial values of switch currents
Hlin	noutput-by-ninput-by-nfreq complex transfer function of impedances of the linear system corresponding to the frequencies contained in the frequencies vector. For a particular frequency, Hlin is defined by yss(:,i) = Hlin(:,:,i) * uss(:,i)
OscillatoryModes	Display the oscillatory modes of the state-space system

The table uses the following conventions:

- nstates is the number of states.
- ninput is the number of inputs.
- noutput is the number of outputs.
- nfreq is the number of input source frequencies.

[A,B,C,D,xO,states,inputs,outputs,uss,xss,yss,frequencies,Hlin] =...
power_analyze('sys') returns the state-space calculations in separate variables.

Output Arguments: Sort

sps = power_analyze('sys','**sort**') returns a structure array sps with the following fields related to the interconnection of SimPowerSystems blocks in a model. The fields are defined in the following order.

Field	Description
circuit	Name of the model
SampleTime	Sample time for discrete systems
RlcBranch	rlc matrix in the power_statespace format
RlcBranchNames	List of blocks containing the state variable
SourceBranch	Source matrix in the power_statespace format
SourceBranchNames	Names of the blocks defined as sources

Field	Description
InputNames	Names of the inputs of the system
OutputNames	Names of the outputs of the system
OutputExpressions	Output expression in the power_statespace format
OutputMatrix	Output expression in matrix format (internal)
MeasurementBlocks	Names of the voltage and current measurement blocks

Output Arguments: ss

sps = power_analyze('sys','**ss**') creates a continuous state-space model of the model sys with matrices *A, B, C, D*. You must have Control System Toolbox software installed for this option. The output is a state-space object.

Output Arguments: Net

sps = power_analyze('sys','**net**') generates a netlist stored in a file, sys.net. The file contains the node numbers automatically generated by power_analyze, as well as parameter values of all linear elements. See the formats described in the power_statespace reference page.

Output Arguments: getSwitchStatus

SW = power_analyze('sys','getSwitchStatus') returns a structure array with switch names and their initial status. You can use the SW structure to specify switch statuses for a particular circuit topology and to compute the corresponding state-space matrices using the command sps = power_analyze('sys','setSwitchStatus',SW). The SW structure contains the following fields.

Field	Description
SwitchNames	Names of the switches of the system
SwitchStatus	Vector of initial states of switches

Output Arguments: setSwitchStatus
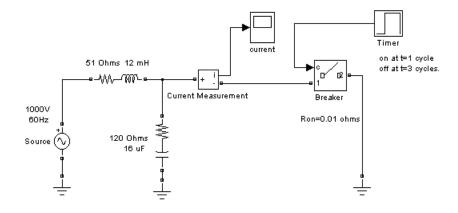
`sps = power_analyze('sys','setSwitchStatus',SW)` creates a structure array `sps` with fields and values describing the state-space matrices of model `sys` for the switch status defined in `SW`. Use the command
`SW = power_analyze('sys','getSwitchStatus')` to obtain the `SW` structure array.

Field	Description
A	`nstates`-by-`nstates` state-space *A* matrix
B	`nstates`-by-`ninput` state-space *B* matrix
C	`noutput`-by-`nstates` state-space *C* matrix
D	`noutput`-by-`ninput` state-space *D* matrix
x0	`nstates`-by-1 vector of initial conditions of the state variables listed in states

Example

Obtain the state-space matrices and steady-state voltages and currents for the power_netsim2 circuit.

The command

```
sps = power_analyze('power_netsim2','structure');
```

returns the state-space model in the sps structure variable.

```
sps.A =
   1.0e+04 *
         0       6.2500
   -0.0083    -1.4250

sps.uss =
 0
 1000

sps.xss =
   1.0e+02 *
   4.8392 - 5.1314i
   0.0310 + 0.0292i

sps.yss =
   1.0e+02 *
   8.5535 - 1.6287i
  0

sps.inputs =
 I_Breaker
 U_Source

sps.outputs =
 U_Breaker
 I_Current Measurement
```

The inductor current of the 51-ohm, 12-mH block and the capacitor voltage of the 120-ohm, 16-µF block are the two state variables in this circuit. The Breaker block is a nonlinear element that is represented by a current source (the first input) driven by the voltage across its terminals (the first output).

See Also
power_statespace | power_init | Powergui

power_AsynchronousMachineParams

Estimate electrical parameters of double cage asynchronous machine based on standard manufacturer specifications

Syntax

```
power_AsynchronousMachineParams
params = power_AsynchronousMachineParams(spec)
params = power_AsynchronousMachineParams(spec, options)
[params, spec2] = power_AsynchronousMachineParams(spec, options)
[params, spec2, errors] = power_AsynchronousMachineParams(spec,
options)
```

Description

`power_AsynchronousMachineParams` opens a graphical user interface to compute the mask parameters required by the double-cage asynchronous machine block based on standard manufacturer specifications.

`params = power_AsynchronousMachineParams(spec)` computes the machine parameters from the input structure `spec`, which contains the manufacturer data. The solution is returned in the output structure `params`.
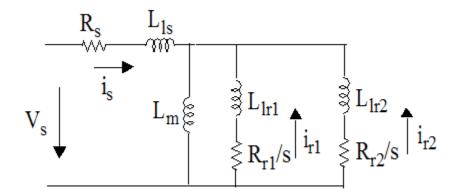
`params = power_AsynchronousMachineParams(spec, options)` lets you specify more options (display details, draw graphs, parameter units, and graph units) in the input structure `options`.

`[params, spec2] = power_AsynchronousMachineParams(spec, options)` returns the input manufacturer data along with some additional derived data (synchronous speed, number of pole pairs, nominal slip, starting torque, and so on) in the structure `spec2`.

`[params, spec2, errors] = power_AsynchronousMachineParams(spec, options)` returns the relative errors between the input manufacturer data and the equivalent data obtained with the computed parameters in the structure `errors`.

Electrical Parameters of a Double-Cage Asynchronous Machine

The following figure shows the steady-state equivalent circuit of a double-cage asynchronous machine.

R_s, L_{ls}, R_{r1}, L_{lr1}, R_{r2}, L_{lr2}, L_m are the seven electrical parameters of the machine. They form the fields of the `params` structure, as described in the "Output Arguments" on page 2-14 section.

The `power_AsynchronousMachineParams` function computes the seven machine parameters by solving the nonlinear equations in the form $f(x) = 0$ with:

$$f_1(x) = \frac{T_n - T(s_n)}{T_n}$$

$$f_2(x) = \frac{I_n - I(s_n)}{I_n}$$

$$f_3(x) = \frac{pf - pf(s_n)}{pf}$$

$$f_4(x) = \frac{I_{st} - I(1)}{I_{st}}$$

$$f_5(x) = \frac{T_{br} - T(s_{br})}{T_{br}}$$

$$f_6(x) = \frac{T_{st} - T(1)}{T_{st}}$$

where $f = (f_1, f_2, f_3, f_4, f_5, f_6)$ and $x = (R_s, L_m, R_{r1}, L_{lr1}, R_{r2}, L_{lr2})$. The L_{ls} parameter is obtained by assuming that the stator and outer cage leakage inductances are equal ($L_{ls} = L_{lr2}$). s_n and s_{br} are the slip at nominal and breakdown torque, respectively. For details on the functions used in these equations, see [1].

T_n, I_n, pf, I_{st}, I_{br}, T_{st} are the standard manufacturer specifications of the machine. They form the fields of the spec structure, as described in the "Input Arguments" on page 2-13 section.

Note: To solve these nonlinear equations, power_AsynchronousMachineParams is using the Optimization Toolbox function lsqnonlin. This function is based on a nonlinear least-squares algorithm and returns a solution x that minimizes $f(x)$. If the Optimization Toolbox is not installed, you can still open preset data for several machine ratings and load the corresponding machine parameters in your selected block.

Input Arguments

spec contains the manufacturer data in a structure with the following fields.

Field	Description
Vn	Nominal line-to-line rms voltage (V)
fn	Nominal frequency (Hz)
In	Nominal (full load) line current (A)

Field	Description
Tn	Nominal (full load) torque (N.m)
Ns, or p	You can either specify the Synchronous speed (rpm) or the pole pairs
Nn	Nominal (full load) mechanical speed (rpm)
Ist_In	Starting current to nominal current ratio
Tst_Tn	Starting torque to full load torque ratio
Tbr_Tn	Breakdown torque to full load torque ratio
pf	Nominal power factor (%)

options contains additional options to the function in a structure with the following fields.

Field	Description
DisplayDetails	If set to 1, displays detailed information (results, errors between the specified and the computed data) in the MATLAB Command window. By default, this field is set to 0.
DrawGraphs	If set to 1, plots torque versus speed and stator current versus speed characteristics. By default, this field is set to 0.
units	Specifies the units of machine parameters in 'SI' or 'p.u.'. By default, this field is set to 'SI'.
graphUnits	Specifies the graph units in 'SI' or 'p.u.'. By default, this field is set to 'SI'.

Output Arguments

params returns the machine parameters in a structure with the following fields.

Field	Description
Rs	Stator resistance (ohm or pu)
Lls	Stator leakage inductance (H or pu)
Rr1	Cage 1 (inner cage) resistance (ohm or pu)
Llr1	Cage 1 (inner cage) leakage inductance (H or pu)

Field	Description
Rr2	Cage 2 (outer cage) resistance (ohm or pu)
Llr2	Cage 2 (outer cage) leakage inductance (H or pu)
Lm	Magnetizing inductance (H or pu)

spec2 returns the input manufacturer data structure along with the following additional derived data fields.

Field	Description
cosphi	Nominal power factor (0-1)
Ns	Synchronous speed (rpm)
p	Number of pole pairs
we	Nominal electrical angular speed (rad/s)
Vin	Nominal phase voltage (V)
sn	Nominal (full-load) slip
Ist	Starting current (A)
Tst	Starting torque (N.m)
Tbr	Breakdown torque (N.m)
Pn	Nominal (full load) mechanical power (W)
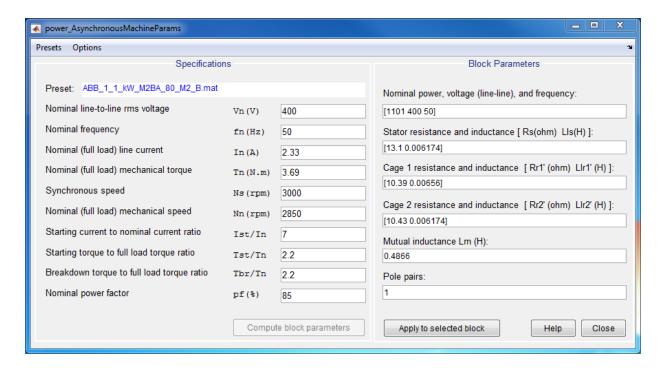
errors returns the relative errors between the input manufacturer data and the equivalent data obtained with the computed parameters in a structure with the following fields.

Field	Description
In	Relative error with respect to specified nominal current (%)
Tn	Relative error with respect to specified nominal torque (%)
pf	Relative error with respect to specified nominal power factor (%)
Ist	Relative error with respect to specified starting current (%)
Ist_Iin	Relative error with respect to specified starting current to nominal current ratio (%)
Tst	Relative error with respect to specified starting torque (%)

Field	Description
Tst_Tn	Relative error with respect to specified starting torque to full load torque ratio (%)
Tbr	Relative error with respect to specified breakdown torque (%)
Tbr_Tn	Relative error with respect to specified breakdown torque to full load torque ratio (%)
maxError	Maximum relative error (maximum of above fields) (%)

Dialog Box

power_AsynchronousMachineParams command opens a graphical user interface (GUI) that you can use to estimate parameters of the double-cage Asynchronous Machine block.

Specifications

Enter the manufacturer specifications. If you loaded a motor preset in the interface, the name of the MAT file is displayed in the upper section of the panel.

Compute Block Parameters

Compute the electrical parameters of the double-cage asynchronous machine and display the solution in the **Block Parameters** section. The button is grayed out when the block parameters have been estimated or if the Optimization Toolbox is not installed.

The button is reenabled when you enter new values in the **Specifications** section, to indicate that the displayed block parameters no longer correspond to the displayed specifications.

If the **Display detailed results in the command window** check box is selected, the errors between the specified manufacturer parameters and the obtained parameters are displayed in the command window. This allows you to check that the estimated RL machine parameters are satisfactory. For example, the errors obtained with the `Baldor_2,2_kw_208_V.mat` preset motor are shown below:

```
Asynchronous machine parameter estimation results
---------------------------------------------------------------
  Parameter        Specified      Obtained        Error (%)
  ---------        ---------      ---------        ---------
  In (A)                 8.3      8.26016             -0.48
  Tn (N.m)             12.27      12.3656              0.78
  Ist (A)             66.483      66.0075             -0.72
  Ist/In ()             8.01      7.99106             -0.24
  Tst (N.m)          43.3131      43.2625             -0.12
  Tst/Tn ()             3.53      3.49861             -0.89
  Tmax (N.m)         47.7303      47.9587              0.48
  Tbr/Tn ()             3.89      3.87839             -0.30
  pf (%)                  87      86.4635             -0.62
```

Block Parameters

This section displays the asynchronous machine block parameters corresponding to the given manufacturer specifications. These fields are empty the first time you open the interface, or when the function failed to find a solution. The block parameters are noneditable. They can be loaded in your Asynchronous Machine block by using the **Apply to selected block** button.

Apply to selected block

Open your model, select the machine you want to parametrize, then click the **Apply to selected block** button to load the displayed block parameters in the block. The

block is grayed out when the **Block Parameters** fields are empty. The button is enabled when a valid solution is displayed in the **Block Parameters** section.

The button has no effect on a selected block that is not an Asynchronous Machine block.

Presets

Select **New** to clear the **Block Parameters** and **Specifications** sections. The **Compute Block Parameters** and **Apply to selected block** buttons are then disabled.

Select **Open preset motor** to load in the interface a given set of manufacturer specifications. The corresponding block parameters are also loaded when they are available in the preset file.

Note: If the Optimization Toolbox software is not installed, you can still open the preset data and load the corresponding machine parameters in your selected block.

Select **Save preset motor** to save the specifications displayed in the interface. The block parameters are also saved when available.

Note: The **New** and **Save preset motor** options are unavailable when the Optimization Toolbox is not installed.

Options

If the **Draw graph after computation** option in the **Compute Block Parameters** submenu is selected, then when you click the **Compute Block Parameters** button the function displays the graphs of torque versus speed and stator current versus speed, corresponding to the block parameters. This option is not selected by default.

If the **Display detailed results in the command window** option in the **Compute Block Parameters** submenu is selected, then when you click the **Compute Block Parameters** button the function displays the errors between the specified manufacturer parameters and the obtained parameters are displayed in the command window. This option is selected by default.

If the **Ask me before overwriting rotor type and preset model of selected block** option in the **Apply button** submenu is selected, then when you click the

Apply to selected block button it gives you a warning if you try to download double squirrel-cage parameters in a selected block that has a squirrel-cage or wound rotor, or if you try to overwrite a selected block using a preset model. This option is selected by default.

Note: The **Options** parameter is unavailable when the Optimization Toolbox is not installed.

Examples

Consider a three-phase 400V, 110 kW asynchronous machine with the following manufacturer specification:

Data	Values
Vn	400 V
fn	50 Hz
In	194 A
Tn	352 N.m
Nn	2982 rpm
Ist/In	7.6
Tst/Tn	2
Tbr/Tn	3
pf	86%

To obtain the electrical parameters (`Rs`, `Lls`, `Lm`, `Rr1`, `Llr1`, `Rr2`, `Llr2`) in per unit (pu) for the double cage asynchronous machine model based on this specification, enter the following commands in the MATLAB Command window:

```
spec.Vn = 400;
spec.fn = 50;
spec.In = 194;
spec.Tn = 352;
spec.Ns = 3000;
spec.Nn = 2982;
spec.Ist_In = 7.6;
```

```
spec.Tst_Tn = 2;
spec.Tbr_Tn = 3;
spec.pf = 86;

options.DisplayDetails = 1;
options.units = 'p.u.';

[params,spec2,errors] = power_AsynchronousMachineParams(spec,options)
```

You should get the following results:

```
Asynchronous machine parameter estimation results
-----------------------------------------------------------------
  Parameter          Specified        Obtained         Error (%)
  ---------          ---------        ---------         ---------
  In (A)                194           193.991            -0.00
  Tn (N.m)              352           352.023             0.01
  Ist (A)              1474.4         1474.35            -0.00
  Ist/In ()             7.6            7.6001             0.00
  Tst (N.m)             704            703.8             -0.03
  Tst/Tn ()              2             1.9993            -0.03
  Tmax (N.m)           1056            1056               0.00
  Tbr/Tn ()              3             2.99981           -0.01
  pf (%)                86            85.9949            -0.01


params =

      Rs: 0.0303
     Lls: 0.0506
      Lm: 1.9066
    Llr1: 0.0868
     Rr1: 0.0056
    Llr2: 0.0506
     Rr2: 0.0762


spec2 =

        fn: 50
        In: 194
        Tn: 352
        Ns: 3000
        Nn: 2982
     Ist_In: 7.6000
```
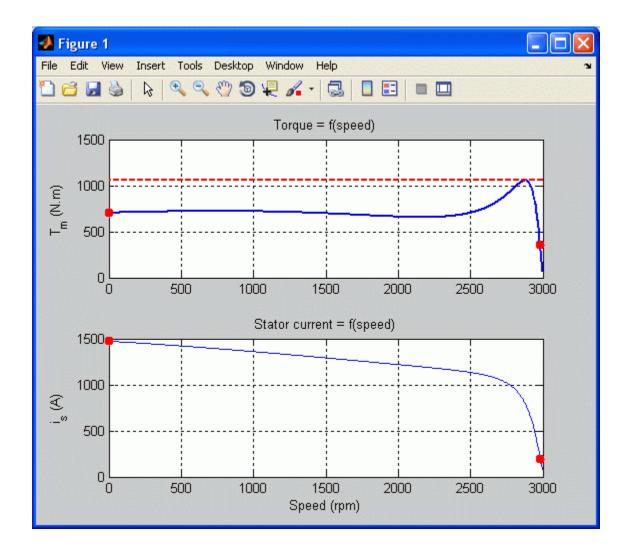
```
    Tst_Tn: 2
    Tbr_Tn: 3
        pf: 86
        Vn: 400
         p: 1
     cosphi: 0.8600
        we: 314.1593
       Vin: 230.9401
        sn: 0.0060
       Ist: 1.4744e+003
       Tst: 704
       Tbr: 1056
        Pn: 1.0992e+005


errors =

         In: -0.0048
         Tn: 0.0066
         pf: -0.0059
        Ist: -0.0035
     Ist_In: 0.0013
        Tst: -0.0284
     Tst_Tn: -0.0349
        Tbr: 2.1990e-004
     Tbr_Tn: -0.0063
   maxError: 0.0349
```

To draw graphs of torque versus speed and stator current versus speed, enter the following commands:

```
options.DrawGraphs = 1;
options.DisplayDetails = 0;
params = power_AsynchronousMachineParams(spec,options);
```

The following figure shows the resulting graph:

References

[1] Pedra, Joaquin, "On the Determination of Induction Motor Parameters From Manufacturer Data for Electromagnetic Transient Programs." *IEEE Transactions on Power Systems*, vol.23, no.4, pp. 1709-1718, November 2008.

power_cableparam

Compute RLC parameters of radial copper cables with single screen, based on conductor and insulator characteristics

Syntax

```
power_cableparam
```
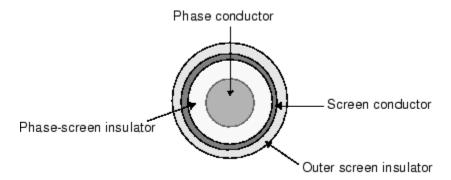
Description

For a set of N cables, `power_cableparam` computes the self- and mutual impedances, the phase-to-screen, and screen to ground capacitances of radial cables with screen.

The `power_cableparam` function assumes that a cable consists of an inner copper phase conductor with an outer screen conductor, using cross-linked polyethylene (XLPE) insulator material.

The Cable and Insulator Parameters

The following figure shows a typical high-voltage cable.

The variables used in the equations below are:

N: The number of cables

n: the number of strands contained in the phase conductor.

d: the diameter of one strand (m)

f: the nominal frequency of the cable application

r: the radius of the phase conductor

μ*r*: the relative permeability of phase conductor

rint, *rext*: the internal and external radius of phase-screen insulator

GMD: Geometric mean distance between the phase conductors.

ρ: Resistivity of the phase-screen insulator

ε*rax*: Relative permittivity of the phase-screen insulator

ε*rxe*: Relative permittivity of the outer screen insulator

dax,Dax: the internal and external diameter of phase-screen insulator

dxe,Dxe: the internal and external diameter of the outer screen insulator

Self-Impedance of Phase Conductor(s)

The self-impedance of the copper phase conductor is calculated as follow

$$Z_{aa} = R_\phi + R_e + jk_1 \log\left(\frac{D_e}{GMR_\phi}\right) \quad \Omega\,/\,\mathrm{km}$$

The DC resistance of phase conductor is given by

$$R_\phi = \rho_{Cu}\frac{1000}{S_{Cu}} = (17.8e-9)\frac{1000}{n\pi(d\,/\,2)^2} \quad \Omega\,/\,\mathrm{km}$$

The resistance of earth return is given by

$$R_e = \pi^2 \cdot 10^{-4} \cdot f \quad \Omega / \text{km}$$

The frequency factor is given by

$$k_1 = 0.0529 \cdot \frac{f}{0.3048 \cdot 60} \quad units \ (\Omega / \text{km})$$

The distance to equivalent earth return path is given by

$$D_e = 1650 \sqrt{\rho_{Cu} / (2\pi f)} \qquad m$$
$$\rho_{Cu} = 17.8e - 9 \qquad \Omega / m$$

The geometric mean radius of phase conductor is given by

$$GMR_\phi = r \cdot \exp\left(-\frac{\mu_r}{4} \right)$$

Self Impedance of Screen Conductor(s)

The self-impedance of the screen conductor is calculated as follow

$$Z_{xx} = R_N + R_e + jk_1 \log\left(\frac{D_e}{GMR_N} \right) \quad \Omega / \text{km}$$

The DC resistance of phase-screen insulator is given by

$$R_N = \rho \frac{1000}{S} \quad \Omega / \text{km}$$

The geometric mean radius of phase-screen insulator is given by

$$GMR_N = \frac{r_{ext} - r_{\text{int}}}{2}$$

Mutual Impedance Between the Phase and Screen Conductors

The mutual impedance between the phase conductor and its corresponding screen conductor is calculated as follow

$$Z_{ax} = R_e + jk_1 \log\left(\frac{D_e}{D_n}\right) \quad \Omega\,/\,\mathrm{km}$$

Dn corresponds to the distance between the phase conductor and the mean radius of the phase-screen insulator.

