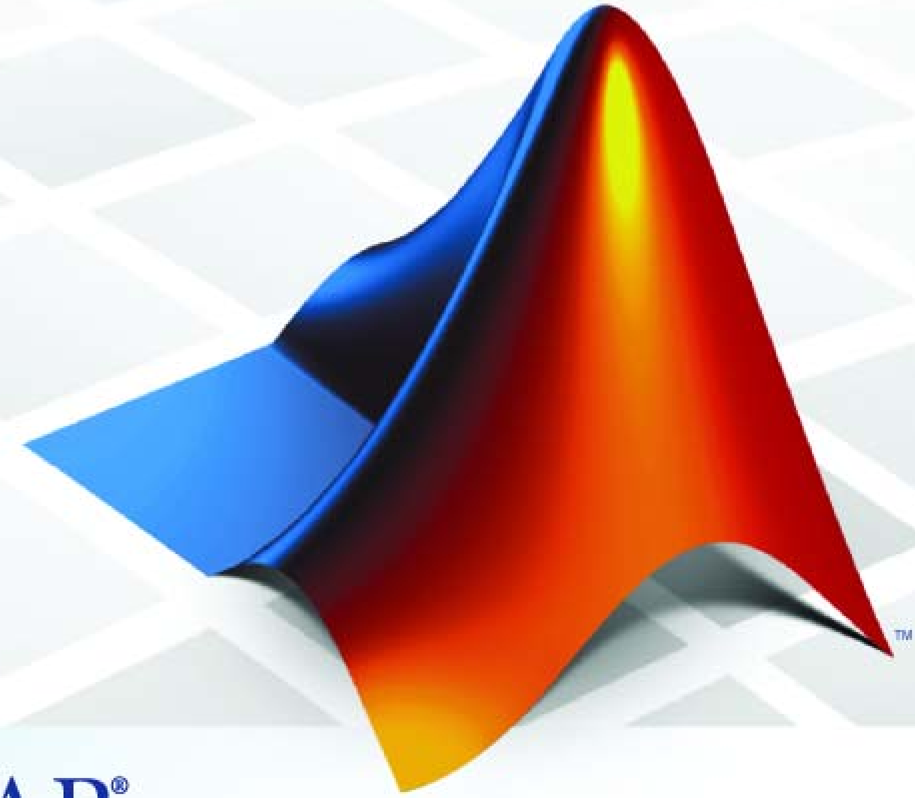
SimPowerSystems™ 5

Reference

Hydro-Québec



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SimPowerSystems™ Reference

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Revision History

January 1998	First printing	Version 1.0 (Release 10)
September 2000	Second printing	Revised for Version 2.1 (Release 12)
June 2001	Online only	Revised for Version 2.2 (Release 12.1)
July 2002	Online only	Revised for Version 2.3 (Release 13) (Renamed from *Power System Blockset User's Guide*)
February 2003	Third printing	Revised for Version 3.0 (Release 13SP1)
June 2004	Online only	Revised for Version 3.1 (Release 14)
October 2004	Fourth printing	Revised for Version 4.0 (Release 14SP1)
March 2005	Online only	Revised for Version 4.0.1 (Release 14SP2)
May 2005	Online only	Revised for Version 4.1 (Release 14SP2+)
September 2005	Online only	Revised for Version 4.1.1 (Release 14SP3)
March 2006	Online only	Revised for Version 4.2 (Release 2006a)
September 2006	Online only	Revised for Version 4.3 (Release 2006b)
March 2007	Online only	Revised for Version 4.4 (Release 2007a)
September 2007	Online only	Revised for Version 4.5 (Release 2007b)
March 2008	Online only	Revised for Version 4.6 (Release 2008a)
October 2008	Online only	Revised for Version 5.0 (Release 2008b)
March 2009	Online only	Revised for Version 5.1 (Release 2009a)
September 2009	Online only	Revised for Version 5.2 (Release 2009b)
March 2010	Online only	Revised for Version 5.2.1 (Release 2010a)

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Block Reference

Electrical Sources

AC Current Source	Implement sinusoidal current source
AC Voltage Source	Implement sinusoidal voltage source
Battery	Implement generic battery model
Controlled Current Source	Implement controlled current source
Controlled Voltage Source	Implement controlled voltage source
DC Voltage Source	Implement DC voltage source
Three-Phase Programmable Voltage Source	Implement three-phase voltage source with programmable time variation of amplitude, phase, frequency, and harmonics
Three-Phase Source	Implement three-phase source with internal R-L impedance

Elements

Breaker	Implement circuit breaker opening at current zero crossing
Connection Port	Create Physical Modeling connector port for subsystem
Distributed Parameter Line	Implement N-phase distributed parameter transmission line model with lumped losses
Ground	Provide connection to ground
Grounding Transformer	Implement three-phase grounding transformer providing a neutral in three-wire system
Linear Transformer	Implement two- or three-winding linear transformer

Multi-Winding Transformer	Implement multi-winding transformer with taps
Mutual Inductance	Implement inductances with mutual coupling
Neutral	Implement common node in circuit
Parallel RLC Branch	Implement parallel RLC branch
Parallel RLC Load	Implement linear parallel RLC load
PI Section Line	Implement single-phase transmission line with lumped parameters
Saturable Transformer	Implement two- or three-winding saturable transformer
Series RLC Branch	Implement series RLC branch
Series RLC Load	Implement linear series RLC load
Surge Arrester	Implement metal-oxide surge arrester
Three-Phase Breaker	Implement three-phase circuit breaker opening at current zero crossing
Three-Phase Dynamic Load	Implement three-phase dynamic load with active power and reactive power as function of voltage or controlled from external input
Three-Phase Fault	Implement programmable phase-to-phase and phase-to-ground fault breaker system
Three-Phase Harmonic Filter	Implement four types of three-phase harmonic filters using RLC components
Three-Phase Mutual Inductance Z1-Z0	Implement three-phase impedance with mutual coupling among phases
Three-Phase Parallel RLC Branch	Implement three-phase parallel RLC branch

Three-Phase Parallel RLC Load	Implement three-phase parallel RLC load with selectable connection
Three-Phase PI Section Line	Implement three-phase transmission line section with lumped parameters
Three-Phase Series RLC Branch	Implement three-phase series RLC branch
Three-Phase Series RLC Load	Implement three-phase series RLC load with selectable connection
Three-Phase Transformer (Three Windings)	Implement three-phase transformer with configurable winding connections
Three-Phase Transformer (Two Windings)	Implement three-phase transformer with configurable winding connections
Three-Phase Transformer 12 Terminals	Implement three single-phase, two-winding transformers where all terminals are accessible
Three-Phase Transformer Inductance Matrix Type (Three Windings)	Implement three-phase three-winding transformer with configurable winding connections and core geometry
Three-Phase Transformer Inductance Matrix Type (Two Windings)	Implement three-phase two-winding transformer with configurable winding connections and core geometry
Zigzag Phase-Shifting Transformer	Implement zigzag phase-shifting transformer with configurable secondary winding connection

Power Electronics

Diode	Implement diode model
GTO	Implement gate turn off (GTO) thyristor model
Ideal Switch	Implement ideal switch device
IGBT	Implement insulated gate bipolar transistor (IGBT)
IGBT/Diode	Implements ideal IGBT, GTO, or MOSFET and antiparallel diode
MOSFET	Implement MOSFET model
Three-Level Bridge	Implement three-level neutral point clamped (NPC) power converter with selectable topologies and power switching devices
Thyristor	Implement thyristor model
Universal Bridge	Implement universal power converter with selectable topologies and power electronic devices

Machines

Asynchronous Machine	Model the dynamics of three-phase asynchronous machine, also known as induction machine
DC Machine	Implement wound-field or permanent magnet DC machine
Excitation System	Provide excitation system for synchronous machine and regulate its terminal voltage in generating mode

Generic Power System Stabilizer	Implement generic power system stabilizer for synchronous machine
Hydraulic Turbine and Governor	Model hydraulic turbine and proportional-integral-derivative (PID) governor system
Machine Measurement Demux	Split measurement signal of machine models into separate signals
Multiband Power System Stabilizer	Implement multiband power system stabilizer
Permanent Magnet Synchronous Machine	Model the dynamics of three-phase permanent magnet synchronous machine with sinusoidal or trapezoidal back electromotive force (back EMF)
Simplified Synchronous Machine	Model the dynamics of simplified three-phase synchronous machine
Single Phase Asynchronous Machine	Model the dynamics of single phase asynchronous machine with squirrel-cage rotor
Steam Turbine and Governor	Model the dynamics of speed governing system, steam turbine, and multimass shaft
Stepper Motor	Implement stepper motor model
Switched Reluctance Motor	Model the dynamics of switched reluctance motor
Synchronous Machine	Model the dynamics of three-phase round-rotor or salient-pole synchronous machine

Applications

Electric Drives (p. 1-7)	AC and DC electric drives models
Flexible AC Transmission Systems (FACTS) (p. 1-9)	FACTS models
Distributed Resources (DR) (p. 1-10)	Wind turbine models

Electric Drives

DC Drives (p. 1-7)	DC electric drives
AC Drives (p. 1-8)	AC electric drives
Shafts and Speed Reducers (p. 1-8)	Shafts and speed reducers
Extra Sources (p. 1-9)	Extra electrical sources

DC Drives

Four-Quadrant Chopper DC Drive	Implement four-quadrant chopper DC drive
Four-Quadrant Single-Phase Rectifier DC Drive	Implement single-phase dual-converter DC drive with circulating current
Four-Quadrant Three-Phase Rectifier DC Drive	Implement three-phase dual-converter DC drive with circulating current
One-Quadrant Chopper DC Drive	Implement one-quadrant chopper (buck converter topology) DC drive
Two-Quadrant Chopper DC Drive	Implement two-quadrant chopper (buck-boost converter topology) DC drive

Two-Quadrant Single-Phase Rectifier DC Drive	Implement two-quadrant single-phase rectifier DC drive
Two-Quadrant Three-Phase Rectifier DC Drive	Implement two-quadrant three-phase rectifier DC drive

AC Drives

Brushless DC Motor Drive	Implement brushless DC motor drive using Permanent Magnet Synchronous Motor (PMSM) with trapezoidal back electromotive force (BEMF)
DTC Induction Motor Drive	Implement direct torque and flux control (DTC) induction motor drive model
Field-Oriented Control Induction Motor Drive	Implement field-oriented control (FOC) induction motor drive model
PM Synchronous Motor Drive	Implement Permanent Magnet Synchronous Motor (PMSM) vector control drive
Self-Controlled Synchronous Motor Drive	Implement Self-Controlled Synchronous Motor Drive
Six-Step VSI Induction Motor Drive	Implement six-step inverter fed Induction Motor Drive
Space Vector PWM VSI Induction Motor Drive	Implement space vector PWM VSI induction motor drive

Shafts and Speed Reducers

Mechanical Shaft	Implement mechanical shaft
Speed Reducer	Implement speed reducer

Extra Sources

Battery	Implement generic battery model
Fuel Cell Stack	Implement generic hydrogen fuel cell stack model

Flexible AC Transmission Systems (FACTS)

Power-Electronics Based FACTS (p. 1-9)	Power-electronics based models
Transformers (p. 1-10)	Transformer models

Power-Electronics Based FACTS

Static Synchronous Compensator (Phasor Type)	Implement phasor model of three-phase static synchronous compensator
Static Synchronous Series Compensator (Phasor Type)	Implement phasor model of three-phase static synchronous series compensator
Static Var Compensator (Phasor Type)	Implement phasor model of three-phase static var compensator
Unified Power Flow Controller (Phasor Type)	Implement phasor model of three-phase unified power flow controller

Transformers

Three-Phase OLTC Phase Shifting Transformer Delta-Hexagonal (Phasor Type)	Implement phasor model of three-phase OLTC phase-shifting transformer using delta hexagonal connection
Three-Phase OLTC Regulating Transformer (Phasor Type)	Implement phasor model of three-phase OLTC regulating transformer

Distributed Resources (DR)

Wind Turbine	Implement model of variable pitch wind turbine
Wind Turbine Doubly-Fed Induction Generator (Phasor Type)	Implement phasor model of variable speed doubly-fed induction generator driven by wind turbine
Wind Turbine Induction Generator (Phasor Type)	Implement phasor model of squirrel-cage induction generator driven by variable pitch wind turbine

Measurements

Current Measurement	Measure current in circuit
Impedance Measurement	Measure impedance of circuit as function of frequency
Multimeter	Measure voltages and currents specified in dialog boxes of SimPowerSystems™ blocks
Three-Phase V-I Measurement	Measure three-phase currents and voltages in circuit
Voltage Measurement	Measure voltage in circuit

Extras

Signal Measurements (p. 1-11)	Specialized measurement blocks
Signal and Pulse Sources (p. 1-11)	Specialized source blocks

Signal Measurements

abc_to_dq0 Transformation	Perform Park transformation from three-phase (abc) reference frame to dq0 reference frame
Active & Reactive Power	Measure active and reactive powers of voltage-current pair
dq0_to_abc Transformation	Perform Park transformation from dq0 reference frame to abc reference frame
Fourier	Perform Fourier analysis of signal
RMS	Measure root mean square (RMS) value of signal
Three-Phase Sequence Analyzer	Measure positive-, negative-, and zero-sequence components of three-phase signal
Total Harmonic Distortion	Measure total harmonic distortion (THD) of signal

Signal and Pulse Sources

PWM Generator	Generate pulses for carrier-based two-level pulse width modulator (PWM) in converter bridge
Synchronized 12-Pulse Generator	Implement synchronized pulse generator to fire thyristors of twelve-pulse converter

Synchronized 6-Pulse Generator	Implement synchronized pulse generator to fire thyristors of six-pulse converter
Timer	Generate signal changing at specified transition times

Powergui

Powergui	Environment block for SimPowerSystems models

2

Blocks — Alphabetical List

abc_to_dq0 Transformation

Purpose

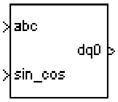
Perform Park transformation from three-phase (abc) reference frame to dq0 reference frame

Library

Extras/Measurements

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

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:

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

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

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

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.

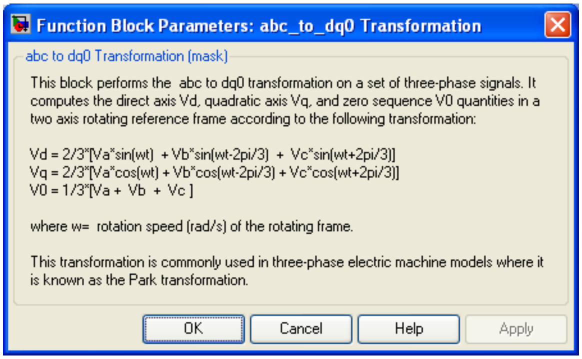
You can use the Math Function block and the Trigonometric Function block to obtain the modulus and angle of V_1:

$$|V_1| = \sqrt{V_q^{\ 2} + V_d^{\ 2}}$$

$$\angle V_1 = \mathrm{atan2}(V_q / V_d)$$

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



This block performs the abc to dq0 transformation on a set of three-phase signals. It computes the direct axis Vd, quadratic axis Vq, and zero sequence V0 quantities in a two axis rotating reference frame according to the following transformation:

Vd = 2/3*[Va*sin(wt) + Vb*sin(wt-2pi/3) + Vc*sin(wt+2pi/3)]
Vq = 2/3*[Va*cos(wt) + Vb*cos(wt-2pi/3) + Vc*cos(wt+2pi/3)]
V0 = 1/3*[Va + Vb + Vc]

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

This transformation is commonly used in three-phase electric machine models where it is known as the Park transformation.

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.

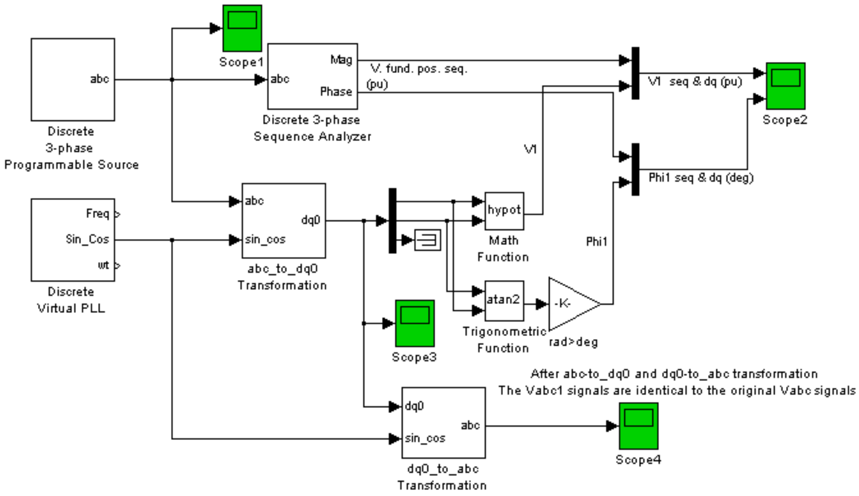
`dq0`

The output is a vectorized signal containing the three sequence components [d q o].

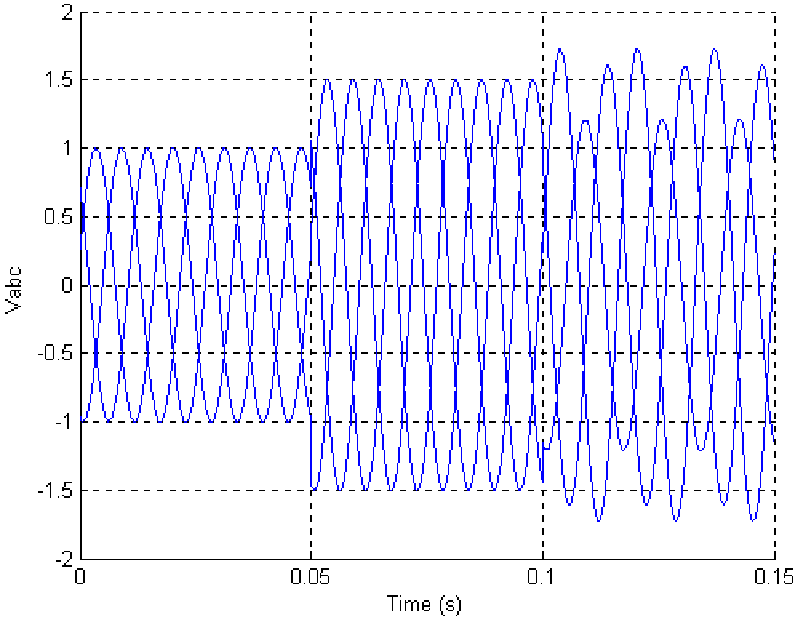
Example

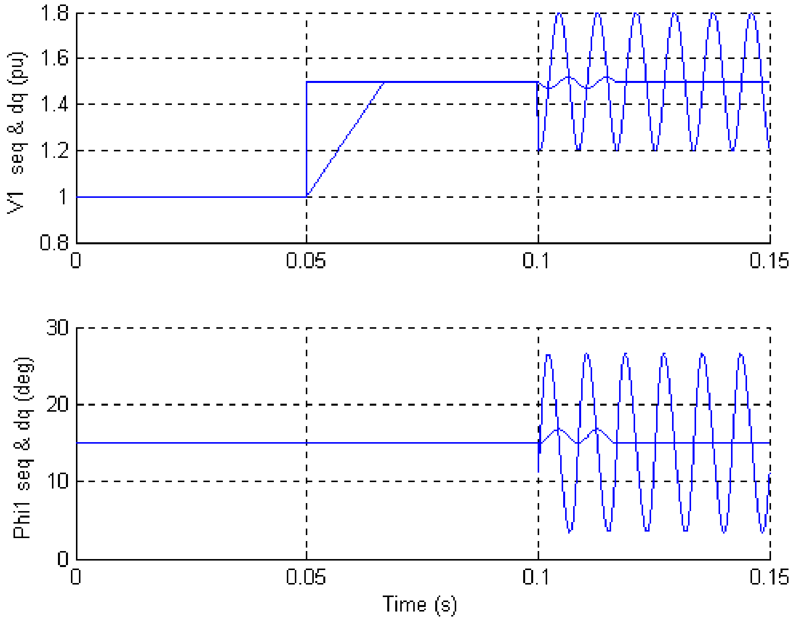
The `power_3phsignaldq` demo uses a Discrete Three-Phase Programmable Source block to generate a 1 pu, 15 degrees positive sequence voltage. At 0.05 second the positive sequence voltage is increased to 1.5 pu and at 0.1 second an imbalance is introduced by the addition of a 0.3 pu negative sequence component 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

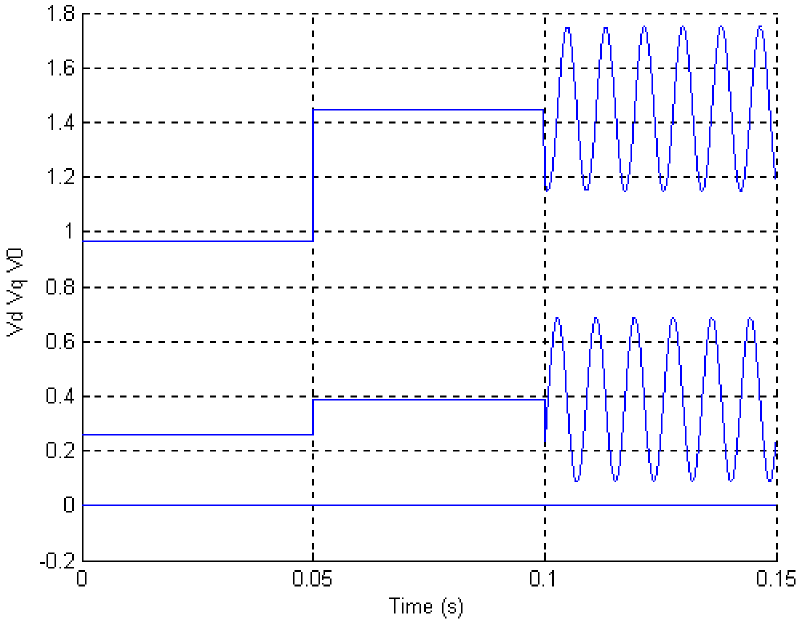


Start the simulation and observe the instantaneous signals Vabc (Scope1), the signals returned by the Sequence Analyzer (Scope2), and the abc-to-dq0 transformation (Scope3).


2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Vabc
0
0.05
0.1
0.15
Time (s)



Note that 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-dqo 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 dq0_to_abc Transformation

AC Current Source

Purpose

Implement sinusoidal current source

Library

Electrical Sources

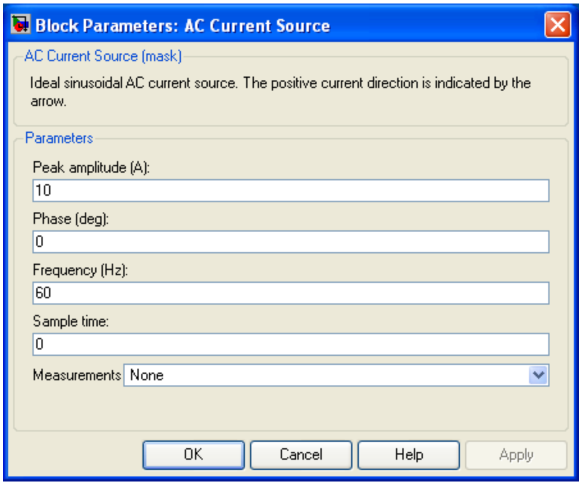
Description

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:

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

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



Block Parameters: AC Current Source

AC Current Source (mask)

Ideal sinusoidal AC current source. The positive current direction is indicated by the arrow.

Parameters

Peak amplitude (A): 10

Phase (deg): 0

Frequency (Hz): 60

Sample time: 0

Measurements: None

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

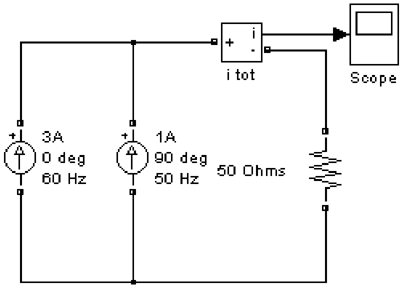
Select `Current` to measure the current flowing through the AC Current Source block.

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` demo uses two AC Current Source blocks in parallel to sum two sinusoidal currents in a resistor.



See Also Controlled Current Source, Multimeter

Purpose

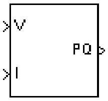
Measure active and reactive powers of voltage-current pair

Library

Extras/Measurements

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

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.

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

$$Q = \frac{1}{T}\int_{(t-T)}^{t} (V(\omega t) \times I(\omega t - \pi/2))dt$$

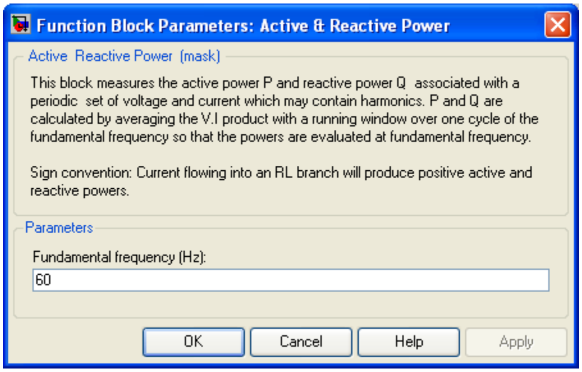
where T = 1/(fundamental frequency).

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 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



Active Reactive Power (mask)

This block measures the active power P and reactive power Q associated with a periodic set of voltage and current which may contain harmonics. P and Q are calculated by averaging the V.I product with a running window over one cycle of the fundamental frequency so that the powers are evaluated at fundamental frequency.

Sign convention: Current flowing into an RL branch will produce positive active and reactive powers.

Parameters

Fundamental frequency (Hz): 60

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.

`I`

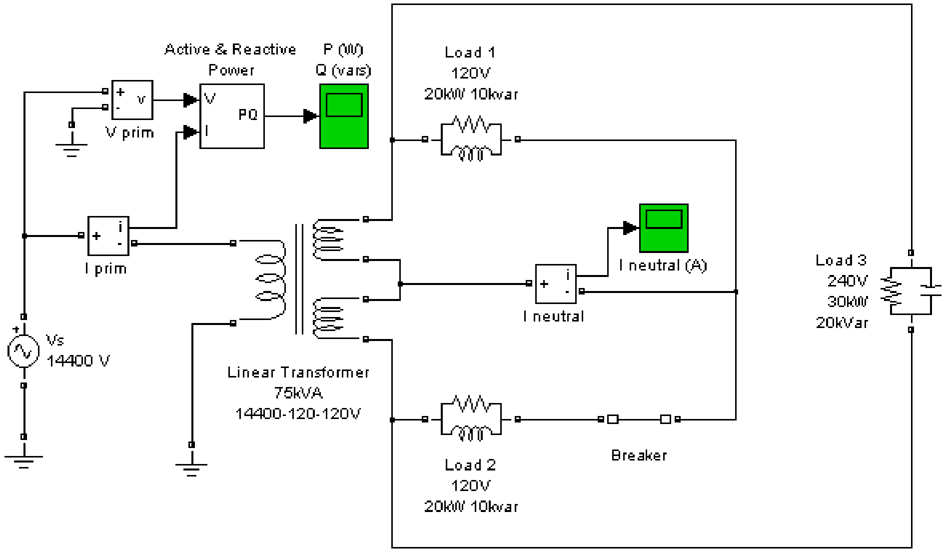
The second input is the instantaneous current.

`PQ`

The output is a vector [P Q] of the active and reactive powers.

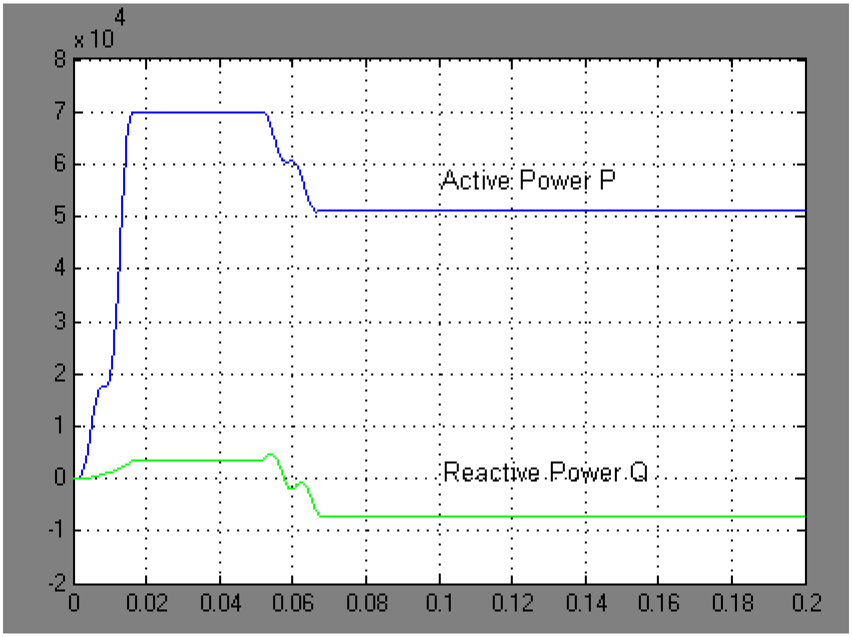
Example

The `power_transfo` demo 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 an Active & Reactive Power block. When the breaker opens, the active power decreases from 70 kW to 50 kW.


x 10^4
8
7
6
5
4
3
2
1
0
-1
-2
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
Active Power P
Reactive Power Q

AC Voltage Source

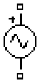
Purpose

Implement sinusoidal voltage source

Library

Electrical Sources

Description

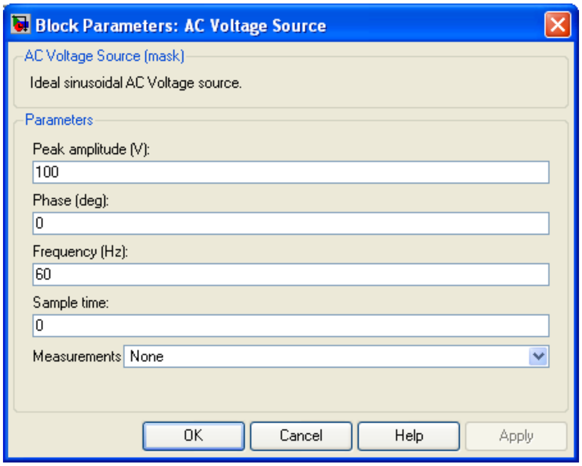


The AC Voltage Source block implements an ideal AC voltage source. The generated voltage U is described by the following relationship:

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

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



Block Parameters: AC Voltage Source

AC Voltage Source (mask)

Ideal sinusoidal AC Voltage source.

Parameters

Peak amplitude (V): 100

Phase (deg): 0

Frequency (Hz): 60

Sample time: 0

Measurements: None

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

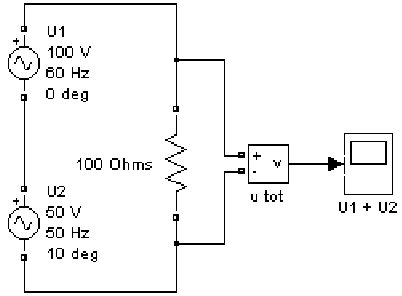
Select `Voltage` to measure the voltage across the terminals of the AC Voltage Source block.

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:`

Example

The `power_acvoltage` demo 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

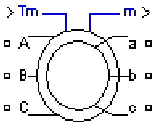
Purpose

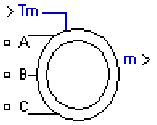
Model the dynamics of three-phase asynchronous machine, also known as induction machine

Library

Machines

Description





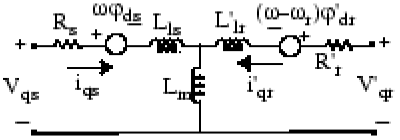
The Asynchronous Machine block operates in either generator or motor mode. The mode of operation is dictated by the sign of the mechanical torque:

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

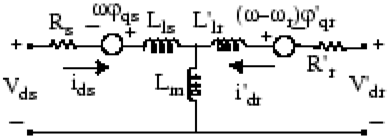
The electrical part of the machine is represented by a fourth-order state-space model and the mechanical part by a second-order system. All electrical variables and parameters are referred to the stator. This is indicated by the prime signs in the machine equations given below. All stator and rotor quantities are in the arbitrary two-axis reference frame (dq frame). The subscripts used are defined as follows:

Subscript	Definition
d	d axis quantity
q	q axis quantity
r	Rotor quantity
s	Stator quantity
l	Leakage inductance
m	Magnetizing inductance

Electrical System



q axis



d axis

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

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

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

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

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

where

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

$$\varphi_{ds} = L_s i_{ds} + L_m i'_{dr}$$

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

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

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

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

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):

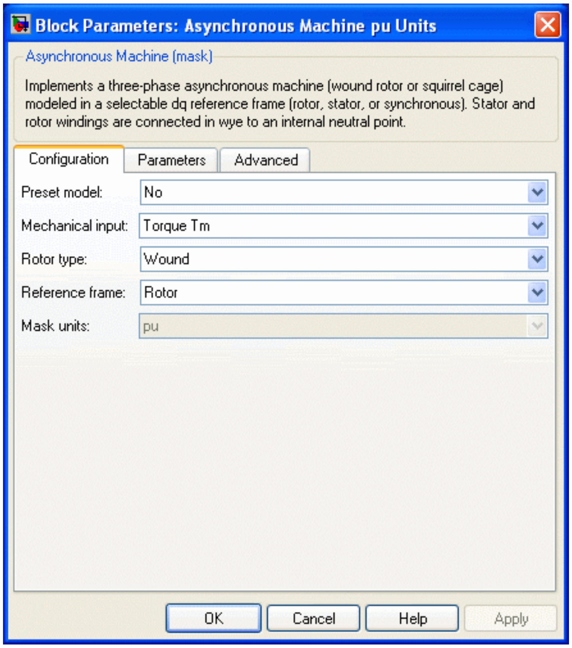
Parameter	Definition
R_s, L_{ls}	Stator resistance and leakage inductance
R'_r, L'_{lr}	Rotor resistance and leakage inductance
L_m	Magnetizing inductance
L_s, L'_r	Total stator and rotor inductances

Parameter	Definition
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. 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

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. Depending on the dialog box you choose to use, SimPowerSystems software automatically converts the parameters you enter into per unit parameters. The Simulink® model of the Asynchronous Machine block uses pu parameters.

Configuration Tab



Block Parameters: Asynchronous Machine pu Units

Asynchronous Machine (mask)

Implements a three-phase asynchronous machine (wound rotor or 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.

Preset model: No

Mechanical input: Torque Tm

Rotor type: Wound

Reference frame: Rotor

Mask units: pu

Preset model

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).

Select one of the preset models to load the corresponding electrical and mechanical parameters in the entries of the dialog box. Note that 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, as described below.

When you select a preset model, the electrical and mechanical parameters in the **Parameters** tab of the dialog box become unmodifiable (grayed out). To start from a given preset model and then modify machine parameters, you have to do the following:

1. Select the desired preset model to initialize the parameters.
2. Change the **Preset model** parameter value to `No`. This will 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 wish, then click **Apply**.

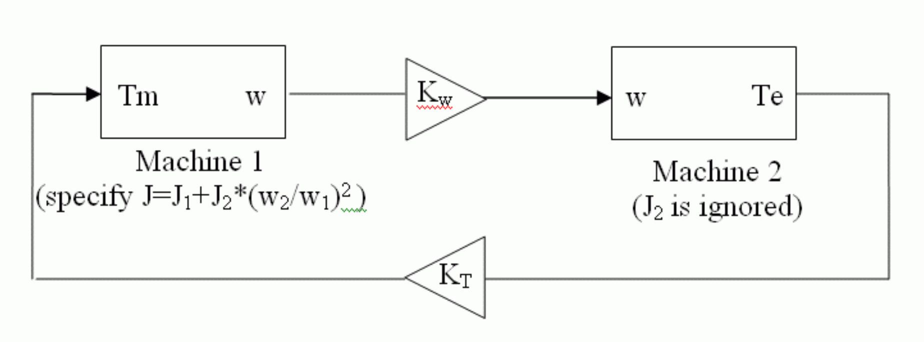
Mechanical input

Allows you to select either the torque applied to the shaft or the rotor speed as the Simulink signal applied to the block's input.

Select **Torque Tm** to specify a torque input, in N.m or in pu, and change labeling of the block's 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 the following: 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's 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 and interfacing with SimMechanics™ and SimDriveline™ models.

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.



Rotor type

Specifies the branching for the rotor windings.

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 also justifies the fact 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 ß in each reference frame (Θ_e is the position of the synchronously rotating reference frame).

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

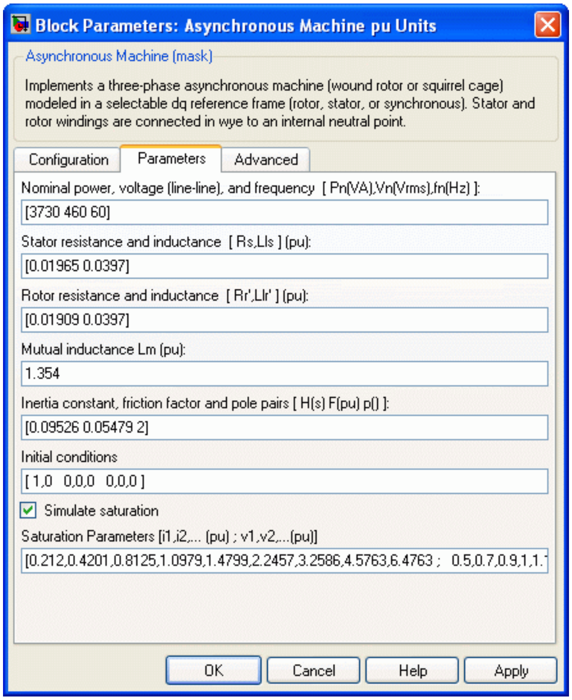
The choice of reference frame affects the waveforms of all dq variables. It also affects the simulation speed and in certain cases the accuracy of the results. The following guidelines are suggested in [1]:

- 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.

Mask units

Specifies the units of the electrical and mechanical parameters of the model. This parameter is not modifiable; it is provided for information purposes only.

Parameters Tab



Block Parameters: Asynchronous Machine pu Units

Asynchronous Machine (mask)

Implements a three-phase asynchronous machine (wound rotor or 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.

Nominal power, voltage (line-line), and frequency [Pn(VA),Vn(Vrms),fn(Hz)]:
[3730 460 60]

Stator resistance and inductance [Rs,Lls] (pu):
[0.01965 0.0397]

Rotor resistance and inductance [Rr',Llr'] (pu):
[0.01909 0.0397]

Mutual inductance Lm (pu):
1.354

Inertia constant, friction factor and pole pairs [H(s) F(pu) p()]:
[0.09526 0.05479 2]

Initial conditions
[1,0 0,0,0 0,0,0]

☑ Simulate saturation

Saturation Parameters [i1,i2,... (pu) ; v1,v2,...(pu)]
[0.212,0.4201,0.8125,1.0979,1.4799,2.2457,3.2586,4.5763,6.4763 ; 0.5,0.7,0.9,1,1.

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.

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}, $phase_{as}$, $phase_{bs}$, $phase_{cs}$]

For the wound-rotor machine, 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}, $phase_{ar}$, $phase_{br}$, $phase_{cr}$]

For the squirrel cage machine, the initial conditions can be computed by the load flow utility in the Powergui block.

Simulate saturation

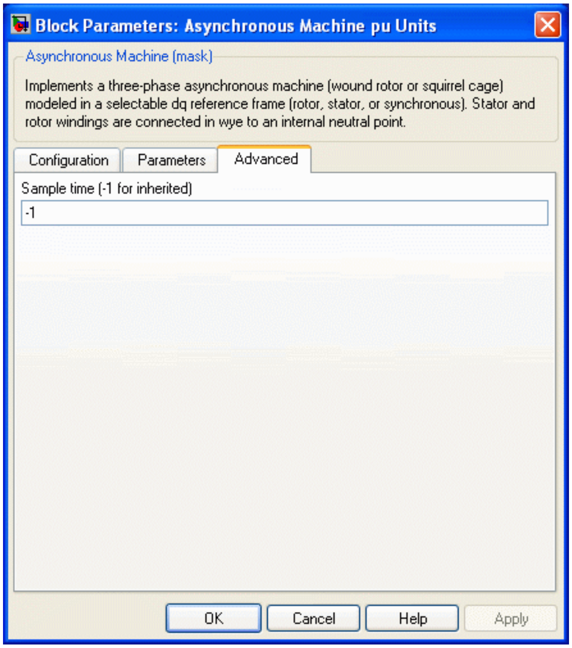
Specifies whether magnetic saturation of rotor and stator iron is simulated or not.

Saturation parameters

Specifies the no-load saturation curve parameters. Magnetic saturation of stator and rotor iron (saturation of the mutual flux) is modeled by a nonlinear function (in this case a polynomial) using points of the no-load saturation curve. You must enter a 2-by-n matrix, where n is the number of points taken from the saturation curve. The first row of this matrix contains the values of stator currents, while the second row contains values of corresponding terminal voltages (stator voltages). The first point (first column of the matrix) must correspond to the point where the effect of saturation begins.

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

Advanced Tab



Block Parameters: Asynchronous Machine pu Units

Asynchronous Machine (mask)

Implements a three-phase asynchronous machine (wound rotor or 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.

Sample time (-1 for inherited): -1

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'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, in rad/s.

`m`

The Simulink output of the block is a vector containing 21 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.

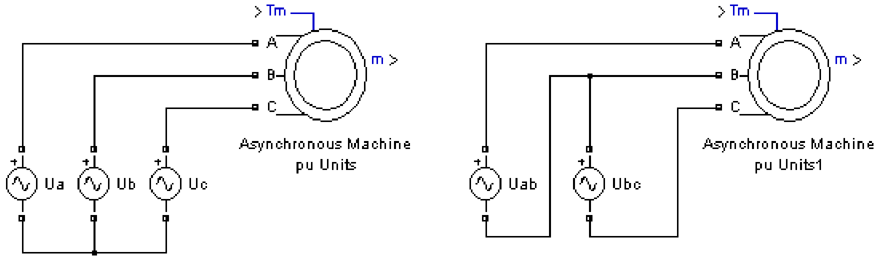
Signal	Definition	Units	Symbol
1	Rotor current ir_a	A or pu	i'_{ra}
2	Rotor current ir_b	A or pu	i'_{rb}
3	Rotor current ir_c	A or pu	i'_{rc}
4	Rotor current iq	A or pu	i'_{qr}
5	Rotor current id	A or pu	i'_{dr}
6	Rotor flux phir_q	V.s or pu	φ'_{qr}
7	Rotor flux phir_d	V.s or pu	φ'_{dr}
8	Rotor voltage Vr_q	V or pu	v'_{qr}
9	Rotor voltage Vr_d	V or pu	v'_{d}
10	Stator current is_a	A or pu	i_{sa}
11	Stator current is_b	A or pu	i_{sb}

Signal	Definition	Units	Symbol
12	Stator current is_c	A or pu	i_{sc}
13	Stator current is_q	A or pu	i_{qs}
14	Stator current is_d	A or pu	i_{ds}
15	Stator flux phis_q	V.s or pu	φ_{qs}
16	Stator flux phis_d	V.s or pu	φ_{ds}
17	Stator voltage vs_q	V or pu	v_{qs}
18	Stator voltage vs_d	V or pu	v_{ds}
19	Rotor speed	rad/s	ω_m
20	Electromagnetic torque Te	N.m or pu	T_e
21	Rotor angle thetam	rad	Θ_m

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

Limitations

1. 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.



2 When you use Asynchronous Machine blocks in discrete systems, you might have to use a small parasitic resistive load, connected at the machine terminals, in order 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 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 should be sufficient.

Examples

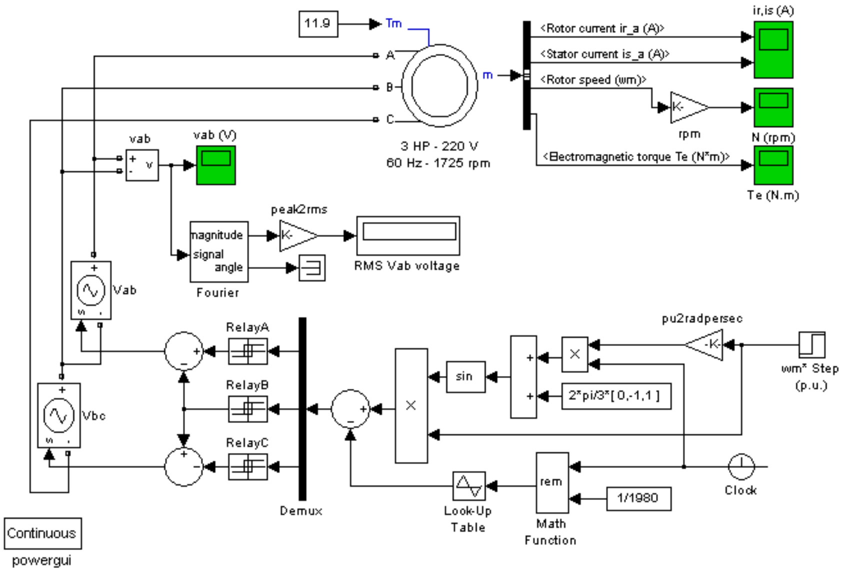
Example 1: Use of the Asynchronous Machine Block in Motor Mode

The `power_pwm` demo 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's 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, which is described in [2]. The base frequency of the sinusoidal reference wave is set at 60 Hz and the triangular carrier wave's frequency is set at 1980 Hz. This corresponds to a frequency modulation factor m_f of 33 (60 Hz x 33 = 1980). It is recommended in [2] that m_f be an odd multiple of three and that the value be as high as possible.

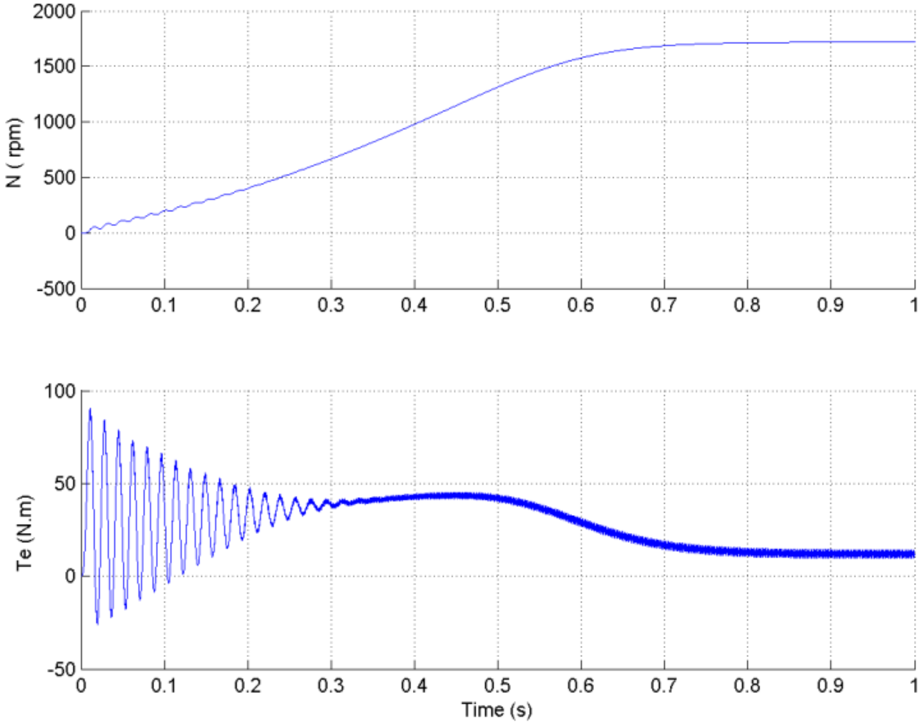
The 3 HP machine is connected to a constant load of nominal value (11.9 N.m). It is started and reaches the set point speed of 1.0 pu at t = 0.9 second.

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



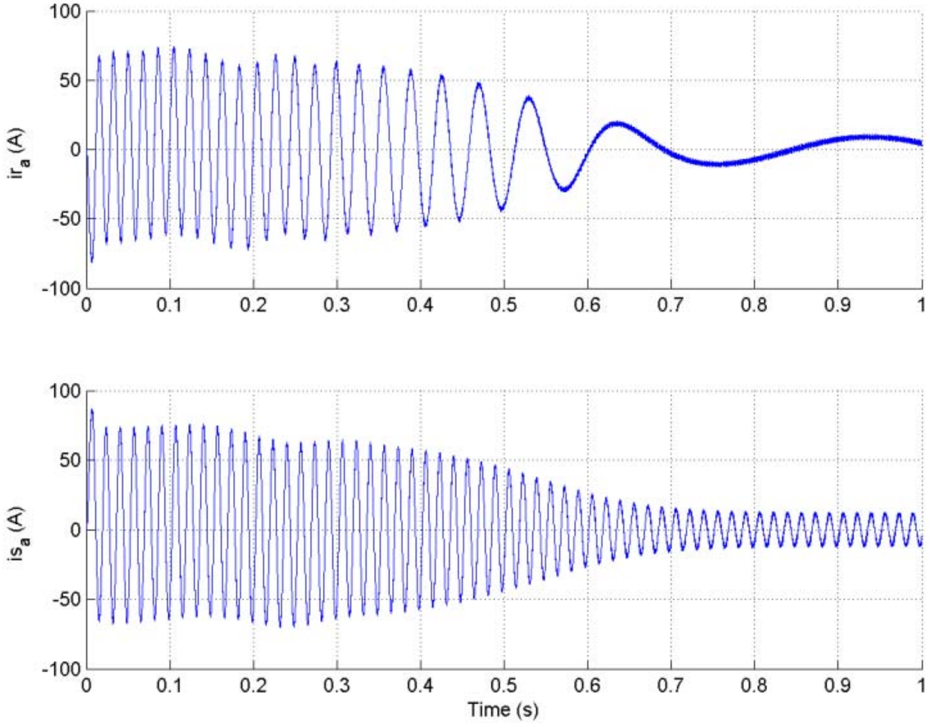
Open the `power_pwm` demo. Note in the simulation parameters that a small relative tolerance is required because of the high switching rate of the inverter.

Run the simulation and observe the machine’s speed and torque.

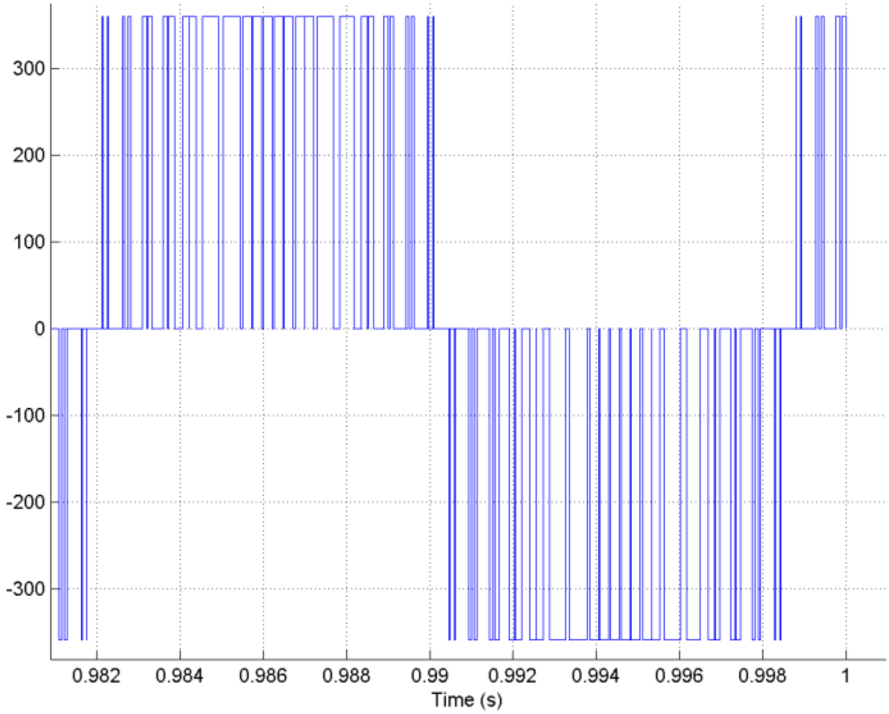


The first graph shows the machine's speed going from 0 to 1725 rpm (1.0 pu). The second graph shows the electromagnetic torque developed by the machine. Because the stator is fed by a PWM inverter, a noisy torque is observed.

However, this noise is not visible in the speed because it is filtered out by the machine's inertia, but it can also be seen in the stator and rotor currents, which are observed next.



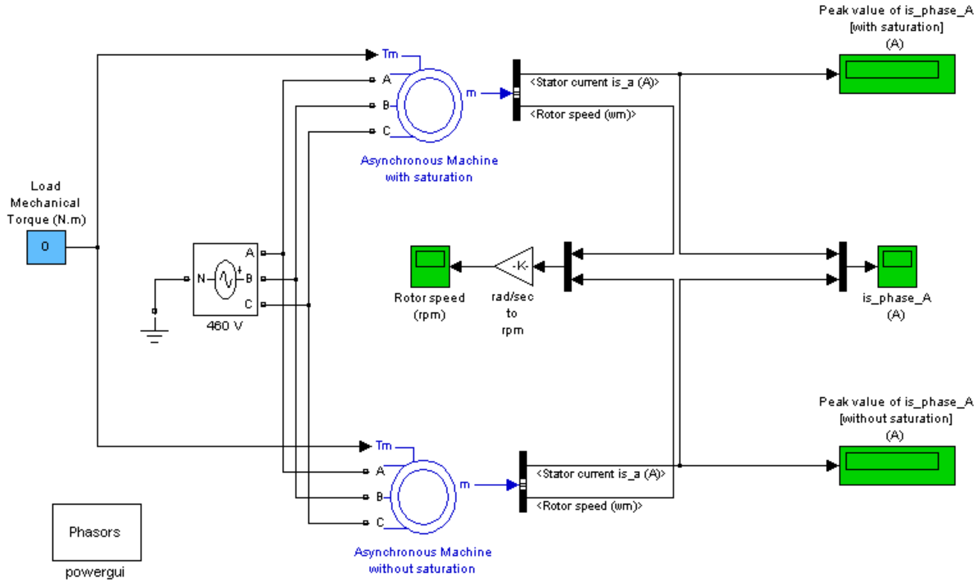
Finally, look at the output of the PWM inverter. Because nothing of interest can be seen at the simulation time scale, the graph concentrates on the last moments of the simulation.



Example 2: Effect of Saturation of the Asynchronous Machine Block

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

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 demo.

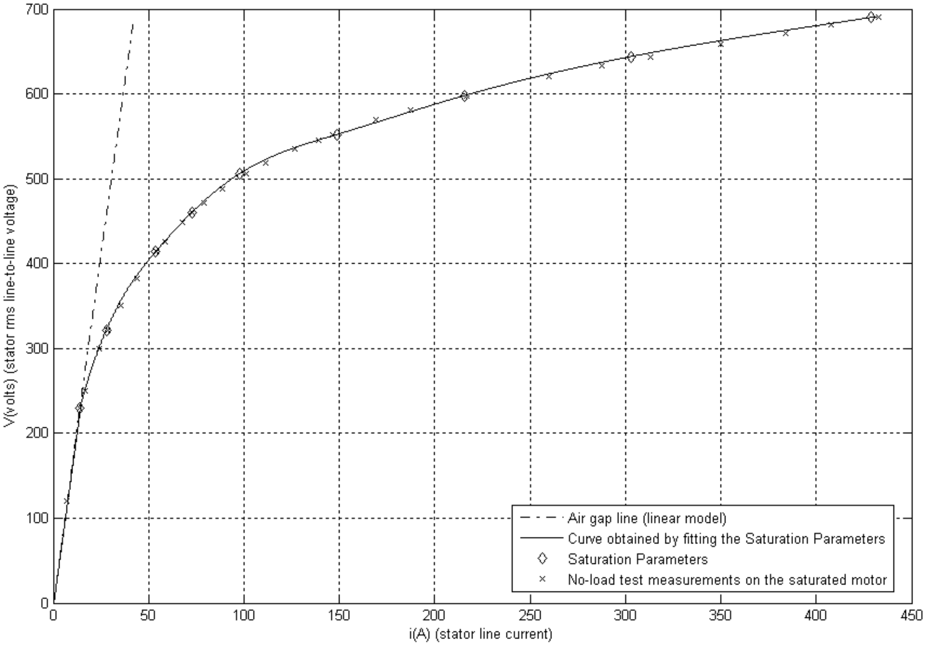


The first simulation, is the no-load steady-state test. The table below contains the values of the **Saturation Parameters** and the measurements obtained by simulating different operating points on the saturated motor (no-load and in steady-state).

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
322	27.81	322	28.39
-	-	351	35.22

Saturation Parameters		Measurements	
Vsat (Vrms L-L)	Isat (peak A)	Vrms L-L	Is_A (peak A)
-	-	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 graph below illustrates these results and shows the accuracy of the saturation model. As you can see, the measured operating points fit well the curve that is plotted from the **Saturation Parameters** data.



Running the simulation with a blocked rotor or with many different values of load torque will allow the observation of other effects of saturation on the stator currents.

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, Section 8.4.1.

See Also

Powergui

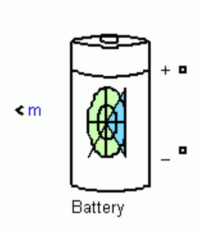
Purpose

Implement generic battery model

Library

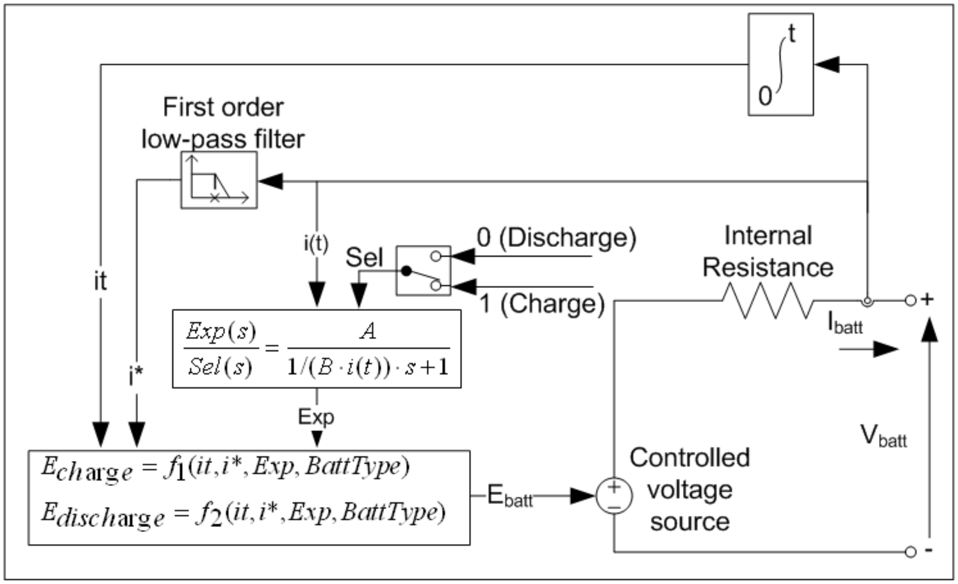
Electrical Sources, Electric Drives/Extra Sources

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)

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

Charge Model (i* < 0)

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

Lithium-Ion Model

Discharge Model (i* > 0)

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

Charge Model (i* < 0)

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

Nickel-Cadmium and Nickel-Metal-Hydride Model

Discharge Model (i* > 0)

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

Charge Model (i*< 0)

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

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)

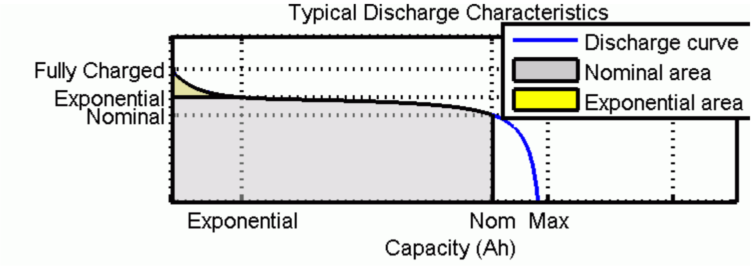
it = Extracted capacity (Ah)

Q = Maximum battery capacity (Ah)

A = Exponential voltage (V)

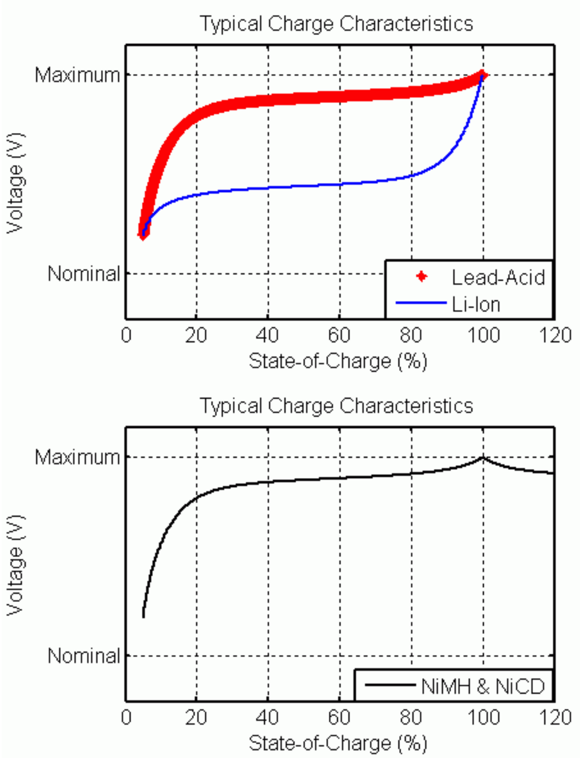
B = Exponential capacity $(Ah)^{-1}$

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:



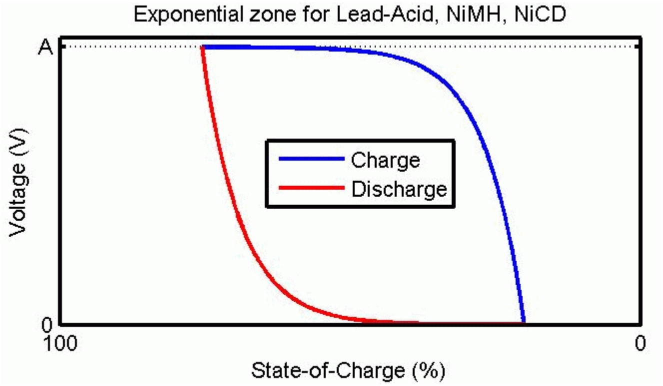
The first section represents the exponential voltage drop when the battery is charged. Depending on the battery type, this area is more or less wide. The second section represents the charge that can be extracted from the battery until the voltage drops below the battery nominal voltage. Finally, the 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:



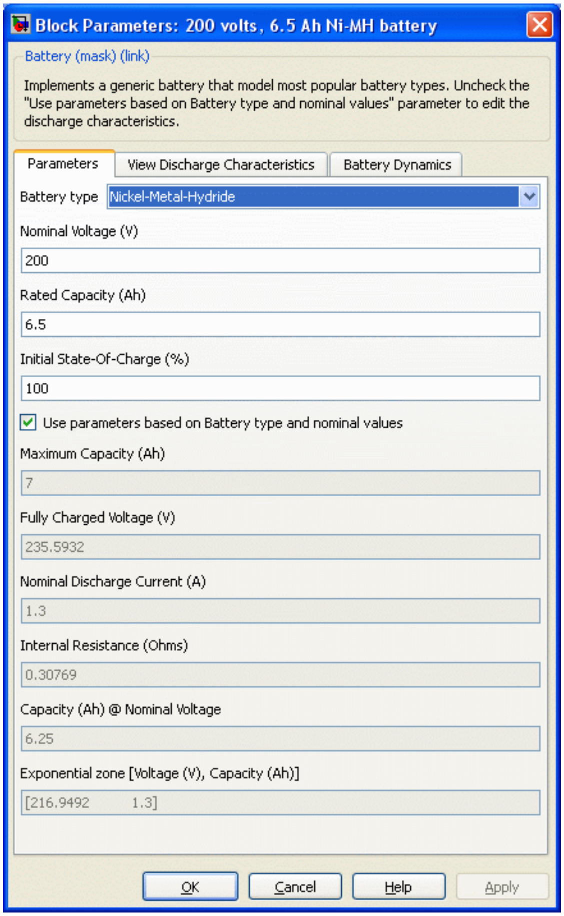
Note that the parameters of the model are deduced from discharge characteristics and assumed to be the same for charging.

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
A
0
Voltage (V)
100
0
State-of-Charge (%)
Charge
Discharge

Dialog Box and Parameters

Parameters Tab



Block Parameters: 200 volts, 6.5 Ah Ni-MH battery

Battery (mask) (link)

Implements a generic battery that model most popular battery types. Uncheck the "Use parameters based on Battery type and nominal values" parameter to edit the discharge characteristics.

Battery type: Nickel-Metal-Hydride

Nominal Voltage (V): 200

Rated Capacity (Ah): 6.5

Initial State-Of-Charge (%): 100

☑ Use parameters based on Battery type and nominal values

Maximum Capacity (Ah): 7

Fully Charged Voltage (V): 235.5932

Nominal Discharge Current (A): 1.3

Internal Resistance (Ohms): 0.30769

Capacity (Ah) @ Nominal Voltage: 6.25

Exponential zone [Voltage (V), Capacity (Ah)]: [216.9492 1.3]

Battery type

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

- Lead-Acid

- Lithium-Ion
- Nickel-Cadmium
- Nickel-Metal-Hydride

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).

Use parameters based on Battery type and nominal values

Load the corresponding parameters in the entries of the dialog box, depending on the selected **Battery 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 **Use parameters based on Battery type and nominal values** 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.

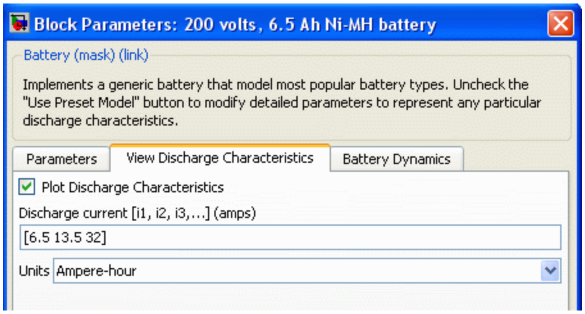
Capacity (Ah) @ Nominal Voltage

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*.

View Discharge Characteristics Tab



Block Parameters: 200 volts, 6.5 Ah Ni-MH battery

Battery (mask) (link)

Implements a generic battery that model most popular battery types. Uncheck the "Use Preset Model" button to modify detailed parameters to represent any particular discharge characteristics.

☑ Plot Discharge Characteristics

Discharge current [i1, i2, i3,...] (amps): [6.5 13.5 32]

Units: Ampere-hour

Plot Discharge Characteristics

If selected, 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. When the checkbox is active, the graph remains on and updates itself when a parameter changes in the dialog box. To clear the figure, uncheck and close the figure.

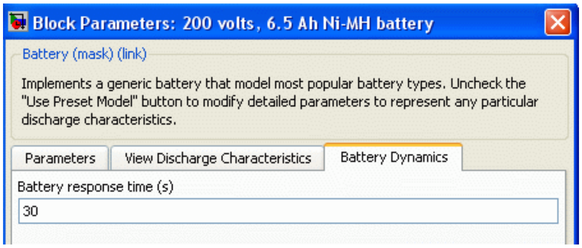
Discharge current

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.

Battery Dynamics Tab



Block Parameters: 200 volts, 6.5 Ah Ni-MH battery

Battery (mask) (link)

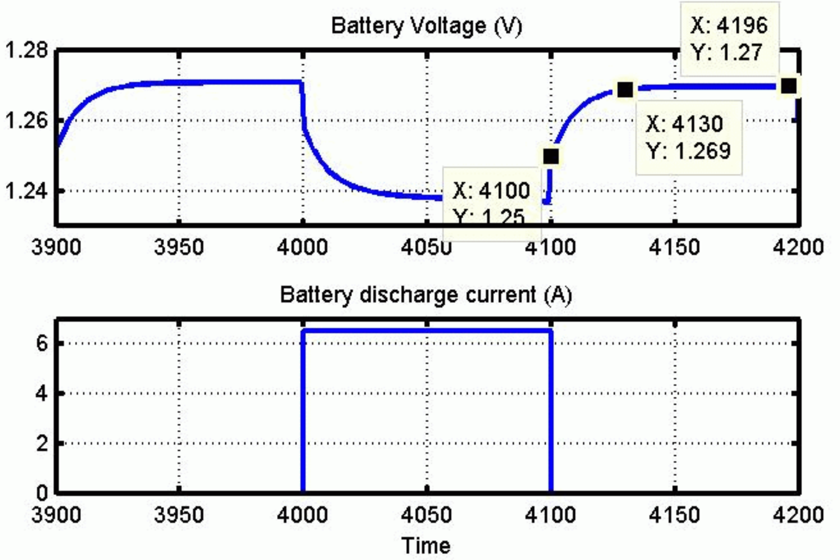
Implements a generic battery that model most popular battery types. Uncheck the "Use Preset Model" button to modify detailed parameters to represent any particular discharge characteristics.

Battery response time (s): 30

Battery response time (s)

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

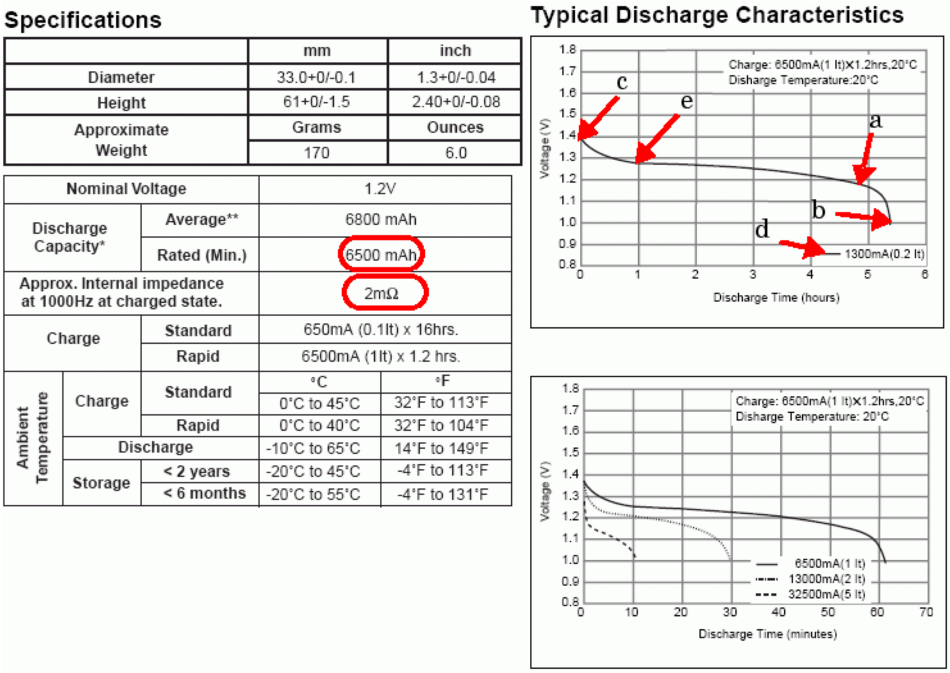
This value represents the voltage dynamics and can be observed when a current step is applied:



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

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 (0.1It) x 16hrs.	
	Rapid		6500mA (1It) x 1.2 hrs.	
Ambient Temperature	Charge	Standard	°C	°F
			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

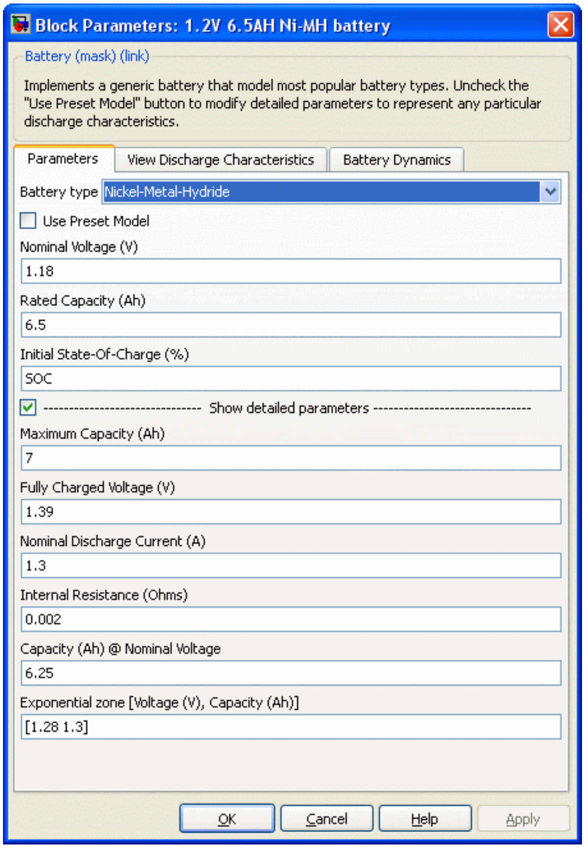
From the specification tables, we obtain the rated capacity and the internal resistance. The other detailed parameters are deduced from the Typical Discharge Characteristics plot:

Parameter	Value
Rated capacity	6.5 Ah
Internal Resistance	2 mΩ
Nominal Voltage [(a)]	1.18 V
Rated Capacity	6.5 Ah

Parameter	Value
Maximum Capacity (b)	7 Ah (5.38h * 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 parameters obtained from the data sheet are entered in the mask of the Battery block as in the following picture:



Battery (mask) (link)

Implements a generic battery that model most popular battery types. Uncheck the "Use Preset Model" button to modify detailed parameters to represent any particular discharge characteristics.

Battery type: Nickel-Metal-Hydride

☐ Use Preset Model

Nominal Voltage (V): 1.18

Rated Capacity (Ah): 6.5

Initial State-Of-Charge (%): SOC

☑ ------------------------------ Show detailed parameters ------------------------------

Maximum Capacity (Ah): 7

Fully Charged Voltage (V): 1.39

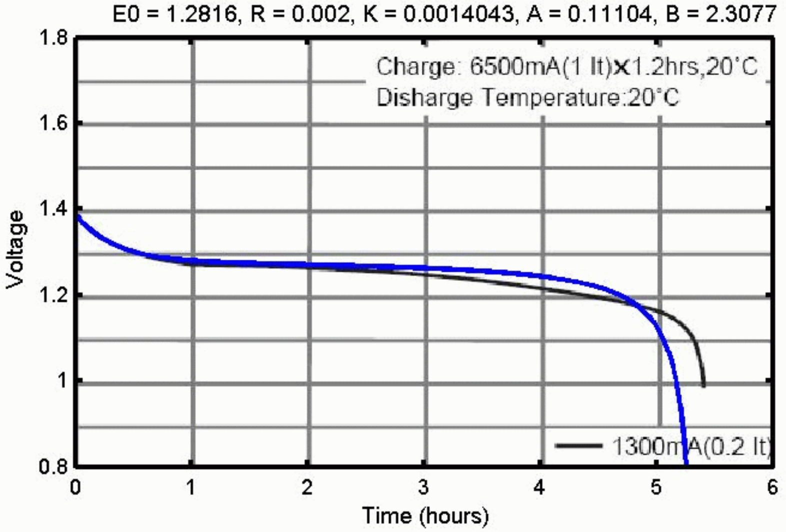
Nominal Discharge Current (A): 1.3

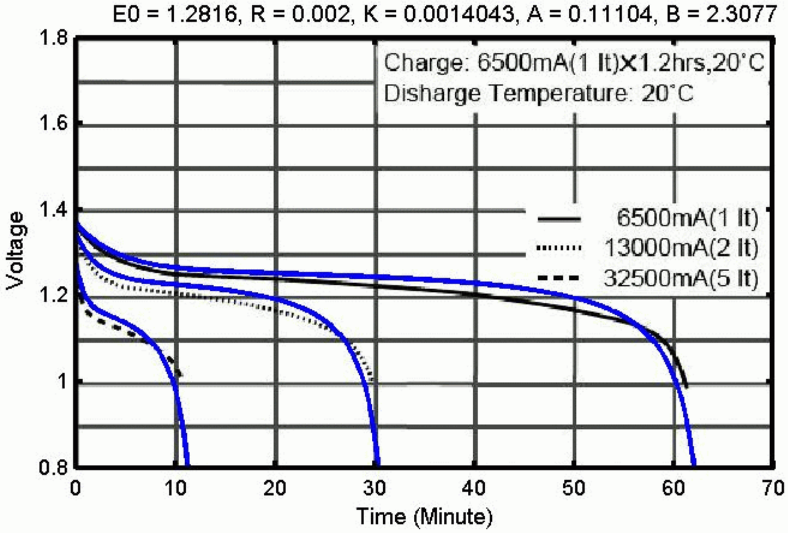
Internal Resistance (Ohms): 0.002

Capacity (Ah) @ Nominal Voltage: 6.25

Exponential zone [Voltage (V), Capacity (Ah)]: [1.28 1.3]

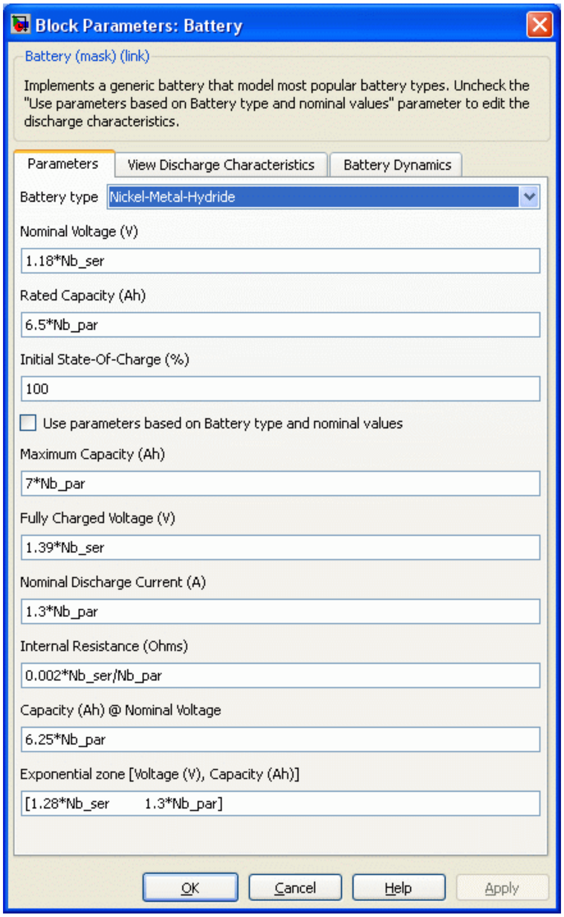
The discharge curves (the dotted line curves in the following plots) obtained with these parameters are similar to the data sheet curves.


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)
Voltage
Time (hours)
1.8
1.6
1.4
1.2
1
0.8
0
1
2
3
4
5
6


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)
Voltage
Time (Minute)
1.8
1.6
1.4
1.2
1
0.8
0
10
20
30
40
50
60
70

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 figure 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:



Implements a generic battery that model most popular battery types. Uncheck the "Use parameters based on Battery type and nominal values" parameter to edit the discharge characteristics.

Battery type: Nickel-Metal-Hydride

Nominal Voltage (V): 1.18*Nb_ser

Rated Capacity (Ah): 6.5*Nb_par

Initial State-Of-Charge (%): 100

☐ Use parameters based on Battery type and nominal values

Maximum Capacity (Ah): 7*Nb_par

Fully Charged Voltage (V): 1.39*Nb_ser

Nominal Discharge Current (A): 1.3*Nb_par

Internal Resistance (Ohms): 0.002*Nb_ser/Nb_par

Capacity (Ah) @ Nominal Voltage: 6.25*Nb_par

Exponential zone [Voltage (V), Capacity (Ah)]: [1.28*Nb_ser 1.3*Nb_par]

Block Inputs and Outputs

`m`

The Simulink output of the block is a vector containing three signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Signal	Definition	Units
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: $SOC = 100\left(1 - \frac{\int_0^t i\,dt}{Q}\right)$	%
Current	The Battery current	A
Voltage	The Battery voltage	V

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 doesn't vary with the amplitude of the current.
- The parameters of the model are deduced from discharge characteristics and assumed to be the same for charging.
- The capacity of the battery doesn't change with the amplitude of current (No Peukert effect).
- The model doesn't take the temperature into account.
- The Self-Discharge of the battery is not represented. It can be represented by adding a large resistance in parallel with the battery terminals.

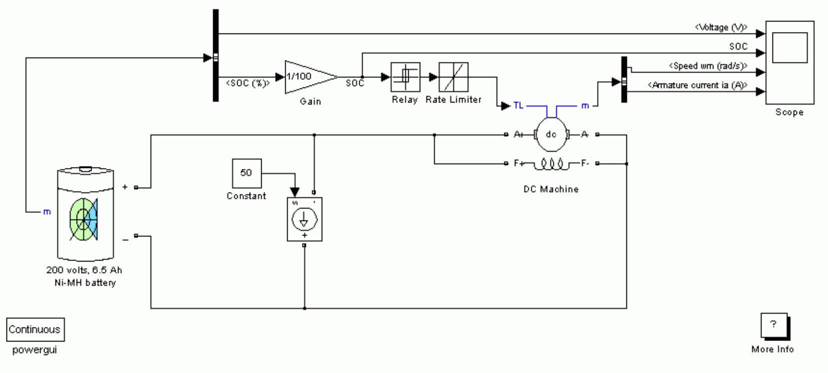
- The battery has no memory effect.

Limitations

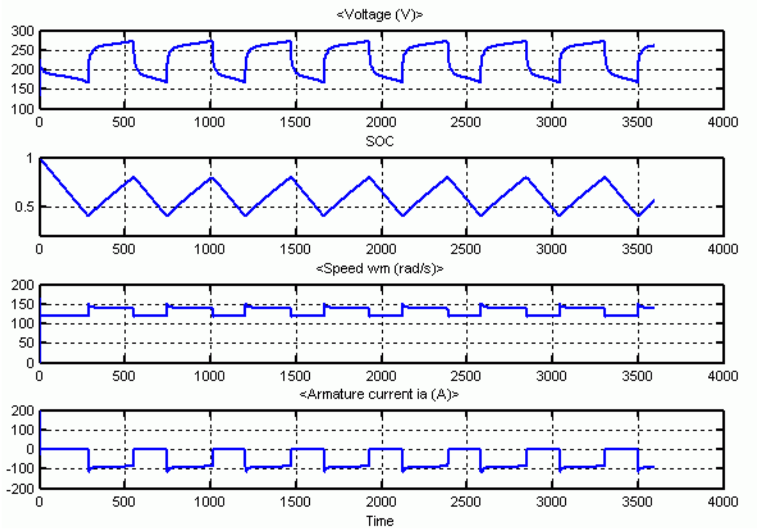
- The minimum no-load battery voltage is 0 volt and the maximum battery voltage is equal to 2*E0.
- The minimum capacity of the battery is 0 Ah and the maximum capacity is Qmax.

Example

The `power_battery` demo 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.



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] C. M. Shepherd, "Design of Primary and Secondary Cells - Part 2. An equation describing battery discharge," Journal of Electrochemical Society, Volume 112, Jul. 1965, pp. 657-664

[2] 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

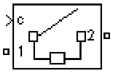
Purpose

Implement circuit breaker opening at current zero crossing

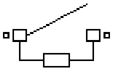
Library

Elements

Description



Breaker



Breaker1

Breaker2

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.

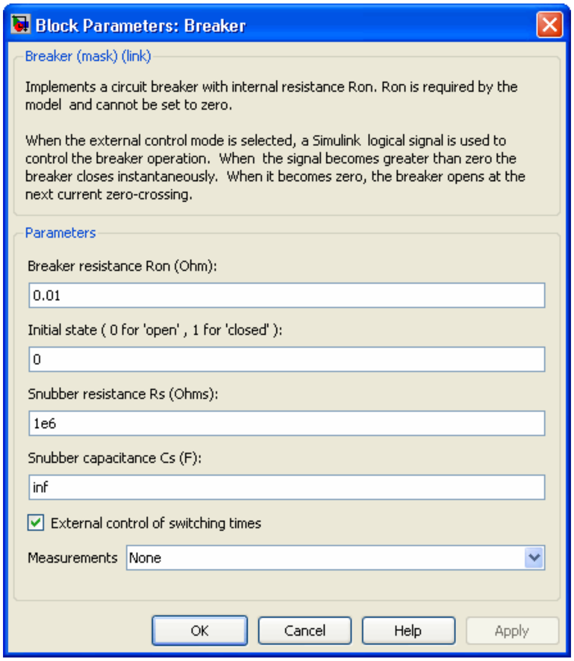
When the breaker is closed, it is represented by a resistance Ron. The Ron value can be set as small as necessary in order to be negligible compared with external components (a typical value is 10 mohms). When the breaker is open, it has an infinite resistance.

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)
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



Implements a circuit breaker with internal resistance Ron. Ron is required by the model and cannot be set to zero.

When the external control mode is selected, a Simulink logical signal is used to control the breaker operation. When the signal becomes greater than zero the breaker closes instantaneously. When it becomes zero, the breaker opens at the next current zero-crossing.

Breaker resistance Ron (Ohm): 0.01

Initial state (0 for 'open' , 1 for 'closed'): 0

Snubber resistance Rs (Ohms): 1e6

Snubber capacitance Cs (F): inf

☑ External control of switching times

Measurements: None

Breaker resistance Ron

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

Initial state

The initial state of the breaker. A closed contact is displayed in the block icon when the **Initial state** 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.

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.

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 state. For example, if the **Initial state** 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 visible in the dialog box if the **External control of switching times** parameter is selected.

External control of switching times

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.

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:`
Branch current	`Ib:`

Limitations

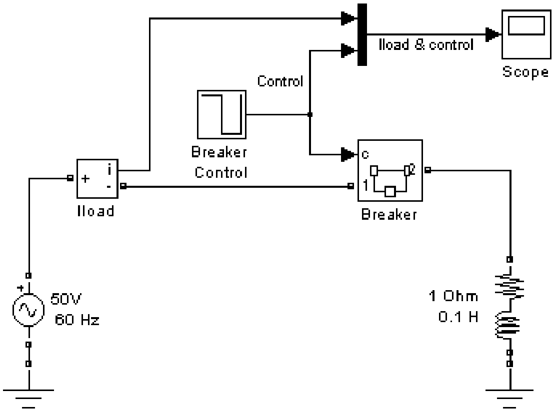
When the block is connected in series with an inductor or another current source, you must add the snubber circuit. In most applications you can use a resistive snubber (**Snubber capacitance** parameter set to `inf`) with a large resistor value (**Snubber resistance** parameter set to `1e6` or so). 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.

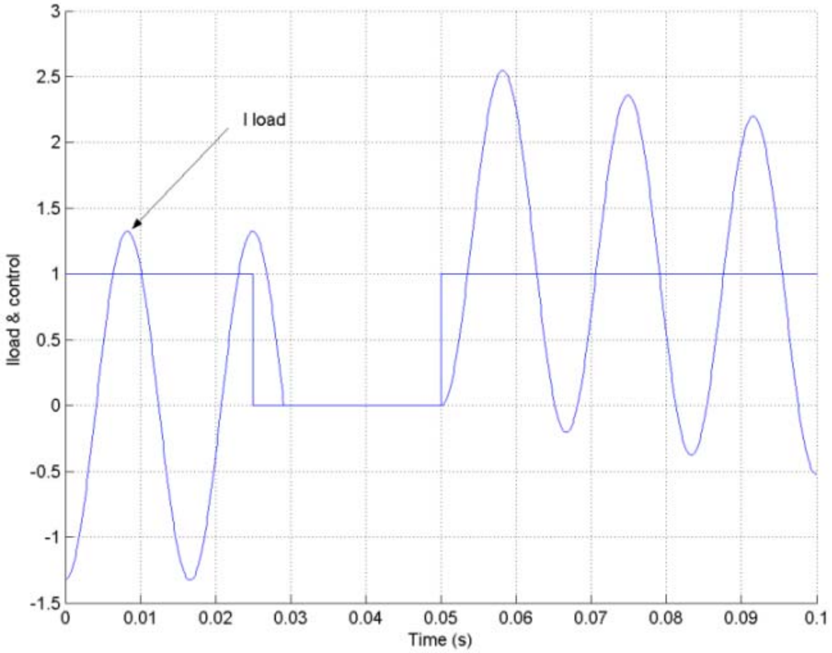
For discretized models, the control signal must stay at 1 for a minimum of 3 sampling time periods to correctly close the Breaker block, otherwise the device stays open.

Example

The `power_breaker` demo illustrates a circuit breaker connected in series with a series RL circuit on a 60 Hz voltage source. The switching times of the Breaker block are controlled by a Simulink signal. The breaker device is initially closed and an opening order is given at t = 1.5 cycles, when current reaches a maximum. The current stops at the next zero crossing, then the breaker is reclosed at a zero crossing of voltage at t = 3 cycles.



Simulation produces the following results.



Note that the breaker device opens only when the load current has reached zero, after the opening order.

See Also

Three-Phase Fault

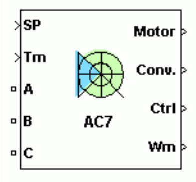
Purpose

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

Library

Electric Drives/AC drives

Description

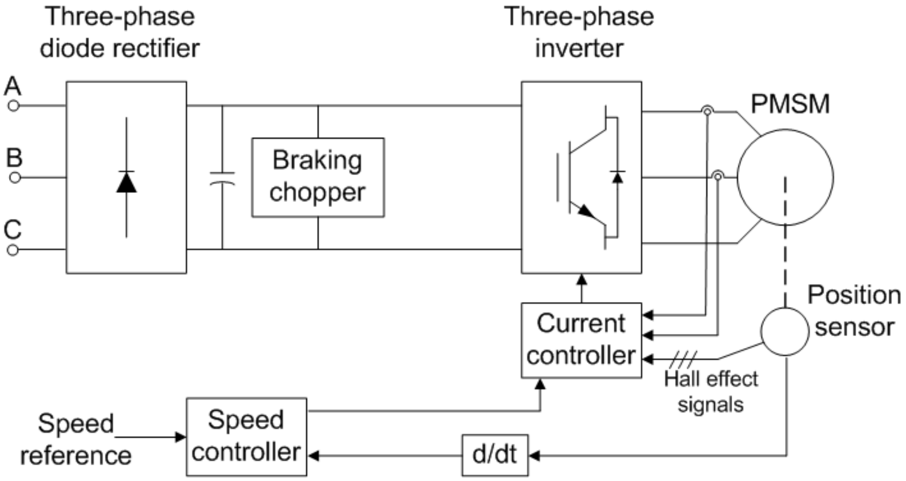


The high-level schematic shown below is built from six main blocks. The PMSM, the three-phase inverter, and the three-phase diode rectifier models are provided with the SimPowerSystems library. The speed controller, the braking chopper, and the current controller models are specific to the Electric Drives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

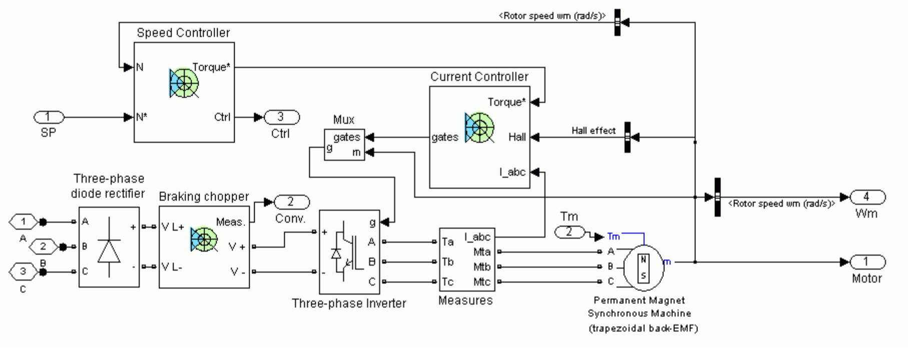
Note In SimPowerSystems software, the Brushless DC Motor Drive block is commonly called the `AC7` motor drive.

Brushless DC Motor Drive

High-Level Schematic

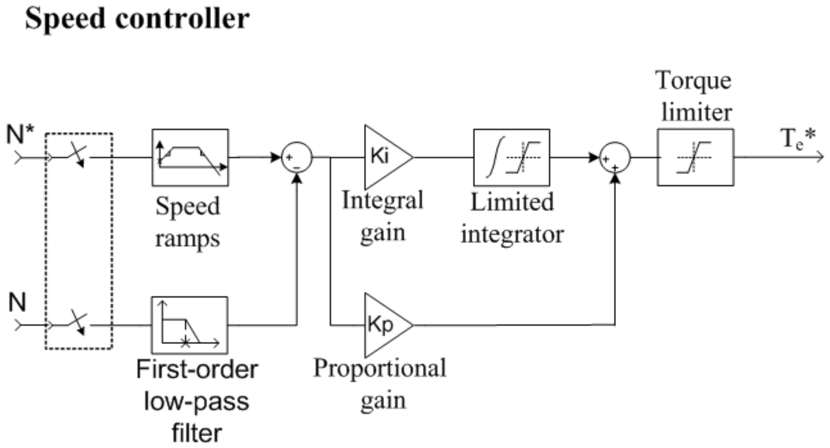


Simulink Schematic



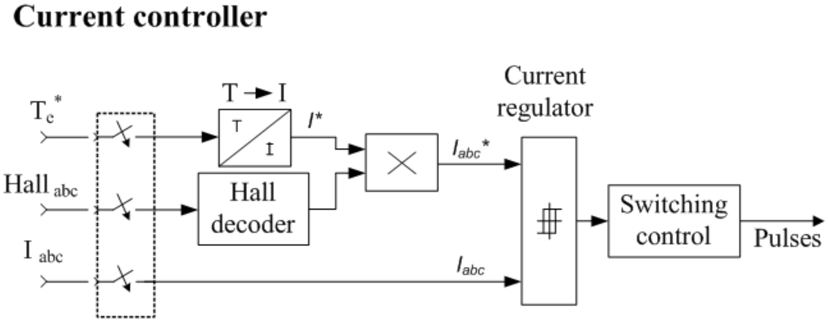
Speed Controller

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.



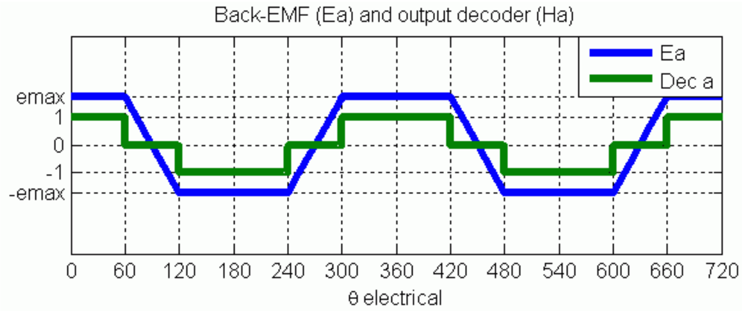
Current Controller

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's 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 type 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 specified by the user.

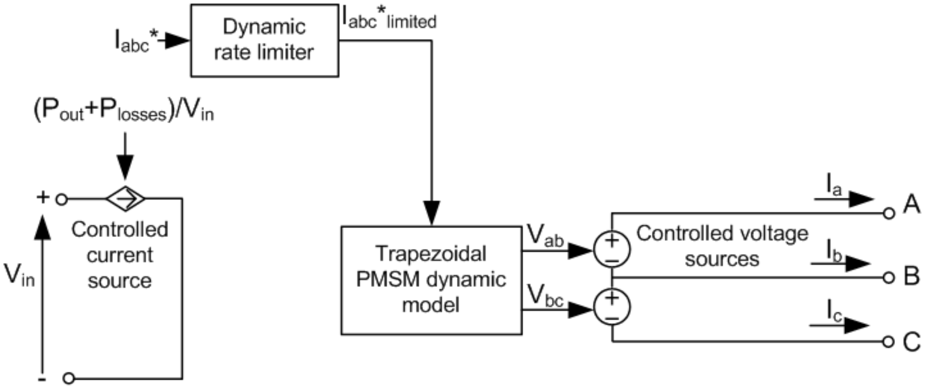
When using the average-value inverter, the *abc* current references are sent to the simplified inverter.

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 of 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

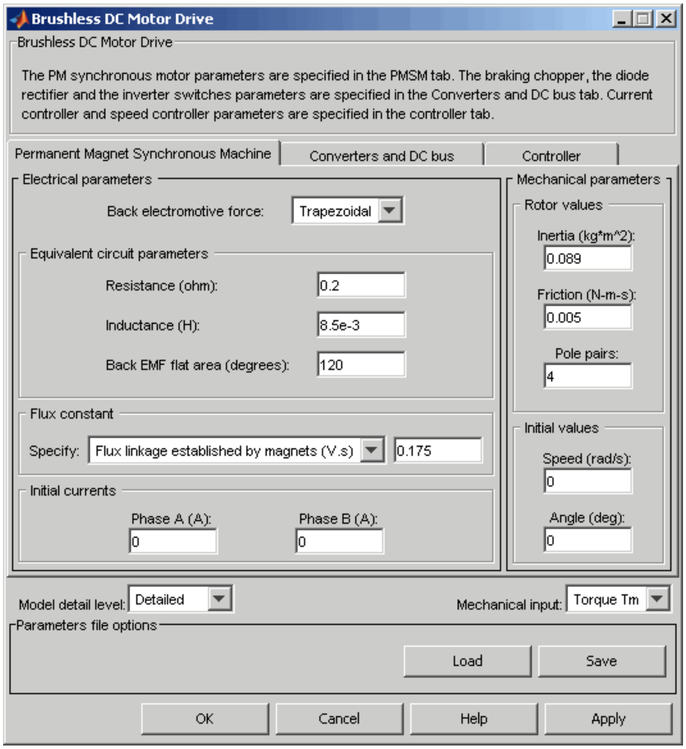
The model is discrete. Good simulation results have been obtained with a 2 μs time step. To simulate a digital controller device, the control system has two different sampling times:

- 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

PM Synchronous Machine Tab



Brushless DC Motor Drive

The PM synchronous motor parameters are specified in the PMSM tab. The braking chopper, the diode rectifier and the inverter switches parameters are specified in the Converters and DC bus tab. Current controller and speed controller parameters are specified in the controller tab.

Electrical parameters

Back electromotive force: Trapezoidal

Equivalent circuit parameters

Resistance (ohm): 0.2

Inductance (H): 8.5e-3

Back EMF flat area (degrees): 120

Flux constant

Specify: Flux linkage established by magnets (V.s) 0.175

Initial currents

Phase A (A): 0

Phase B (A): 0

Mechanical parameters

Rotor values

Inertia (kg*m^2): 0.089

Friction (N-m-s): 0.005

Pole pairs: 4

Initial values

Speed (rad/s): 0

Angle (deg): 0

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

The PM synchronous machine tab displays the parameters of the PM synchronous machine block of the powerlib library. Refer to Permanent Magnet Synchronous Machine for more information on the PM synchronous machine parameters.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Allows you to select either the load torque or the motor speed as mechanical input. Note that if you select and apply a load torque, you will obtain as output the motor speed according to

the following differential equation that describes the mechanical system dynamics:

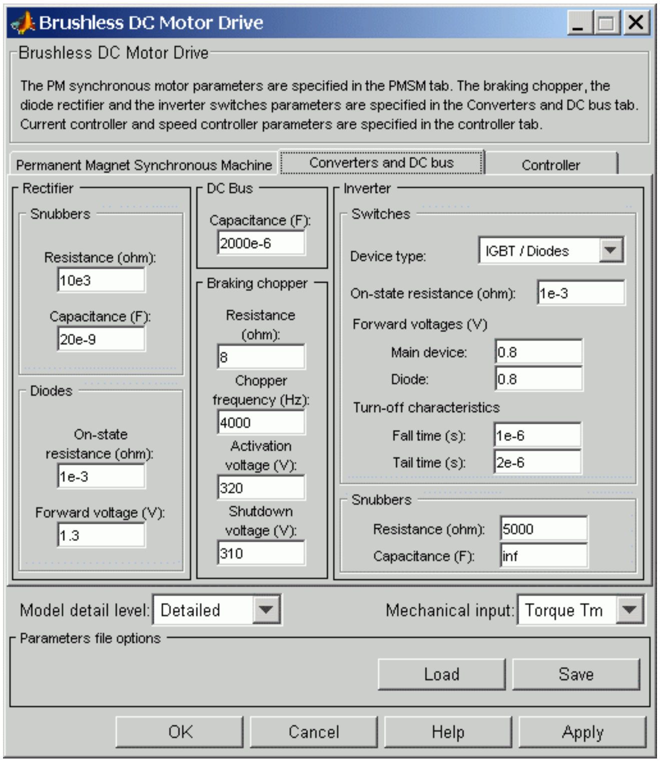
$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

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

See for example “Mechanical Coupling of Two Motor Drives”.

Converters and DC Bus Tab



Brushless DC Motor Drive

The PM synchronous motor parameters are specified in the PMSM tab. The braking chopper, the diode rectifier and the inverter switches parameters are specified in the Converters and DC bus tab. Current controller and speed controller parameters are specified in the controller tab.

Rectifier

Snubbers

Resistance (ohm): 10e3

Capacitance (F): 20e-9

Diodes

On-state resistance (ohm): 1e-3

Forward voltage (V): 1.3

DC Bus

Capacitance (F): 2000e-6

Braking chopper

Resistance (ohm): 8

Chopper frequency (Hz): 4000

Activation voltage (V): 320

Shutdown voltage (V): 310

Inverter

Switches

Device type: IGBT / Diodes

On-state resistance (ohm): 1e-3

Forward voltages (V)

Main device: 0.8

Diode: 0.8

Turn-off characteristics

Fall time (s): 1e-6

Tail time (s): 2e-6

Snubbers

Resistance (ohm): 5000

Capacitance (F): inf

Model detail level: Detailed

Mechanical input: Torque Tm

Rectifier section

The rectifier section of the Converters and DC bus tab displays the parameters of the Universal Bridge block of the 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 Brige block of the 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).

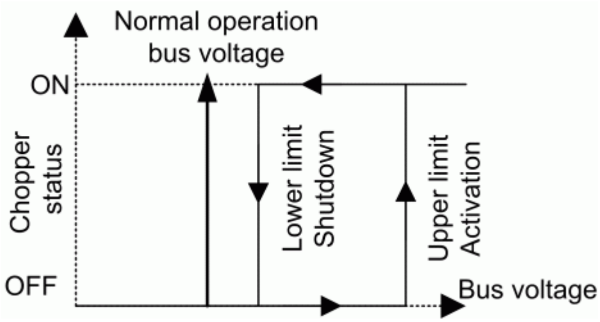
Braking Chopper Section

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).

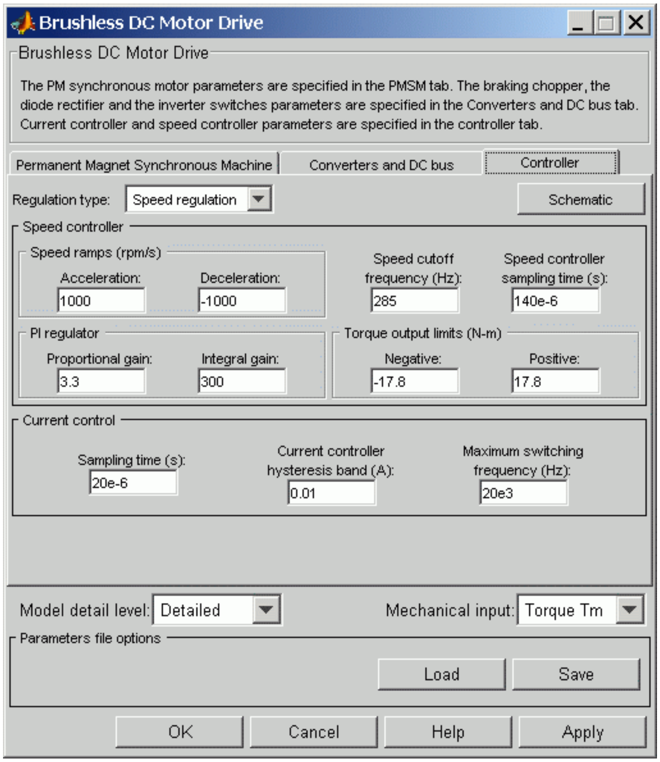
Frequency
The braking chopper frequency (Hz).

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



Brushless DC Motor Drive

The PM synchronous motor parameters are specified in the PMSM tab. The braking chopper, the diode rectifier and the inverter switches parameters are specified in the Converters and DC bus tab. Current controller and speed controller parameters are specified in the controller tab.

Regulation type: Speed regulation

Speed controller

Speed ramps (rpm/s)

Acceleration: 1000

Deceleration: -1000

Speed cutoff frequency (Hz): 285

Speed controller sampling time (s): 140e-6

PI regulator

Proportional gain: 3.3

Integral gain: 300

Torque output limits (N-m)

Negative: -17.8

Positive: 17.8

Current control

Sampling time (s): 20e-6

Current controller hysteresis band (A): 0.01

Maximum switching frequency (Hz): 20e3

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

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

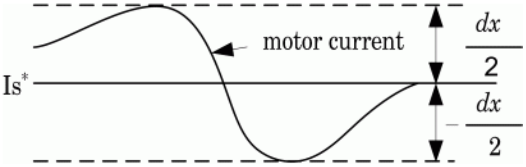
Sampling Time

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. Note that 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).

`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

Model Specifications

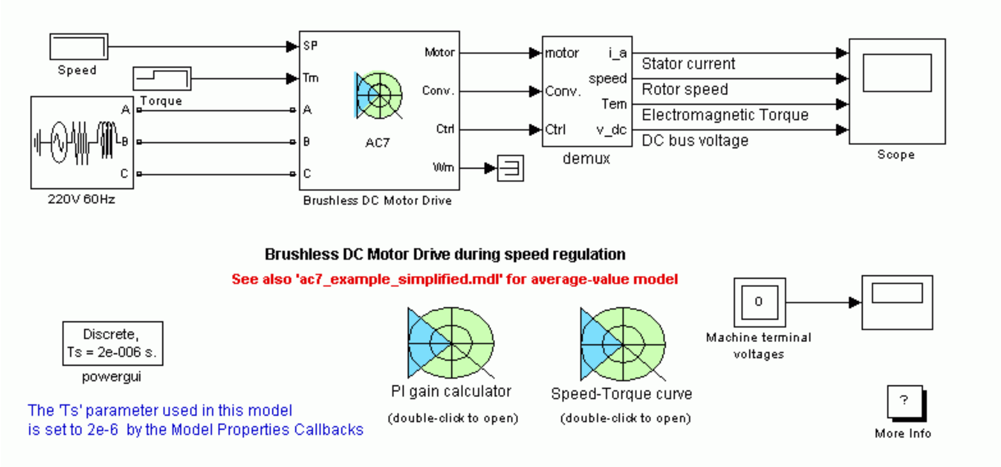
The library contains a 3 hp drive parameter set. The specifications of the 3 hp drive are shown in the following table.

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



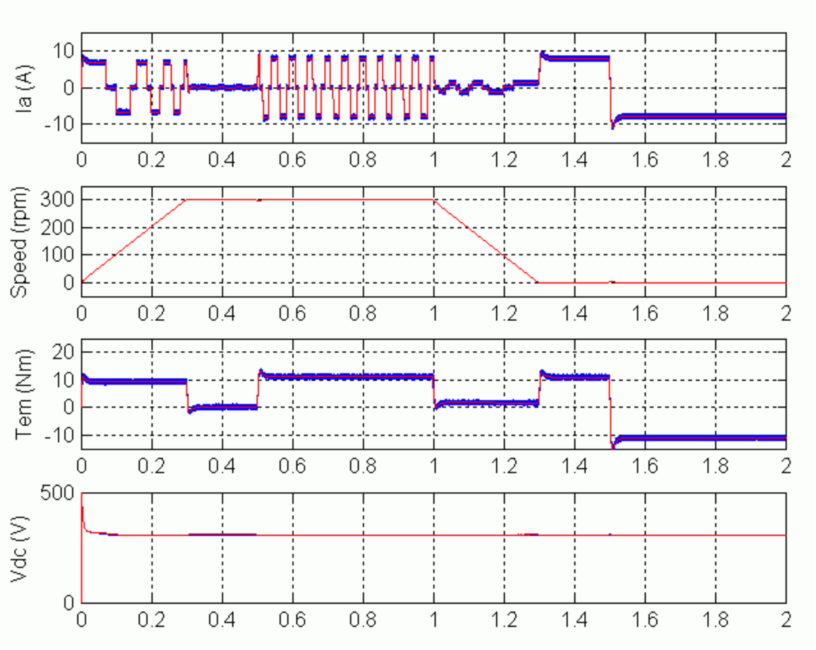
Brushless DC Motor Drive during speed regulation

See also 'ac7_example_simplified.mdl' for average-value model

The 'Ts' parameter used in this model is set to 2e-6 by the Model Properties Callbacks

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.

Connection Port

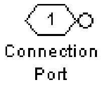
Purpose

Create Physical Modeling connector port for subsystem

Library

Elements

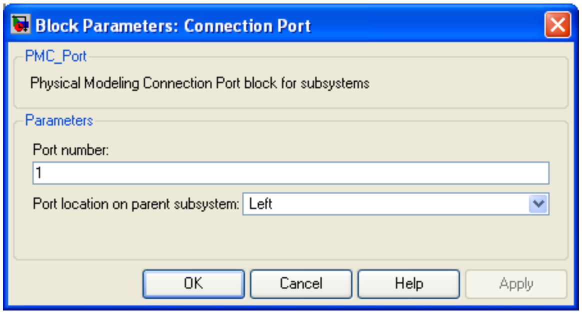
Description



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



Block Parameters: Connection Port

PMC_Port

Physical Modeling Connection Port block for subsystems

Parameters

Port number:

1

Port location on parent subsystem: Left

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`.

See Also

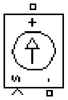
See “Working with Block Masks” in the Simulink documentation

Controlled Current Source

Purpose Implement controlled current source

Library Electrical Sources

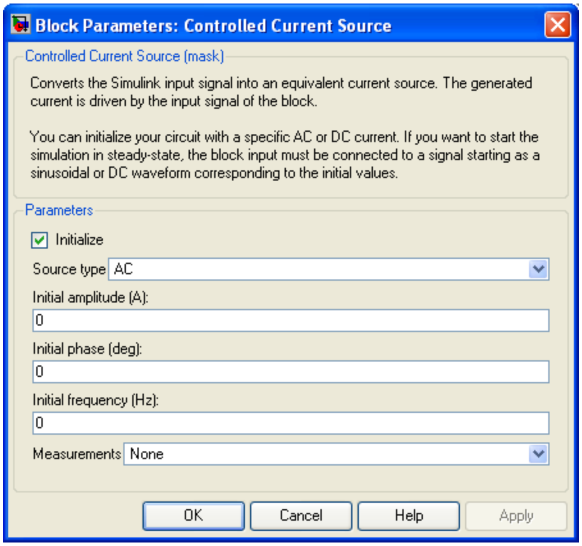
Description The Controlled Current Source block converts the Simulink input signal into an equivalent current source. The generated current is driven by the input signal of the block. The positive current direction is as shown by the arrow in the block icon.



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



Block Parameters: Controlled Current Source

Controlled Current Source (mask)

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

You can initialize your circuit 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.

Parameters

☑ Initialize

Source type: AC

Initial amplitude (A): 0

Initial phase (deg): 0

Initial frequency (Hz): 0

Measurements: None

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

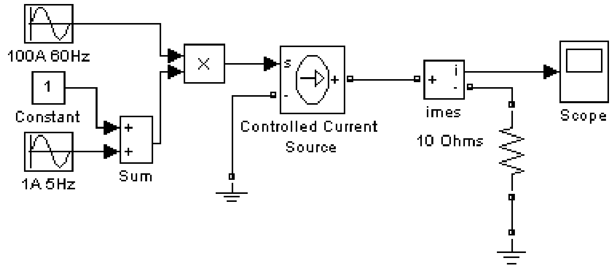
Select `Current` to measure the current flowing through the Controlled Current Source block.

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:

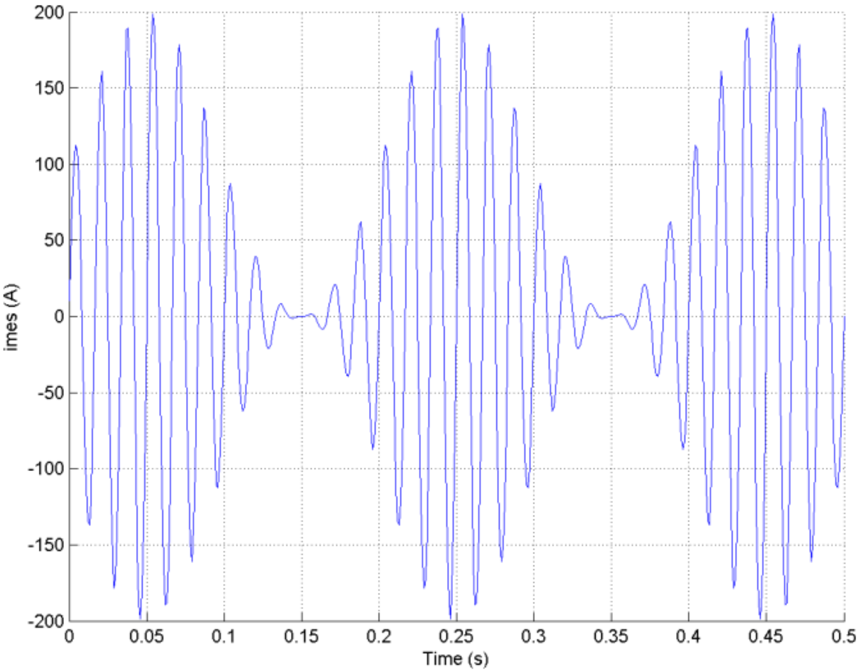
Measurement	Label
Current	`Isrc:`

Example

The `power_controlcurr` demo 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

Controlled Voltage Source

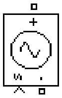
Purpose

Implement controlled voltage source

Library

Electrical Sources

Description

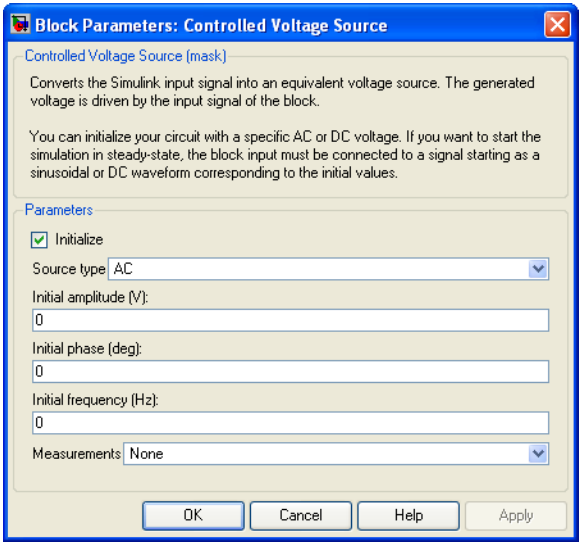


The Controlled Voltage Source block converts the Simulink input signal into an equivalent voltage source. The generated voltage is driven by the input signal of the block.

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

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.

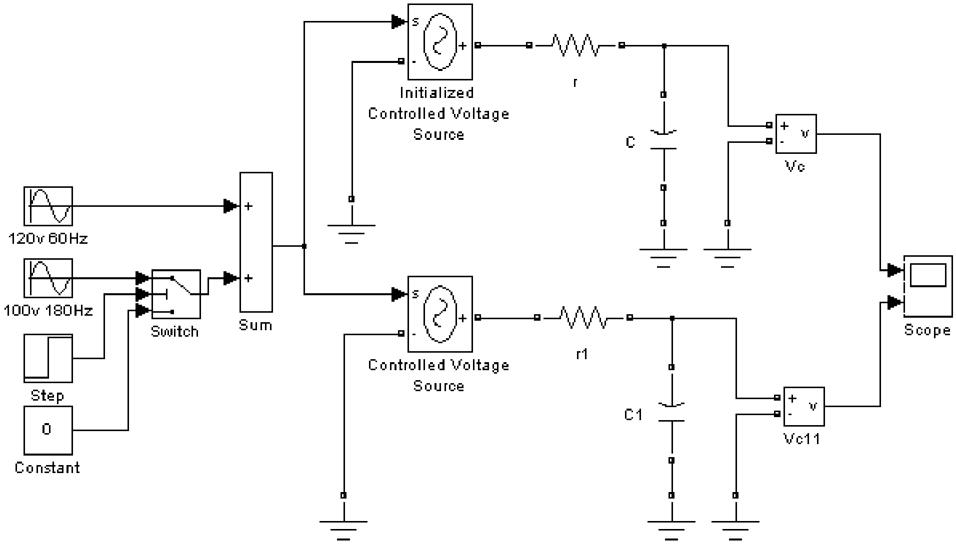
Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurement is identified by a label followed by the block name:

Measurement	Label
Voltage	`Usrc:`

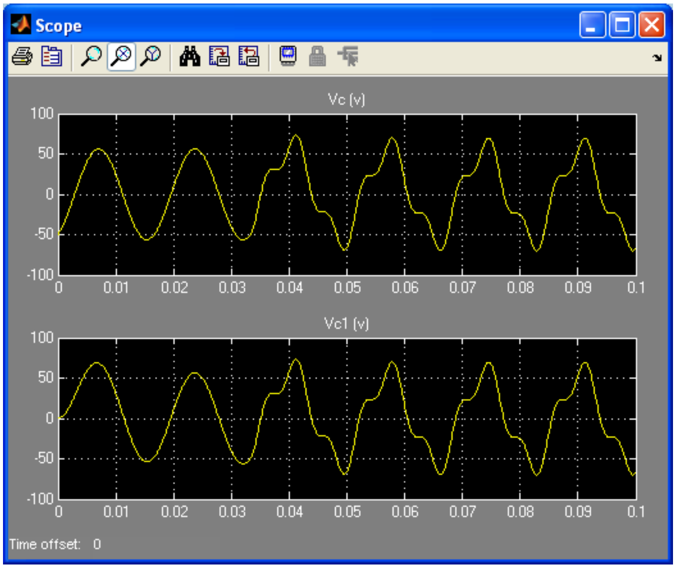
Example

The `power_controlvolt` demo 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

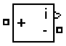
Purpose

Measure current in circuit

Library

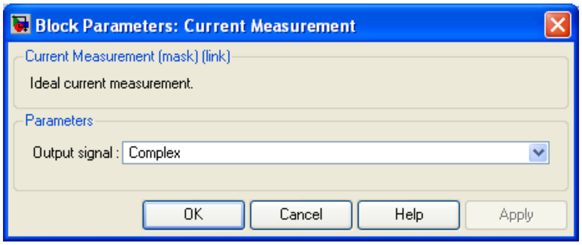
Measurements

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



Ideal current measurement.

Output signal : Complex

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.

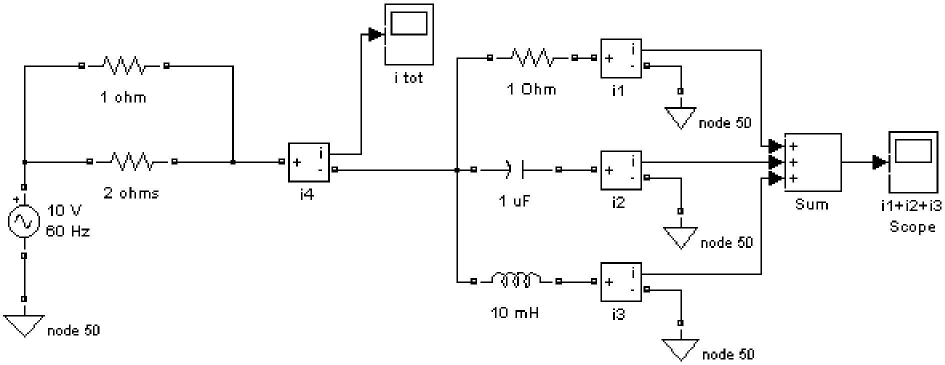
Set to `Real-Imag` to output the real and imaginary parts of the measured current. The output is a vector of two elements.

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



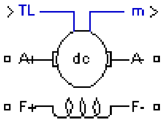
See Also

Powergui, Three-Phase V-I Measurement, Voltage Measurement

Purpose Implement wound-field or permanent magnet DC machine

Library Machines

Description The DC Machine block implements a wound-field or permanent magnet DC machine.



For the wound-field DC machine, an 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:

$$K_E = L_{af} I_f$$

where L_{af} is the field-armature mutual inductance.

The electromechanical torque developed by the DC machine is proportional to the armature current Ia.

$$T_e = K_T I_a$$

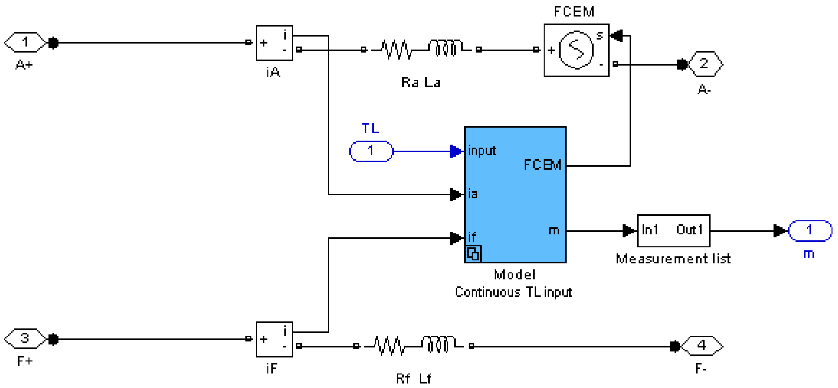
where K_T is the torque constant. The sign convention for T_e and T_L is

$$T_e T_L > 0 \ : \text{Motor mode}$$
$$T_e T_L < 0 \ : \text{Generator mode}$$

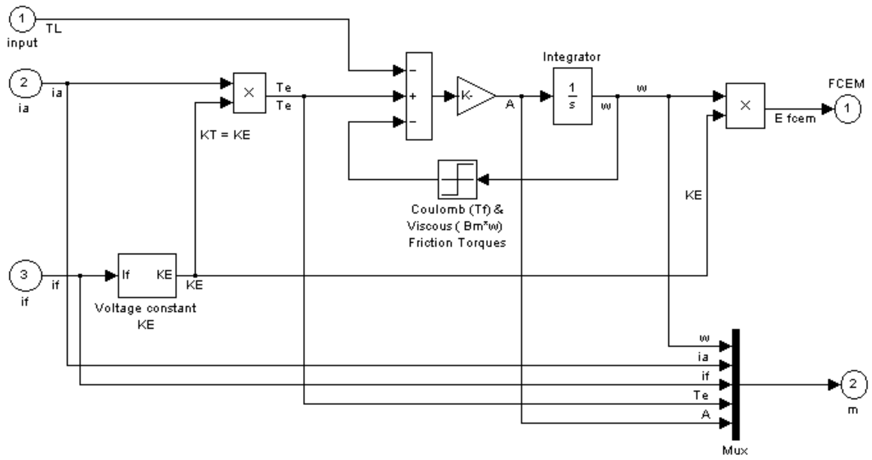
The torque constant is equal to the voltage constant.

$$K_T = K_E$$

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.



Mechanical part:



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.

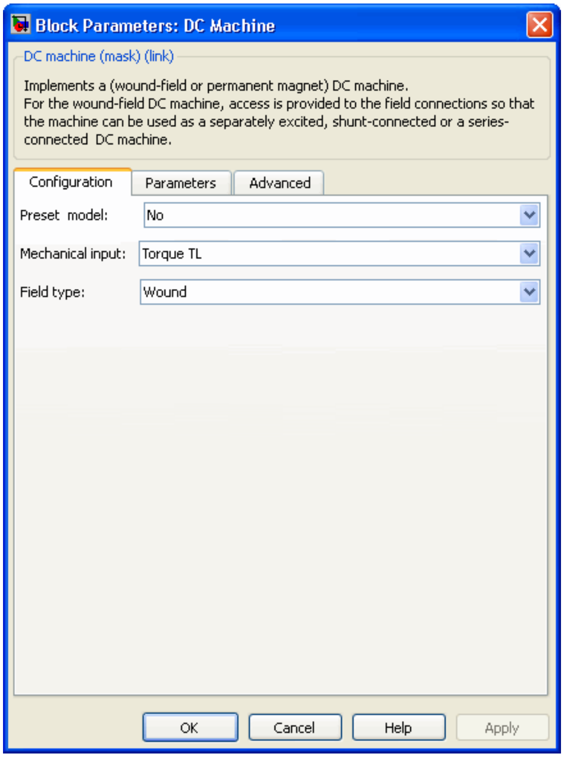
The mechanical part is represented by Simulink blocks that implement the equation

$$J\frac{d\omega}{dt} = T_e - T_L - B_m\omega - T_f$$

where J = inertia, B_m = viscous friction coefficient, and T_f = Coulomb friction torque.

Dialog Box and Parameters

Configuration Tab



DC machine (mask) (link)

Implements a (wound-field or permanent magnet) DC machine.
For the wound-field DC machine, access is provided to the field connections so that the machine can be used as a separately excited, shunt-connected or a series-connected DC machine.

Preset model: No

Mechanical input: Torque TL

Field type: Wound

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 only available for the wound-field DC machine model, that is, when the **Field type** parameter is set to `Wound`.

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 unmodifiable (grayed out). To start from a given preset model and then modify machine parameters, you have to do the following:

1. Select the desired preset model to initialize the parameters.
2. Change the **Preset model** parameter value to `No`. This will 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 wish, then click **Apply**.

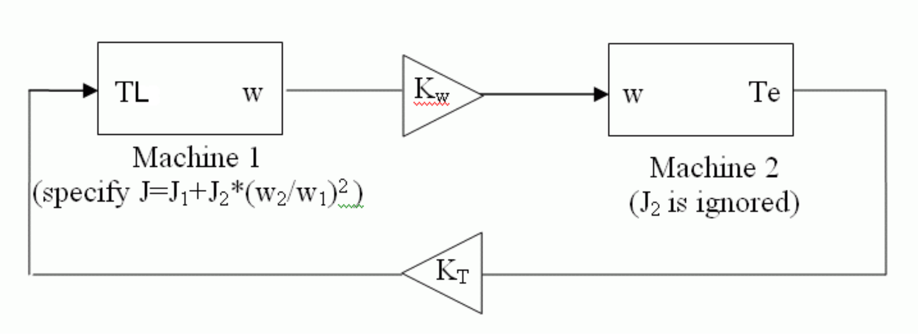
Mechanical input

Allows you to select either the torque applied to the shaft or the rotor speed as the Simulink signal applied to the block's input.

Select **Torque TL** to specify a torque input, in N.m, and change labeling of the block's 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 the following: 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's 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 and interfacing with SimMechanics and SimDriveline models.

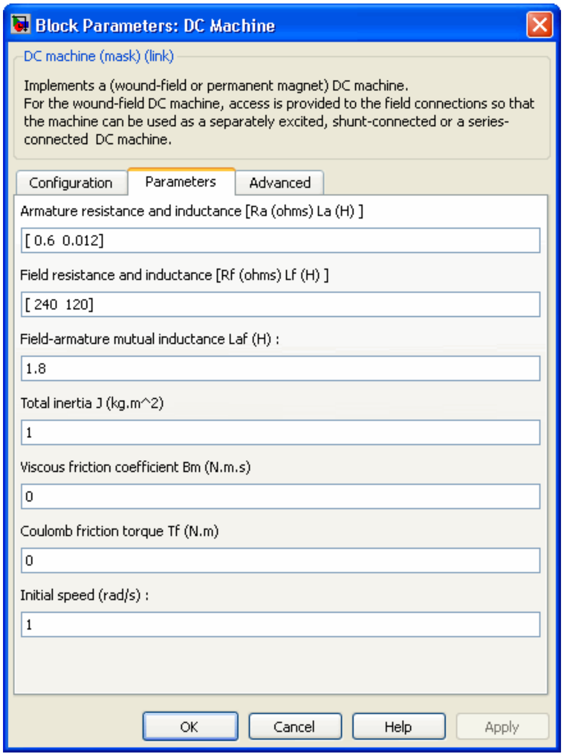
The next figure indicates how to model a stiff shaft interconnection in a motor-generator. The speed output of machine 1 (motor) is connected to the speed input of machine 2 (generator), while machine 2 electromagnetic torque output Te is applied to the mechanical load torque input TL of machine 1. The 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.



Field type

Allows you to select between the wound-field and the permanent magnet DC machine.

Parameters Tab



Block Parameters: DC Machine

DC machine (mask) (link)

Implements a (wound-field or permanent magnet) DC machine.
For the wound-field DC machine, access is provided to the field connections so that the machine can be used as a separately excited, shunt-connected or a series-connected DC machine.

Armature resistance and inductance [Ra (ohms) La (H)]
[0.6 0.012]

Field resistance and inductance [Rf (ohms) Lf (H)]
[240 120]

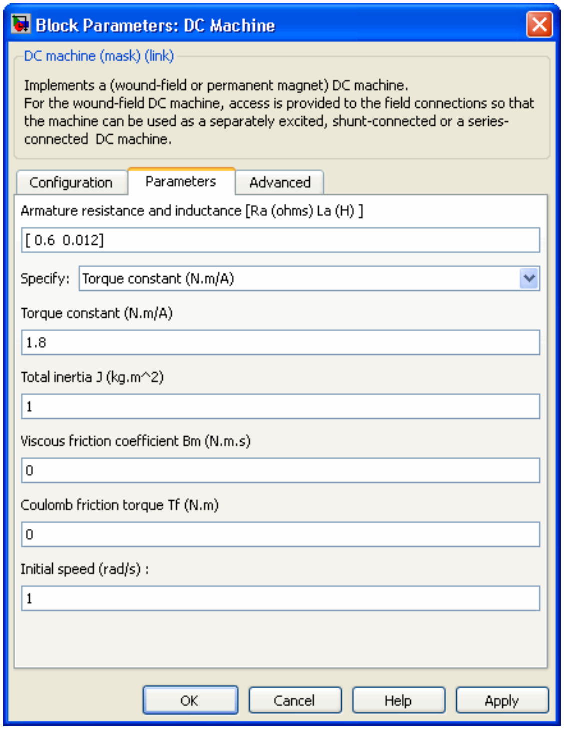
Field-armature mutual inductance Laf (H) :
1.8

Total inertia J (kg.m^2)
1

Viscous friction coefficient Bm (N.m.s)
0

Coulomb friction torque Tf (N.m)
0

Initial speed (rad/s) :
1



Implements a (wound-field or permanent magnet) DC machine.
For the wound-field DC machine, access is provided to the field connections so that the machine can be used as a separately excited, shunt-connected or a series-connected DC machine.

Armature resistance and inductance [Ra (ohms) La (H)]
[0.6 0.012]

Specify: Torque constant (N.m/A)

Torque constant (N.m/A)
1.8

Total inertia J (kg.m^2)
1

Viscous friction coefficient Bm (N.m.s)
0

Coulomb friction torque Tf (N.m)
0

Initial speed (rad/s) :
1

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 only visible 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 only visible 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 only visible 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.

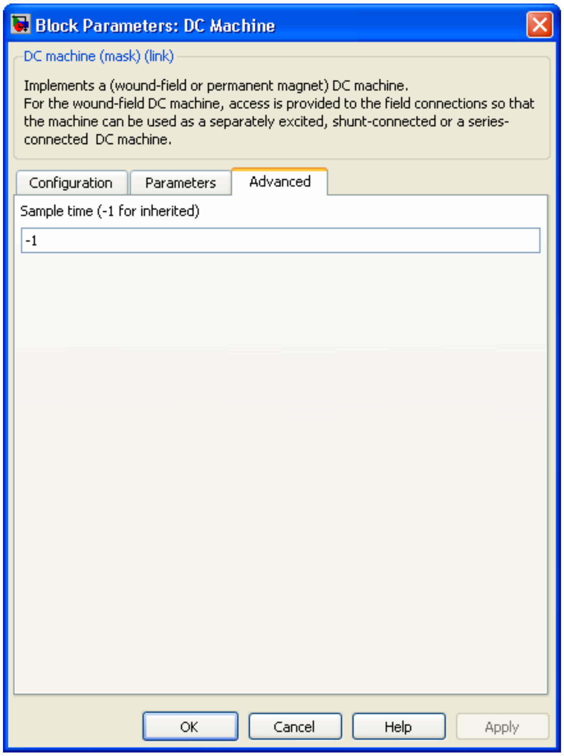
Coulomb friction torque Tf

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



Implements a (wound-field or permanent magnet) DC machine.
For the wound-field DC machine, access is provided to the field connections so that the machine can be used as a separately excited, shunt-connected or a series-connected DC machine.

Sample time (-1 for inherited): -1

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

`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.

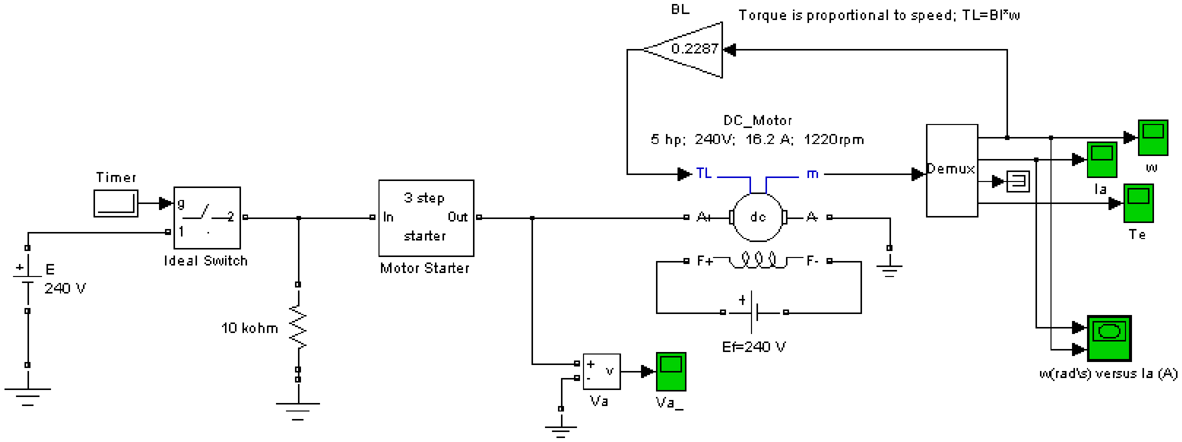
`m`

The output of the block is a vector containing four signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

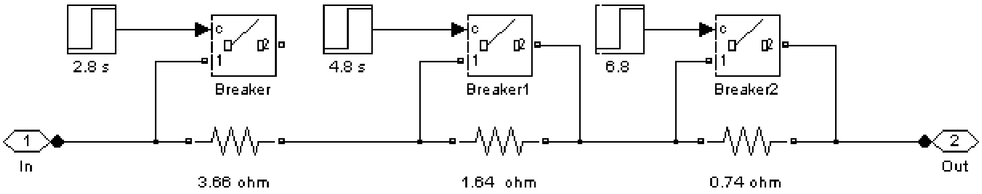
Signal	Definition	Units
1	Speed wm	rad/s
2	Armature current ia	A
3	Field current if	A
4	Electrical torque Te	N.m

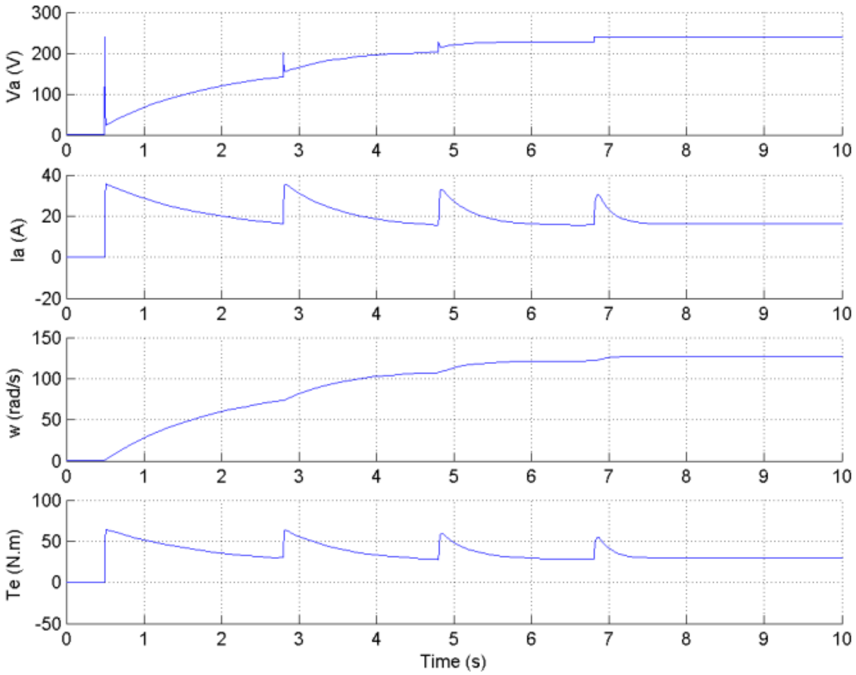
Example

The `power_dcmotor` demo illustrates the starting of a 5 HP 240 V DC machine with a three-step resistance starter.



The Motor Starter subsystem is





References

[1] *Analysis of Electric Machinery,* Krause et al., pp. 89-92.

See Also

Asynchronous Machine, Synchronous Machine

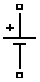
Purpose

Implement DC voltage source

Library

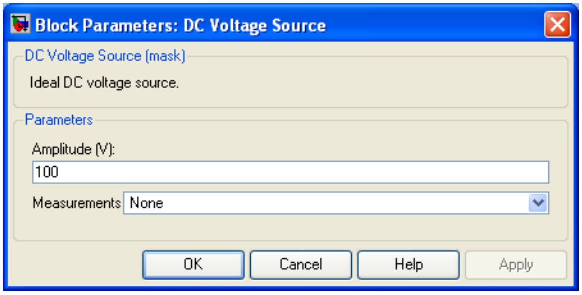
Electrical Sources

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



Block Parameters: DC Voltage Source

DC Voltage Source (mask)

Ideal DC voltage source.

Parameters

Amplitude (V): 100

Measurements: None

Amplitude

The amplitude of the source, in volts (V).

Measurements

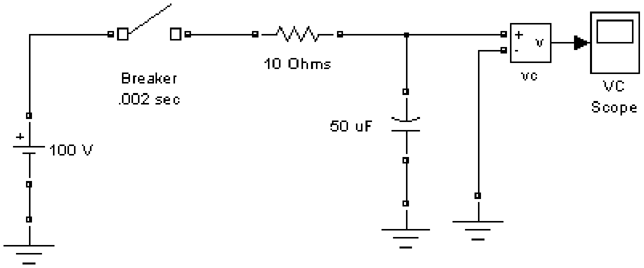
Select `Voltage` to measure the voltage across the terminals of the DC Voltage Source block.

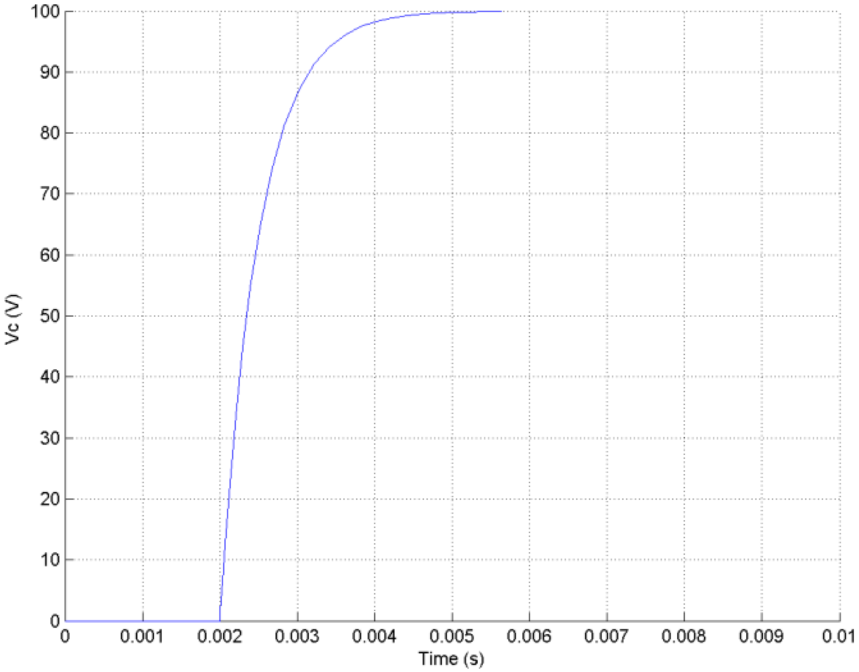
Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurement is identified by a label followed by the block name:

Measurement	Label
Voltage	`Usrc:`

Example

The `power_dcvoltage` demo illustrates the simulation of the transient response of a first-order RC circuit.





See Also

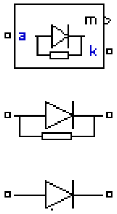
AC Voltage Source, Controlled Voltage Source

Diode

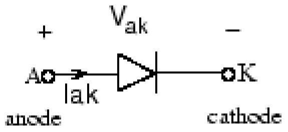
Purpose Implement diode model

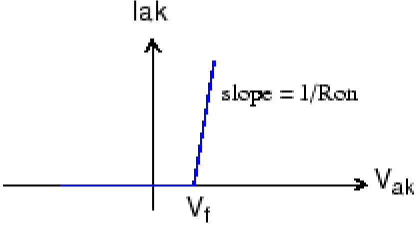
Library Power Electronics

Description

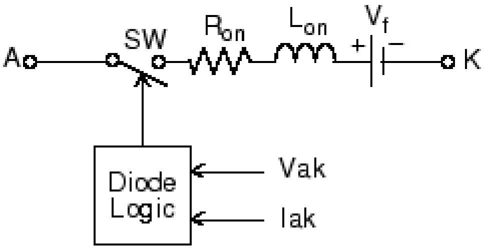


The diode is a semiconductor device that is controlled by its own voltage Vak and current Iak. When a diode is forward biased (Vak > 0), it starts to conduct with a small forward voltage Vf across it. It turns off when the current flow into the device becomes 0. When the diode is reverse biased (Vak < 0), it stays in the off state.



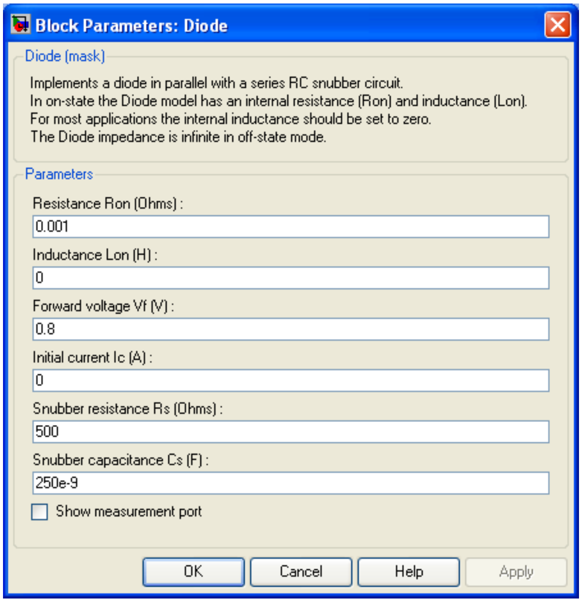


The Diode block is simulated by a resistor, an inductor, and a DC voltage source connected in series with a switch. The switch operation is controlled by the voltage Vak and the current Iak.



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



Diode (mask)

Implements a diode in parallel with a series RC snubber circuit.
In on-state the Diode model has an internal resistance (Ron) and inductance (Lon).
For most applications the internal inductance should be set to zero.
The Diode impedance is infinite in off-state mode.

Parameters

Resistance Ron (Ohms) : 0.001

Inductance Lon (H) : 0

Forward voltage Vf (V) : 0.8

Initial current Ic (A) : 0

Snubber resistance Rs (Ohms) : 500

Snubber capacitance Cs (F) : 250e-9

☐ Show measurement port

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.

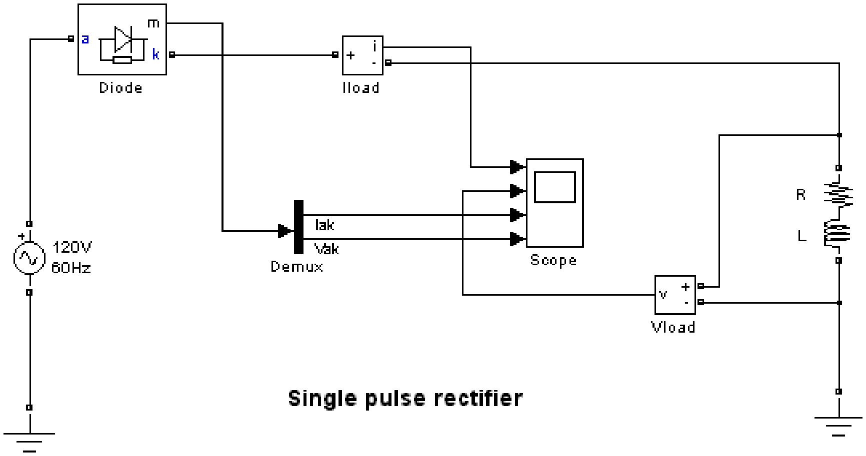
Depending on the value of the inductance Lon, the diode is modeled either as a current source (Lon > 0) or as a variable topology circuit (Lon = 0). The Diode block cannot be connected in series with an inductor, a current source, or an open circuit, unless its snubber circuit is in use. See Improving Simulation Performance for more details on this topic.

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.

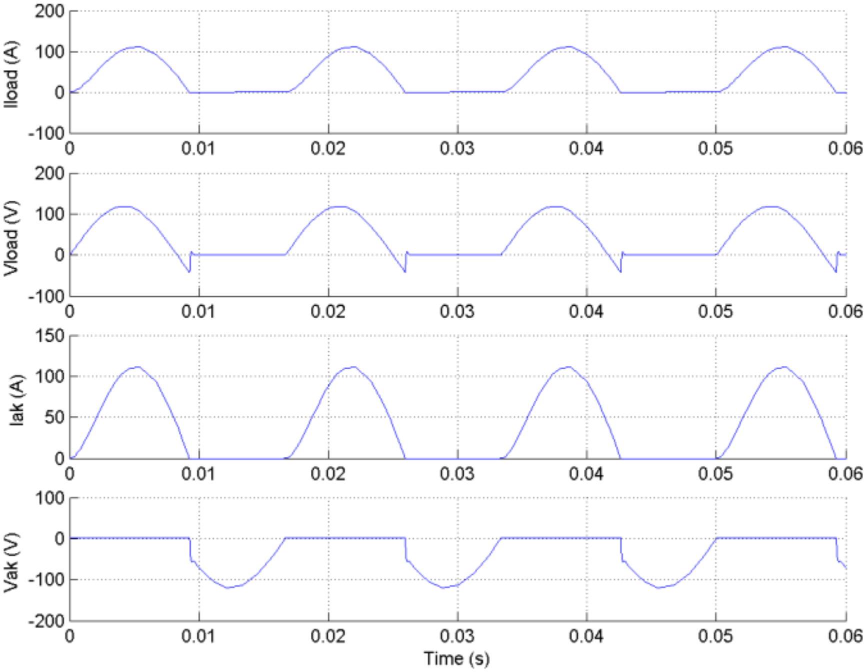
The inductance Lon is forced to 0 if you choose to discretize your circuit.

Example

The `power_diode` demo illustrates a single pulse rectifier consisting of a Diode block, an RL load, and an AC Voltage source block.



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

Discrete System

Purpose 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

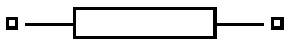
Purpose

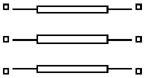
Implement N-phase distributed parameter transmission line model with lumped losses

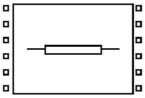
Library

Elements

Description

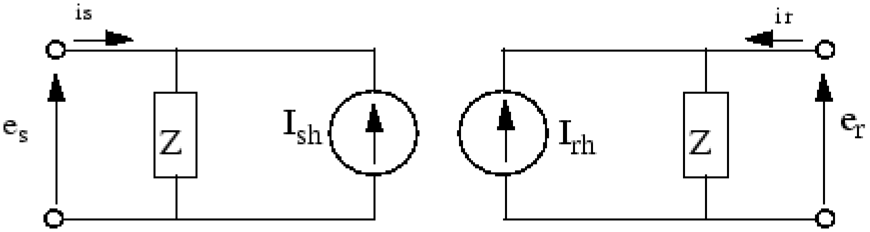






The Distributed Parameter Line block implements an N-phase distributed parameter line model with lumped losses. The model is based on the Bergeron's traveling wave method used by the Electromagnetic Transient Program (EMTP) [1]. In this model, the lossless distributed LC line is characterized by two values (for a single-phase line): the surge impedance $Z_c = \sqrt{L/C}$ and the phase velocity $v = 1/\sqrt{LC}$.

The model uses the fact that the quantity *e*+*Zi* (where *e* is line voltage and *i* is line current) entering one end of the line must arrive unchanged at the other end after a transport delay of $\tau = d/v$, where *d* is the line length. By lumping *R*/4 at both ends of the line and *R*/2 in the middle and using the current injection method of SimPowerSystems software, the following two-port model is derived,



$$I_{sh}(t) = \left(\frac{1+h}{2}\right)\left[\frac{1}{Z}e_r(t-\tau) + hi_r(t-\tau)\right] + \left(\frac{1-h}{2}\right)\left[\frac{1}{Z}e_s(t-\tau) + hi_s(t-\tau)\right]$$

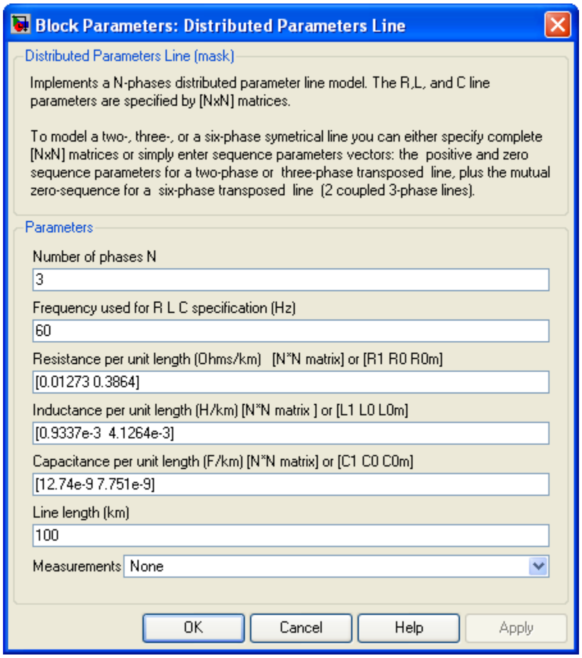
$$I_{rh}(t) = \left(\frac{1+h}{2}\right)\left[\frac{1}{Z}e_s(t-\tau) + hi_s(t-\tau)\right] + \left(\frac{1-h}{2}\right)\left[\frac{1}{Z}e_r(t-\tau) + hi_r(t-\tau)\right]$$

where $Z = Z_C + \frac{R}{4}$, $h = \frac{Z_C - \frac{R}{4}}{Z_C + \frac{R}{4}}$, $Z_C = \sqrt{\frac{L}{C}}$, and $\tau = d\sqrt{LC}$.

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



Block Parameters: Distributed Parameters Line

Distributed Parameters Line (mask)

Implements a N-phases distributed parameter line model. The R,L, and C line parameters are specified by [NxN] matrices.

To model a two-, three-, or a six-phase symetrical line you can either specify complete [NxN] matrices or simply enter sequence parameters vectors: the positive and zero sequence parameters for a two-phase or three-phase transposed line, plus the mutual zero-sequence for a six-phase transposed line (2 coupled 3-phase lines).

Parameters

Number of phases N: 3

Frequency used for R L C specification (Hz): 60

Resistance per unit length (Ohms/km) [N*N matrix] or [R1 R0 R0m]: [0.01273 0.3864]

Inductance per unit length (H/km) [N*N matrix] or [L1 L0 L0m]: [0.9337e-3 4.1264e-3]

Capacitance per unit length (F/km) [N*N matrix] or [C1 C0 C0m]: [12.74e-9 7.751e-9]

Line length (km): 100

Measurements: None

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 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 provide you 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:

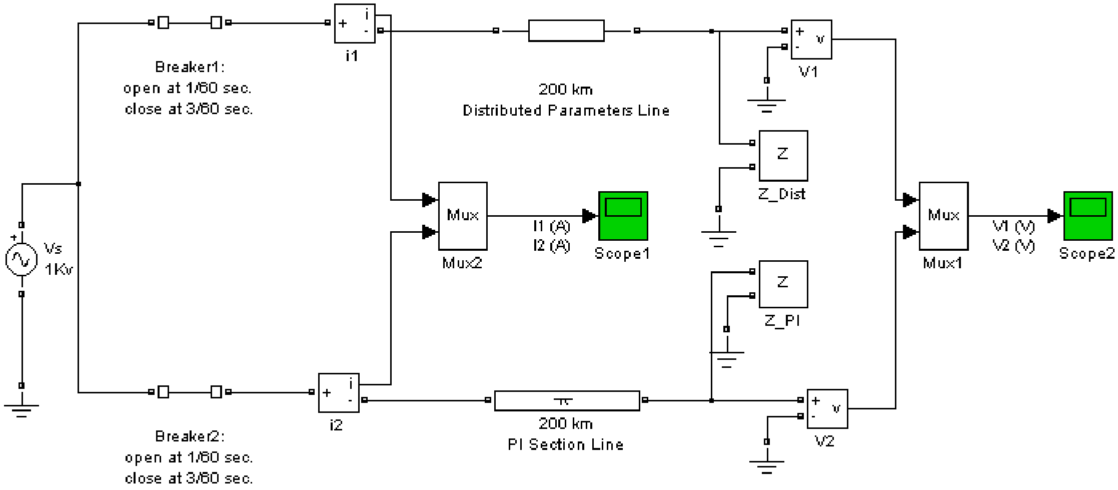
Measurement	Label
Phase-to-ground voltages, sending end	`Us_ph1_gnd:`, `Us_ph2_gnd:`, `Us_ph3_gnd:`, etc.
Phase-to-ground voltages, receiving end	`Ur_ph1_gnd:`, `Ur_ph2_gnd:`, `Ur_ph3_gnd:`, etc.

Limitations

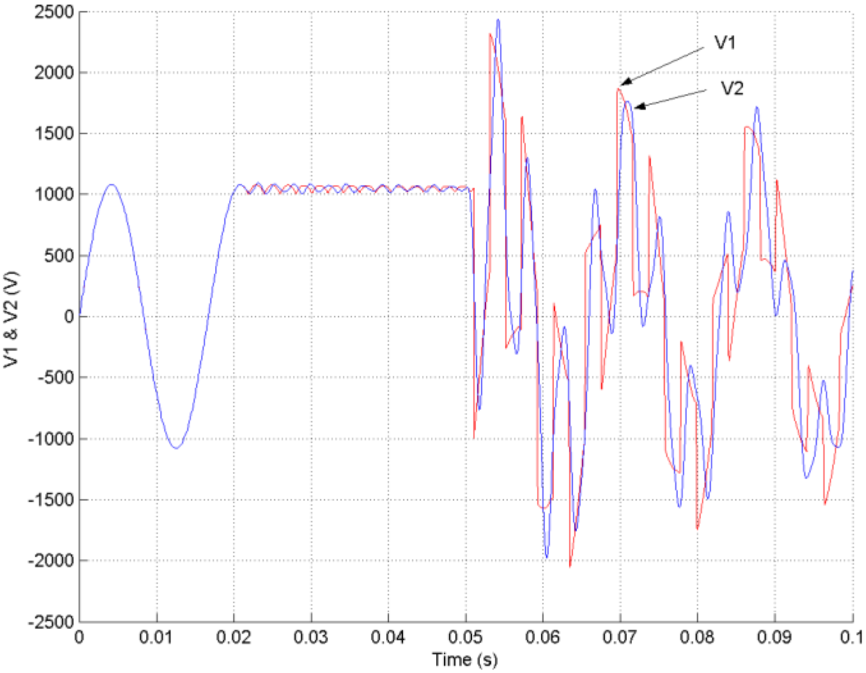
This model does not represent accurately the frequency dependence of RLC parameters of real power lines. Indeed, because of the skin effects in the conductors and ground, the *R* and *L* matrices exhibit strong frequency dependence, causing an attenuation of the high frequencies.

Example

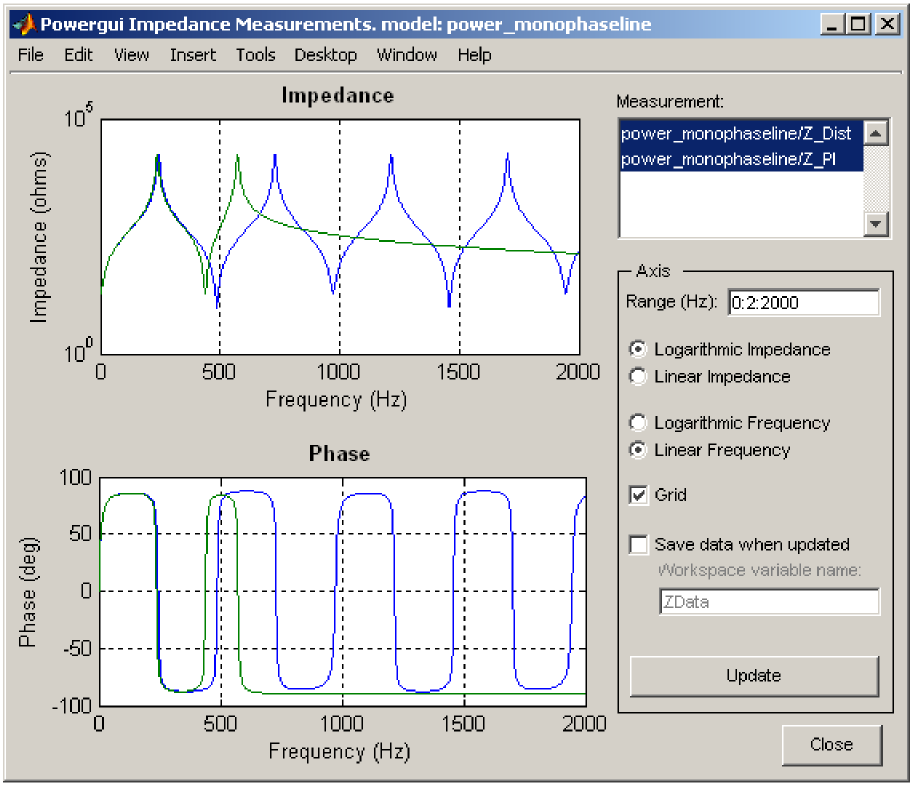
The `power_monophaseline` demo illustrates a 200 km line connected on a 1 kV, 60 Hz infinite source. The line is de-energized and then reenergized after 2 cycles. The simulation is performed simultaneously with the Distributed Parameter Line block and with the PI Section Line block.