Mutual Impedance Between the Phase Conductors

If more than one cable is modeled (N>1), the mutual impedance between the N phase conductors is calculated as follow

$$Z_{ab} = R_e + jk_1 \log\left(\frac{D_e}{GMD}\right) \quad \Omega\,/\,\mathrm{km}$$

In general, the Geometric Mean Distance (GMD) between the phase conductors of a given set of cables can be calculated as follow

$$GMD = \sqrt[n]{\prod_1^n d_{xy}}$$

where n is the total number of distances between the conductors. However the GMD value is not calculated by the function and need to be specified directly as an input parameter.

Capacitance Between the Phase and Screen Conductors

The capacitance between the phase conductor and its corresponding screen conductor is calculated as follow

$$C_{ax} = \frac{1}{0.3048}\left(\frac{0.00736\varepsilon_{rax}}{\log\,(D_{ax}\,/\,d_{ax})}\right) \quad \mu F\,/\,\mathrm{km}$$

The cross-linked polyethylene (XLPE) insulator material is assumed in this equation.

Capacitance Between the Screen Conductor and the Ground

The same equation is used to calculate the capacitance between the screen conductor and the ground

$$C_{xe} = \frac{1}{0.3048} \left(\frac{0.00736 \varepsilon_{rxe}}{\log{(D_{xe} / d_{xe})}} \right) \ \mu F \, / \, \text{km}$$

Capacitance Between the Phase Conductors

The capacitive effect between the phase conductors is negligible and therefore not computed by the power_cableparam function.

Input Arguments

`[r,l,c,z] = power_cableparam(CableData)` computes the impedances and capacitances of a given set of cables with screen conductor. The conductor and insulator characteristics are given in the `CableParam` structure with the following fields

Field	Description
N	the number of cables
f	the frequency in hertz to be used to evaluate RLC parameters
rh0_e	the ground resistivity (in ohm.meters)
n_ba	the number of strands contained in one phase conductor
d_ba	diameter of one strand (in m)
rho_ba	DC resistance of conductor in ohms/m.
mu_r_ba	relative permeability of the conductor material.
D_a	phase conductor outside diameter (in m)
rho_x	DC resistance of the screen conductor in ohms/m.
S_x	Total section of screen conductor (in m^2)
d_x	screen conductor internal diameter (in m)

Field	Description
D_x	screen conductor external diameter (in m)
GMD_phi	Geometric Mean Distance between the cables.
d_iax	phase-screen insulator internal diameter (in m)
D_iax	phase-screen insulator external diameter (in m)
epsilon_iax	relative permittivity of the phase-screen insulator material.
d_ixe	outer screen insulator internal diameter (in m)
D_ixe	Specify the outer screen insulator external diameter (in m)
epsilon_ixe	Specify the relative permittivity of the outer screen insulator material.

Output Arguments

The output arguments are of the form of structure variables with the following fields

Variable, Field	Description
`r.aa`	Self resistance of phase conductor, in Ohm/Km
r.xx	Self resistance of screen conductor, in Ohm/Km
r.ab	Mutual resistance between the phase conductors, in Ohm/Km
r.ax	Mutual resistance between phase and screen conductors, in Ohm/Km
l.aa	Self inductance of phase conductor, in Henries/Km
l.xx	Self inductance of screen conductor, in Henries/Km
l.ab	Mutual inductance between the phase conductors, in Henries/Km
l.ax	Mutual inductance between phase and screen conductor, in Henries/Km
c.ax	Capacitance between the phase conductor and its screen conductor, in Farad/Km
c.xe	Capacitance between the screen conductor and the ground, in Farad/Km
z.aa	Self impedance of phase conductor, in Ohm/Km

Variable, Field	Description
z.xx	Self impedance of screen conductor, in Ohm/Km
z.ab	Mutual impedance between phase conductors, in Ohm/Km
z.ax	Mutual impedance between phase and corresponding screen conductors, in Ohm/Km

Building the RLC Matrices

These computed resistances, impedances, and capacitances need to be organized into 2N-by-2N matrices that can be directly used in the Cable block. See the power_cable example for an example on how to build a block that represents a 4-Cables with Screen block.
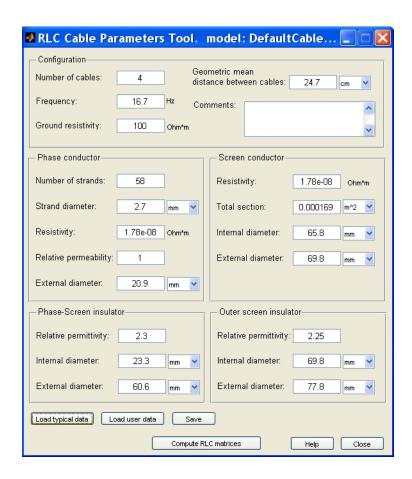
The RLC matrices are defined as follow (the example is given for a 3-cables configuration):

$$
R = \begin{bmatrix}
r_{aa} & r_{ax} & r_{ab} & r_{ab} & r_{ab} & r_{ab} \\
r_{ax} & r_{xx} & r_{ab} & r_{ab} & r_{ab} & r_{ab} \\
r_{ab} & r_{ab} & r_{aa} & r_{ax} & r_{ab} & r_{ab} \\
r_{ab} & r_{ab} & r_{ax} & r_{xx} & r_{ab} & r_{ab} \\
r_{ab} & r_{ab} & r_{ab} & r_{ab} & r_{aa} & r_{ax} \\
r_{ab} & r_{ab} & r_{ab} & r_{ab} & r_{ax} & r_{xx}
\end{bmatrix}
\quad
L = \begin{bmatrix}
l_{aa} & l_{ax} & l_{ab} & l_{ab} & l_{ab} & l_{ab} \\
l_{ax} & l_{xx} & l_{ab} & l_{ab} & l_{ab} & l_{ab} \\
l_{ab} & l_{ab} & l_{aa} & l_{ax} & l_{ab} & l_{ab} \\
l_{ab} & l_{ab} & l_{ax} & l_{xx} & l_{ab} & l_{ab} \\
l_{ab} & l_{ab} & l_{ab} & l_{ab} & l_{aa} & l_{ax} \\
l_{ab} & l_{ab} & l_{ab} & l_{ab} & l_{ax} & l_{xx}
\end{bmatrix}
$$

$$
C = \begin{bmatrix}
c_{ax} & -c_{ax} & 0 & 0 & 0 & 0 \\
-c_{ax} & c_{xe} & 0 & 0 & 0 & 0 \\
0 & 0 & c_{ax} & -c_{ax} & 0 & 0 \\
0 & 0 & -c_{ax} & c_{xe} & 0 & 0 \\
0 & 0 & 0 & 0 & c_{ax} & -c_{ax} \\
0 & 0 & 0 & 0 & -c_{ax} & c_{xe}
\end{bmatrix}
$$

Dialog Box

power_cableparam command opens a graphical user interface (GUI) that is used to specify the cable parameters and to compute the electrical R, L, C cable parameters.

Configuration Parameters

Number of cables

Specify the number of cables. A cable consists of an inner phase conductor, an outer screen conductor, and insulator. This parameter determines the dimension of the R,L, and C matrices as follows: 2N-by-2N, where N is the number of cables.

Frequency

Specify the frequency in hertz to be used to evaluate RLC parameters.

Ground resistivity

Specify the ground resistivity in ohm.meters.

Geometric mean distance between cables

Specify the Geometric Mean Distance (GMD) between the cables. Set this value to zero if the Number of cables parameter is set 1.

Comments

Use this window to type comments that you want to save with the line parameters, for example, voltage level, conductor types, and other information.

Phase Conductor Parameters

Number of strands

Specify the number of strands contained in the phase conductor.

Strand diameter

Specify the diameter of one strand (in mm, cm, or m).

Resistivity

Specify the DC resistance of conductor in ohm*m.

Relative permeability

Specify the relative permeability of the conductor material.

External diameter

Specify the phase conductor outside diameter (in mm, cm, or m).

Screen Conductor Parameters

Resistivity

Specify the DC resistance of conductor in ohm*m.

Total section

Total section of screen conductor (in mm^2, cm^2, or m^2).

The screen total section value is sometimes provided in datasheets. If you do not know this value, you can compute it as follows:

Total section = pi*r_out^2 – pi*r_in^2

where:
   r_out is the external radius of screen conductor
   r_in is the internal radius of screen conductor

Internal diameter

Specify the phase conductor outside diameter (in mm, cm, or m).

External diameter

Specify the phase conductor outside diameter (in mm, cm, or m).

Phase-Screen Insulator Parameters

Relative permittivity

Specify the relative permittivity of the phase-screen material.

Internal diameter

Specify the phase conductor outside diameter (in mm, cm, or m).

External diameter

Specify the phase conductor outside diameter (in mm, cm, or m).

Outer Screen Insulator Parameters

Relative permittivity

Specify the relative permittivity of the outer-screen material.

Internal diameter

Specify the phase conductor outside diameter (in mm, cm, or m).

External diameter

Specify the phase conductor outside diameter (in mm, cm, or m).

Buttons

Load typical data

Load the default cable parameters provided with SimPowerSystems software. Opens a browser window where you can select the `DefaultCableParameters.mat` file, which represents the four-cable configuration used in the `power_cable` example.

Load user data

Opens a browser window letting you select your own cable data. Select the desired `.mat` file.

Save

Saves your cable data by generating a `.mat` file that contains the GUI information and the cable data.

Compute RLC matrices

Computes the RLC matrices for a given cable. After completion of the parameters computation, results are displayed in a new window, entitled Display RLC Values. See "Display RLC Values GUI" on page 2-67 for more details on this window. The obtained results are of the form of 2N-by-2N RLC matrices that can be directly used in the cable block. For an example, see the 4 Cables with screen block in the `power_cable` example.

Examples

See the power_cable example for an example using the `power_cableparam` function.

See Also
`power_lineparam`

power_customize

Prepare a SimPowerSystems Specialized Technology block for customization

Syntax

```
power_customize
```

Description

`power_customize` lets you customize SimPowerSystems Specialized Technology blocks to:
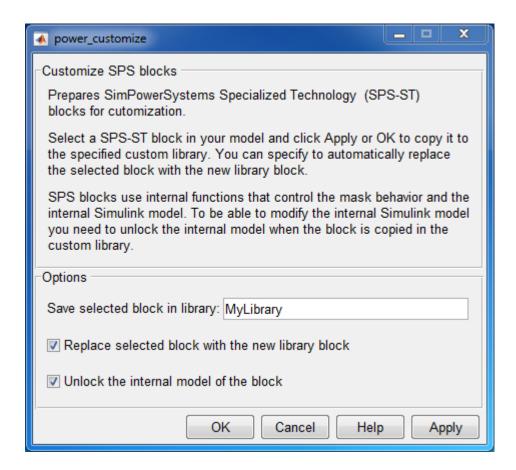
- Model behaviors that are not provided in the library blocks
- Build more advanced models
- Develop simplified models
- Provide additional user interfaces to existing blocks

SimPowerSystems blocks you customize cannot have broken or inactive library links. In other words, you cannot disable or break the library link of a block and start customizing the block directly in your model. If you want to modify a block, you make a copy of the block in a custom library, break the block link to the product library, and start doing your modifications in the custom library. The function `power_customize` automates these steps and helps you to prepare a SimPowerSystems Specialized Technology block for customization.

You can call the function from the command line with `power_customize`, or you can click **Customize SPS blocks** in the **Tools** tab of the Powergui block to open the dialog box.

In the typical workflow, you open the power_customize dialog box, select the block you want to customize in a model, specify the name of a custom library to save the block in, and apply your changes. Then you customize the block in your library. The dialog box also has the option to replace the block in your model with a library link to the new custom block.

Dialog Box

Save selected block in library

Specify the name of a custom library to save the selected block to. If the specified library does not exist, `power_customize` creates it. The block is copied to the library and the name appended with the string (`custom`) when you apply the changes. The library opens, and you can then customize the block in your library.

The default value is `MyLibrary`.

Replace selected block with the new library block

Replace the selected block in your model with a copy of the block (i.e., a library link) from the specified library. When you apply your changes, the function replaces the block in your model with the library link to the new custom block. When `power_customize` creates the library block and the link in the model, it appends the block name with the string (`custom`).

This parameter is selected by default.

Unlock the internal model of the block

SimPowerSystems Specialized Technology blocks use internal functions that control the mask behavior and the internal Simulink model. For example, the function replaces the internal Simulink model of a Synchronous Machine block with a discrete model when the **Simulation type** parameter of the Powergui is set to `Discrete` or to a phasor model when set to `Phasor`.

Select **Unlock the internal model of the block** to enable customizing of the internal Simulink model of the selected block. The internal model of the block is then no longer controlled by the Powergui **Simulation type** parameter.

If you do not plan to customize the internal Simulink model but instead plan to rework other parts of the block, you can clear this check box. The internal model of the block remains under control of the **Simulation type** parameter of Powergui.

This parameter is selected by default.

Examples

The power_V2G example model, which shows a 24-hour simulation of a vehicle-to-grid system, contains a customized Asynchronous Machine block (under the Load subsystem). The electrical internal model (a phasor model) was optimized to provide faster simulation in phasor mode. This custom block and the V2Glib custom library were prepared for customization using `power_customize`.

Introduced in R2015a

power_fftscope

Fourier analysis of simulation data signals

Syntax

```
power_fftscope
FFTDATA = power_fftscope(ScopeData)
FFTDATA = power_fftscope(FFTDATA)
power_fftscope(ScopeData)
power_fftscope(FFTDATA)
```

Description

`power_fftscope` opens the FFT Analysis Tool dialog box to perform Fourier analysis of simulation data signals. The dialog box provides access to all the simulation data signals that are defined in your workspace. This tool can also be activated from the Powergui block dialog box by selecting **FFT Analysis**.

`FFTDATA = power_fftscope(ScopeData)` returns the FFT results for the signal saved in the ScopeData structure. `fftdata` is a structure with the fields in the following table:

Field	Description
time	The time vector of the simulation data signal saved in the ScopeData variable.
signals	The signals saved in the ScopeData variable.
blockName	The name of the Scope block associated to the ScopeData variable.
input	The input signal of the selected simulation data variable.
signal	The index of the selected input signal specified by the input field.
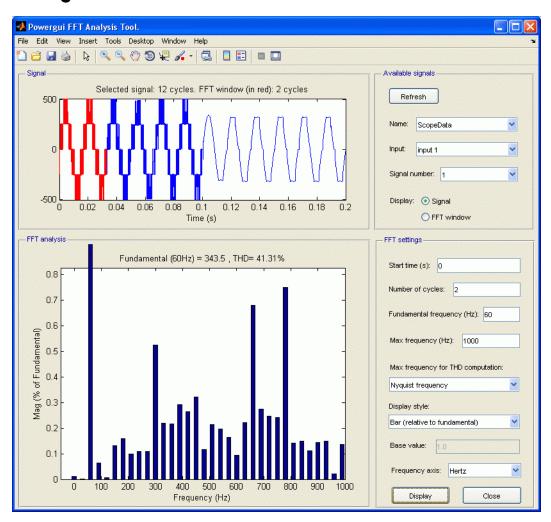
Field	Description
StartTime	The start time of the FFT window.
cycles	The number of cycles of the FFT window.
fundamental	The fundamental frequency of analyzed signal.
MaxFrequency	The maximum frequency evaluated by the FFT analysis.
THDmaxFrequency	The maximum frequency for the THD calculation. Set the value to inf to calculate the THD at the Nyquist frequency.
FFTdata	The analyzed signal (FFT window data).
THDbase	The base used to compute the THD. Set to "fund" to normalize the THD with respect to fundamental value. Set the THDbase to "DC" to normalize the THD with respect to the DC component value.
mag	The computed magnitude of FFT.
phase	The computed phase of FFT.
freq	The frequency vector.
THD	The computed Total Harmonic Distortion for the analyzed signal. The THD calculation includes all the inter-harmonics of the selected input signal.
samplingTime	Returns the sampling time of the selected input signal.
samplePerCycle	Returns the number of samples per cycle of the selected input signal.
DCcomponent	Returns the DC component value of the selected input signal.
magFundament	Return the fundamental component value of the selected input signal.

FFTDATA = power_fftscope(FFTDATA) uses the FFTDATA structure as a template variable to modify analysis settings and signal selection, and to perform FFT analysis.

power_fftscope(ScopeData) plots the FFT analysis results for the last simulation cycle of the signal saved in the ScopeData variable.

power_fftscope(FFTDATA) plots the FFT analysis results for the signal options specified in the FFTDATA structure.

Dialog Box

Refresh

If selected, refresh the list of simulation data variables in the Available signals list. Refreshing allows you to import additional simulations signals without the need to close and reopen the tool.

Name

Lists the simulation data variables that are present in your workspace. These structures are generated by the Scope or To Workspace blocks in your model. You can refresh the list of available signals by clicking the **Refresh** button. Use the drop-down list to select the variable that you want to analyze.

Input

Select the input signal of the selected simulation data variables specified in the **Structure** field. Variables having multiple inputs can be generated by a Scope block having multiple input ports.

Signal number

Indicates the index of the selected input signal specified by the **Input** parameter. For example, the **Signal number** parameter allows you to select the phase A signal of a three-phase signal connected to input 2 of a Scope block.

Display Signal

If selected, in the upper plot, displays the signal selected by the **Name**, **Input**, and **Signal number** parameters.

Display FFT window

If selected, in the upper plot, displays the portion of the selected signal where the FFT analysis is performed.

Start time(s)

Specifies the start times for the FFT analysis. The FFT analysis is performed on the portion of the signal starting at the specified time and for the specified number of cycles.

Number of cycles

Specifies the number of cycles of the selected signal to analyze for the FFT analysis.

Fundamental frequency

Specifies the fundamental frequency, in hertz (Hz), as a reference frequency for the FFT analysis.

Max Frequency

Specifies the maximum frequency, in hertz (Hz), for the FFT analysis.

Max frequency for THD computation

Select the `Nyquist frequency` to compute the THD to a maximum frequency equal to the Nyquist frequency. The Nyquist frequency is half the sampling frequency of the selected signal.

Select the `Same` as Max frequency to compute the THD to a maximum frequency equal to the frequency specified in the **Max frequency** parameter.

The THD calculation includes all the inter-harmonics of the selected input signal.

Display style

In the drop-down list, select `Bar(relative to fundamental)` to display the spectrum as a bar graph relative to the fundamental frequency. Select `Bar(relative to specified base)` to display the spectrum as a bar graph relative to the base defined by the **Base value** parameter. Select `Bar(relative to DC component)` to display the spectrum as a bar graph relative to the DC component of the signal.

Select `List(relative to fundamental)` to display the spectrum as a list in % relative to the fundamental or DC component. Select `List(relative to specified base)` to display the spectrum as a list in % relative to the base value defined by the **Base value** parameter. Select `List(relative to DC component)` to display the spectrum as a list relative to the DC component of the signal.

Base value

Enter a base value for the display of harmonics.

Frequency axis

In the drop-down list, select `Hertz` to display the spectrum frequency axis in hertz. Select `Harmonic order` to display the spectrum frequency axis in harmonic order relative to the fundamental frequency.

Display

In the lower plot, displays the FFT analysis results for the selected simulation data signal.

Close

Closes the FFT Analysis Tool window.

power_flicker

Perform statistical analysis of instantaneous flicker level signal

Syntax
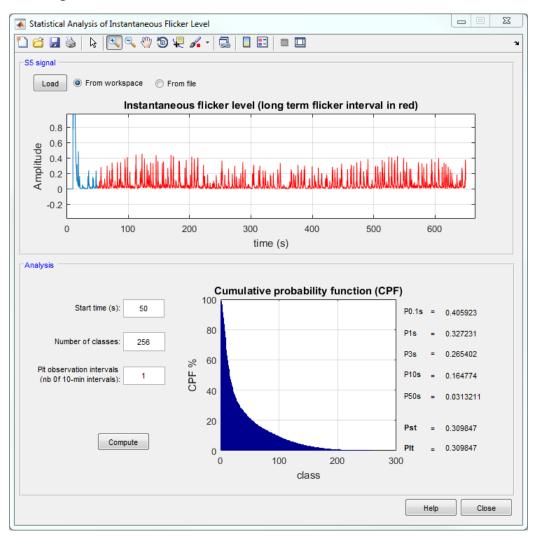
```
power_flicker
```

Description

`power_flicker` opens a tool that computes the short-term flicker severity (Pst) and long-term flicker severity (Plt) and displays the cumulative probability function (CPF) of an instantaneous flicker level signal (S5 signal).

Note: You must have a Control System Toolbox license to use the `power_flicker` function.

Dialog Box

Load

> Load the S5 signal into the module. Choose between **From file** and **From workspace**. The default value is **From workspace**.