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.



Measurement:
power_monophaseline/Z_Dist
power_monophaseline/Z_PI

Range (Hz): 0:2:2000

● Logarithmic Impedance
○ Linear Impedance

○ Logarithmic Frequency
● Linear Frequency

☑ Grid

☐ Save data when updated
Workspace variable name: ZData

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

$$T = \text{traveling time} = l\sqrt{LC} = 1.028\ \text{ms}$$

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

dq0_to_abc Transformation

Purpose

Perform Park transformation from dq0 reference frame to abc reference frame

Library

Extras/Measurements

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

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:

$$V_a = V_d \sin(\omega t) + V_q \cos(\omega t) + V_0$$

$$V_b = V_d \sin(\omega t - 2\pi/3) + V_q \cos(\omega t - 2\pi/3) + V_0$$

$$V_c = V_d \sin(\omega t + 2\pi/3) + V_q \cos(\omega t + 2\pi/3) + V_0$$

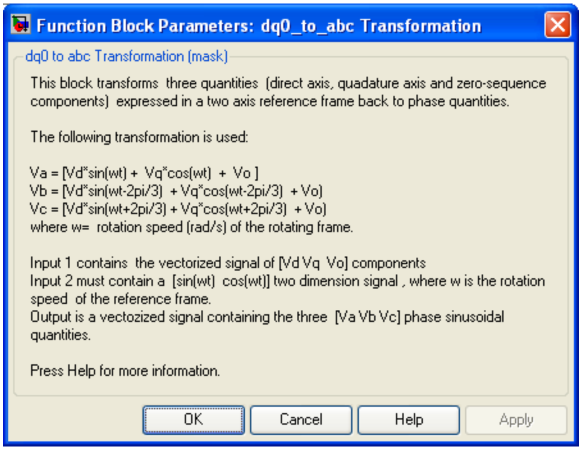
where

$$\omega = \text{rotation speed (rad/s) of the rotating frame}$$

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



dq0 to abc Transformation (mask)

This block transforms three quantities (direct axis, quadature axis and zero-sequence components) expressed in a two axis reference frame back to phase quantities.

The following transformation is used:

Va = [Vd*sin(wt) + Vq*cos(wt) + Vo]
Vb = [Vd*sin(wt-2pi/3) + Vq*cos(wt-2pi/3) + Vo)
Vc = [Vd*sin(wt+2pi/3) + Vq*cos(wt+2pi/3) + Vo)
where w= rotation speed (rad/s) of the rotating frame.

Input 1 contains the vectorized signal of [Vd Vq Vo] components
Input 2 must contain a [sin(wt) cos(wt)] two dimension signal , where w is the rotation speed of the reference frame.
Output is a vectozized signal containing the three [Va Vb Vc] phase sinusoidal quantities.

Press Help for more information.

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].

Example

See the demo of the abc_to_dq0 Transformation block for an example using 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 Transformation

DTC Induction Motor Drive

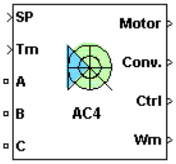
Purpose

Implement direct torque and flux control (DTC) induction motor drive model

Library

Electric Drives/AC drives

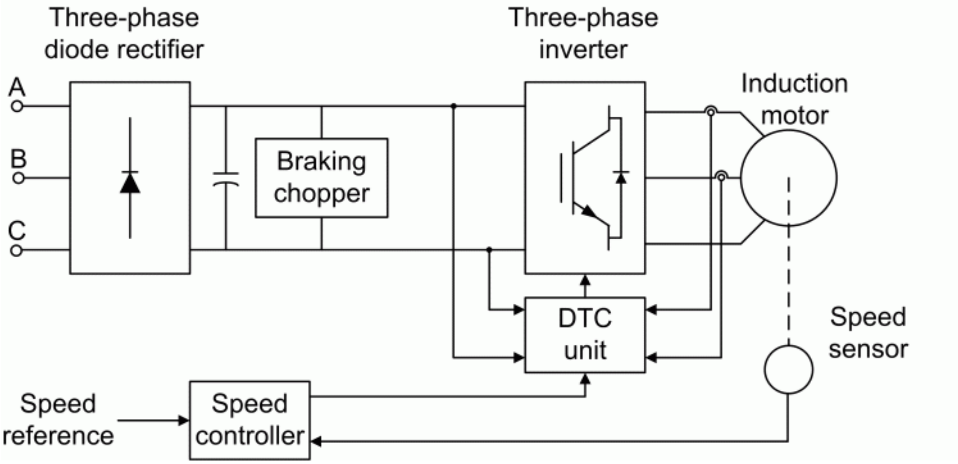
Description



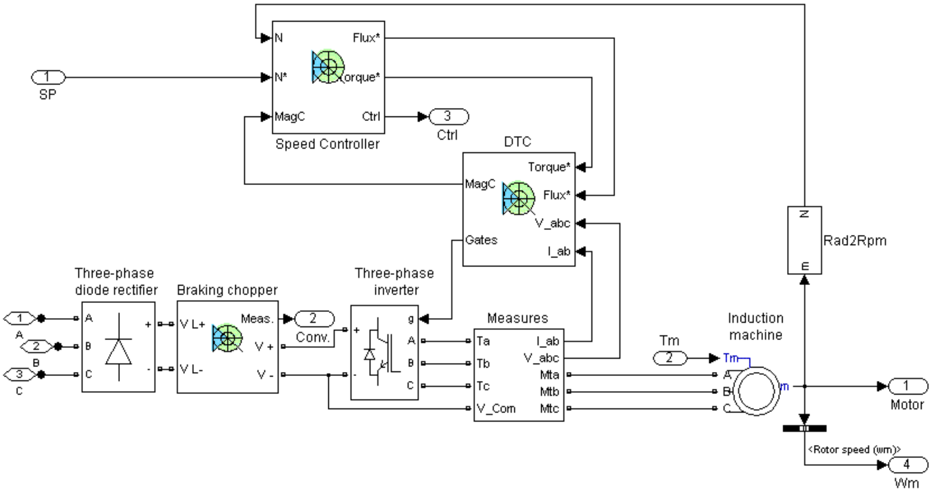
The high-level schematic shown below is built from six main blocks. The induction motor, the three-phase inverter, and the three-phase diode rectifier models are provided with the SimPowerSystems library. More details on these three blocks are available in the reference sections of each block. The speed 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

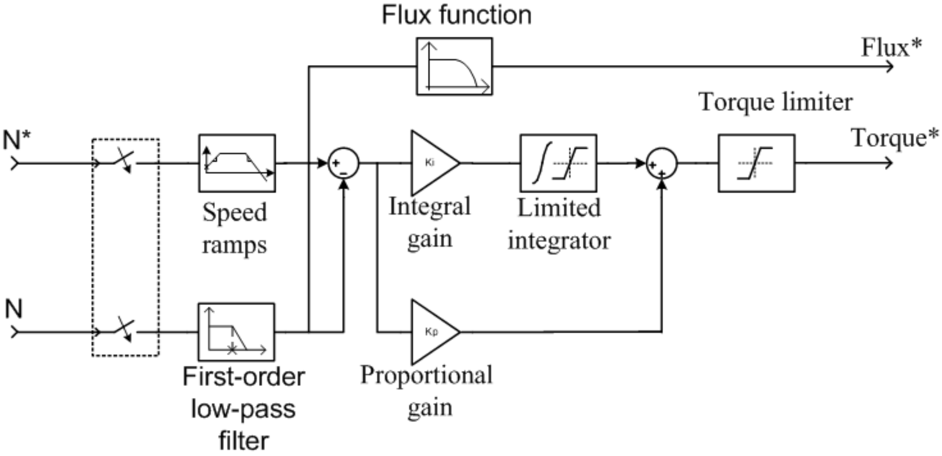


Simulink Schematic



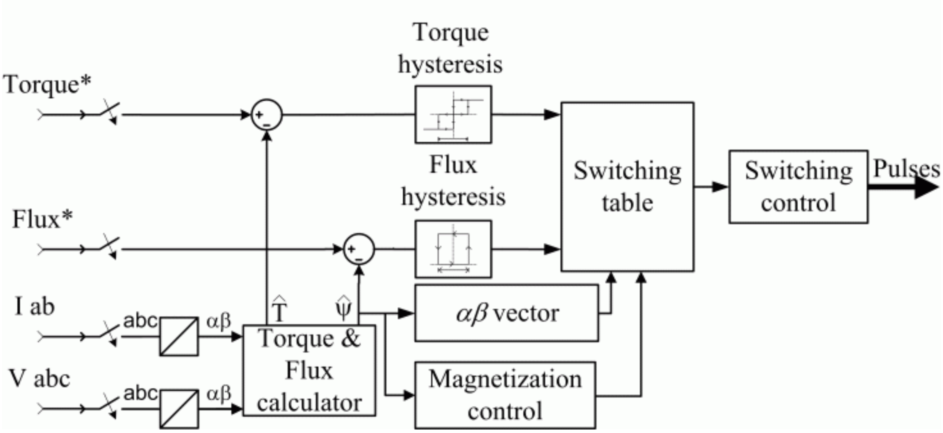
Speed Controller

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.



DTC Controller

The Direct Torque and Flux Control (DTC) 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

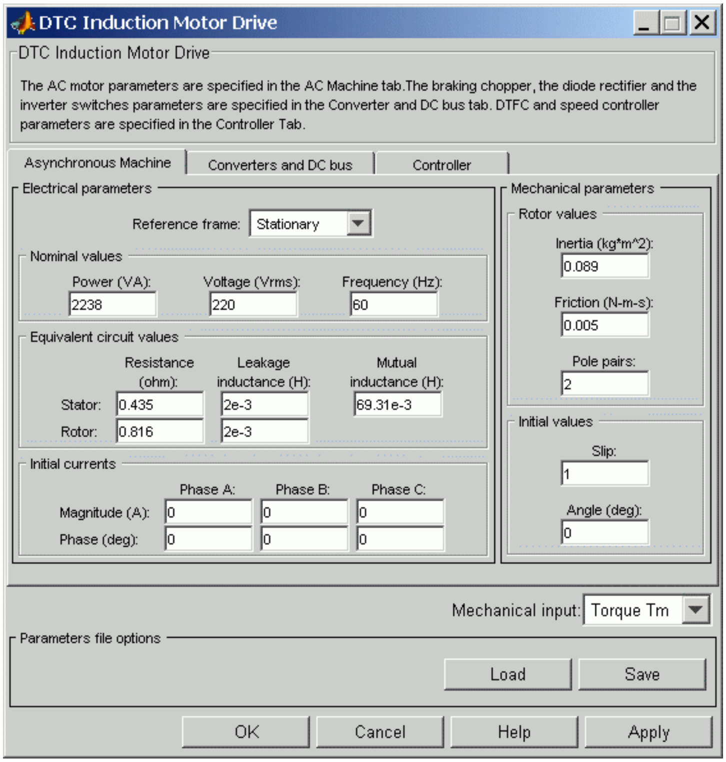
The model is discrete. Good simulation results have been obtained with a 2 µs time step. In order to simulate a digital controller device, the control system has two different sampling times:

- 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



DTC Induction Motor Drive

The AC motor parameters are specified in the AC Machine tab.The braking chopper, the diode rectifier and the inverter switches parameters are specified in the Converter and DC bus tab. DTFC and speed controller parameters are specified in the Controller Tab.

Electrical parameters

Reference frame: Stationary

Nominal values

Power (VA):	Voltage (Vrms):	Frequency (Hz):
2238	220	60

Equivalent circuit values

	Resistance (ohm):	Leakage inductance (H):	Mutual inductance (H):
Stator:	0.435	2e-3	69.31e-3
Rotor:	0.816	2e-3	

Initial currents

	Phase A:	Phase B:	Phase C:
Magnitude (A):	0	0	0
Phase (deg):	0	0	0

Mechanical parameters

Rotor values

Inertia (kg*m^2): 0.089

Friction (N-m-s): 0.005

Pole pairs: 2

Initial values

Slip: 1

Angle (deg): 0

Mechanical input: Torque Tm

Parameters file options

The asynchronous machine tab displays the parameters of the asynchronous machine block of the powerlib library. Refer to the Asynchronous Machine for more information on the Asynchronous Machine tab parameters.

Mechanical input

Allows you to select either the load torque or the motor speed as mechanical input. Note that if you select and apply a load torque, you will obtain as output the motor speed according to the following differential equation that describes the mechanical system dynamics:

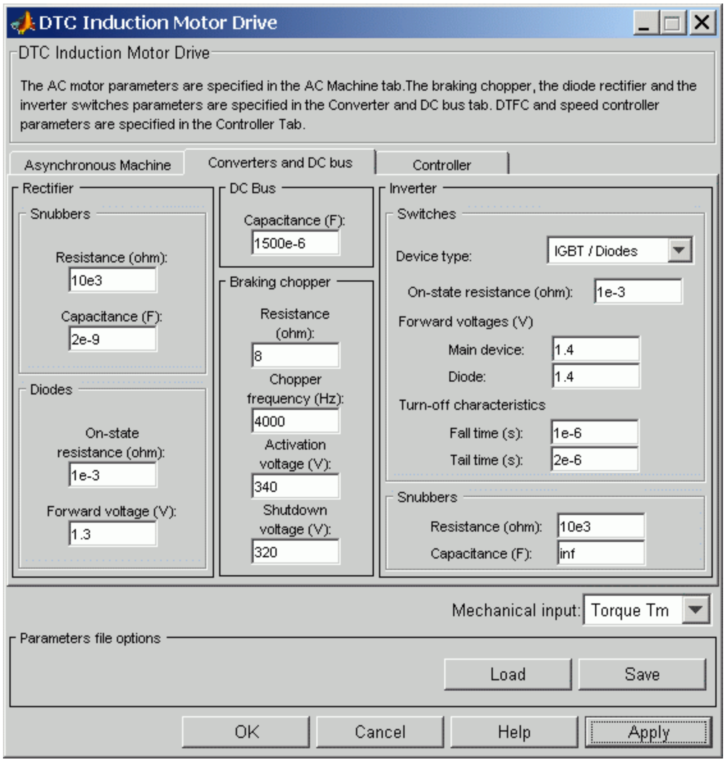
$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

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

See for example “Mechanical Coupling of Two Motor Drives”.

Converters and DC Bus Tab



DTC Induction Motor Drive

The AC motor parameters are specified in the AC Machine tab.The braking chopper, the diode rectifier and the inverter switches parameters are specified in the Converter and DC bus tab. DTFC and speed controller parameters are specified in the Controller Tab.

Rectifier

Snubbers

Resistance (ohm): 10e3
Capacitance (F): 2e-9

Diodes

On-state resistance (ohm): 1e-3
Forward voltage (V): 1.3

DC Bus

Capacitance (F): 1500e-6

Braking chopper

Resistance (ohm): 8
Chopper frequency (Hz): 4000
Activation voltage (V): 340
Shutdown voltage (V): 320

Inverter

Switches

Device type: IGBT / Diodes
On-state resistance (ohm): 1e-3
Forward voltages (V)
Main device: 1.4
Diode: 1.4
Turn-off characteristics
Fall time (s): 1e-6
Tail time (s): 2e-6

Snubbers

Resistance (ohm): 10e3
Capacitance (F): inf

Mechanical input: Torque Tm

Parameters file options

Rectifier Section

The rectifier section of the Converters and DC Bus tab displays the parameters of the rectifier block of the 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 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

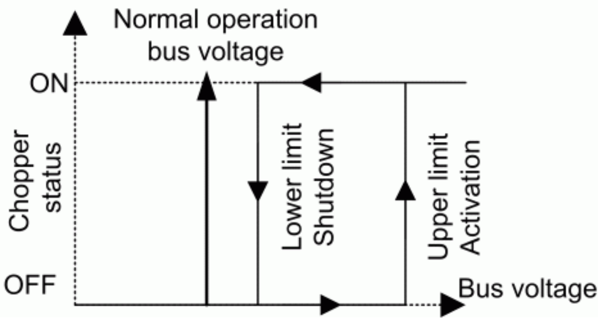
The braking chopper frequency (Hz).

Braking Chopper section: Activation Voltage

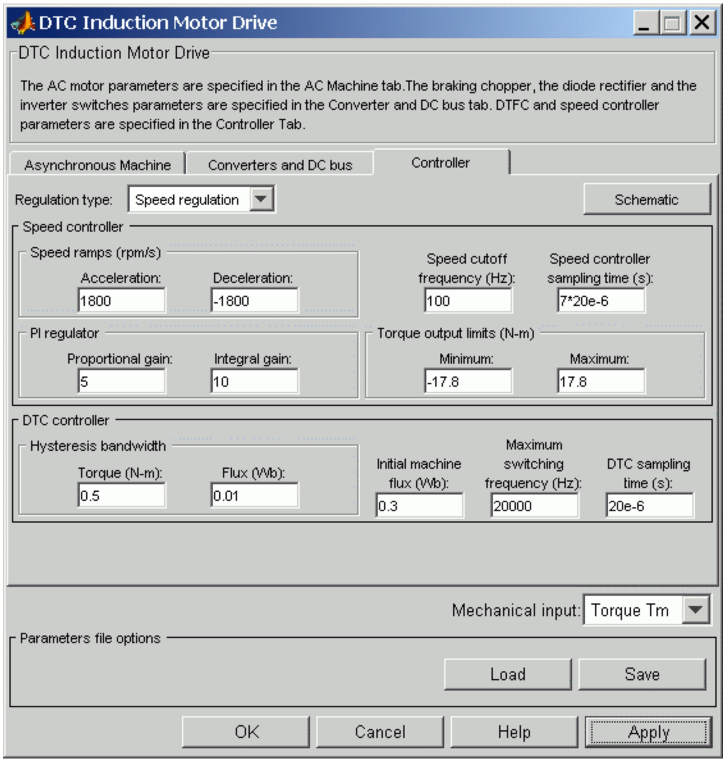
The dynamic braking is activated when the bus voltage reaches the upper limit of the hysteresis band. The following figure illustrates the braking chopper hysteresis logic.

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



The AC motor parameters are specified in the AC Machine tab.The braking chopper, the diode rectifier and the inverter switches parameters are specified in the Converter and DC bus tab. DTFC and speed controller parameters are specified in the Controller Tab.

Regulation type: Speed regulation

Speed ramps (rpm/s) Acceleration: 1800
Speed ramps (rpm/s) Deceleration: -1800
Speed cutoff frequency (Hz): 100
Speed controller sampling time (s): 7*20e-6
PI regulator Proportional gain: 5
PI regulator Integral gain: 10
Torque output limits (N-m) Minimum: -17.8
Torque output limits (N-m) Maximum: 17.8

Hysteresis bandwidth Torque (N-m): 0.5
Hysteresis bandwidth Flux (Wb): 0.01
Initial machine flux (Wb): 0.3
Maximum switching frequency (Hz): 20000
DTC sampling time (s): 20e-6

Mechanical input: Torque Tm

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

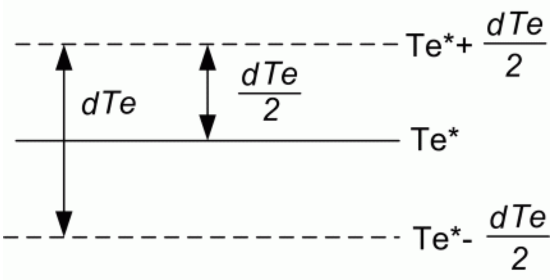
The desired initial stator flux established before the DTC drive module begins to produce an electromagnetic torque. This flux is produced by applying a constant voltage vector at the motor terminals (Wb).

DTC sampling time

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

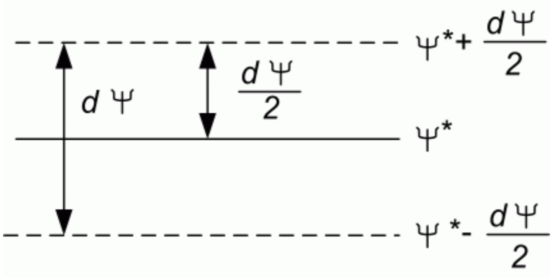
Hysteresis bandwidth — Torque

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 $d\psi$.



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. Note that 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).

`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

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

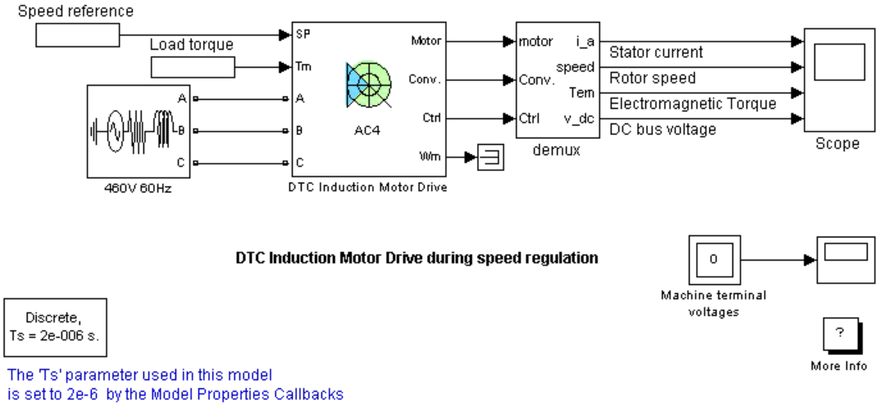
		3 HP Drive	200 HP Drive
Drive Input Voltage			
	Amplitude	220 V	460 V
	Frequency	60 Hz	60 Hz
Motor Nominal Values			
	Power	3 hp	200 hp

Drive Specifications (Continued)

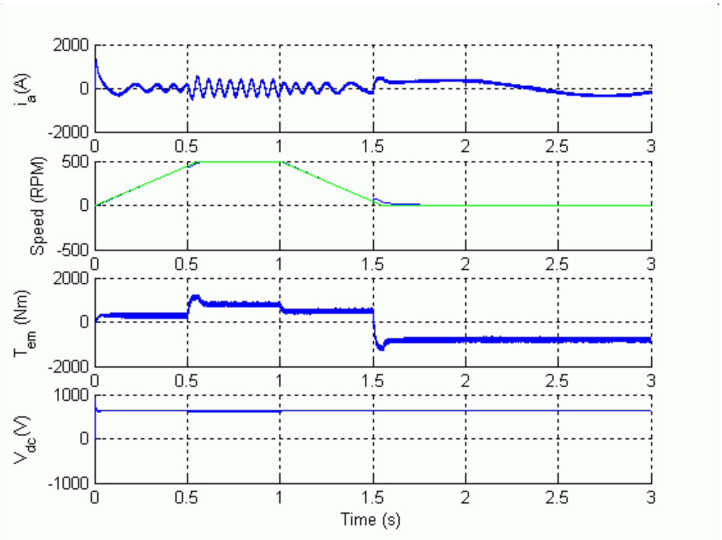
		3 HP Drive	200 HP Drive
Drive Input Voltage			
	Speed	1705 rpm	1785 rpm
	Voltage	220 V	460 V

Example

The `ac4_example` demo 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.

Excitation System

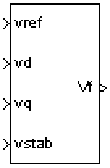
Purpose

Provide excitation system for synchronous machine and regulate its terminal voltage in generating mode

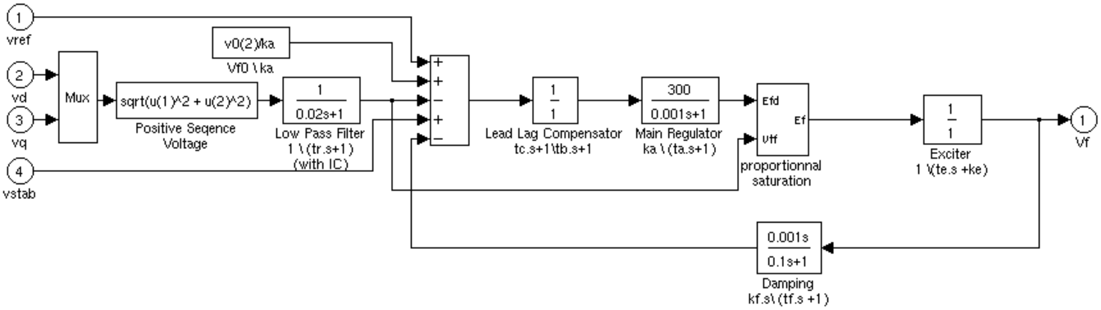
Library

Machines

Description



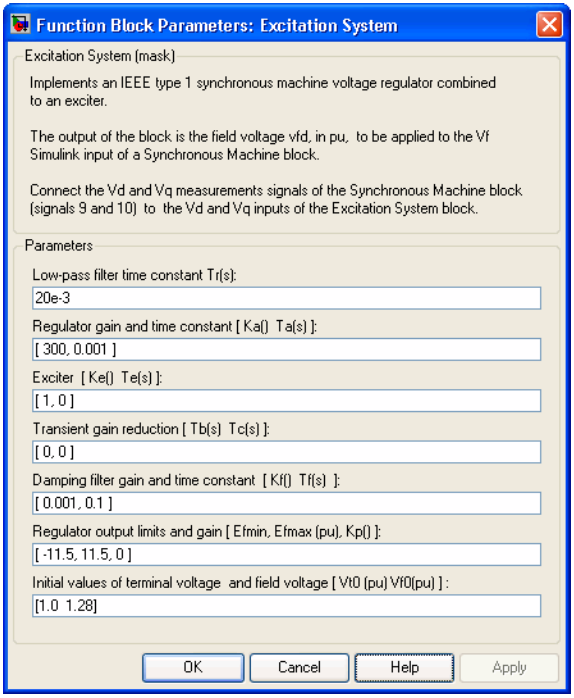
The Excitation System block is a Simulink system implementing a DC exciter described in [1], without the exciter's saturation function. The basic elements that form the Excitation System block are the voltage regulator and the exciter.



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



Excitation System (mask)

Implements an IEEE type 1 synchronous machine voltage regulator combined to an exciter.

The output of the block is the field voltage vfd, in pu, to be applied to the Vf Simulink input of a Synchronous Machine block.

Connect the Vd and Vq measurements signals of the Synchronous Machine block (signals 9 and 10) to the Vd and Vq inputs of the Excitation System block.

Parameters

Low-pass filter time constant Tr(s): 20e-3

Regulator gain and time constant [Ka() Ta(s)]: [300, 0.001]

Exciter [Ke() Te(s)]: [1, 0]

Transient gain reduction [Tb(s) Tc(s)]: [0, 0]

Damping filter gain and time constant [Kf() Tf(s)]: [0.001, 0.1]

Regulator output limits and gain [Efmin, Efmax (pu), Kp()]: [-11.5, 11.5, 0]

Initial values of terminal voltage and field voltage [Vt0 (pu) Vf0(pu)] : [1.0 1.28]

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

Field-Oriented Control Induction Motor Drive

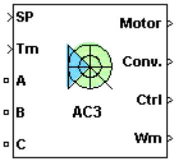
Purpose

Implement field-oriented control (FOC) induction motor drive model

Library

Electric Drives/AC drives

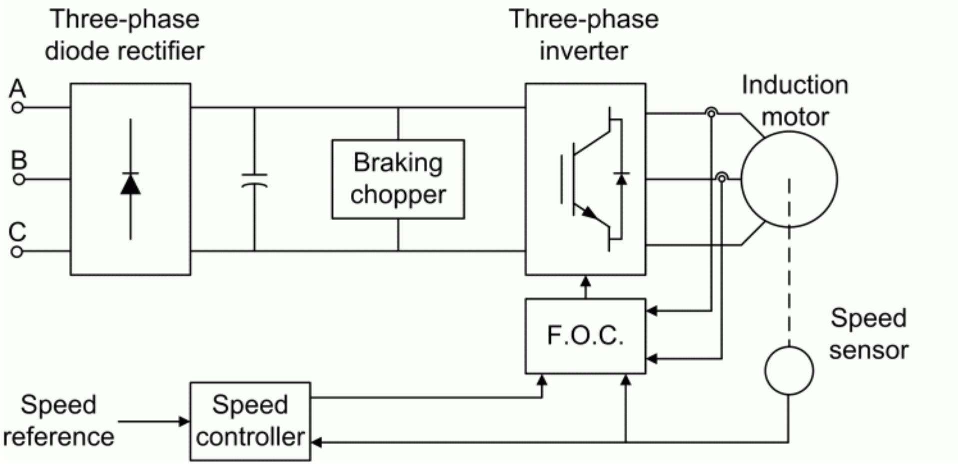
Description



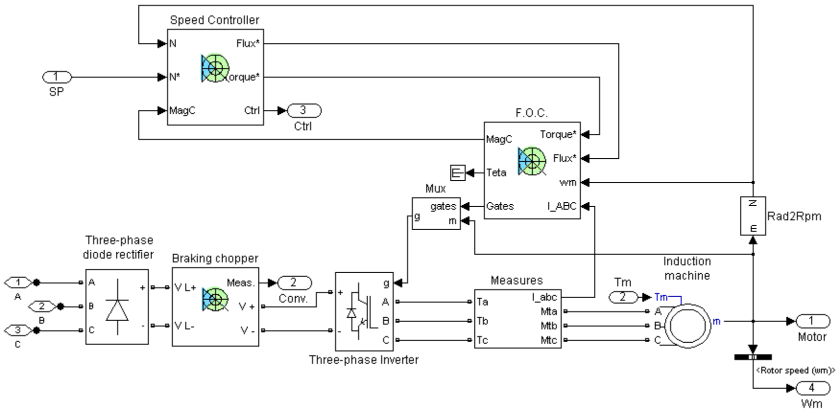
The high-level schematic shown below is built from six main blocks. The induction motor, the three-phase inverter, and the three-phase diode rectifier models are from blocks provided in the SimPowerSystems library. The speed controller, the braking chopper, and the FOC models are from blocks provided 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

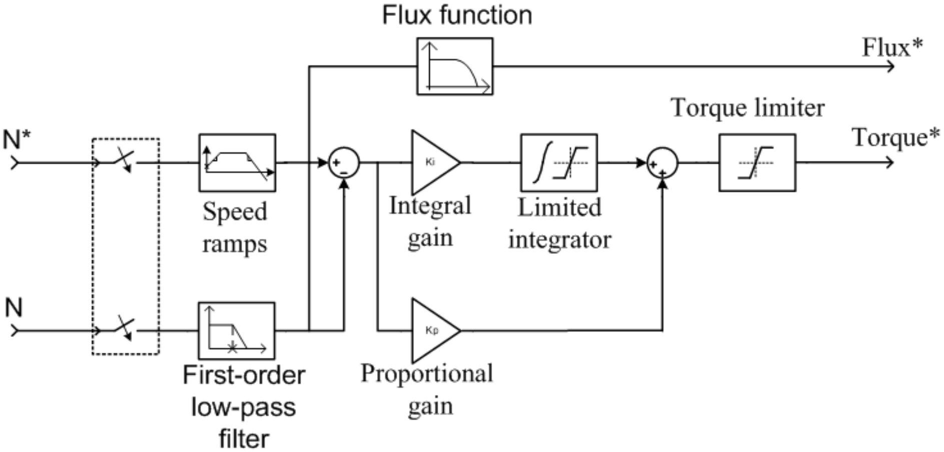


Simulink Schematic



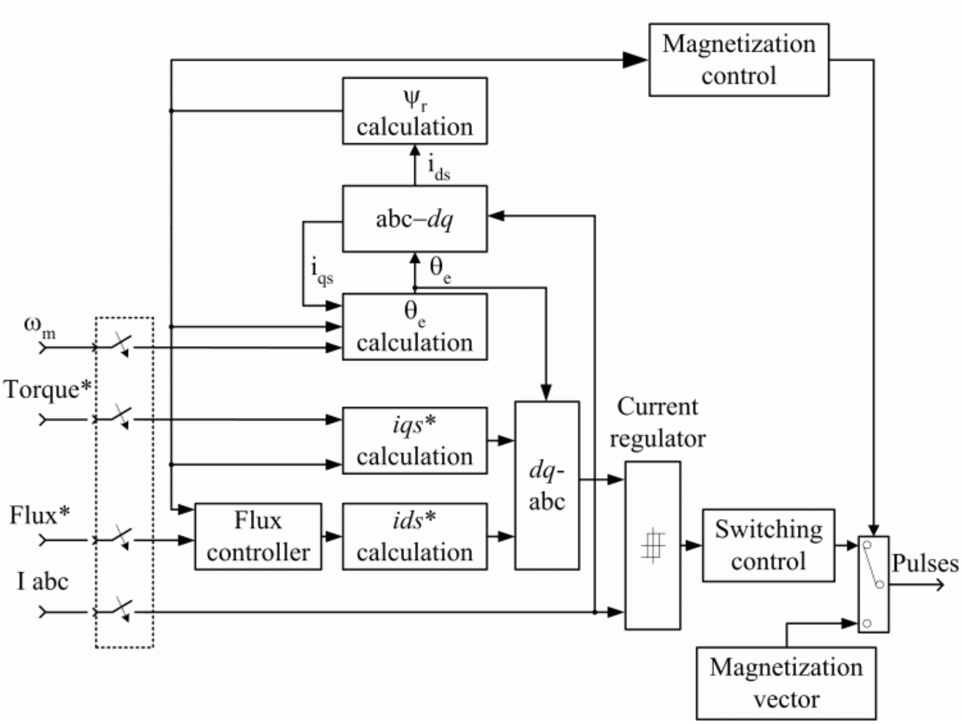
Speed Controller

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 ψ_r *calculation* block is used to estimate the motor's rotor flux. This calculation is based on motor equation synthesis.

The Θ_e *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.

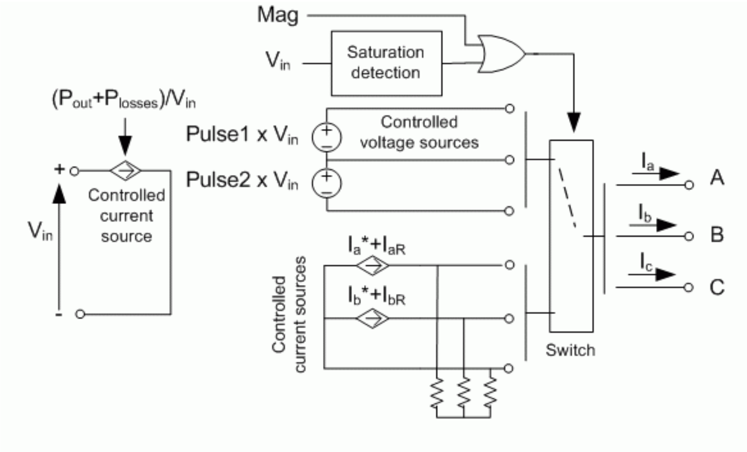
The *magnetization control* unit contains the logic used to switch between the magnetization and normal operation mode.

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

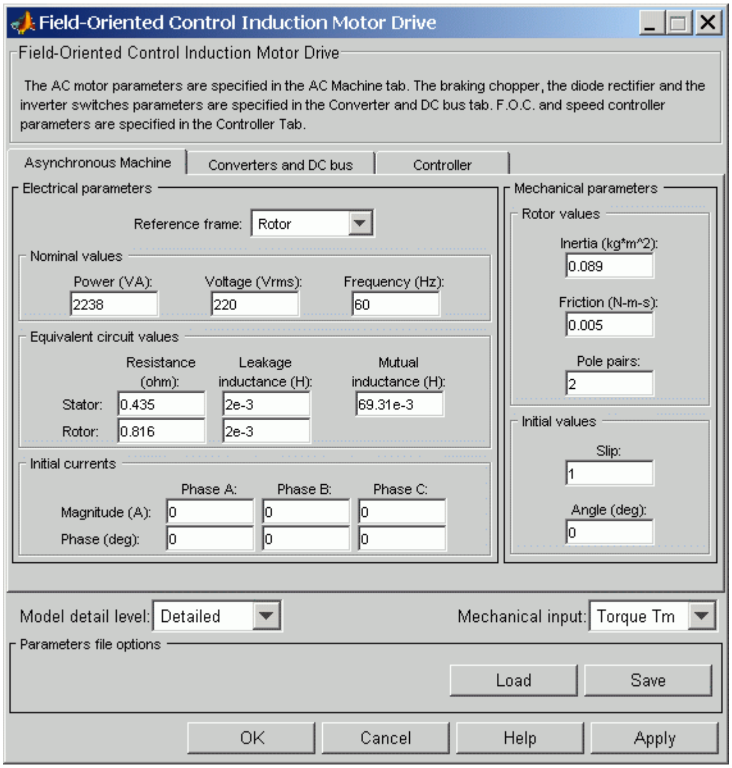
The model is discrete. Good simulation results have been obtained with a 2 μs time step. To simulate a digital controller device, the control system has two different sampling times:

- 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

Asynchronous Machine Tab



Field-Oriented Control Induction Motor Drive

The AC motor parameters are specified in the AC Machine tab. The braking chopper, the diode rectifier and the inverter switches parameters are specified in the Converter and DC bus tab. F.O.C. and speed controller parameters are specified in the Controller Tab.

Reference frame: Rotor

Power (VA):	Voltage (Vrms):	Frequency (Hz):
2238	220	60

	Resistance (ohm):	Leakage inductance (H):	Mutual inductance (H):
Stator:	0.435	2e-3	69.31e-3
Rotor:	0.816	2e-3	

	Phase A:	Phase B:	Phase C:
Magnitude (A):	0	0	0
Phase (deg):	0	0	0

Inertia (kg*m^2): 0.089
Friction (N-m-s): 0.005
Pole pairs: 2
Slip: 1
Angle (deg): 0

Model detail level: Detailed
Mechanical input: Torque Tm

The **Asynchronous Machine** tab displays the parameters of the asynchronous machine block of the powerlib library. Refer to the Asynchronous Machine for more information on the Asynchronous Machine parameters.

Model detail level
Select between the detailed and the average-value inverter.

Mechanical input
Allows you to select either the load torque or the motor speed as mechanical input. Note that if you select and apply a load

torque, you will obtain as output the motor speed according to the following differential equation that describes the mechanical system dynamics:

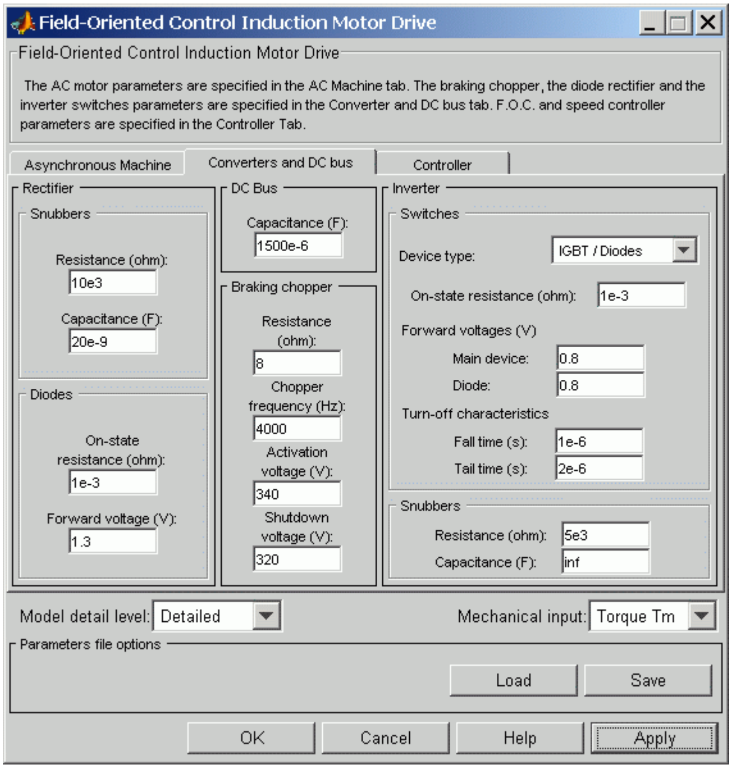
$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

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

See for example “Mechanical Coupling of Two Motor Drives”.

Converters and DC Bus Tab



Field-Oriented Control Induction Motor Drive

The AC motor parameters are specified in the AC Machine tab. The braking chopper, the diode rectifier and the inverter switches parameters are specified in the Converter and DC bus tab. F.O.C. and speed controller parameters are specified in the Controller Tab.

Rectifier

Snubbers

Resistance (ohm): 10e3

Capacitance (F): 20e-9

Diodes

On-state resistance (ohm): 1e-3

Forward voltage (V): 1.3

DC Bus

Capacitance (F): 1500e-6

Braking chopper

Resistance (ohm): 8

Chopper frequency (Hz): 4000

Activation voltage (V): 340

Shutdown voltage (V): 320

Inverter

Switches

Device type: IGBT / Diodes

On-state resistance (ohm): 1e-3

Forward voltages (V)

Main device: 0.8

Diode: 0.8

Turn-off characteristics

Fall time (s): 1e-6

Tail time (s): 2e-6

Snubbers

Resistance (ohm): 5e3

Capacitance (F): inf

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

Rectifier Section

The **Rectifier** section of the **Converters and DC Bus** tab displays the parameters of the Universal Bridge block of the 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 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).

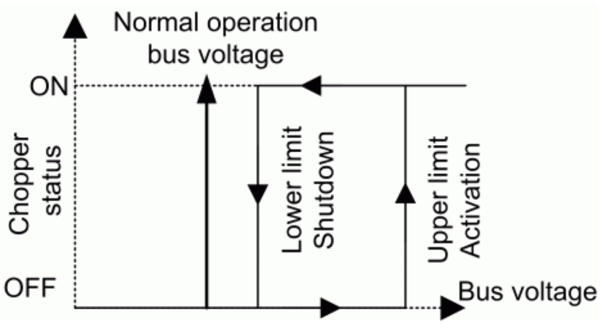
Braking Chopper section

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).

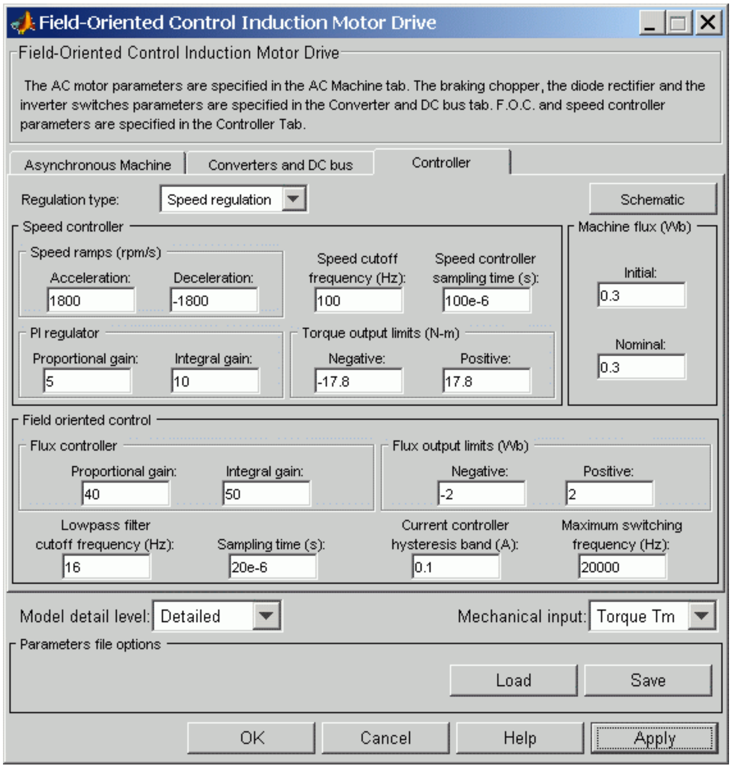
Frequency
The braking chopper frequency (Hz).

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



Field-Oriented Control Induction Motor Drive

Field-Oriented Control Induction Motor Drive

The AC motor parameters are specified in the AC Machine tab. The braking chopper, the diode rectifier and the inverter switches parameters are specified in the Converter and DC bus tab. F.O.C. and speed controller parameters are specified in the Controller Tab.

Regulation type: Speed regulation

Speed controller

Speed ramps (rpm/s)

Acceleration: 1800

Deceleration: -1800

Speed cutoff frequency (Hz): 100

Speed controller sampling time (s): 100e-6

PI regulator

Proportional gain: 5

Integral gain: 10

Torque output limits (N-m)

Negative: -17.8

Positive: 17.8

Machine flux (Wb)

Initial: 0.3

Nominal: 0.3

Field oriented control

Flux controller

Proportional gain: 40

Integral gain: 50

Flux output limits (Wb)

Negative: -2

Positive: 2

Lowpass filter cutoff frequency (Hz): 16

Sampling time (s): 20e-6

Current controller hysteresis band (A): 0.1

Maximum switching frequency (Hz): 20000

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

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).

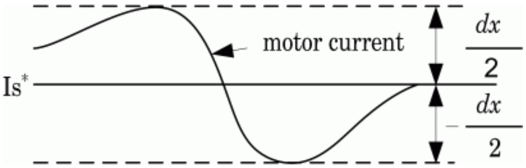
Flux output limits — Negative
The flux controller maximum negative output (Wb).

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. Note that 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).

`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

Model Specifications

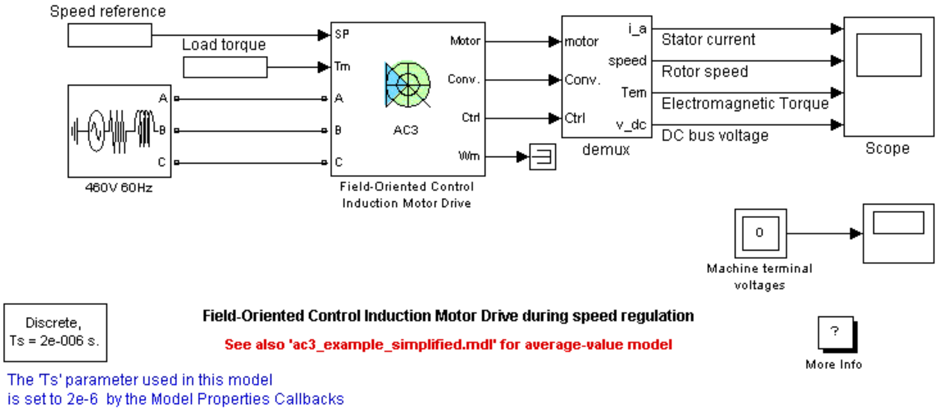
The library contains a 3 hp and a 200 hp drive parameter set. The specifications of these two drives are shown in the following table.

3 HP and 200 HP Drive Specifications

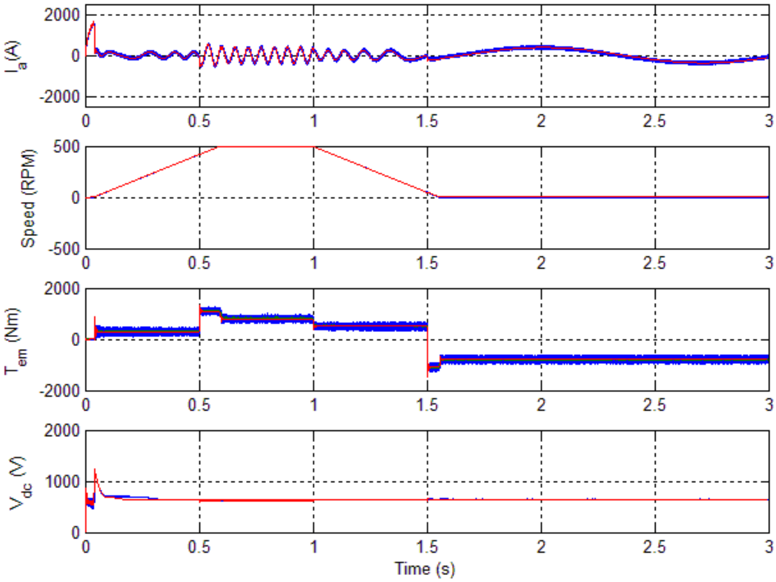
		3 HP Drive	200 HP Drive
Drive Input Voltage			
	Amplitude	220 V	460 V
	Frequency	60 Hz	60 Hz
Motor Nominal Values			
	Power	3 hp	200 hp
	Speed	1705 rpm	1785 rpm
	Voltage	220 V	460 V

Example

The `ac3_example` demo 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.

Fourier

Purpose

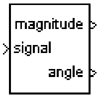
Perform Fourier analysis of signal

Library

Extras/Measurements

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

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 the following equations:

$$|H_n| = \sqrt{a_n^2 + b_n^2}$$

$$\angle H_n = \mathrm{atan2}\left(\frac{a_n}{b_n}\right)$$

where

$$a_n = \frac{2}{T} + \int_{t-T}^{t} f(t)\cos(n\omega t)dt$$

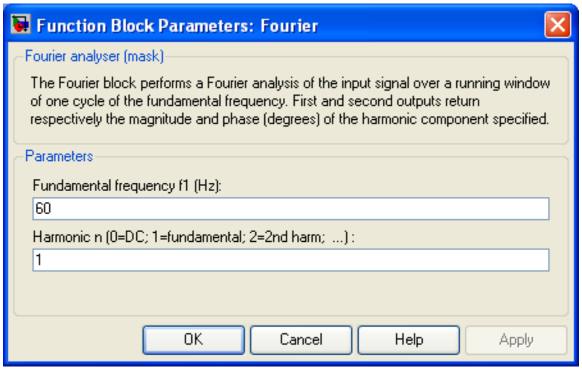
$$b_n = \frac{2}{T} + \int_{t-T}^{t} f(t)\sin(n\omega t)dt$$

$$T = \frac{1}{f_1}$$

f_1 : Fundamental frequency

As this block uses a running average window, one cycle of simulation has to be completed before the outputs give the correct magnitude and angle. 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.

Dialog Box and Parameters



The Fourier block performs a Fourier analysis of the input signal over a running window of one cycle of the fundamental frequency. First and second outputs return respectively the magnitude and phase (degrees) of the harmonic component specified.

Fundamental frequency f1 (Hz): 60

Harmonic n (0=DC; 1=fundamental; 2=2nd harm; ...) : 1

Fundamental frequency f1
The fundamental frequency, in hertz, of the input signal.

Harmonic n (0 = DC; 1 = fundamental; 2 = 2nd harm; etc.)
Specify the harmonic component you want to perform the Fourier analysis. Enter 0 if you want to analyze the DC component. Enter 1 if you want to analyze the fundamental frequency, or enter a number corresponding to the desired harmonic.

Inputs and Outputs

`signal`

Connect to the signal to be analyzed. Typical input signals are voltages or currents measured by Current Measurement blocks or Voltage Measurement blocks.

`magnitude`

The first output returns the magnitude of the harmonic component specified, in the same units as the input signal.

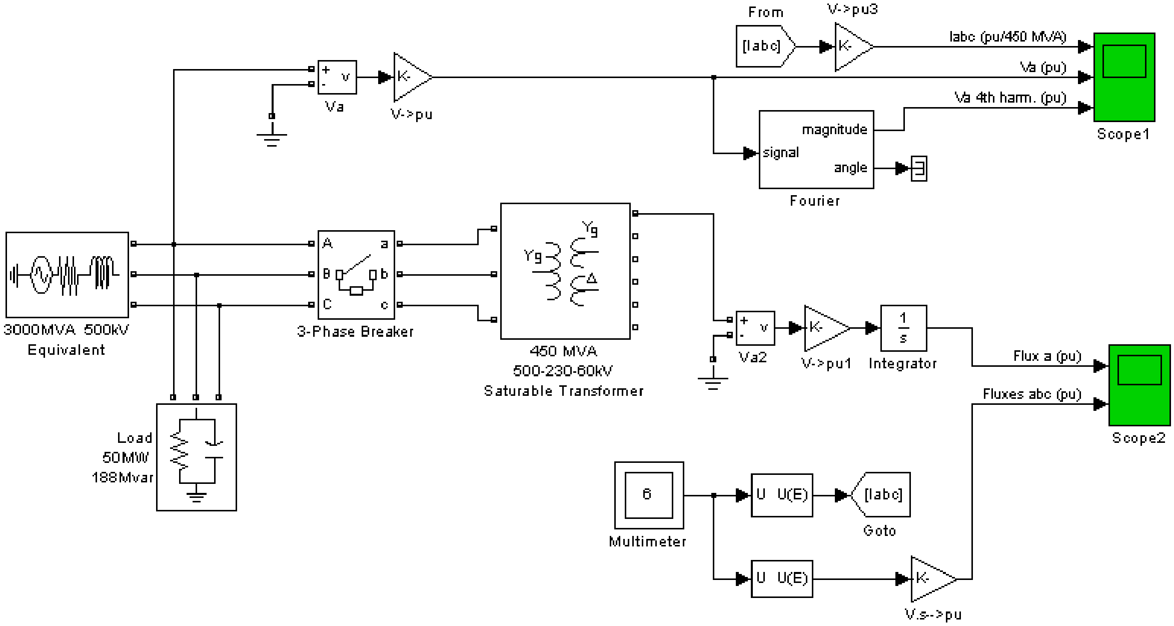
`phase`

The second output returns the phase, in degrees, of the harmonic component specified.

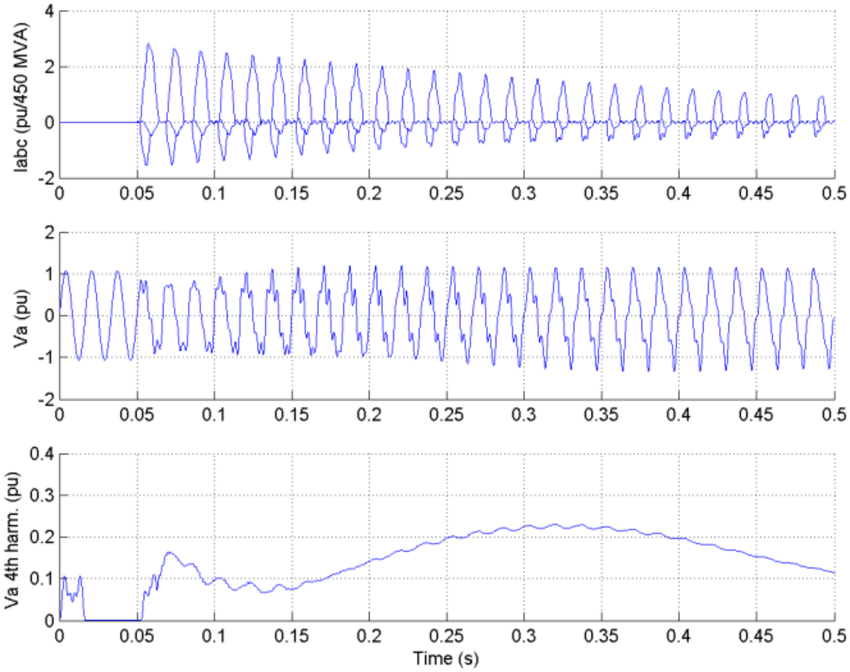
Example

The `power_transfosat` demo shows the energization of a 450 MVA three-phase transformer on a 500 kV network. The power system is simulated by an equivalent circuit consisting of an inductive source having a short-circuit power of 3000 MVA and a parallel RC load.

The load capacitance is set to produce a resonance at 240 Hz (fourth harmonic). A Fourier block is used to measure the fourth harmonic content of phase A of the primary voltage.



The Fourier block measures a high level fourth harmonic in the voltage (on the second trace of Scope1) because of the fourth harmonic content of the current injected into the network resonating at that particular frequency (240 Hz).


Iabc (pu/450 MVA)
4
2
0
-2
Va (pu)
2
1
0
-1
-2
Va 4th harm. (pu)
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Time (s)

Four-Quadrant Chopper DC Drive

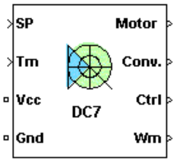
Purpose

Implement four-quadrant chopper DC drive

Library

Electric Drives/DC drives

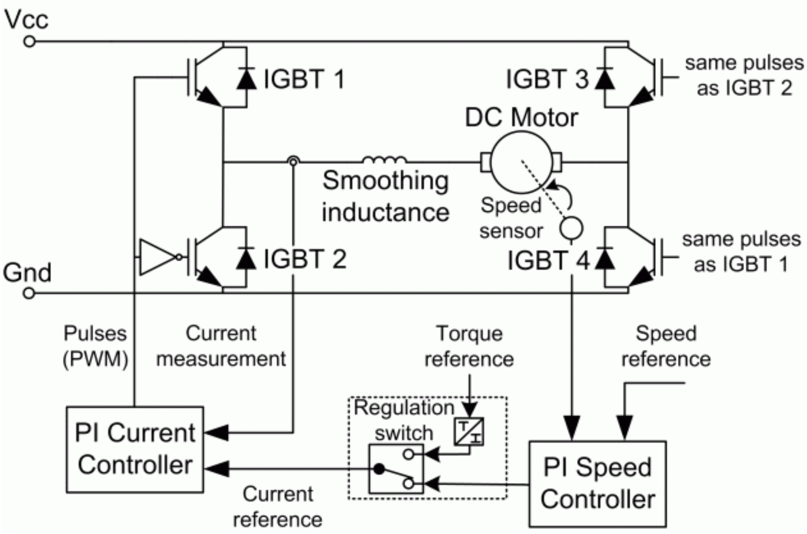
Description



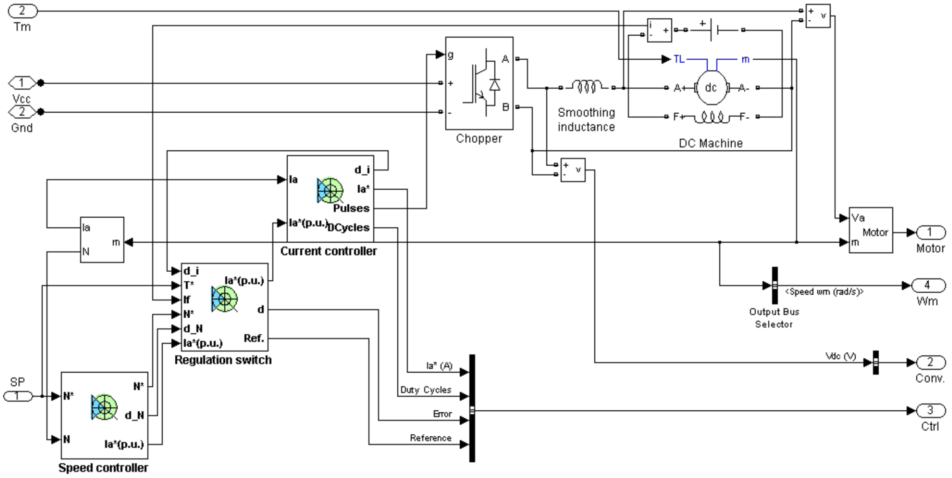
The high-level schematic shown below is built from four main blocks. The DC motor and the IGBT/Diode devices (within the Universal Bridge block) are provided with the SimPowerSystems library. More details on these two blocks are available in the reference sections of these blocks. The two other blocks 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



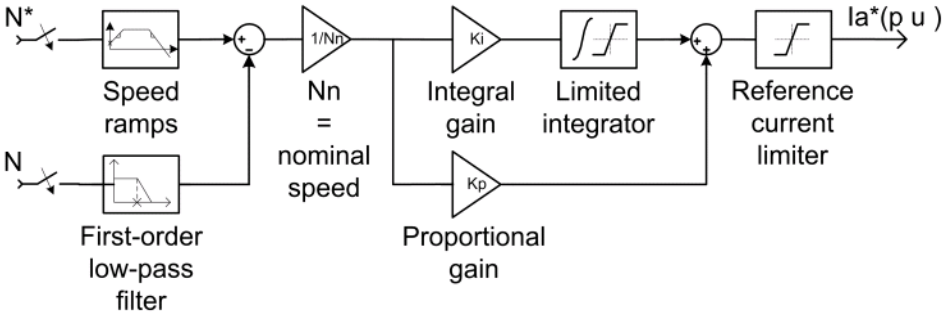
Speed Controller

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.

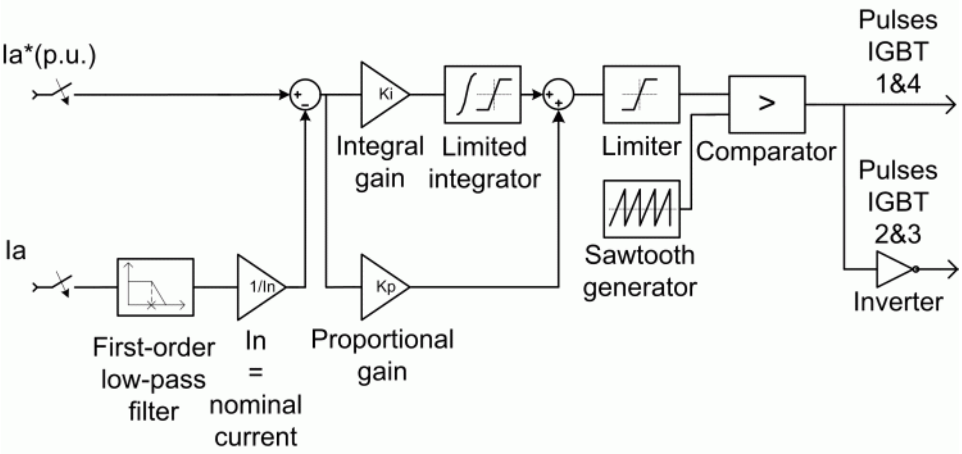


Current Controller

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.

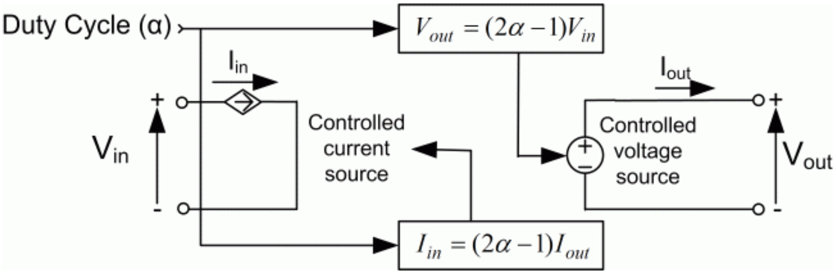
The controller takes the current reference (in pu) and the armature current flowing through the motor as inputs. The current reference is either provided by the speed controller during speed regulation or computed from the torque reference provided by the user during torque regulation. This is managed 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) on page 2-169).



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 :

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

with α 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 :

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

with V_{in} being the input voltage.

Remarks

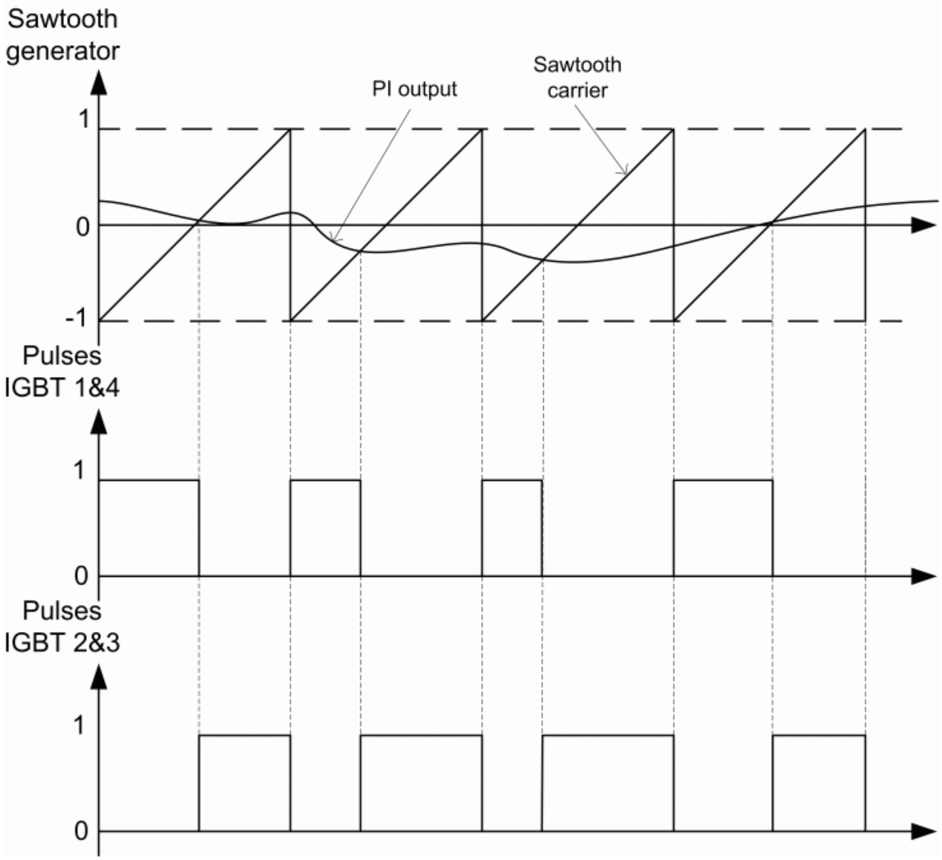
The machine is separately excited with a constant DC field voltage source. There is thus no field voltage control. By default, the field current is set to its steady-state value when a simulation is started.

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

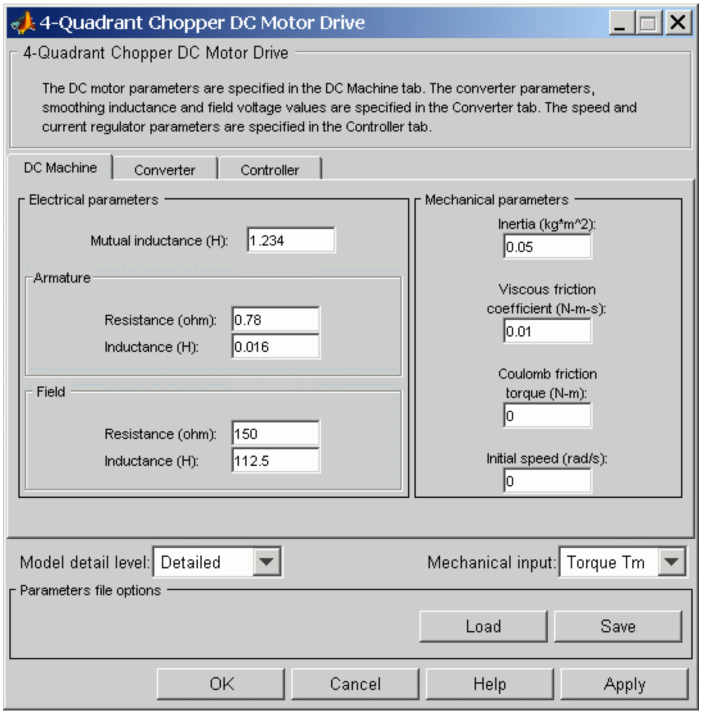
The speed controller sampling time has to be a multiple of the current sampling time. The latter sampling time has to be a multiple of the simulation time step.



Pulse Width Modulation (PWM)

Dialog Box

DC Machine Tab



4-Quadrant Chopper DC Motor Drive

4-Quadrant Chopper DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The speed and current regulator parameters are specified in the Controller tab.

Electrical parameters

Mutual inductance (H): 1.234

Armature

Resistance (ohm): 0.78

Inductance (H): 0.016

Field

Resistance (ohm): 150

Inductance (H): 112.5

Mechanical parameters

Inertia (kg*m^2): 0.05

Viscous friction coefficient (N-m-s): 0.01

Coulomb friction torque (N-m): 0

Initial speed (rad/s): 0

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

The DC Machine tab displays the parameters of the DC machine block of the powerlib library. Refer to the DC Machine for more information on the DC machine block parameters.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Allows you to select either the load torque or the motor speed as mechanical input. Note that if you select and apply a load torque, you will obtain as output the motor speed according to the following differential equation that describes the mechanical system dynamics:

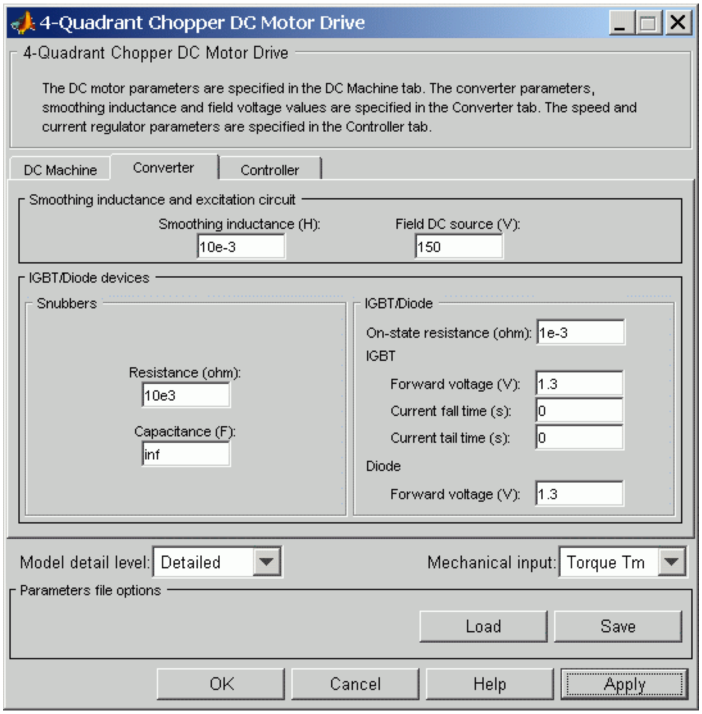
$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

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

See for example “Mechanical Coupling of Two Motor Drives”.

Converter Tab



4-Quadrant Chopper DC Motor Drive

4-Quadrant Chopper DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The speed and current regulator parameters are specified in the Controller tab.

Smoothing inductance and excitation circuit

Smoothing inductance (H): 10e-3

Field DC source (V): 150

IGBT/Diode devices

Snubbers

Resistance (ohm): 10e3

Capacitance (F): inf

IGBT/Diode

On-state resistance (ohm): 1e-3

IGBT

Forward voltage (V): 1.3

Current fall time (s): 0

Current tail time (s): 0

Diode

Forward voltage (V): 1.3

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

IGBT/Diode Devices section

The IGBT/Diode section of the Converter tab displays the parameters of the Universal Bridge block of the powerlib library. Refer to the Universal Bridge for more information on the Universal Bridge block parameters.

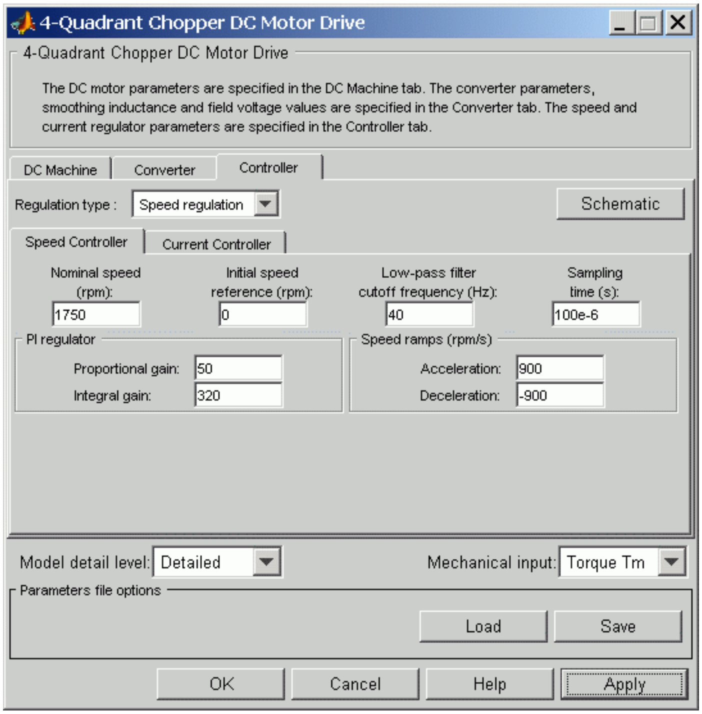
Smoothing Inductance

The smoothing inductance value (H).

Field DC Source

The DC motor field voltage value (V).

Controller Tab



4-Quadrant Chopper DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The speed and current regulator parameters are specified in the Controller tab.

Regulation type : Speed regulation

Nominal speed (rpm): 1750

Initial speed reference (rpm): 0

Low-pass filter cutoff frequency (Hz): 40

Sampling time (s): 100e-6

PI regulator

Proportional gain: 50

Integral gain: 320

Speed ramps (rpm/s)

Acceleration: 900

Deceleration: -900

Model detail level: Detailed

Mechanical input: Torque Tm

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.

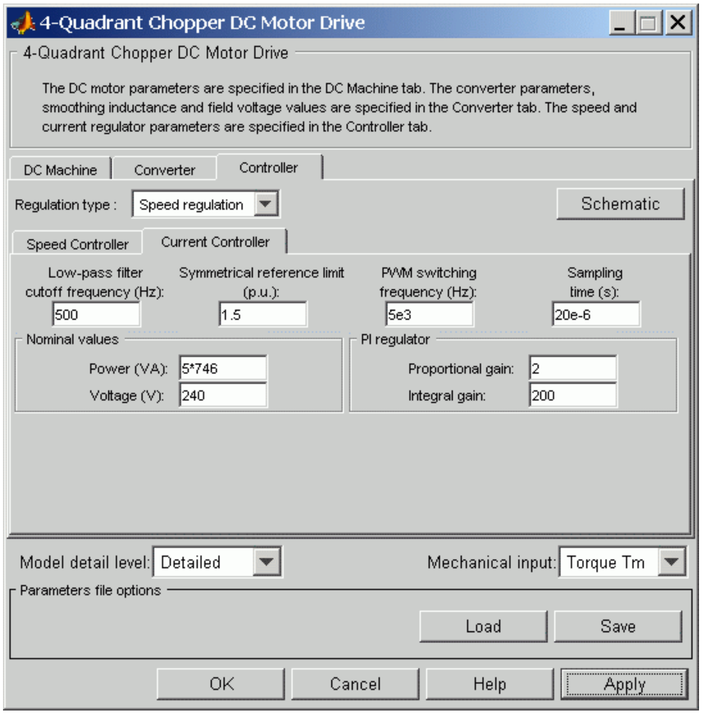
Proportional Gain
The proportional gain of the PI speed controller.

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



4-Quadrant Chopper DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The speed and current regulator parameters are specified in the Controller tab.

Regulation type : Speed regulation

Low-pass filter cutoff frequency (Hz): 500

Symmetrical reference limit (p.u.): 1.5

PWM switching frequency (Hz): 5e3

Sampling time (s): 20e-6

Power (VA): 5*746

Voltage (V): 240

Proportional gain: 2

Integral gain: 200

Model detail level: Detailed

Mechanical input: Torque Tm

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. Note that 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).

`Vcc, Gnd`
The DC voltage source electric connections. The voltage must be adequate for the motor size.

`Wm` or `Te`
The mechanical output: motor speed (Wm) or electromagnetic torque (Te).

`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

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

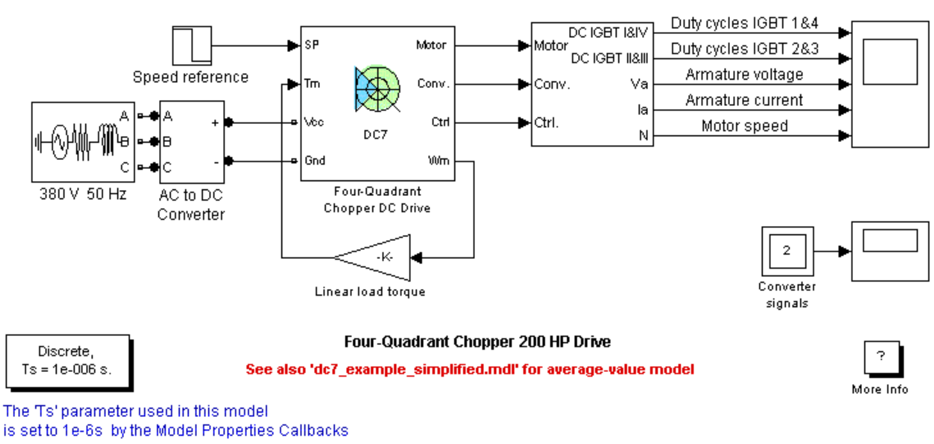
		5 HP Drive	200 HP Drive
Drive Input Voltage			
	Amplitude	280 V	500 V
Motor Nominal Values			
	Power	5 hp	200 hp

5 HP and 200 HP Drive Specifications (Continued)

		5 HP Drive	**200 HP Drive**
Drive Input Voltage			
	Speed	1750 rpm	1184 rpm
	Voltage	240 V	440 V

Example

The `dc7_example` demo 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.

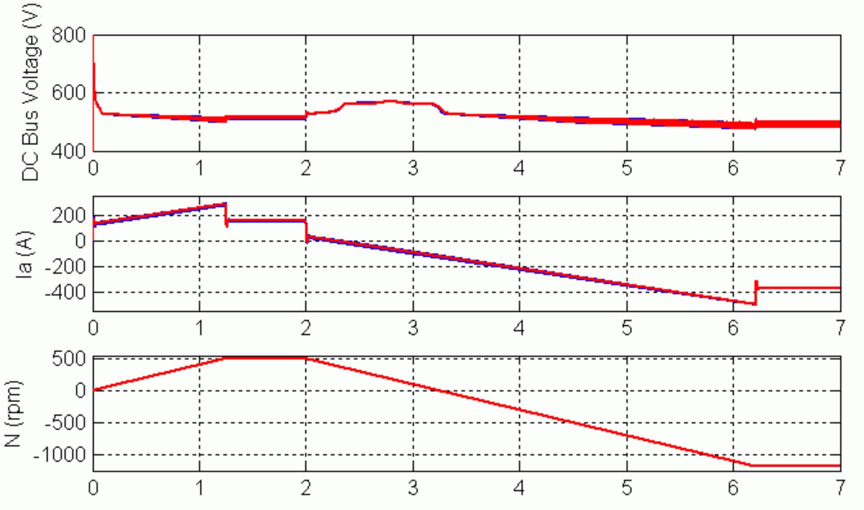
The armature current follows the current reference very well, with fast response time and small ripples. Notice that the current ripple frequency is 5 kHz.

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.

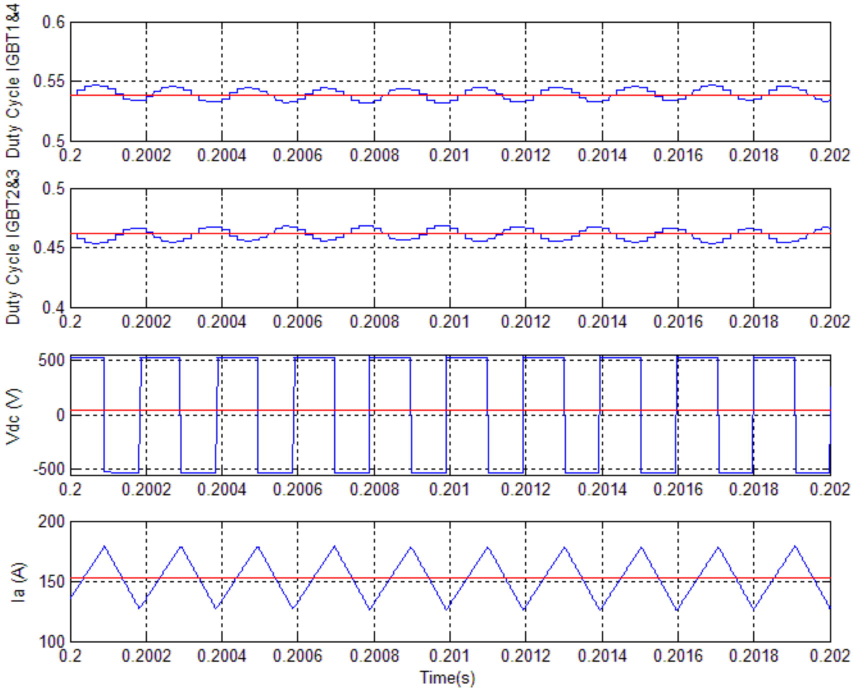
At t = 3.25 s, the motor reaches 0 rpm and the load torque reverses and becomes negative. The negative current now produces an accelerating electromagnetic torque to allow the motor to follow the negative speed ramp (-400 rpm/s). At t = 6.3 s, the speed reaches -1184 rpm and stabilizes around its reference.

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.

Four-Quadrant Single-Phase Rectifier DC Drive

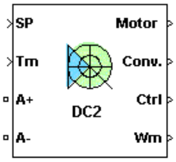
Purpose

Implement single-phase dual-converter DC drive with circulating current

Library

Electric Drives/DC drives

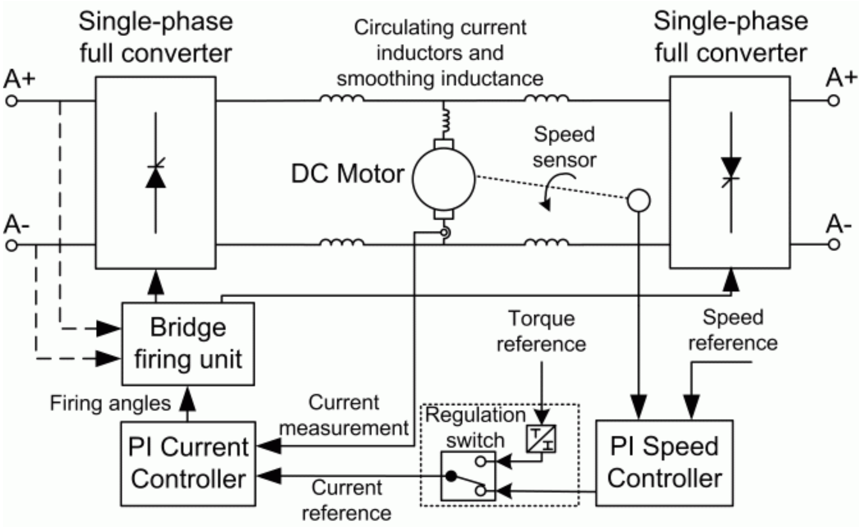
Description



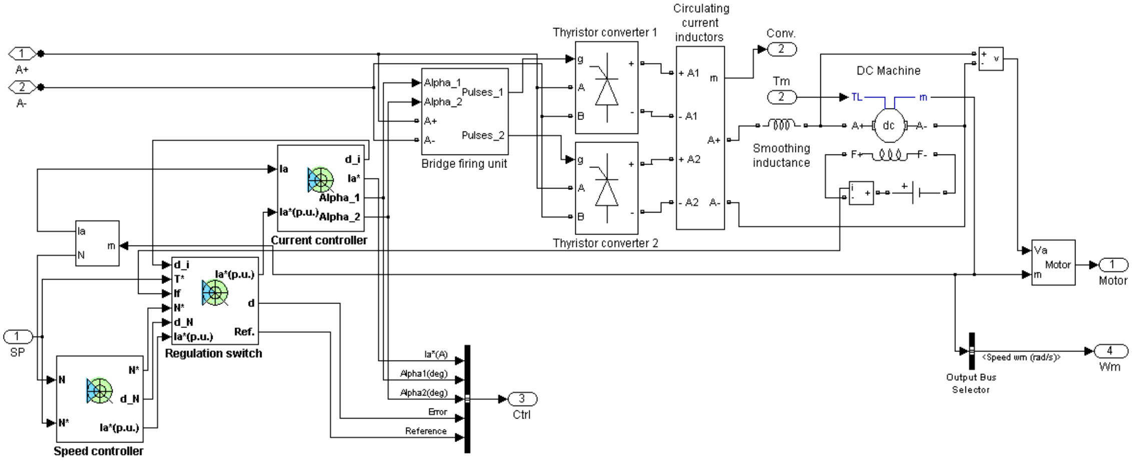
The high-level schematic shown below is built from six main blocks. The DC motor, the two single-phase full converters, and the bridge firing unit are provided with the SimPowerSystems library. More details on these blocks are available in the reference sections of these blocks. The two other blocks 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

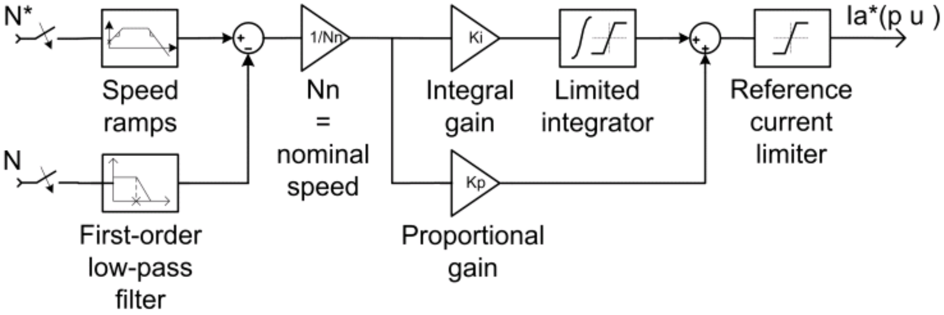


Speed Controller

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.



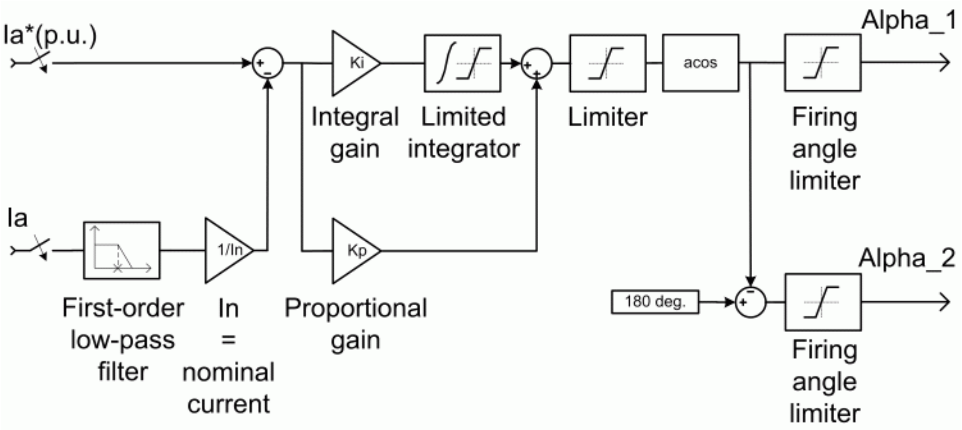
Current Controller

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.

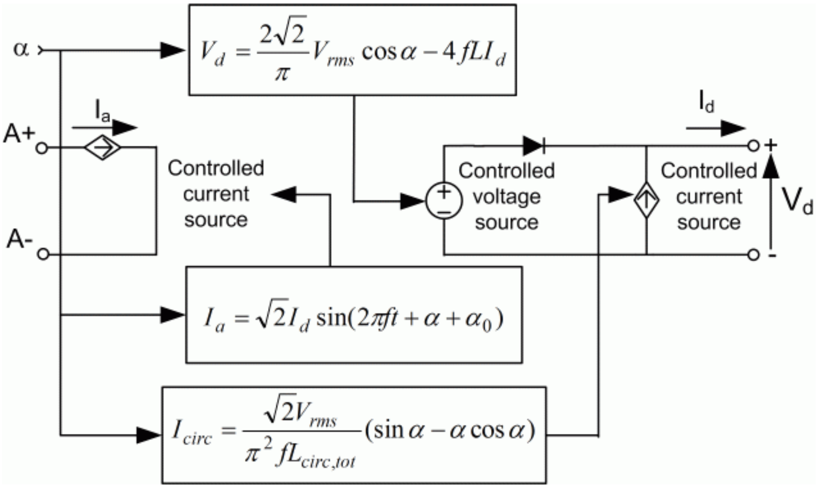
The armature current input is filtered by a first-order low-pass filter. An arccosine function is used to linearize the control system. The firing angle can vary between 0 and 180 degrees. You can limit the lower and upper limits to intermediate values.

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

$$I_a = \sqrt{2} I_d \sin(2\pi ft + \alpha + \alpha_0)$$

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

$$V_d = \frac{2\sqrt{2}}{\pi} V_{rms} \cos\alpha - 4fLI_d$$

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

$$I_{circ} = \frac{\sqrt{2}}{\pi^2 f L_{circ,\,tot}} V_{rms}(\sin\alpha - \alpha\cos\alpha)$$

with $L_{circ,\,tot}$ being the total circulation inductance of the circulation current loop.

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.

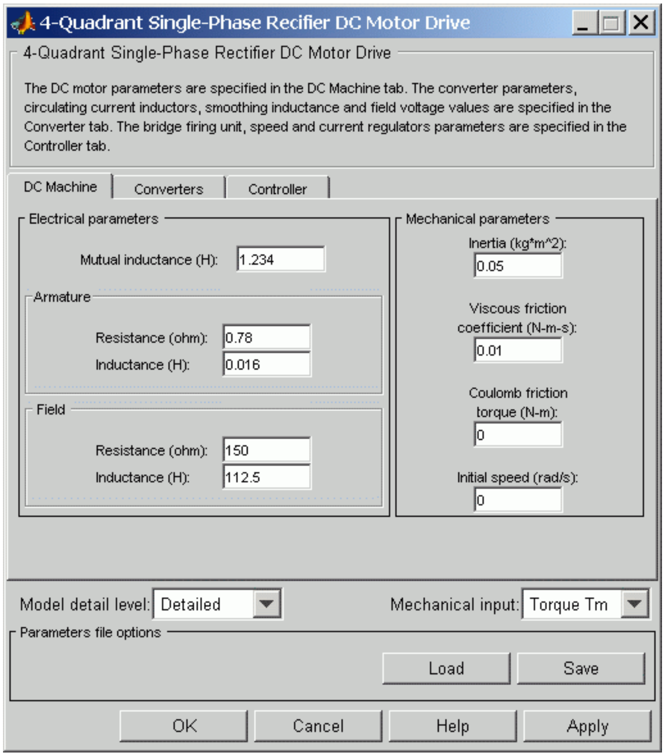
The average-value converter represents the average behavior of a single-phase rectifier for continuous armature current in a dual-converter topology. This model is thus not suitable for simulating DC drives under discontinuous armature current conditions. The converter outputs a continuous voltage value 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

DC Machine Tab



4-Quadrant Single-Phase Recifier DC Motor Drive

4-Quadrant Single-Phase Rectifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, circulating current inductors, smoothing inductance and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulators parameters are specified in the Controller tab.

Electrical parameters

Mutual inductance (H): 1.234

Armature

Resistance (ohm): 0.78
Inductance (H): 0.016

Field

Resistance (ohm): 150
Inductance (H): 112.5

Mechanical parameters

Inertia (kg*m^2): 0.05
Viscous friction coefficient (N-m-s): 0.01
Coulomb friction torque (N-m): 0
Initial speed (rad/s): 0

Model detail level: Detailed
Mechanical input: Torque Tm

Parameters file options

The DC Machine tab displays the parameters of the DC machine block of the powerlib library. Refer to the DC Machine for more information on the DC machine block parameters.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Allows you to select either the load torque or the motor speed as mechanical input. Note that if you select and apply a load torque, you will obtain as output the motor speed according to

the following differential equation that describes the mechanical system dynamics:

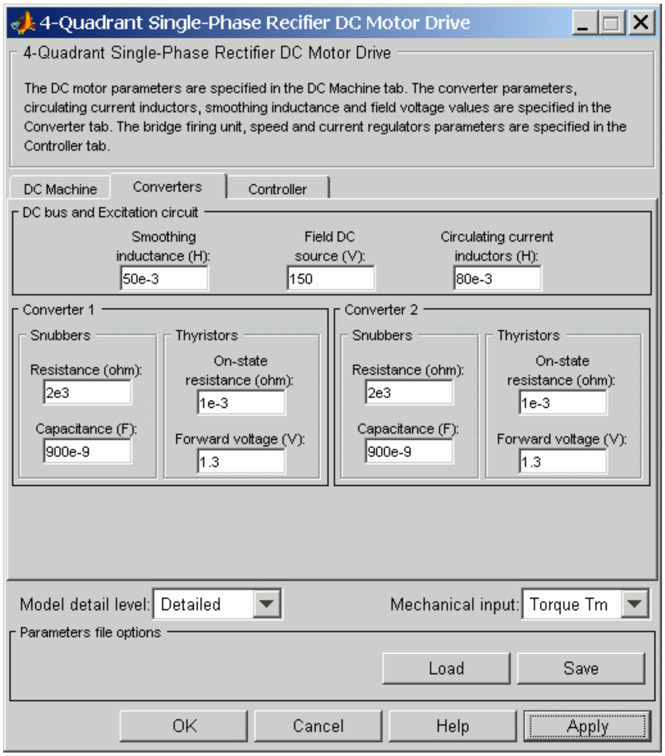
$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

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

See for example “Mechanical Coupling of Two Motor Drives”.

Converter Tab



4-Quadrant Single-Phase Recifier DC Motor Drive

4-Quadrant Single-Phase Rectifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, circulating current inductors, smoothing inductance and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulators parameters are specified in the Controller tab.

Smoothing inductance (H): 50e-3

Field DC source (V): 150

Circulating current inductors (H): 80e-3

Resistance (ohm): 2e3

Capacitance (F): 900e-9

On-state resistance (ohm): 1e-3

Forward voltage (V): 1.3

Resistance (ohm): 2e3

Capacitance (F): 900e-9

On-state resistance (ohm): 1e-3

Forward voltage (V): 1.3

Model detail level: Detailed

Mechanical input: Torque Tm

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 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.

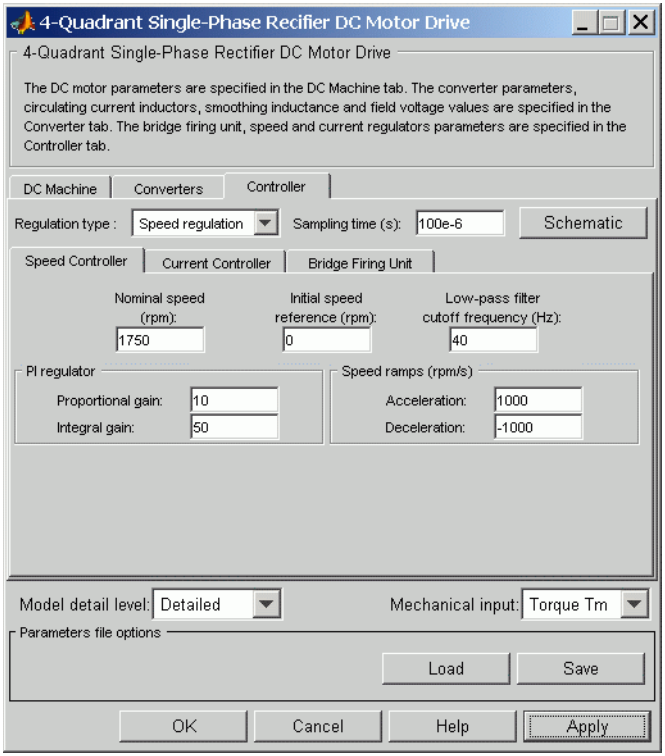
Source Inductance

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



4-Quadrant Single-Phase Recifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, circulating current inductors, smoothing inductance and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulators parameters are specified in the Controller tab.

Regulation type : Speed regulation

Sampling time (s): 100e-6

Nominal speed (rpm): 1750

Initial speed reference (rpm): 0

Low-pass filter cutoff frequency (Hz): 40

PI regulator

Proportional gain: 10

Integral gain: 50

Speed ramps (rpm/s)

Acceleration: 1000

Deceleration: -1000

Model detail level: Detailed

Mechanical input: Torque Tm

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).

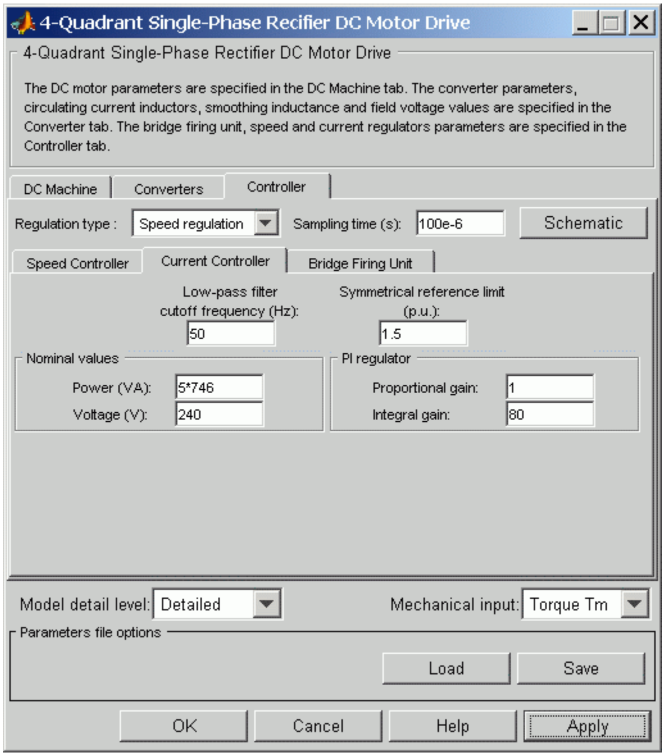
Proportional Gain
The proportional gain of the PI speed controller.

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


4-Quadrant Single-Phase Recifier DC Motor Drive

4-Quadrant Single-Phase Rectifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, circulating current inductors, smoothing inductance and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulators parameters are specified in the Controller tab.

Regulation type : Speed regulation

Sampling time (s): 100e-6

Low-pass filter cutoff frequency (Hz): 50

Symmetrical reference limit (p.u.): 1.5

Nominal values

Power (VA): 5*746

Voltage (V): 240

PI regulator

Proportional gain: 1

Integral gain: 80

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

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.

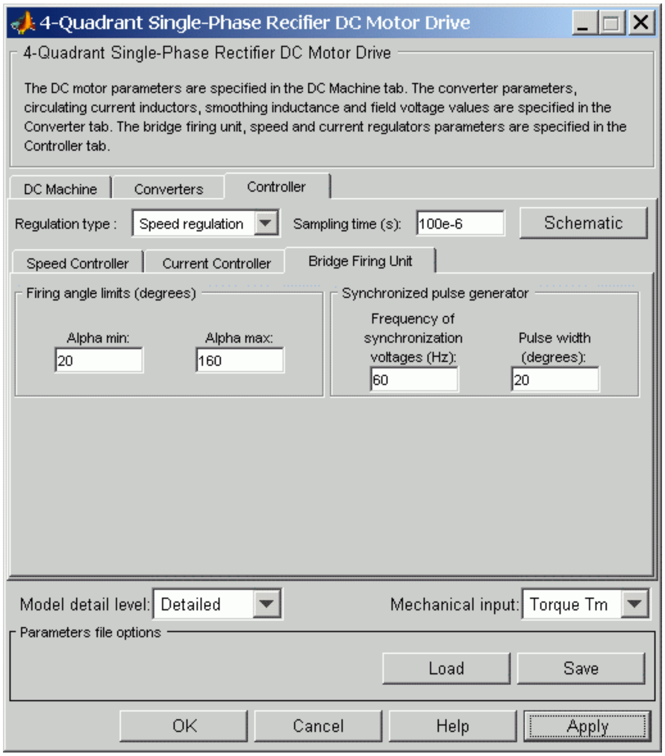
Low-Pass Filter Cutoff Frequency

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


4-Quadrant Single-Phase Recifier DC Motor Drive

4-Quadrant Single-Phase Rectifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, circulating current inductors, smoothing inductance and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulators parameters are specified in the Controller tab.

Regulation type : Speed regulation

Sampling time (s): 100e-6

Firing angle limits (degrees)

Alpha min: 20

Alpha max: 160

Synchronized pulse generator

Frequency of synchronization voltages (Hz): 60

Pulse width (degrees): 20

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

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. Note that 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+, A-`
The single-phase electric connections. The applied voltage must be adequate for the motor size.

`Wm` or `Te`
The mechanical output: motor speed (Wm) or electromagnetic torque (Te).

`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

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

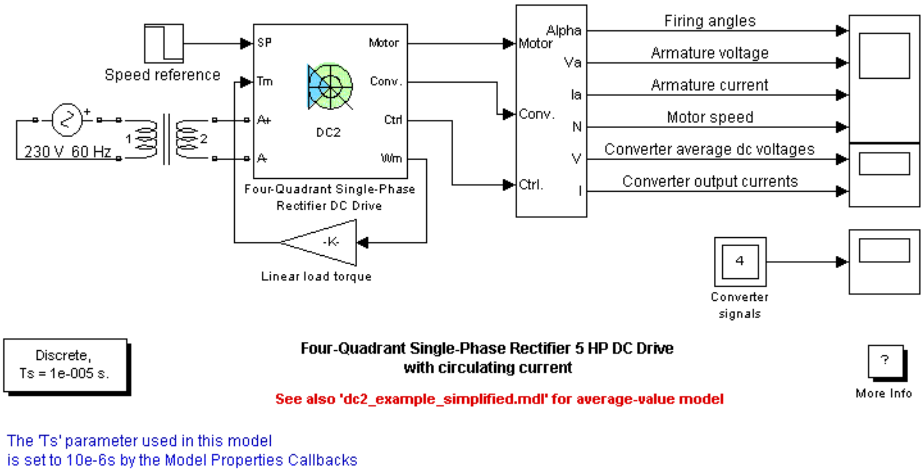
Drive Input Voltage		
	Amplitude	320 V
	Frequency	60 Hz

5 HP Drive Specifications (Continued)

Drive Input Voltage		
Motor Nominal Values		
	Power	5 hp
	Speed	1750 rpm
	Voltage	240 V

Example

The `dc2_example` demo 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.



Four-Quadrant Single-Phase Rectifier 5 HP DC Drive
with circulating current

See also 'dc2_example_simplified.mdl' for average-value model

The 'Ts' parameter used in this model
is set to 10e-6s by the Model Properties Callbacks

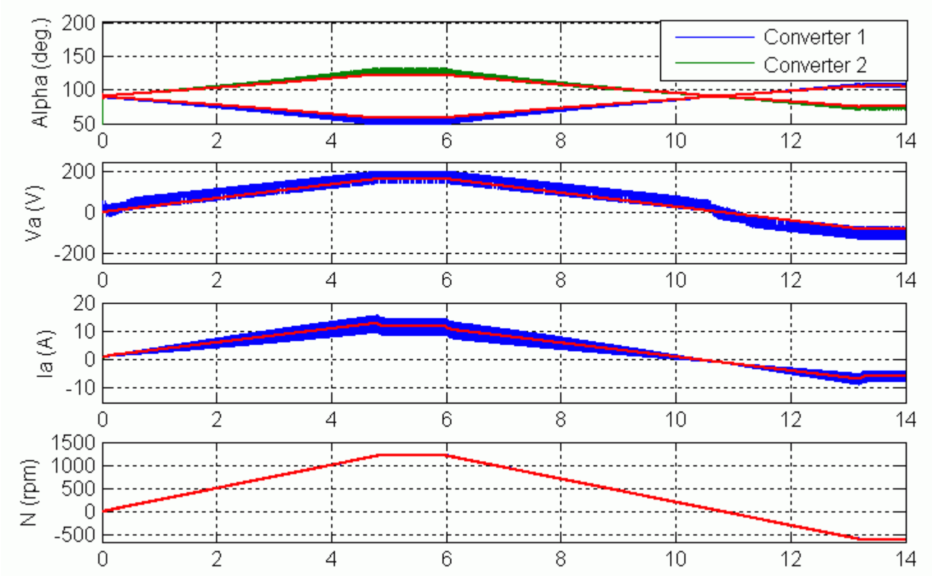
During this simulation, the motor is coupled to a linear load, which means that the mechanical torque produced by the load is proportional to the speed.

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.

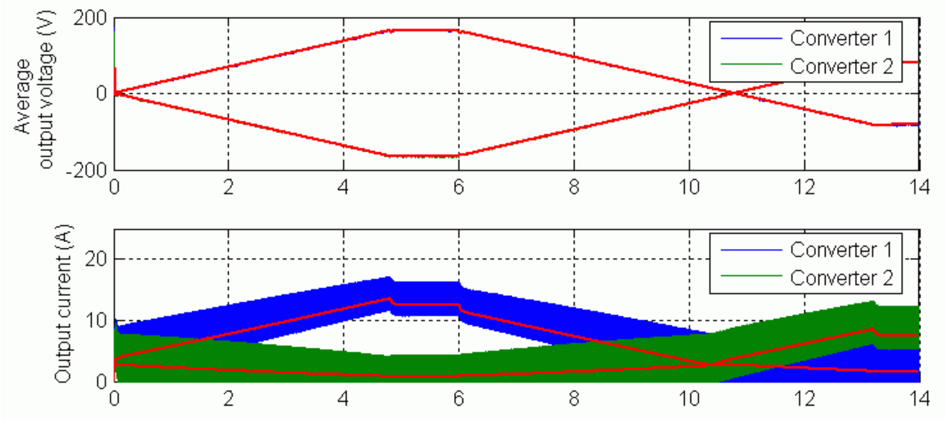
Observe that the motor speed follows the reference ramp accurately (+250 rpm/s) and reaches steady state after 5.5 s. The armature current follows the current reference very well and stabilizes around 12 A.

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.

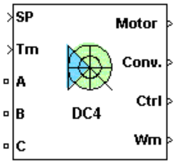
Purpose

Implement three-phase dual-converter DC drive with circulating current

Library

Electric Drives/DC drives

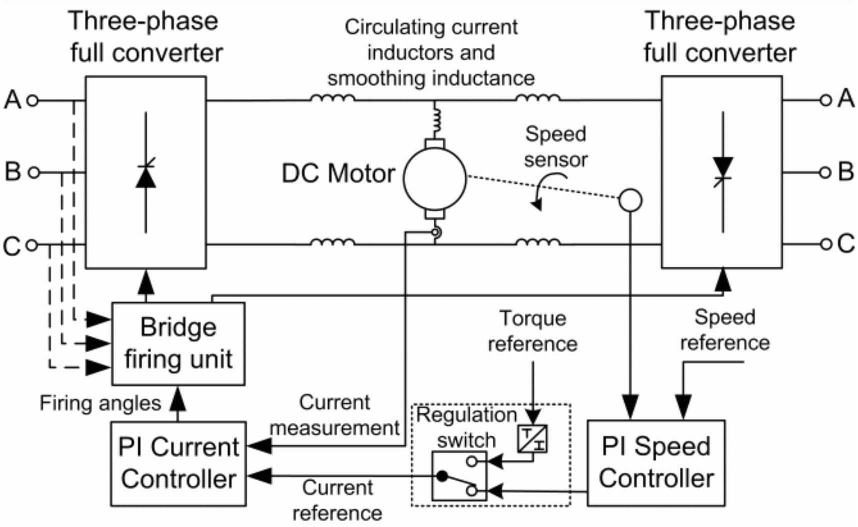
Description



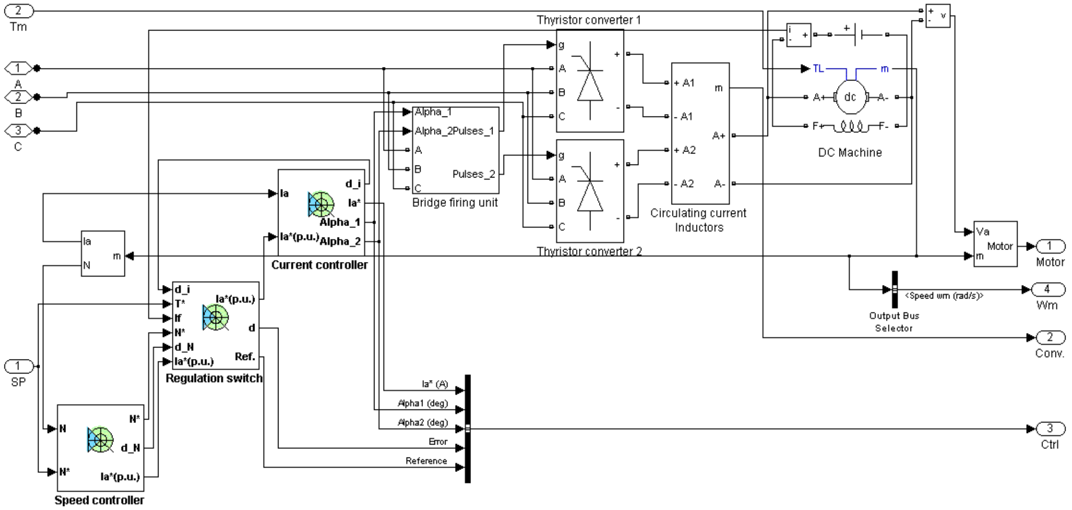
The high-level schematic shown below is built from six main blocks. The DC motor, the two three-phase full converters, and the bridge firing unit are provided with the SimPowerSystems library. More details on these blocks are available in the reference pages for each block. The two other blocks are specific 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

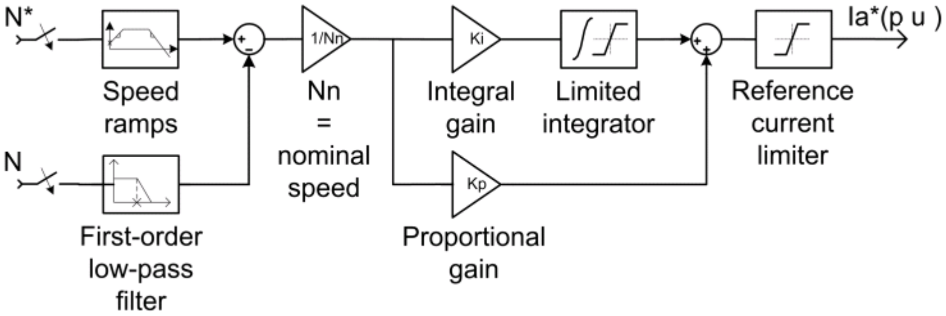


Speed Controller

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.



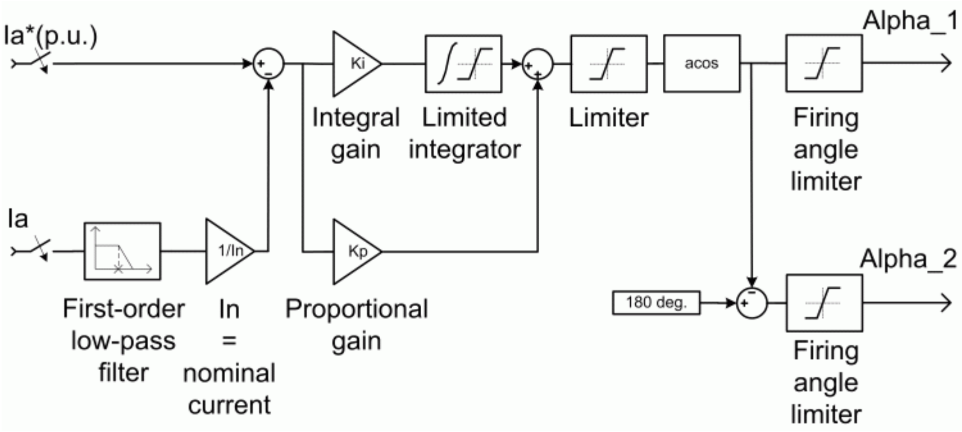
Current Controller

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.

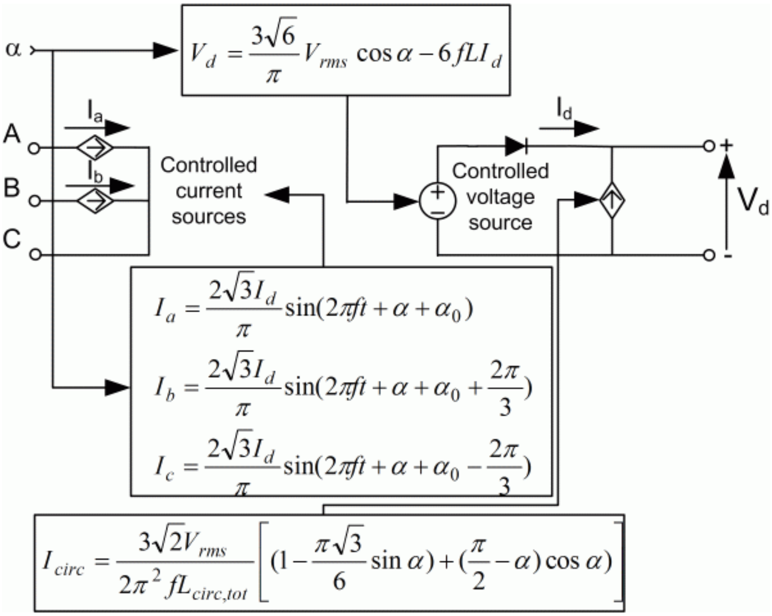
The armature current input is filtered by a first-order low-pass filter. An arccosine function is used to linearize the control system. The firing angle can vary between 0 and 180 degrees. You can limit the lower and upper limits to intermediate values.

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

$$I_a = \frac{2\sqrt{3}}{\pi} I_d \sin(2\pi f t + \alpha + \alpha_0)$$

$$I_b = \frac{2\sqrt{3}}{\pi} I_d \sin\left(2\pi f t + \alpha + \alpha_0 + \frac{2\pi}{3}\right)$$

with αbeing 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 according to the next equation

$$V_d = \frac{3\sqrt{6}}{\pi} V_{rms} \cos\alpha - 6 f L I_d$$

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

$$V_d = \frac{3\sqrt{2}}{2\pi^2 f L_{circ,tot}} V_{rms}\left(1 - \frac{\pi\sqrt{3}}{6}\sin\alpha + \left(\frac{\pi}{2} - \alpha\right)\cos\alpha\right)$$

with $L_{circ,tot}$ 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.

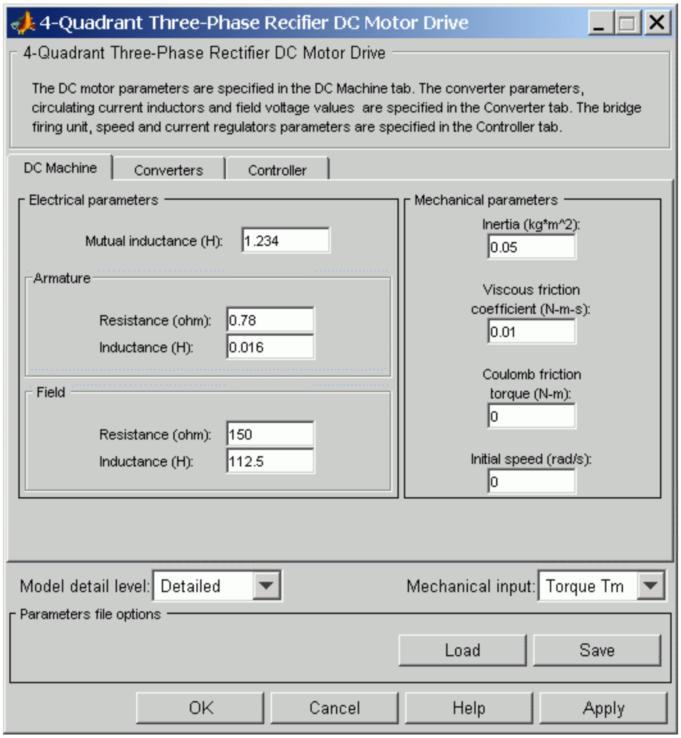
The average-value converter represents the average behavior of a three-phase rectifier for continuous armature current in a dual-converter topology. This model is thus not suitable for simulating DC drives under discontinuous armature current conditions. The converter outputs a continuous voltage value 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

DC Machine Tab



4-Quadrant Three-Phase Rectifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, circulating current inductors and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulators parameters are specified in the Controller tab.

Mutual inductance (H): 1.234

Armature Resistance (ohm): 0.78

Armature Inductance (H): 0.016

Field Resistance (ohm): 150

Field Inductance (H): 112.5

Inertia (kg*m^2): 0.05

Viscous friction coefficient (N-m-s): 0.01

Coulomb friction torque (N-m): 0

Initial speed (rad/s): 0

Model detail level: Detailed

Mechanical input: Torque Tm

The DC Machine tab displays the parameters of the DC machine block of the powerlib library. Refer to the DC Machine for more information on the DC machine block parameters.

Model detail level
Select between the detailed and the average-value inverter.

Mechanical input
Allows you to select either the load torque or the motor speed as mechanical input. Note that if you select and apply a load torque, you will obtain as output the motor speed according to

the following differential equation that describes the mechanical system dynamics:

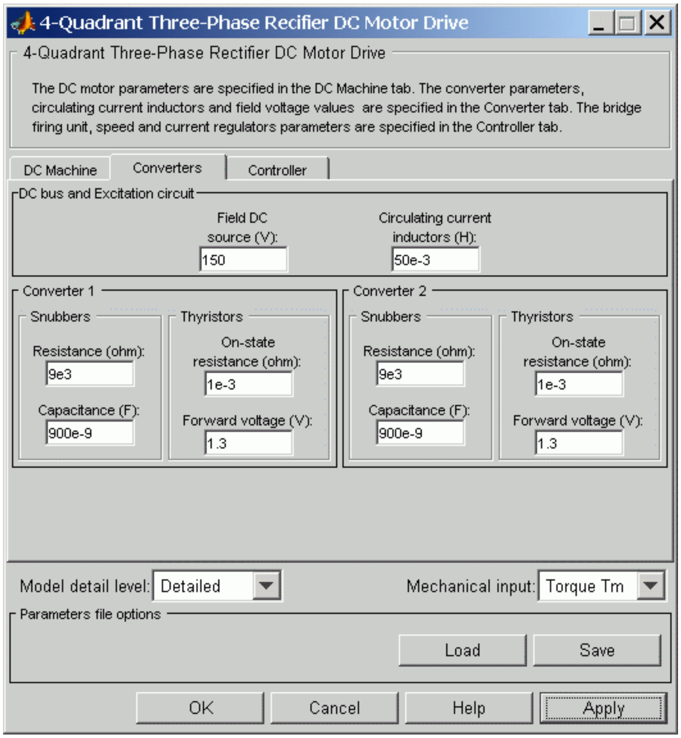
$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

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

See for example “Mechanical Coupling of Two Motor Drives”.

Converter Tab



4-Quadrant Three-Phase Rectifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, circulating current inductors and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulators parameters are specified in the Controller tab.

DC bus and Excitation circuit

Field DC source (V): 150

Circulating current inductors (H): 50e-3

Converter 1

Snubbers

Resistance (ohm): 9e3

Capacitance (F): 900e-9

Thyristors

On-state resistance (ohm): 1e-3

Forward voltage (V): 1.3

Converter 2

Snubbers

Resistance (ohm): 9e3

Capacitance (F): 900e-9

Thyristors

On-state resistance (ohm): 1e-3

Forward voltage (V): 1.3

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

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 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.

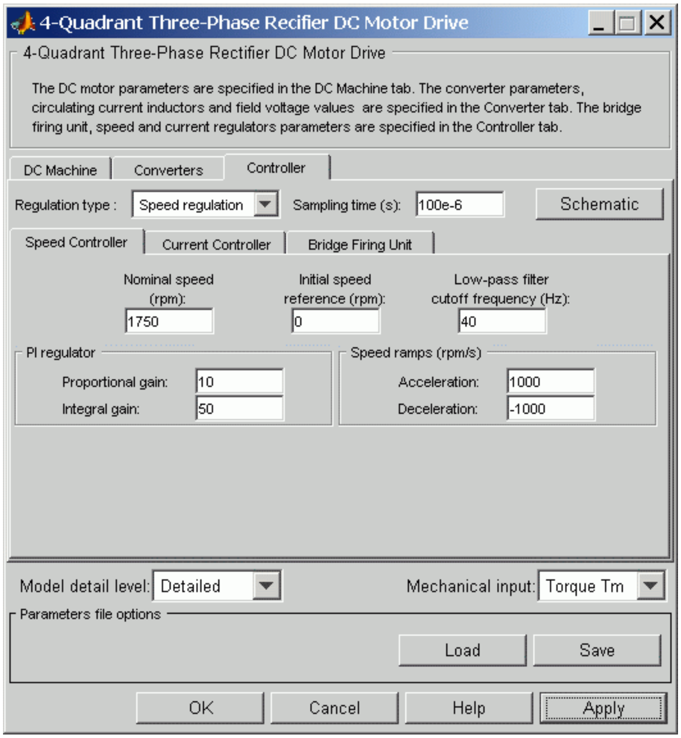
Source Inductance

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



4-Quadrant Three-Phase Recifier DC Motor Drive

4-Quadrant Three-Phase Rectifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, circulating current inductors and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulators parameters are specified in the Controller tab.

Regulation type : Speed regulation

Sampling time (s): 100e-6

Nominal speed (rpm): 1750

Initial speed reference (rpm): 0

Low-pass filter cutoff frequency (Hz): 40

PI regulator

Proportional gain: 10

Integral gain: 50

Speed ramps (rpm/s)

Acceleration: 1000

Deceleration: -1000

Model detail level: Detailed

Mechanical input: Torque Tm

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.

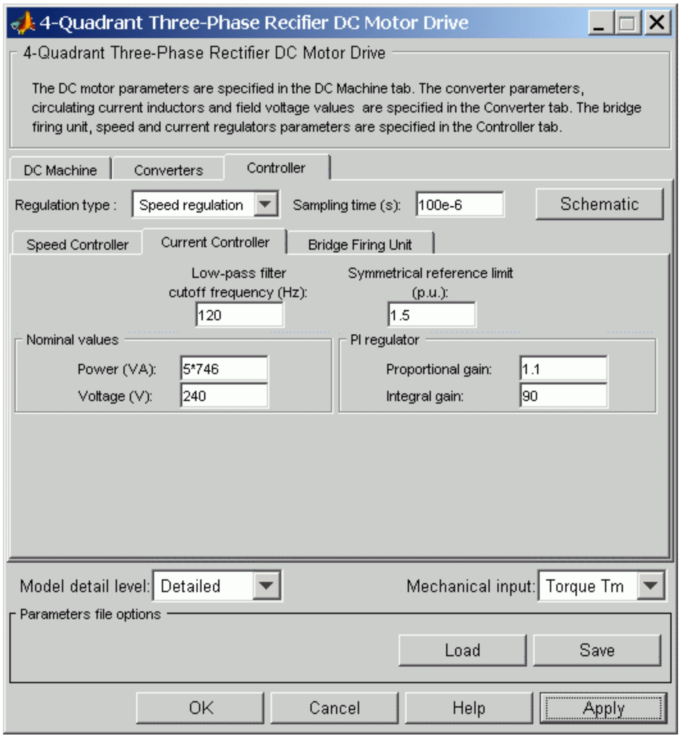
Acceleration

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



The DC motor parameters are specified in the DC Machine tab. The converter parameters, circulating current inductors and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulators parameters are specified in the Controller tab.

Regulation type : Speed regulation

Sampling time (s): 100e-6

Low-pass filter cutoff frequency (Hz): 120

Symmetrical reference limit (p.u.): 1.5

Nominal values

Power (VA): 5*746

Voltage (V): 240

PI regulator

Proportional gain: 1.1

Integral gain: 90

Model detail level: Detailed

Mechanical input: Torque Tm

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.

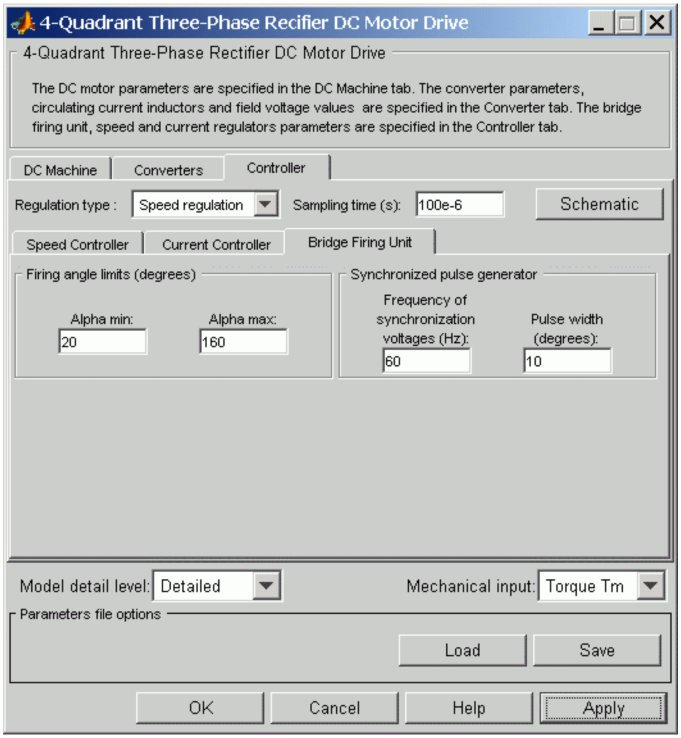
Integral Gain

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



The DC motor parameters are specified in the DC Machine tab. The converter parameters, circulating current inductors and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulators parameters are specified in the Controller tab.

Regulation type : Speed regulation
Sampling time (s): 100e-6
Alpha min: 20
Alpha max: 160
Frequency of synchronization voltages (Hz): 60
Pulse width (degrees): 10
Model detail level: Detailed
Mechanical input: Torque Tm

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. Note that 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`

T he 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).

`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

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

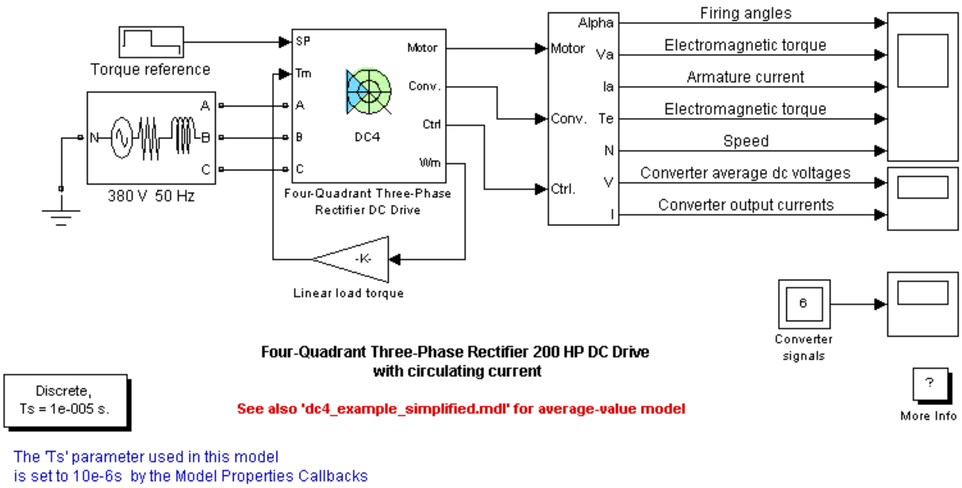
5 HP and 200 HP Drive Specifications (Continued)

		5 HP Drive	200 HP Drive
Drive Input Voltage			
Motor Nominal Values			
	Power	5 hp	200 hp
	Speed	1750 rpm	1184 rpm
	Voltage	240 V	440 V

Example

The `dc4_example` demo 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.



Four-Quadrant Three-Phase Rectifier 200 HP DC Drive
with circulating current

See also 'dc4_example_simplified.mdl' for average-value model

The 'Ts' parameter used in this model
is set to 10e-6s by the Model Properties Callbacks

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.

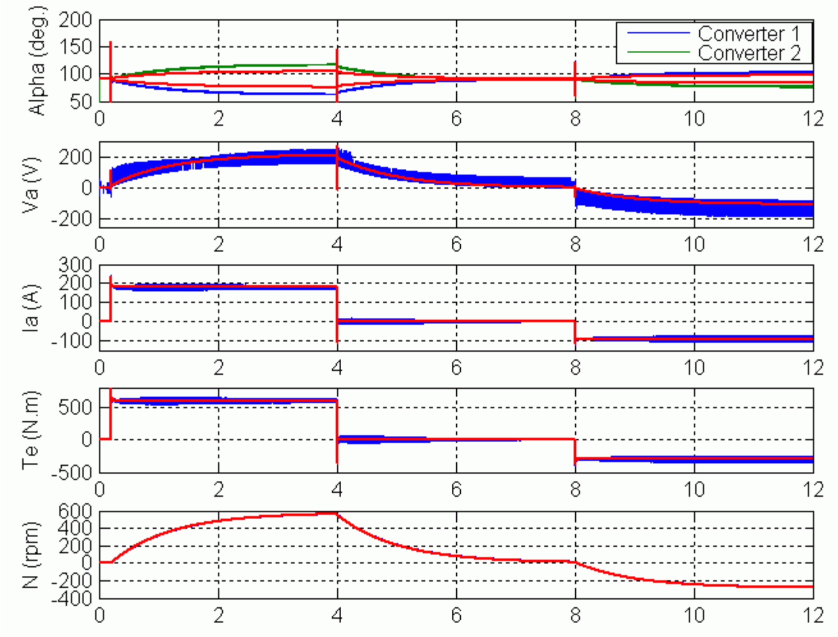
The electromagnetic torque produced by the armature current flow causes the motor to accelerate. The speed rises and starts to stabilize around t = 4 s at about 560 rpm, the sum of the load and viscous friction torques beginning to equalize the electromagnetic torque.

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.

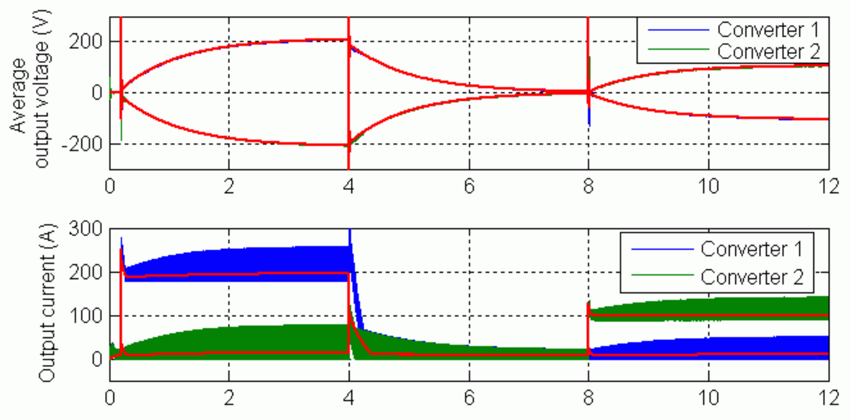
At t = 8 s, the torque reference is set to -300 N.m. The armature current jumps down to -90 A and is now delivered by converter 2 while converter 1 only handles the circulating current. Converter 2 is now working in rectifier mode and converter 1 in inverter mode.

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

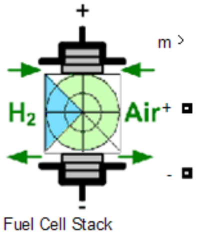
Purpose

Implement generic hydrogen fuel cell stack model

Library

Electric Drives/Extra Sources

Description

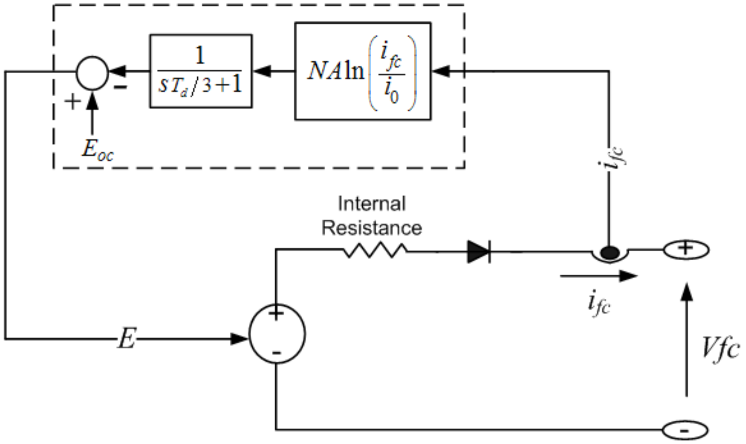


The Fuel Cell Stack block implements a generic model parameterized to represent most popular types of fuel cell stacks fed with hydrogen and air.

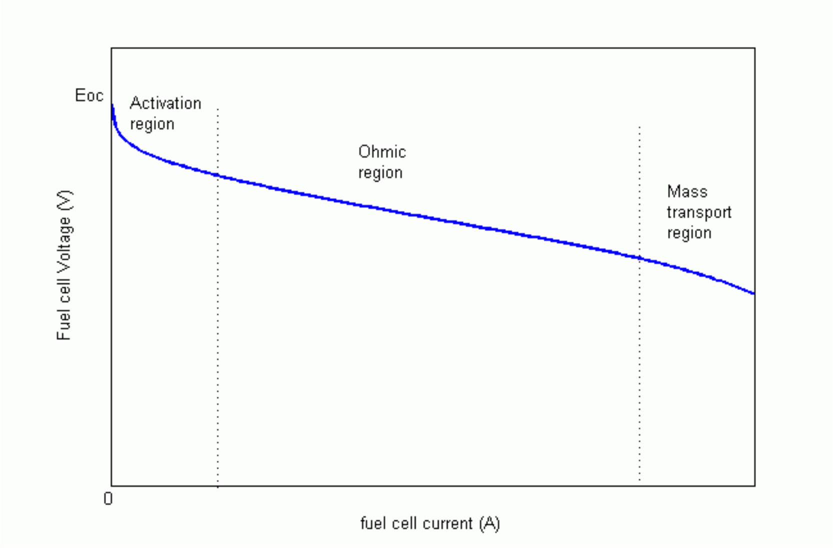
The block represents two versions of the stack model: a simplified model and a detailed model. You can switch between the two models by selecting the level in the mask under **Model detail level** in the block dialog box.

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:

$$E_{oc} = K_c E_n$$

$$i_0 = \frac{zFk(P_{H_2} + P_{O_2})}{Rh} e^{\frac{-\Delta G}{RT}}$$

$$A = \frac{RT}{z\alpha F}$$

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_{H2} = Partial pressure of hydrogen inside the stack (atm)

P_{O2} = Partial pressure of oxygen inside the stack (atm)

k = Boltzmann's constant = 1.38×10^{-23} J/K

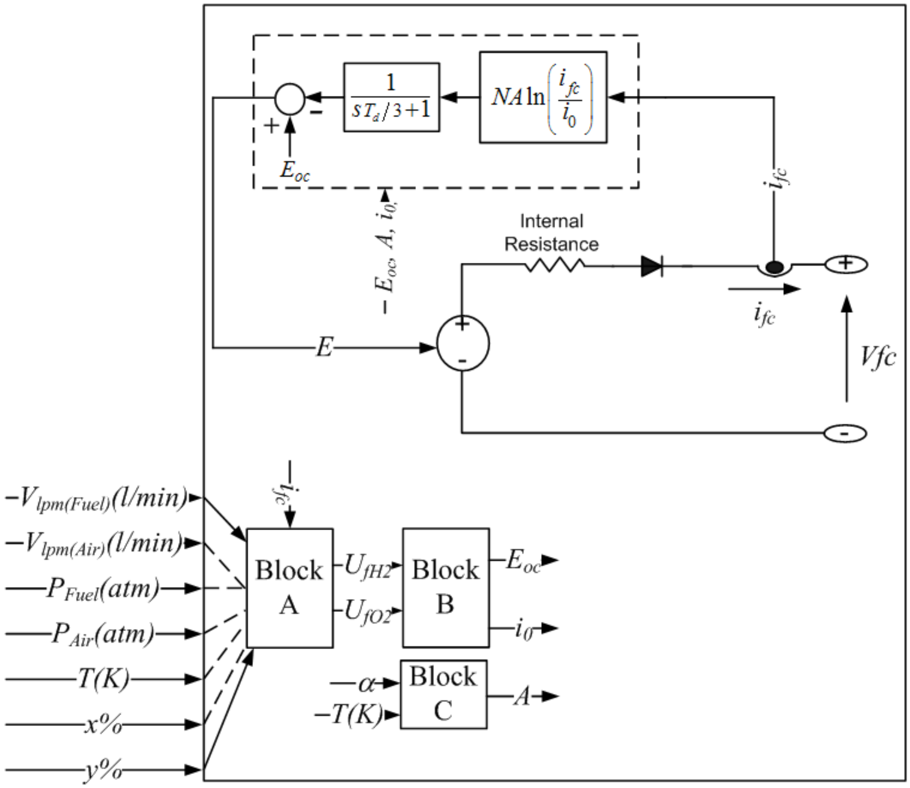
h = Planck's constant = 6.626×10^{-34} J s

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:

$$\begin{cases} U_{fH_2} = \dfrac{n^{r}_{H_2}}{n^{in}_{H_2}} = \dfrac{60000RTNi_{fc}}{zFP_{fuel}V_{lpm(fuel)}x\%} \\ U_{fO_2} = \dfrac{n^{r}_{O_2}}{n^{in}_{O_2}} = \dfrac{60000RTNi_{fc}}{2zFP_{air}V_{lpm(air)}y\%} \end{cases}$$

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 partial pressures and the Nernst voltage are determined in Block B as follows:

$$\begin{cases} P_{H_2} = (1-U_{f_{H_2}})x\%P_{fuel} \\ P_{H_2O} = (w+2y\%U_{f_{O_2}})P_{air} \\ P_{O_2} = (1-U_{f_{O_2}})y\%P_{air} \end{cases}$$

and

$$E_n = \begin{cases} 1.229 + (\text{T-298})\dfrac{-44.43}{zF} + \dfrac{RT}{zF}\ln\left(P_{H_2}P_{O_2}^{\frac{1}{2}}\right) & T \le 100^0 C \\ 1.229 + (\text{T-298})\dfrac{-44.43}{zF} + \dfrac{RT}{zF}\ln\left(\dfrac{P_{H_2}P_{O_2}^{\frac{1}{2}}}{P_{H_2O}}\right) & T > 100^0 C \end{cases}$$

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:

$$U_{f_{H_2}} = \frac{\eta_{nom}\Delta h^0(H_2O(gas))N}{zFV_{nom}}$$

and

$$U_{f_{O_2}} = \frac{60000RT_{nom}NI_{nom}}{2zFP_{air_{nom}}V_{lpm(air)_{nom}} \times 0.21}$$

where

η_{nom}= Nominal LHV efficiency of the stack (%)

$\Delta h^0(H_2O(gas))$=241.83 × 10^3 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 ($Uf_{O2(peak)}$) 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:

$$E_n = \begin{cases} E_n - K(U_{f_{O_2}} - U_{f_{O_2(nom)}}) & U_{f_{O_2}} > U_{f_{O_2(nom)}} \\ E_n & U_{f_{O_2}} \le U_{f_{O_2(nom)}} \end{cases}$$

where

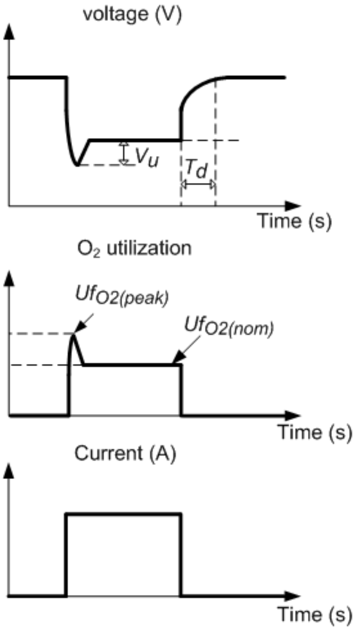
K = voltage undershoot constant

$U_{fO2(nom)}$ = nominal oxygen utilization

K is determined as follows:

$$K = \frac{V_u}{K_c(U_{f_{O_2}(peak)} - U_{f_{O_2}(nom)})}$$

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, $Uf_{O2(peak)}$ and V_u).

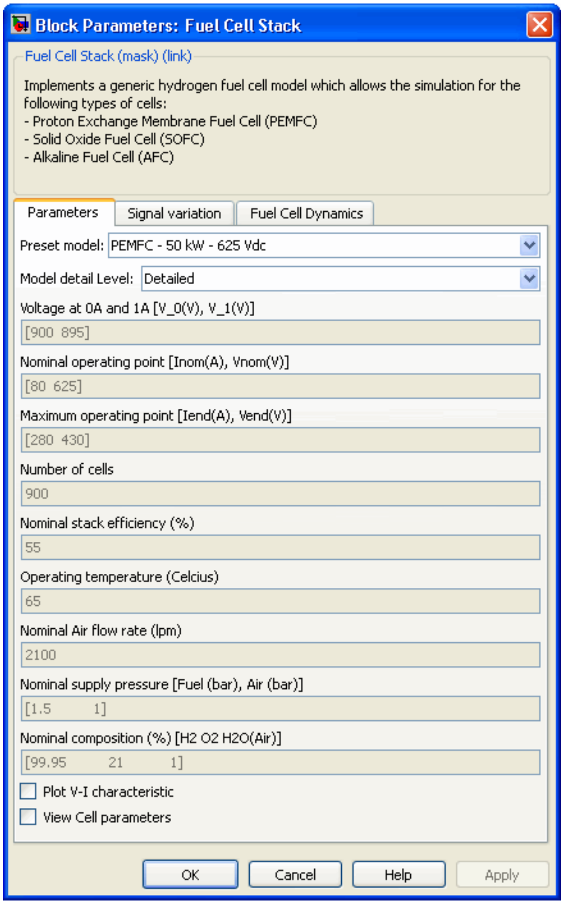


The response time (T_d) depends on the fuel cell stack itself and is usually given on the datasheet. The parameters for flow dynamics ($Uf_{O2(peak)}$ and V_u) depend on the dynamics of external equipments (compressor, regulator and loads) and they are not provided by manufacturers as their values vary with the user application. For simulation, the user may assume values of $Uf_{O2(peak)}$ between 60% to 70% and V_u between 2-5% of the stack nominal voltage.

Note In R2009b, the fuel cell model has been improved to better represent the cell dynamics. The model parameters and the meaning of some detailed parameters have changed since the last release. See "Changes to the Fuel Cell Stack Block " in the *SimPowerSystems Release Notes*.

Dialog Box and Parameters

Parameters Tab



Block Parameters: Fuel Cell Stack

Fuel Cell Stack (mask) (link)

Implements a generic hydrogen fuel cell model which allows the simulation for the following types of cells:
- Proton Exchange Membrane Fuel Cell (PEMFC)
- Solid Oxide Fuel Cell (SOFC)
- Alkaline Fuel Cell (AFC)

Preset model: PEMFC - 50 kW - 625 Vdc

Model detail Level: Detailed

Voltage at 0A and 1A [V_0(V), V_1(V)]: [900 895]

Nominal operating point [Inom(A), Vnom(V)]: [80 625]

Maximum operating point [Iend(A), Vend(V)]: [280 430]

Number of cells: 900

Nominal stack efficiency (%): 55

Operating temperature (Celcius): 65

Nominal Air flow rate (lpm): 2100

Nominal supply pressure [Fuel (bar), Air (bar)]: [1.5 1]

Nominal composition (%) [H2 O2 H2O(Air)]: [99.95 21 1]

☐ Plot V-I characteristic

☐ View Cell parameters

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

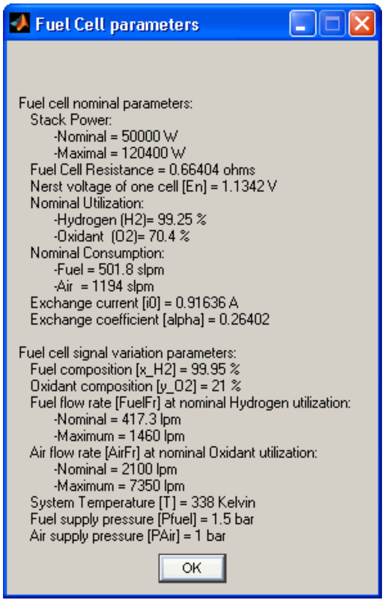
The rated percentage of hydrogen (x) in the fuel, oxygen (y) and water (w) in the oxidant. This parameter is available only for a detailed model.

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). To plot the graphs, select the checkbox. This checkbox is available only for a detailed model.

View cell parameters

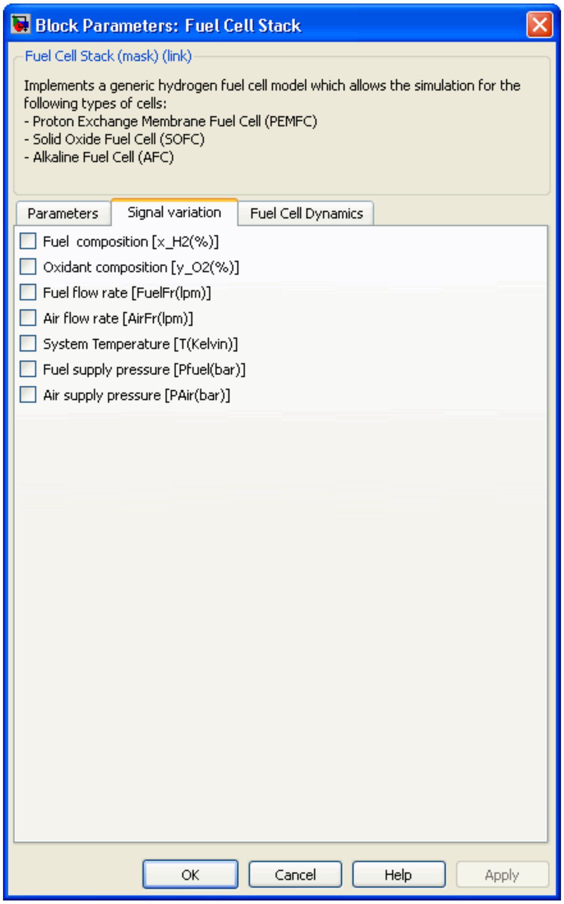
Presents the overall parameters of the stack. This checkbox is available only for a detailed model. Select the checkbox to view the parameters. The dialog box is shown below.



```
Fuel cell nominal parameters:
   Stack Power:
         -Nominal = 50000 W
         -Maximal = 120400 W
   Fuel Cell Resistance = 0.66404 ohms
   Nerst voltage of one cell [En] = 1.1342 V
   Nominal Utilization:
         -Hydrogen (H2)= 99.25 %
         -Oxidant  (O2)= 70.4 %
   Nominal Consumption:
         -Fuel = 501.8 slpm
         -Air  = 1194 slpm
   Exchange current [i0] = 0.91636 A
   Exchange coefficient [alpha] = 0.26402

Fuel cell signal variation parameters:
   Fuel composition [x_H2] = 99.95 %
   Oxidant composition [y_O2] = 21 %
   Fuel flow rate [FuelFr] at nominal Hydrogen utilization:
         -Nominal = 417.3 lpm
         -Maximum = 1460 lpm
   Air flow rate [AirFr] at nominal Oxidant utilization:
         -Nominal = 2100 lpm
         -Maximum = 7350 lpm
   System Temperature [T] = 338 Kelvin
   Fuel supply pressure [Pfuel] = 1.5 bar
   Air supply pressure [PAir] = 1 bar
```

Signal Variation Tab (Detailed Model Only)



Block Parameters: Fuel Cell Stack

Fuel Cell Stack (mask) (link)

Implements a generic hydrogen fuel cell model which allows the simulation for the following types of cells:
- Proton Exchange Membrane Fuel Cell (PEMFC)
- Solid Oxide Fuel Cell (SOFC)
- Alkaline Fuel Cell (AFC)

☐ Fuel composition [x_H2(%)]
☐ Oxidant composition [y_O2(%)]
☐ Fuel flow rate [FuelFr(lpm)]
☐ Air flow rate [AirFr(lpm)]
☐ System Temperature [T(Kelvin)]
☐ Fuel supply pressure [Pfuel(bar)]
☐ Air supply pressure [PAir(bar)]

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.

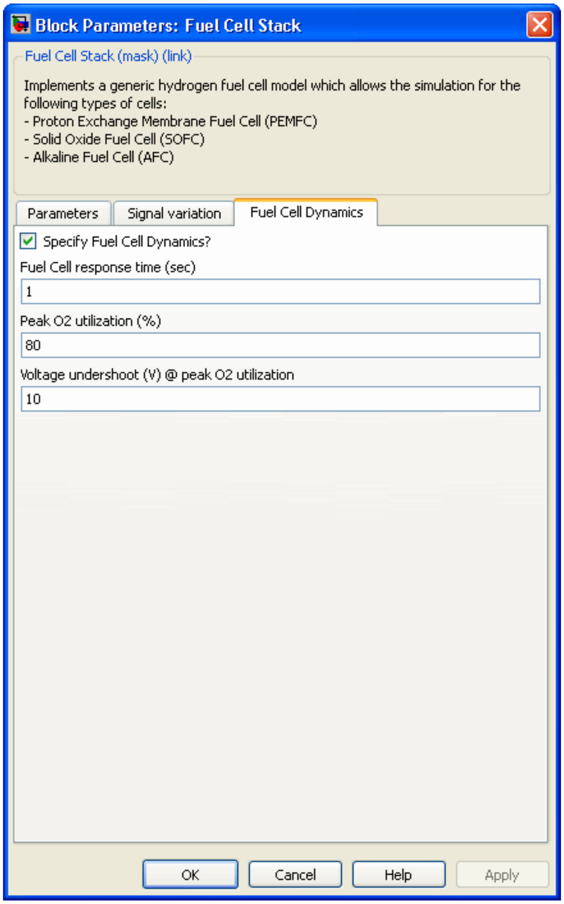
Fuel supply pressure

Fuel supply pressure in bars.

Air supply pressure

Air supply pressure in bars.

Fuel Cell Dynamics Tab



Implements a generic hydrogen fuel cell model which allows the simulation for the following types of cells:
- Proton Exchange Membrane Fuel Cell (PEMFC)
- Solid Oxide Fuel Cell (SOFC)
- Alkaline Fuel Cell (AFC)

☑ Specify Fuel Cell Dynamics?

Fuel Cell response time (sec): 1

Peak O2 utilization (%): 80

Voltage undershoot (V) @ peak O2 utilization: 10

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.

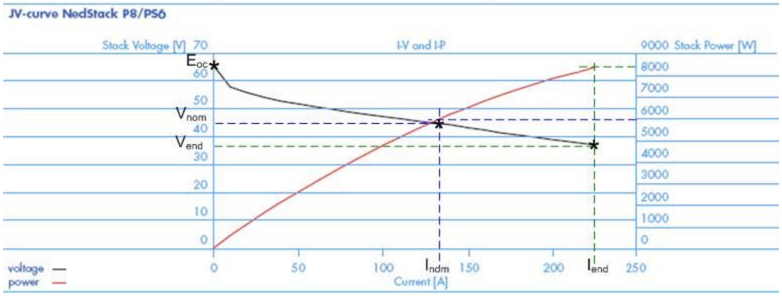
Voltage undershoot (V) @ peak O2 utilization

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 % (stock) / 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 (stock)
	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



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:

  $$N = \frac{2 \times 96485 \cdot V_{nom}}{241.83 \times 10^3 \cdot \eta_{nom}}$$

  In this case,

  $$N = \frac{2 \times 96485 \cdot 45}{241.83 \times 10^3 \cdot 0.55} = 65.28 = 65 \text{ cells}$$
- 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:

  $$V_{lpm(air)_{nom}} = \frac{I_{nom} \times V_{lpm(air)_{max}}}{I_{end}}$$

  In this case,

$$V_{lpm(air)_{nom}} = \frac{133.3 \times 500}{225} = 297\,\text{liters/min}$$

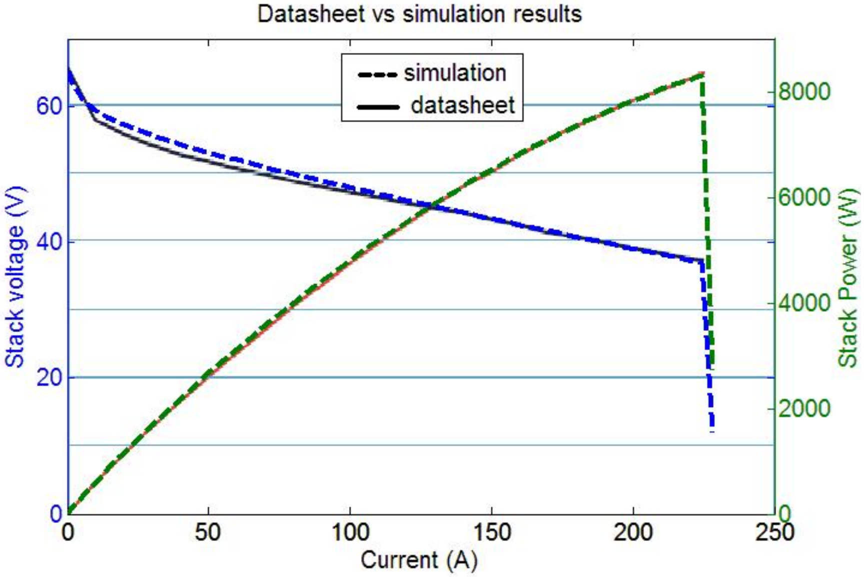
In case no information is given, assume the rate of conversion of oxygen to be 50% (as it is usually the case for most fuel cell stacks) and use the formulae below to determine the nominal air flow rate.

$$V_{lpm(air)_{nom}} = \frac{60000 R T_{nom} N I_{nom}}{2zFP_{air_{nom}} 0.5 \times 0.21}$$

- Fuel cell response time = 10s

Note The parameters [E_{oc}, V_1], [I_{nom}, V_{nom}] and [I_{end},V_{end}] are approximate and depend on the precision of the points obtained from the polarization curve. The higher the accuracy of theses 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.



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.

				Model detail level (Signal availability)	
Signal	Definition	Units	Symbol	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

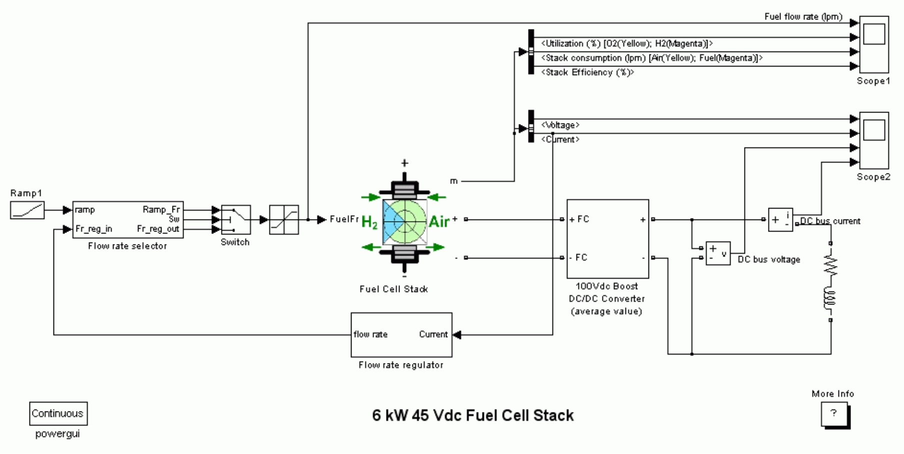
- Chemical reaction dynamics caused by partial pressure changes of chemical species inside the cell are not considered
- The stack output power is limited by the fuel and air flow rates supplied
- The effect of temperature and humidity of the membrane on the internal resistance is not considered
- The flow of gases or water through the membrane is not considered

Example

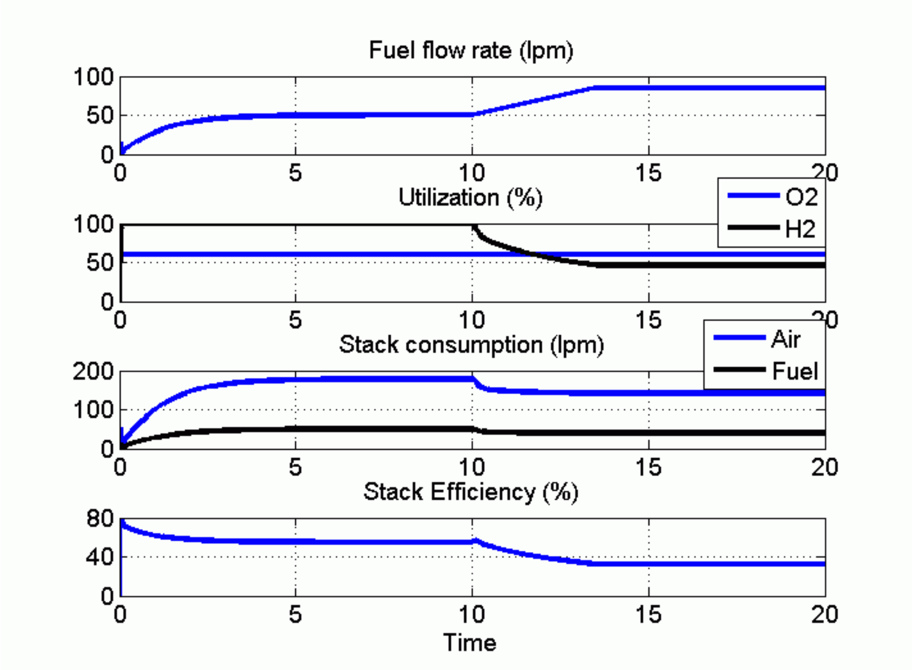
The `power_fuel_cell` demo illustrates a 6 kW, 45 volts Proton Exchange Membrane (PEM) Fuel Cell Stack model feeding a 100Vdc DC/DC converter.

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.

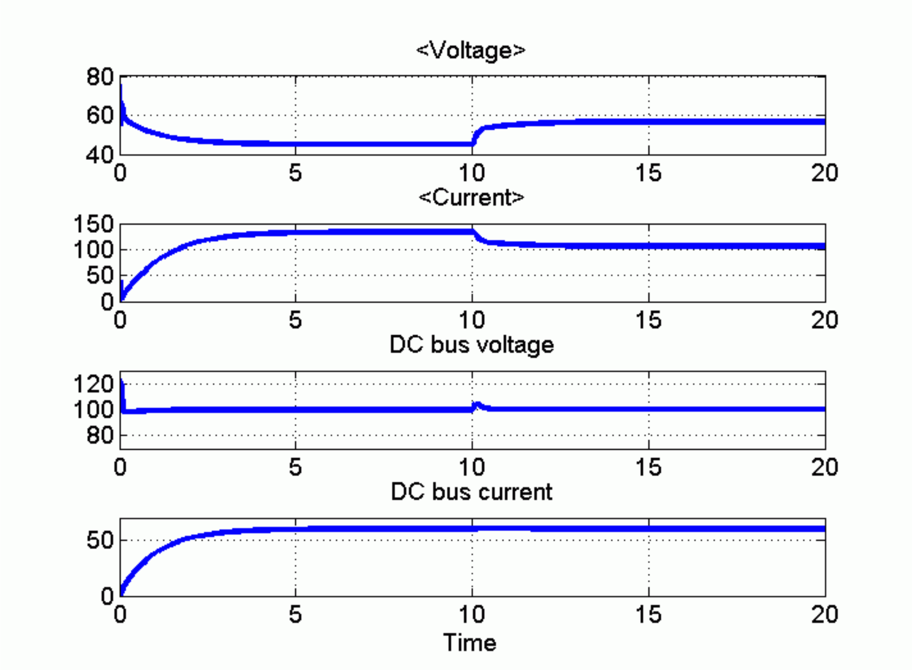
Note As the **Air flow rate** checkbox under Signal variation pane is not selected, the stack will operate at fixed, nominal oxygen utilization (59.3%).