Start time (s)

Specify the time, in seconds, of the beginning of the observed period. The default value is 0.

Number of classes

Specify the number of classes, which are used by the tool to compute the cumulative probability function of the instantaneous flicker level. The default value is 256.

Pit observation intervals (nb of 10–min intervals)

Specify the number of 10-minute intervals used by the tool to measure the long-term flicker severity (Plt). The default value is 1.

Compute

Compute the percentiles P0.1s, P1s, P3s, P10s, and P50s, which are the flicker levels exceeded for 0.1%, 1%, 3%, 10%, and 50% of the time during the observed period. Computes the short-term flicker severity (Pst) and long-term flicker severity (Plt) and displays the cumulative probability function (CPF) of the S5 signal.

See Also

Digital Flickermeter

Introduced in R2015b

power_hysteresis

View and edit hysteresis characteristic for saturable core of Saturable Transformer blocks

Syntax
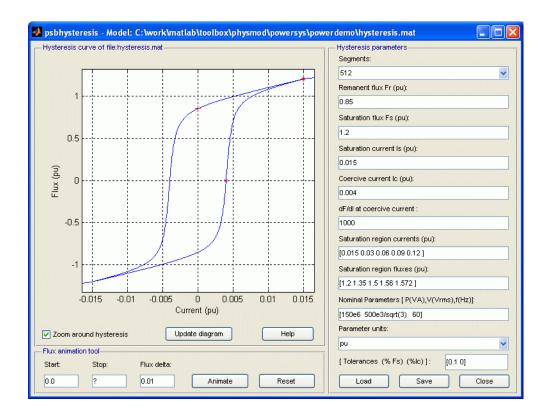
```
power_hysteresis
hparam = power_hysteresis(matfile)
```

Description

The `power_hysteresis` command opens a graphical user interface (GUI) that allows you to view and edit a hysteresis characteristic for the saturable core of the Multi-Winding Transformer, the Saturable Transformer, the Three-Phase Two Windings Transformer, and the Three-Phase Three Windings Transformer blocks. Hysteresis characteristic includes the saturation region located at the limits of the hysteresis loop. This GUI can also be activated from the Powergui block dialog box.

`hparam = power_hysteresis(matfile)` returns a structure variable `hparam` with hysteresis parameter values defining the hysteresis characteristic of the specified MAT file.

A default hysteresis characteristic is first displayed when you open the GUI, but you can build as many hysteresis characteristics as you want and save them in different MAT files names. You can use the same characteristic for all of your transformer blocks, or you can use different ones for each transformer block in the circuit. You need to select the **Simulate hysteresis** check box in the masks of the transformer blocks and specify a MAT file to be used by the model.

Hysteresis Parameters

Segments

In the pull-down menu, specify the number of linear segments used to define the right side of the hysteresis loop. The left side of the loop is the symmetric image of the right side.

Remanent flux Fr

Specify the remanent flux point of the hysteresis characteristic (flux at zero current). It is identified by a + mark in the plot.

Saturation flux Fs

Specify the saturation flux point where the hysteresis loop becomes a single-valued saturation curve. It is identified by a * mark in the plot.

Saturation current Is

Specify the saturation current point where the hysteresis loop becomes a single-valued saturation curve. The saturation region is defined by the **Saturation region currents** parameter.

Coercive current Ic

Specify the coercive current point of the hysteresis characteristic.

dF/dI at coercive current

Set the slope of the flux at the coercive current point (current at zero flux).

Saturation region currents

Specify the vector of current values that define the saturation characteristic. The number of specified points must be the same as for the **Saturation region fluxes** parameter. You only need to specify the positive part of the characteristic.

Saturation region fluxes

Specify the vector of flux values that define the saturation characteristic. The number of specified points must be the same as for the **Saturation region currents** parameter. You only need to specify the positive part of the characteristic.

Nominal Parameters

Specify the nominal parameters (nominal power in VA, nominal voltage of winding 1 in volts RMS, and nominal frequency in Hz) used in the conversion of the hysteresis parameters.

Parameter units

Convert the fluxes and currents that define the hysteresis characteristic from SI to pu or from pu to SI.

Load

Load an existing hysteresis characteristic from a MAT file.

Save

Save current hysteresis characteristic into a MAT file.

Close

Close the hysteresis GUI window.

Hysteresis Curve

Zoom around the hysteresis

If selected, zoom the plot around the hysteresis curve. The default is selected.

Update diagram

When the parameters are entered, you can click **Display** to visualize the hysteresis characteristic.

Flux Animation Tool

The Flux Animation tool can be used to visualize how the simulation of the hysteresis is performed by SimPowerSystems software. This is an optional tool that is not necessary for the model parameterization. The initial trajectory will be calculated according to the defined hysteresis characteristic.

The model assumes that the last reversal point before starting flux is located on the major loop. The operating point will travel till the defined stop flux.

Start

Specify the starting flux.

Stop

Specify the flux at which the flux animation will stop.

Flux delta

Specify flux increment (in pu, or in SI) that is used to go from start flux to stop flux.

Animate

Start the Flux Animation tool.

Reset

Reset the Flux Animation tool.

Tolerances Tool

The Tolerances tool is an advanced tool mainly used to minimize the generation of superfluous very small internal loops or new trajectories because they have little effect and they consume computer memory space (the model can memorize at any time up to 50 embedded minor loops).

The `TOL_F` parameter is the tolerance value used to detect whether, after a flux reversal, the operating point remains on the same minor loop or a new embedded loop is created. The smaller the value, the lesser is the effect on the normal trajectory behavior. The bigger the value, the lesser is the generated number of embedded minor loops.

Finally, when the distance between the I coordinate of the actual point of reversal and the penultimate one is less than TOL_I, then evolution within these two points will follow a line segment instead of a loop.

See Also
Powergui

power_init

Set initial state values of model built with Simulink and SimPowerSystems software

Syntax

```
[x0,states] = power_init(sys)
[x0,states] = power_init(sys,'look')
[x0,states] = power_init(sys,'states')
[x0,states] = power_init(sys,'ForceToZero')
[x0,states] = power_init(sys,'ResetToDefault')
[x0,states] = power_init(sys,'x0')
power_init(sys,'look')
power_init(sys,'reset')
power_init(sys,'steady')
```

Description

Power_init deals with two types of state variables: the Simulink State variables and the Electrical State variables. The Simulink States consists of the entire set of state variables of a model (including the Electrical states) seen by Simulink software. The Electrical States are the particular Simulink states that defines the capacitor initial voltages and inductor initial currents of the SimPowerSystems blocks of your model.

`[x0,states] = power_init(sys)` returns the initial states values and state names of your model.

`[x0,states] = power_init(sys,'look')` returns the electrical initial states values and state names of sys.

`[x0,states] = power_init(sys,'states')` displays in a two-column format the initial state values and names of your model.

`[x0,states] = power_init(sys,'ForceToZero')` sets to zero the initial states your model. It uses the **Data import/export initial state** option from the **Simulation > Model Configuration Parameters** menu in the **Simulink Editor** to specify the initial state values. Use the **ResetToDefault** option of power_init to reset the Simulink configuration parameters to its previous settings.

[x0,states] = power_init(sys,'**ResetToDefault**') resets the initial state of
Simulink configuration parameters to the settings prior to the use of the **ForceToZero**
option of power_init. This option has no effect on system if the **ForceToZero** option is
not used before.

[x0,states] = power_init(sys,'**x0**') sets the initial state values equal to the
vector specified by x0. The ordering of the states variables is given by the **state** option
of power_init. This option uses the **Data import/export initial state** option from the
Simulation > Model Configuration Parameters menu in the **Simulink Editor** to
specify the initial state values.

power_init(sys,'**look**') displays in a two-column format the electrical initial states
names and values of your model.

power_init(sys,'**reset**') resets the electrical initial states of sys to zero.

power_init(sys,'**steady**') sets the electrical initial states of sys to simulate the
electrical circuit in the steady state.

See Also
power_analyze | Powergui

power_initstates

Compute and modify initial values of voltages and currents of model

Syntax

```
power_initstates('sys')
sps = power_initstates('sys')
```

Description
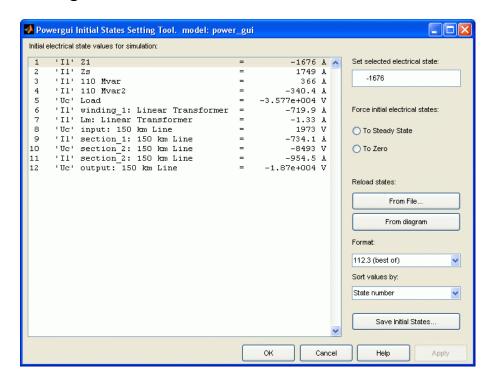
power_initstates('sys') opens the Initial States Setting Tool dialog box that lets you display the initial values of the electrical state variables (inductor currents and capacitor voltages) of a model, as well as modify the initial electrical states in order to start the simulation from any initial conditions. This tool can also be activated from the Powergui block dialog box by selecting **Initial States Setting**.

sps = power_initstates('sys') returns a structure with the fields:

Field	Description
circuit	The name of the model
States	The names of the electrical state variables
x0	The current initial states vector used for the simulation of the model
x0_steady	The computed initial states that ensure a steady-state simulation
x0_blocks	Default initial states values, defined in blocks
DependentStates	The names of the dependent states, if any
x0DependentStates	Initial state values of dependent states
UseInitialStatesFrom	Defines the set of initial states that is used for the simulation of the model; the value is a string: 'block', 'steady', or 'zero'

Field	Description
	If set to `'block'`, the default initial states are used. If set to `'steady'`, the computed initial states that ensure a steady-state simulation are used. If set to `'zero'`, the initial states are forced to 0.

Dialog Box

Initial state values for simulation

Display names of model state variables and their initial values.

Set selected state

Enter a value here to set the initial value of the variable selected in the **Initial state values for simulation** list.

Force initial electrical states

If **To Steady State** is selected, force all initial electrical state values to steady-state values. When this option is selected, the **Set selected state** option is disabled, because all states are forced to steady-state values.

If **To Zero** is selected, force all initial electrical state values to zero. When this option is selected, the **Set selected state** option is disabled, because all states are forced to zero. If you want to set all states to zero, and then set one or several states to something else, do this by using the **Set selected state** option: first, select all states, enter 0, and click **Apply**; then select the states that you want to set to something else and modify their values individually.

If neither **To Steady State** nor **To Zero** is selected, initial state values defined in blocks are used for the simulation.

Reload states

If **From File** is selected, allows you to choose a previously saved file storing the model's states. If **From Diagram** is selected, sets all initial state values to their current values (either steady state values or last modified values).

Format

In the pull-down menu, choose the format in which you want your measurements displayed. The `floating point` option is displayed in mantissa-exponent form with five significant figures. The `best of` option displays with four significant figures and uses mantissa-exponent form only for numbers larger than 9999. The final option is displayed in plain numbers with two figures to the right of the decimal point. The default is `floating point`.

Sort values by

Select order of displayed initial state values. Selecting `Default order` displays the value by block order in the diagram. Selecting `State number` displays the values according to the states' ordering in the state-space model. Selecting `Type` displays the values grouped by capacitors and inductors. The default is `Default order`.

Save Initial States

Save the model's initial state settings in a file.

Sign Conventions for Voltages and Currents

Unlike Simulink signal lines and input and output ports, the Physical Modeling connection lines and terminal ports □ lack intrinsic directionality. The voltage and

current polarities are determined, not by line direction, but instead by block orientation. To find out a block orientation, first click on the block to select it. Then enter the following command:

```
get_param(gcb,'Orientation')
```

The following table indicates the polarities of the currents and voltages for single-phase and three-phase RLC elements (branches or loads), surge arresters, and single-phase and three-phase breakers. The table also indicates the polarities of their state variables (inductor currents and capacitor voltages).

Block Orientation	Positive Current Direction	Measured Voltage
right	left —> right	Vleft – Vright
left	right —> left	Vright – Vleft
down	top —> bottom	Vtop – Vbottom
up	bottom —> top	Vbottom – Vtop

The natural orientation of the blocks (that is, their orientation in the Element library) is *right* for horizontal blocks and *down* for vertical blocks.

For single-phase transformers (linear or saturable), with the winding connectors appearing on the left and right sides, the winding voltages are the voltages of the top connector with respect to the bottom connector whatever the block orientation (*right* or *left*). The winding currents are the currents entering the top connector. For three-phase transformers, the voltage polarities and positive current directions are indicated by the signal labels used in the Multimeter block.

power_lineparam

Compute RLC parameters of overhead transmission line from its conductor characteristics and tower geometry

Syntax

```
power_lineparam
LDATA = power_lineparam('new')
LDATA = power_lineparam(LDATA)
LDATA = power_lineparam('MYLINEDATA')
power_lineparam(LDATA,'BLK')
power_lineparam('MYLINEDATA','BLK')
```

Description

power_lineparam opens a graphical user interface (GUI) to enter the line parameters and return the electrical R, L, and C line parameters. You can also activate this GUI from the Powergui block dialog box by selecting **Compute RLC Line Parameters**.

LDATA = power_lineparam('new') returns a structure variable with default line geometry parameters. You can use LDATA as a template variable to configure a new line geometry and to compute RLC line parameters.
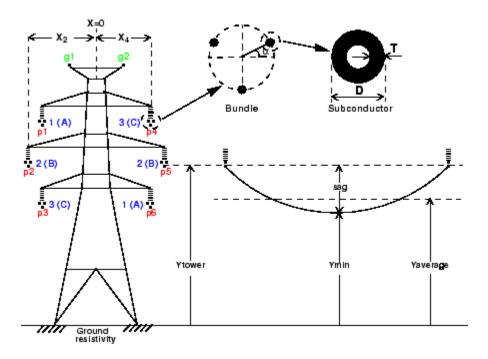
LDATA = power_lineparam(LDATA) computes the RLC line parameters for the geometric line parameters in the LDATA structure. The returned structure contains both geometric data and computed RLC line parameters.

LDATA = power_lineparam('MYLINEDATA') computes the RLC line parameters for the geometric line parameters in the specified file. 'MYLINEDATA' is the name of a MAT file. The MAT file must contain a structure variable of the same format as LDATA variable, or you can generate it using the function GUI.

power_lineparam(LDATA,'BLK') power_lineparam('MYLINEDATA','BLK') uploads the RLC line parameters in the specified PI Section Line, PI Section Cable, Distributed Parameters Line, or Three-Phase PI Section Line block. 'BLK' is a block path name.
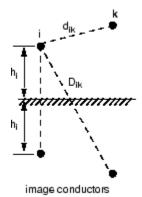
The `power_lineparam` function computes the resistance, inductance, and capacitance matrices of an arbitrary arrangement of conductors of an overhead transmission line. For a three-phase line, the symmetrical component RLC values are also computed.

The following figure shows a typical conductor arrangement for a three-phase double-circuit line. This line configuration illustrates the various line parameters you enter in the GUI.

Configuration of a Three-Phase Double-Circuit Line

For a set of N conductors, `power_lineparam` computes three N-by-N matrices: the series resistance and inductance matrices [R] and [L] and the shunt capacitance matrix [C]. These matrices are required by the Distributed Parameter Line block for modeling N-phase asymmetrical lines and by the single-phase PI Section Line block. `power_lineparam` also computes the symmetrical component RLC parameters required by the Three-Phase PI Section Line block. For two coupled conductors i and k, the self and mutual terms of the R, L, and C matrices are computed using the concept of image conductors [1]

image conductors

Self and mutual resistance terms:

$$R_{ii} = R_{\text{int}} + \Delta R_{ii} \quad \Omega \, / \, \text{km}$$

$$R_{ik} = \Delta R_{ik} \quad \Omega \, / \, \text{km}$$

Self and mutual inductance terms:

$$L_{ii} = L_{\text{int}} + \frac{\mu_0}{2\pi} \cdot \log \frac{2h_i}{r_i} + \Delta L_{ii} \quad H \, / \, \text{km}$$

$$L_{ik} = \frac{\mu_0}{2\pi} \cdot \log \frac{D_{ik}}{d_{ik}} + \Delta L_{ik} \quad H \, / \, \text{km}$$

Self and mutual potential coefficients terms:

$$P_{ii} = \frac{1}{2\pi\varepsilon_0} \cdot \log \frac{2h_i}{r_i} \quad \text{km} \, / \, \text{F}$$

$$P_{ik} = \frac{1}{2\pi\varepsilon_0} \cdot \log\frac{D_{ik}}{d_{ik}} \quad \text{km / F}$$

$$[C] = [P]^{-1} \quad F \text{ / km}$$

μ_0: permeability of free space = $4\pi.10^{-4}$ H/km

ε_0: permittivity of free space = $8.8542.10^{-9}$ F/km

r_i: radius of conductor i in meters

d_{ik}: distance between conductors i and k in meters

D_{ik}: distance between conductor i and image of k in meters

h_i= average height of conductor i above ground, in meters

Rint, Lint: internal resistance and inductance of conductor

ΔR_{ii}, ΔR_{ik}: Carson R correction terms due to ground resistivity

ΔL_{ii}, ΔL_{ik}: Carson L correction terms due to ground resistivity

The conductor self-inductance is computed from the magnetic flux circulating inside and outside the conductor, and produced by the current flowing in the conductor itself. The part of flux circulating inside the conducting material contributes to the internal inductance Lint, which is dependent on the conductor geometry. Assuming a hollow or solid conductor, the internal inductance is computed from the T/D ratio where D is the conductor diameter and T is the thickness of the conducting material (see the figure Configuration of a Three-Phase Double-Circuit Line). The conductor self-inductance is computed by means of modified Bessel functions from the conductor diameter, T/D ratio, resistivity, and relative permeability of conducting material and specified frequency [1].

The conductor self-inductance can be also computed from parameters that are usually found in tables provided by conductor manufacturers: the Geometric Mean Radius (GMR) or the "Reactance at one-foot spacing."

The GMR is the radius of the equivalent hollow conductor with zero thickness, producing no internal flux, giving the same self-inductance. The conductor self-inductance is then derived from the GMR using the following equation.

$$L_{ii} = \frac{\mu_0}{2\pi} \cdot \log\frac{2h_i}{GMR} + \Delta L_{ii} \quad H \text{ / km}$$

For a solid conductor (T/D=0.5), the GMR is

$$GMR = r \cdot e^{-\mu_r/4}$$

r = radius of conductor
μ_r = relative permeability of conducting material

The GMR obtained from this equation assumes a uniform current density in the conductor. This assumption is strictly valid in DC. In AC, the GMR is slightly higher. For example, for a 3 cm diameter solid aluminum conductor (Rdc = 0.040 Ω/km), the GMR increases from 1.1682 cm in DC to 1.1784 cm at 60 Hz. Manufacturers usually give the GMR at the system nominal frequency (50 Hz or 60 Hz).

The reactance X_a at 1-foot spacing (or 1-meter spacing if metric units are used) is the positive-sequence reactance of a three-phase line having one foot (or one meter) spacing between the three phases and infinite conductor heights. The reactance at one-foot spacing (or 1-meter spacing) at frequency f is related to the GMR by the following equation:
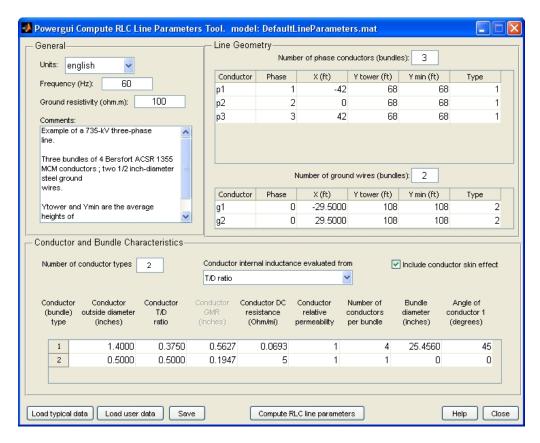
$$X_a = \omega \cdot \frac{\mu_0}{2\pi} \cdot \log \frac{1}{GMR} \quad \Omega/\text{km}$$

GMR = Geometric Mean Radius in feet or meters
ω = 2π.f in rad/s
f = frequency in hertz

The conductor resistance matrix at a particular frequency depends on the DC resistance of the conductor corrected for skin effect and ground resistivity. Both the resistance matrix and the inductance matrix are dependent on the ground resistivity and frequency. Correction terms for the R and L terms as developed by J.R. Carson in 1926 [2] are implemented in `power_lineparam`.

Line Parameters GUI

When you type the `power_lineparam` command, the GUI is displayed.

The default parameters are for a single-circuit three-phase line with two ground wires. You enter your own line parameters in three different sections:

- The upper-left section where you enter general parameters (units, frequency, ground resistivity, and comments)
- The table of conductor types defining the conductor characteristics for each type (bottom section)
- The table of conductors specifying the line geometry and the conductor types (upper-right section)

Units

In the drop-down list, select metric if you want to specify conductor diameter, GMR, and bundle diameter in centimeters and conductor positions in meters. Select

english if you want to specify conductor diameter, GMR, and bundle diameter in inches and conductor positions in feet.

Frequency

Specify the frequency in hertz to evaluate RLC parameters.

Ground resistivity

Specify the ground resistivity in ohm.meters. A zero value (perfectly conducting ground) is allowed.

Comments

Use this text box to type comments that you want to save with the line parameters, for example, voltage level, conductor types and characteristics, etc.

Number of conductor types

Specify the number of conductor types (single conductor or bundle of subconductors). This parameter determines the number of rows of the table of conductors types. The phase conductors and ground wires can be either single conductors or bundles of subconductors. For voltage levels of 230 kV and higher, phase conductors are usually bundled to reduce losses and electromagnetic interferences due to corona effect. Ground wires are usually not bundled.

For a simple AC three-phase line, single- or double-circuit, there are usually two types of conductors: one type for the phase conductors and one type for the ground wires. You need more than two types for several lines in the same corridor, DC bipolar lines or distribution feeders, where neutral and sheaths of TV and telephone cables are represented.

Conductor internal inductance evaluated from

Select one of the following three parameters to specify how the conductor internal inductance is computed: T/D ratio, Geometric Mean Radius (GMR), or Reactance Xa at 1-foot spacing (or 1-meter spacing if the **Units** parameter is set to metric).

If you select T/D ratio, the internal inductance is computed from the T/D value specified in the table of conductors, assuming a hollow or solid conductor. D is the conductor diameter and T is the thickness of the conducting material (see the figure Configuration of a Three-Phase Double-Circuit Line). The conductor self-inductance and resistance are computed from the conductor diameter, T/D ratio, DC resistance, and relative permeability of conducting material and specified frequency.

If you select Geometric Mean Radius (GMR), the conductor GMR evaluates the internal inductance. When the conductor inductance is evaluated from the GMR, the

specified frequency does not affect the conductor inductance. You must provide the manufacturer's GMR for the desired frequency (usually 50 Hz or 60 Hz). When you are using the `T/D ratio` option, the corresponding conductor GMR at the specified frequency is displayed.

Selecting `Reactance Xa at 1-foot spacing` (or `1-meter spacing`) uses the positive-sequence reactance at the specified frequency of a three-phase line having 1-foot (or 1-meter) spacing between the three phases to compute the conductor internal inductance.

Include conductor skin effect

Select this check box to include the impact of frequency on conductor AC resistance and inductance (skin effect). If this parameter is not selected, the resistance is kept constant at the value specified by the **Conductor DC resistance** parameter and the inductance is kept constant at the value computed in DC, using the **Conductor outside diameter** and the **conductor T/D ratio**. When skin effect is included, the conductor AC resistance and inductance are evaluated considering a hollow conductor with T/D ratio (or solid conductor if T/D = 0.5). The T/D ratio evaluates the AC resistance even if the conductor inductance is evaluated from the GMR or from the reactance at one-foot spacing or one-meter spacing. The ground skin effect is always considered and it depends on the ground resistivity.

Conductor (bundle) type

Lists the conductor or bundle types by increasing number, starting from 1 and ending at the value specified in the parameter **Number of conductor types**. You cannot change this value.

Conductor outside diameter

Specify the conductor outside diameter in centimeters or inches.

Conductor T/D ratio

Specify the T/D ratio of the hollow conductor. T is the thickness of conducting material and D is the outside diameter. This parameter can vary between 0 and 0.5. A T/D value of 0.5 indicates a solid conductor. For Aluminum Cable Steel Reinforced (ACSR) conductors, you can ignore the steel core and consider a hollow aluminum conductor (typical T/D ratios comprised between 0.3 and 0.4). The T/D ratio is used to compute the conductor AC resistance when the **Include conductor skin effect** parameter is selected. It is also used to compute the conductor self-inductance when the parameter **Conductor internal inductance evaluated from** is set to `T/D ratio`.

Conductor GMR

This parameter is accessible only when the parameter **Conductor internal inductance evaluated from** is set to `Geometric Mean Radius (GMR)`. Specify the GMR in centimeters or inches. The GMR at 60 Hz or 50 Hz is usually provided by conductor manufacturers. When the parameter **Conductor internal inductance evaluated from** is set to `T/D ratio`, the value of the corresponding GMR giving the same conductor inductance is displayed. When the parameter **Conductor internal inductance evaluated from** is set to `Reactance Xa at 1-foot spacing` or (`1-meter spacing`), the title of the column changes to the parameter name.

Reactance Xa at 1-meter spacing (1-foot spacing)

This parameter is accessible only when **Conductor internal inductance specified from** is set to `Reactance Xa at 1-meter spacing` or (`1-foot spacing`). Specify the Xa value in ohms/km or ohms/mile at the specified frequency. The X_a value at 60 Hz or 50 Hz is usually provided by conductor manufacturers.

Conductor DC resistance

Specify the DC resistance of conductor in ohms/km or ohms/mile.

Conductor relative permeability

Specify the relative permeability μ_r of the conducting material. $\mu_r = 1.0$ for nonmagnetic conductors (aluminum, copper). This parameter is not accessible when the **Include conductor skin effect** parameter is not selected.

Number of conductors per bundle

Specify the number of subconductors in the bundle or 1 for single conductors.

Bundle diameter

Specify the bundle diameter in centimeters or inches. This parameter is not accessible when the **Number of conductors per bundle** is set to 1. When you specify bundled conductors, the subconductors are assumed to be evenly spaced on a circle. If this is not the case, you must enter individual subconductor positions in the **Line Geometry** table and lump these subconductors by giving them the same **Phase number** parameter.

Angle of conductor 1

Specify an angle in degrees that determines the position of the first conductor in the bundle with respect to a horizontal line parallel to ground. This angle determines the bundle orientation. This parameter is not accessible when the **Number of conductors per bundle** is set to 1.

Number of phase conductors (bundles)

Specify the number of phase conductors (single conductors or bundles of subconductors).

Number of ground wires (bundles)

Specify the number of ground wires (single conductors or bundles of subconductors). Ground wires are not usually bundled.

Conductor

Lists the conductor or bundle identifiers. Phase conductors are identified p1, p2,..., pn. Ground wires are identified g1,g2,..., gn.

Phase

Specify the phase number to which the conductor belongs. Several conductors may have the same phase number. All conductors having the same phase number are lumped together and are considered as a single equivalent conductor in the R, L, and C matrices. For example, if you want to compute the line parameters of a three-phase line equivalent to a double-circuit line such as the one represented in the figure Configuration of a Three-Phase Double-Circuit Line, you specify phase numbers 1, 2, 3 for conductors p1, p2, p3 (circuit 1) and phase numbers 3, 2, 1 for conductors p4, p5, p6 (circuit 2), respectively. If you prefer to simulate this line as two individual circuits and have access to the six phase conductors, you specify phase numbers 1, 2, 3, 6, 5, 4 respectively for conductors p1, p2, p3, p4, p5 and p6.

In three-phase systems, the three phases are usually labeled A, B, and C. The correspondence with the phase number is:
1, 2, 3, 4, 5, 6, 7, 8, 9,.... = A, B, C, A, B, C A, B, C,...

You can also use the phase number to lump conductors of an asymmetrical bundle.

For ground wires, the phase number is forced to zero. All ground wires are lumped with the ground and they do not contribute to the R, L, and C matrix dimensions. If you need to access the ground wire connections in your model, you must specify these ground wires as normal phase conductors and manually connect them to the ground.

X

Specify the horizontal position of the conductor in meters or feet. The location of the zero reference position is arbitrary. For a symmetrical line, you normally choose X = 0 at the center of the line.

Y tower

Specify the vertical position of the conductor (at the tower) with respect to ground, in meters or feet.

Y min

Specify the vertical position of the conductor with respect to ground at mid-span, in meters or feet.

The average height of the conductor (see the figure Configuration of a Three-Phase Double-Circuit Line) is produced by this equation:

$$Y_{average} = Y_{\min} + \frac{sag}{3} = \frac{2Y_{\min} + Y_{tower}}{3}$$

Y_{tower} = height of conductor at tower
$Y_{\min}$ = height of conductor at mid span
sag = $Y_{tower} - Y_{\min}$

Instead of specifying two different values for Y_{tower} and $Y_{\min}$, you may specify the same $Y_{average}$ value.

Type

Specify one of the conductor or bundle type numbers listed in the first column of the table of conductor characteristics.

Load typical data

Opens a browser window where you can select examples of line configurations provided with SimPowerSystems software. Select the desired `.mat` file.

Selecting **Load typical data** allows you to load one of the following line configurations:

Line_25kV_4wires.mat	25-k V, three-phase distribution feeder with accessible neutral conductor.
Line_315kV_2circ.mat	315-k V, three-phase, double-circuit line using bundles of two conductors. Phase numbering is set to obtain the RLC parameters of the two individual circuits (six-phase line).
Line_450kV.mat	Bipolar +/−450-k V DC line using bundles of four conductors.
Line_500kV_2circ.mat	500-k V, three-phase, double-circuit line using bundles of three conductors. Phase numbering is set to obtain the RLC parameters of the three-phase line circuit equivalent to the two circuits connected in parallel.
Line_735kV.mat	735-k, V three-phase, line using bundles of four conductors.

Load user data

Opens a browser window letting you select your own line data. Select the desired `.mat` file.

Save
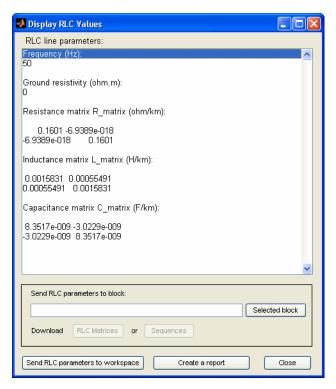
Saves your line data by generating a `.mat` file that contains the GUI information and the line data.

Compute RLC line parameters

Computes the RLC parameters. After completion of the parameters computation, results are displayed in a new window, entitled Display RLC Values.

Display RLC Values GUI

When you click the **Compute RLC line parameters**, the **Display RLC Values** window opens. In this window, you can view and download parameters into your workspace and into your transmission line models.

The frequency and ground resistivity used for evaluation of the R, L, and C matrices are displayed first. Then the computed RLC parameters are displayed.

Note The R, L, and C parameters are always displayed respectively in ohms/km, henries/km, and farads/km, even if the English units specify the input parameters.

If the number of phase conductors is 3 or 6, the symmetrical component parameters are also displayed:

- For a three-phase line (one circuit), R10, L10, and C10 vectors of two values are displayed for positive-sequence and zero-sequence RLC values.
- For a six-phase line (two coupled three-phase circuits), R10, L10, and C10 vectors of five values containing the following RLC sequence parameters are displayed: positive-sequence and zero-sequence of circuit 1, mutual zero-sequence between circuit 1 and circuit 2, positive-sequence and zero-sequence of circuit 2.

Send RLC parameters to workspace

Sends the R, L, and C matrices, as well as the symmetrical component parameters to the MATLAB workspace. The following variables are created in your workspace: R_matrix, L_matrix, C_matrix, and R10, L10, C10 for symmetrical components.

Send RLC parameters to block

Sends the RLC parameters into one of the following three blocks that you previously selected in your model: the Distributed Parameter Line block (either matrices or sequence RLC parameters), the single-phase PI Section Line block (one dimension matrix required), or the Three-Phase PI Section Line block (sequence components only).

Selected block

Confirms the block selection. The name of the selected block appears in the left window.

RLC Matrices

Downloads RLC matrices into the selected block.

Sequences

Downloads RLC sequence parameters into the selected block.

Create a report

Creates a file, XXX.rep, containing the line input parameters and the computed RLC parameters. The MATLAB editor opens to display the contents of the XXX.rep file.

Close

Closes the Display RLC Values window.

Examples

These examples illustrate the inputs and outputs of the `power_lineparam` GUI.

The first example uses a simple line consisting of two conductors spaced by 1 meter at an average height of 8 meters above a perfect ground (ground resistivity $\rho_g = 0$). The two conductors are solid aluminum conductors (resistivity $\rho_c = 28.3 \, 10^{-9}$ Ω.m at 20° C) having a 15-mm diameter.

The DC resistance per km of each conductor is:

$$r = \frac{\rho_c \cdot l}{A} = \frac{28.3 \times 10^{-9} \times 1000}{\pi \cdot \left(\dfrac{15 \times 10^{-3}}{2}\right)^2} = 0.1601 \quad \Omega / \text{km}$$

As ground is supposed to be perfect, the off-diagonal terms of the R matrix are zero and the diagonal terms represent the conductor resistances:

$$R = \begin{bmatrix} 0.1601 & 0 \\ 0 & 0.1601 \end{bmatrix} \Omega / \text{km}$$

For the solid conductors, the GMR is:

$$GMR = r \cdot e^{-\mu_r / 4} = \frac{1.5}{2} e^{-1/4} = 0.5841 \quad \text{cm}$$
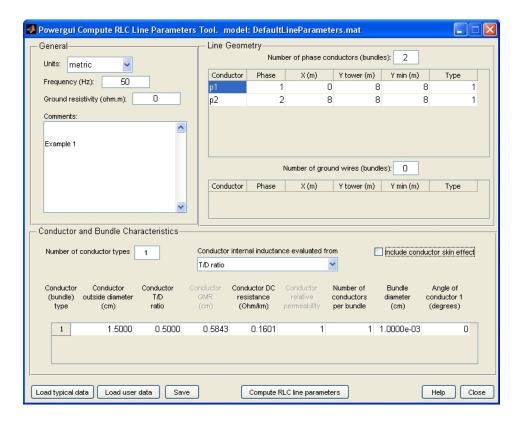
The self- and mutual- inductances are computed as follows. The ΔL correction terms are ignored because ground resistivity is zero.

$$L_{11} = L_{22} = \frac{\mu_0}{2\pi} \cdot \log \frac{2h_i}{GMR} = 2\times10^{-4} \log \frac{2\times8}{0.5841\times10^{-2}} = 1.583\times10^{-3} H / km$$

$$L_{12} = L_{21} = \frac{\mu_0}{2\pi} \cdot \log \frac{D_{12}}{d_{12}} = 2\times10^{-4} \log \frac{\sqrt{16^2 +1}}{1} = 0.5549\times10^{-3} H / km$$

$$L = \begin{bmatrix} L_{11} & L_{12} \\ L_{21} & L_{22} \end{bmatrix} = \begin{bmatrix} 1.583\times10^{-3} & 0.5549\times10^{-3} \\ 0.5549\times10^{-3} & 1.583\times10^{-3} \end{bmatrix} H / km$$

The self- and mutual- capacitances are computed as follows:
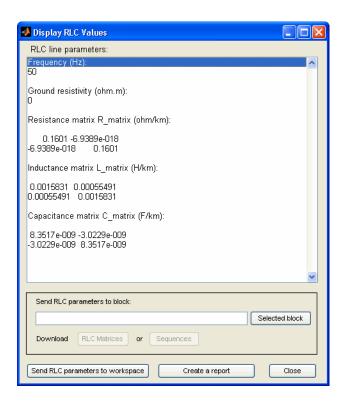
$$P_{11} = P_{22} = \frac{1}{2\pi\varepsilon_o} \log \frac{2h}{r_i} = 1.7975\times10^7 \log \frac{2\times8}{0.75\times10^{-2}} = 1.3779\times10^8 km / F$$

$$P_{12} = P_{21} = \frac{1}{2\pi\varepsilon_o} \log \frac{D_{12}}{d_{12}} = 1.7975\times10^7 \log \frac{\sqrt{16^2 +1}}{1} = 4.9872\times10^7 km / F$$

$$C = \begin{bmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{bmatrix}^{-1} = \begin{bmatrix} 8.352\times10^{-9} & -3.023\times10^{-9} \\ -3.023\times10^{-9} & 8.352\times10^{-9} \end{bmatrix} F / km$$

In the `power_lineparam` GUI, make sure that the specified frequency is 50 Hz. Select `T/D ratio` for computing the line inductance. Do not select **Include conductor skin effect**.
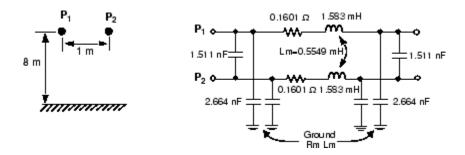
The displayed GMR value (0.58433 cm) is the GMR value that you must use to include the change of conductor inductance due to frequency. This GMR value is slightly higher than the theoretical DC value (0.5841 cm). This 0.04% increase is due to skin effect at 50 Hz which produces a nonuniform current distribution. In this case, the line parameters are evaluated in DC because we are not including the skin effect.

Click **Compute RLC line parameters**. The Display RLC Values window opens. Compare the RLC matrices with their theoretical values.

The PI model for a 1-km line is obtained from the R, L, and C matrices. The PI RLC values are deduced from the self- and mutual- terms of the R, L, and C matrices. Subscripts s and m designate the self- and mutual- terms in the R, L, and C matrices.

$R_{p1} = R_{p2} = R_s = 0.1601\ \Omega/\text{km}$

$L_{p1} = L_{p2} = L_s = 1.583\ \text{mH/km}$

$C_{p1} = C_{p2} = C_s + C_m = 8.352 - 3.023 = 5.329\ \text{nF/km}$ (2.664 nF at each end of PI section)

$C_{p1p2} = -\ C_m = 3.023\ \text{nF/km}$ (1.511 nF at each end of PI section)

You can also vary the ground resistivity and the frequency. Observe their impact on the resistance and inductance of the conductor and of the ground return.

Vary the ground resistivity from zero to 10000 Ω.m while keeping the frequency constant at 50 Hz. You should get values listed in the following table. The expressions Rs-Rm and Ls-Lm represent respectively the resistance and the inductance of the conductor, whereas Rm and Lm are the resistance and the inductance of the ground return.

Impact of Ground Resistivity (Frequency = 50 Hz; Skin Effect Not Included)

Ground Resistivity (Ω.m)	Conductor Rs-Rm (Ω/km)	Ground Rm (Ω/km)	Conductor Ls-Lm (mH/km)	Ground Lm (mH/km)
0	0.1601	0	1.028	0.5549
10	0.1601	0.04666	1.029	1.147
100	0.1601	0.04845	1.029	1.370
10 000	0.1601	0.04925	1.029	1.828

When the ground resistivity varies in a normal range (between 10 Ω.m for humid soil and 10 000 Ω.m for dry, rocky ground), the ground resistance remains almost constant at 0.05 Ω/km, whereas its inductance increases from 1.15 mH/km to 1.83 mH/km.

Now select **Include conductor skin effect** and repeat the computation with different frequencies ranging from 0.05 Hz to 50 kHz, while keeping a ground resistivity of 100 Ω.m.
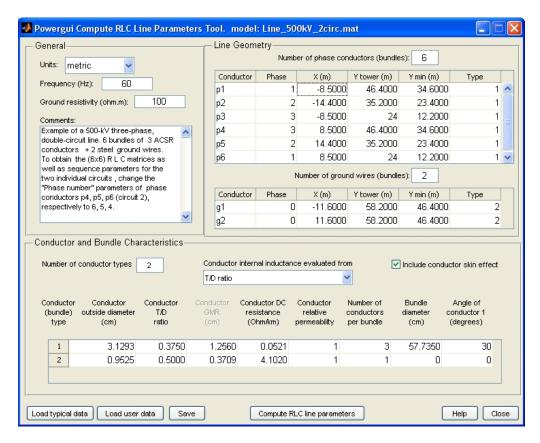
Impact of Frequency (Ground Resistivity = 100 Ω.m; with Conductor Skin Effect)

Frequency (Hz)	Conductor Rs-Rm (Ω/km)	Ground Rm (Ω/km)	Conductor Ls-Lm (mH/km)	Ground Lm (mH/km)
0.05	0.1601	4.93e-5	1.029	2.058
50	0.1606	0.04844	1.029	1.370
500	0.2012	0.4666	1.022	1.147
5000	0.5442	4.198	0.9944	0.9351
50 000	1.641	32.14	0.9836	0.7559

This table shows that frequency has a very large impact on ground resistance but a much lower influence on ground inductance. Because of skin effect in the ground, when frequency increases, the ground current flows closer to the surface, reducing the equivalent section of the ground conductor and thereby increasing its resistance. As ground current travels at a lower depth at high frequencies, the loop inductance of conductor plus ground return (or self-inductance Ls) decreases.

Because of conductor skin effect, frequency has a noticeable impact on conductor resistance from a few hundreds of hertz, but a negligible impact on conductor inductance. At nominal system frequency (50 Hz or 60 Hz), the increase of conductor resistance with respect to DC resistance (0.1601 Ω/km) is only 0.3%.

This example corresponds to a 500-kV, three-phase, double-circuit line. Using the **Load** button, load the `Line_500kV_2circ.mat` line configuration saved in the typical line data. The following figure is `power_lineparam` GUI:

Power is transmitted over six phase conductors forming the two three-phase circuits. The line is protected against lightning by two ground wires. The phase conductors use bundles of three subconductors. Subconductors are located at the top of an equilateral triangle of 50 cm side, corresponding to a 57.735 cm bundle diameter. This line configuration corresponds to the one shown in the figure Configuration of a Three-Phase Double-Circuit Line.

Phase numbering has been set to obtain the line parameters of the three-phase line equivalent to the two circuits connected in parallel. Click **Compute RLC line parameters** to display the R, L, and C matrices and sequence parameters.

The positive-sequence and zero-sequence parameters of the transposed line are displayed in the Display RLC Values window in the R10 and L10 vectors:
R1 = 0.009009 Ω/km R0=0.2556 Ω/km

L1 = 0.4408 mH/km L0= 2.601 mH/km
C1 =25.87 nF/km C0=11.62 nF/km

You can also get the parameters of the two individual circuits and have access to the six phase conductors. Change the phase numbers of conductors p4, p5, and p6 (circuit 2) to 6, 5, 4, respectively. The positive-sequence, zero-sequence, and mutual zero-sequence parameters of the transposed line are:
R1 = 0.01840 Ω/km R0 =0.2649 Ω/km R0m = 0.2462 Ω/km
L1 = 0.9296 mH/km L0 = 3.202 mH/km L0m = 2.0 mH/km
C1 =12.57 nF/km C0 =7.856 nF/km C0m = −2.044 nF/km

As the line is symmetrical, the positive- and zero-sequence parameters for circuit 2 are identical to the parameters of circuit 1.

References

[1] Dommel, H., et al., *Electromagnetic Transients Program Reference Manual* (EMTP Theory Book), 1986.

[2] Carson, J. R., "Wave Propagation in Overhead Wires with Ground Return," *Bell Systems Technical Journal*, Vol. 5, pp 539-554, 1926.