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).

Generic Power System Stabilizer

Purpose

Implement generic power system stabilizer for synchronous machine

Library

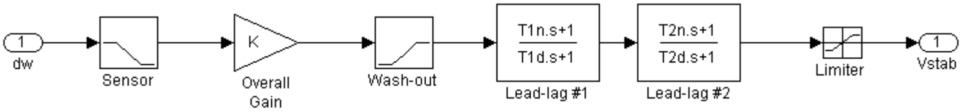
Machines

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:

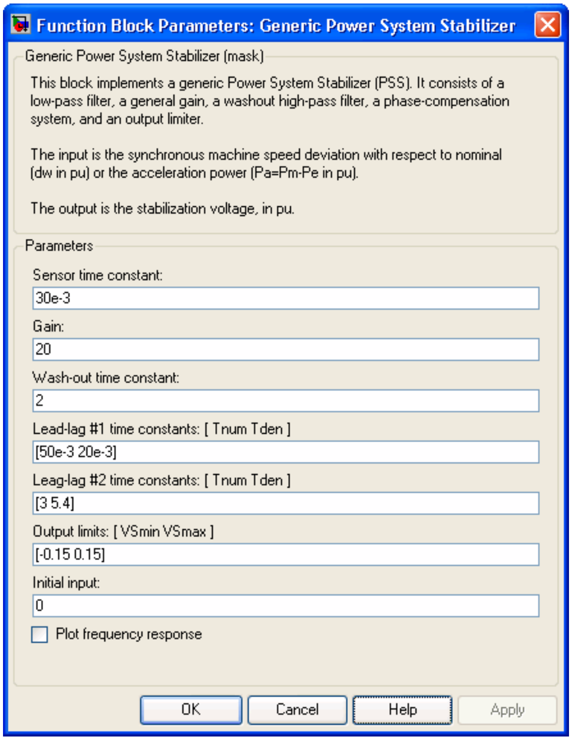


To ensure a robust damping, the PSS should provide a moderate phase advance at frequencies of interest in order to compensate for the inherent lag between the field excitation and the electrical torque induced by the PSS action.

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



Function Block Parameters: Generic Power System Stabilizer

Generic Power System Stabilizer (mask)

This block implements a generic Power System Stabilizer (PSS). It consists of a low-pass filter, a general gain, a washout high-pass filter, a phase-compensation system, and an output limiter.

The input is the synchronous machine speed deviation with respect to nominal (dw in pu) or the acceleration power (Pa=Pm-Pe in pu).

The output is the stabilization voltage, in pu.

Parameters

Sensor time constant: 30e-3

Gain: 20

Wash-out time constant: 2

Lead-lag #1 time constants: [Tnum Tden] [50e-3 20e-3]

Leag-lag #2 time constants: [Tnum Tden] [3 5.4]

Output limits: [VSmin VSmax] [-0.15 0.15]

Initial input: 0

☐ Plot frequency response

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` demo model.

References

[1] Kundur, P., *Power System Stability and Control*, McGraw-Hill, 1994, Section 12.5.

See Also

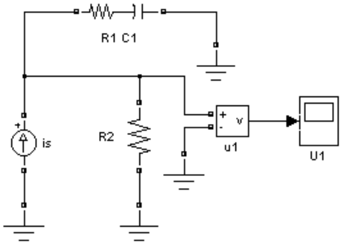
Multiband Power System Stabilizer

Purpose Provide connection to ground

Library Elements

Description The Ground block implements a connection to the ground.

Example The `power_ground` demo shows an application of the Ground block.



See Also Neutral

Grounding Transformer

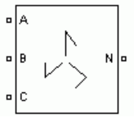
Purpose

Implement three-phase grounding transformer providing a neutral in three-wire system

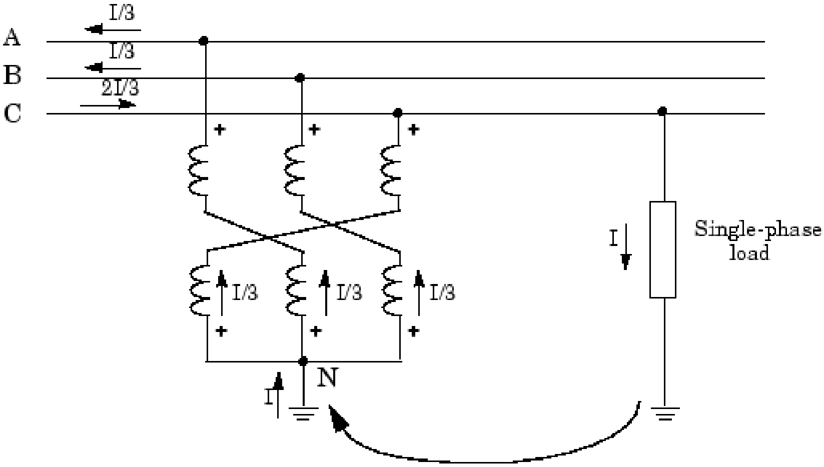
Library

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

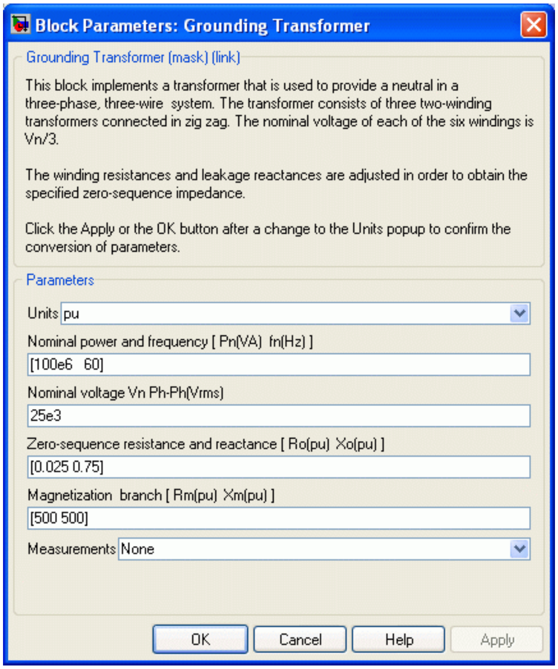
The positive-sequence impedance Z_1 and the zero-sequence impedance Z_0 of the grounding transformer are given by:

$$Z_1 = R_1 + jX_1 = 3\frac{jR_{mag}X_{mag}}{(R_{mag} + jX_{mag})}$$

$$Z_0 = R_o + jX_0 = 2(R + jX)$$

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



Block Parameters: Grounding Transformer

Grounding Transformer (mask) (link)

This block implements a transformer that is used to provide a neutral in a three-phase, three-wire system. The transformer consists of three two-winding transformers connected in zig zag. The nominal voltage of each of the six windings is Vn/3.

The winding resistances and leakage reactances are adjusted in order to obtain the specified zero-sequence impedance.

Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

Parameters

Units: pu

Nominal power and frequency [Pn(VA) fn(Hz)]: [100e6 60]

Nominal voltage Vn Ph-Ph(Vrms): 25e3

Zero-sequence resistance and reactance [Ro(pu) Xo(pu)]: [0.025 0.75]

Magnetization branch [Rm(pu) Xm(pu)]: [500 500]

Measurements: None

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)

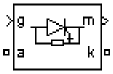
Purpose

Implement gate turn off (GTO) thyristor model

Library

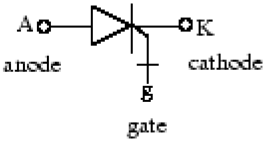
Power Electronics

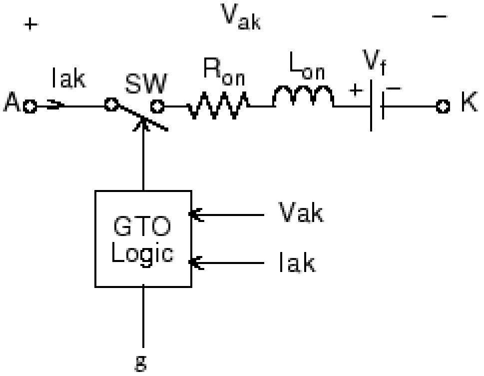
Description



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.



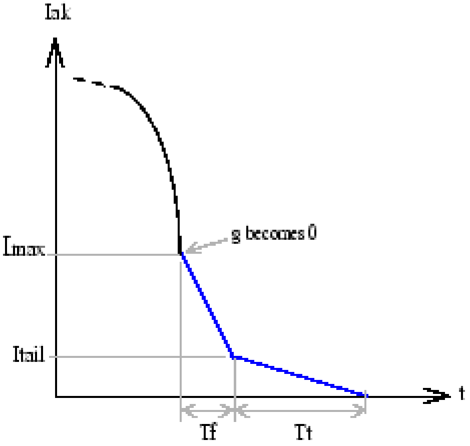


The Vf, Ron, and Lon parameters are the forward voltage drop while in conduction, the forward conducting resistance, and the inductance of the device. The GTO block also contains a series Rs-Cs snubber circuit that can be connected in parallel with the GTO device (between terminal ports A and K).

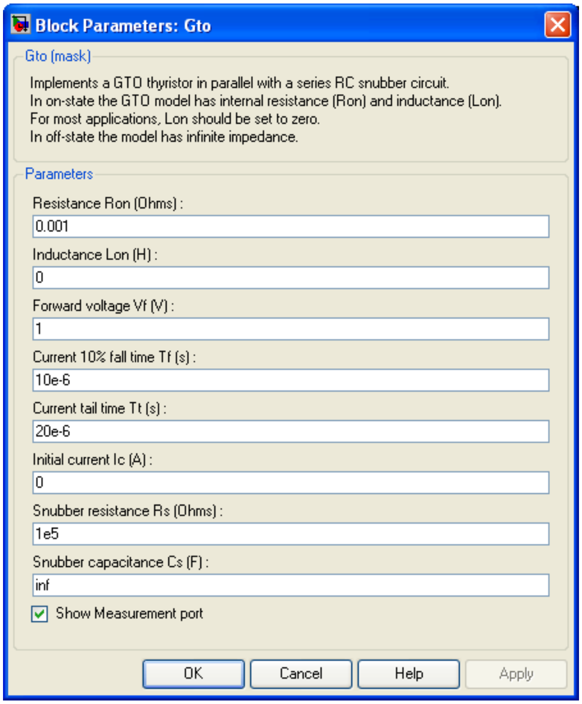
The GTO thyristor turns on when the anode-cathode voltage is greater than Vf and a positive pulse signal is present at the gate input (g > 0).

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



Block Parameters: Gto

Gto (mask)

Implements a GTO thyristor in parallel with a series RC snubber circuit.
In on-state the GTO model has internal resistance (Ron) and inductance (Lon).
For most applications, Lon should be set to zero.
In off-state the model has infinite impedance.

Parameters

Resistance Ron (Ohms) : 0.001

Inductance Lon (H) : 0

Forward voltage Vf (V) : 1

Current 10% fall time Tf (s) : 10e-6

Current tail time Tt (s) : 20e-6

Initial current Ic (A) : 0

Snubber resistance Rs (Ohms) : 1e5

Snubber capacitance Cs (F) : inf

☑ Show Measurement port

Resistance Ron

The internal resistance Ron, in ohms (Ω).

Inductance Lon

The internal inductance Lon, in henries (H). The **Inductance Lon** parameter cannot be 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. See Improving Simulation Performance for more details on this topic.

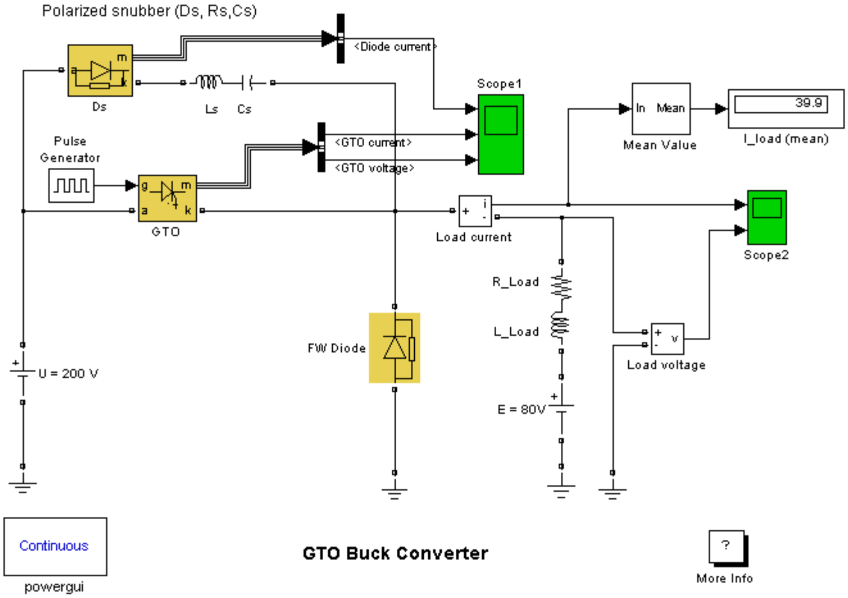
Use the Powergui block to specify either continuous simulation or discretization of your electrical circuit containing GTO blocks. When using a continuous model, the `ode23tb` solver with a relative tolerance of 1e-4 is recommended for best accuracy and simulation speed.

The inductance Lon is forced to 0 if you choose to discretize your circuit.

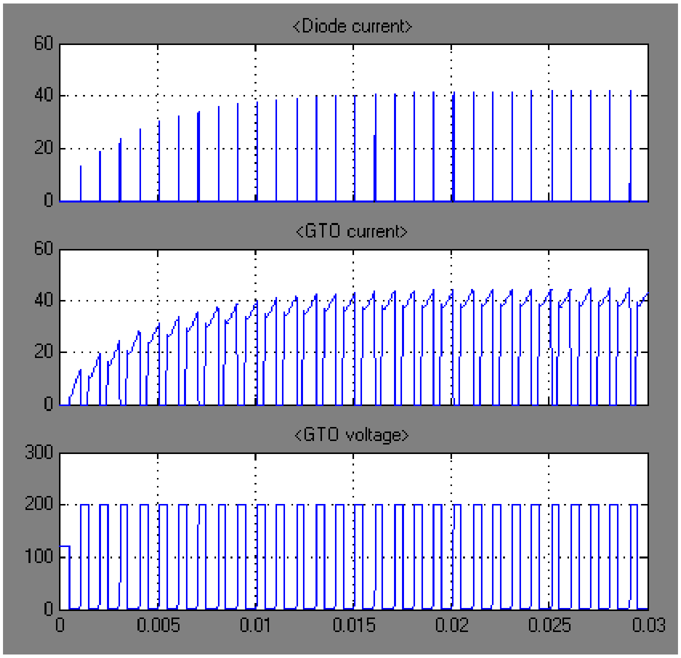
Example

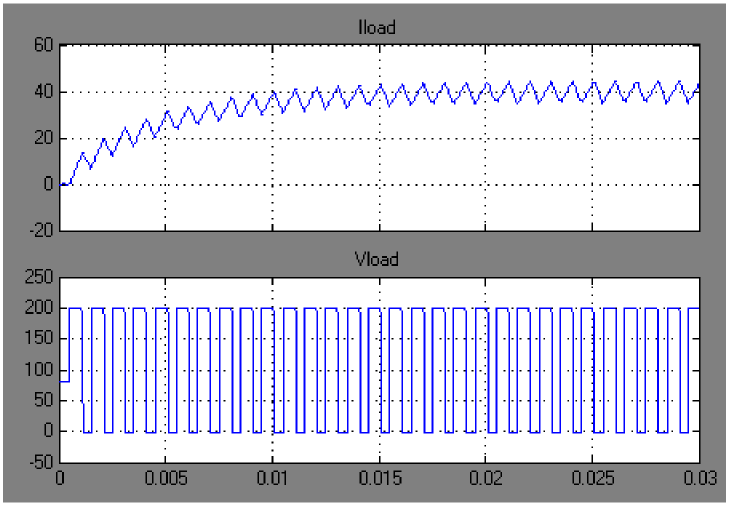
The `power_buckconv` demo illustrates the use of the GTO block in a buck converter topology. The basic polarized snubber circuit is connected across the GTO block. The snubber circuit consists of a capacitor Cs, a resistor Rs, and a diode Ds. The parasitic inductance Ls of the snubber circuit is also 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%).



Run the simulation. Observe the GTO voltage and current as well as the load voltage and current.


<Diode current>
60
40
20
0
<GTO current>
60
40
20
0
<GTO voltage>
300
200
100
0
0
0.005
0.01
0.015
0.02
0.025
0.03


Iload
60
40
20
0
-20
Vload
250
200
150
100
50
0
-50
0
0.005
0.01
0.015
0.02
0.025
0.03

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

Hydraulic Turbine and Governor

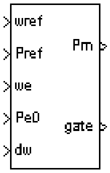
Purpose

Model hydraulic turbine and proportional-integral-derivative (PID) governor system

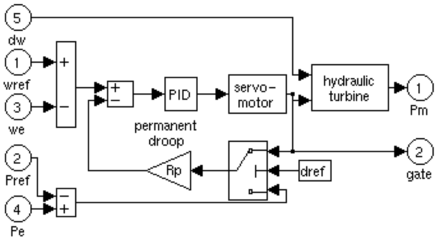
Library

Machines

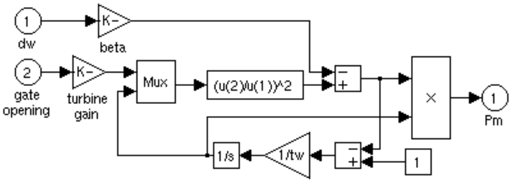
Description



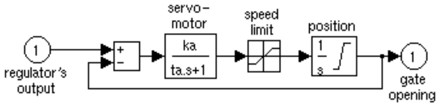
The Hydraulic Turbine and Governor block implements a nonlinear hydraulic turbine model, a PID governor system, and a servomotor [1].



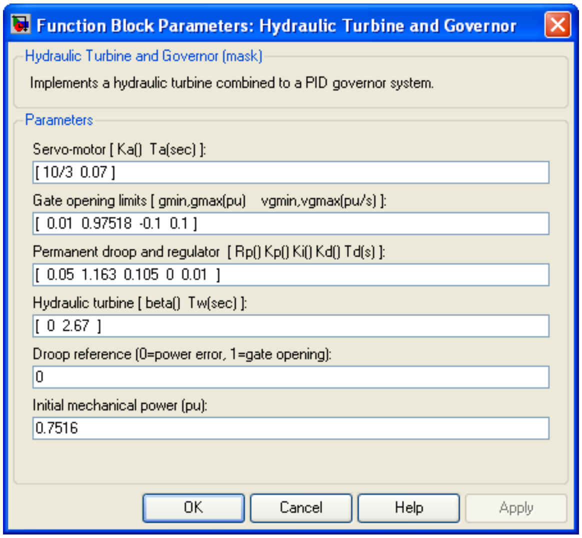
The hydraulic turbine is modeled by the following nonlinear system.



The gate servomotor is modeled by a second-order system.



Dialog Box and Parameters



Implements a hydraulic turbine combined to a PID governor system.

Servo-motor [Ka() Ta(sec)]: [10/3 0.07]

Gate opening limits [gmin,gmax(pu) vgmin,vgmax(pu/s)]: [0.01 0.97518 -0.1 0.1]

Permanent droop and regulator [Rp() Kp() Ki() Kd() Td(s)]: [0.05 1.163 0.105 0 0.01]

Hydraulic turbine [beta() Tw(sec)]: [0 2.67]

Droop reference (0=power error, 1=gate opening): 0

Initial mechanical power (pu): 0.7516

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 β 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`

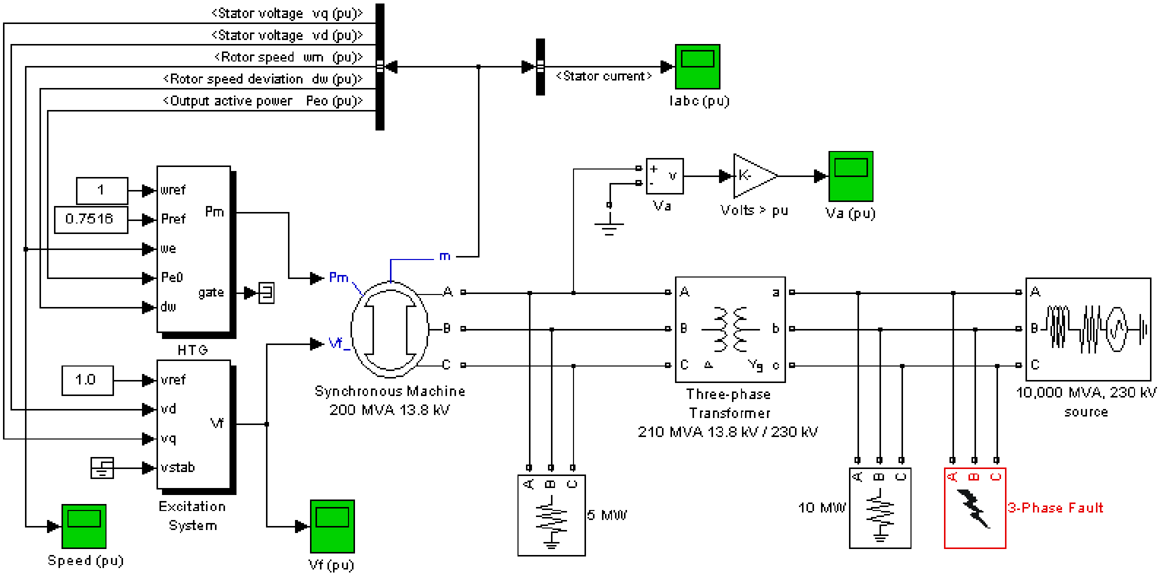
Gate opening, in pu.

Example

This `power_turbine` demo 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 load flow 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 **Load flow and 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:

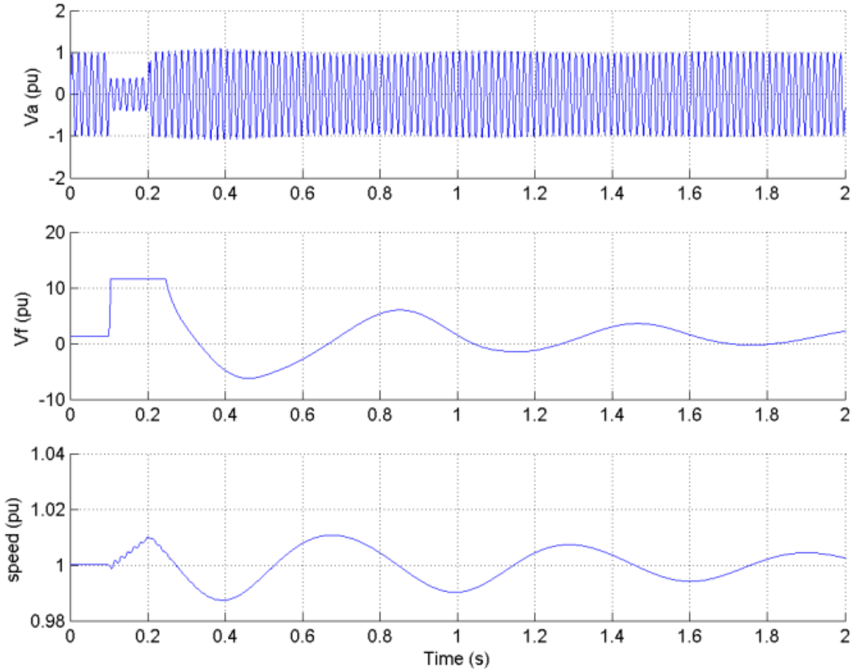
- Terminal voltage U AB (Vrms) = 13800
- Active power (watts) = 150e6



Then click the **Update Load Flow** button. Once the load flow has been solved, the line-to-line machine voltages as well as the phase currents flowing out of the machine. 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 load flow also initializes the HTG and Excitation System blocks. Open the HTG block menu and notice that the initial mechanical power is set to 0.5007 pu (100.14 MW). Then open the Excitation System block menu 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.

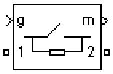
See Also Excitation System, Steam Turbine and Governor, Synchronous Machine

Ideal Switch

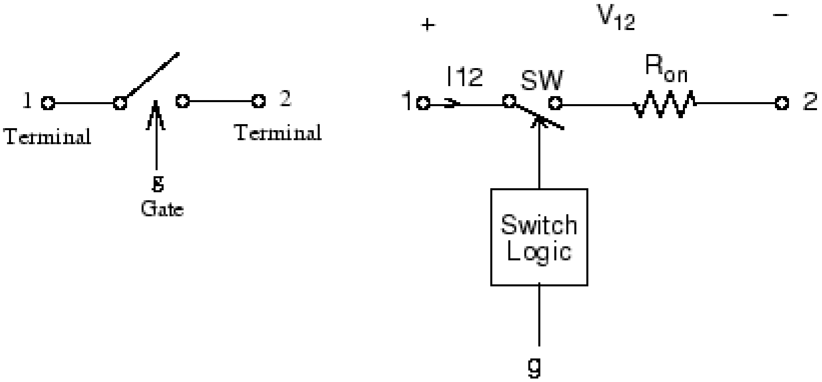
Purpose Implement ideal switch device

Library 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.

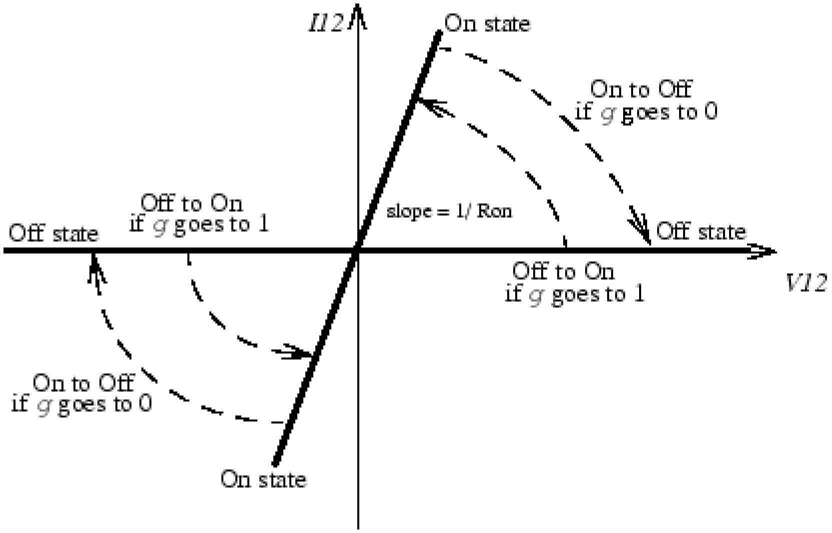


The Ideal Switch block is fully controlled by the gate signal (g > 0 or g = 0). It has the following characteristics:

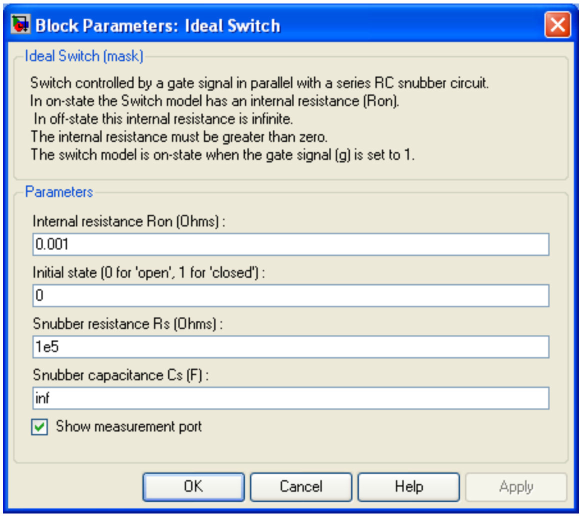
- Blocks any forward or reverse applied voltage with 0 current flow when g = 0
- Conducts any bidirectional current with quasi-zero voltage drop when g > 0
- Switches instantaneously between on and off states when triggered

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



Ideal Switch (mask)

Switch controlled by a gate signal in parallel with a series RC snubber circuit.
In on-state the Switch model has an internal resistance (Ron).
In off-state this internal resistance is infinite.
The internal resistance must be greater than zero.
The switch model is on-state when the gate signal (g) is set to 1.

Parameters

Internal resistance Ron (Ohms) : 0.001

Initial state (0 for 'open', 1 for 'closed') : 0

Snubber resistance Rs (Ohms) : 1e5

Snubber capacitance Cs (F) : inf

☑ Show measurement port

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

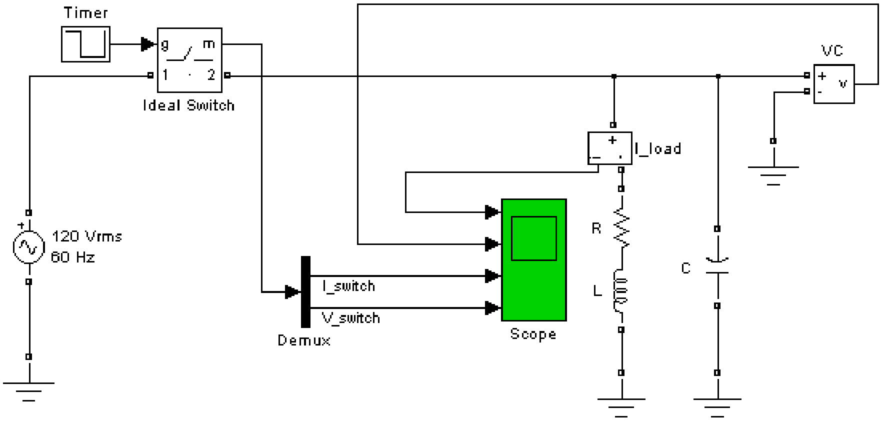
Assumptions and Limitations

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. See Improving Simulation Performance for more details on this topic.

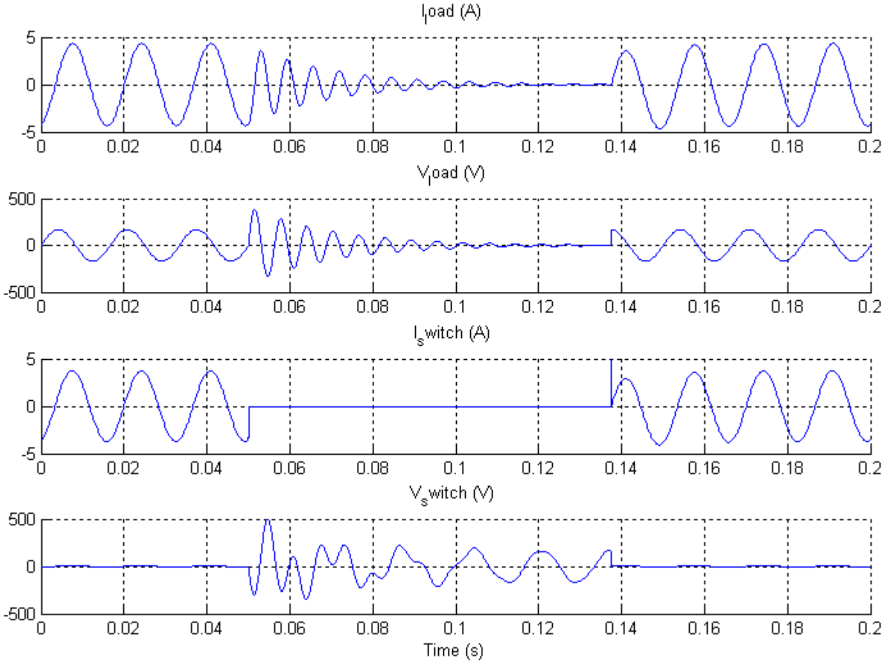
Use the Powergui block to specify either continuous simulation or discretization of your electrical circuit containing ideal switches. When using a continuous model, the `ode23tb` solver with a relative tolerance of 1e-4 is recommended for best accuracy and simulation speed.

Example

The `power_switch` demo 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

IGBT

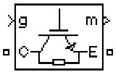
Purpose

Implement insulated gate bipolar transistor (IGBT)

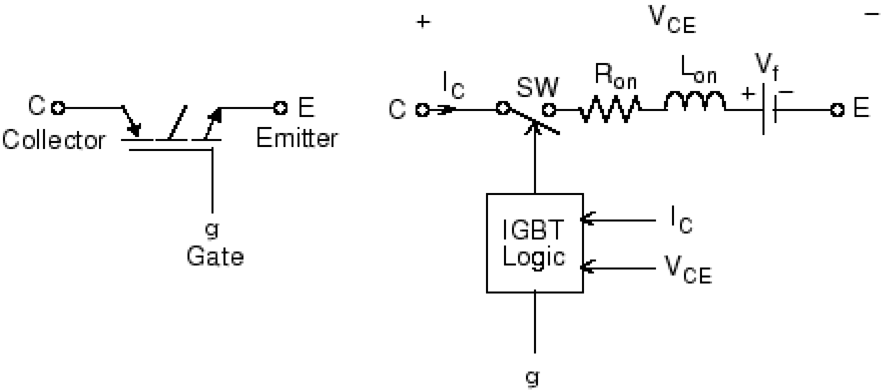
Library

Power Electronics

Description



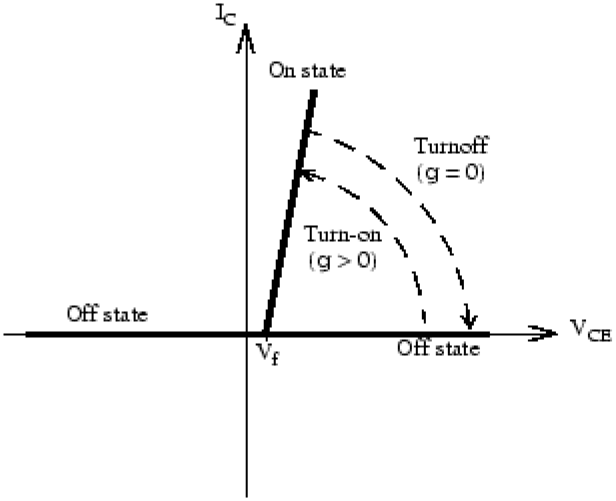
The IGBT block implements a semiconductor device controllable by the gate signal. The IGBT is simulated as a series combination of a resistor Ron, inductor Lon, and a DC voltage source Vf in series with a switch controlled by a logical signal (g > 0 or g = 0)



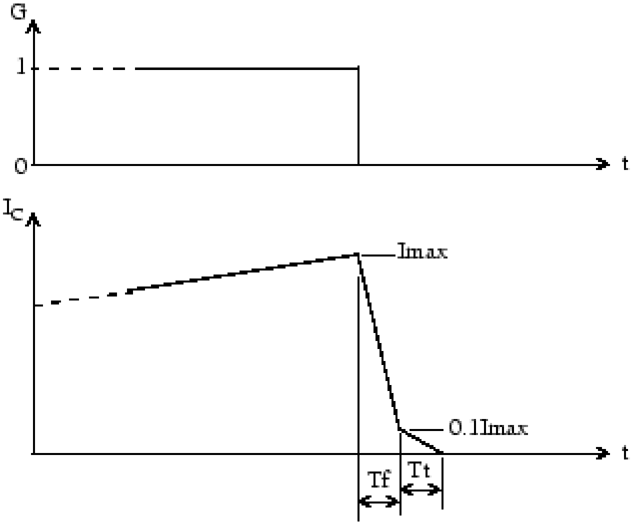
The IGBT turns on when the collector-emitter voltage is positive and greater than Vf and a positive signal is applied at the gate input (g > 0). It turns off when the collector-emitter voltage is positive and a 0 signal is applied at the gate input (g = 0).

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.

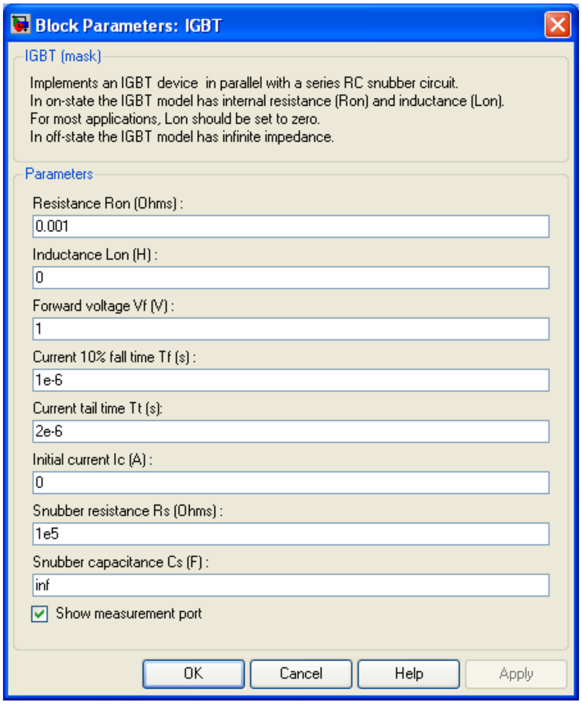
The IGBT block contains a series Rs-Cs snubber circuit, which is connected in parallel with the IGBT device (between terminals C and E).



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).


G
1
0
t
I_C
Imax
0.1Imax
t
Tf
Tt

Dialog Box and Parameters



Block Parameters: IGBT

IGBT (mask)

Implements an IGBT device in parallel with a series RC snubber circuit.
In on-state the IGBT model has internal resistance (Ron) and inductance (Lon).
For most applications, Lon should be set to zero.
In off-state the IGBT model has infinite impedance.

Parameters

Resistance Ron (Ohms) : 0.001

Inductance Lon (H) : 0

Forward voltage Vf (V) : 1

Current 10% fall time Tf (s) : 1e-6

Current tail time Tt (s): 2e-6

Initial current Ic (A) : 0

Snubber resistance Rs (Ohms) : 1e5

Snubber capacitance Cs (F) : inf

☑ Show measurement port

Resistance Ron

The internal resistance Ron, in ohms (Ω).

Inductance Lon

The internal inductance Lon, in henries (H). The **Inductance Lon** parameter cannot be 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. See Improving Simulation Performance for more details on this topic.

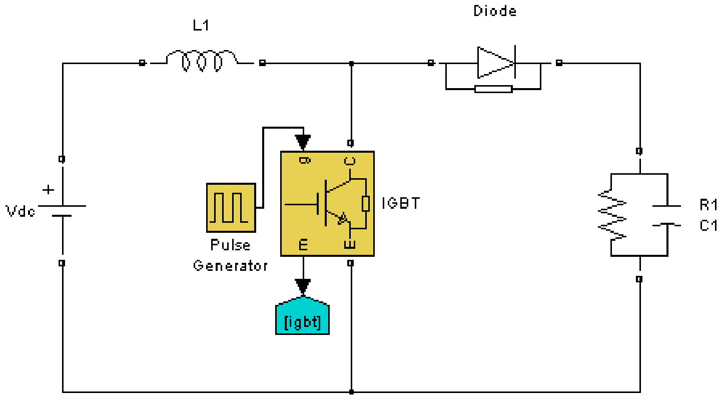
Use the Powergui block to specify either continuous simulation or discretization of your electrical circuit containing IGBT blocks. When using a continuous model, the `ode23tb` solver with a relative tolerance of 1e-4 is recommended for best accuracy and simulation speed.

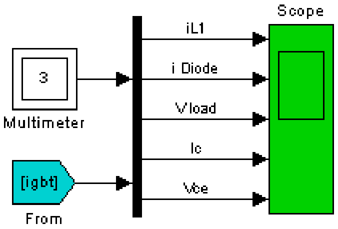
The inductance Lon is forced to 0 if you choose to discretize your circuit.

Example

The `power_igbtconv` demo 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:

$$V_R = \frac{1}{1-\alpha} V_{dc}$$

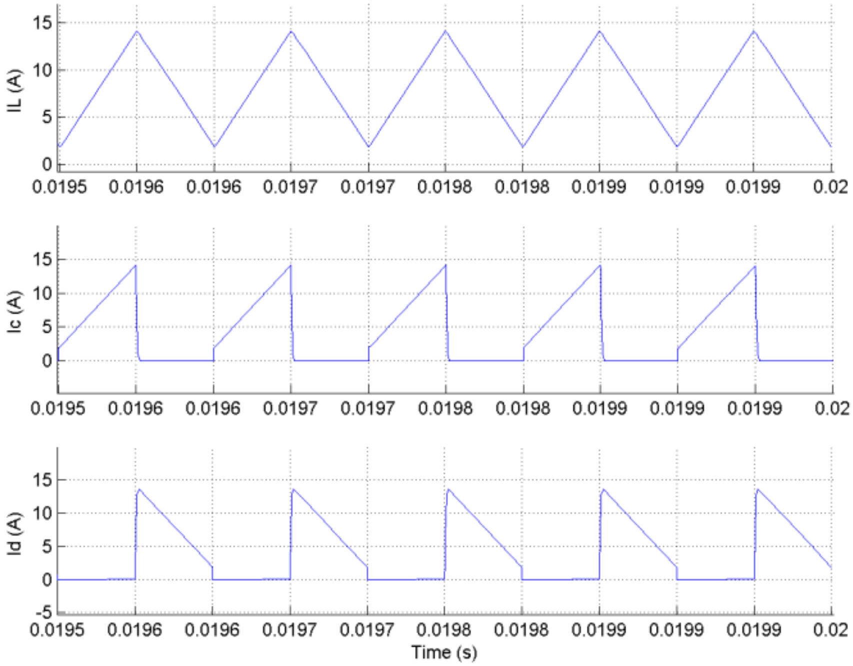


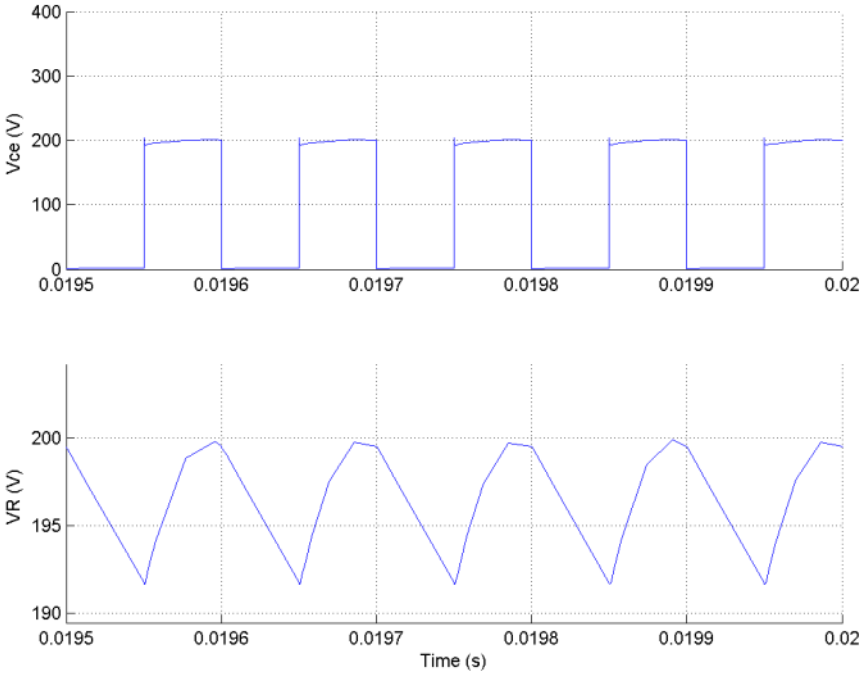


In our example, α = 0.5 so that the theoretical value of V_R is 200 V, assuming no voltage drop across the diode and the IGBT.

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).


IL (A)
Ic (A)
Id (A)
15
10
5
0
-5
0.0195
0.0196
0.0196
0.0197
0.0197
0.0198
0.0198
0.0199
0.0199
0.0199
0.02
Time (s)



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

Purpose

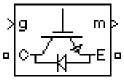
Implements ideal IGBT, GTO, or MOSFET and antiparallel diode

Library

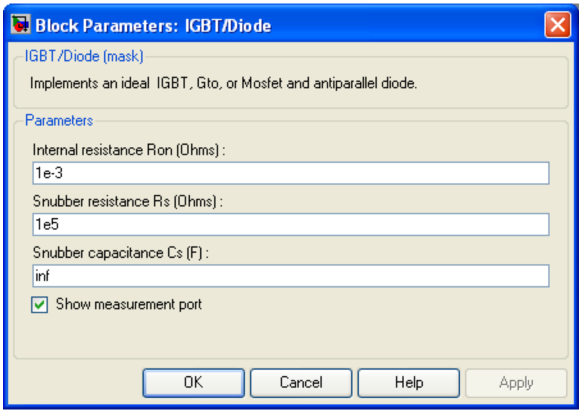
Power Electronics

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



Block Parameters: IGBT/Diode

IGBT/Diode (mask)

Implements an ideal IGBT, Gto, or Mosfet and antiparallel diode.

Parameters

Internal resistance Ron (Ohms) :

1e-3

Snubber resistance Rs (Ohms) :

1e5

Snubber capacitance Cs (F) :

inf

☑ Show measurement port

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. See Improving Simulation Performance for more details on this topic.

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

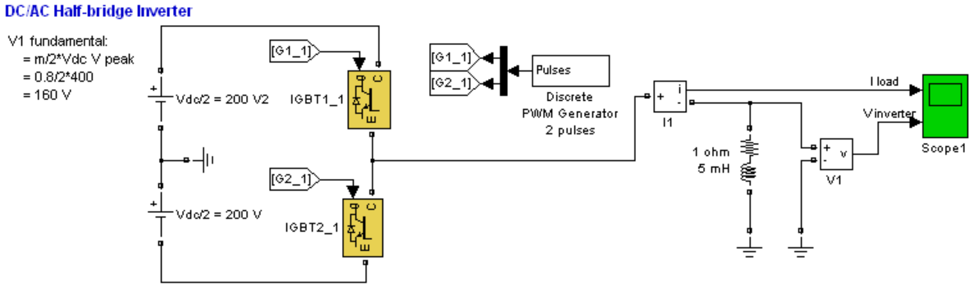
The `power_1phPWM_IGBT` demo illustrates use of the IGBT/Diode block in voltage-sourced converters. The system consists of two independent circuits illustrating single-phase PWM voltage-sourced converters (VSC):

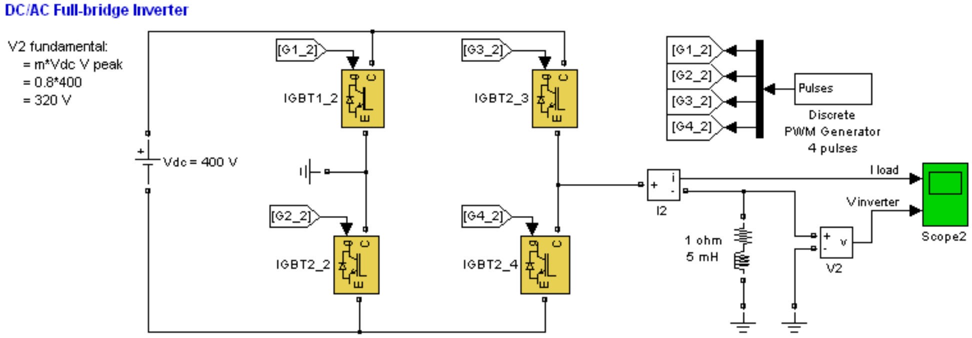
1. Half-bridge converter
2. Full-bridge converter

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 Discrete PWM Generator block available in the Extras/Discrete Control Blocks 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

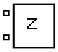
IGBT, Diode

Impedance Measurement

Purpose Measure impedance of circuit as function of frequency

Library Measurements

Description



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.

$$H(s) = \frac{V_z(s)}{I_z(s)}$$

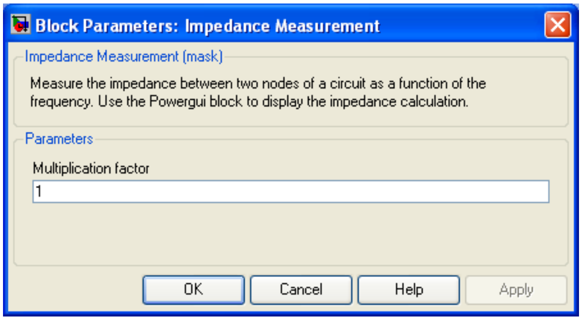
The impedance (magnitude and phase) as function of frequency is displayed by using the Impedance vs Frequency Measurement tool of the Powergui block.

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



Measure the impedance between two nodes of a circuit as a function of the frequency. Use the Powergui block to display the impedance calculation.

Multiplication factor: 1

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`

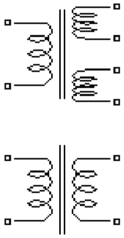
Purpose

Implement two- or three-winding linear transformer

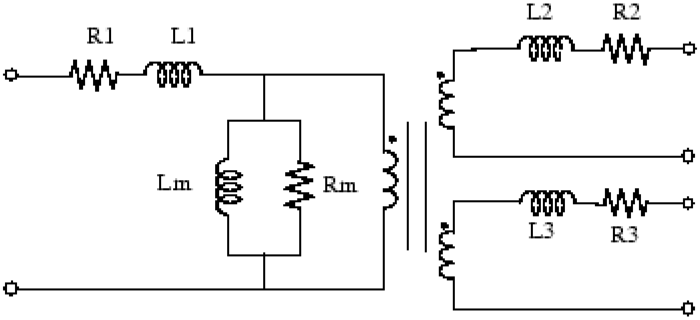
Library

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:

$$R_{base} = \frac{(735e3)^2}{220e6} = 2161\Omega$$

$$L_{base} = \frac{2161}{2\pi 60} = 5.732H$$

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

$$R_1 = \frac{4.32\Omega}{2161\Omega} = 0.002pu$$

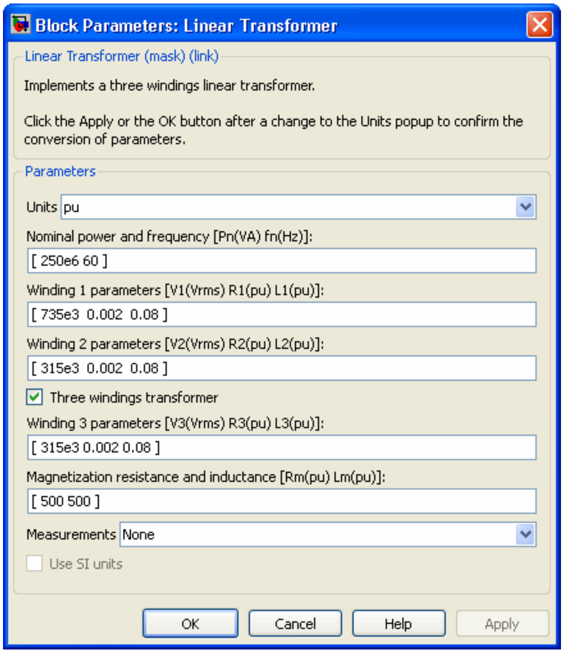
$$L_1 = \frac{0.4586H}{5.732H} = 0.08pu$$

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



Implements a three windings linear transformer.

Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

Units: pu

Nominal power and frequency [Pn(VA) fn(Hz)]: [250e6 60]

Winding 1 parameters [V1(Vrms) R1(pu) L1(pu)]: [735e3 0.002 0.08]

Winding 2 parameters [V2(Vrms) R2(pu) L2(pu)]: [315e3 0.002 0.08]

☑ Three windings transformer

Winding 3 parameters [V3(Vrms) R3(pu) L3(pu)]: [315e3 0.002 0.08]

Magnetization resistance and inductance [Rm(pu) Lm(pu)]: [500 500]

Measurements: None

☐ Use SI units

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

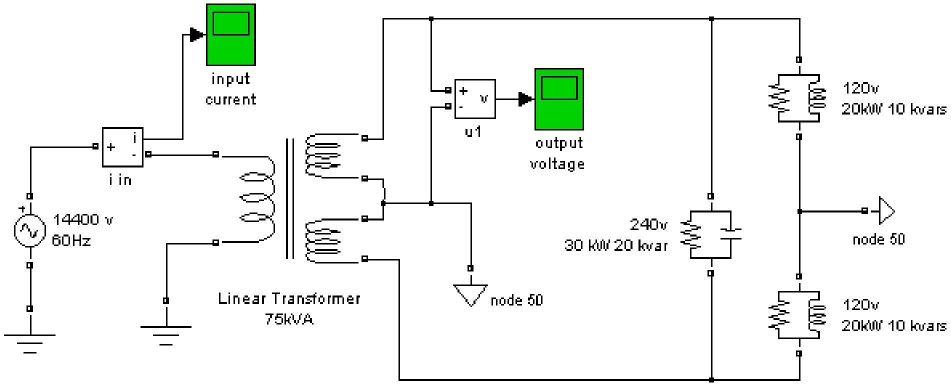
Windings can be left floating (that is, not connected to the rest of the circuit). However, an internal resistor is automatically added between the floating winding and the main circuit. This internal connection does not affect voltage and current measurements.

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` demo 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)

Machine Measurement Demux

Purpose

Split measurement signal of machine models into separate signals

Library

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.

Mechanical Shaft

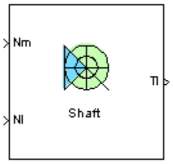
Purpose

Implement mechanical shaft

Library

Electric Drives/Shafts and Speed Reducers

Description

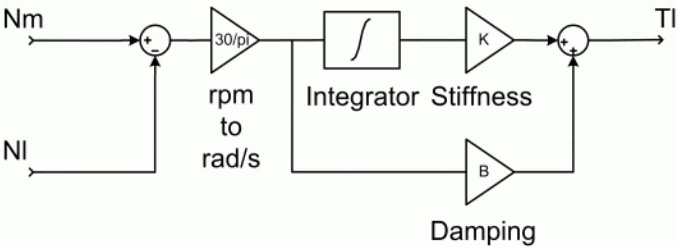


The model outputs the transmitted torque through the shaft regarding the speed difference between the driving side and the loaded side of the shaft.

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

$$K = \frac{T}{\theta}$$

where T is the torsional torque applied to the shaft and θ the resulting angular deflection (rad).

The stiffness can also be determined by

$$K = \frac{G \cdot J}{l}$$

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

$$J = \frac{\pi \cdot D^4}{32}$$

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

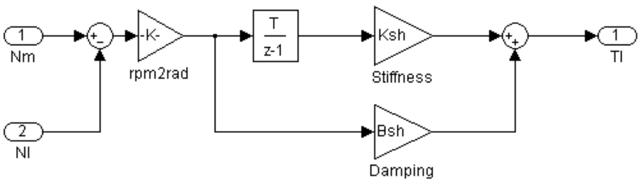
P (HP)	N (rpm)	T (N.m)	Tmax (N.m) (=1.5 T)	K (N.m)
5	1750	20	30	17190
200	1750	815	1223	700730
200	1200	1190	1785	1022730

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



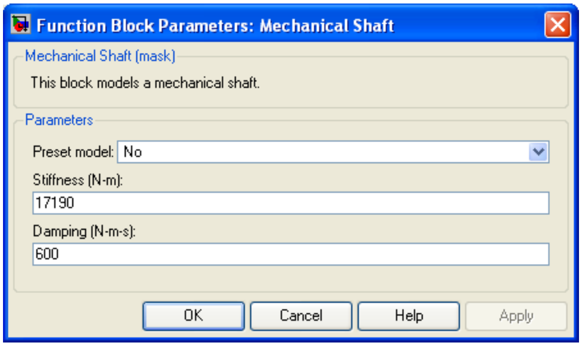
Remarks

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


Function Block Parameters: Mechanical Shaft

Mechanical Shaft (mask)

This block models a mechanical shaft.

Parameters

Preset model: No

Stiffness (N-m):

17190

Damping (N-m-s):

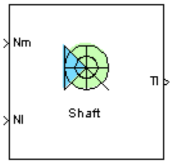
600

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:

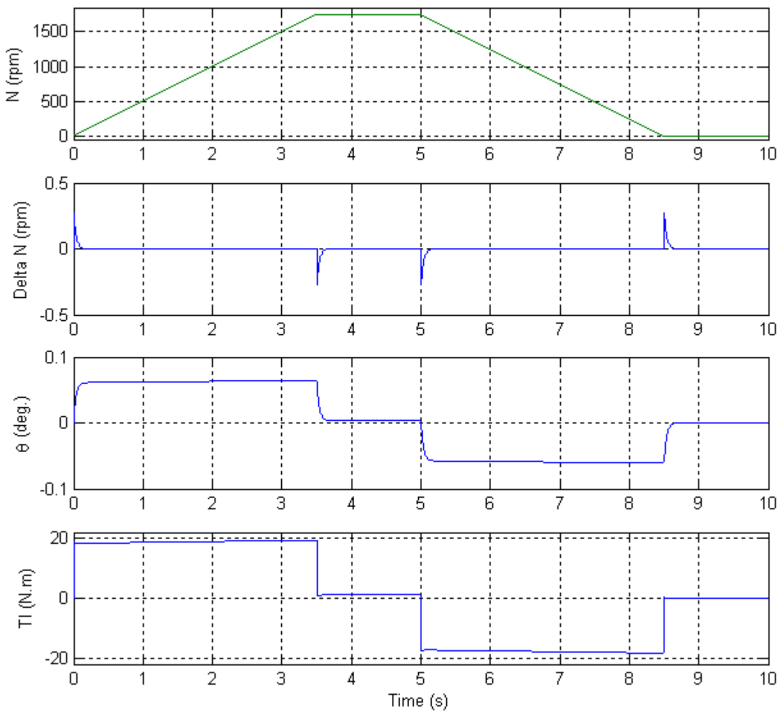
Preset Mechanical Shaft Models

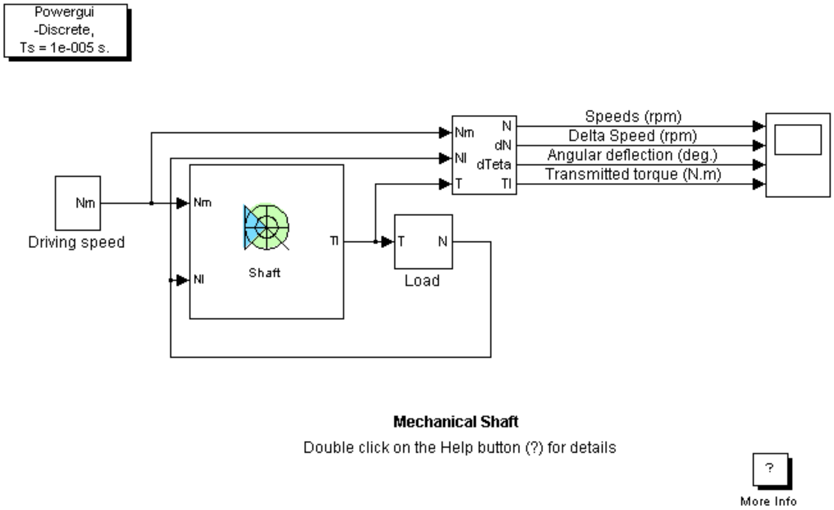
	1st	2nd	3rd
Nominal torque (N.m)	20	815	1190

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` demo illustrates the mechanical shaft model.





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.

MOSFET

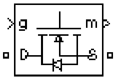
Purpose

Implement MOSFET model

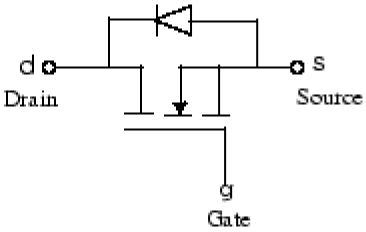
Library

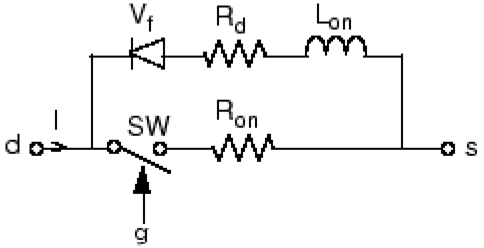
Power Electronics

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.

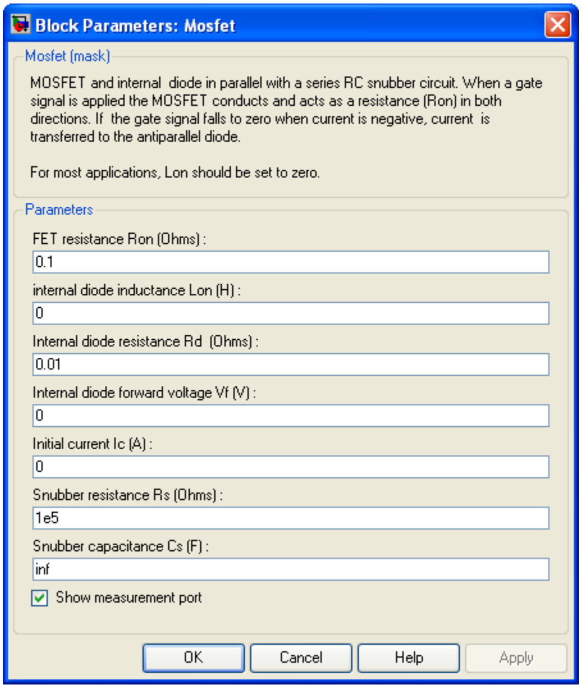
The on state voltage Vds varies

- 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



MOSFET and internal diode in parallel with a series RC snubber circuit. When a gate signal is applied the MOSFET conducts and acts as a resistance (Ron) in both directions. If the gate signal falls to zero when current is negative, current is transferred to the antiparallel diode.

For most applications, Lon should be set to zero.

FET resistance Ron (Ohms) : 0.1

internal diode inductance Lon (H) : 0

Internal diode resistance Rd (Ohms) : 0.01

Internal diode forward voltage Vf (V) : 0

Initial current Ic (A) : 0

Snubber resistance Rs (Ohms) : 1e5

Snubber capacitance Cs (F) : inf

☑ Show measurement port

FET Resistance Ron

The internal resistance Ron, in ohms (Ω).

Internal diode inductance Lon

The internal inductance Lon, in henries (H). The **Inductance Lon** parameter cannot be 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].

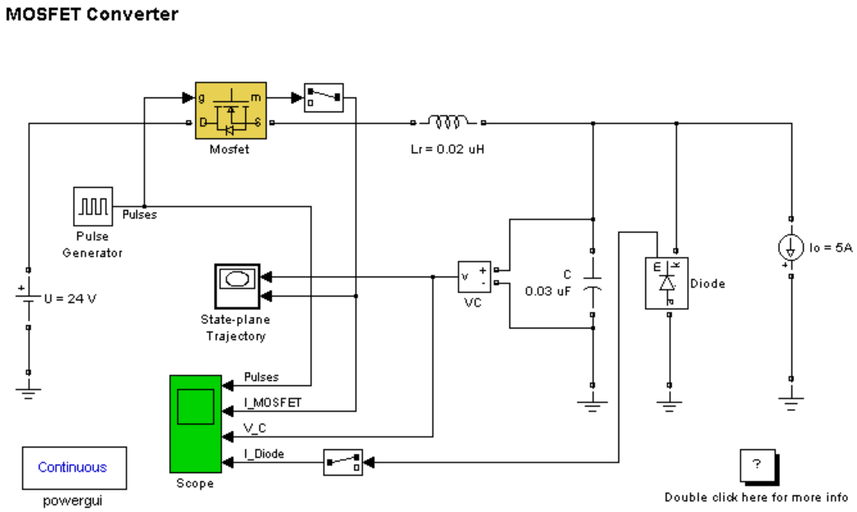
Depending on the value of the inductance Lon, the MOSFET is modeled either as a current source (Lon > 0) or as a variable topology circuit (Lon = 0). The MOSFET block cannot be connected in series with an inductor, a current source, or an open circuit, unless its snubber circuit is in use. See Improving Simulation Performance for more details on this topic.

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.

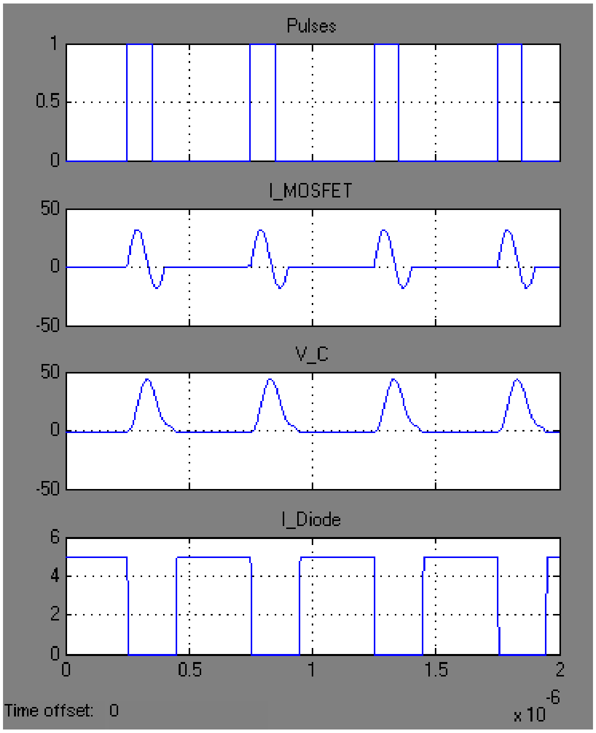
The inductance Lon is forced to 0 if you choose to discretize your circuit.

Example

The `power_mosconv` demo 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%).



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

Purpose

Implement multiband power system stabilizer

Library

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:

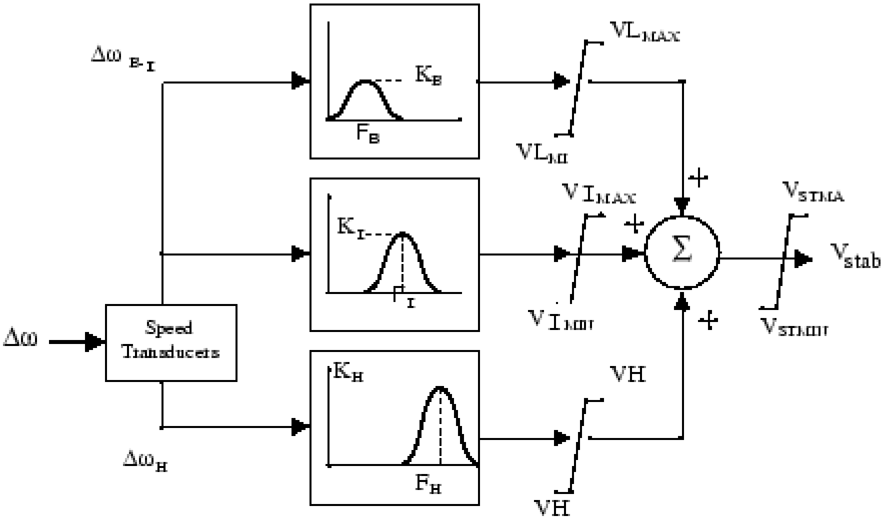
- Local oscillations: between a unit and the rest of the generating station and between the latter and the rest of the power system. Their frequencies typically range from 0.8 to 4.0 Hz.
- Interplant oscillations: between two electrically close generation plants. Frequencies can vary from 1 to 2 Hz.
- 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).

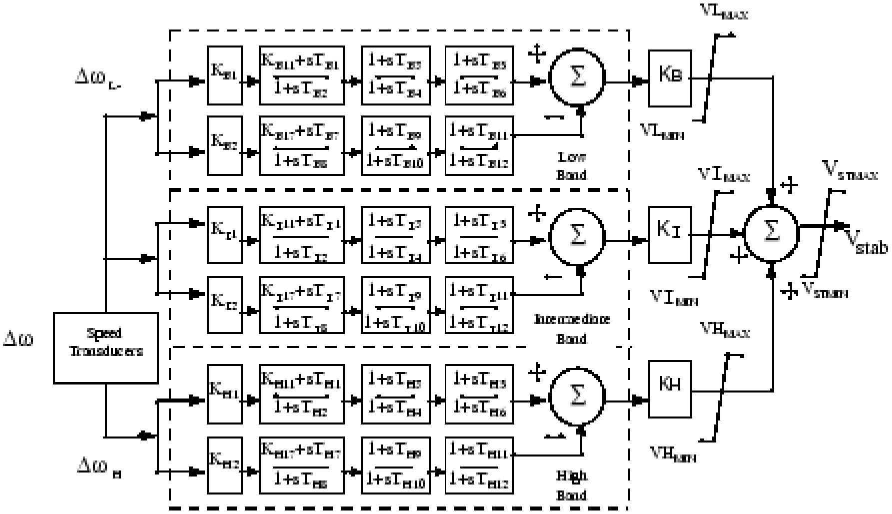
As its name reveals, the MB-PSS structure is based on multiple working bands. Three separate bands are used, respectively dedicated to the low-, intermediate-, and high-frequency modes of oscillations: the low band is typically associated with the power system global mode, the intermediate with the interarea 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 on page 2-317). 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 on page 2-318, 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:

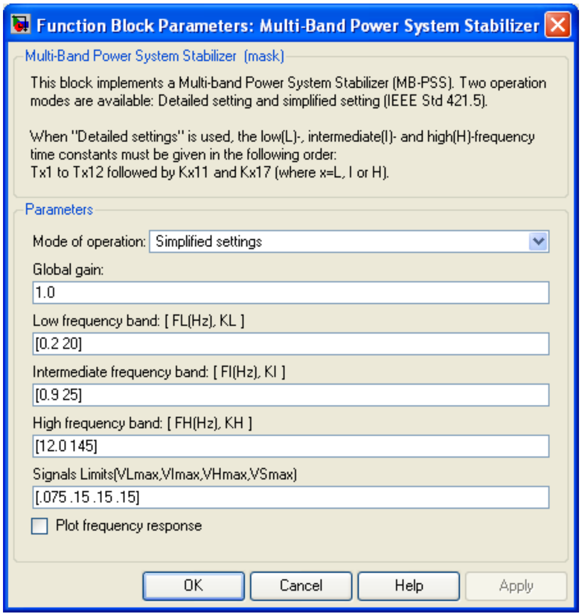
   Only the first lead-lag block of each frequency band is used to tune the Multiband Power System Stabilizer block. The differential filters are assumed to be symmetrical bandpass filters respectively tuned at the center frequency F_L, F_I, and F_H. The peak magnitude of the frequency responses (see the figure called Conceptual Representation on page 2-317) 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 on page 2-318 have to be specified in the dialog box.

Dialog Box and Parameters

Simplified Settings Mode



Function Block Parameters: Multi-Band Power System Stabilizer

Multi-Band Power System Stabilizer (mask)

This block implements a Multi-band Power System Stabilizer (MB-PSS). Two operation modes are available: Detailed setting and simplified setting (IEEE Std 421.5).

When "Detailed settings" is used, the low(L)-, intermediate(I)- and high(H)-frequency time constants must be given in the following order:
Tx1 to Tx12 followed by Kx11 and Kx17 (where x=L, I or H).

Parameters

Mode of operation: Simplified settings

Global gain:
1.0

Low frequency band: [FL(Hz), KL]
[0.2 20]

Intermediate frequency band: [FI(Hz), KI]
[0.9 25]

High frequency band: [FH(Hz), KH]
[12.0 145]

Signals Limits(VLmax,VImax,VHmax,VSmax)
[.075 .15 .15 .15]

☐ Plot frequency response

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.

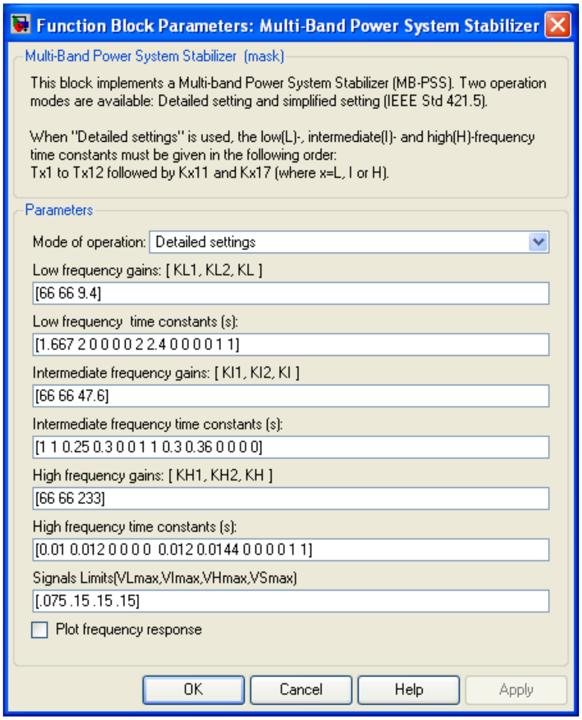
Intermediate frequency band: [FI KI]
The center frequency, in hertz, and peak gain of the intermediate-frequency bandpass filter.

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



This block implements a Multi-band Power System Stabilizer (MB-PSS). Two operation modes are available: Detailed setting and simplified setting (IEEE Std 421.5).

When "Detailed settings" is used, the low(L)-, intermediate(I)- and high(H)-frequency time constants must be given in the following order:
Tx1 to Tx12 followed by Kx11 and Kx17 (where x=L, I or H).

Mode of operation: Detailed settings

Low frequency gains: [KL1, KL2, KL]
[66 66 9.4]

Low frequency time constants (s):
[1.667 2 0 0 0 0 2 2.4 0 0 0 0 1 1]

Intermediate frequency gains: [KI1, KI2, KI]
[66 66 47.6]

Intermediate frequency time constants (s):
[1 1 0.25 0.3 0 0 1 1 0.3 0.36 0 0 0 0]

High frequency gains: [KH1, KH2, KH]
[66 66 233]

High frequency time constants (s):
[0.01 0.012 0 0 0 0 0.012 0.0144 0 0 0 0 1 1]

Signals Limits(VLmax,VImax,VHmax,VSmax)
[.075 .15 .15 .15]

☐ Plot frequency response

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` demo 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

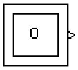
Purpose

Measure voltages and currents specified in dialog boxes of SimPowerSystems blocks

Library

Measurements

Description



The Multimeter block is used to measure voltages and currents of the measurements described by the dialog boxes of SimPowerSystems blocks.

The **powerlib** blocks listed in the following table have a special parameter (**Measurements**) that allows you to measure voltages or currents related to the block. Choosing voltages or currents through this measurement parameter is equivalent to connecting an internal voltage or current measurement block inside your blocks. The measured signals can be observed through a Multimeter block placed in your circuit.

Drag the Multimeter block into the top-level system of your circuit and double-click the icon to open the dialog box.

Block Name	Block Name
AC Current Source	PI Section Line
AC Voltage Source	Saturable Transformer
Breaker	Series RLC Branch
Controlled Current Source	Series RLC Load
Controlled Voltage Source	Surge Arrester
DC Voltage Source	Three-Level Bridge
Distributed Parameter Line	Three-Phase Harmonic Filter
Linear Transformer	Three-Phase Load (Series and Parallel)
Multi-Winding Transformer	Three-Phase Branch (Series and Parallel)

Block Name	Block Name
Mutual Inductance	Three-Phase Transformer (Two and Three Windings)
Parallel RLC Branch	Universal Bridge
Parallel RLC Load	Zigzag Phase-Shifting Transformer

Sign Conventions for Voltages and Currents

When you measure a current using a Current Measurement block, the positive direction of current is indicated on the block icon (positive current flowing from + terminal to – terminal). Similarly, when you measure a voltage using a Voltage Measurement block, the measured voltage is the voltage of the + terminal with respect to the – terminal. However, when voltages and currents of blocks from the Elements library are measured using the Multimeter block, the voltage and current polarities are not immediately obvious because blocks might have been rotated and there are no signs indicating polarities on the block icons.

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 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 measured with the Multimeter block 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).

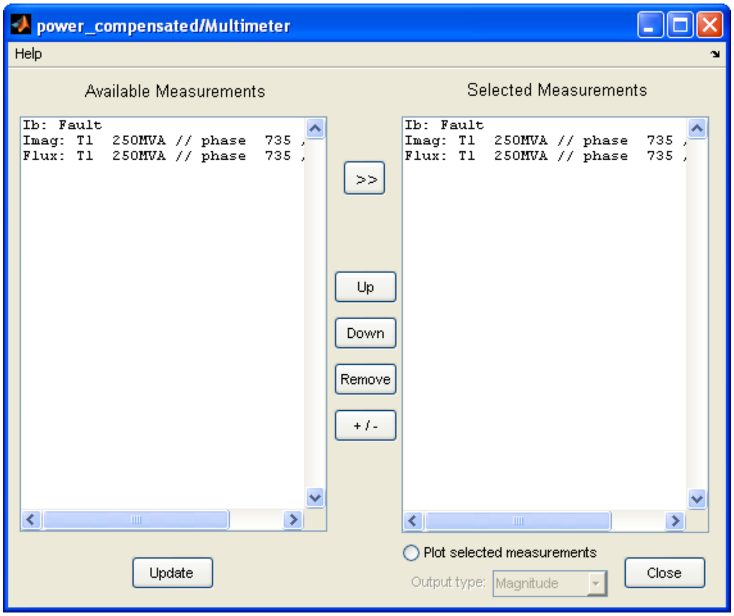
Block Orientation	**Positive Current Direction**	**Measured Voltage**
`right`	left —> right	Vleft – Vright
`left`	right —> left	Vright – Vleft
`down`	top —> bottom	Vtop – Vbottom
`up`	bottom —> top	Vbottom – Vtop

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. For example, Uan_w2 = phase A-to-neutral voltage of the Y connected winding #2, Iab_w1 = winding current flowing from A to B in the delta-connected winding #1.

Dialog Box and Parameters



```
Ib: Fault
Imag: T1  250MVA // phase  735 ,
Flux: T1  250MVA // phase  735 ,
```

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 in the Multimeter block.

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. See the reference sections of blocks listed in the previous table for a description of these measurements.

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 using 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.

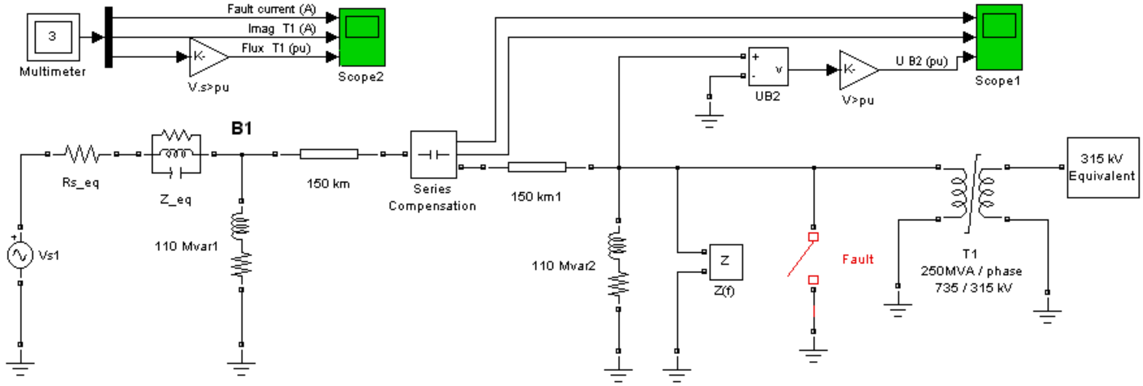
Set to `Real-Imag` to output the real and imaginary parts of the measurements. For each selected measurement, the multimeter outputs the real and imaginary parts.

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` demo 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.



A Multimeter block is dragged 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 Mvar1 block, set it to `Branch voltage` and in the 110 Mvar2 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 shown on the Dialog Box and Parameters section. Notice the labels used to define the available measurements in the Multimeter block. See the reference section of the Saturable Transformer block and Series RLC Load block for a description of these labels.

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

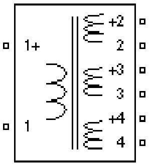
Purpose

Implement multi-winding transformer with taps

Library

Elements

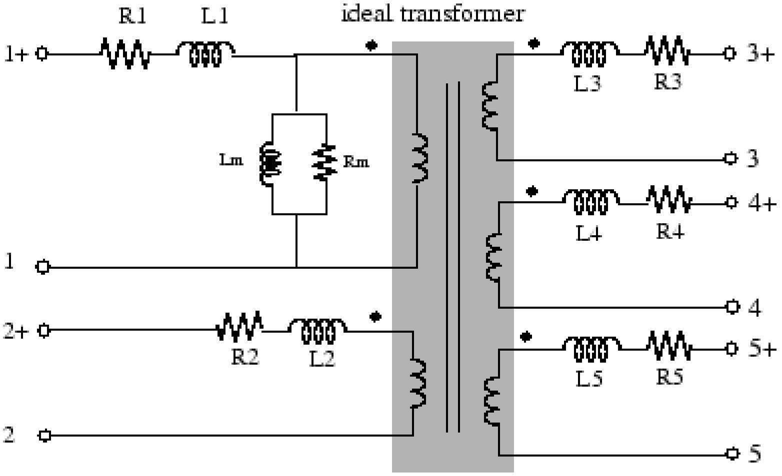
Description



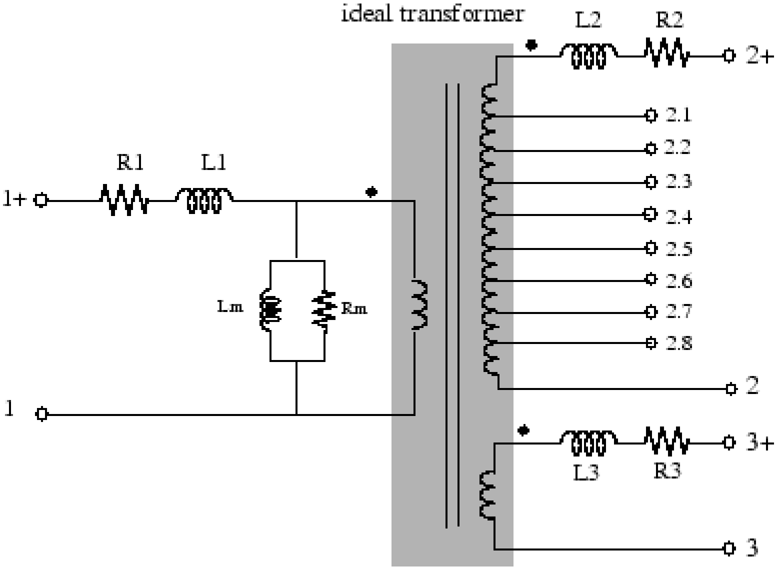
The Multi-Winding Transformer block implements a transformer where the number of windings can be specified for both the primary (left side windings) and the secondary (right side windings).

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.

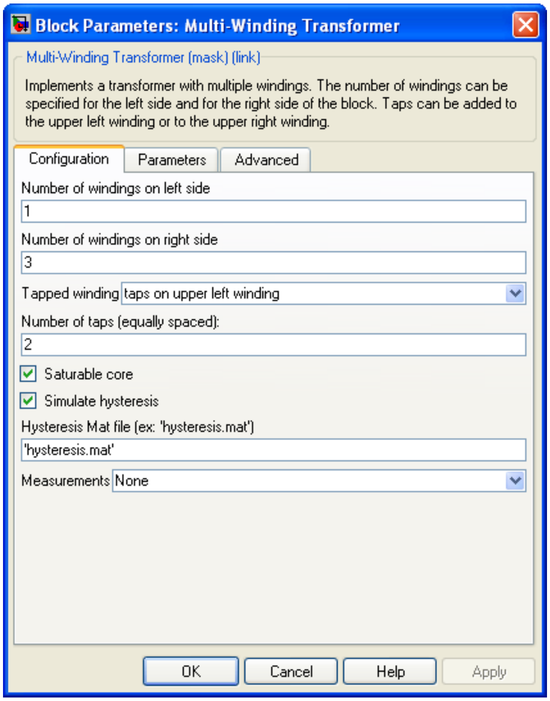


The winding terminals are identified by the corresponding winding number. The first winding is the first one on the primary side (upper-left side) and the last winding is the last one on the secondary side (bottom-right side). The polarity of the windings are defined by a plus sign.

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



Multi-Winding Transformer (mask) (link)

Implements a transformer with multiple windings. The number of windings can be specified for the left side and for the right side of the block. Taps can be added to the upper left winding or to the upper right winding.

Number of windings on left side: 1

Number of windings on right side: 3

Tapped winding: taps on upper left winding

Number of taps (equally spaced): 2

☑ Saturable core

☑ Simulate hysteresis

Hysteresis Mat file (ex: 'hysteresis.mat'): 'hysteresis.mat'

Measurements: None

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.

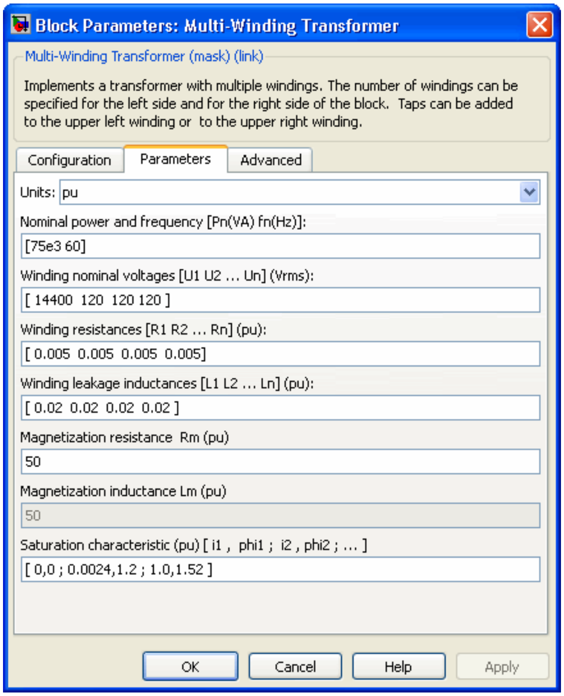
Select `All measurement (V, I, Flux)` to measure the winding voltages, currents, magnetization currents, and the flux linkage.

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



Block Parameters: Multi-Winding Transformer

Multi-Winding Transformer (mask) (link)

Implements a transformer with multiple windings. The number of windings can be specified for the left side and for the right side of the block. Taps can be added to the upper left winding or to the upper right winding.

Units: pu

Nominal power and frequency [Pn(VA) fn(Hz)]: [75e3 60]

Winding nominal voltages [U1 U2 ... Un] (Vrms): [14400 120 120 120]

Winding resistances [R1 R2 ... Rn] (pu): [0.005 0.005 0.005 0.005]

Winding leakage inductances [L1 L2 ... Ln] (pu): [0.02 0.02 0.02 0.02]

Magnetization resistance Rm (pu): 50

Magnetization inductance Lm (pu): 50

Saturation characteristic (pu) [i1 , phi1 ; i2 , phi2 ; ...]: [0,0 ; 0.0024,1.2 ; 1.0,1.52]

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.

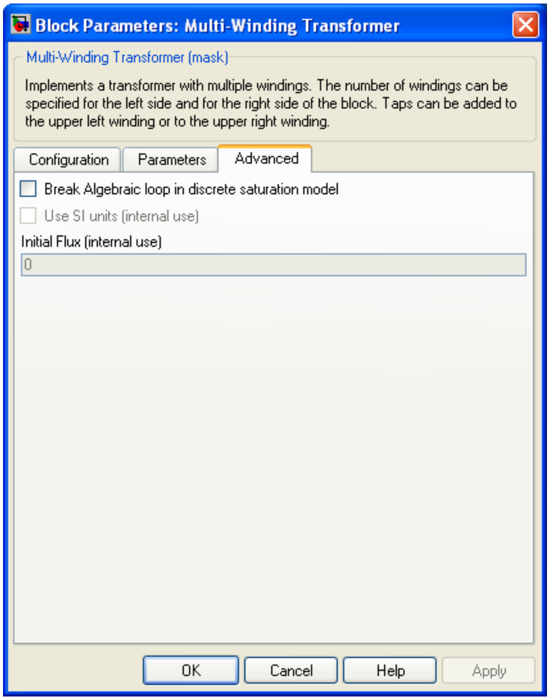
The magnetization inductance Lm, in Henry or in pu, for a nonsaturable core.

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



Block Parameters: Multi-Winding Transformer

Multi-Winding Transformer (mask)

Implements a transformer with multiple windings. The number of windings can be specified for the left side and for the right side of the block. Taps can be added to the upper left winding or to the upper right winding.

☐ Break Algebraic loop in discrete saturation model

☐ Use SI units (internal use)

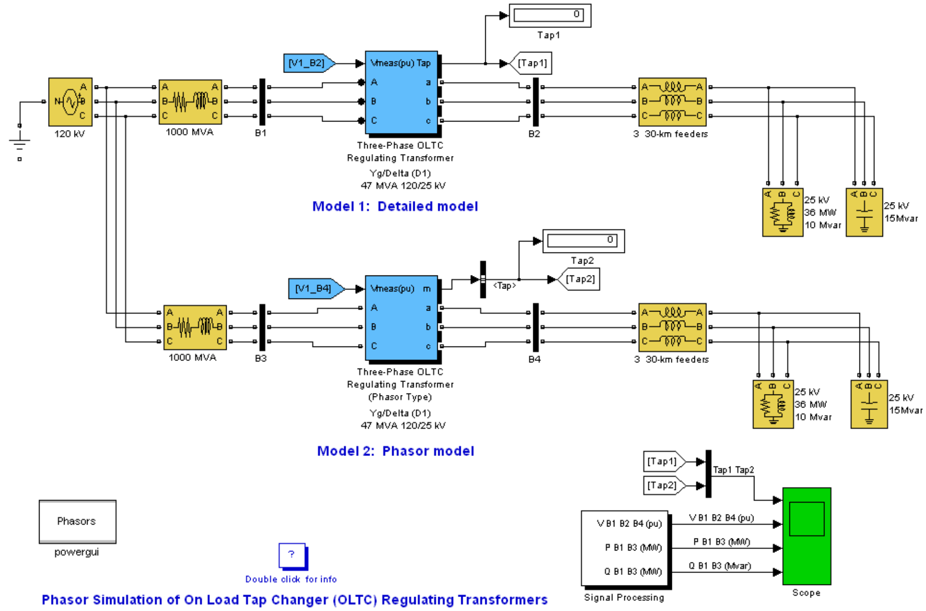
Initial Flux (internal use): 0

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` demo 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 demo 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 demo) 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 demo. Double-click the Double click for info block to get details.

Mutual Inductance

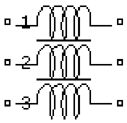
Purpose

Implement inductances with mutual coupling

Library

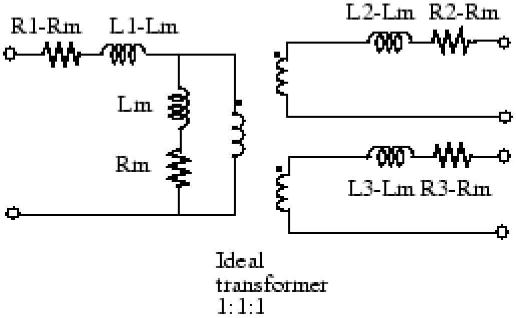
Elements

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.

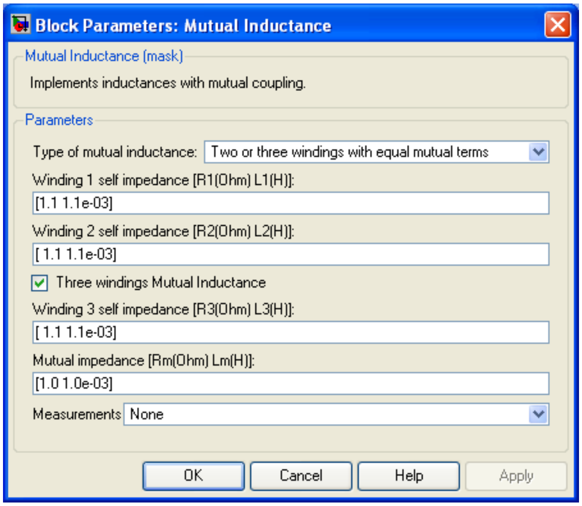
If you choose to model two- or three-windings inductances with equal mutual coupling, you specify the self-resistance and inductance of each winding plus the mutual resistance and inductance. The electrical model for this block in this case is given below:



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:



Block Parameters: Mutual Inductance

Mutual Inductance (mask)

Implements inductances with mutual coupling.

Parameters

Type of mutual inductance: Two or three windings with equal mutual terms

Winding 1 self impedance [R1(Ohm) L1(H)]: [1.1 1.1e-03]

Winding 2 self impedance [R2(Ohm) L2(H)]: [1.1 1.1e-03]

☑ Three windings Mutual Inductance

Winding 3 self impedance [R3(Ohm) L3(H)]: [1.1 1.1e-03]

Mutual impedance [Rm(Ohm) Lm(H)]: [1.0 1.0e-03]

Measurements None

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.

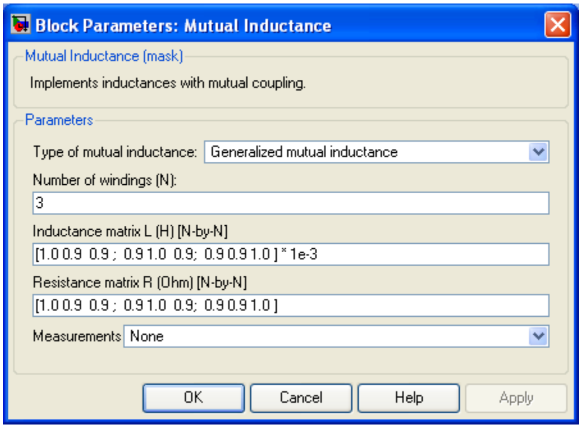
Winding 3 self impedance

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:



Implements inductances with mutual coupling.

Type of mutual inductance: Generalized mutual inductance

Number of windings (N): 3

Inductance matrix L (H) [N-by-N]: [1.0 0.9 0.9 ; 0.9 1.0 0.9; 0.9 0.9 1.0] * 1e-3

Resistance matrix R (Ohm) [N-by-N]: [1.0 0.9 0.9 ; 0.9 1.0 0.9; 0.9 0.9 1.0]

Measurements None

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:

$$R_1, R_2, \ldots, R_N \neq R_m$$

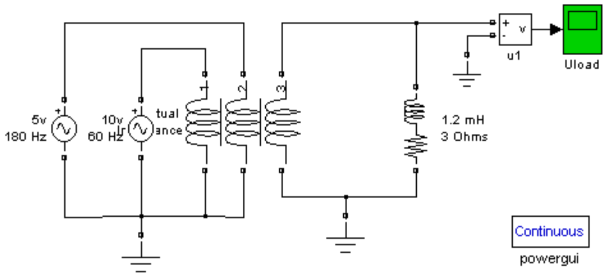
$$L_1, L_2, \ldots, L_N \neq L_m$$

Negative values are allowed for the self- and mutual inductances as long as the self-inductances are different from the mutual inductance.

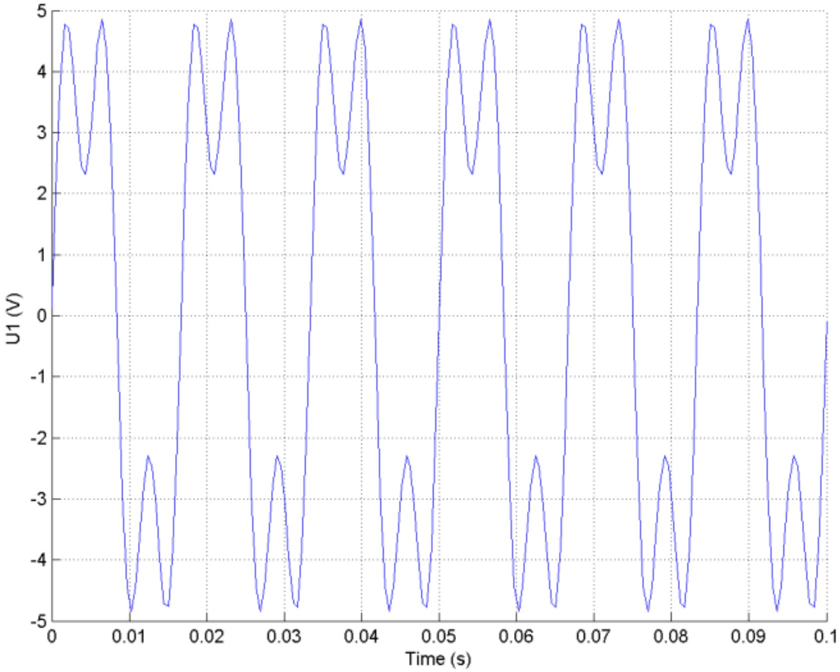
Windings can be left floating (not connected by an impedance to the rest of the circuit). However an internal resistor between the floating winding and the main circuit is automatically added. This internal connection does not affect voltage and current measurements.

Example

The `power_mutual` demo 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

Purpose

Implement common node in circuit

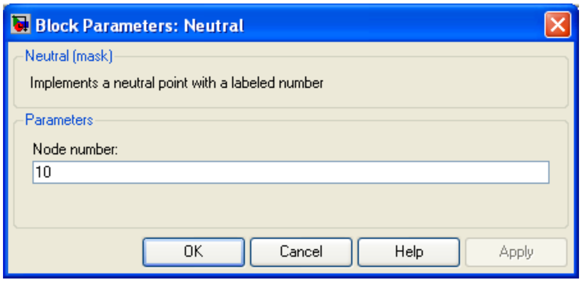
Library

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



Block Parameters: Neutral

Neutral (mask)

Implements a neutral point with a labeled number

Parameters

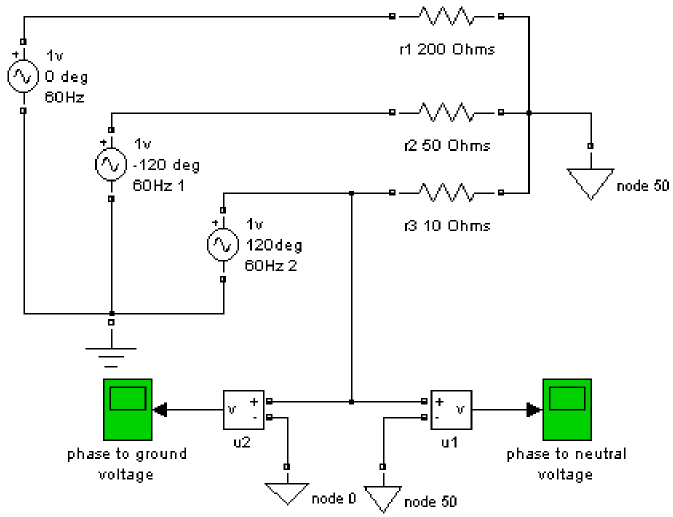
Node number: 10

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` demo 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

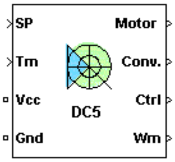
Purpose

Implement one-quadrant chopper (buck converter topology) DC drive

Library

Electric Drives/DC drives

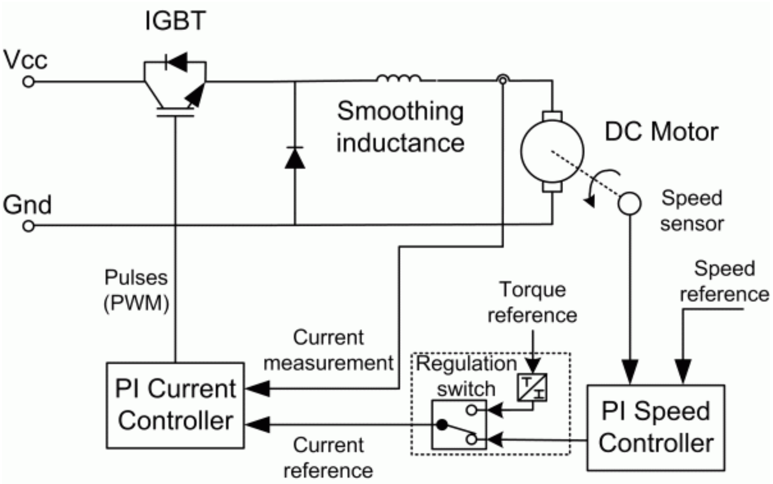
Description



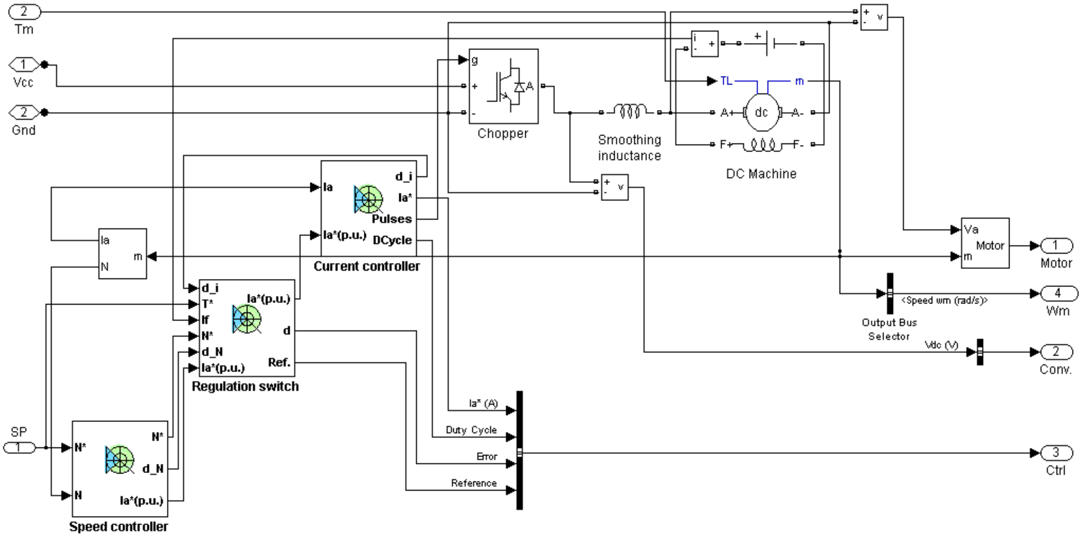
The high-level schematic shown below is built from four main blocks. The DC motor and the IGBT/Diode device (within the Universal Bridge block) are provided with the SimPowerSystems library. More details are available in the reference pages for these blocks. The two other blocks are specific to the Electric 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



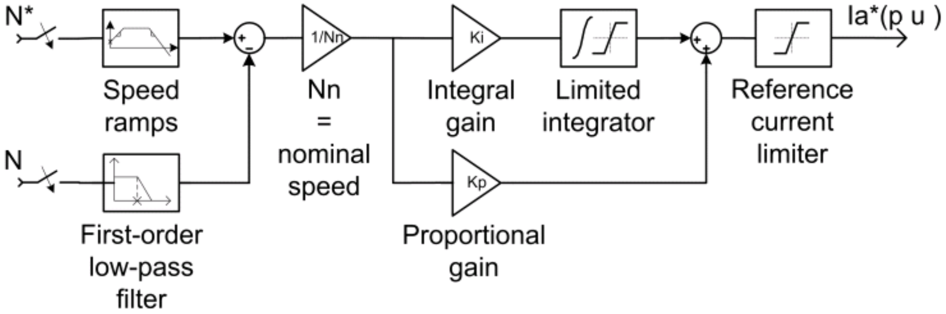
Speed Controller

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.

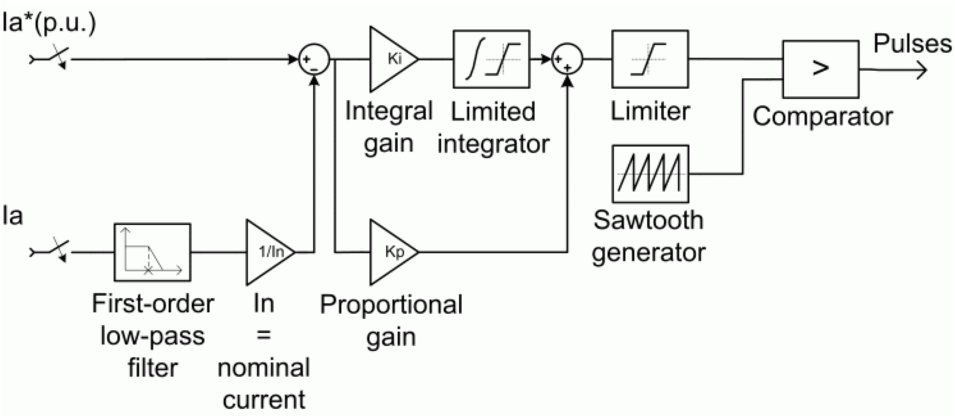


Current Controller

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.

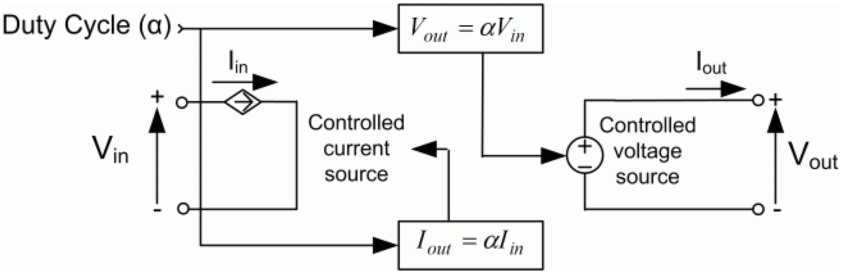
The controller takes the current reference (in pu) and the armature current flowing through the motor as inputs. The current reference is either provided by the speed controller during speed regulation or computed from the torque reference provided by the user during torque regulation. This is managed 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) on page 2-354).



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:

$$I_{in} = \alpha I_{out} \text{ when } I_{out} > 0$$
$$I_{in} = I_{out} \text{ when } I_{out} \leq 0$$

with α 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 :

$V_{out} = \alpha V_{in}$ when $I_{out} > 0$

$V_{out} = V_{in}$ when $I_{out} \le 0$

with V_{in} being the input voltage.

Remarks

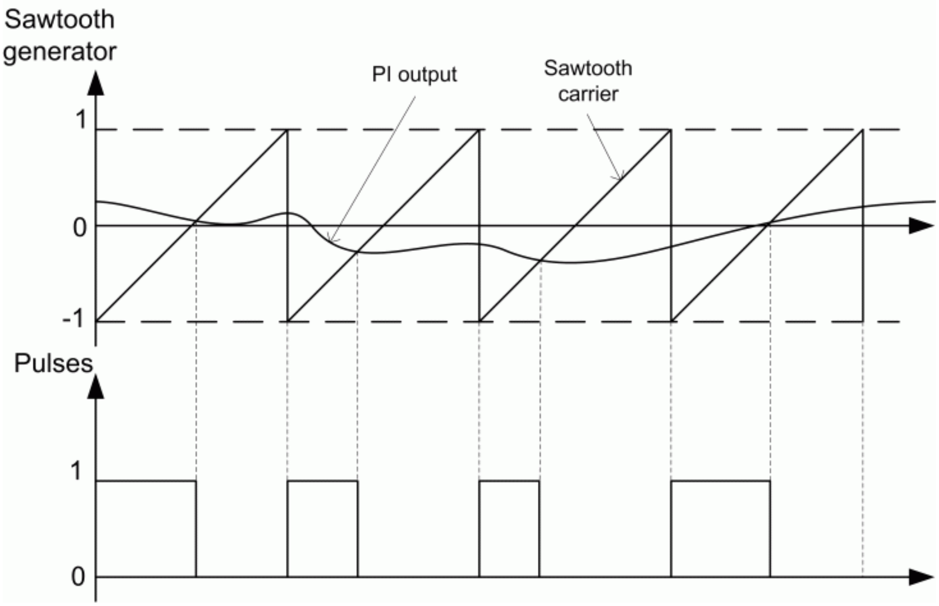
The machine is separately excited with a constant DC field voltage source. There is thus no field voltage control. By default, the field current is set to its steady-state value when a simulation is started.

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

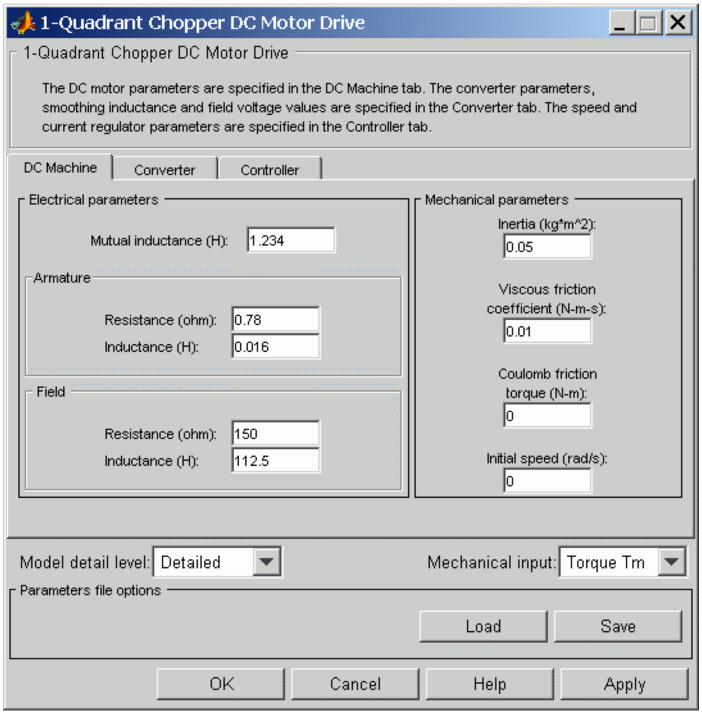
The speed controller sampling time has to be a multiple of the current sampling time. The latter sampling time has to be a multiple of the simulation time step.



Pulse Width Modulation (PWM)

Dialog Box

DC Machine Tab



1-Quadrant Chopper DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The speed and current regulator parameters are specified in the Controller tab.

Mutual inductance (H): 1.234

Armature

Resistance (ohm): 0.78
Inductance (H): 0.016

Field

Resistance (ohm): 150
Inductance (H): 112.5

Inertia (kg*m^2): 0.05
Viscous friction coefficient (N-m-s): 0.01
Coulomb friction torque (N-m): 0
Initial speed (rad/s): 0

Model detail level: Detailed
Mechanical input: Torque Tm

The DC Machine tab displays the parameters of the DC machine block of the powerlib library. Refer to the DC Machine for more information on the DC machine block parameters.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Allows you to select either the load torque or the motor speed as mechanical input. Note that if you select and apply a load torque, you will obtain as output the motor speed according to the following differential equation that describes the mechanical system dynamics:

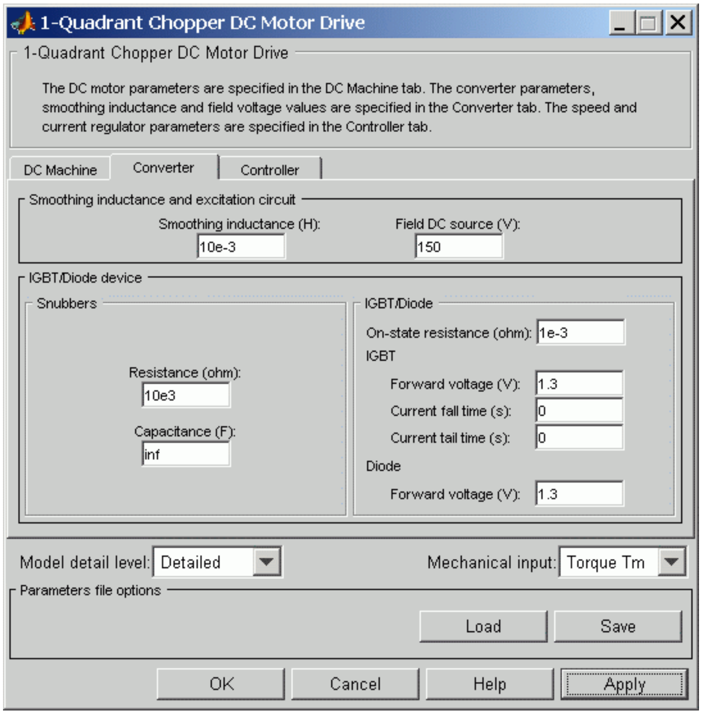
$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

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

See for example “Mechanical Coupling of Two Motor Drives”.

Converter Tab



1-Quadrant Chopper DC Motor Drive

1-Quadrant Chopper DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The speed and current regulator parameters are specified in the Controller tab.

Smoothing inductance and excitation circuit

Smoothing inductance (H): 10e-3

Field DC source (V): 150

IGBT/Diode device

Snubbers

Resistance (ohm): 10e3

Capacitance (F): inf

IGBT/Diode

On-state resistance (ohm): 1e-3

IGBT

Forward voltage (V): 1.3

Current fall time (s): 0

Current tail time (s): 0

Diode

Forward voltage (V): 1.3

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

IGBT/Diode Device section

The IGBT/Diode Device section of the Converter tab displays the parameters of the Universal Bridge block of the powerlib library. Refer to the Universal Bridge for more information on the Universal Bridge block parameters.

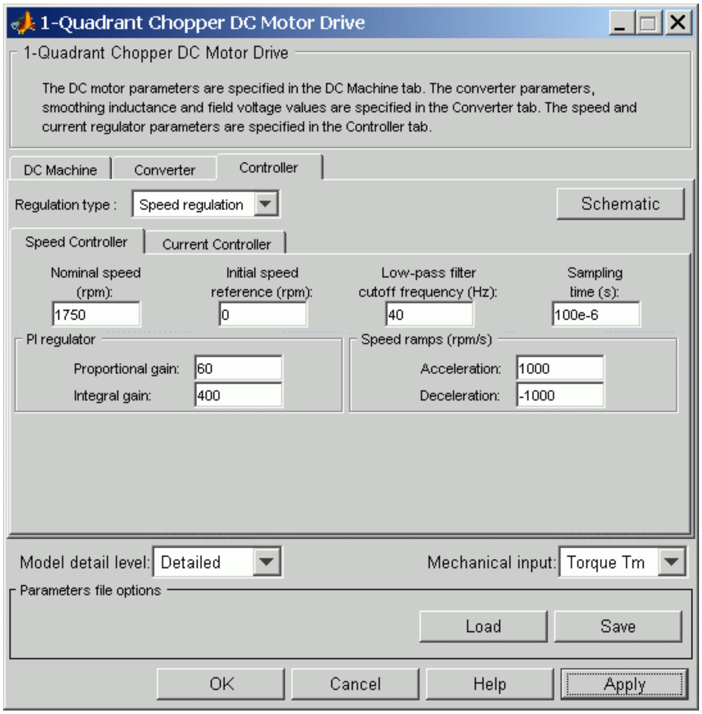
Smoothing Inductance

The smoothing inductance value (H).

Field DC Source

The DC motor field voltage value (V).

Controller Tab



The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The speed and current regulator parameters are specified in the Controller tab.

Regulation type : Speed regulation

Nominal speed (rpm): 1750

Initial speed reference (rpm): 0

Low-pass filter cutoff frequency (Hz): 40

Sampling time (s): 100e-6

Proportional gain: 60

Integral gain: 400

Acceleration: 1000

Deceleration: -1000

Model detail level: Detailed

Mechanical input: Torque Tm

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.

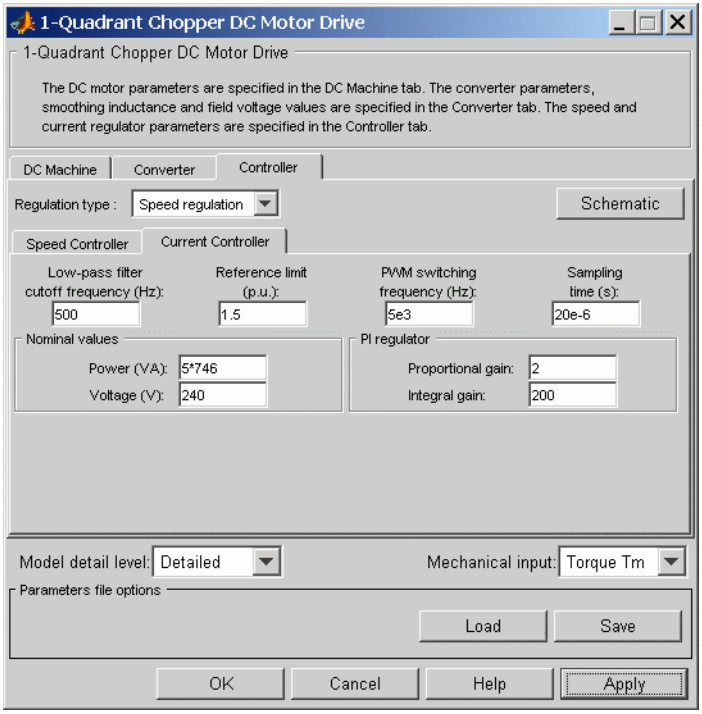
Proportional Gain
The proportional gain of the PI speed controller.

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



1-Quadrant Chopper DC Motor Drive

1-Quadrant Chopper DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The speed and current regulator parameters are specified in the Controller tab.

Regulation type : Speed regulation

Low-pass filter cutoff frequency (Hz): 500

Reference limit (p.u.): 1.5

PWM switching frequency (Hz): 5e3

Sampling time (s): 20e-6

Nominal values

Power (VA): 5*746

Voltage (V): 240

PI regulator

Proportional gain: 2

Integral gain: 200

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

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. Note that 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).

`Vcc, Gnd`

The DC voltage source electric connections. The voltage must be adequate for the motor size.

`Wm` or `Te`

The mechanical output: motor speed (Wm) or electromagnetic torque (Te).

`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

Model Specifications

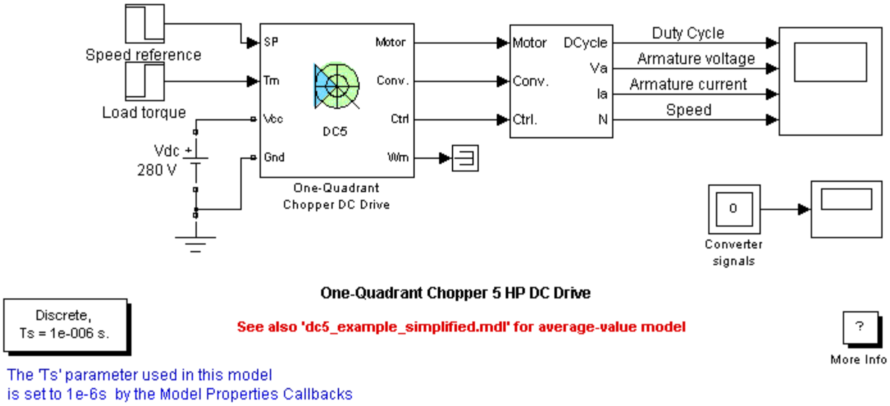
The library contains a 5 hp drive parameter set. The specifications of the 5 hp drive are shown in the following table.

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` demo illustrates the one-quadrant chopper drive used with the 5 hp drive parameter set during speed regulation.



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.

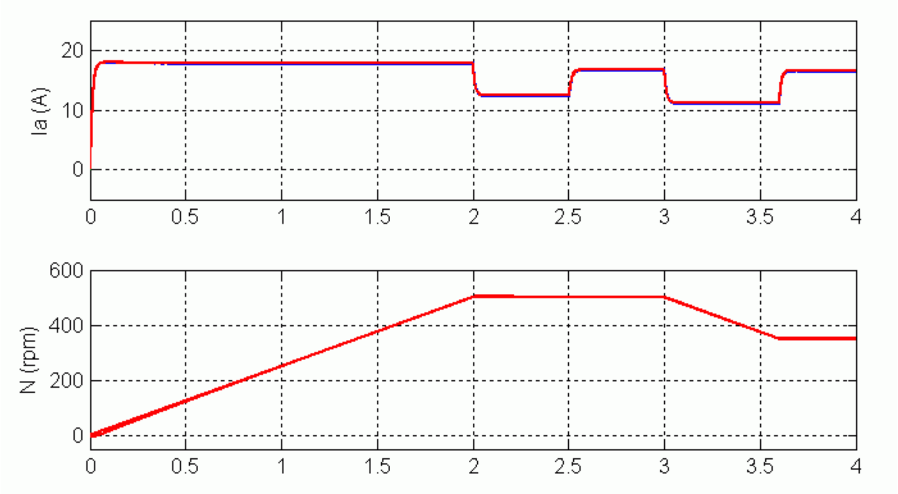
The armature current follows the current reference very well, with fast response time and small ripples. Notice that the current ripple frequency is 5 kHz.

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.

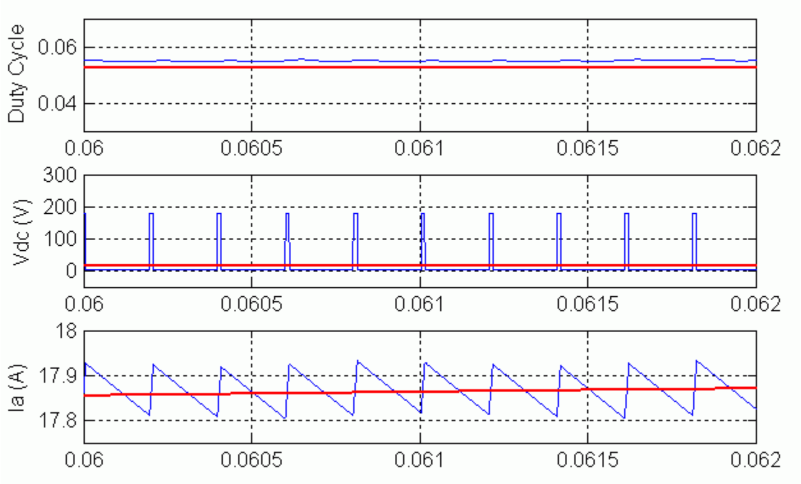
At t = 4 s, the speed stabilizes around its reference.

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.

Parallel RLC Branch

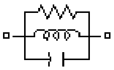
Purpose

Implement parallel RLC branch

Library

Elements

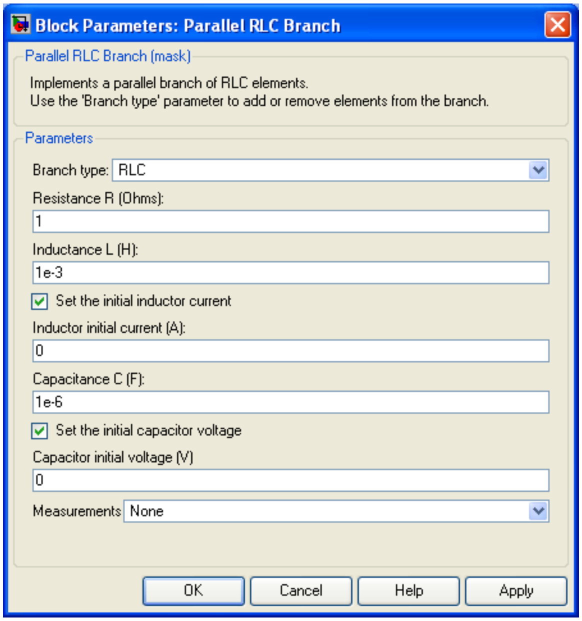
Description



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. If you eliminate either the resistance, inductance, or capacitance of the branch, the R, L, and C values are automatically set respectively to infinity (`inf`), infinity (`inf`), and `0` and the corresponding parameters no longer appear in the block dialog box. Only existing elements are displayed in the block icon.

Negative values are allowed for resistance, inductance, and capacitance.

Dialog Box and Parameters



Block Parameters: Parallel RLC Branch

Parallel RLC Branch (mask)

Implements a parallel branch of RLC elements.
Use the 'Branch type' parameter to add or remove elements from the branch.

Parameters

Branch type: RLC

Resistance R (Ohms): 1

Inductance L (H): 1e-3

☑ Set the initial inductor current

Inductor initial current (A): 0

Capacitance C (F): 1e-6

☑ Set the initial capacitor voltage

Capacitor initial voltage (V): 0

Measurements: None

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).

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.

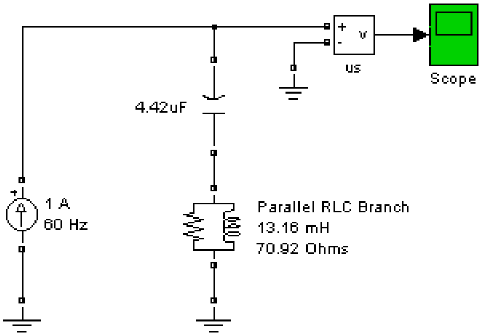
Select `Branch voltage and current` to measure the voltage and the current of the Parallel RLC Branch block.

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:`
Branch current	`Ib:`

Example

The `power_paralbranch` demo 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

$$Z(s) = \frac{V(s)}{I(s)} = \frac{RLCs^2 + Ls + R}{LCs^2 + RCs}$$

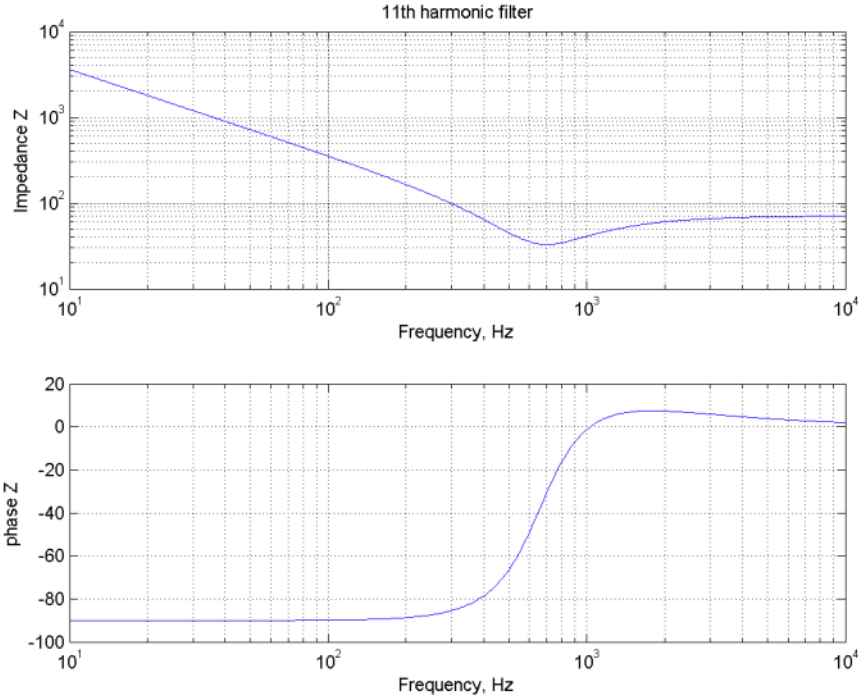
To obtain the frequency response of the impedance you have to get the state-space model (A B C D matrices) of the system.

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

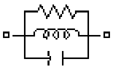
Purpose

Implement linear parallel RLC load

Library

Elements

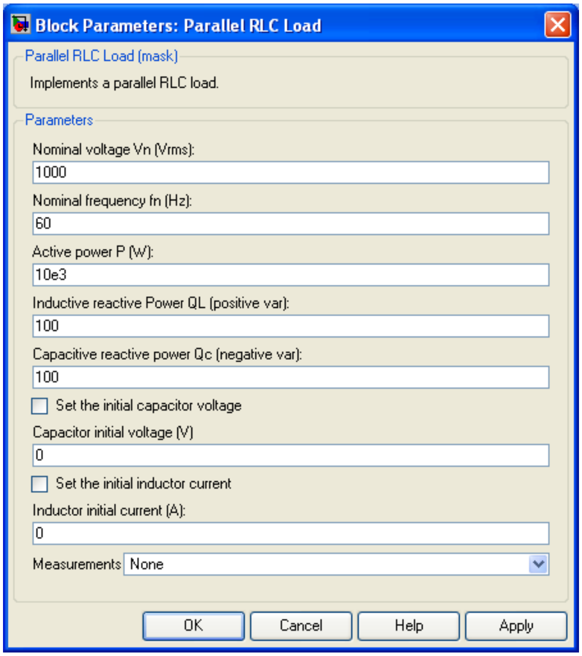
Description



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



Block Parameters: Parallel RLC Load

Parallel RLC Load (mask)

Implements a parallel RLC load.

Parameters

Nominal voltage Vn (Vrms): 1000

Nominal frequency fn (Hz): 60

Active power P (W): 10e3

Inductive reactive Power QL (positive var): 100

Capacitive reactive power Qc (negative var): 100

☐ Set the initial capacitor voltage

Capacitor initial voltage (V): 0

☐ Set the initial inductor current

Inductor initial current (A): 0

Measurements: None

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.

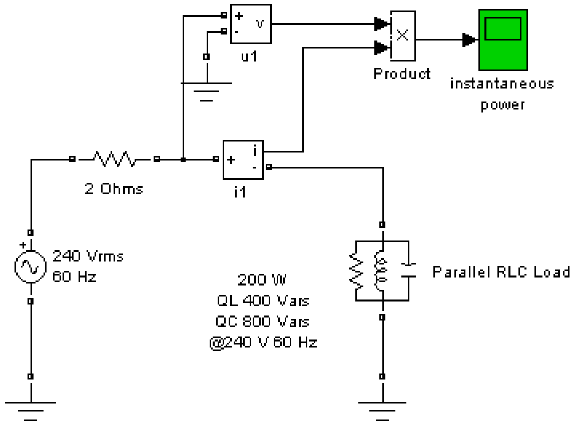
Select **Branch voltage and current** to measure the voltage and the current of the Parallel RLC Load block.

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:`

Example

The `power_paralload` demo 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

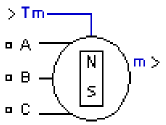
Purpose

Model the dynamics of three-phase permanent magnet synchronous machine with sinusoidal or trapezoidal back electromotive force (back EMF)

Library

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. For the trapezoidal machine, the 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.

Sinusoidal Model Electrical System

These equations are expressed in the rotor reference frame (qd frame).

$$\frac{d}{dt}i_d = \frac{1}{L_d}v_d - \frac{R}{L_d}i_d + \frac{L_q}{L_d}p\omega_r i_q$$

$$\frac{d}{dt}i_q = \frac{1}{L_q}v_q - \frac{R}{L_q}i_q - \frac{L_d}{L_q}p\omega_r i_d - \frac{\lambda p\omega_r}{L_q}$$

$$T_e = 1.5p[\lambda i_q + (L_d - L_q)i_d i_q]$$

where (all quantities in the rotor reference frame are referred to the stator)

L_q, L_d	q and d axis inductances
R	Resistance of the stator windings

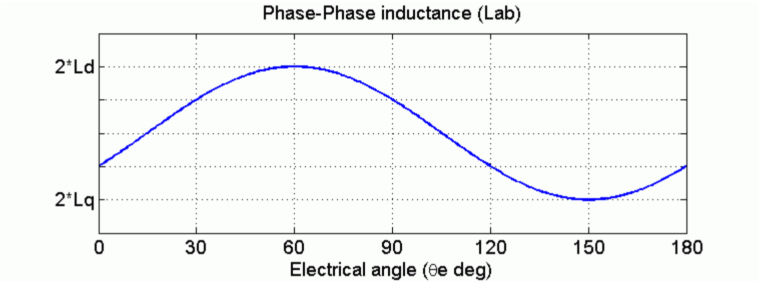
i_q, i_d	q and d axis currents
v_q, v_d	q and d axis voltages
ω_r	Angular velocity of the rotor
λ	Amplitude of the flux induced by the permanent magnets of the rotor in the stator phases
p	Number of pole pairs
T_e	Electromagnetic torque

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:

$$L_{ab} = L_d + L_q + \left(L_q - L_d\right)\cos\left(2\theta_e + \frac{\pi}{3}\right)$$

where Θ_e represents the electrical angle.

The next figure shows the variation of the line-line inductance in function of the electrical angle of the rotor:



- For a round rotor, there is no variation in the phase inductance. Therefore,

$$L_d = L_q = \frac{L_{ab}}{2}$$

- For a salient round rotor, the dq inductances are given by:

$$L_d = \frac{\max(L_{ab})}{2}$$

and

$$L_q = \frac{\min(L_{ab})}{2}$$

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.

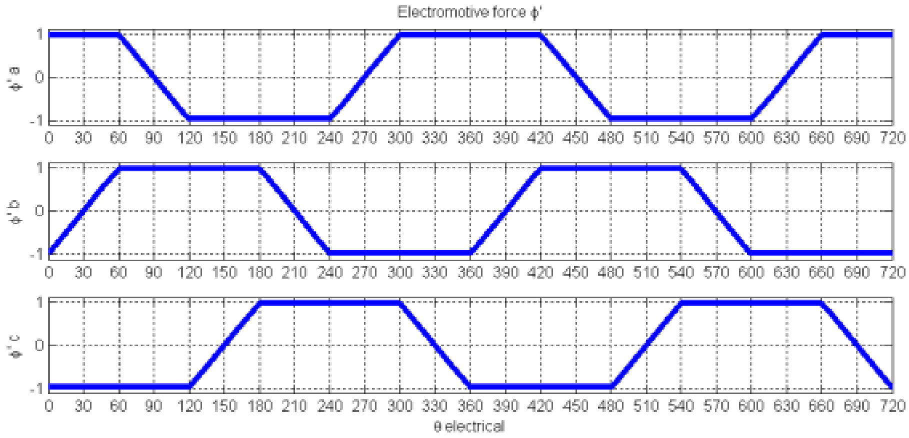
$$\frac{d}{dt}i_a = \frac{1}{3L_s}[2v_{ab} + v_{bc} - 3R_s i_a + \lambda p \omega_r(-2\Phi_a' + \Phi_b' + \Phi_c')]$$

$$\frac{d}{dt}i_b = \frac{1}{3L_s}[-v_{ab} + v_{bc} - 3R_s i_b + \lambda p \omega_r(\Phi_a' - 2\Phi_b' + \Phi_c')]$$

$$\frac{d}{dt}i_c = -\left(\frac{d}{dt}i_a + \frac{d}{dt}i_b\right)$$

$$T_e = p\lambda(\Phi_a' \cdot i_a + \Phi_b' \cdot i_b + \Phi_c' \cdot i_c)$$

where 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_r	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 both models)

$$\frac{d}{dt}\omega_r = \frac{1}{J}(T_e - F\omega_r - T_m)$$

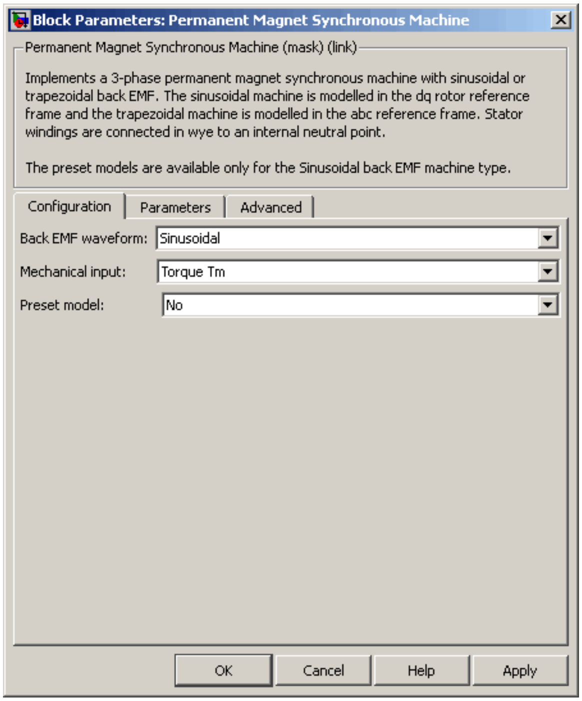
$$\frac{d\theta}{dt} = \omega_r$$

where

J	Combined inertia of rotor and load
F	Combined viscous friction of rotor and load
Θ	Rotor angular position
T_m	Shaft mechanical torque

Dialog Box and Parameters

Configuration Tab



Permanent Magnet Synchronous Machine (mask) (link)

Implements a 3-phase permanent magnet synchronous machine with sinusoidal or trapezoidal back EMF. The sinusoidal machine is modelled in the dq rotor reference frame and the trapezoidal machine is modelled in the abc reference frame. Stator windings are connected in wye to an internal neutral point.

The preset models are available only for the Sinusoidal back EMF machine type.

Back EMF waveform: Sinusoidal

Mechanical input: Torque Tm

Preset model: No

Back EMF waveform

Allows to select between the sinusoidal and the trapezoidal electromotive force.

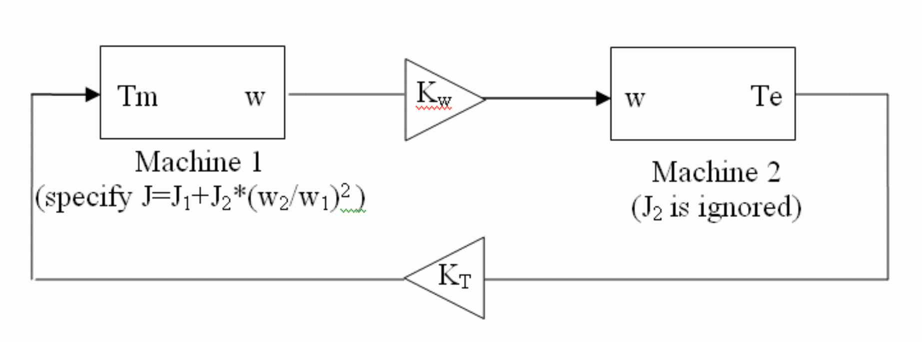
Mechanical input

Allows you to select either the torque applied to the shaft or the rotor speed as the Simulink signal applied to the block's input.

Select **Torque Tm** to specify a torque input, in N.m., and change labeling of the block's 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 the following: 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's 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 and interfacing with SimMechanics and SimDriveline models.

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.



Preset Model

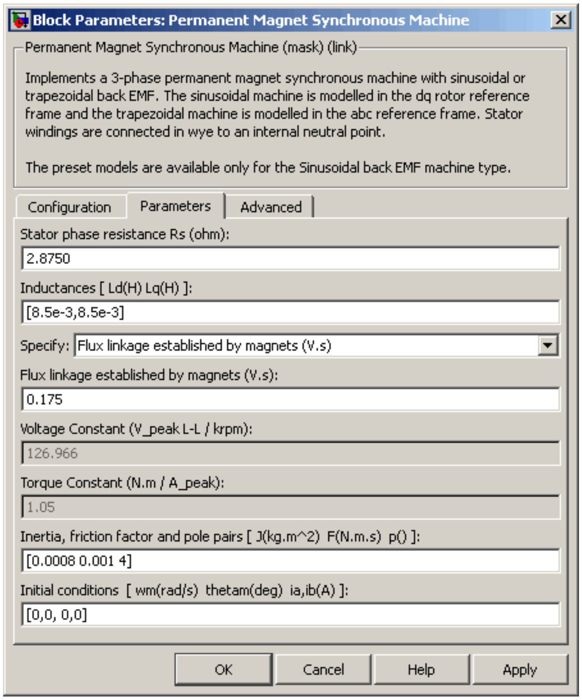
Provides a set of predetermined electrical and mechanical parameters for various permanent magnet synchronous motor ratings of torque (N.m), DC bus voltage (V), rated speed (rpm), and continuous stall torque (N.m) . This parameter is available only for sinusoidal machine.

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 unmodifiable (grayed out). To start from a given preset model and then modify machine parameters, you have to do the following:

1. Select the desired preset model to initialize the parameters.
2. Change the **Preset model** parameter value to `No`. This will 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 wish, then click **Apply**.

Parameters Tab



Permanent Magnet Synchronous Machine (mask) (link)

Implements a 3-phase permanent magnet synchronous machine with sinusoidal or trapezoidal back EMF. The sinusoidal machine is modelled in the dq rotor reference frame and the trapezoidal machine is modelled in the abc reference frame. Stator windings are connected in wye to an internal neutral point.

The preset models are available only for the Sinusoidal back EMF machine type.

Stator phase resistance Rs (ohm): 2.8750

Inductances [Ld(H) Lq(H)]: [8.5e-3,8.5e-3]

Specify: Flux linkage established by magnets (V.s)

Flux linkage established by magnets (V.s): 0.175

Voltage Constant (V_peak L-L / krpm): 126.966

Torque Constant (N.m / A_peak): 1.05

Inertia, friction factor and pole pairs [J(kg.m^2) F(N.m.s) p()]: [0.0008 0.001 4]

Initial conditions [wm(rad/s) thetam(deg) ia,ib(A)]: [0,0, 0,0]

Stator phase resistance
The stator phase resistance Rs (Ω).

Stator inductances

- Sinusoidal model: The d-axis and q-axis stator inductances Ld (H) and Lq (H).
- Trapezoidal model: The stator phase inductance Ls (H).

Specify a machine constant
Lets you select the machine constant that you wish 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 and are only shown for information.

Flux linkage established by magnets
The constant flux λ (Wb) 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 (see `ac6_example_simplified.mdl` for more detail).
- Trapezoidal model: A square ware current is assumed (see `ac7_example_simplified.mdl` for more detail).

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).

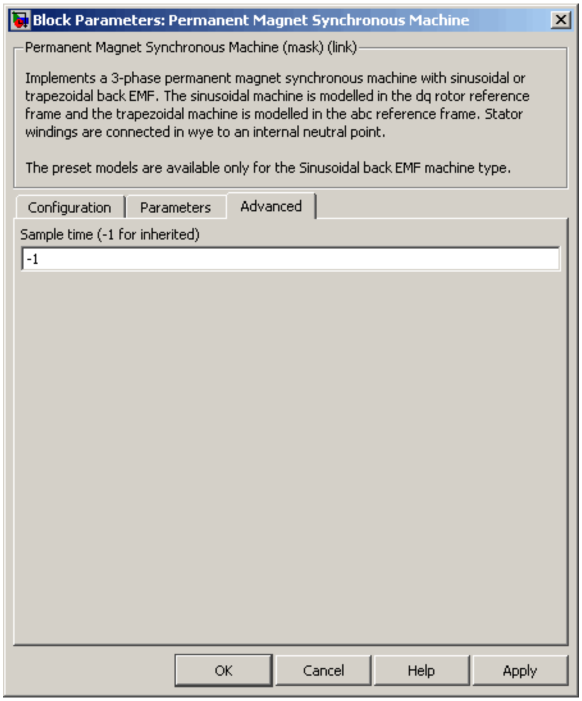
Inertia, friction factor and pole pairs
The combined machine and load inertia coefficient J (kg.m^2), combined viscous friction coefficient F (N.m.s), and pole pairs p.

Initial conditions
Specifies the mechanical speed (rad/s), mechanical angle Θ_m (degrees), and instantaneous stator current (A):

$[w_m, \Theta_m, i_a, i_b]$

Note that since the stator is wye-connected, the current i_c is given by $i_c = -i_a - i_b$.

Advanced Tab



Permanent Magnet Synchronous Machine (mask) (link)

Implements a 3-phase permanent magnet synchronous machine with sinusoidal or trapezoidal back EMF. The sinusoidal machine is modelled in the dq rotor reference frame and the trapezoidal machine is modelled in the abc reference frame. Stator windings are connected in wye to an internal neutral point.

The preset models are available only for the Sinusoidal back EMF machine type.

Sample time (-1 for inherited): -1

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 is the mechanical torque at the machine's shaft. This input should normally be positive because the

Permanent Magnet Synchronous Machine block is usually used as a motor. Nevertheless, you can apply a negative torque input if you choose to use the block in generator mode.

w

The alternative block input (depending on the value of the **Mechanical input** parameter) is the machine speed, in rad/s.

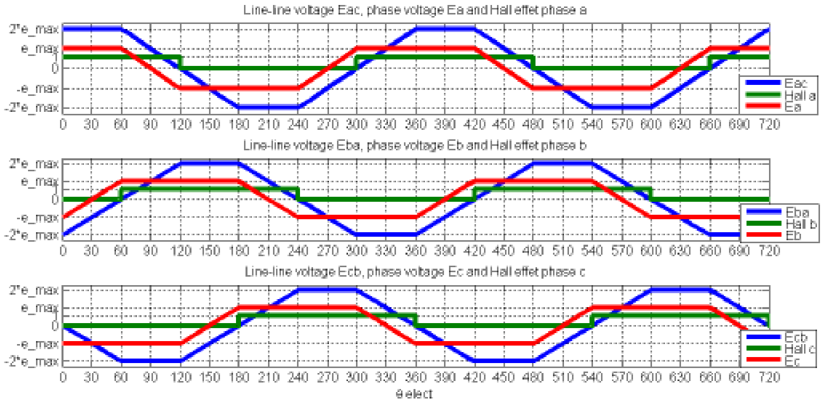
m

The Simulink output of the block is a vector containing 13 signals for the sinusoidal model and 12 signals for the trapezoidal model. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Definition	**Units**	**Symbol**	**Signal number**	
			Sinusoidal model	**Trapezoidal model**
Stator current is_a	A	i_a	1	1
Stator current is_b	A	i_b	2	2
Stator current is_c	A	i_c	3	3
Stator current is_q	A	i_q	4	N/A
Stator current is_d	A	i_d	5	N/A
Stator voltage Vs_q	V	v_q	6	N/A
Stator voltage Vs_d	V	v_d	7	N/A
Phase back EMF e_a	V	e_a	N/A	4
Phase back EMF e_b	V	e_b	N/A	5
Phase back EMF e_c	V	e_c	N/A	6
Hall effect signal h_a*	logic 0-1	h_a	8	7
Hall effect signal h_b*	logic 0-1	h_b	9	8
Hall effect signal h_c*	logic 0-1	h_c	10	9

Definition	Units	Symbol	Signal number	
			Sinusoidal model	Trapezoidal model
Rotor speed wm	rad/s	ω_r	11	10
Rotor angle thetam	rad	Θ_r	12	11
Electromagnetic torque Te	N.m	T_e	13	12

The Hall effect signal provides a logical indication of the back EMF positioning. This signal is very useful to control directly 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

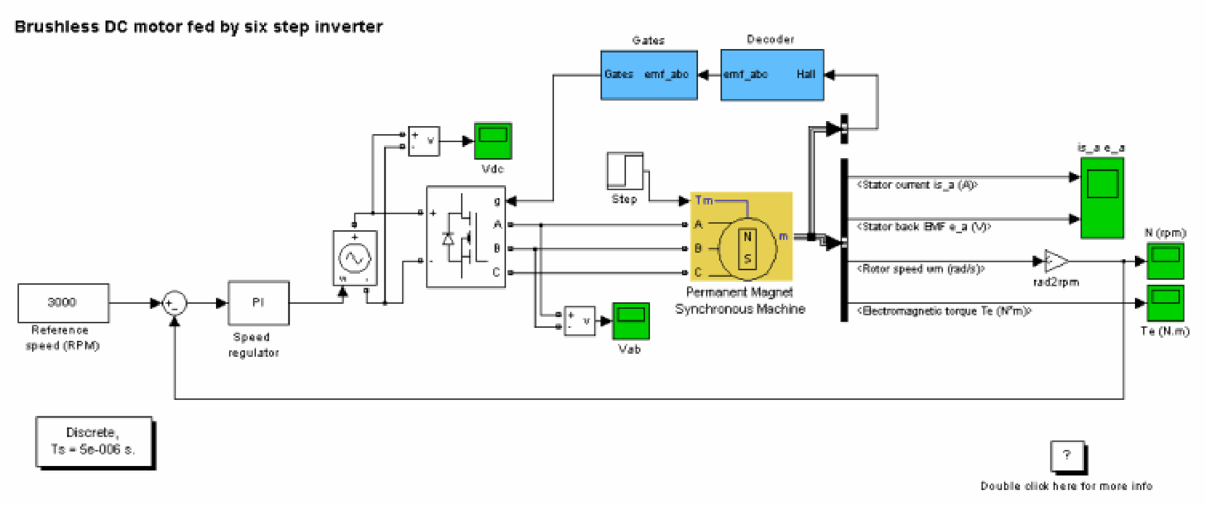
The Permanent Magnet Synchronous Machine block assumes a linear magnetic circuit with no saturation of the stator and rotor iron. This assumption can be made because of the large air gap usually found in permanent magnet synchronous machines.

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, in order 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 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 should be sufficient.

Example

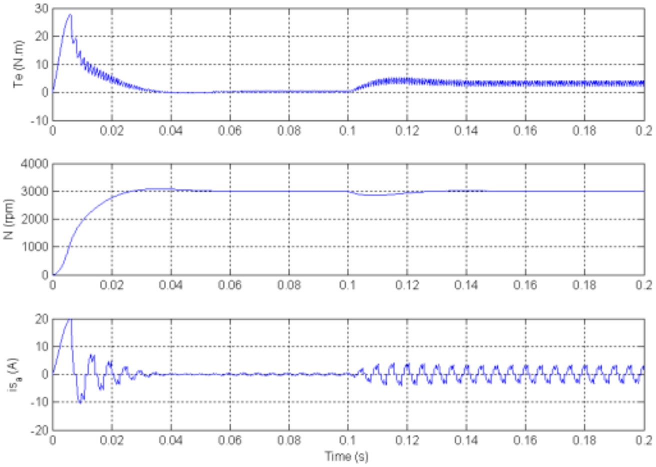
The `power_brushlessDCmotor` demo illustrates the use of the Permanent Magnet Synchronous Machine block in motoring mode with a closed-loop control system built entirely with Simulink blocks. The complete system includes a six step inverter block from the SimPowerSystems library. Two control loops are 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. The parameters of the machine are found in the dialog box section.



Set the simulation parameters as follows:

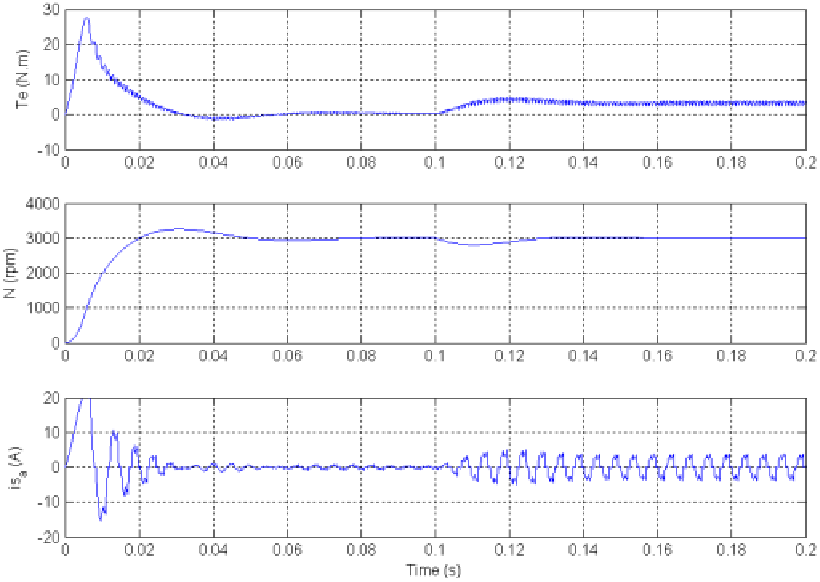
- Type: Fixed-step
- Integrator type: `Runge-Kutta`, `ode4`
- Sample time: 5e-6 (set automatically by the **Model properties**)
- Stop time: `0.2`

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 when the motor starts and stabilizes rapidly when the motor reaches the 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's 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.

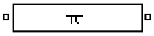
Purpose

Implement single-phase transmission line with lumped parameters

Library

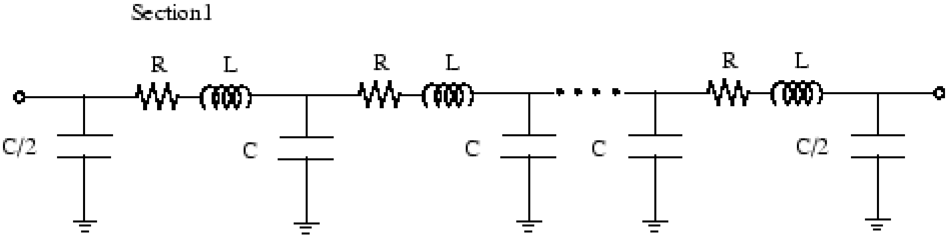
Elements

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.

A good 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 Parameters

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 parameters to be used 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 parameters given by the above equations must be corrected in order to get an exact line model at a specified frequency. The RLC line parameters 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:

Positive sequence

$$r = 0.01273\ \Omega/\text{km}$$

$$l = 0.9337 \times 10^{-3}\ \text{H/km}$$

$$c = 12.74 \times 10^{-9}\ \text{F/km}$$

Zero sequence

$$r = 0.3864\ \Omega/\text{km}$$

$$l = 4.1264 \times 10^{-3}\ \text{H/km}$$

$$c = 7.751 \times 10^{-9}\ \text{F/km}$$

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:

$$r = 4.153\ \Omega$$

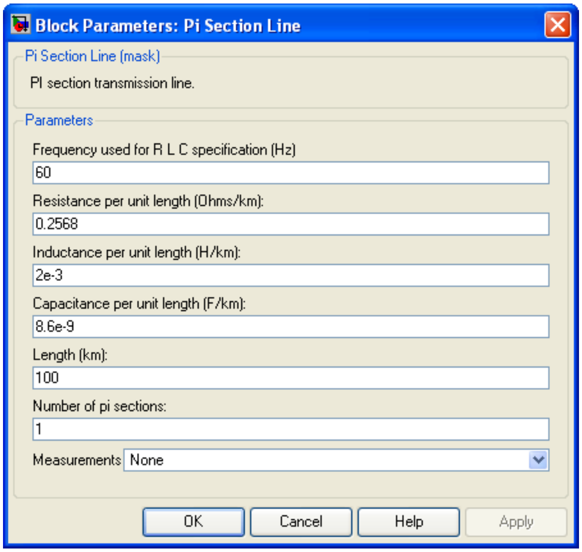
$$l = 0.3156\ \text{H}$$

$$c = 4.538 \times 10^{-6}\ \text{F}$$

For these particular parameters and long line section (350 km), corrections for positive-sequence RLC parameters 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



Block Parameters: Pi Section Line

Pi Section Line (mask)

PI section transmission line.

Parameters

Frequency used for R L C specification (Hz): 60

Resistance per unit length (Ohms/km): 0.2568

Inductance per unit length (H/km): 2e-3

Capacitance per unit length (F/km): 8.6e-9

Length (km): 100

Number of pi sections: 1

Measurements: None

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 to RLC parameters 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.

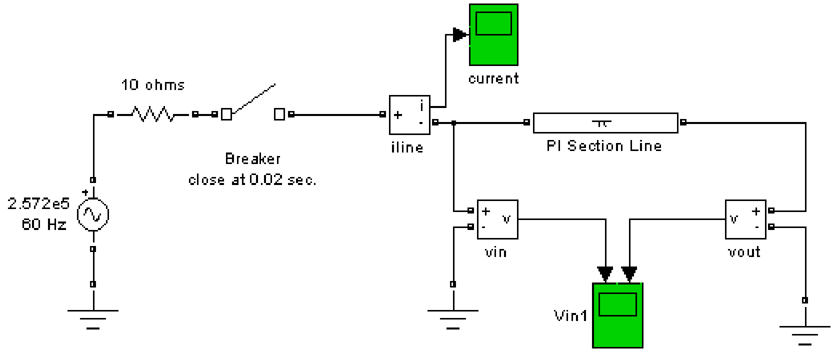
Select `All voltages and currents` to measure the sending end and receiving end voltages and currents of the line model.

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.