See Also
```
Powergui | Distributed Parameter Line | Three-Phase PI Section Line |
PI Section Line
```

power_loadflow

Perform positive-sequence load flow or unbalanced load flow. Initialize models containing three-phase machines and dynamic load blocks

Syntax

```
power_loadflow('-v2',sys)
power_loadflow('-v2',sys,'AddBuses')
LF = power_loadflow('-v2',sys)
LF = power_loadflow('-v2',sys,'solve')
LF = power_loadflow('-v2',sys,'noupdate')
LF = power_loadflow('-v2',sys,'solve','report')
LF = power_loadflow('-v2',sys,'solve','report',fname)
LF = power_loadflow('-v2',sys,'solve','ExcelReport',fname)
power_loadflow(sys)
Mparam = power_loadflow(sys)
MI = power_loadflow(sys,Mparam)
```

Description

The `power_loadflow` function contains two different tools for performing load flow and initializing three-phase models with machines.

Load Flow Tool

The Load Flow tool uses the Newton-Raphson method to provide a robust and fast convergence solution. It offers most of the functionality of other load flow software available in the power utility industry.

The `-v2` option in `power_loadflow` function syntax allows you to access this tool from the command line.

`power_loadflow('-v2',sys)` opens a graphical user interface to edit and perform load flow of `sys` using the Newton Raphson algorithm.

`power_loadflow('-v2',sys,'AddBuses')` adds Load Flow Bus blocks to the model `sys`. The added blocks are single-connector Load Flow Bus blocks, which specify bus parameters for a positive-sequence load flow.

`LF = power_loadflow('-v2',sys)` returns the current load flow parameters of `sys`.

`LF = power_loadflow('-v2',sys,'solve')` computes the load flow of `sys`. The model is initialized with the load flow solution.

`LF = power_loadflow('-v2',sys,'noupdate')` computes the load flow but does not initialize the model with the load flow solution.

`LF = power_loadflow('-v2',sys,'solve','report')` computes the load flow and then opens the editor to save the load flow report.

`LF = power_loadflow('-v2',sys,'solve','report',fname)` computes the load flow and then saves detailed information in `fname` file.

`LF = power_loadflow('-v2',sys,'solve','ExcelReport',fname)` computes the load flow and then saves detailed information in the `fname` Excel® file. This capability is available only for the positive-sequence load flow.

Machine Initialization Tool

The Machine Initialization tool offers simplified load flow features to initialize the machine initial currents of your models.
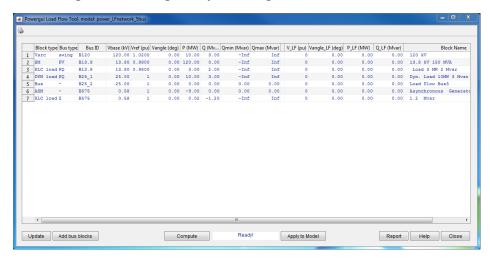
`power_loadflow(sys)` opens the Machine Initialization tool dialog box to perform machine initialization.

`Mparam = power_loadflow(sys)` returns the machine initialization parameter values of `sys`. Use `Mparam` as a template variable to perform new machine initialization.

`MI = power_loadflow(sys,Mparam)` computes the machine initial conditions using the load flow parameters given in `Mparam`. Create an instance of `Mparam` using `Mparam = power_loadflow(sys)`, and then edit the initialization parameter values based on this template.

Load Flow Tool GUI

Open this dialog box by entering the `power_loadflow('-v2', sys)` command, or from the Powergui block dialog box by selecting **Load Flow**.

Update

Click to get the latest changes in the model. Any previous load flow solution is cleared from the table.

Add bus blocks

Click to add load flow bus blocks to the model. The `power_loadflow` function determines the load flow bus required for your model and adds load flow bus blocks only in places where there is no load flow bus block already connected.

Compute

Click to solve the load flow. The solution is displayed in the `V_LF`, `Vangle_LF`, `P_LF`, and `Q_LF` columns of the Load Flow tool table. The load flow is performed at the frequency, base power, PQ tolerance, and max iterations specified in the **Preference** tab of the Powergui block.

Apply to Model

Click to apply the load flow solution to the model.

Report

Click to save in Excel or MATLAB format a load flow report showing power flowing toward each bus.

Close

Close the Load Flow tool.

Load Flow Parameters

The Load flow parameters and solution are returned in a structure with the following fields.
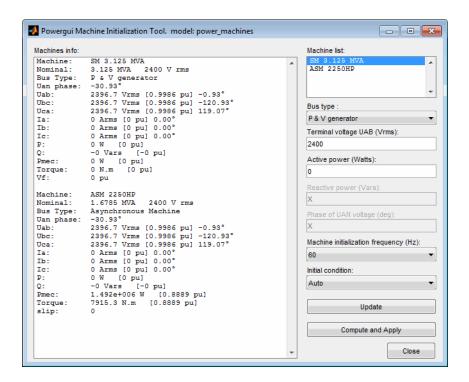
Field	Description
model	The name of the model.
frequency	The load flow frequency, in hertz. This value corresponds to the **Load flow frequency** parameter of the Powergui block.
basePower	The base power used by the Load Flow tool. This value corresponds to the **Base power Pbase** parameter of the Powergui block.
tolerance	The tolerance used by the Load Flow tool. This value corresponds to the **PQ Tolerance** parameter of the Powergui block.
bus	[1 x Nbus] structure with fields defining the bus parameters. For a positive-sequence load flow, Nbus is the number of three-phase buses in the model. For an unbalanced load flow, Nbus is the total number of single-phase buses in the model.
sm	[1 x Nsm] structure with fields defining the load flow parameters of the Synchronous Machine blocks. Nsm is the number of Synchronous Machine blocks in the model.
asm	[1 x Nasm] structure with fields defining the load flow parameters of the Asynchronous Machine blocks. Nasm is the

Field	Description
	number of Asynchronous Machine blocks in the model.
vsrc	[1 x Nsrc] structure with fields defining the load flow parameters of the Three-Phase Source, Three-Phase Programmable Voltage Source, and AC Voltage Source blocks. Nsrc is the number of single-phase and three-phase voltage source blocks in the model.
pqload	[1 x Npq] structure with fields defining the load flow parameters of the Three-Phase Dynamic Load blocks. Npq is the number of Three-Phase Dynamic Load blocks in the model.
rlcload	[1 x Nrlc] structure with fields defining the load flow parameters of the Three-Phase Parallel RLC Load, Three-Phase Series RLC Load, Parallel RLC Load, and Series RLC Load blocks. Nrlc is the number of three-phase and single-phase blocks in the model.
Ybus1	[Nbus x Nbus] positive-sequence complex admittance matrix in pu/Pbase used for positive-sequence load flow solution.
Ybus	[Nbus x Nbus] complex admittance matrix in pu/Pbase used for unbalanced load flow solution.
Networks	Lists the bus numbers of each independent network.
status	Returns 1 when a solution is found, and -1 when no solution is found.
iterations	The number of iterations that the solver took to solve the load flow.
error	Displays an error message when no solution is found.

Field	Description
`LoadFlowSolver`	The type of load flow solver: `'PositiveSequence'` or `'Unbalanced'`

Machine Initialization Tool Dialog Box

You can open this dialog box by entering the `power_loadflow(sys)` command, or from the Powergui block dialog box by selecting **Machine Initialization**.

Machines info

>   Displays the names of the Simplified Synchronous Machines, the Synchronous Machines, the Asynchronous Machine, and the Three-Phase Dynamic Load blocks of your model. Select a machine or a load in the list box to set its parameters.

Bus type

If **Bus type** is set to `P&V Generator`, you can set the terminal voltage and active power of the machine. If **Bus type** is set to `PQ generator`, you can set the active and reactive powers. If **Bus type** is set to `Swing Bus`, you can set the terminal voltage, enter an active power guess, and specify the phase of the UAN terminal voltage of the machine.

If you select an Asynchronous Machine block machine, you have to enter only the mechanical power delivered by the machine. If you select a Three-Phase Dynamic Load block, you must specify the active and reactive powers consumed by the load.

Terminal voltage UAB

Specify the terminal line-to-line voltage of the selected machine.

Active power

Specify the active power of the selected machine or load.

Active power guess

Specify an active power guess to start iterations when the specified machine bus type is `Swing Bus`.

Reactive power

Specify the reactive power of the selected machine or load.

Phase of UAN voltage

This parameter is activated only when the bus type is `Swing Bus`.

Specify the phase of the phase-to-neutral voltage of phase A of the selected machine.

Mechanical power

In motor mode, specify the mechanical power developed by the squirrel cage induction machine. In generator mode, specify the mechanical power absorbed by the machine as a negative number.

Machine initialization frequency

Specify the frequency to be used in the calculations (normally 60 Hz or 50 Hz).

Initial condition

Normally, you keep the default setting **Auto** to let the tool automatically adjust the initial conditions before starting iterations. If you select **Start from previous solution**, the tool starts with initial conditions corresponding to the previous solution. Try this option if the load flow fails to converge after a change has been made to the power and voltage settings of the machines or to the circuit parameters.

Update Machine list

Update the list of machines, voltage and current phasors, as well as the powers, if you have made a change in your model while the Machine Initialization tool is open. The new voltages and powers displayed are computed by using the machine currents obtained from the last computation (the three currents stored in the **Initial conditions** parameter of the machine blocks).

Compute and Apply

Executes the calculations for the given machine parameters.

Machine Initialization Parameters

The Machine Initialization parameters of a model are organized in a structure with the following fields.

Field	Description
`name`	Cell array of string values defining the names of the machine blocks of the model.
`type`	Cell array of string values (`'Asynchronous Machine'`, `'Simplified Synchronous Machine'`, `'Synchronous Machine'`, or `'Three Phase Dynamic Load'`) defining the mask type of the machine and load blocks.
`set`	Structure with variable fields defining the parameters specific to each machine or dynamic load (Bus Type, Terminal Voltage, Active Power, Reactive Power, Mechanical Power).
`LoadFlowFrequency`	Parameter defining the frequency used by the tool, in hertz. The frequency is specified only in the first element of the Machine Initialization parameters structure.
`InitialConditions`	String value defining the initial condition type (`'Auto'`,`'Start from previous solution'`). The initial condition status is specified only in the first element of

Field	Description
	the Machine Initialization parameter structure.
`DisplayWarnings`	String value (`'on'`,`'off'`) controlling the display of warning messages during the Machine Initialization computation.

For example, you obtain the initialization parameters for the `power_machines` example by doing:

```
Mparam = power_loadflow('power_machines');
Mparam(1)

ans =
                    name: 'SM 3.125 MVA'
                    type: 'Synchronous Machine'
                     set: [1x1 struct]
       LoadFlowFrequency: 60
       InitialConditions: 'Auto'
         DisplayWarnings: 'on'
lfparam(2)
                    name: 'ASM 2250HP'
                    type: 'Asynchronous Machine'
                     set: [1x1 struct]
       LoadFlowFrequency: []
       InitialConditions: []
         DisplayWarnings: []
```

If you use the `Mparam = power_loadflow(sys)` command to create the initialization parameters structure, you do not need to edit or modify the name and type fields of `lfparam`. The `set` field is where you specify new parameter values, `lfparam(1).LoadFlowFrequency` is where you define the frequency. `lfparam(1).Initialconditions` is where you specify the initial conditions status.

If your model does not contain any Asynchronous, Simplified Synchronous, or Synchronous Machine blocks and no Three Phase Dynamic Load block, `lfparam` returns an empty variable.

Initialization Parameters of Asynchronous Machine Block

For the Asynchronous Machine blocks you can specify only the mechanical power of the machine. The `set` field is a structure with the following field.

Field	Description
`MechanicalPower`	The mechanical power, in watts, of the machine.

For example, the mechanical power of the Asynchronous Machine in the `power_machines` example is:

```
Mparam = power_loadflow('power_machines');
Mparam(2).set

ans =
    MechanicalPower: 1492000
```

Initialization Parameters of Synchronous Machine Blocks

For the Simplified Synchronous Machine and Synchronous Machine blocks, the `set` field is a structure with these fields.

Field	Description
`BusType`	String (`'P & V generator'`, `'P & Q generator'`, or `'Swing bus'`) defining the bus type of the machine.
`TerminalVoltage`	Parameter defining the terminal voltage, in volts rms.
`ActivePower`	Parameter defining the active power, in watts.
`ReactivePower`	Parameter defining the reactive power, in vars.
`PhaseUan`	Parameter defining the phase voltage, in degrees, of the Uan voltage.

For example, the initialization parameter values of the Synchronous Machine block in the `power_machines` example are:

```
Mparam = power_loadflow('power_machines');
Mparam(1).set

ans =
```

```
          BusType: 'P & V generator'
   TerminalVoltage: 2400
      ActivePower: O
    ReactivePower: O
        PhaseUan: 0
```

Initialization Parameters of Three-Phase Dynamic Load Block

For the Three-Phase Dynamic Load block, the set field is a structure with the following fields.

Field	Description
ActivePower	Parameter defining the Active power, in watts.
ReactivePower	Parameter defining the reactive power, in vars.

Machine Initialization Results

The results are organized in a structure with the following fields.

Field	Description
status	Status returns 1 when a solution is found, and returns 0 when no solution is found. The status is given only in the first element of Machine Initialization structure; it returns an empty value for the other elements.
Machine	The names of the machines or loads.
Nominal	The nominal parameters [nominal power, nominal voltage] of the machines or loads.
BusType	The bus type of the machines or loads.
UanPhase	The phase angles, in degrees, of the phase A-to-neutral voltage at machine or load terminals.

Field	Description
Uab,Ubc,Uca	The steady-state, phase-to-phase terminal voltages of the machines or loads. The voltages are returned in a 1-by-3 vector containing the voltage in volts, the voltage in p.u. based on the nominal power of the machine, and the phase in degrees.
Ia,Ib,Ic	The steady-state phase currents of the machines or loads. The currents are returned in a 1-by-3 vector representing the current in amperes, the current in p.u. based on the nominal power of the machine, and the phase in degrees.
P	The active power of the machine is returned in a 1-by-2 vector, representing the power in watts and in p.u. based on the nominal power of the machine.
Q	The reactive power of the machine is returned in a 1-by-2 vector, representing the power in vars and in p.u. based on the nominal power of the machine.
Pmec	The mechanical power of the machine is returned in a 1-by-2 vector, representing the mechanical power in watts and in p.u. based on the nominal parameters of the machine.
Torque	The mechanical torque of the machine is returned in a 1-by-2 vector, representing the torque in N.m and in p.u. based on the nominal power and speed of the machine.
Vf	The computed field voltage of Synchronous Machine blocks. This parameter is set to an empty value for the other types of machines and loads.

Field	Description
Slip	The computed slip of Asynchronous Machine blocks. This parameter is set to an empty value for the other types of machines and loads.

Examples

Change Motor to Generator Mode and Set Initial Currents for Steady-State Simulation

The power_machines example illustrates a rated 2250 HP, 2.4 kV asynchronous motor connected on a 25 kV distribution network. The motor develops a mechanical power of 2000 HP (1.492 MW). You change its mechanical power to −1.0 MW (generator mode) and initialize the machine initial currents to start the simulation in steady state.

In the Command Window, type:

```
power_machines
```

The model opens.

Obtain the initialization parameters for the model:

```
Mparam = power_loadflow('power_machines');
Mparam(2).set

ans =
    MechanicalPower: 1492000
```

Change the mechanical power of the asynchronous motor to switch it to generator mode:

```
Mparam(2).set.MechanicalPower = -1e6;
```

Initialize the machine initial currents to start the simulation in steady state:

```
MI = power_loadflow('power_machines',Mparam);
```

View the Synchronous Machine block parameters:

```
MI(1)

ans =
     status: 1
    Machine: 'SM 3.125 MVA'
```

```
     Nominal: [3125000 2400]
     BusType: 'P & V generator'
    UanPhase: -30.3047
         Uab: [2.4000e+003 1.0000 -0.3047]
         Ubc: [2.4000e+003 1.0000 -120.3047]
         Uca: [2.4000e+003 1.0000 119.6953]
          Ia: [140.1689 0.1865 -120.3047]
          Ib: [140.1689 0.1865 119.6953]
          Ic: [140.1689 0.1865 -0.3047]
           P: [-5.8208e-011 -1.8626e-017]
           Q: [5.8267e+005 0.1865]
        Pmec: [391.1104 1.2516e-004]
      Torque: [2.0749 1.2516e-004]
          Vf: 1.2909
        Slip: []
```

The `MI(1).status` is set to `1`, meaning that the function has found a solution for the given parameters.

View the Asynchronous Machine block parameters:

```
MI(2)
```

```
ans =
      status: []
     Machine: 'ASM 2250HP'
     Nominal: [1678500 2400]
     BusType: 'Asynchronous Machine'
    UanPhase: -30.3047
         Uab: [2.4000e+003 1.0000 -0.3047]
         Ubc: [2.4000e+003 1.0000 -120.3047]
         Uca: [2.4000e+003 1.0000 119.6953]
          Ia: [268.7636 0.6656 177.3268]
          Ib: [268.7636 0.6656 57.3268]
          Ic: [268.7636 0.6656 -62.6732]
           P: [-9.8981e+005 -0.5897]
           Q: [5.1815e+005 0.3087]
        Pmec: [-1000000 -0.5958]
      Torque: [-5.2844e+003 -0.5934]
          Vf: []
        Slip: -0.0039
```

The mechanical torque reference input for the Asynchronous Machine block is now set to –5284.43 watts and the slip is S = –0.0039, meaning that the machine now behaves as a generator instead of a motor. Run the simulation and verify that it starts in steady state.

power_ltiview

Create state-space object of model for use with the Linear System Analyzer tool

Syntax
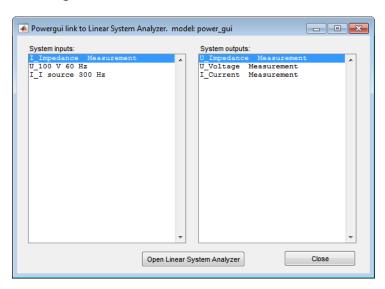
Linear System Analyzer

```
power_ltiview('sys')
```

Description

`power_ltiview('sys')` creates a state-space object (SS) of the linear part of the electrical circuit (ABCD state-space matrices representing the RLC devices in the model). The nonlinear elements, such as the distributed parameter line blocks, are modeled as inputs and outputs to the SS object (because they are modeled as current source in feedback to the state-space system). You can analyze the time and frequency responses of this SS object with the Linear System Analyzer. The command opens the Linear System Analyzer dialog box. This tool can also be activated from the Powergui block dialog box by selecting **Use Linear System Analyzer**. The Linear System Analyzer functionality is provided with Control System Toolbox software.

Dialog Box

System inputs

Lists the inputs of the state-space model of your circuit. Select the inputs to be used by the Linear System Analyzer.

System outputs

Lists the outputs of the state-space model of your circuit. Select the outputs to be used by the Linear System Analyzer.

Open Linear System Analyzer

Generates the state-space model of the circuit and opens the Linear System Analyzer for the selected system inputs and outputs.

power_new

Create new SimPowerSystems model populated by required and commonly used blocks

Syntax

`power_new`

Description

`power_new` creates a new SimPowerSystems model, with the Powergui block already on the model canvas and the Simulink solver set to `ode23tb` with the relative tolerance set to `1e-4`.

The function also opens the power_new_palette library that contains commonly used SimPowerSystems, Simulink, and Simscape blocks.

To help you fine-tune your model settings, the SimPowerSystems Assistant block is also added to the canvas.

SimPowerSystems Assistant Block

Click here to optimize Simulink and Powergui settings
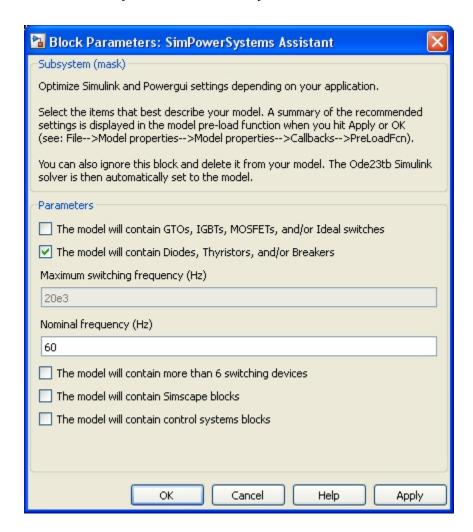
Use the SimPowerSystems Assistant block to optimize Simulink and Powergui settings depending on your application. In the block mask, select the items that best describe your model. The block automatically sets the optimal solver type (continuous or discrete) of the Powergui block, computes the optimal sample time (if the model is discrete), and selects the appropriate Simulink solver settings.

When you click **Apply** or **OK**, a summary of the settings performed by the block is displayed in the model pre-load function. The required simulation variables are assigned in the base workspace.

Alternatively, you can ignore this block and delete it from your model, or keep it for future use once you know more about your model.

The model will contain GTOs, IGBTs, MOSFETs, and/or Ideal switches

Select if your model contains at least one GTO, IGBT, MOSFET, or ideal switch device.

The model will contain Diodes, Thyristors, and/or Breakers

Select if your model contains at least one diode, thyristor, or breaker device.

Maximum switching frequency (Hz)

Specify the maximum switching frequency of the switching circuit. This parameter is enabled only when the **The model will contain GTOs, IGBTs, MOSFETs, and/or Ideal switches** parameter is selected, indicating that the sample time Ts, to discretize the electrical model, is calculated using this frequency.

Nominal frequency (Hz)

Specify the nominal frequency of the system. This parameter is enabled only when the **The model will contain Diodes, Thyristors, and/or Breakers** parameter is selected and the **The model will contain GTOs, IGBTs, MOSFETs, and/or Ideal switches** parameter is not selected, indicating that the sample time Ts, to discretize the electrical model, is calculated using this frequency.