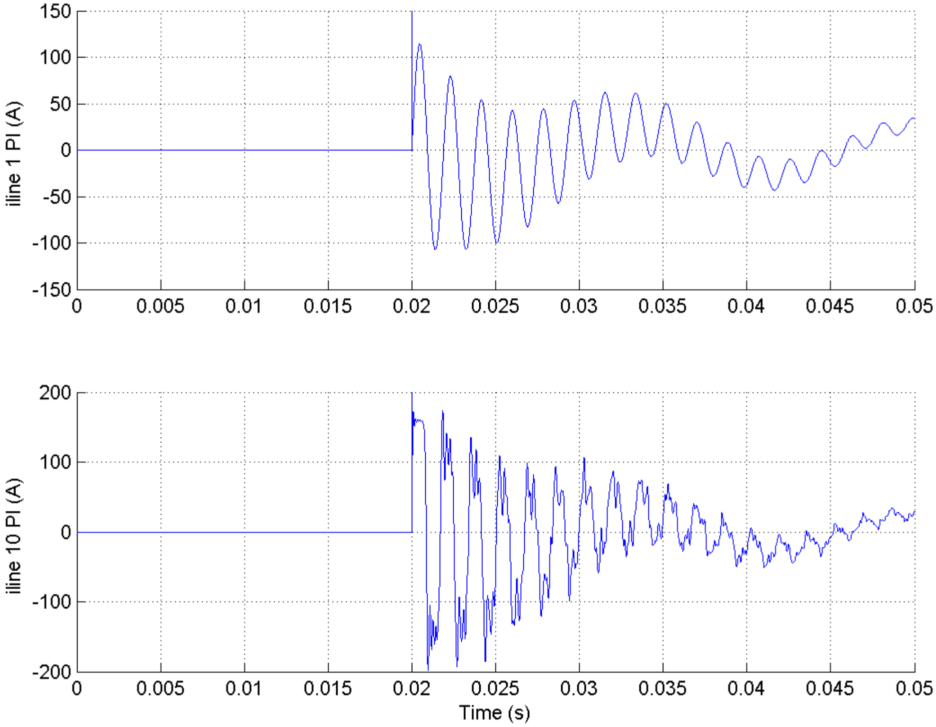
Measurement	Label
Sending end voltage (block input)	`Us:`
Receiving end voltage (block output)	`Ur:`
Sending end current (input current)	`Is:`
Receiving end current (output current)	`Ir:`

Example

The `power_piline` demo 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

PM Synchronous Motor Drive

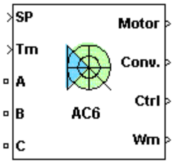
Purpose

Implement Permanent Magnet Synchronous Motor (PMSM) vector control drive

Library

Electric Drives/AC drives

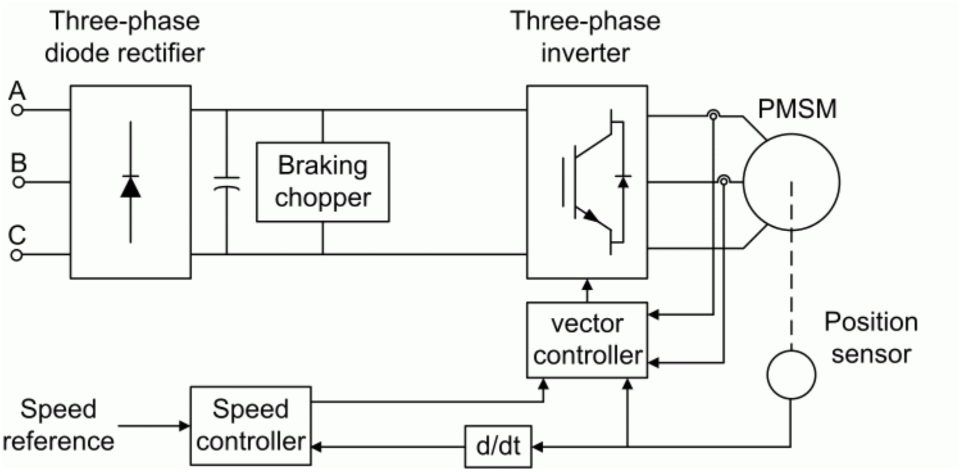
Description



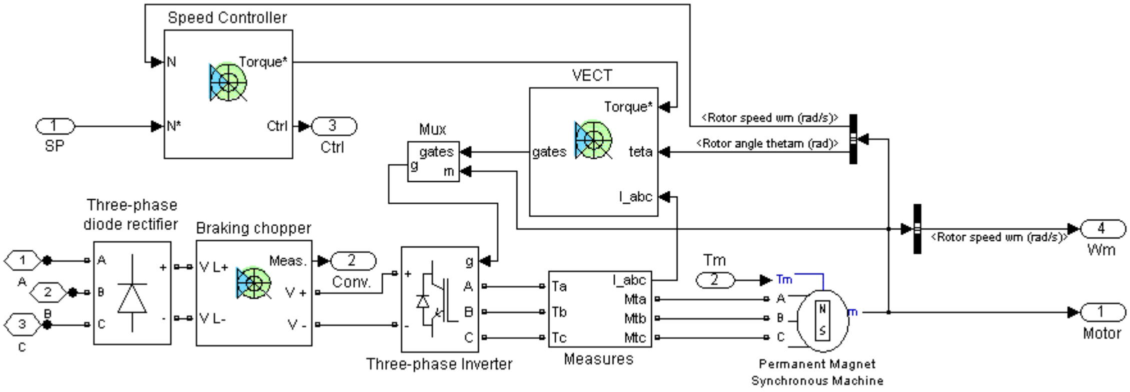
The high-level schematic shown below is built from six main blocks. The PMSM motor, the three-phase inverter, and the three-phase diode rectifier models are provided with the SimPowerSystems library. More details are available in the reference pages for these blocks. The speed controller, the braking 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

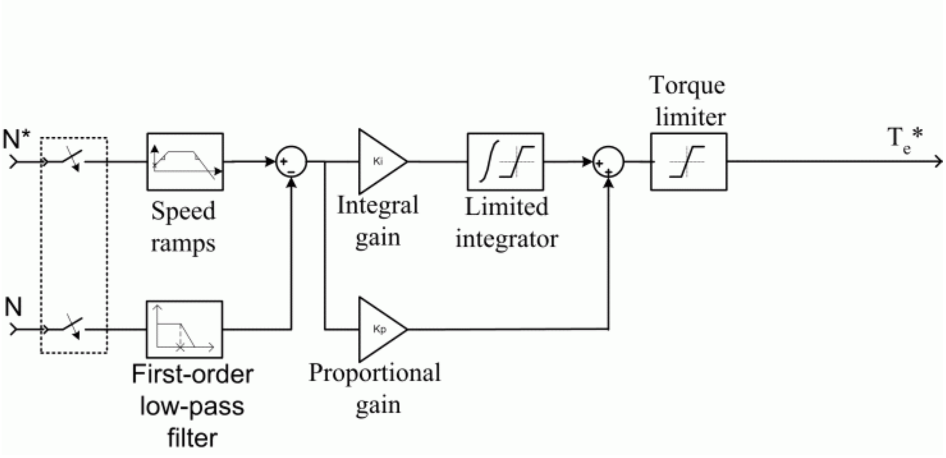


Simulink Schematic



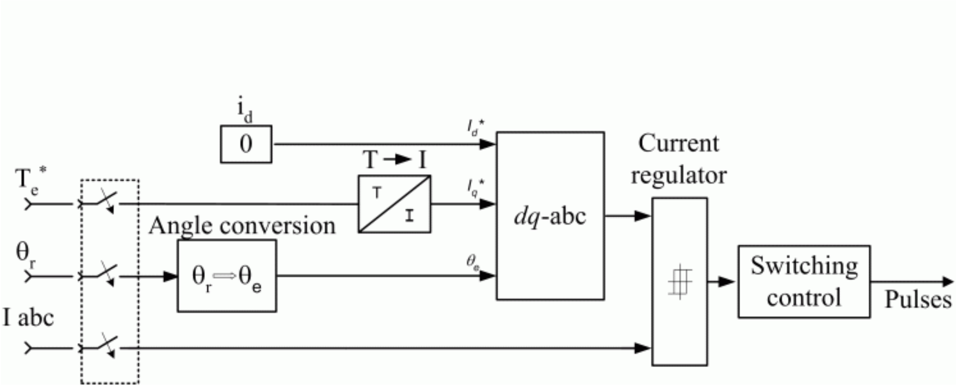
Speed Controller

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.

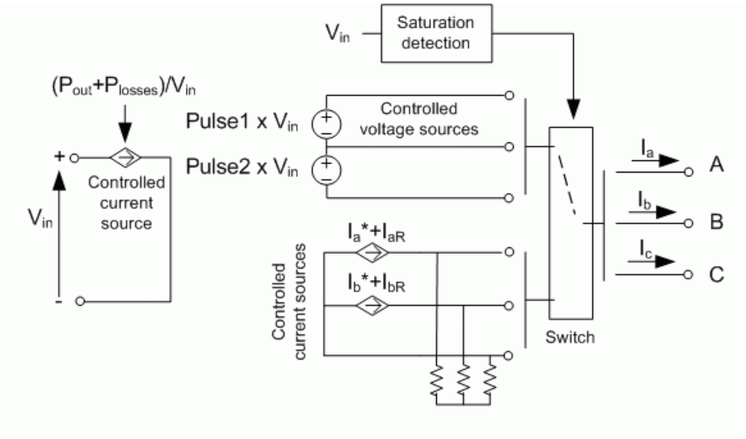
When using the average-value inverter, the *ab* current references are sent to the inverter, as well as switching pulses from a slightly modified *Switching control block.*

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:

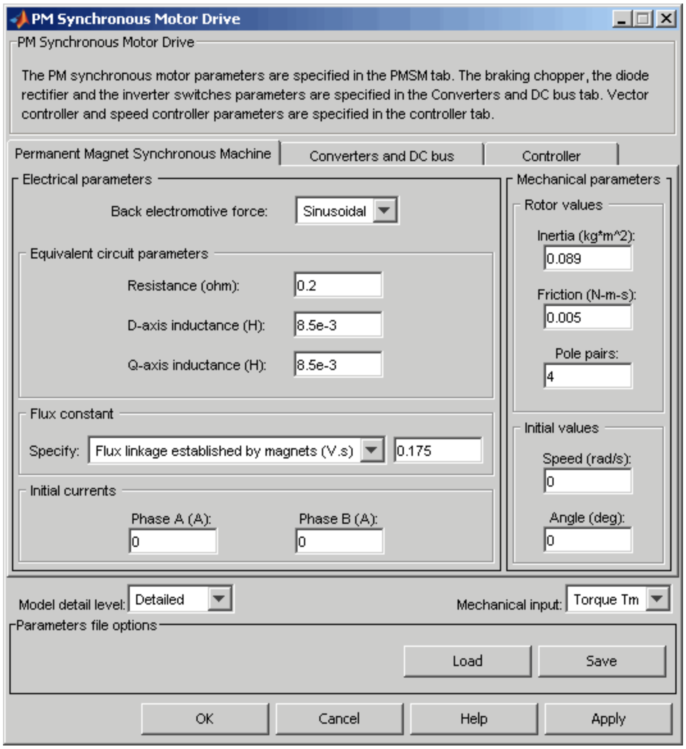
- Speed controller sampling time
- Vector controller sampling time

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

PM Synchronous Machine Tab



PM Synchronous Motor Drive

The PM synchronous motor parameters are specified in the PMSM tab. The braking chopper, the diode rectifier and the inverter switches parameters are specified in the Converters and DC bus tab. Vector controller and speed controller parameters are specified in the controller tab.

Back electromotive force: Sinusoidal

Resistance (ohm): 0.2

D-axis inductance (H): 8.5e-3

Q-axis inductance (H): 8.5e-3

Specify: Flux linkage established by magnets (V.s) 0.175

Phase A (A): 0

Phase B (A): 0

Inertia (kg*m^2): 0.089

Friction (N-m-s): 0.005

Pole pairs: 4

Speed (rad/s): 0

Angle (deg): 0

Model detail level: Detailed

Mechanical input: Torque Tm

The PM synchronous machine tab displays the parameters of the PM synchronous machine block of the powerlib library. Refer to Permanent Magnet Synchronous Machine for more information on the PM synchronous machine parameters.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Allows you to select either the load torque or the motor speed as mechanical input. Note that if you select and apply a load torque, you will obtain as output the motor speed according to

the following differential equation that describes the mechanical system dynamics:

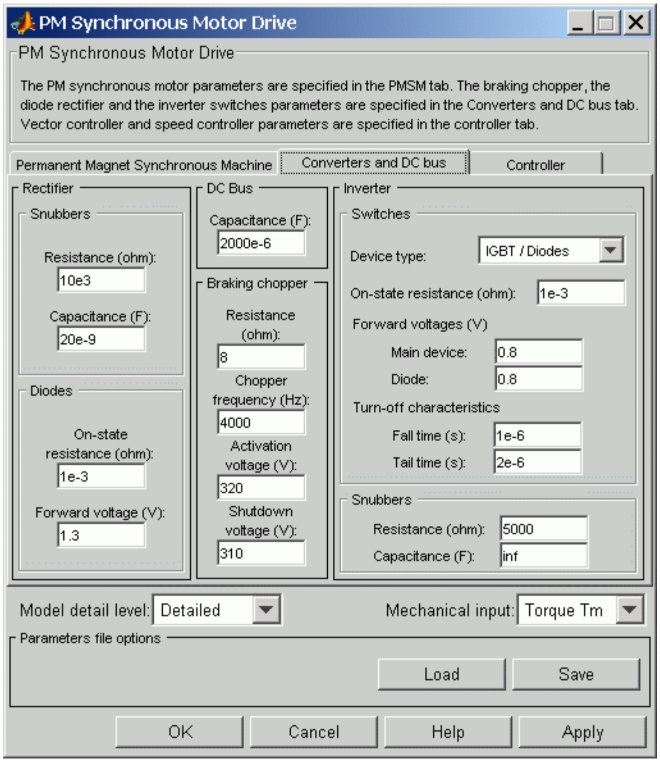
$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

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

See for example “Mechanical Coupling of Two Motor Drives”.

Converters and DC Bus Tab



PM Synchronous Motor Drive

The PM synchronous motor parameters are specified in the PMSM tab. The braking chopper, the diode rectifier and the inverter switches parameters are specified in the Converters and DC bus tab. Vector controller and speed controller parameters are specified in the controller tab.

Rectifier

Snubbers

Resistance (ohm): 10e3

Capacitance (F): 20e-9

Diodes

On-state resistance (ohm): 1e-3

Forward voltage (V): 1.3

DC Bus

Capacitance (F): 2000e-6

Braking chopper

Resistance (ohm): 8

Chopper frequency (Hz): 4000

Activation voltage (V): 320

Shutdown voltage (V): 310

Inverter

Switches

Device type: IGBT / Diodes

On-state resistance (ohm): 1e-3

Forward voltages (V)

Main device: 0.8

Diode: 0.8

Turn-off characteristics

Fall time (s): 1e-6

Tail time (s): 2e-6

Snubbers

Resistance (ohm): 5000

Capacitance (F): inf

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

Rectifier section

The rectifier section of the Converters and DC bus tab displays the parameters of the Universal Bridge block of the 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 Brige block of the 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

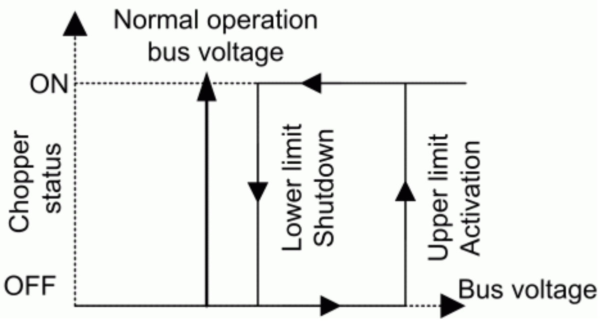
The braking chopper frequency (Hz).

Activation Voltage

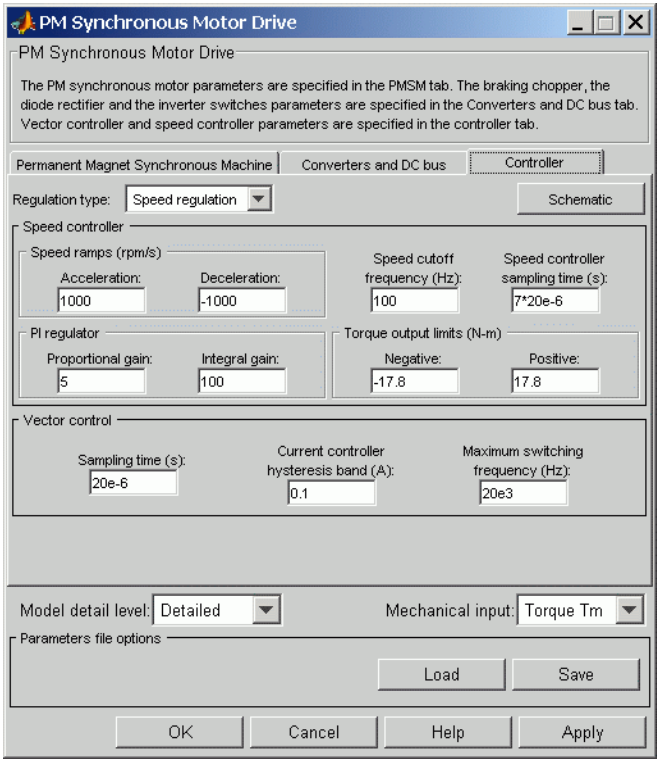
The dynamic braking is activated when the bus voltage reaches the upper limit of the hysteresis band. The following figure illustrates the braking chopper hysteresis logic.

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



PM Synchronous Motor Drive

The PM synchronous motor parameters are specified in the PMSM tab. The braking chopper, the diode rectifier and the inverter switches parameters are specified in the Converters and DC bus tab. Vector controller and speed controller parameters are specified in the controller tab.

Regulation type: Speed regulation

Speed controller

Speed ramps (rpm/s)

Acceleration: 1000

Deceleration: -1000

Speed cutoff frequency (Hz): 100

Speed controller sampling time (s): 7*20e-6

PI regulator

Proportional gain: 5

Integral gain: 100

Torque output limits (N-m)

Negative: -17.8

Positive: 17.8

Vector control

Sampling time (s): 20e-6

Current controller hysteresis band (A): 0.1

Maximum switching frequency (Hz): 20e3

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

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).

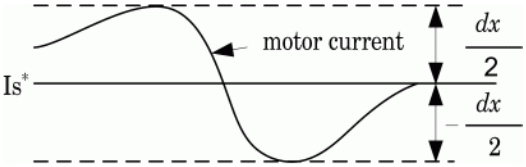
Torque output limits — Positive
The maximum positive demanded torque applied to the motor by the current controller (N.m).

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. Note that 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).

`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

Model Specifications

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

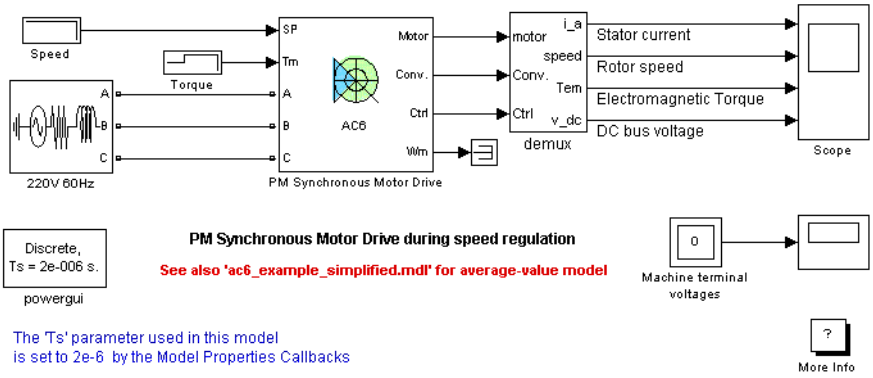
3 HP Drive Specifications

Drive Input Voltage		
	Amplitude	220 V
	Frequency	60 Hz
Motor Nominal Values		
	Power	3 hp
	Speed	1800
	Voltage	300

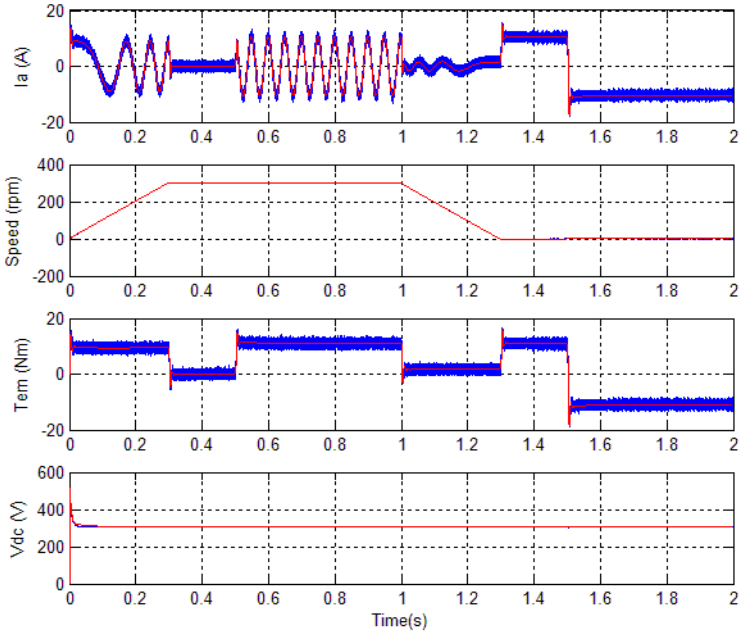
.

Example

The `ac6_example` demo 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.

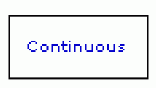
Purpose

Environment block for SimPowerSystems models

Library

powerlib

Description



The Powergui block allows you to choose one of the following methods to solve your circuit:

- Continuous method, which uses a variable step Simulink solver
- Ideal Switching continuous method
- Discretization of the electrical system for a solution at fixed time steps
- Phasor solution method

The Powergui block is necessary for simulation of any Simulink model containing SimPowerSystems blocks. It is used to store the equivalent Simulink circuit that represents the state-space equations of the model.

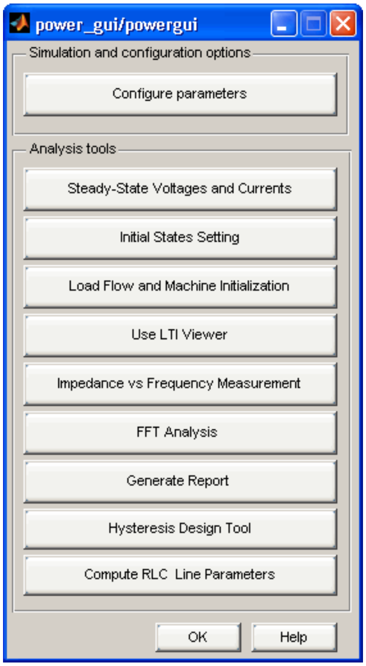
You must follow these rules when using this block in a model:

- Place the Powergui block at the top level of diagram for optimal performance. However, you can place it anywhere inside subsystems for your convenience; its functionality will not be affected.
- You can have a maximum of one Powergui block per model
- You must name the block `powergui`

Graphical User Interface Tools

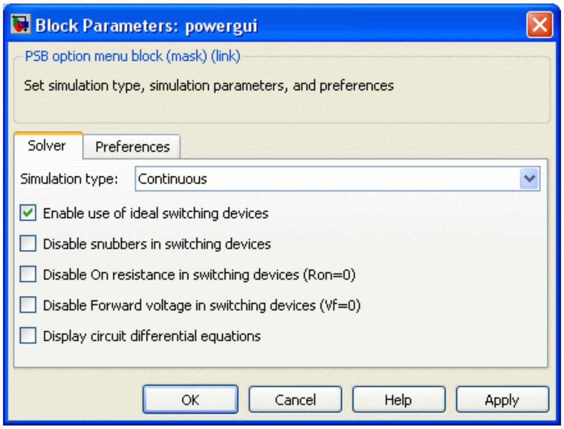
The Powergui block also gives you access to various graphical user interface (GUI) tools and functions for the steady-state analysis of SimPowerSystems models, the analysis of simulation results, and for the design of advanced block parameters.

Dialog Box and Parameters



Simulation and Configuration Options

To specify the simulation type, parameters, and preferences, select **Configure parameters** in the Powergui dialog. This opens another dialog box with the Powergui block parameters. This dialog box contains two tabs, **Solver** and **Preferences**. The configuration of the **Solver** tab depends on the option selected from the **Simulation type** drop-down list.



Block Parameters: powergui

PSB option menu block (mask) (link)

Set simulation type, simulation parameters, and preferences

Solver | Preferences

Simulation type: Continuous

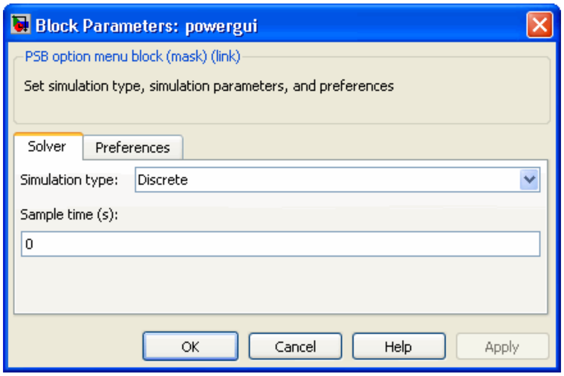
☑ Enable use of ideal switching devices

☐ Disable snubbers in switching devices

☐ Disable On resistance in switching devices (Ron=0)

☐ Disable Forward voltage in switching devices (Vf=0)

☐ Display circuit differential equations



Block Parameters: powergui

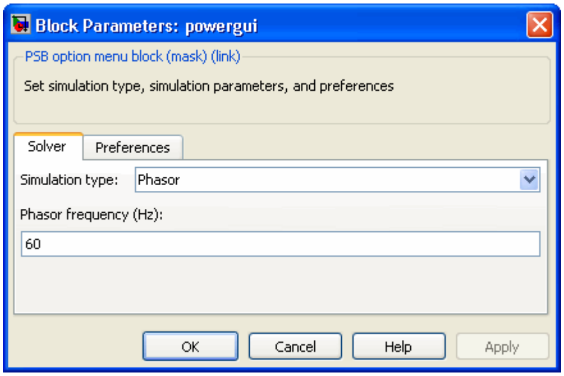
PSB option menu block (mask) (link)

Set simulation type, simulation parameters, and preferences

Solver | Preferences

Simulation type: Discrete

Sample time (s): 0

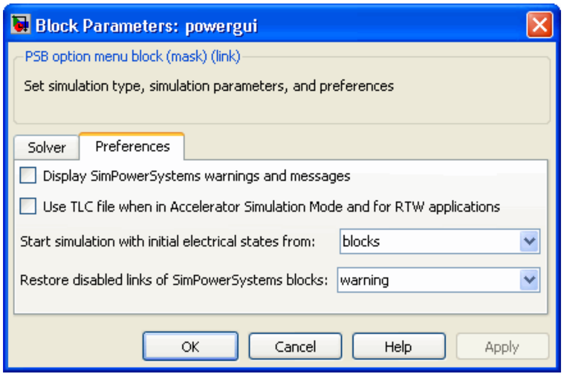

Block Parameters: powergui

PSB option menu block (mask) (link)

Set simulation type, simulation parameters, and preferences

Simulation type: Phasor

Phasor frequency (Hz): 60


Block Parameters: powergui

PSB option menu block (mask) (link)

Set simulation type, simulation parameters, and preferences

☐ Display SimPowerSystems warnings and messages

☐ Use TLC file when in Accelerator Simulation Mode and for RTW applications

Start simulation with initial electrical states from: blocks

Restore disabled links of SimPowerSystems blocks: warning

Simulation type

Select `Continuous` to perform a continuous solution of the model.

Select `Discrete` to perform a discretization of the model. The sample time is specified by the **Sample time** parameter.

Select `Phasor` to perform phasor simulation of the model, at the frequency specified by the **Phasor frequency** parameter.

Enable use of ideal switching devices

If selected, the switches and power electronic blocks are modeled by an alternative method allowing ideal or quazi-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`.

Disable snubbers in switching devices
If selected, the snubber devices of the power electronic and breaker blocks in your model are disabled and not modeled. This parameter is visible only if **Enable use of ideal switching devices** is selected.

Disable On resistance in switching devices (Ron=0)
If selected, the internal resistance Ron of switches and power electronic devices is disabled and forced to zero ohms. This parameter is visible only if **Enable use of ideal switching devices** is selected.

Disable Forward voltage in switching devices (Vf=0)
If selected, the internal forward voltage Vf of power electronic devices is disabled and forced to zero volts. This parameter is visible only if **Enable use of ideal switching devices** is selected.

Display circuit differential equations
If selected, differential equations of the model are displayed in the command window when the simulation starts. This parameter is visible only if **Enable use of ideal switching devices** is selected. For more information, see “Using the Ideal Switching Device Method”.

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`.

The **Sample time** parameter must be set to a value greater than 0. The icon displays the value of the sample time.

Phasor frequency (Hz)

Specify the frequency used by the software to perform the phasor simulation of the model. This parameter is visible only when the **Simulation type** parameter is set to `Phasor`.

Display SimPowerSystems warnings and messages

If selected, the command line echo messages are enabled during the analysis and simulation of the model.

Use TLC file when in Accelerator Simulation Mode and for RTW applications

If selected, TLS state-space S-function (`sfun_spssw_discc.tlc`) will be used 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 is observed if you have the LCC compiler installed as the default compiler for building external interface (`mex`).

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.

Restore disabled links of SimPowerSystems blocks

If `yes` is selected, the Powergui block detects SimPowerSystems blocks that have a disabled link at the simulation start and restores the link automatically.

If `warning` is selected, the Powergui block detects SimPowerSystems blocks that have a disabled link at the simulation start and displays a warning.

If `no` is selected, SimPowerSystems blocks with disabled links will not be detected and relinked.

Analysis Tools

Steady-State Voltages and Currents

Open the Steady-State Voltages and Currents Tool dialog box that displays the steady-state voltages and currents of the model. For more information, see the `power_steadystate` reference page.

Initial States Setting

Open the Initial States Setting Tool dialog box that allows you to display and modify initial capacitor voltages and inductor currents of the model. For more information, see the `power_initstates` reference page.

Load Flow and Machine Initialization

Open the Machine Load Flow Tool dialog box to perform load flow and initialize three-phase networks containing three-phase machines, so that the simulation starts in steady state. For more information, see the `power_loadflow` reference page.

Use LTI Viewer

Open a window to generate the state-space model of your system (if you have Control System Toolbox software installed) and automatically open the LTI Viewer interface for time and frequency domain responses. For more information, see the `power_ltiview` reference page.

Impedance vs Frequency 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 the `power_zmeter` reference page.

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 the `power_fftscope` reference page.

An example of using the FFT Analysis tool is described in “Performing Harmonic Analysis Using the FFT Tool”.

Generate Report

Open 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. For more information, see the `power_report` reference page.

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 the `power_hysteresis` reference page.

Compute RLC Line Parameters

Open a window to compute RLC parameters of overhead transmission line from its conductor characteristics and tower geometry. For more information, see the `power_lineparam` reference page.

See Also

`power_fftscope`, `power_hysteresis`, `power_initstates`, `power_lineparam`, `power_loadflow`, `power_ltiview`, `power_report`, `power_steadystate`, `power_zmeter`

PWM Generator

Purpose

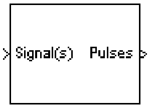
Generate pulses for carrier-based two-level pulse width modulator (PWM) in converter bridge

Library

Extras/Control Blocks

A discrete version of this block is available in the Extras/Discrete Control Blocks library.

Description



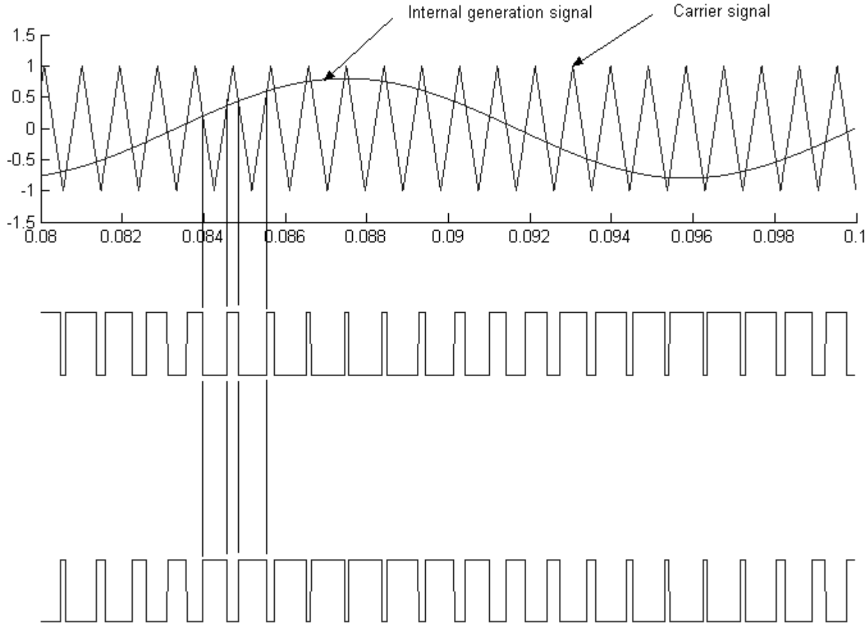
The PWM Generator block generates pulses for carrier-based pulse width modulation (PWM) converters using two-level topology. The block can be used to fire the forced-commutated devices (FETs, GTOs, or IGBTs) of single-phase, two-phase, three-phase, two-level bridges or a combination of two three-phase 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.

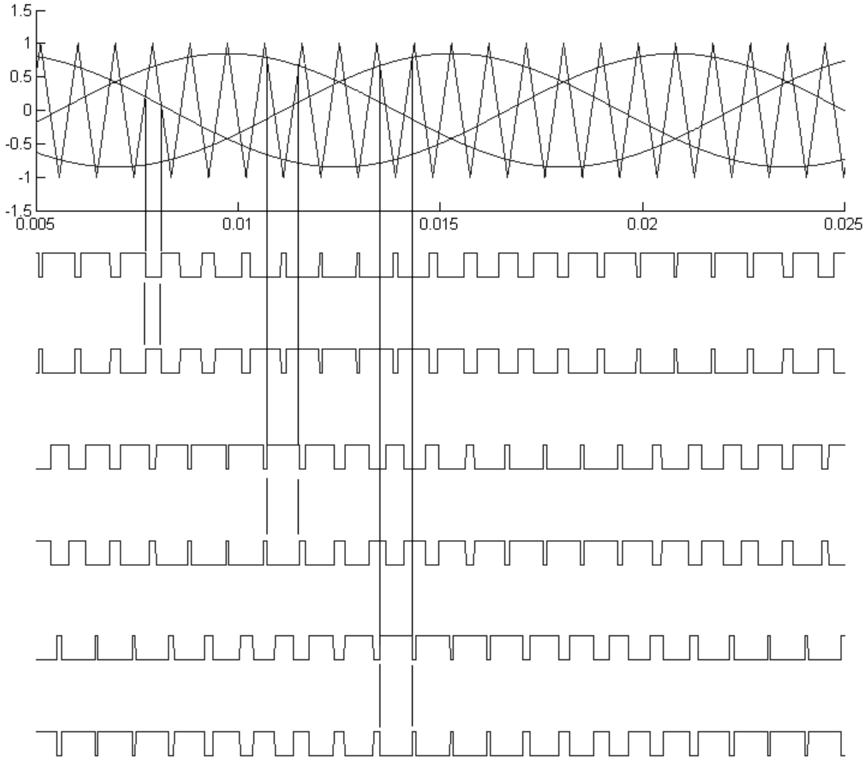
The following figure displays the two pulses generated by the PWM Generator block when it is programmed to control a one-arm bridge.



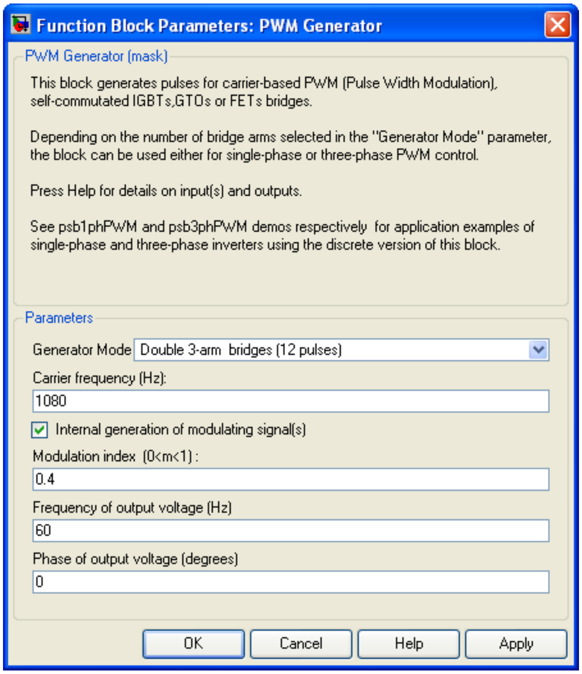
The triangular carrier signal is compared with the sinusoidal modulating signal. When the modulating signal is greater than the carrier pulse 1 is high (1) and pulse 2 is low (0).

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.


1.5
1
0.5
0
-0.5
-1
-1.5
0.005
0.01
0.015
0.02
0.025

Dialog Box and Parameters



Function Block Parameters: PWM Generator

PWM Generator (mask)

This block generates pulses for carrier-based PWM (Pulse Width Modulation), self-commutated IGBTs,GTOs or FETs bridges.

Depending on the number of bridge arms selected in the "Generator Mode" parameter, the block can be used either for single-phase or three-phase PWM control.

Press Help for details on input(s) and outputs.

See psb1phPWM and psb3phPWM demos respectively for application examples of single-phase and three-phase inverters using the discrete version of this block.

Parameters

Generator Mode: Double 3-arm bridges (12 pulses)

Carrier frequency (Hz): 1080

☑ Internal generation of modulating signal(s)

Modulation index (0<m<1) : 0.4

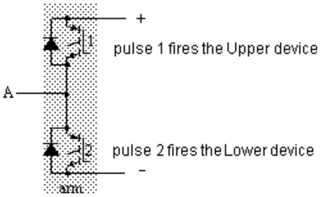
Frequency of output voltage (Hz): 60

Phase of output voltage (degrees): 0

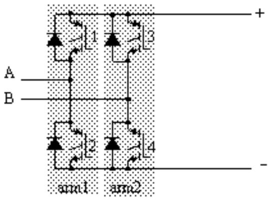
Generator Mode

Specify the number of pulses to generate. The number of pulses is proportional to the number of bridge arms to fire.

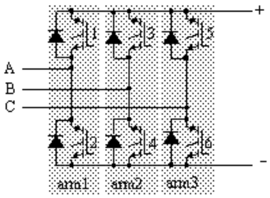
Select `1-arm bridge (2 pulses)` to fire the self-commutated devices of a one-arm bridge. Pulse 1 fires the upper device and pulse 2 fires the lower device.



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

If selected, the modulating signal is generated by the block. Otherwise, external modulating signals are used for pulse generation.

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.

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.

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.

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.

Example

See the `power_1phPWM` and `power_3phPWM` demos for examples of single-phase and three-phase two-level inverters.

See Also

Universal Bridge

Purpose

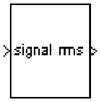
Measure root mean square (RMS) value of signal

Library

Extras/Measurements

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

Description



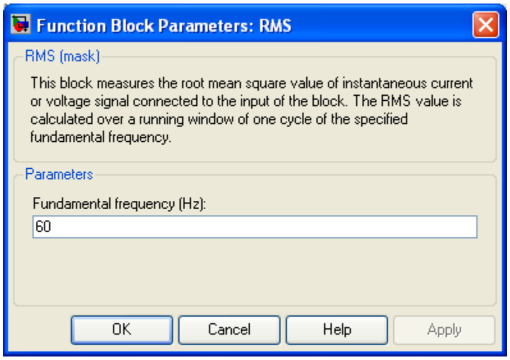
This block measures the root mean square value of an instantaneous current or voltage signal connected to the input of the block. The RMS value of the input signal is calculated over a running average window of one cycle of the specified fundamental frequency.

$$RMS(f(t)) = \sqrt{\frac{1}{T}\int_{(t-T)}^{t} f(t)^2}$$

$f(t)$: input signal, $T = 1/\text{fundamental frequency}$

as this block uses a running average window, one cycle of simulation has to be completed before the output gives the correct value. The discrete version of this block allows you to specify the initial magnitude of inputs. For the first cycle of simulation the output is held to the RMS value of the specified initial input.

Dialog Box and Parameters



RMS (mask)

This block measures the root mean square value of instantaneous current or voltage signal connected to the input of the block. The RMS value is calculated over a running window of one cycle of the specified fundamental frequency.

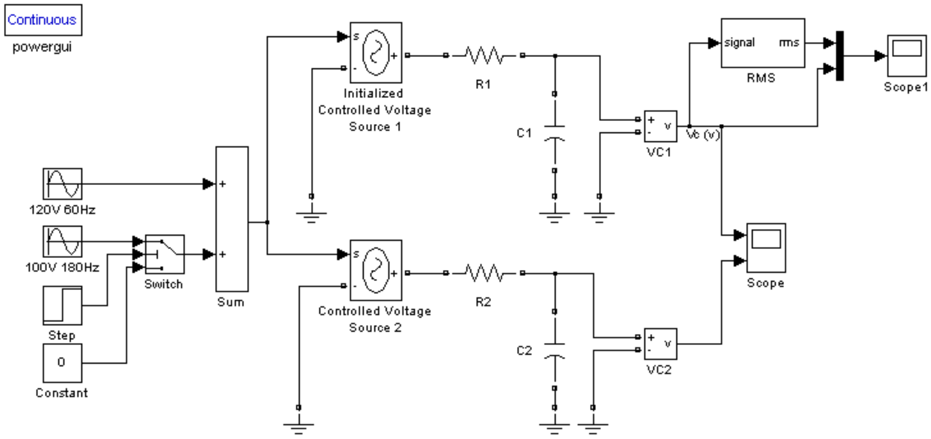
Parameters

Fundamental frequency (Hz): 60

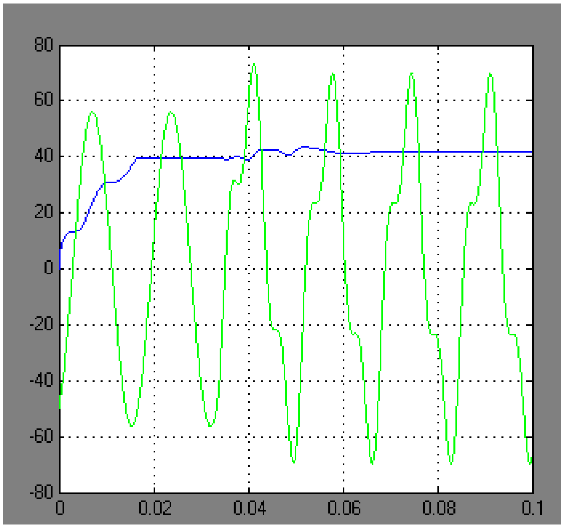
Fundamental frequency
The fundamental frequency, in hertz, of the input signal.

Example

In the `power_controlvolt` demo, you can add an RMS block as shown below to measure the RMS value of the capacitor voltage. The Controlled Voltage Source block introduces a third harmonic (180 Hz) in the voltage at t = 0.4 seconds.



At the beginning of the simulation, the RMS block needs one cycle of the fundamental frequency (60Hz) to calculate the RMS value of the voltage. At t = 0.4 seconds the RMS value slightly increases because of the addition of the third harmonic in the signal. Again, the RMS block needs one cycle of the fundamental signal to stabilize and give the correct result.

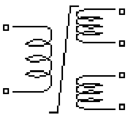

80
60
40
20
0
-20
-40
-60
-80
0
0.02
0.04
0.06
0.08
0.1

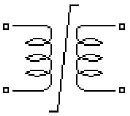
Saturable Transformer

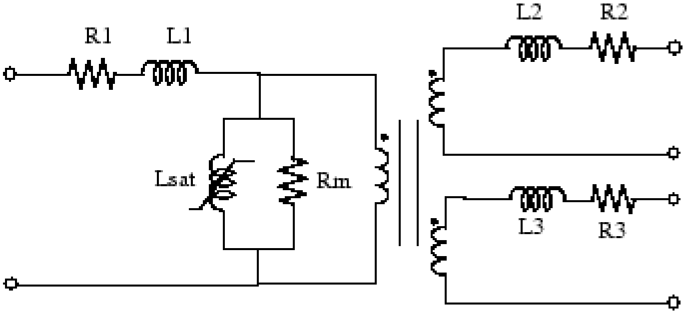
Purpose Implement two- or three-winding saturable transformer

Library 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

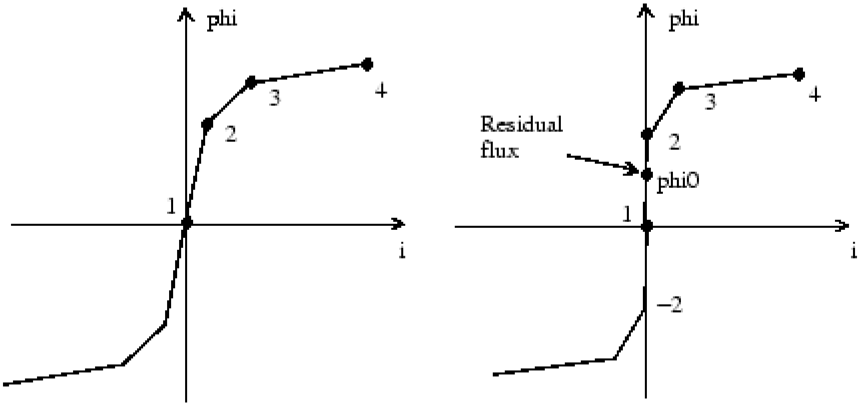
1. Model saturation without hysteresis. The total iron losses (eddy current + hysteresis) are modeled by a linear resistance, Rm.

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 Φpu and the vector of currents Ipu into standard units to be used in the saturation model of the Saturable Transformer block:

$$\Phi = \Phi_{pu}\Phi_{base}$$
$$I = I_{pu}I_{base}$$

where the base flux linkage (Φbase) and base current (Ibase) are the peak values obtained at nominal voltage power and frequency:

$$I_{base} = \frac{Pn}{V_1}\sqrt{2} \qquad \Phi_{base} = \frac{V_1}{2\pi f_n}\sqrt{2} \text{ (Flux linkage in volts-seconds)}$$

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:

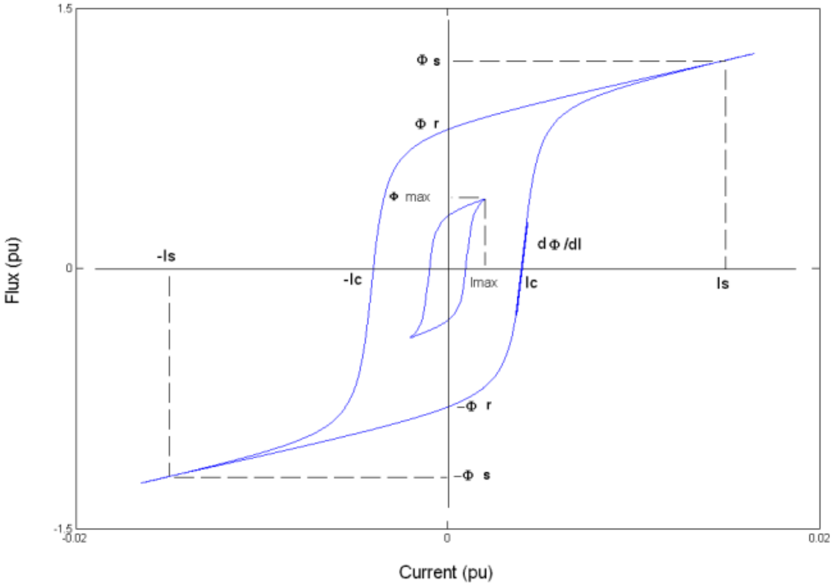
$$\Phi_{base} = \text{Base flux} \times \text{number of turns of winding 1}$$

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 Φ(I) and its inverse I(Φ) 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 (dΦ/dI) at (0, Ic) point as shown in the next figure.



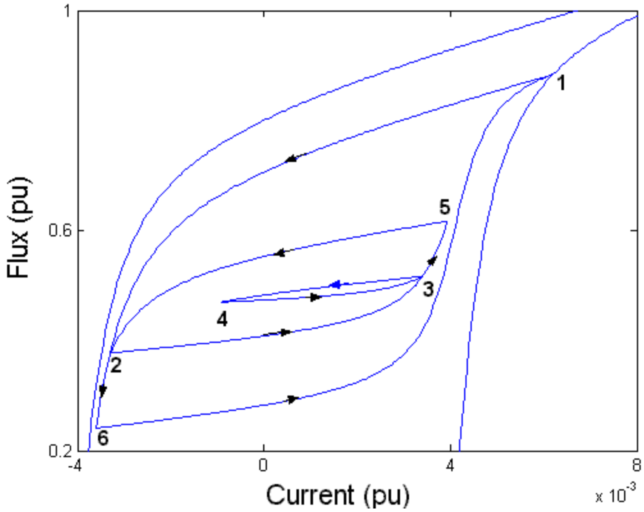
The major loop half cycle is defined by a series of N equidistant points connected by line segments. The value of N is defined in the **Hysteresis design tool** of the Powergui block. Using N = 256 yields a smooth curve and usually gives satisfactory results.

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

$$R(\text{p.u.}) = \frac{R(\Omega)}{R_{base}}$$

$$L(\text{p.u.}) = \frac{L(H)}{L_{base}}$$

The base resistance and base inductance used for each winding are

$$R_{base} = \frac{(Vn)^2}{Pn}$$

$$L_{base} = \frac{R_{base}}{2\pi fn}$$

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:

$$R_{base} = \frac{(735e3/\sqrt{3})^2}{250e6} = 720.3\Omega \qquad L_{base} = \frac{720.3}{2\pi 60} = 1.91H$$

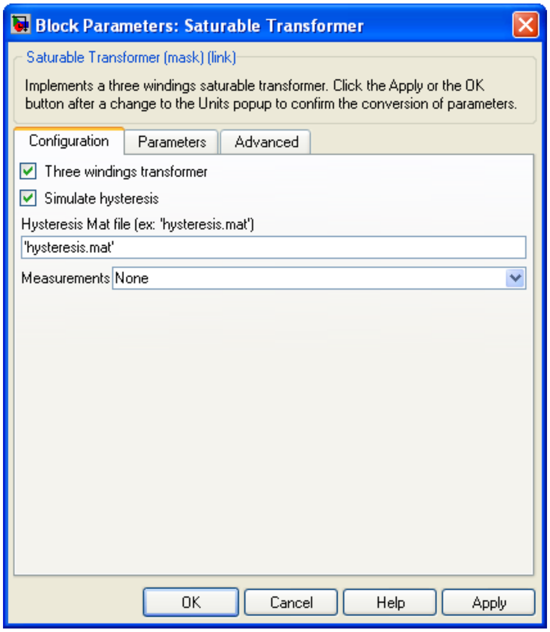
For example, if winding 1 parameters are R1 = 1.44 Ω and L1 = 0.1528 H, the corresponding values to enter in the dialog box are

$$R_1 = \frac{1.44\Omega}{720.3\Omega} = 0.002\ \text{p.u.}$$

$$L_1 = \frac{0.1528H}{1.91H} = 0.08\ \text{p.u.}$$

Dialog Box and Parameters

Configuration Tab



Implements a three windings saturable transformer. Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

☑ Three windings transformer

☑ Simulate hysteresis

Hysteresis Mat file (ex: 'hysteresis.mat')

'hysteresis.mat'

Measurements None

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.

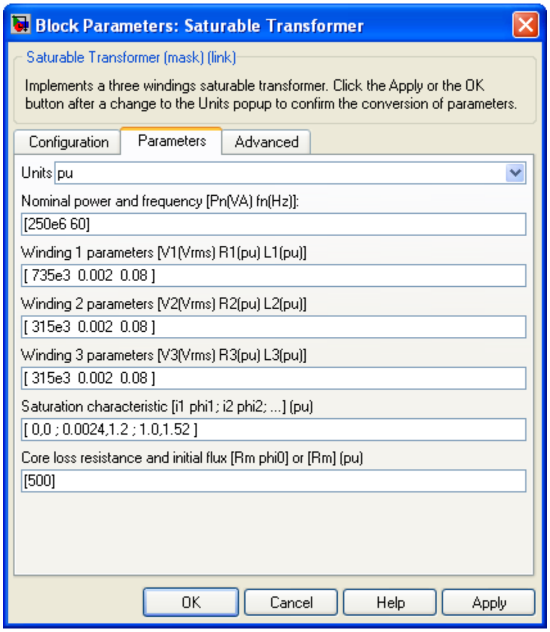
Place a Multimeter block in your model to display the selected measurements during the simulation.

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:`

Measurement	Label
Magnetization current	`Imag:`
Flux linkage	`Flux:`

Parameters Tab



Saturable Transformer (mask) (link)

Implements a three windings saturable transformer. Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

Units pu

Nominal power and frequency [Pn(VA) fn(Hz)]: [250e6 60]

Winding 1 parameters [V1(Vrms) R1(pu) L1(pu)]: [735e3 0.002 0.08]

Winding 2 parameters [V2(Vrms) R2(pu) L2(pu)]: [315e3 0.002 0.08]

Winding 3 parameters [V3(Vrms) R3(pu) L3(pu)]: [315e3 0.002 0.08]

Saturation characteristic [i1 phi1 ; i2 phi2; ...] (pu): [0,0 ; 0.0024,1.2 ; 1.0,1.52]

Core loss resistance and initial flux [Rm phi0] or [Rm] (pu): [500]

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.

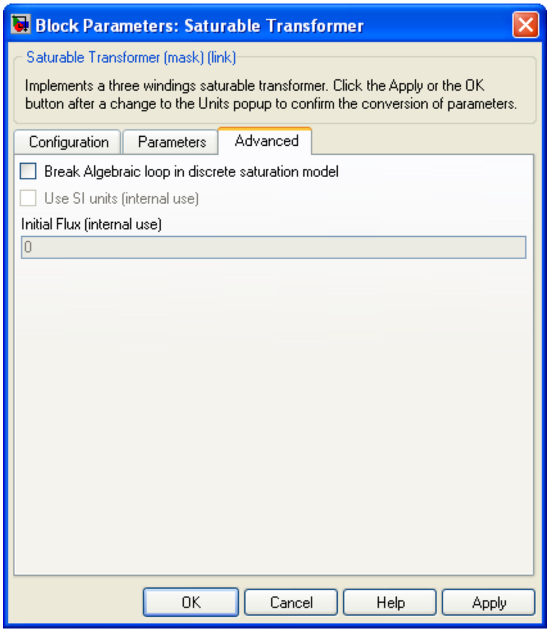
Saturation characteristic

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



Saturable Transformer (mask) (link)

Implements a three windings saturable transformer. Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

☐ Break Algebraic loop in discrete saturation model

☐ Use SI units (internal use)

Initial Flux (internal use): 0

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.

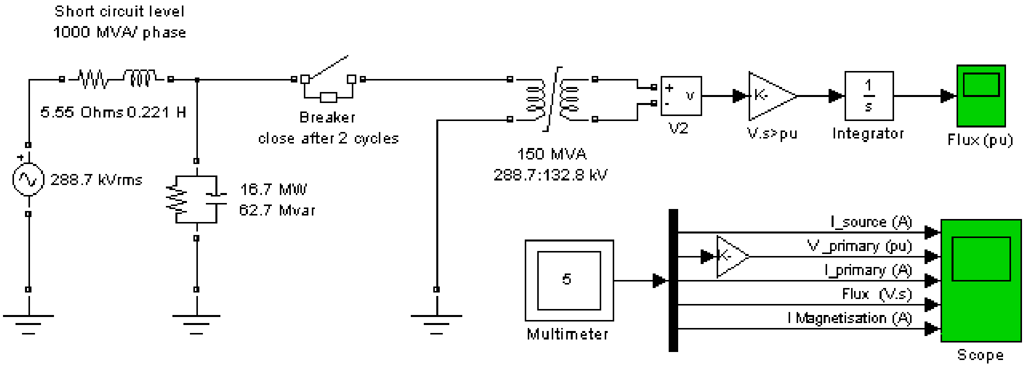
Limitations

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` demo 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	

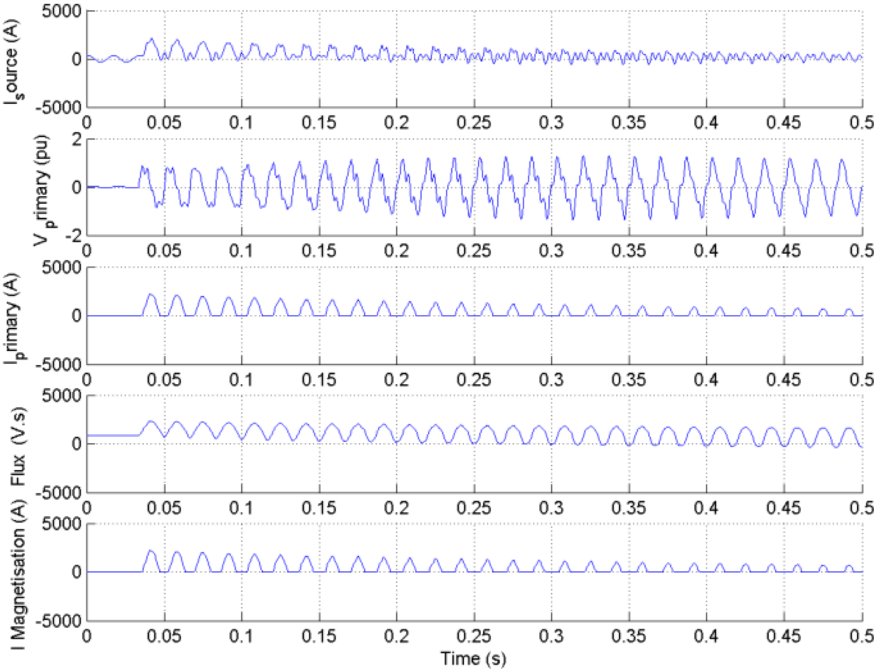


Simulation of this circuit illustrates the saturation effect on the transformer current and voltage.

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)

Self-Controlled Synchronous Motor Drive

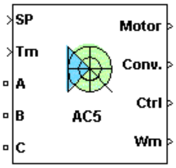
Purpose

Implement Self-Controlled Synchronous Motor Drive

Library

Electric Drives/AC drives

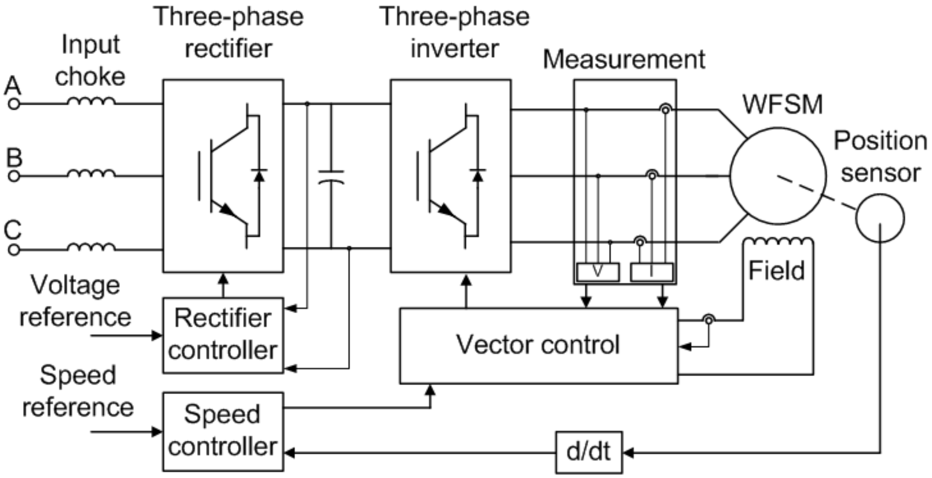
Description



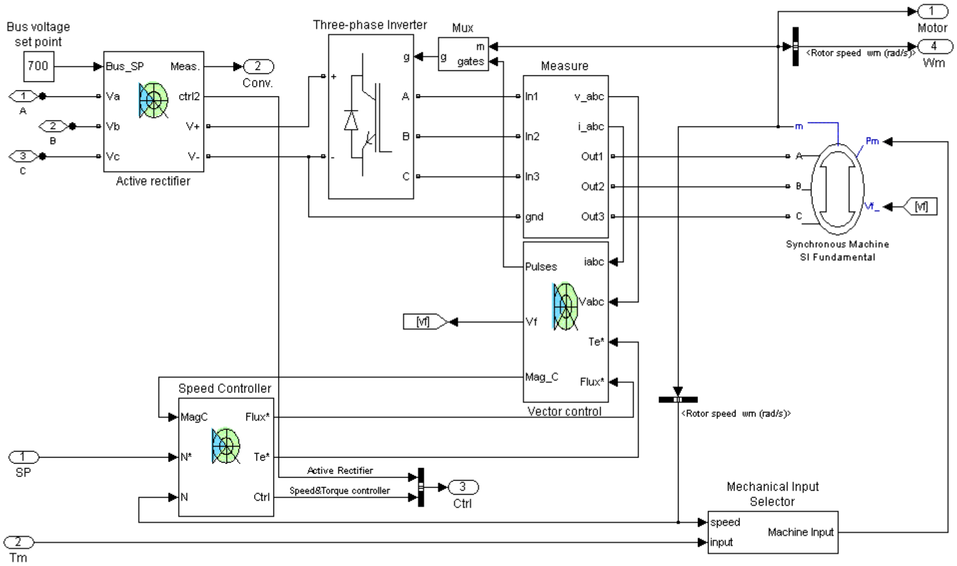
This block models a wound field synchronous motor (WFSM) vector control drive model. The high-level schematic shown below is built from six main blocks. The WFSM motor, the three-phase inverter, and the three-phase rectifier models are provided with the SimPowerSystems library. More details are available 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

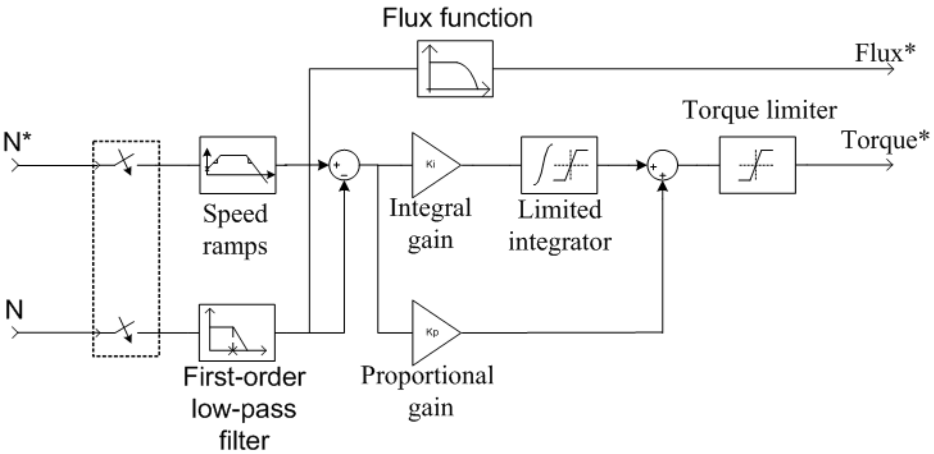


Simulink Schematic



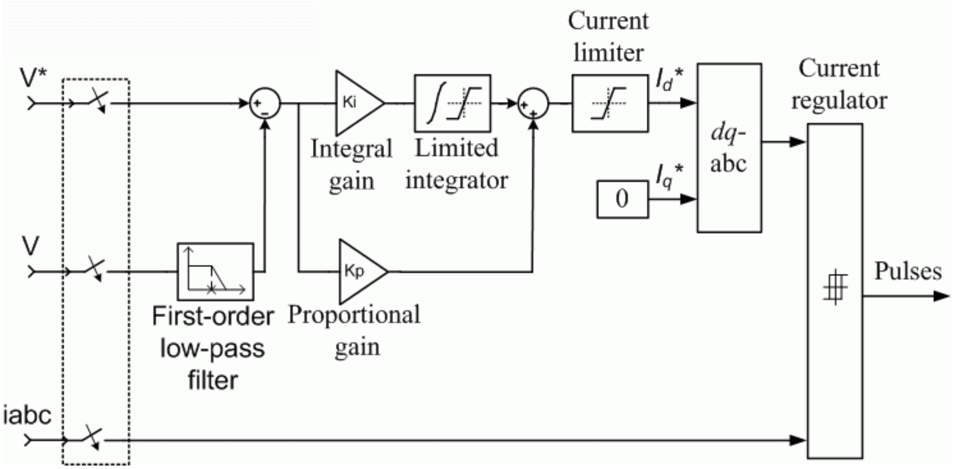
Speed Controller

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.

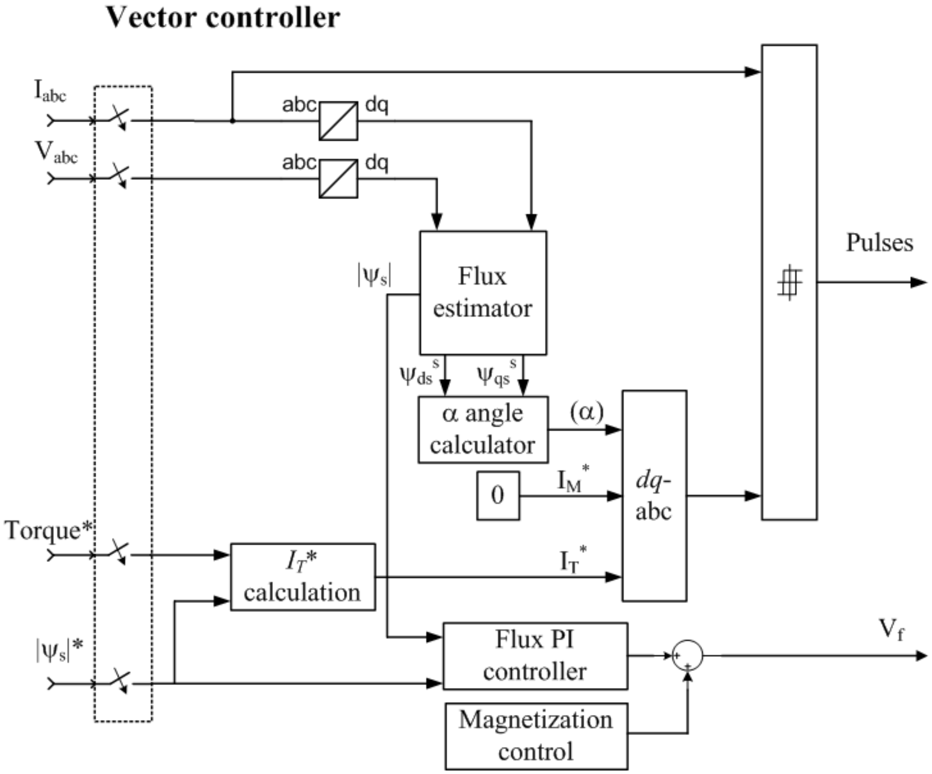


The *dq-abc* block performs the conversion of the *dq* current components into *abc* phase variables.

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.



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.

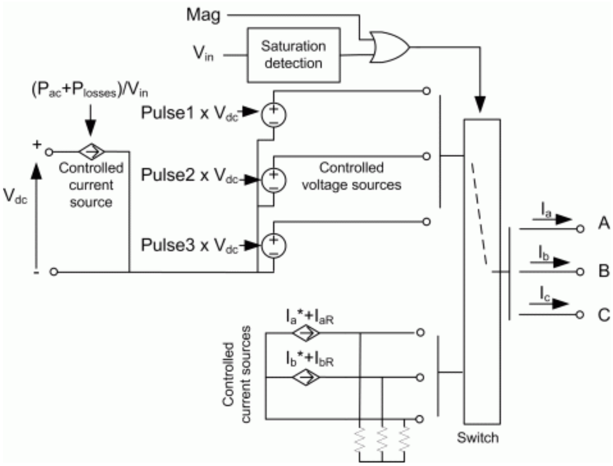
The *dq2abc* block performs the conversion of the *dq* current components into *abc* phase variables.

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:

$$I_{dc} = \frac{P_{ac}+P_{losses}}{V_{dc}}$$

with P_{ac} being the AC side instantaneous power, P_{losses} the losses in the power electronics devices and V_{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 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:

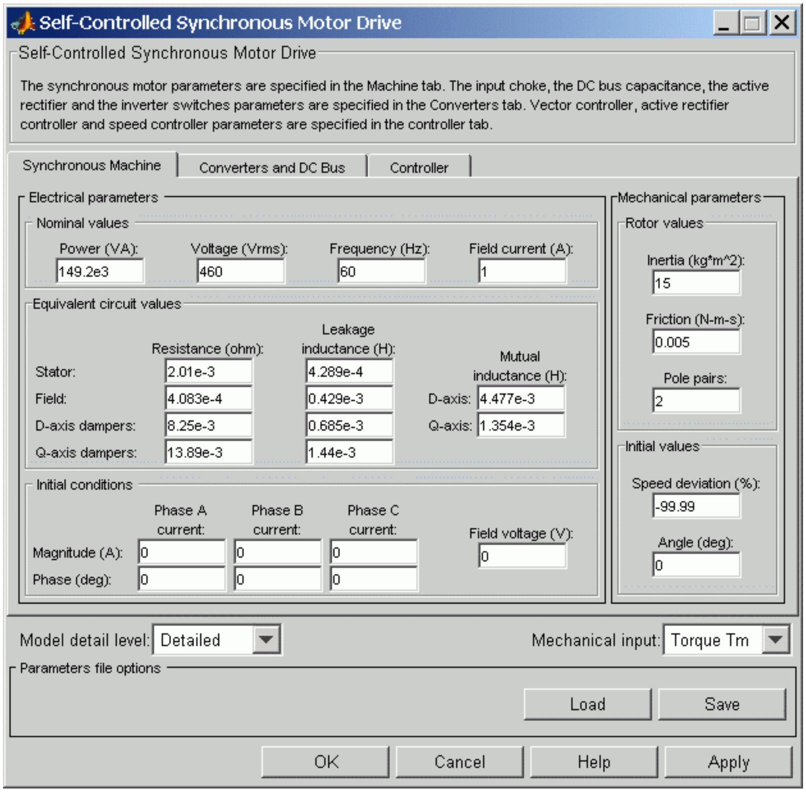
- Speed controller sampling time
- Active rectifier controller and vector controller sampling time

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



Self-Controlled Synchronous Motor Drive

Self-Controlled Synchronous Motor Drive

The synchronous motor parameters are specified in the Machine tab. The input choke, the DC bus capacitance, the active rectifier and the inverter switches parameters are specified in the Converters tab. Vector controller, active rectifier controller and speed controller parameters are specified in the controller tab.

Electrical parameters

Nominal values

Power (VA): 149.2e3
Voltage (Vrms): 460
Frequency (Hz): 60
Field current (A): 1

Equivalent circuit values

	Resistance (ohm):	Leakage inductance (H):
Stator:	2.01e-3	4.289e-4
Field:	4.083e-4	0.429e-3
D-axis dampers:	8.25e-3	0.685e-3
Q-axis dampers:	13.89e-3	1.44e-3

Mutual inductance (H):
D-axis: 4.477e-3
Q-axis: 1.354e-3

Initial conditions

	Phase A current:	Phase B current:	Phase C current:
Magnitude (A):	0	0	0
Phase (deg):	0	0	0

Field voltage (V): 0

Mechanical parameters

Rotor values

Inertia (kg*m^2): 15
Friction (N-m-s): 0.005
Pole pairs: 2

Initial values

Speed deviation (%): -99.99
Angle (deg): 0

Model detail level: Detailed
Mechanical input: Torque Tm

Parameters file options

The synchronous machine tab displays the parameters of the synchronous machine block of the powerlib library. Refer to the Synchronous Machine for more information on the synchronous machine parameters.

Model detail level
Select between the detailed and the average-value inverter.

Mechanical input

Allows you to select either the load torque or the motor speed as mechanical input. Note that if you select and apply a load torque, you will obtain as output the motor speed according to the following differential equation that describes the mechanical system dynamics:

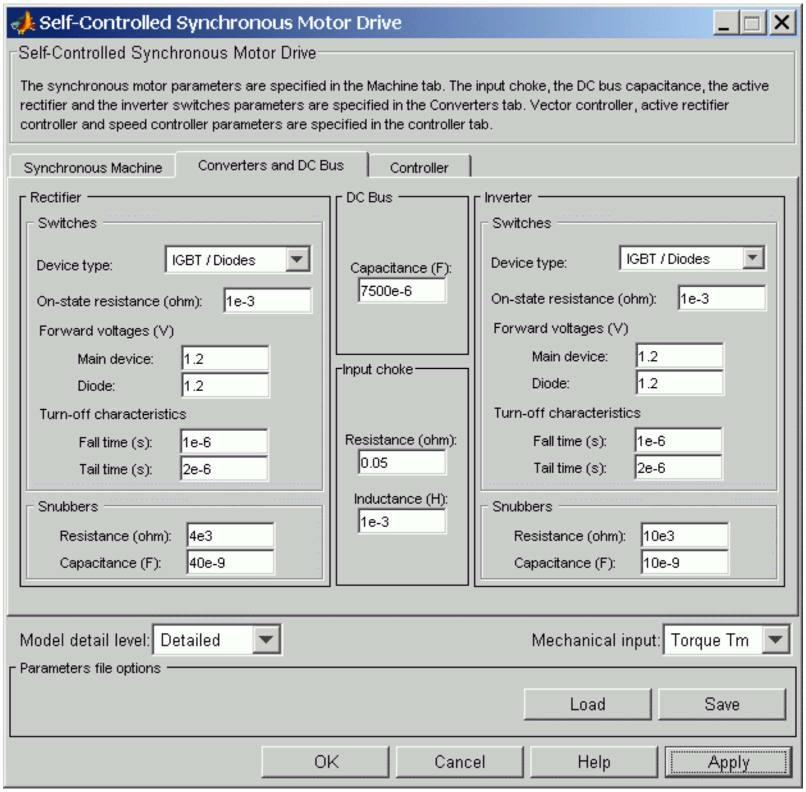
$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

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

See for example “Mechanical Coupling of Two Motor Drives”.

Converters and DC bus tab



Self-Controlled Synchronous Motor Drive

Self-Controlled Synchronous Motor Drive

The synchronous motor parameters are specified in the Machine tab. The input choke, the DC bus capacitance, the active rectifier and the inverter switches parameters are specified in the Converters tab. Vector controller, active rectifier controller and speed controller parameters are specified in the controller tab.

Rectifier

Switches

Device type: IGBT / Diodes

On-state resistance (ohm): 1e-3

Forward voltages (V)

Main device: 1.2

Diode: 1.2

Turn-off characteristics

Fall time (s): 1e-6

Tail time (s): 2e-6

Snubbers

Resistance (ohm): 4e3

Capacitance (F): 40e-9

DC Bus

Capacitance (F): 7500e-6

Input choke

Resistance (ohm): 0.05

Inductance (H): 1e-3

Inverter

Switches

Device type: IGBT / Diodes

On-state resistance (ohm): 1e-3

Forward voltages (V)

Main device: 1.2

Diode: 1.2

Turn-off characteristics

Fall time (s): 1e-6

Tail time (s): 2e-6

Snubbers

Resistance (ohm): 10e3

Capacitance (F): 10e-9

Model detail level: Detailed

Mechanical input: Torque Tm

Rectifier section

The rectifier section of the Converters and DC bus tab displays the parameters of the Universal Bridge block of the 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 Brige block of the 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. Theses values are needed for startup and for square wave mode.

DC Bus Capacitance
The DC bus capacitance value (F).

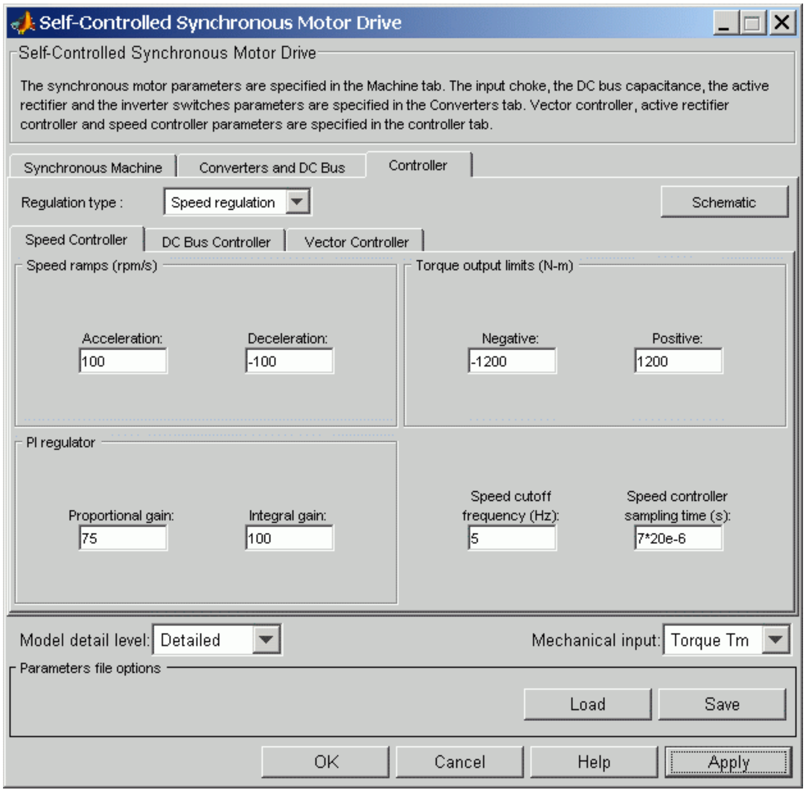
Input Choke section

Input chokes reduce line current harmonics.

Resistance
The input choke resistance value (ohms).

Inductance
The input choke inductance value (H).

Controller tab



Self-Controlled Synchronous Motor Drive

The synchronous motor parameters are specified in the Machine tab. The input choke, the DC bus capacitance, the active rectifier and the inverter switches parameters are specified in the Converters tab. Vector controller, active rectifier controller and speed controller parameters are specified in the controller tab.

Regulation type : Speed regulation

Speed ramps (rpm/s)

Acceleration: 100

Deceleration: -100

Torque output limits (N-m)

Negative: -1200

Positive: 1200

PI regulator

Proportional gain: 75

Integral gain: 100

Speed cutoff frequency (Hz): 5

Speed controller sampling time (s): 7*20e-6

Model detail level: Detailed

Mechanical input: Torque Tm

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).

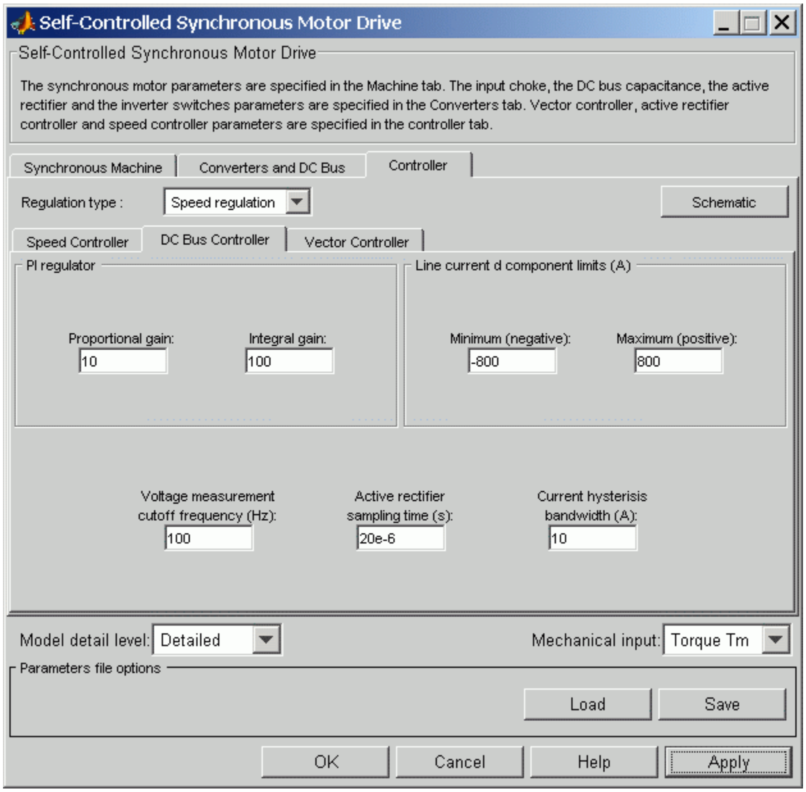
PI regulator — Proportional gain
The speed controller proportional gain.

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



Self-Controlled Synchronous Motor Drive

The synchronous motor parameters are specified in the Machine tab. The input choke, the DC bus capacitance, the active rectifier and the inverter switches parameters are specified in the Converters tab. Vector controller, active rectifier controller and speed controller parameters are specified in the controller tab.

Regulation type : Speed regulation

PI regulator

Proportional gain: 10

Integral gain: 100

Line current d component limits (A)

Minimum (negative): -800

Maximum (positive): 800

Voltage measurement cutoff frequency (Hz): 100

Active rectifier sampling time (s): 20e-6

Current hysterisis bandwidth (A): 10

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

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).

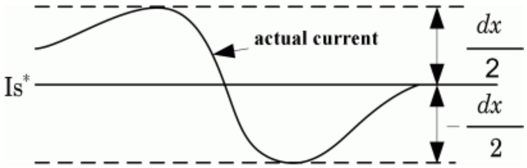
Active rectifier sampling time

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

Current hysteresis bandwidth

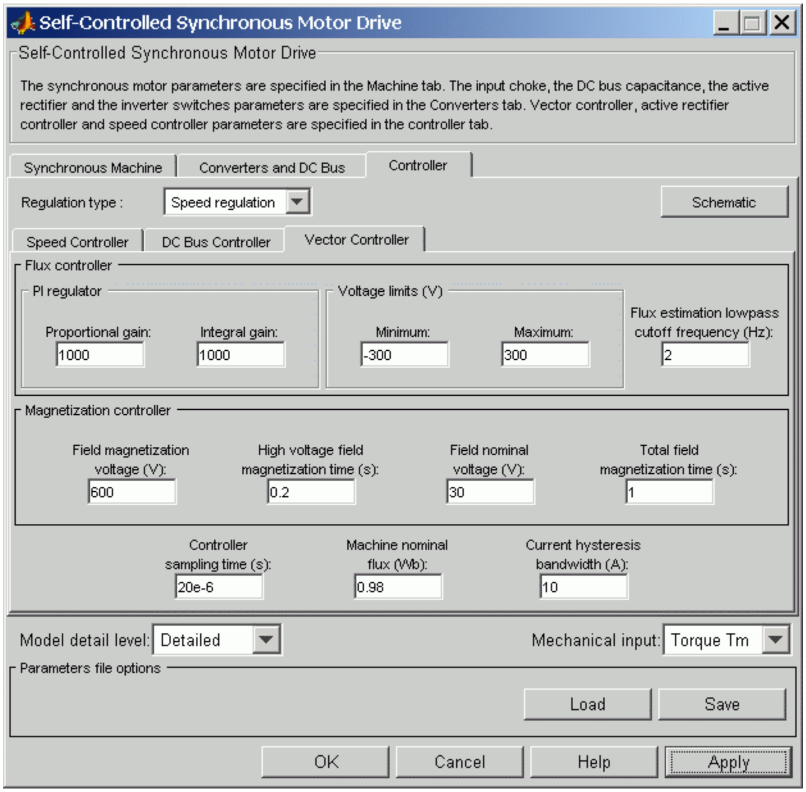
The current hysteresis bandwidth. This value is the total bandwidth distributed symmetrically around the current set point (A). The following figure illustrates a case where the current set point is Is* and the current hysteresis bandwidth is set to dx.