The model will contain more than 6 switching devices

Select if your model contains more than 6 switching devices, regardless of their type. This parameter is enabled when the **The model will contain Diodes, Thyristors, and/or Breakers** parameter or the **The model will contain GTOs, IGBTs, MOSFETs, and/or Ideal switches** parameter is selected.

The model will contain Simscape blocks

Select if the model contains Simscape blocks. For models containing Simscape blocks, the ode23t solver is set for the model.

The model will contain control systems blocks
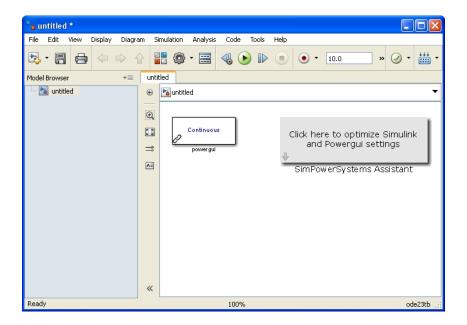
Select if your model contains Simulink blocks to control your SimPowerSystems model. The Assistant block will create a sample time variable, Ts_control.

Example
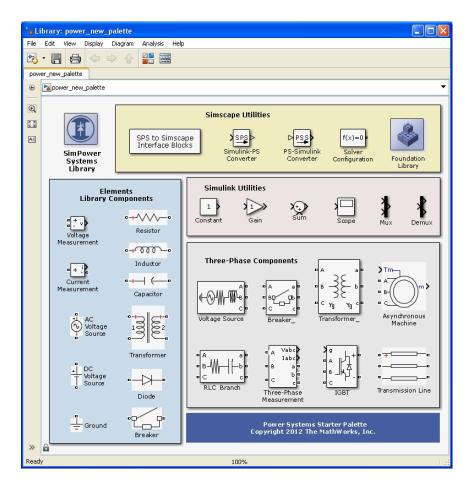
To create a generic SimPowerSystems model, type:

```
power_new
```
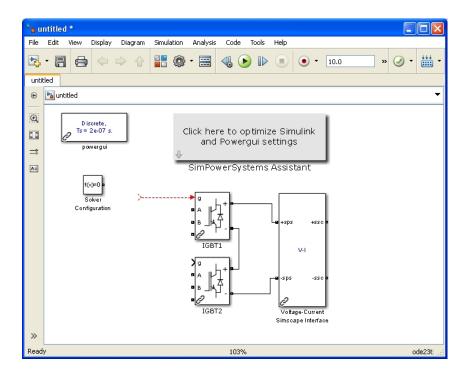
The software creates a new, untitled model with the default solver set to ode23tb. The new model contains a Powergui block set to continuous mode and the SimPowerSystems Assistant block.
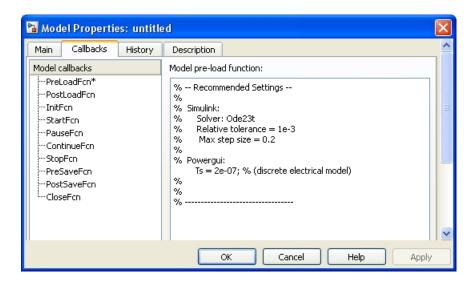
The software also opens the power_new_palette library that contains commonly used SimPowerSystems, Simulink, and Simscape blocks. This library contains a link to the `powerlib` SimPowerSystems library, to the `fl_lib` Foundation Library of Simscape, and to the Commonly Used blocks library of Simulink (by clicking the **Simulink Utilities** title).

In the SimPowerSystems assistant block, the model contains more than 6 IGBTs, has a maximum switching frequency of 20e3 Hz, and contains Simscape blocks. After clicking **OK**, the Powergui block is discretized to a sample time of 2e-7 sec, the Simscape Solver Configuration block is added to the canvas, and the Simulink solver is changed to `ode23t`.

After using power_new, continue developing your model by copying the blocks, as needed, and adding other blocks from the SimPowerSystems libraries. In the preceding example two IGBT bridges to the model (12 switching devices) are added, and a Voltage-Current Simscape Interface block that allows the connection of Simscape electrical blocks to the SimPowerSystems model. In the Model pre-load function (File/Model properties/ Callbacks/PreLoadFcn) a summary of the recommended settings is displayed when you click **OK**, or **Apply**.

The Ts sample time value used by the model is assigned in the base workspace and is defined automatically the next time that you open your model.

power_PMSynchronousMachineParams

Convert manufacturer specifications to mask parameters of Permanent Magnet Synchronous Machine block

Syntax

```
power_PMSynchronousMachineParams
params = power_PMSynchronousMachineParams(spec)
```

Description

power_PMSynchronousMachineParams opens a graphical user interface to compute the parameters of the Permanent Magnet Synchronous Machine block from standard manufacturer specifications.

params = power_PMSynchronousMachineParams(spec) computes the block parameters from the input structure spec which contains the manufacturer specifications. The solution is returned in the output structure params.

The electrical and mechanical parameters of the Permanent Magnet Synchronous Machine block along with their units are in the following table.

Parameter	Unit
Stator phase resistance Rs	ohm
Stator phase inductance Ls (trapezoidal back EMF waveform model)	H
Armature inductance L (sinusoidal back EMF round rotor type)	H
Inductances [Ld, Lq] (sinusoidal back EMF salient-pole rotor type)	H
Flux linkage established by magnets	V.s
Voltage constant ke (peak line to line voltage per 1000 rpm)	Vpeak/krpm
Torque constant kt (torque per ampere constant)	N.m/Apeak

Parameter	Unit
Inertia J (combined machine and load inertia)	$kg.m^2$
Viscous damping F (combined machine and load viscous damping)	N.m.s

Manufacturers provide machine parameters in several units, usually different from the units required by the Permanent Magnet Synchronous Machine block. This table provides the parameters and units commonly found in manufacturer specifications.

Manufacturer Specification	Units
Line-to-line resistance R	ohm (line-line)
Line-to-line inductance Lab	mH (line-line)
d- and q-axis phase inductances Ld, Lq	mH
Voltage Constant ke	Vpeak/krpm Vrms/krpm Vpeak/rad/s Vrms/rad/s
Torque Constant kt	N.m/Apeak N.m/Arms N.cm/Apeak oz.in/Arms lb.in/Apeak lb.ft/Arms
Inertia J	$kg.m^2$ $kg.cm^2$ $g.cm^2$ $lb.in^2$ $kg.cm.s^2$ $lb.in.s^2$ $oz.in.s^2$
Viscous damping F	N.m.s N.m/rpm oz.in/rpm oz.in/krpm

The `power_PMSynchronousMachineParams` function converts the given manufacturer parameters and units to the parameters required by the Permanent Magnet Synchronous Machine block. The function computes the machine parameters with:

Stator phase resistance:

$$R_s = \frac{R}{2}$$

Stator phase inductance:

$$L_s = \frac{L_{ab}}{2}$$

Armature inductance:

$$L = L_{ab}$$

Voltage Constant:

$$1\frac{V_{peak}}{krpm} = \frac{3}{100 \cdot \pi} \frac{V_{peak}}{(rad \, / \, s)} = \frac{1}{\sqrt{2}} \frac{V_{rms}}{krpm} = \frac{3}{100\sqrt{2 \cdot \pi}} \frac{V_{rms}}{rad \, / \, s}$$

Torque Constant:

$$1\frac{N.m}{A_{peak}} = \sqrt{2} \frac{N.m}{A_{rms}} = 200 \frac{oz.in}{A_{rms}} = 8.85 \frac{lb.in}{A_{peak}} = 1.043 \frac{lb.ft}{A_{rms}}$$

Inertia:

$$1 \, kg.m^2 = 2.926 \times 10^{-4} \, lb.in^2 = 10.197 \, kg.cm.s^2 = 141.612 \, oz.in.s^2$$

Viscous damping:

$$1 N.m.s = 0.1047 \frac{N.m}{rpm} = 14.829 \frac{oz.in}{rpm} = 14.829 \times 10^3 \frac{oz.in}{krpm}$$

Input Arguments

spec

The manufacturer data is specified in a structure with the following fields

Field	Description
backEMF	Specifies the shape of back EMF waveform {'sinusoidal','trapezoidal'}
rotorType	Specifies the type of rotor {'round','salient'}
R	Line-to-line resistance (ohm)
Lab	Line-to-line inductance (mH). Specify this field only for a round rotor machine.
Ld	D-axis phase inductance (mH). Specify this field only for a salient-pole rotor machine.
Lq	Q-axis phase inductance (mH). Specify this field only for a salient-pole rotor machine.
suppliedConstant	Specifies the type of constant (k) provided to the function {'voltage','torque'}
k	The value of the voltage or torque constant.
kUnitsNum	The units of the voltage or torque constant numerator {'Vpeak','Vrms','N.m','N.cm', 'oz.in','lb.in','lb.ft'}
kUnitsDenom	The units of the voltage or torque constant denominator {'krpm','rad/s','Apeak','Arms'}
J	Moment of inertia
inertiaUnits	Units for moment of inertia {'kg.m^2', 'kg.cm^2','g.cm^2','lb.in.s^2','oz.in.s^2'}
F	Viscous damping

Field	Description
frictionUnits	Units for viscous damping {'N.m.s', 'N.m/rpm','oz.in/rpm','oz.in/krpm'}
p	Number of pole pairs

params contains additional options to the function in a structure with the following fields.

Output Arguments
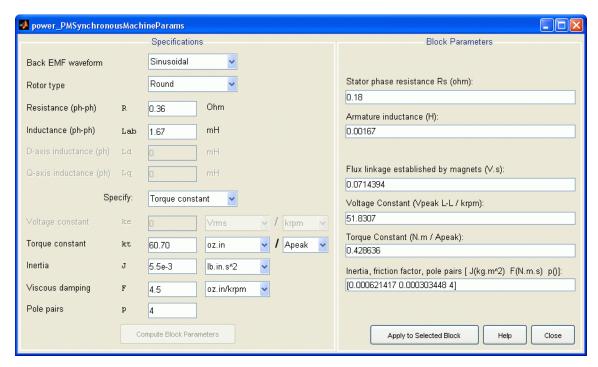
params

The Permanent Magnet Synchronous Machine block parameters are returned in a structure with these following fields

Field	Description
lambda	Flux induced by magnets (V.s)
ke	Voltage constant (Vpeak/krpm)
kt	Torque constant (N.m/Apeak)
J	Machine inertia (kg.m^2)
F	Machine viscous damping (N.m.s)
Rs	Stator phase resistance (ohm)
Ls	Stator phase inductance (H). Computed for the round rotor machine
Ld	D-axis phase inductance (H). Computed for a sinusoidal back EMF with salient-pole rotor machine.
Lq	Q-axis phase inductance (H). Computed for a sinusoidal back EMF and salient-pole rotor machine.
p	Number of pole pairs

Interface

You can also obtain the mask parameters of the Permanent Magnet Synchronous machine block through the user interface of the function.

Specifications

Enter the manufacturer specifications. Depending on the option that you select in the **Back EMF waveform**, **Rotor type**, and **Specify** parameters, some specifications are not available. Parameters that are unavailable are not taken into account in block parameter computation.

Compute Block Parameters

Compute the electrical parameters and display the solution in the **Block Parameters** section. When you have obtained the block parameters, the button is not available.

When you enter new values in the **Specifications** section, the button is enabled to indicate that the displayed block parameters no longer correspond to the displayed specifications.

Block Parameters

Displays the parameters corresponding to the given manufacturer specifications. The first time that you open the interface, these fields are empty. You cannot edit these block parameters.

When the **Rotor type** is set to **Salient-pole**, the **Armature inductance** parameter is unavailable, indicating that its value is not computed using the **Compute Block Parameters** button.

When the Rotor type is set to Round, the **Inductances** parameter is unavailable, indicating that its value is not computed using the **Compute Block Parameters** button.

Apply to Selected Block

Open your model, select the machine you want to parametrize, then click the **Apply to selected block** button to load the displayed block parameters in the block. When the **Block Parameters** fields are empty, the button is unavailable. The button is enabled when a valid solution is displayed in the **Block Parameters** section.

The button has no effect on a selected block that is not a Permanent Magnet Synchronous Machine block

Help

Opens the help page of the power_PMSynchronousMachineParams function.

Close

Closes the interface.

Examples

Consider a 4kW, permanent magnet synchronous machine (round rotor and sinusoidal back emf) with the following manufacturer specification:

Data	Values
R	0.36 ohm (line-line)
Lab	1.67 mH (line-line)
kt	60.70 oz.in/Apeak
J	5.5E-03 lb.in.sec^2
B	4.5 oz.in/krpm
p	4

Based on this specification, to obtain the required mask parameters for the Permanent Magnet Synchronous Machine block, in the Command Window, enter the following commands:

```
spec.backEMF = 'sinusoidal';
spec.rotorType = 'round' ;
spec.R = 0.36;
spec.Lab = 1.67;
spec.suppliedConstant = 'torque';
spec.k = 60.70;
spec.kUnitsNum = 'oz.in';
spec.kUnitsDenom = 'Apeak';
spec.J = 5.5e-3;
spec.inertiaUnits = 'lb.in.s^2' ;
spec.F = 4.5;
spec.frictionUnits = 'oz.in/krpm';
spec.p = 4;

params = power_PMSynchronousMachineParams(spec)
```

You get the following results:

```
params =

  lambda: 0.0714
  ke: 51.8307
  kt: 0.4286
   J: 6.2142e-004
   F: 3.0345e-004
  Rs: 0.1800
  Ls: 8.3500e-004
  Ld: []
  Lq: []
   p: 4
```

See Also

power_AsynchronousMachineParams

power_report

Generate report of steady state variables, initial states, and machine load flow for model
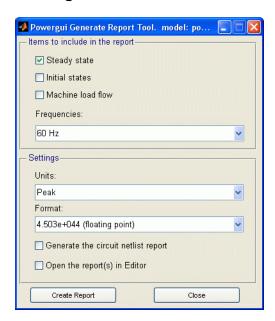
Syntax

```
power_report('sys')
```

Description

power_report('sys') opens the Generate Report Tool dialog box that allow you to generate a report of steady state variables, initial states, and machine load flow for a model. This tool can also be activated from the Powergui block dialog box by selecting **Steady-State Voltages and Currents**.

Dialog Box

Items to include in the report

In the check boxes, select any combination of measurements to include in the generated report, **Steady state**, **Initial states**, and **Machine load flow**. The default is unselected for all three.

Frequencies

Select the frequency or frequencies to include in the generated report, `60 Hz` or `All`. The default is `60 Hz`.

Units

Set the **Units** parameter to `Peak values` to display the peak values of the selected values. Set the **Units** parameter to `RMS` to display the root-mean-square (RMS) values of the selected values.

Format

In the pull-down menu, choose the format in which you want your measurements displayed. The `floating point` option is displayed in mantissa-exponent form with five significant figures. The `best of` option is displayed with four significant figures and uses mantissa-exponent form only for numbers larger than 9999. The final option is displayed in plain numbers with two figures to the right of the decimal point. The default is `floating point`.

Generate the circuit netlist report

Generates a netlist stored in a file, `sys.net`. The file contains the node numbers automatically generated by `power_analyze`, as well as parameter values of all linear elements. See the formats described in the `power_statespace` reference page.

Open the report(s) in Editor

Lets you edit the report.

Create Report

Generate a report and save it to a file.

See Also

`power_analyze` | `power_statespace`

power_statespace

Compute state-space model of linear electrical circuit

Syntax

You must call `power_statespace` with a minimum of seven input arguments.

```
[A,B,C,D,states,x0,x0sw,rlsw,u,x,y,freq,Asw,Bsw,Csw,Dsw,Hlin] =
power_statespace(rlc,switches,source,line_dist,yout,y_type,unit
)
```

You can also specify optional arguments. To use these optional arguments, the number of input arguments must be 12, 13, 14 or 16.

```
[A,B,C,D,states,x0,x0sw,rlsw,u,x,y,freq,Asw,Bsw,Csw,Dsw,Hlin] =
power_statespace(rlc,switches,source,line_dist,yout,y_type,unit
,
net_arg1,net_arg2,net_arg3,...,netsim_flag,fid_outfile,
freq_sys,ref_node,vary_name,vary_val)
```

Description

The `power_statespace` command computes the state-space model of a linear electrical circuit expressed as

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

where *x* is the vector of state-space variables (inductor currents and capacitor voltages), *u* is the vector of voltage and current inputs, and *y* is the vector of voltage and current outputs.

When you build a circuit from SimPowerSystems Specialized Technology blocks, `power_statespace` is automatically called by the `power_analyze` command. `power_statespace` is also available as a stand-alone command for expert users. This allows you to generate state-space models without using the SimPowerSystems Specialized Technology block modeling interface and to access options that are not available through the Specialized Technology library. For example, using `power_statespace`, you can model transformers and mutual inductances with more than three windings.

The linear circuit can contain any combination of voltage and current sources, RLC branches, multiwinding transformers, mutually coupled inductances, and switches. The state variables are inductor currents and capacitor voltages.

The state-space representation (matrices A,B,C,D, and vector x0) computed by power_statespace can then be used in a Simulink system, via a State-Space block, to perform simulation of the electrical circuit (see "Examples" on page 2-120). Nonlinear elements (mechanical or power electronic switches, transformer saturation, machines, distributed parameter lines, etc.) can be connected to the linear circuit.

These Simulink models are interfaced with the linear circuit through voltage outputs and current inputs of the state-space model. You can find the models of the nonlinear elements provided with SimPowerSystems software in the Specialized Technology library.

Input Arguments

The number of input arguments must be 7, 12, 13, 14, or 16. Arguments 8 to 16 are optional. The first seven arguments that must be specified are

- rlc: Branch matrix specifying the network topology as well as the resistance R, inductance L, and capacitance C values. See format below.
- switches: Switch matrix. Specify an empty variable if no switches are used. See format below.
- source: Source matrix specifying the parameters of the electrical voltage and current sources. Specify an empty variable if no sources are used. See format below.
- line_dist: Distributed parameter line matrix. Specify an empty variable if no distributed lines are used. See format below.
- yout: String matrix of output expressions. See format below.
- y_type: Integer vector indicating output types (0 for voltage output, 1 for current output).
- unit: String specifying the units to be used for R, L, and C values in the rlc matrix. If unit = 'OHM', R L C values are specified in ohms Ω at the fundamental frequency specified by freq_sys (default value is 60 Hz). If unit = 'OMU', R L C values are specified in ohms (Ω), millihenries (mH), and microfarads (µF).

The last nine arguments are optional. The first three are used to pass arguments from the power_analyze command. Hereafter, only the arguments to be specified when power_statespace is used as a stand-alone command are described:

2-111

- net_arg1, net_arg2, net_arg3: Used to pass arguments from power_analyze. Specify an empty variable [ ] for each of these arguments.

- netsim_flag: Integer controlling the messages displayed during the execution of power_statespace. Default value is 0.

  If netsim_flag = 0, the version number, number of states, inputs, outputs, and modes are displayed. Output values are displayed in polar form for each source frequency.

  If netsim_flag = 1, only version number, number of states, inputs, and outputs are displayed.

  If netsim_flag = 2, no message is displayed during execution.

- fid_outfile: File identifier of the power_statespace output file containing parameter values, node numbers, steady-state outputs, and special messages. Default value is 0.

- freq_sys: Fundamental frequency (Hz) considered for specification of X_L and X_C reactances if unit is set to 'OHM'. Default value is 60 Hz.

- ref_node: Reference node number used for ground of PI transmission lines. If -1 is specified, the user is prompted to specify a node number.

- vary_name: String matrix containing the symbolic variable names used in output expressions. These variables must be defined in your MATLAB workspace.

- vary_val: Vector containing the values of the variable names specified in vary_name.

Output Arguments

- A,B,C,D: state-space matrices of the linear circuit with all switches open.

  ```
  A(nstates, nstates) , B(nstates, ninput),
  C(noutput, nstates) , D(noutput, ninput),
  ```

  where nstates is the number of state variables, ninput is the number of inputs, and noutput is the number of outputs.

- states: String matrix containing the names of the state variables. Each string has the following format:

  Inductor currents: Il_bxx_nzz1_zz2

Capacitor voltages: `Uc_bxx_nzz1_zz2`

where

```
xx = branch number
zz1 = first node number of the branch
zz2 = second node number of the branch
```

The last lines of the `states` matrix, which are followed by an asterisk, indicate inductor currents and capacitor voltages that are not considered as state variables. This situation arises when inductor currents or capacitor voltages are not independent (inductors forming a cut set – for example, inductors connected in series – or capacitors forming a loop). The currents and voltages followed by asterisks can be expressed as a linear combination of the other state variables:

- `x0`: Column vector of initial values of state variables considering the open or closed status of switches.

- `x0sw`: Vector of initial values of switch currents.

- `rlsw`: Matrix (`nswitch`,2) containing the R and L values of series switch impedances in ohms (Ω) and henries (H). `nswitch` is the number of switches in the circuit.

- `u,x,y`: Matrices u(`ninput`,`nfreq`), x(`nstates`,`nfreq`), and y(`noutput`,`nfreq`) containing the steady-state complex values of inputs, states, and outputs. `nfreq` is the length of the `freq` vector. Each column corresponds to a different source frequency, as specified by the next argument, `freq`.

- `freq`: Column vector containing the source frequencies ordered by increasing frequency.

- `Asw,Bsw,Csw,Dsw`: State-space matrices of the circuit including the closed switches. Each closed switch with an internal inductance adds one extra state to the circuit.

- `Hlin`: Three-dimensional array (`nfreq`, `noutput`, `ninput`) of the `nfreq` complex transfer impedance matrices of the linear system corresponding to each frequency of the `freq` vector.

Format of the RLC Input Matrix

Two formats are allowed:

- Six columns: Implicit branch numbering. Branch numbers correspond to the RLC line numbers.

- Seven columns: Explicit branch numbering. Branch number `Nobr` is assigned by the user.

Each line of the `RLC` matrix must be specified according to the following format.

`[node1, node2, type, R, L, C, Nobr]` for RLC branch or line branch

`[node1, node2, type, R, L, C, Nobr]` for transformer magnetizing branch

`[node1, node2, type, R, L, U, Nobr]` for transformer winding

`[node1, node2, type, R, L, U, Nobr]` for mutual inductances

- `node1`: First node number of the branch. The node number must be positive or zero. Decimal node numbers are allowed.
- `node2`: Second node number of the branch. The node number must be positive or zero. Decimal node numbers are allowed.
- `type`: Integer indicating the type of connection of RLC elements, or, if negative, the transmission line length:

    `type = 0`: Series RLC element

    `type = 1`: Parallel RLC element

    `type = 2`: Transformer winding

    `type = 3`: Coupled (mutual) winding

    If `type` is negative, the transmission line is modeled by a PI section of length | `type`|. See details below.

For a mutual inductor or a transformer having N windings, N+1 consecutive lines must be specified in `RLC` matrix:

1 N lines with `type = 2` or `type = 3`; (one line per winding). Each line specifies `R/L/U` or `R/Xl/Xc` where `[R/L, R/Xl` = winding resistance and leakage reactance for a transformers or winding resistance and self reactance for mutually coupled windings. `U` is the nominal voltage of transformer winding (specify 0 if `type = 3`).

2 One extra line with `type = 1` for the magnetizing branch of a transformer (parallel `Rm/Lm` or `Rm/Xm`) or one line with `type = 0` for a mutual impedance (series `Rm/Lm` or `Rm/Xm`).

For a transformer magnetizing branch or a mutual impedance, the first node number is an internal node located behind the leakage reactance of the first winding. The second node number must be the same as the second node number of the first winding.

To model a saturable transformer, you must use a nonlinear inductance instead of the linear inductance simulating the reactive losses. Set the `Lm/Xm` value to `0` (no linear inductance) and use the `Saturable Transformer` block, set with proper flux-current characteristics.

This block can be found in the Fundamental Blocks/Elements library. It must be connected to the linear part of the system (State-Space block or S-function) between a voltage output (voltage across the magnetizing branch) and a current input (current source injected into the transformer internal node). See the "Examples" on page 2-120.

If type is negative, its absolute value specifies the length (km) of a transmission line simulated by a PI section. For a transmission line, the R/L/C or R/Xl/Xc values must be specified in Ω/km, mH/km, and µF/km, or in Ω/km.

Parameter	Description
R	Branch resistance (Ω)
Xl	Branch inductive reactance (Ω at `freq_sys`) or transformer winding leakage reactance (Ω at `freq_sys`)
L	Branch inductance (mH)
Xc	Branch capacitive reactance (Ω at `freq_sys`). The negative sign of Xc is optional.
C	Capacitance (µF)
U	Nominal voltage of transformer winding. The same units (volts or kV) must be used for each winding. For a mutual inductance (`type=3`), this value must be set to zero.
Zero value for R, L or Xl, C or Xc in a series or parallel branch indicates that the corresponding element does not exist.	

The following restrictions apply for transformer winding R-L values. Null values are not allowed for secondary impedances if some transformer secondaries form loops (as in a three-phase delta connection). Specify a very low value for R or L or both (e.g., `1e-6` pu based on rated voltage and power) to simulate a quasi-ideal transformer. The resistive and inductive parts of the magnetizing branch can be set to infinite (no losses; specify `Xm = Rm = inf`).

Format of the Source Input Matrix

Three formats are allowed:

- Five columns: All sources are generating the same frequency specified by `freq_sys`.
- Six columns: The frequency of each source is specified in column 6.
- Seven columns: The seventh column is used to specify the type of nonlinear element modeled by the current source.

Each line of the source matrix must be specified according to the following format:

`[ node1, node2, type, amp, phase, freq, model ]`

- `node1`, `node2`: Node numbers corresponding to the source terminals. These are the polarity conventions:

    - Voltage source: `node1` is the positive terminal.
    - Current source: Positive current flowing from `node1` to `node2` inside the source.

- `type:` Integer indicating the type of source: `0` for voltage source, `1` for current source.
- `amp:` Amplitude of the AC or DC voltage or current (V or A).
- `phase`: Phase of the AC voltage or current (degree).
- `freq`: Frequency (Hz) of the generated voltage or current. Default value is 60 Hz. For a DC voltage or current source, specify `phase = 0` and `freq = 0`. `amp` can be set to a negative value. The generated signals are

    `amp * sin(2π*freq*t + phase)`for AC, `amp` for DC.
- `model:` Integer specifying the type of nonlinear element modeled by the current source (saturable inductance, thyristor, switch,...). Used by `power_analyze` only.

Order in Which Sources Must Be Specified

The commands that compute the state-space representation of a system expect the sources in a certain order. You must respect this order in order to obtain correct results. You must be particularly careful if the system contains any switches. This is the proper ordering of sources:

1 The currents from all switches that have a null inductance (Lon = 0), if any.
2 The currents from all nonlinear models that have a finite inductance (switches with Lon > 0, the magnetizing inductance in saturable transformers, etc.), if any.

3 All other voltage and current sources in any order, if any.

Refer to the Example section below for an example illustrating proper ordering of sources for a system containing nonlinear elements.

Format of the Switches Input Matrix

Switches are nonlinear elements simulating mechanical or electronic devices such as circuit breakers, diodes, or thyristors. Like other nonlinear elements, they are simulated by current sources driven by the voltage appearing across their terminals. Therefore, they cannot have a null impedance. They are simulated as ideal switches in series with a series R-L circuit. Various models of switches (circuit breaker, ideal switch, and power electronic devices) are available in the SimPowerSystems Specialized Technology library. They must be interconnected to the linear part of the system through appropriate voltage outputs and current inputs.

The switch parameters must be specified in a line of the switches matrix in seven different columns, according to the following format.

```
[ node1, node2, status, R, L/Xl , no_I , no_U ]
```

Parameter	Description
node1, node2	Node numbers corresponding to the switch terminals
status	Code indicating the initial status of the switch at t = 0: 0 = open; 1 = closed
R	Resistance of the switch when closed (Ω)
L/Xl	Inductance of the switch when closed (mH) or inductive reactance (Ω at freq_sys)
For these last two fields, you must use the same units as those specified for the RLC matrix. Either field can be set to 0, but not both.	

The next two fields specify the current input number and the voltage output number to be used for interconnecting the switch model to the State-Space block. The output number corresponding to the voltage across a particular switch must be the same as the input number corresponding to the current from the same switch (see Example section below):

- no_I: Current input number coming from the output of the switch model

- no_U: Voltage output number driving the input of the switch model

Format of the Line_Dist Matrix

The distributed parameter line model contains two parts:

1 A linear part containing current sources and resistances that are connected at the line sending and receiving buses together with the linear circuit.

2 A nonlinear part available in the `Distributed Parameter Line` block of the Elements library. This block performs the phase-to-mode transformations of voltage and currents and simulates the transmission delays for each mode. The *distributed_param_line* block must be connected to appropriate voltage outputs and current inputs of the linear part of the system. The line parameters have to be specified in the `line_dist` matrix and also in the Distributed Parameter Line block.

Each row of the `line_dist` matrix is used to specify a distributed parameter transmission line. The number of columns of `line_dist` depends on the number of phases of the transmission line.

For an `nphase` line, the first (`4 + 3 * nphase + nphase^2`) columns are used. For example, for a three-phase line, 22 columns are used.

`[nphase, no_I, no_U, length, L/Xl, Zc, Rm, speed, Ti]`

Parameter	Description
nphase	Number of phases of the transmission line
no_I	Input number in the source matrix corresponding to the first current source Is_1 of the line model. Each line model uses 2*nphase current sources specified in the source matrix as follows: Is_1, Is_2,..., Is_nphase for the sending end followed by Ir_1, Ir_2,..., Ir_nphase for the receiving end.
no_U	Output number of the state-space corresponding to the first voltage output Vs_1 feeding the line model. Each line model uses 2*nphase voltage outputs in the source matrix as follows: Vs_1, Vs_2,..., Vs_nphase for the sending end followed by Vr_1, Vr_2,..., Vr_nphase for the receiving end.
length	Length of the line (km)
Zc	Vector of the nphase modal characteristic impedances (Ω)

Parameter	Description
Rm	Vector of the nphase modal series resistances (Ω/km)
speed	Vector of the nphase modal propagation speeds (km/s)
Ti	Transformation matrix from mode to phase currents such that Iphase = Ti * Imod. The nphase * nphase matrix must be given in vector format, [col_1, col_2,... col_nphase].

Format of the Yout Matrix

The desired outputs are specified by a string matrix yout. Each line of the yout matrix must be an algebraic expression containing a linear combination of states and state derivatives, specified according to the following format.

Parameter	Description
Uc_bn	Capacitor voltage of branch n
Il_bn	Inductor current of branch n
dUc_bn	Derivative of Uc_bn or Il_bn
Un, In	Source voltage or current specified by line n of the source matrix
U_nx1_x2	Voltage between nodes x1 and x2 = Ux1 −Ux2
I_bn	Current in branch n flowing from node1 to node2 (See format of RLC matrix). For a parallel RLC branch, I_bn corresponds to the total current IR + IL + IC.
I_bn_nx	Current flowing into node x of a PI transmission line specified by line n of the RLC matrix. This current includes the series inductive branch current and the capacitive shunt current.

Each output expression is built from voltage and current variable names defined above, their derivatives, constants, other variable names, parentheses and operators (+ - * / ^), in order to form a valid MATLAB expression. For example

```
yout =
char(['R1*I_b1+Uc_b3-L2*dIl_b2','U_n10_20','I2+3*I_b5']);
```

If variable names are used (R1 and L2 in the above example), their names and values must be specified by the two input arguments vary_name and vary_val.

Sign Conventions for Voltages and Currents

Parameter	Sign Convention
I_bn, Il_bn, In	Branch current, inductor current of branch *n*, or current of source #n is oriented from `node1` to `node2`
I_bn_nx	Current at one end (node x) of a PI transmission line. If x = `node1`, the current is entering the line. If x = `node2`, the current is leaving the line.
Uc_bn, Un	Voltage across capacitor or source voltage (`Unode1` - `Unode2`)
U_nx1_x2	Voltage between nodes x1 and x2 = Ux1 − Ux2. Voltage of node x1 with respect to node x2.

Order in Which Outputs Must Be Specified
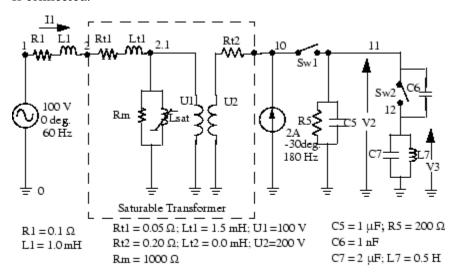
The commands that compute the state-space representation of a system expect the outputs to be in a certain order. You must respect this order in order to obtain correct results. You must be particularly careful if the system contains any switches. The following list gives the proper ordering of outputs:

1 The voltages across all switches that have a null inductance (Lon = 0), if any

2 The currents of all switches that have a null inductance (Lon = 0), if any, in the same order as the voltages above

3 The voltages across all nonlinear models that have a finite inductance (switches with Lon > 0, the magnetizing inductance in saturable transformers, etc.)

4 All other voltage and current measurements that you request, in any order

Refer to the Example section below for an example illustrating proper ordering of outputs for a system containing nonlinear elements.

Examples

The following circuit consists of two sources (one voltage source and one current source), two series RLC branches (R1-L1 and C6), two parallel RLC branches (R5-C5 and L7-C7), one saturable transformer, and two switches (Sw1 and Sw2). Sw1 is initially closed whereas Sw2 is initially open. Three measurement outputs are specified (I1, V2, and V3). This circuit has seven nodes numbered 0, 1, 2, 2.1, 10, 11, and 12. Node 0 is used for the

ground. Node 2.1 is the internal node of the transformer where the magnetization branch is connected.

R1 = 0.1 Ω
L1 = 1.0 mH

Rt1 = 0.05 Ω; Lt1 = 1.5 mH; U1 = 100 V
Rt2 = 0.20 Ω; Lt2 = 0.0 mH; U2 = 200 V
Rm = 1000 Ω

C5 = 1 μF; R5 = 200 Ω
C6 = 1 nF
C7 = 2 μF; L7 = 0.5 H

Sw1: R = 0.01 W; L = 0H; initial state = closed
Sw2: R = 0.1 W; L = 0H; initial state = open

Linear State-Space

You can use the `power_statespace` command to find the state-space model of the linear part of the circuit. The nonlinear elements Sw1, Sw2, and `Lsat` must be modeled separately by means of current sources driven by the voltages appearing across their terminals. Therefore you must provide three additional current sources and three additional voltage outputs for interfacing the nonlinear elements to the linear circuit.

You can find the state-space model of the circuit by entering the following commands in a MATLAB script file. The example is available in the power_circ2ss.m file. Notice that an output text file named `power_circ2ss.net` containing information on the system is requested in the call to `power_statespace`.

```
unit='OMU'; % Units = ohms, mH, and uF

rlc=[
%N1 N2 type R L C(uF)/U(V)
1 2 0 0.1 1 0 %R1 L1
2 0 2 0.05 1.5 100 %transfo Wind.#1
10 0 2 0.20 0 200 %transfo Wind.#2
2.1 0 1 1000 0 0 %transfo mag. branch
```

```
11 0 1 200 0 1 %R5 C5
11 12 0 0 0 1e-3 %C6
12 0 1 0 500 2 %L7 C7
];

source=[
%N1 N2 type U/I phase freq
10 11 1 0 0 0 %Sw1
11 12 1 0 0 0 %Sw2
2.1 0 1 0 0 0 %Saturation
1 0 0 100 0 60 %Voltage source
0 10 1 2 -30 180 %Current source
];

switches=[
%N1 N2 status R(ohm) L(mH) I# U#  #
10 11 1 0.01 0 1 1 %Sw1
11 12 0 0.1 0 2 2 %Sw2
];

%outputs
%
% Both switches have Lon=0, so their voltages must be the first
outputs,
% immediately followed by their currents (in the same order as
the voltages).
% The voltage across all nonlinear models that don't have L=0
follow
% (in this case the saturable transformer's magnetizing
inductor).
% The measurements that you request follow, in any order.
%
y_u1='U_n10_11';   %U_Sw1= Voltage across Sw1
y_u2='U_n11_12';   %U_Sw2= Voltage across Sw2
y_i3='I1';    %I1= Switch current Sw1
y_i4='I2';    %I2= Switch current Sw2
y_u5='U_n2.1_0';   %U_sat= Voltage across saturable reactor
y_i6='I_b1';   %I1 measurement
y_u7='U_n11_0';   %V2 measurement
y_u8='U_n12_0';   %V3 measurement

yout=char(y_u1,y_u2,y_i3,y_i4,y_u5,y_i6,y_u7,y_u8);       % outputs
y_type=[0,0,1,1,0,1,0,0];    %output types; 0=voltage 1=current

% Open file that contains power_statespace output information
fid=fopen('power_circ2ss.net','w');

[A,B,C,D,states,x0,x0sw,rlsw,u,x,y,freq,Asw,Bsw,Csw,Dsw,Hlin]=
power_statespace(rlc,switches,source,[],yout,y_type,unit,[],[],
[],0,fid);
```

Command Line Messages

While power_statespace is executing, the following messages are displayed.

```
Computing state space representation of linear electrical circuit
(V2.0)...
(4 states ; 5 inputs ; 7 outputs)

Oscillatory modes and damping factors:
F=159.115Hz zeta=4.80381e-08

Steady state outputs @ F=O Hz :
y_u1= OVolts
y_u2= OVolts
y_i3= OAmperes
y_i4= OAmperes
y_u5= OVolts
y_i6= OAmperes
y_u7= OVolts
y_u8= OVolts
Steady state outputs @ F=60 Hz :
y_u1 = 0.009999 Volts < 3.168 deg.
y_u2 = 199.4 Volts < -1.148 deg.
y_i3 = 0.9999 Amperes < 3.168 deg.
y_i4 = 0 Amperes < 0 deg.
y_u5 = 99.81 Volts < -1.144 deg.
y_i6 = 2.099 Amperes < 2.963 deg.
y_u7 = 199.4 Volts < -1.148 deg.
y_u8 = 0.01652 Volts < 178.9 deg.

Steady state outputs @ F=180 Hz :
y_u1 = 0.00117 Volts < 65.23 deg.
y_u2 = 22.78 Volts < 52.47 deg.
y_i3 = 0.117 Amperes < 65.23 deg.
y_i4 = 0 Amperes < 0 deg.
y_u5 = 11.4 Volts < 53.48 deg.
y_i6 = 4.027 Amperes < 146.5 deg.
y_u7 = 22.83 Volts < 52.47 deg.
y_u8 = 0.0522 Volts < 52.47 deg.
```

State-Space Output

The names of the state variables are returned in the `states` string matrix.

```
states
states =
Il_b2_n2_2.1
Uc_b5_n11_0
Uc_b6_n11_12
Il_b7_n12_0
Il_b1_n1_2*
Uc_b7_n12_0*
```

Although this circuit contains a total of six inductors and capacitors, there are only four state variables. The names of the state variables are given by the first four lines of the `states` matrix. The last two lines are followed by an asterisk indicating that these two variables are a linear combination of the state variables. The dependencies can be viewed in the output file `power_circ2ss.net`.

```
The following capacitor voltages are dependent:
Uc_b7_n12_0 =  + Uc_b5_n11_0  - Uc_b6_n11_12
The following inductor currents are dependent:
Il_b1_n1_2 =  + Il_b2_n2_0
```

The A,B,C,D matrices contain the state-space model of the circuit without nonlinear elements (all switches open). The x0 vector contains the initial state values considering the switch Sw1 closed. The Asw, Bsw, Csw, and Dsw matrices contain the state-space model of the circuit considering the closed switch Sw1. The x0sw vector contains the initial current in the closed switch.

```
A
A =
 -4.0006e+05 0 0 0
          0 -4995 0 -499.25
          0 -4992.5 0 4.9925e+05
          0 2 -2 0

Asw
Asw =
   -80.999 -199.99 0 0
 4.9947e+05 -5244.7 0  -499.25
 4.9922e+05 -5242.1 0 4.9925e+05
          0 2 -2 0
```

The system source frequencies are returned in the freq vector.

```
freq
freq =
     0    60    180
```

The corresponding steady-state complex outputs are returned in the (6-by-3) y matrix where each column corresponds to a different source frequency.

For example, you can obtain the magnitude of the six voltage and current outputs at 60 Hz as follows.

```
abs(y(:,2))
ans =
    0.0099987
    199.42
    0.99987
    0
    99.808
```

```
2.0993
199.41
0.016519
```

The initial values of the four state variables are returned in the `x0` vector. You must use this vector in the State-Space block to start the simulation in steady state.
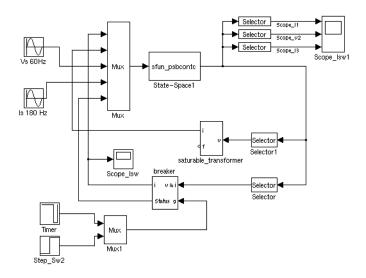
```
x0
x0 =
 2.3302
 14.111
 14.07
 3.1391e-05
```

The initial values of switch currents are returned in `x0sw`. To start the simulation in steady state, you must use these values as initial currents for the nonlinear model simulating the switches.
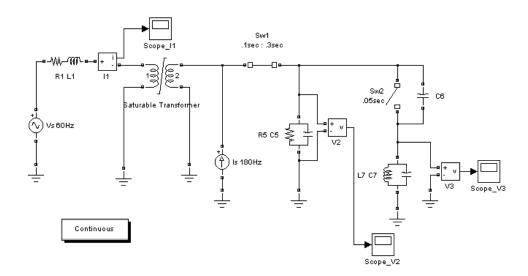
```
x0sw
x0sw =
    0.16155
    0
```

The Simulink diagram of the circuit shown in the following figure is available in the power_circ2ss_slk model. If no resistive switches had been used, the linear part of the circuit could have been simulated with the State-Space block of the Simulink/Continuous library. However, as resistive switches are used, the `sfun_psbcontc` S-function is used instead of the State-Space block. This S-function reevaluates the state-space matrices during simulation when the circuit topology is changing (after a switch is opened or closed). Appropriate inputs and outputs are used to connect the switch and saturable reactance models to the linear system. Notice that the status of each switch is fed back from the breaker to the S-function, after the inputs mentioned earlier. You can find the Breaker and Saturable Transformer blocks in the Fundamental Blocks/Elements library containing all the nonlinear continuous models used by SimPowerSystems software. As the breaker model is vectorized, a single block is used to simulate the two switches `Sw1` and `Sw2`.

If you use the SimPowerSystems Specialized Technology library to build your circuit, the same Simulink system is generated automatically by the `power_analyze` command. The SimPowerSystems Specialized Technology version of this system is also available in the power_circ2ss_sps model and is shown below.

power_circ2ss_slk Example Diagram

power_circ2ss_sps Example Diagram

See Also

power_analyze

power_steadystate

Compute steady-state values of voltages and currents of model

Syntax

```
power_steadystate('sys')
sps = power_steadystate('sys')
```

Description

power_steadystate('sys') opens the Steady-State Voltages and Currents Tool dialog box that allows you to view steady-state values of the inductor currents and capacitor voltages (electrical state variables), steady-state voltages and currents of measurement blocks and sources, as well as steady-state voltages and currents of nonlinear blocks of a model. This tool can also be activated from the Powergui block dialog box by selecting **Steady-State Voltages and Currents**.

If the model contains power electronic switches (diodes, thyristors, IGBTs, and so on) the steady-state values are computed considering them as open-circuit. If the model contains breakers (Breaker, Three-Phase Breaker, Three-Phase Fault blocks) the steady-state values are computed considering their initial status (open-circuit or short-circuit).
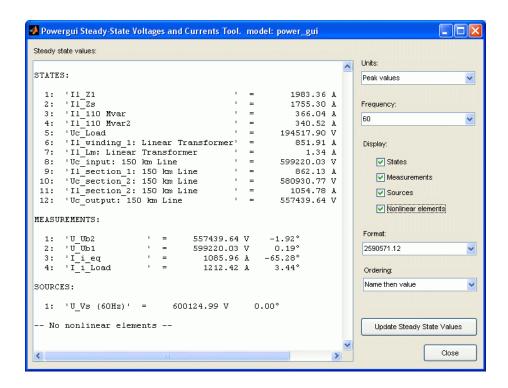
sps = power_steadystate('sys') returns a structure with the fields:

Field	Description
circuit	The name of the model
Frequencies	Vector listing the source frequencies in the model
States	The names of the electrical states of the model
Xss	The steady-state values of electrical states of the model
DependentStates	The names of the dependent states, if any
Measurements	The names of the Measurement blocks of the model

Field	Description
Yss_Measurements	The steady-state values of measurement blocks of the model
Sources	The names of the electrical source blocks of the model
Uss_Sources	The steady-state values of the electrical sources of the model
NonlinearOutputs	The names of the outputs corresponding to the nonlinear blocks (current-source injection based models). It consist of the measured terminal voltages used by the nonlinear models to compute the corresponding current sources
Yss_NonlinearOutputs	The steady-state values of outputs used by the nonlinear blocks
NonlinearInputs	The names of the inputs corresponding to the nonlinear blocks of the model
Uss_NonlinearInputs	The steady-state values of current inputs defined by the nonlinear blocks (current-source injection based models)

Note When the model contains more that one source frequency, the Xss, Yss_Measurements, Uss_Sources, Yss_NonlinearOutputs, and Uss_NonlinearInputs fields return a matrix of steady-state values. For every source frequency listed in the Frequencies field, there is a corresponding column of steady-states values in the matrix.

Dialog Box

Steady state values

   Display measurements of steady-state voltages and currents in the model.

Units

   Set the **Units** parameter to Peak values to display the peak values of the selected values. Set the **Units** parameter to RMS to display the root-mean-square (RMS) values of the selected values.

Frequency

   Allows you to choose the frequency, in hertz (Hz), that you want for display of the voltage and current phasors. The **Frequency** parameter lists all the different frequencies of the electrical sources of the model.

States

If selected, the window displays the steady-state phasors of the capacitor voltages and inductor currents of the circuit. The default is unselected.

Measurements

If selected, the window displays the steady-state voltage and current phasors of the measurement blocks of the circuit. The default is selected.

Sources

If selected, the window displays the steady-state voltage and current phasors of the electrical sources of the circuit. The default is unselected.

Nonlinear elements

If selected, the window displays the steady-state voltages and currents of the nonlinear blocks of the circuit. The default is unselected.

Format

In the pull-down menu, choose the format in which you want your measurements displayed. The `floating point` option is displayed in mantissa-exponent form with five significant figures. The `best of` option displays with four significant figures and uses mantissa-exponent form only for numbers larger than 9999. The final option is displayed in plain numbers with two figures to the right of the decimal point. The default is `floating point`.

Ordering

In the pull-down menu, choose the ordering in which you want your measurements displayed. The `Value then name` option displays the steady-state values in the first column followed by the names of the states variables. The `Name then value` option displays the name of the states variables in the first column followed by the steady-state values.

Update Steady State Values

Recompute and display the steady-state measurements.

Sign Conventions for Voltages and Currents

Unlike Simulink signal lines and input and output ports, the Physical Modeling connection lines and terminal ports □ lack intrinsic directionality. The voltage and current polarities are determined, not by line direction, but instead by block orientation. To find out a block orientation, first click on the block to select it. Then enter the following command:

```
get_param(gcb,'Orientation')
```

The following table indicates the polarities of the currents and voltages for single-phase and three-phase RLC elements (branches or loads), surge arresters, and single-phase and three-phase breakers. The table also indicates the polarities of their state variables (inductor currents and capacitor voltages).

Block Orientation	Positive Current Direction	Measured Voltage
right	left —> right	Vleft – Vright
left	right —> left	Vright – Vleft
down	top —> bottom	Vtop – Vbottom
up	bottom —> top	Vbottom – Vtop

The natural orientation of the blocks (that is, their orientation in the Element library) is *right* for horizontal blocks and *down* for vertical blocks.

For single-phase transformers (linear or saturable), with the winding connectors appearing on the left and right sides, the winding voltages are the voltages of the top connector with respect to the bottom connector whatever the block orientation (*right* or *left*). The winding currents are the currents entering the top connector. For three-phase transformers, the voltage polarities and positive current directions are indicated by the signal labels used in the Multimeter block.

power_zmeter

Compute impedance versus frequency of Impedance Measurement blocks of model

Syntax
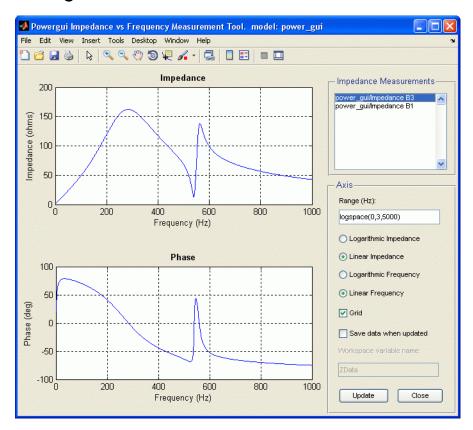
```
power_zmeter('sys')
Zdata = power_zmeter('sys',freq)
```

Description

`power_zmeter('sys')` opens the Impedance vs Frequency Measurement Tool dialog box to display the impedance versus frequency defined by the Impedance Measurement blocks. This tool can also be activated from the Powergui block dialog box by selecting **Impedance vs Frequency Measurement**.

`Zdata = power_zmeter('sys',freq)` returns a structure that contains a list of Impedance Measurement blocks and computed impedances versus frequency for the specified frequency range. For example:

```
Zdata = power_zmeter('power_gui',logspace(0,3,500))
Zdata =

    Blocks: {[1x23 char]  'power_gui/Impedance B1'}
         Z: [500x2 double]
      Freq: [500x1 double]
```

Dialog Box

Measurement

Lists the Impedance Measurement blocks of the model. Select the blocks for which you want to obtain the frequency response. Use the **CTRL** key to select several impedances to be displayed on the same plot.

Range (Hz)

Specify the frequency vector, in hertz (Hz). You can specify in that field any valid MATLAB expression defining a vector of frequencies; for example, `0:2:1000` or `linspace(0,1000,500)`. The default is `logspace(0,3,50)`.

Logarithmic Impedance/Linear Impedance

Choose logarithmic or linear scale for the vertical impedance scale.

Logarithmic Frequency/Linear Frequency

Choose logarithmic or linear scale for the horizontal frequency scales.

Grid

If selected, a grid is displayed for the two plots. Default is unselected.

Save data when updated

If selected, data are saved in a variable in the workspace. The name of the variable is defined by the **Workspace variable name** parameter. The complex impedances are saved in an array together with the corresponding frequencies. Frequency is saved in column 1 and impedances are saved in the next columns. Default is unselected.

Display/Save or Update

Click to initially display the impedance versus frequency measurement and, if the **Save data when updated** check box is selected, save the data to your workspace.

Click to start the impedance versus frequency measurement again and display results after multiple runs of your model.

Technical Conventions

Per Unit System of Units

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International System of Units

SimPowerSystems software uses the International System of Units (SI), as described in the following table.

Quantity	Unit	Symbol
Time	second	s
Length	meter	m
Mass	kilogram	kg
Energy	joule	J
Current	ampere	A
Voltage	volt	V
Active power	watt	W
Apparent power	volt-ampere	VA
Reactive power	var	var
Impedance	ohm	Ω
Resistance	ohm	Ω
Inductance	henry	H
Capacitance	farad	F
Flux linkage	volt-second	V. s
Rotation speed	radians per second revolutions per minute	rad/s rpm

Quantity	Unit	Symbol
Torque	newton-meter	N.m
Inertia	kilogram-meter^2	kg.m^2
Friction factor	newton-meter-second	N.m.s

What Is the Per Unit System?

The per unit system is widely used in the power system industry to express values of voltages, currents, powers, and impedances of various power equipment. It is mainly used for transformers and AC machines.

For a given quantity (voltage, current, power, impedance, torque, etc.) the per unit value is the value related to a base quantity.

$$\text{base value in p.u.} = \frac{\text{quantity expressed in SI units}}{\text{base value}}$$

Generally the following two base values are chosen:

- The base power = nominal power of the equipment
- The base voltage = nominal voltage of the equipment

All other base quantities are derived from these two base quantities. Once the base power and the base voltage are chosen, the base current and the base impedance are determined by the natural laws of electrical circuits.

$$\text{base current} = \frac{\text{base power}}{\text{base voltage}}$$

$$\text{base impedance} = \frac{\text{base voltage}}{\text{base current}} = \frac{(\text{base voltage})^2}{\text{base power}}$$

For a transformer with multiple windings, each having a different nominal voltage, the same base power is used for all windings (nominal power of the transformer). However, according to the above definitions, there are as many base values as windings for voltages, currents, and impedances.

The saturation characteristic of saturable transformer is given in the form of an instantaneous current versus instantaneous flux-linkage curve: [i1 phi1; i2 phi2; ... , in phin].

When the Per Unit system is used to specify the transformer R L parameters, the flux linkage and current in the saturation characteristic must be also specified in pu. The corresponding base values are

$$\text{base instantaneous current} = (\text{base rms current}) \times \sqrt{2}$$

$$\text{base flux linkage} = \frac{(\text{base rms voltage}) \times \sqrt{2}}{2\pi \times (\text{base frequency})}$$

where current, voltage, and flux linkage are expressed respectively in volts, amperes, and volt-seconds.

For AC machines, the torque and speed can be also expressed in pu. The following base quantities are chosen:

- The base speed = synchronous speed
- The base torque = torque corresponding at base power and synchronous speed

$$\text{base torque} = \frac{\text{base power (3 phases) in VA}}{\text{base speed in radians/second}}$$

Instead of specifying the rotor inertia in kg*m^2, you would generally give the inertia constant H defined as

$$H = \frac{\text{kinetic energy stored in the rotor at synchronous speed in joules}}{\text{machine nominal power in VA}}$$

$$H = \frac{\frac{1}{2} \times J \cdot w^2}{Pnom}$$

The inertia constant is expressed in seconds. For large machines, this constant is around 3 to 5 seconds. An inertia constant of 3 seconds means that the energy stored in the rotating part could supply the nominal load during 3 seconds. For small machines, H is lower. For example, for a 3 HP motor, it can be between 0.5 and 0.7 second.

Example 1: Three-Phase Transformer

Consider, for example, a three-phase two-winding transformer. The following typical parameters could be provided by the manufacturer:

- Nominal power = 300 kVA total for three phases

- Nominal frequency = 60 Hz

- Winding 1: connected in wye, nominal voltage = 25 kV RMS line-to-line

  resistance 0.01 pu, leakage reactance = 0.02 pu

- Winding 2: connected in delta, nominal voltage = 600 V RMS line-to-line

  resistance 0.01 pu, leakage reactance = 0.02 pu

- Magnetizing losses at nominal voltage in % of nominal current:

  Resistive 1%, Inductive 1%

The base values for each single-phase transformer are first calculated:

- For winding 1:

Base power	300 kVA/3 = 100e3 VA/phase
Base voltage	25 kV/sqrt(3) = 14434 V RMS
Base current	100e3/14434 = 6.928 A RMS
Base impedance	14434/6.928 = 2083 Ω
Base resistance	14434/6.928 = 2083 Ω
Base inductance	2083/(2π*60)= 5.525 H

- For winding 2:

Base power	300 kVA/3 = 100e3 VA
Base voltage	600 V RMS
Base current	100e3/600 = 166.7 A RMS
Base impedance	600/166.7 = 3.60 Ω
Base resistance	600/166.7 = 3.60 Ω
Base inductance	3.60/(2π*60) = 0.009549 H

The values of the winding resistances and leakage inductances expressed in SI units are therefore

- For winding 1: R1= 0.01 * 2083 = 20.83 Ω; L1= 0.02*5.525 = 0.1105 H
- For winding 2: R2= 0.01 * 3.60 = 0.0360 Ω; L2= 0.02*0.009549 = 0.191 mH

For the magnetizing branch, magnetizing losses of 1% resistive and 1% inductive mean a magnetizing resistance Rm of 100 pu and a magnetizing inductance Lm of 100 pu. Therefore, the values expressed in SI units referred to winding 1 are

- Rm = 100*2083 = 208.3 kΩ
- Lm = 100*5.525 = 552.5 H

Example 2: Asynchronous Machine

Now consider the three-phase four-pole Asynchronous Machine block in SI units provided in the Machines library of Fundamental Blocks library. It is rated 3 HP, 220 V RMS line-to-line, 60 Hz.

The stator and rotor resistance and inductance referred to stator are

- Rs = 0.435 Ω; Ls = 2 mH
- Rr = 0.816 Ω; Lr = 2 mH

The mutual inductance is Lm = 69.31 mH. The rotor inertia is J = 0.089 kg.m^2.

The base quantities for one phase are calculated as follows:

Base power	3 HP*746VA/3 = 746 VA/phase
Base voltage	220 V/sqrt(3) = 127.0 V RMS
Base current	746/127.0 = 5.874 A RMS
Base impedance	127.0/5.874 = 21.62 Ω
Base resistance	127.0/5.874 = 21.62 Ω
Base inductance	21.62/(2π*60)= 0.05735 H = 57.35 mH
Base speed	1800 rpm = 1800*(2π)/60 = 188.5 radians/second
Base torque (3-phase)	746*3/188.5 = 11.87 newton-meters

Using the above base values, you can compute the values in per units.

Rs= 0.435 / 21.62 = 0.0201 pu Ls= 2 / 57.35 = 0.0349 pu
Rr= 0.816 / 21.62 = 0.0377 pu Lr= 2 / 57.35 = 0.0349 pu
Lm = 69.31/57.35 = 1.208 pu

The inertia is calculated from inertia J, synchronous speed, and nominal power.

$$H = \frac{\frac{1}{2} \times J \cdot w^2}{Pnom} = \frac{\frac{1}{2} \times 0.089 \times (188.5)^2}{3 \times 746} = 0.7065 \text{ seconds}$$

If you open the dialog box of the Asynchronous Machine block in pu units provided in the Machines library of Fundamental Blocks (powerlib) library, you find that the parameters in pu are the ones calculated above.

Base Values for Instantaneous Voltage and Current Waveforms

When displaying instantaneous voltage and current waveforms on graphs or oscilloscopes, you normally consider the peak value of the nominal sinusoidal voltage as 1 pu. In other words, the base values used for voltage and currents are the RMS values given above multiplied by $\sqrt{2}$.

Why Use the Per Unit System Instead of the Standard SI Units?

Here are the main reasons for using the per unit system:

- When values are expressed in pu, the comparison of electrical quantities with their "normal" values is straightforward.

  For example, a transient voltage reaching a maximum of 1.42 pu indicates immediately that this voltage exceeds the nominal value by 42%.

- The values of impedances expressed in pu stay fairly constant whatever the power and voltage ratings.

  For example, for all transformers in the 3 kVA to 300 kVA power range, the leakage reactance varies approximately between 0.01 pu and 0.03 pu, whereas the winding resistances vary between 0.01 pu and 0.005 pu, whatever the nominal voltage. For transformers in the 300 kVA to 300 MVA range, the leakage reactance varies approximately between 0.03 pu and 0.12 pu, whereas the winding resistances vary between 0.005 pu and 0.002 pu.

Similarly, for salient pole synchronous machines, the synchronous reactance X_d is generally between 0.60 and 1.50 pu, whereas the subtransient reactance X'_d is generally between 0.20 and 0.50 pu.

It means that if you do not know the parameters for a 10 kVA transformer, you are not making a major error by assuming an average value of 0.02 pu for leakage reactances and 0.0075 pu for winding resistances.

The calculations using the per unit system are simplified. When all impedances in a multivoltage power system are expressed on a common power base and on the nominal voltages of the different subnetworks, the total impedance in pu seen at one bus is obtained by simply adding all impedances in pu, without taking into consideration the transformer ratios.

Park Transformation

The Park transformation used in SimPowerSystems models and functions corresponds to the definition provided in [1].

It transforms three quantities (direct axis, quadratic axis, and zero-sequence components) expressed in a two-axis reference frame back to phase quantities.

The following transformation is used:

$$V_a = V_d \sin(\omega t) + V_q \cos(\omega t) + V_0$$
$$V_b = V_d \sin(\omega t - 2\pi / 3) + V_q \cos(\omega t - 2\pi / 3) + V_0$$
$$V_c = V_d \sin(\omega t + 2\pi / 3) + V_q \cos(\omega t + 2\pi / 3) + V_0,$$

where ω = rotation speed (rad/s) of the rotating frame.

The following reverse transformation is used:

$$V_d = \frac{2}{3}\left(V_a \sin(\omega t) + V_b \sin(\omega t - 2\pi / 3) + V_c \sin(\omega t + 2\pi / 3)\right)$$
$$V_q = \frac{2}{3}\left(V_a \cos(\omega t) + V_b \cos(\omega t - 2\pi / 3) + V_c \cos(\omega t + 2\pi / 3)\right)$$
$$V_0 = \frac{1}{3}\left(V_a + V_b + V_c\right),$$

where ω = rotation speed (rad/s) of the rotating frame.

The transformations are the same for the case of a three-phase current; you simply replace the V_a, V_b, V_c, V_d, V_q, and V_0 variables with the I_a, I_b, I_c, I_d, I_q, and I_0 variables.

References

[1] Krause, P. C. *Analysis of Electric Machinery*. New York: McGraw-Hill, 1994, p.135.

Bibliography

[1] Boldea, Ion, and S.A. Nasar. *Electric Drives*. Boca Raton, Florida: CRC Press, 1999.

[2] Bose, B. K. *Modern Power Electronics and AC Drives*. Upper Saddle River, NJ: Prentice-Hall, 2002.

[3] Casoria, S., P. Brunelle, and G. Sybille. "Hysteresis Modeling in the MATLAB/Power System Blockset." Electrimacs 2002, École de technologie supérieure, Montreal, 2002.

[4] Dommel, H. "Digital Computer Solution of Electromagnetic Transients in Single and Multiple Networks." *IEEE Transactions on Power Apparatus and Systems*. Vol. PAS-88, No. 4, April, 1969.

[5] Frame, J.G., N. Mohan, and Tsu-huei Liu. "Hysteresis modeling in an Electro-Magnetic Transients Program." IEEE PES winter meeting, New York, January 31 to February 5, 1982.

[6] Grelet, G. and G. Clerc. *Actionneurs électriques*. Paris: Éditions Eyrolles, 1997.

[7] Grenier, D., L.-A. Dessaint, O. Akhrif, Y. Bonnassieux, and B. LePioufle. "Experimental Nonlinear Torque Control of a Permanent Magnet Synchronous Motor Using Saliency." *IEEE Transactions on Industrial Electronics*. Vol. 44, No. 5, October 1997, pp.680-687.

[8] Grondin, R., I. Kamwa, L. Soulieres, J. Potvin, and R. Champagne. "An approach to PSS design for transient stability improvement through supplementary damping of the common low frequency." *IEEE Transactions on Power Systems*, 8(3), August 1993, pp. 954-963.

[9] Harunur, M. R. *Power Electronics*. Upper Saddle River, NJ: Prentice-Hall, 1988.

[10] Hingorani, N. G. and L. Gyugyi. "Understanding FACTS; Concepts and Technology of Flexible AC Transmission Systems." *IEEE Press book*, 2000.

[11] Krause, P. C. *Analysis of Electric Machinery*. New York: McGraw-Hill, 1986.

[12] Krause, P. C., O. Wasynczuk, and S. D. Sudhoff. *Analysis of Electric Machinery*. IEEE Press, 2002.

[13] Kundur, P. *Power System Stability and Control*. New York: McGraw-Hill, 1994.

[14] Mohan, N., T. M. Undeland, and W. P. Robbins. *Power Electronics: Converters, Applications, and Design*. New York: John Wiley & Sons, 1995.

[15] Nise, Norman S. *Control Systems Engineering.* . Addison-Wesley Publishing Company, 1995.

[16] Norton, Robert L. *Machine Design.* . Upper Saddle River, NJ: Prentice Hall, 1998.

[17] Rajagopalan, V. *Computer-Aided Analysis of Power Electronic Systems.* New York: Marcel Dekker, 1987.

[18] "Recommended Practice for Excitation System Models for Power System Stability Studies."*IEEE Standard 421.5,* 2002.

[19] Séguier, Guy. *Electronique de puissance*. Paris: Dunod, 1999.

[20] Sen, P.C. *Thyristor DC Drives*. New York: John Wiley & Sons, 1981.

[21] Shepherd, C. M. "Design of Primary and Secondary Cells - Part 2. An equation describing battery discharge." Journal of Electrochemical Society. Volume 112, Jul. 1965, pp. 657–664.

[22] Tremblay, O. *Modélisation, simulation et commande de la machine synchrone à aimants à force contre-électromotrice trapézoïdale.* École de Technologie Supérieure, 2006.

[23] Tremblay, O., Dessaint, L.-A., Dekkiche, A.-I. "A Generic Battery Model for the Dynamic Simulation of Hybrid Electric Vehicles." *Vehicle Power and Propulsion Conference, 2007. VPPC 2007. IEEE* 9–12 Sept. 2007, pp. 284–289.