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



The synchronous motor parameters are specified in the Machine tab. The input choke, the DC bus capacitance, the active rectifier and the inverter switches parameters are specified in the Converters tab. Vector controller, active rectifier controller and speed controller parameters are specified in the controller tab.

Regulation type : Speed regulation

Proportional gain: 1000

Integral gain: 1000

Minimum: -300

Maximum: 300

Flux estimation lowpass cutoff frequency (Hz): 2

Field magnetization voltage (V): 600

High voltage field magnetization time (s): 0.2

Field nominal voltage (V): 30

Total field magnetization time (s): 1

Controller sampling time (s): 20e-6

Machine nominal flux (Wb): 0.98

Current hysteresis bandwidth (A): 10

Model detail level: Detailed

Mechanical input: Torque Tm

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. Note that 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).

`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

Model Specifications

The library contains a 200 hp drive parameter set. The specifications of the 200 hp drive are shown in the following table

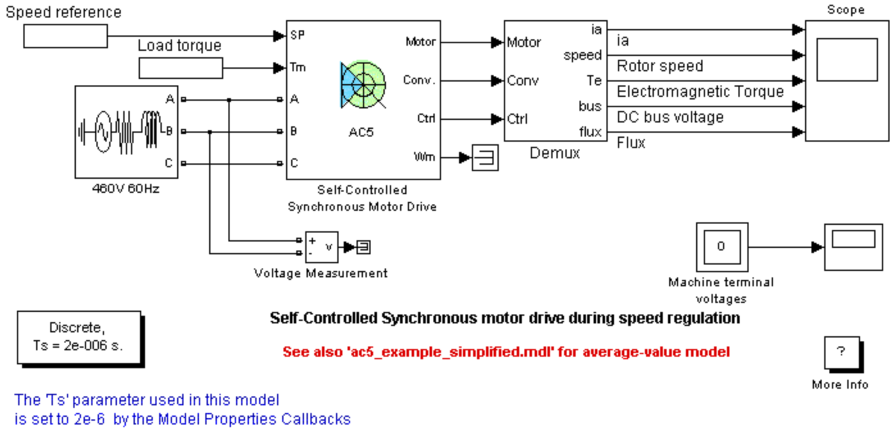
14 HP and 200 HP Drive Specifications

		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

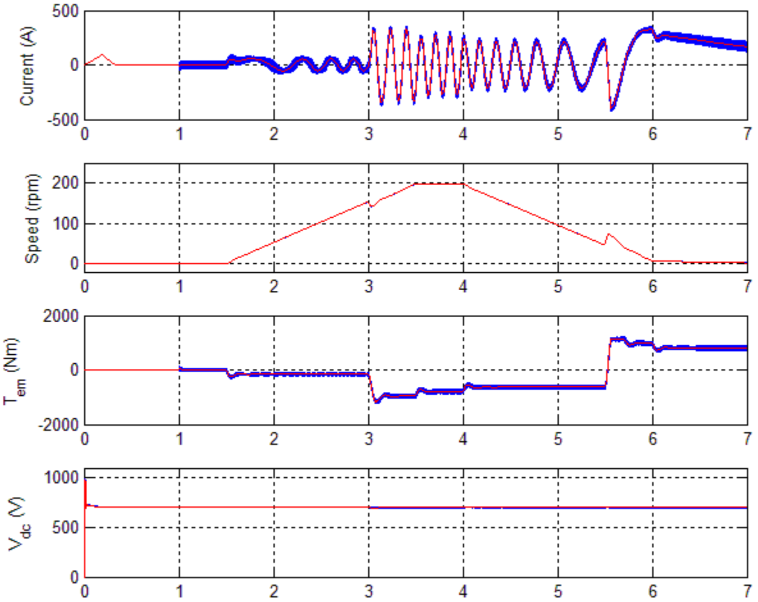
.

Example

The `ac5_example` demo illustrates an AC5 motor drive simulation with standard load condition for the detailed and average-value models. At time t = 0 s, the speed set point is 300 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.

Series RLC Branch

Purpose

Implement series RLC branch

Library

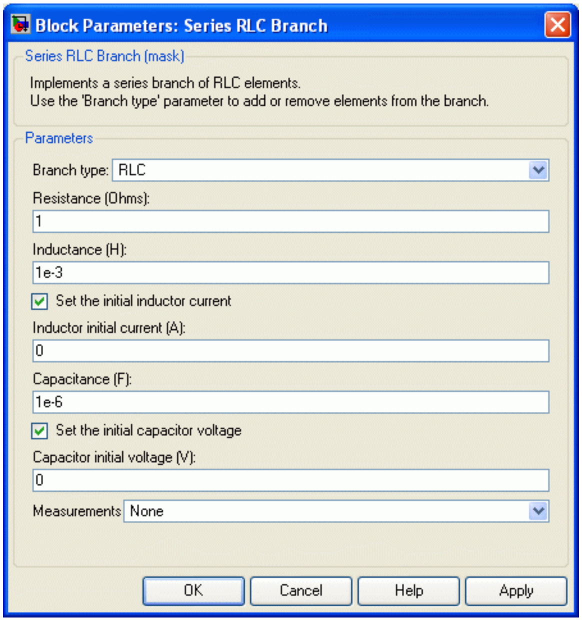
Elements

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. If you eliminate either the resistance, inductance, or capacitance of the branch, the R, L, and C values are automatically set respectively to 0, 0, and infinity (inf) and the corresponding parameters no longer appear in the block dialog box. Only existing elements are displayed in the block icon.

Negative values are allowed for resistance, inductance, and capacitance.

Dialog Box and Parameters



Block Parameters: Series RLC Branch

Series RLC Branch (mask)

Implements a series branch of RLC elements.
Use the 'Branch type' parameter to add or remove elements from the branch.

Parameters

Branch type: RLC

Resistance (Ohms): 1

Inductance (H): 1e-3

☑ Set the initial inductor current

Inductor initial current (A): 0

Capacitance (F): 1e-6

☑ Set the initial capacitor voltage

Capacitor initial voltage (V): 0

Measurements: None

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).

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.

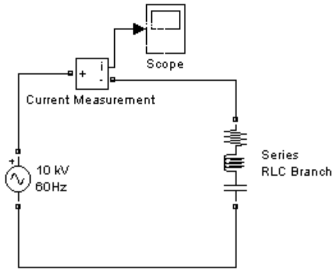
Select `Branch voltage and current` to measure the voltage and the current of the Series RLC Branch block.

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

$$Z(s) = \frac{V(s)}{I(s)} = \frac{LCs^2 + RCs + 1}{Cs}$$

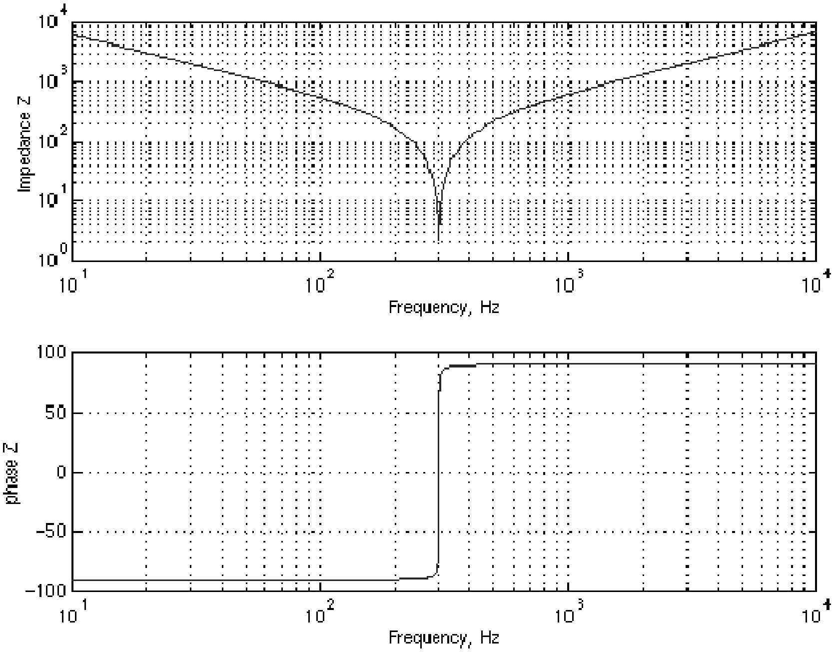
To obtain the frequency response of the impedance you have to get the state-space model (A B C D matrices) of the system.

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,Zphase)
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

Purpose

Implement linear series RLC load

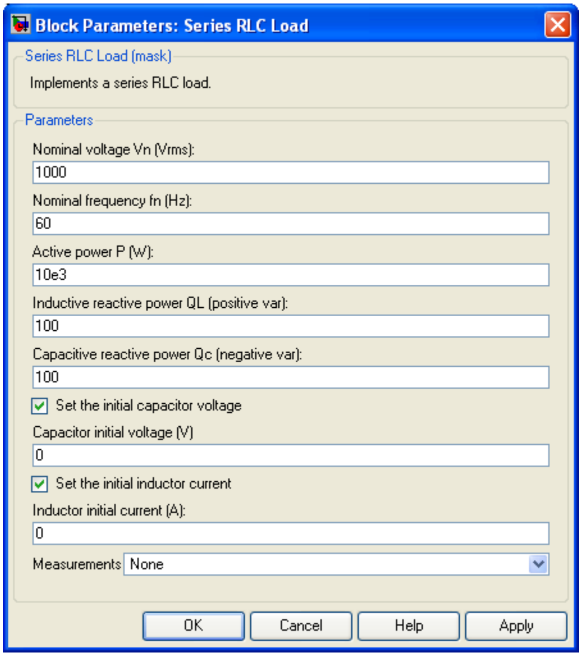
Library

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



Block Parameters: Series RLC Load

Series RLC Load (mask)

Implements a series RLC load.

Parameters

Nominal voltage Vn (Vrms): 1000

Nominal frequency fn (Hz): 60

Active power P (W): 10e3

Inductive reactive power QL (positive var): 100

Capacitive reactive power Qc (negative var): 100

☑ Set the initial capacitor voltage

Capacitor initial voltage (V): 0

☑ Set the initial inductor current

Inductor initial current (A): 0

Measurements: None

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.

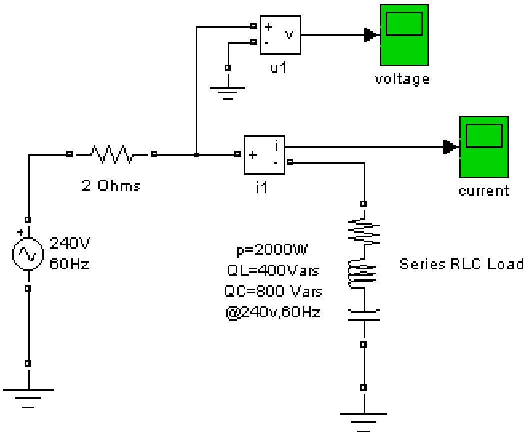
Select `Branch voltage and current` to measure the voltage and the current of the Series RLC Load block.

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:`

Example

The `power_seriesload` demo uses a Series RLC Load block to implement a simple load.



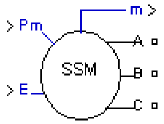
See Also Multimeter, Parallel RLC Branch, Parallel RLC Load, Series RLC Branch

Simplified Synchronous Machine

Purpose Model the dynamics of simplified three-phase synchronous machine

Library 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

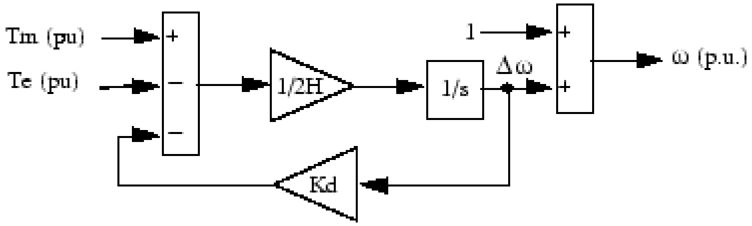
Te = Electromagnetic torque

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. Notice that the model computes a deviation with respect to the speed of operation, and 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:

$$\delta/P_m = (\omega_s/2H)/(s^2 + 2\zeta\omega_n s + \omega_n^2)$$

where

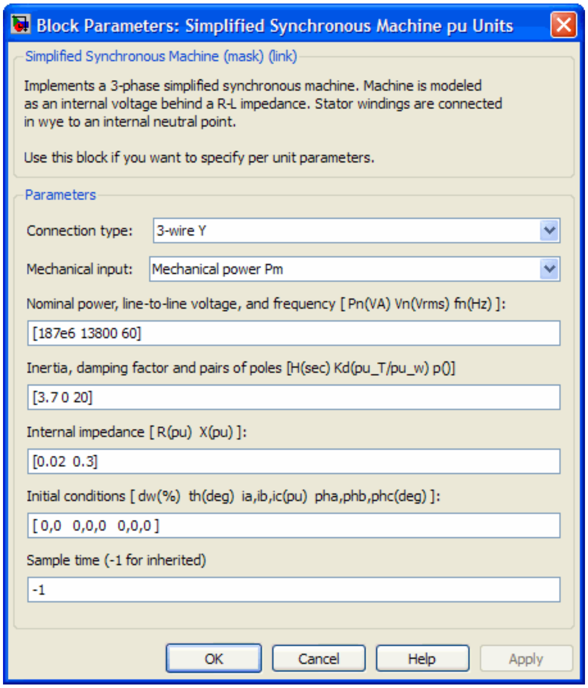
δ	Power angle delta: angle of internal voltage E with respect to terminal voltage, in radians
P_m	Mechanical power in pu
ω_n	Frequency of electromechanical oscillations = $\sqrt{\omega_s \cdot P_{max}/(2H)}$ in rad/s
ζ	Damping ratio = $(K_d/4)\sqrt{2/(\omega_s \cdot H \cdot P_{max})}$
ω_s	Electrical frequency in rad/s
P_{max}	Maximum power in pu transmitted through reactance X at terminal voltage V_t and internal voltage E. $P_{max} = V_t \cdot E/X$ (pu) 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(δ) = δ, is valid for small power angles (δ < 30 degrees). It follows from the above ζ expression that the Kd value required to obtain a given ζ damping ratio is

$$K_d = 4\zeta\sqrt{\omega_s \cdot H \cdot P_{max}/2}$$

Dialog Box and Parameters

In the **powerlib** 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.



Block Parameters: Simplified Synchronous Machine pu Units

Simplified Synchronous Machine (mask) (link)

Implements a 3-phase simplified synchronous machine. Machine is modeled as an internal voltage behind a R-L impedance. Stator windings are connected in wye to an internal neutral point.

Use this block if you want to specify per unit parameters.

Parameters

Connection type: 3-wire Y

Mechanical input: Mechanical power Pm

Nominal power, line-to-line voltage, and frequency [Pn(VA) Vn(Vrms) fn(Hz)]: [187e6 13800 60]

Inertia, damping factor and pairs of poles [H(sec) Kd(pu_T/pu_w) p()] [3.7 0 20]

Internal impedance [R(pu) X(pu)]: [0.02 0.3]

Initial conditions [dw(%) th(deg) ia,ib,ic(pu) pha,phb,phc(deg)]: [0,0 0,0,0 0,0,0]

Sample time (-1 for inherited) -1

Connection type

Specify the number of wires used in three-phase Y connection: either three-wire (neutral not accessible) or four-wire (neutral is accessible).

Mechanical input

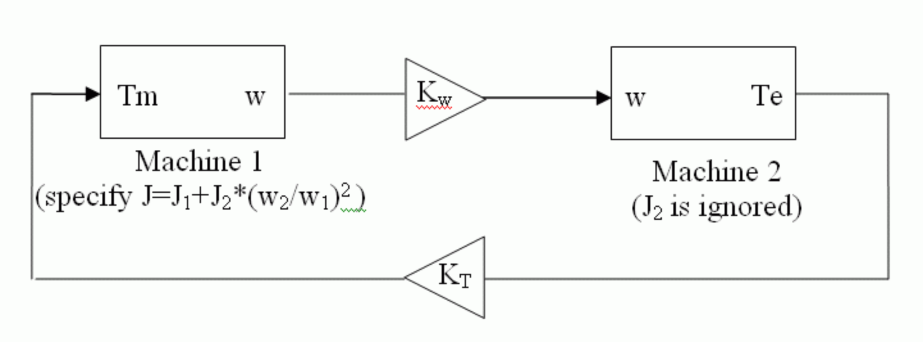
Allows you to select either the torque applied to the shaft or the rotor speed as the Simulink signal applied to the block's input.

Select **Mechanical power Pm** to specify a mechanical power input, in W or in pu, and change labeling of the block's 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 the applied mechanical power Pm, and the internal electromagnetic torque Te. The sign convention for the mechanical power is the following: 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's 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 and interfacing with SimMechanics and SimDriveline models.

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.



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). Used to compute nominal torque and convert 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 should 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 can be 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`.

Note These two blocks simulate exactly the same simplified synchronous machine model; the only difference is the way of entering the parameter units.

Inputs and Outputs

`Pm`

The mechanical power supplied to the machine. 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, these two inputs should be in watts and volts phase-to-phase RMS. If you use the pu units machine, both inputs should be in pu.

`m`

The Simulink output of the block is a vector containing 12 signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Signal	Definition	Units	Symbol
1	Stator current is_a	A or pu	i_{sa}
2	Stator current is_b	A or pu	i_{sb}

Signal	Definition	Units	Symbol
3	Stator current is_c	A or pu	i_{sc}
4	Terminal voltage Va	V or pu	v_a
5	Terminal voltage Vb	V or pu	v_b
6	Terminal voltage Vc	V or pu	v_c
7	Internal voltage Ea	V or pu	E_a
8	Internal voltage Eb	V or pu	E_b
9	Internal voltage Ec	V or pu	E_c
10	Rotor angle theta	rad	Θ
11	Rotor speed wm	rad/s	ω
12	Electrical power Pe	W	P_e

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, in order 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 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

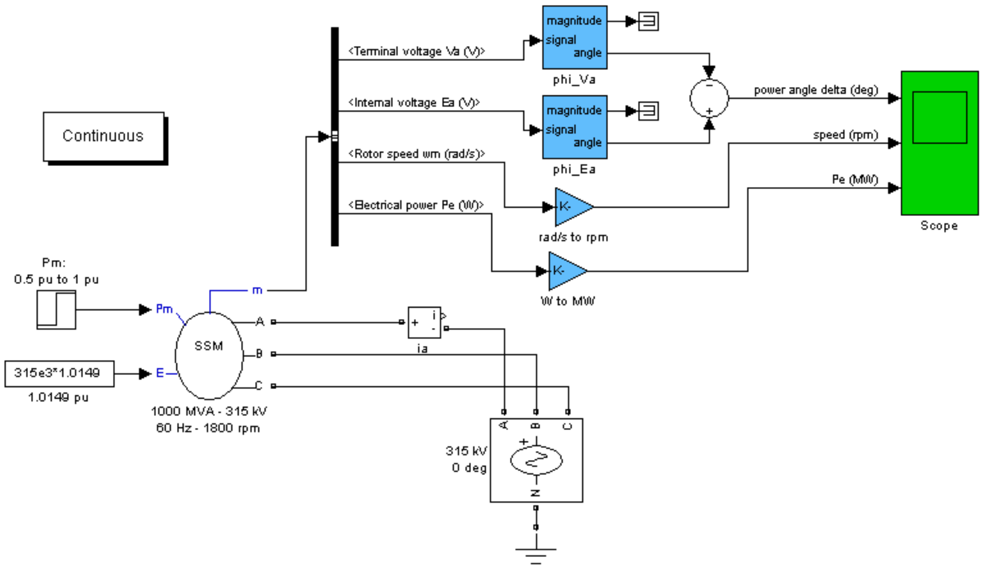
The `power_simplealt` demo uses the Simplified Synchronous Machine block to represent a 1000 MVA, 315 kV, 60 Hz equivalent source connected to an infinite bus (Three-Phase Programmable Voltage Source block). The Simplified Synchronous Machine (SI Units) block is used as a synchronous generator. The internal 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*π*60/2 = 377 rad/s. The machine has two pairs of poles such that its synchronous speed is 2*π*60/2 = 188.5 rad/s or 1800 rpm.

The **Load Flow** option of the Powergui has been used to initialize the machine in order 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 in order to obtain a damping ratio ζ = 0.3. According to the formula given in the Description section, the required Kd value is

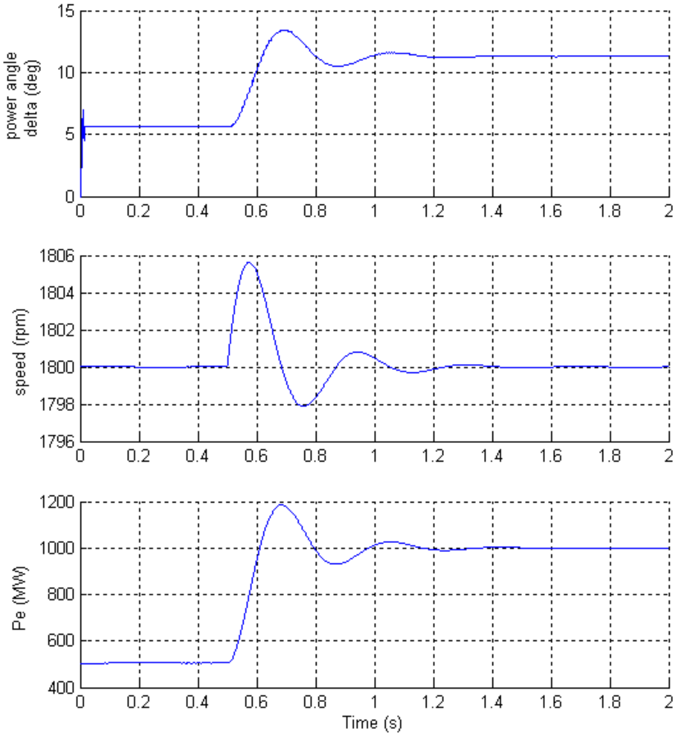
$$K_d = 4\zeta\sqrt{(\omega_s \cdot H \cdot P_{max})/2} = 64.3$$

Two Fourier blocks are used to 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 demo, 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 demo 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:

$$Pe = \frac{V_t \cdot E \cdot \sin\delta}{X} = \frac{1.0 \cdot 1.0149 \cdot \sin(5.65°)}{0.2} = 0.5 \text{ p.u.}$$

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

$$f_n = (1/2\pi) \cdot \sqrt{\omega_s \cdot P_{max}/(2H)} = 2.84 \text{ Hz}$$

See Also Excitation System, Hydraulic Turbine and Governor, Powergui, Steam Turbine and Governor, Synchronous Machine

Single Phase Asynchronous Machine

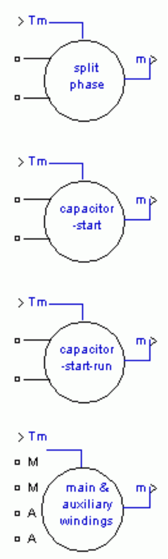
Purpose

Model the dynamics of single phase asynchronous machine with squirrel-cage rotor

Library

Machines

Description

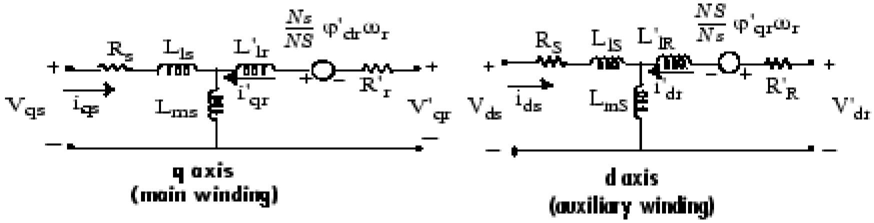


This machine has two windings: the main winding and the auxiliary winding. The model allows to simulate the split-phase, the capacitor-start, the capacitor-start-capacitor-run, and main & auxiliary windings operation modes.

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. This is indicated by the prime signs in the machine equations given below. All stator and rotor quantities are in the stator reference frame (dq frame). The subscripts used are defined as follows:

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



$$V_{qs} = R_s i_{qs} + \frac{d}{dt}\varphi_{qs}$$

$$V_{ds} = R_S i_{ds} + \frac{d}{dt}\varphi_{ds}$$

$$V'_{qr} = R'_r i'_{qr} + \frac{d}{dt}\varphi'_{qr} - \frac{N_s}{N_S}\omega_r \varphi'_{dr}$$

$$V'_{dr} = R'_R i'_{dr} + \frac{d}{dt}\varphi'_{dr} + \frac{N_S}{N_s}\omega_r \varphi'_{dr}$$

$$T_e = p\left(\frac{N_S}{N_s}\varphi'_{qr} i'_{dr} - \frac{N_s}{N_S}\varphi'_{dr} i'_{qr}\right)$$

where

$$\varphi_{qs} = L_{ss} i_{qs} + L_{ms} i'_{qr}$$

$$\varphi_{ds} = L_{SS} i_{ds} + L_{mS} i'_{dr}$$

$$\varphi'_{qr} = L'_{rr} i'_{qr} + L_{ms} i_{qs}$$

$$\varphi'_{dr} = L'_{RR} i'_{dr} + L_{mS} i_{ds}$$

$$L_{ss} = L_{ls} + L_{ms}$$

$$L_{SS} = L_{lS} + L_{mS}$$

$$L'_{rr} = L'_{lr} + L_{ms}$$

$$L'_{RR} = L'_{lR} + L_{mS}$$

Mechanical System

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

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

Reference frame

The reference frame fixed in the stator is used to convert 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):

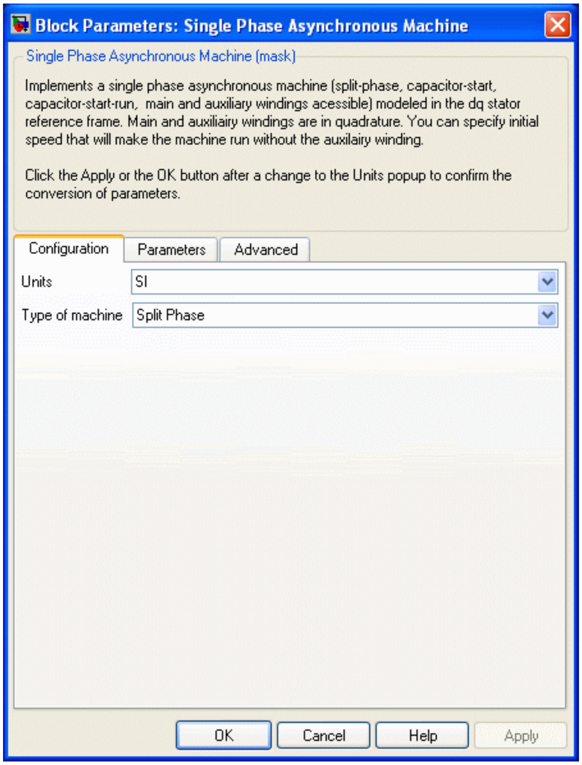
Parameter	Definition
R_s, L_{ls}	Main winding stator resistance and leakage inductance
R_S, L_{lS}	Auxiliary winding stator resistance and leakage inductance
R'_r, L'_{lr}	Main winding rotor resistance and leakage inductance
R'_R, L'_{lR}	Auxiliary winding rotor resistance and leakage inductance
L_{ms}	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
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

Parameter	Definition
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).
F	Set to infinite to simulate locked rotor. Combined rotor and load viscous friction coefficient
H	Combined rotor and load inertia constant in (s). Set to infinite to simulate locked rotor.
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 unit 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 you choose to use, the software automatically converts the parameters you enter into per unit parameters. The Simulink model of the single phase asynchronous machine block uses per unit parameters.

Configuration Tab



Single Phase Asynchronous Machine (mask)

Implements a single phase asynchronous machine (split-phase, capacitor-start, capacitor-start-run, main and auxiliary windings acessible) modeled in the dq stator reference frame. Main and auxiliairy windings are in quadrature. You can specify initial speed that will make the machine run without the auxilairy winding.

Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

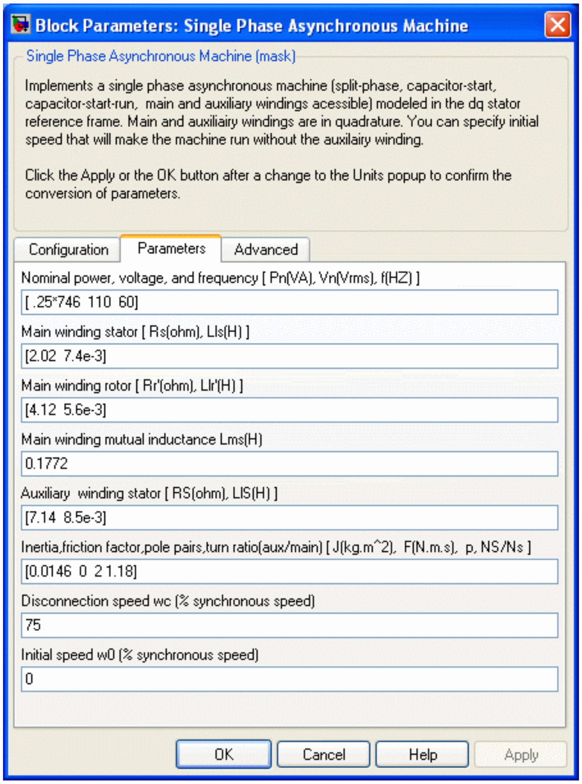
Units: SI

Type of machine: Split Phase

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 machine (the split-phase, the capacitor-start, the capacitor-start-capacitor-run, or the main & auxiliary windings).

Parameters Tab



Single Phase Asynchronous Machine (mask)

Implements a single phase asynchronous machine (split-phase, capacitor-start, capacitor-start-run, main and auxiliary windings acessible) modeled in the dq stator reference frame. Main and auxiliairy windings are in quadrature. You can specify initial speed that will make the machine run without the auxilairy winding.

Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

Nominal power, voltage, and frequency [Pn(VA), Vn(Vrms), f(HZ)]
[.25*746 110 60]

Main winding stator [Rs(ohm), Lls(H)]
[2.02 7.4e-3]

Main winding rotor [Rr'(ohm), Llr'(H)]
[4.12 5.6e-3]

Main winding mutual inductance Lms(H)
0.1772

Auxiliary winding stator [RS(ohm), LlS(H)]
[7.14 8.5e-3]

Inertia,friction factor,pole pairs,turn ratio(aux/main) [J(kg.m^2), F(N.m.s), p, NS/Ns]
[0.0146 0 2 1.18]

Disconnection speed wc (% synchronous speed)
75

Initial speed w0 (% synchronous speed)
0

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).

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), combined viscous friction coefficient F (N.m.s),number of pole pairs p and ratio of number of auxiliary winding's effective turns and number of main winding's effective turns. **pu units** dialog box: the inertia constant H (s), combined viscous friction coefficient F (pu), and number of pole pairs p.

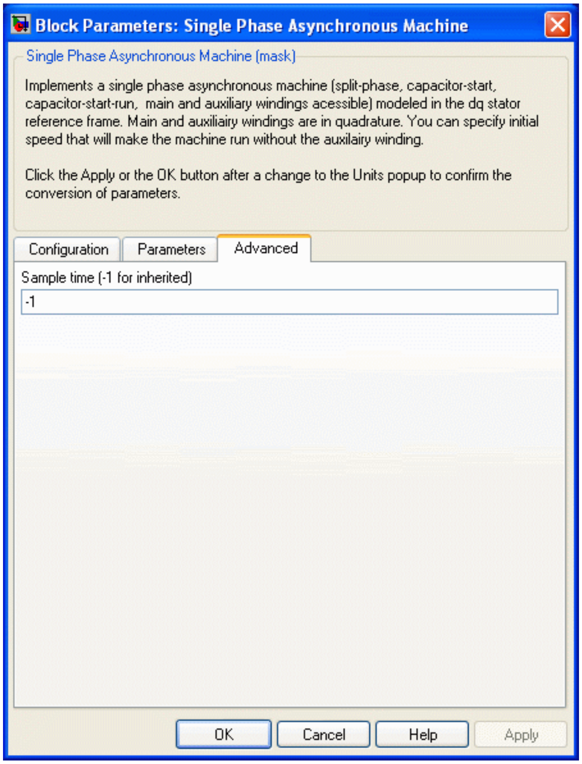
Capacitor-Start
The start capacitance C_s (farad or pu) and capacitor series resistance R_{st}(Ω or pu)

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



Block Parameters: Single Phase Asynchronous Machine

Single Phase Asynchronous Machine (mask)

Implements a single phase asynchronous machine (split-phase, capacitor-start, capacitor-start-run, main and auxiliary windings acessible) modeled in the dq stator reference frame. Main and auxiliairy windings are in quadrature. You can specify initial speed that will make the machine run without the auxilairy winding.

Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

Sample time (-1 for inherited)

-1

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's 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 16 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.

Signal	Definition	Units	Symbol
1	Rotor current ir_a	A or pu	i'_{ra}
2	Rotor current ir_b	A or pu	i'_{rb}
3	Rotor current iq	A or pu	i'_{qr}
4	Rotor current id	A or pu	i'_{dr}
5	Rotor flux phir_q	V.s or pu	φ'_{qr}
6	Rotor flux phir_d	V.s or pu	φ'_{dr}
7	Rotor voltage Vr_q	V or pu	v'_{qr}
8	Rotor voltage Vr_d	V or pu	v'_{d}
9	Main winding stator current ia	A or pu	i_a
10	Auxiliary winding stator current ib	A or pu	i_b
11	Voltage capacitor Vc	V or pu	V_c
12	Stator flux phis_q(V.s)	V.s or pu	φ_{qs}
13	Stator flux phis_d(V.s)	V.s or pu	φ_{ds}
14	Rotor speed	rad/s	ω_m
15	Electromagnetic torque Te	N.m or pu	T_e
16	Rotor angle thetam	rad	Θ_m

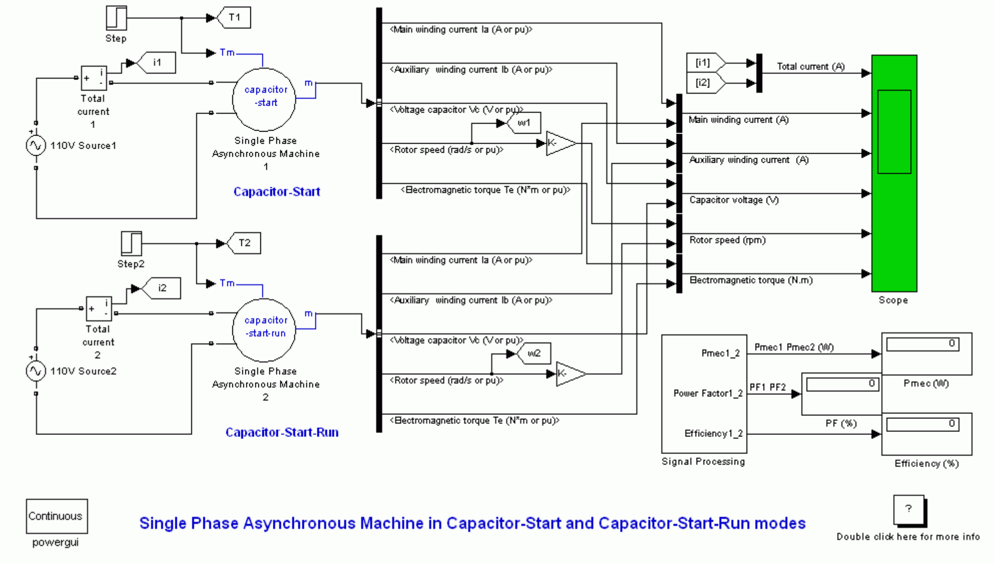
Limitations

The single phase asynchronous machine block does not include a representation of iron losses and saturation.

Example

This example, available in the `power_singlephaseASM` demo, illustrates 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.

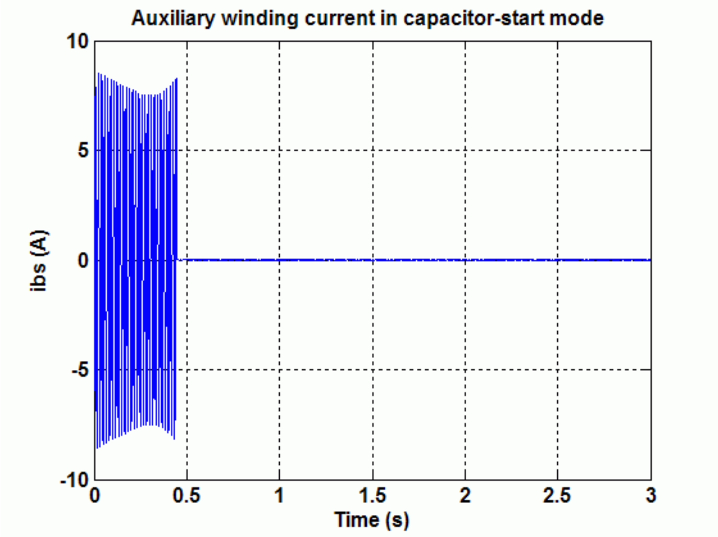


Capacitor-Start Operation Mode

The next series of figures shows the capacitor-start operation where the auxiliary winding is tripped when the machine is speeded up to 75% of the rated speed.

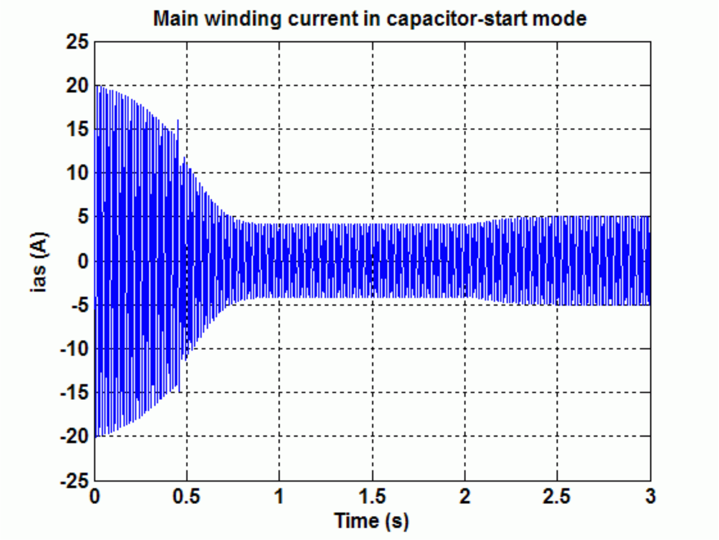
The last figure in the series, Electromagnetic Torque in Capacitor-Start Operation Mode on page 2-501, shows the electromagnetic torque developed by the machine. Since there is a step load of 1 N.m, the average torque will be 1 N.m. The torque ripple amplitude is about

2.5 N.m, or 150% of the rated load. The torque pulsation affects the operation of the machine.

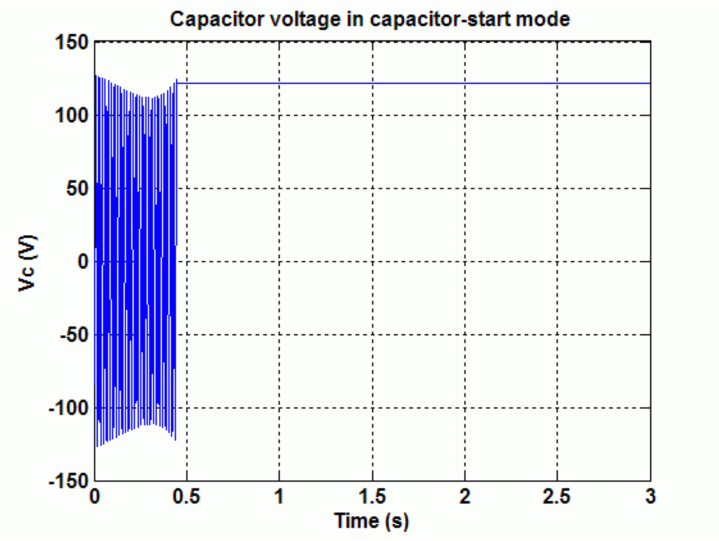


Auxiliary Winding Current in Capacitor-Start Operation Mode

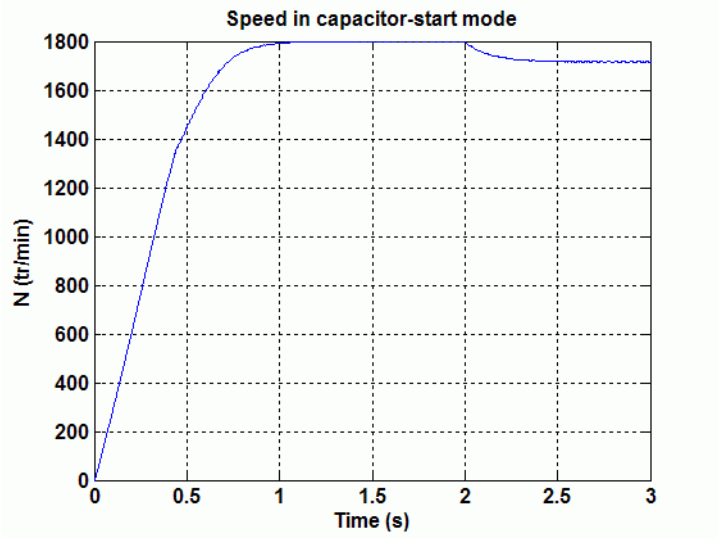
The auxiliary winding current is set to zero when the speed reaches 75% of the rated speed. The voltage across the start-capacitor remains at its maximum value, since current and voltage across a capacitor are in quadrature.



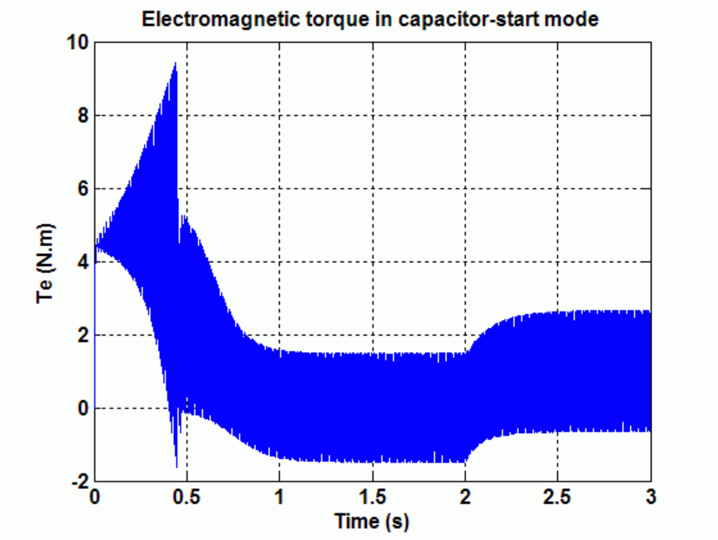
Main Winding Current in Capacitor-Start Operation Mode



Capacitor Voltage in Capacitor-Start Operation Mode



Speed in Capacitor-Start Operation Mode

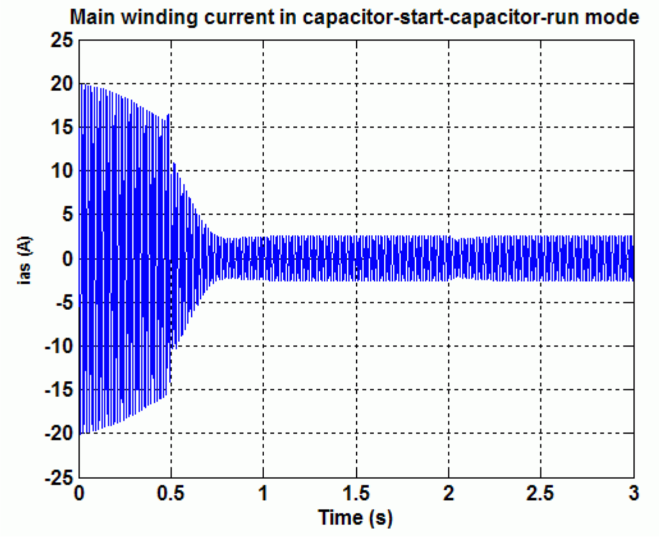


Electromagnetic Torque in Capacitor-Start Operation Mode

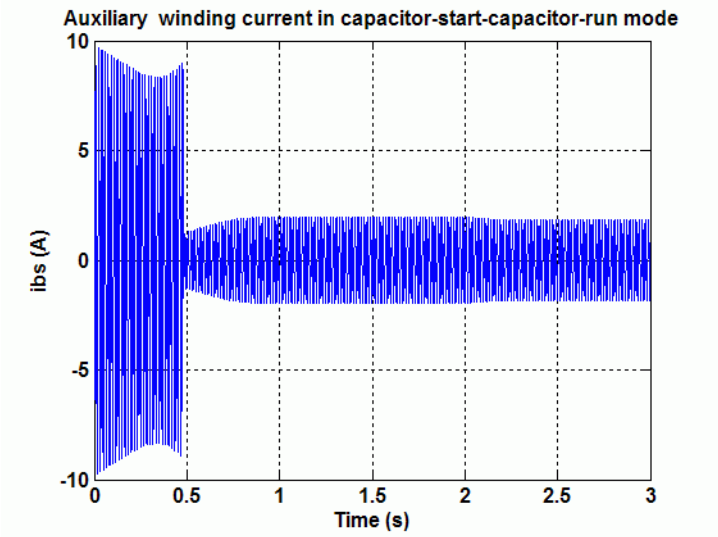
Capacitor-Start-Run Operation Mode

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.

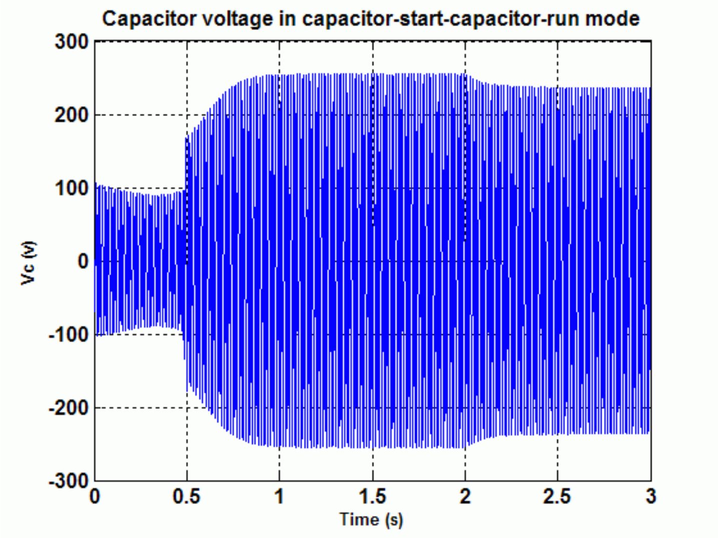
The next figures show the simulation wave forms in the capacitor-start-run operation mode single phase asynchronous machine. The magnitude of the torque ripple at steady state is only about 3% of the load torque. It improves the operation of a single phase asynchronous machine by limiting the shaft's vibrations.



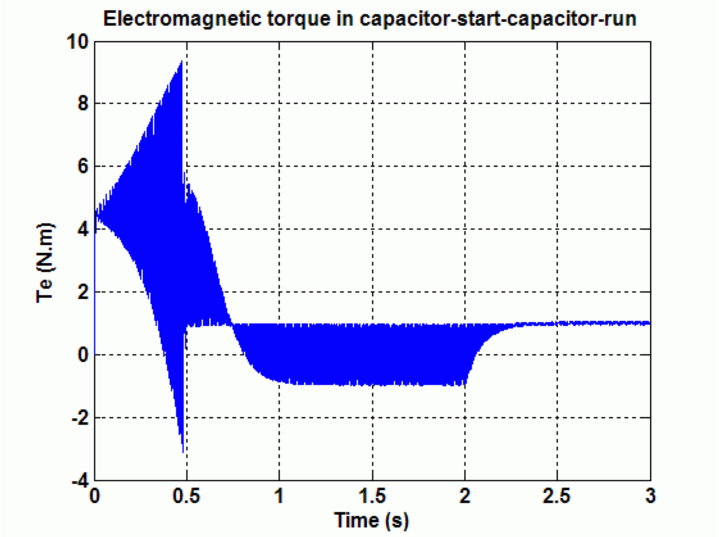
Main Winding Current in Capacitor-Start-Run Operation Mode



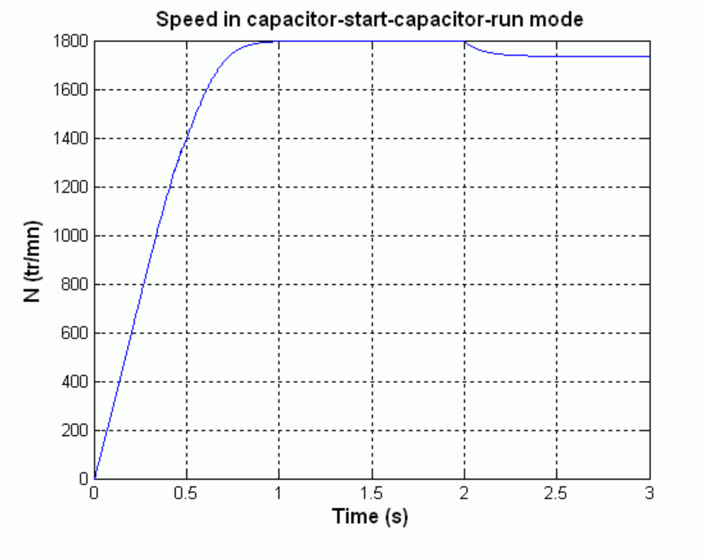
Auxiliary Winding Current in Capacitor-Start-Run Operation Mode



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 VSI Induction Motor Drive

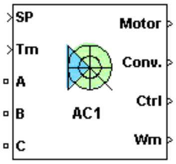
Purpose

Implement six-step inverter fed Induction Motor Drive

Library

Electric Drives/AC drives

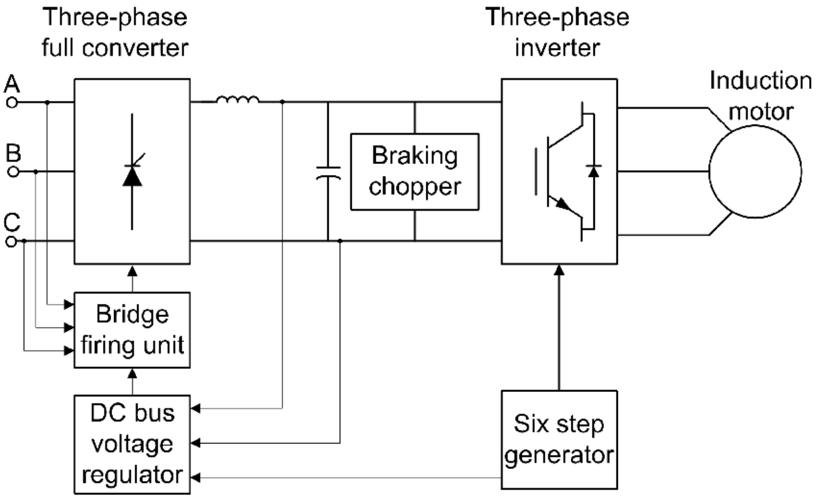
Description



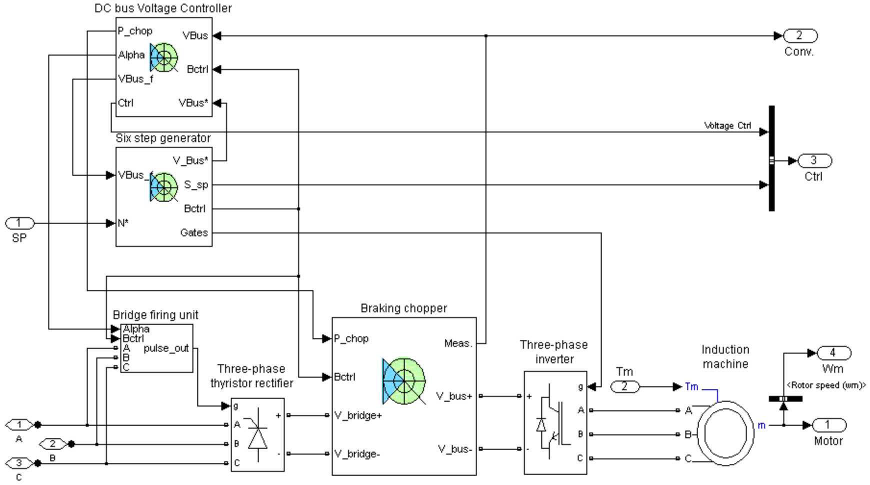
The high-level schematic shown below is built from seven main blocks. The induction motor, the three-phase inverter, the three-phase thyristor rectifier, and the bridge firing unit are provided with the SimPowerSystems library. More details are available in the reference pages for these blocks. The three 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

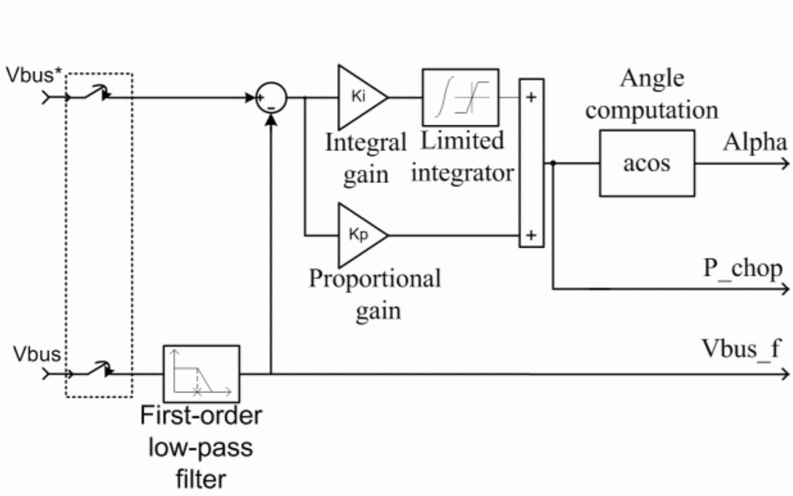


Bridge Firing Unit

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. Refer to the Synchronized 6-Pulse Generator for more information on this block.

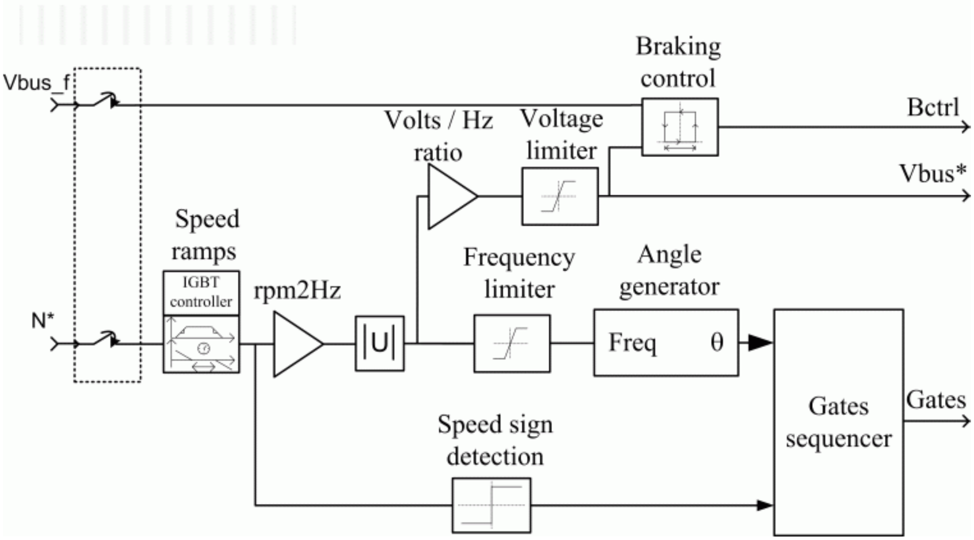
DC Bus Voltage Regulator and Braking Chopper

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.



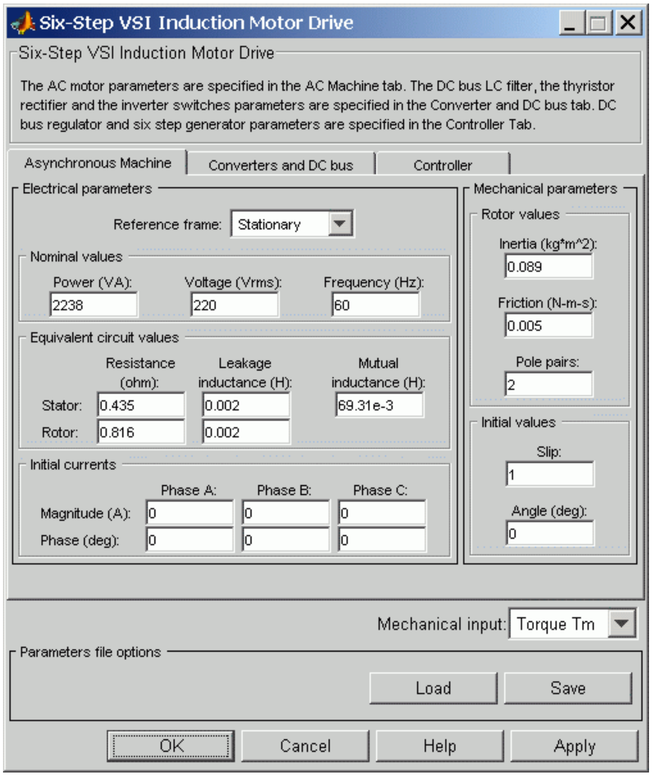
Remarks

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



Six-Step VSI Induction Motor Drive

The AC motor parameters are specified in the AC Machine tab. The DC bus LC filter, the thyristor rectifier and the inverter switches parameters are specified in the Converter and DC bus tab. DC bus regulator and six step generator parameters are specified in the Controller Tab.

Electrical parameters

Reference frame: Stationary

Nominal values

Power (VA):	Voltage (Vrms):	Frequency (Hz):
2238	220	60

Equivalent circuit values

	Resistance (ohm):	Leakage inductance (H):	Mutual inductance (H):
Stator:	0.435	0.002	69.31e-3
Rotor:	0.816	0.002	

Initial currents

	Phase A:	Phase B:	Phase C:
Magnitude (A):	0	0	0
Phase (deg):	0	0	0

Mechanical parameters

Rotor values

Inertia (kg*m^2): 0.089

Friction (N-m-s): 0.005

Pole pairs: 2

Initial values

Slip: 1

Angle (deg): 0

Mechanical input: Torque Tm

Parameters file options

The asynchronous machine tab displays the parameters of the asynchronous machine block of the powerlib library. Refer to the Asynchronous Machine for more information on the asynchronous machine parameters.

Mechanical input

Allows you to select either the load torque or the motor speed as mechanical input. Note that if you select and apply a load torque, you will obtain as output the motor speed according to

the following differential equation that describes the mechanical system dynamics:

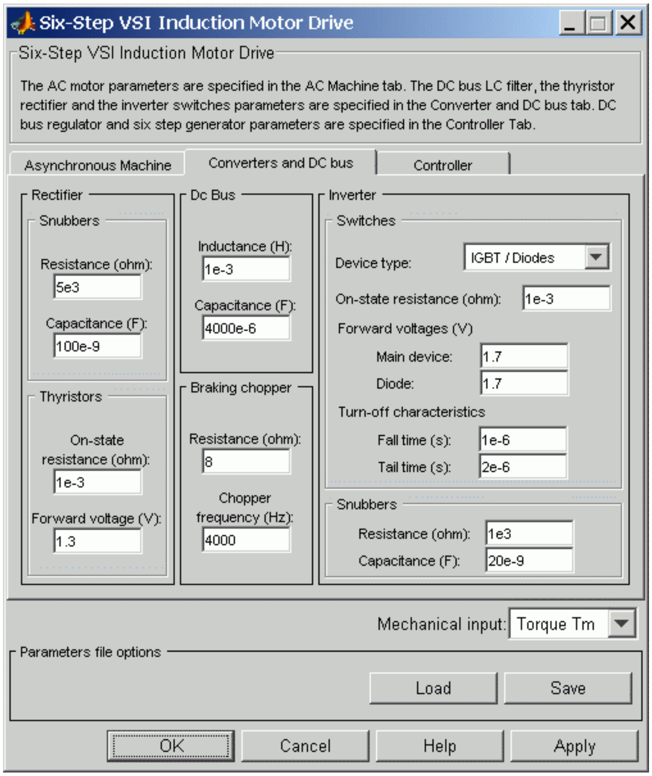
$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

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

See for example “Mechanical Coupling of Two Motor Drives”.

Converters and DC Bus Tab



Six-Step VSI Induction Motor Drive

The AC motor parameters are specified in the AC Machine tab. The DC bus LC filter, the thyristor rectifier and the inverter switches parameters are specified in the Converter and DC bus tab. DC bus regulator and six step generator parameters are specified in the Controller Tab.

Rectifier

Snubbers

Resistance (ohm): 5e3

Capacitance (F): 100e-9

Thyristors

On-state resistance (ohm): 1e-3

Forward voltage (V): 1.3

Dc Bus

Inductance (H): 1e-3

Capacitance (F): 4000e-6

Braking chopper

Resistance (ohm): 8

Chopper frequency (Hz): 4000

Inverter

Switches

Device type: IGBT / Diodes

On-state resistance (ohm): 1e-3

Forward voltages (V)

Main device: 1.7

Diode: 1.7

Turn-off characteristics

Fall time (s): 1e-6

Tail time (s): 2e-6

Snubbers

Resistance (ohm): 1e3

Capacitance (F): 20e-9

Mechanical input: Torque Tm

Parameters file options

Rectifier section

The rectifier section of the Converters and DC bus tab displays the parameters of the Universal Bridge block of the 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 Brige block of the 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).

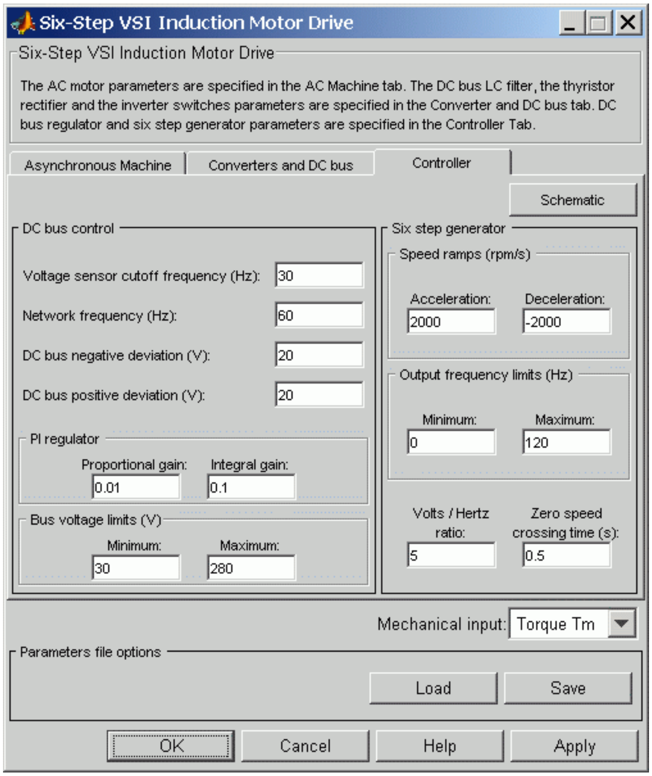
DC Bus Filter — Capacitance
The low-pass DC bus filter capacitance (F).

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



Six-Step VSI Induction Motor Drive

The AC motor parameters are specified in the AC Machine tab. The DC bus LC filter, the thyristor rectifier and the inverter switches parameters are specified in the Converter and DC bus tab. DC bus regulator and six step generator parameters are specified in the Controller Tab.

Voltage sensor cutoff frequency (Hz): 30

Network frequency (Hz): 60

DC bus negative deviation (V): 20

DC bus positive deviation (V): 20

Proportional gain: 0.01

Integral gain: 0.1

Bus voltage limits (V) Minimum: 30

Bus voltage limits (V) Maximum: 280

Speed ramps (rpm/s) Acceleration: 2000

Speed ramps (rpm/s) Deceleration: -2000

Output frequency limits (Hz) Minimum: 0

Output frequency limits (Hz) Maximum: 120

Volts / Hertz ratio: 5

Zero speed crossing time (s): 0.5

Mechanical input: Torque Tm

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

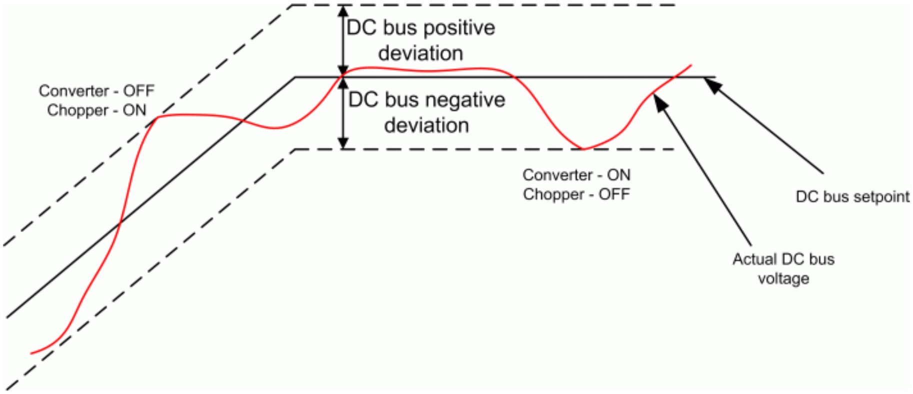
The DC bus voltage measurement first-order filter cutoff frequency (Hz).

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

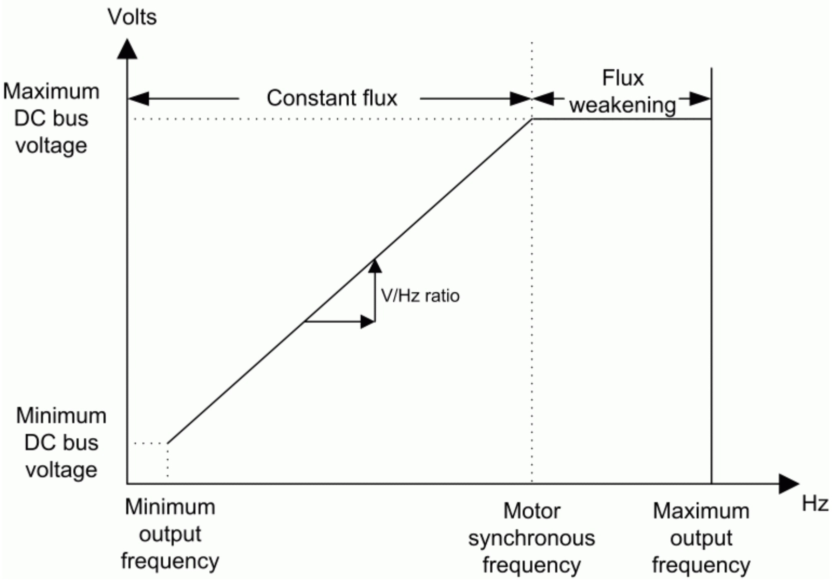
The maximum change of speed allowed during motor deceleration. An excessively large negative value can cause DC bus over-voltage (rpm/s).

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. Note that 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).

`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

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

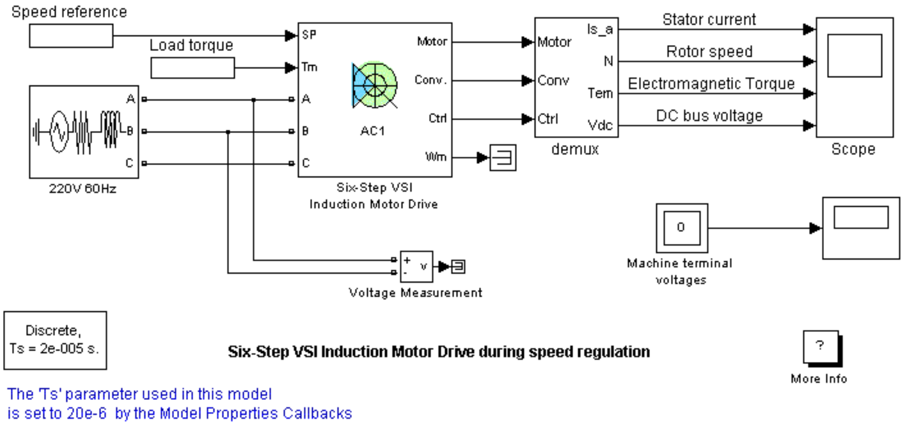
		3 HP Drive	500 HP Drive
Drive Input Voltage			
	Amplitude	220 V	2300 V
	Frequency	60 Hz	60 Hz

3 HP and 500 HP Drive Specifications (Continued)

		3 HP Drive	500 HP Drive
Drive Input Voltage			
Motor Nominal Values			
	Power	3 hp	500 hp
	Speed	1705 rpm	1773 rpm
	Voltage	220 V	2300 V

Example

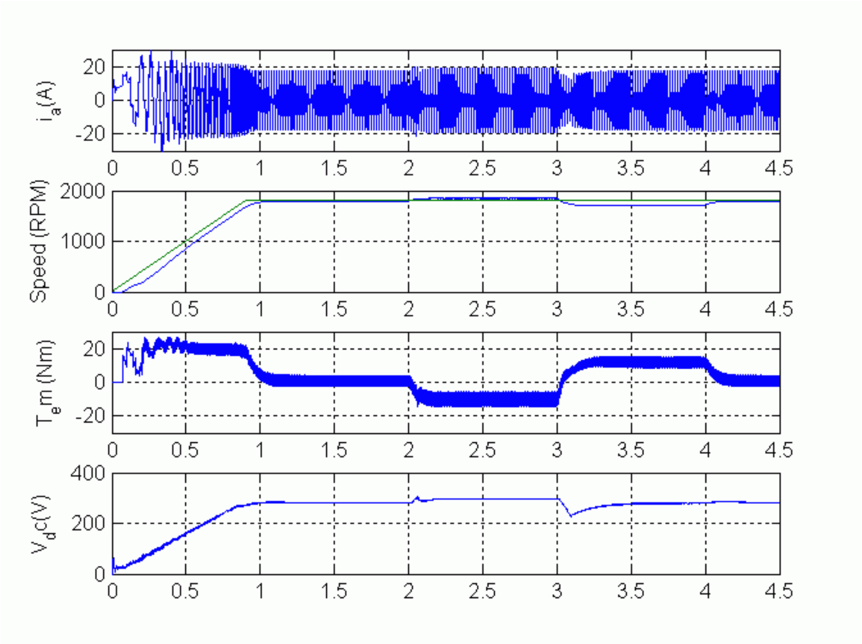
The `ac1_example` demo illustrates a typical operation of the AC1 motor drive. A speed reference step from zero to 1800 rpm is applied at t = 0.



Six-Step VSI Induction Motor Drive during speed regulation

The 'Ts' parameter used in this model
is set to 20e-6 by the Model Properties Callbacks

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.

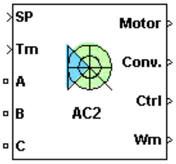
Purpose

Implement space vector PWM VSI induction motor drive

Library

Electric Drives/AC drives

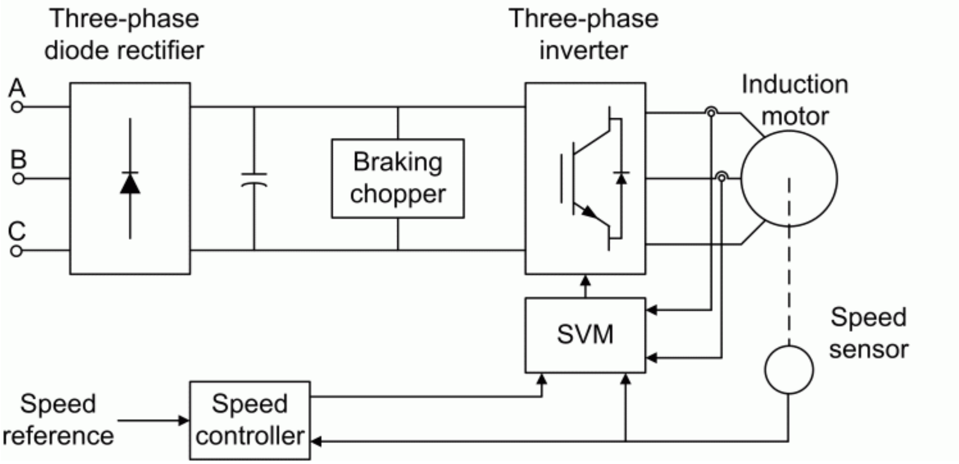
Description



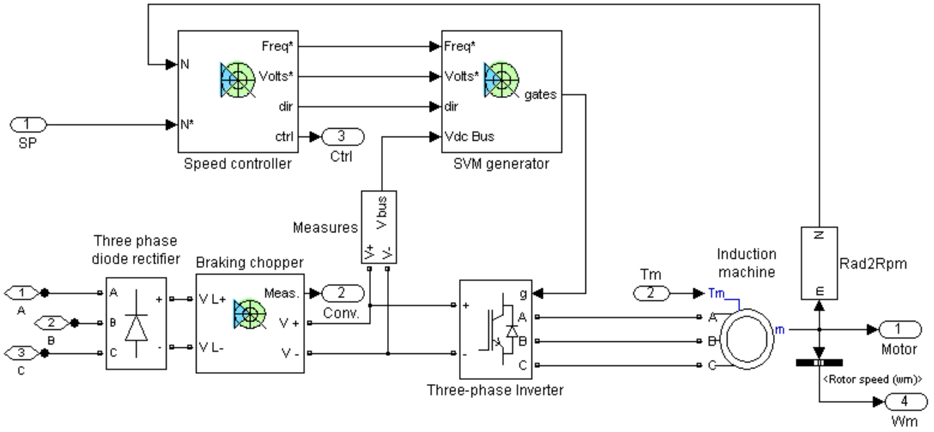
The high-level schematic shown below is built from six main blocks. The induction motor, the three-phase inverter, and the three-phase diode rectifier models are provided with the SimPowerSystems library. More details are available in the reference pages for these blocks. The speed controller, the braking 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

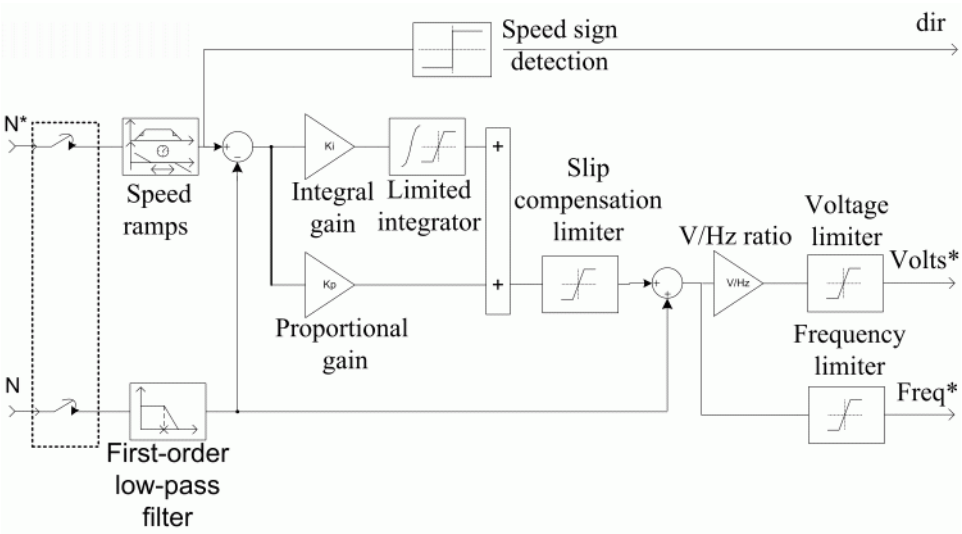


Simulink Schematic



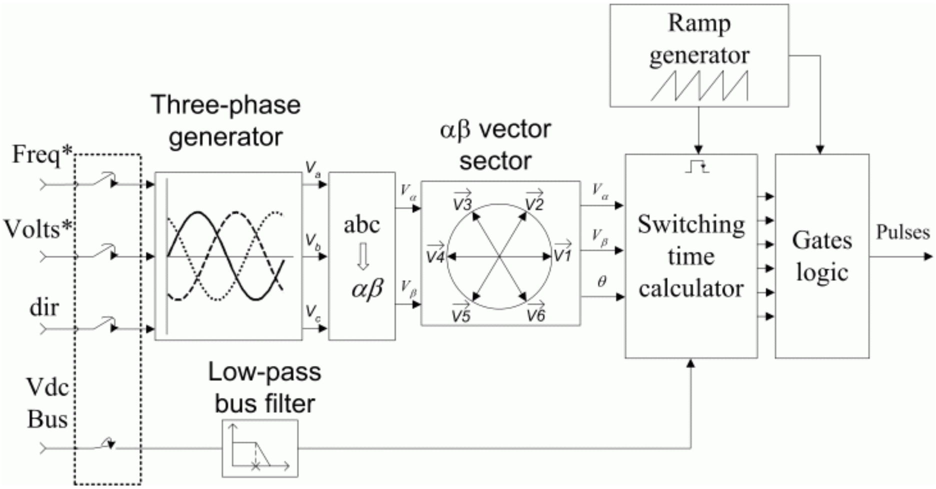
Speed Controller

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.

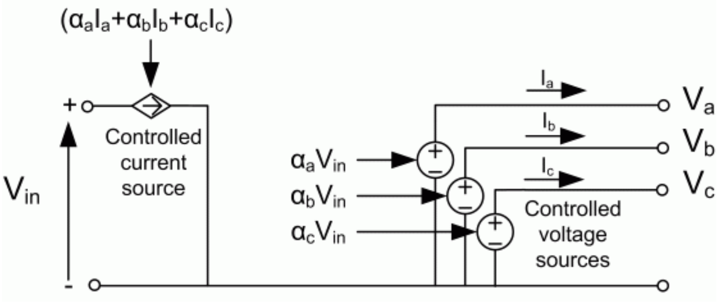
The *switching time calculator* is used to calculate the timing of the voltage vector applied to the motor. The block input is the sector in which the voltage vector lies.

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:

$$I_{dc} = \alpha_a I_a + \alpha_b I_b + \alpha_c I_c$$

with α_a, α_b, α_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:

$$V_a = \alpha_a V_{in}$$

$$V_b = \alpha_b V_{in}$$

$$V_c = \alpha_c V_{in}$$

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.

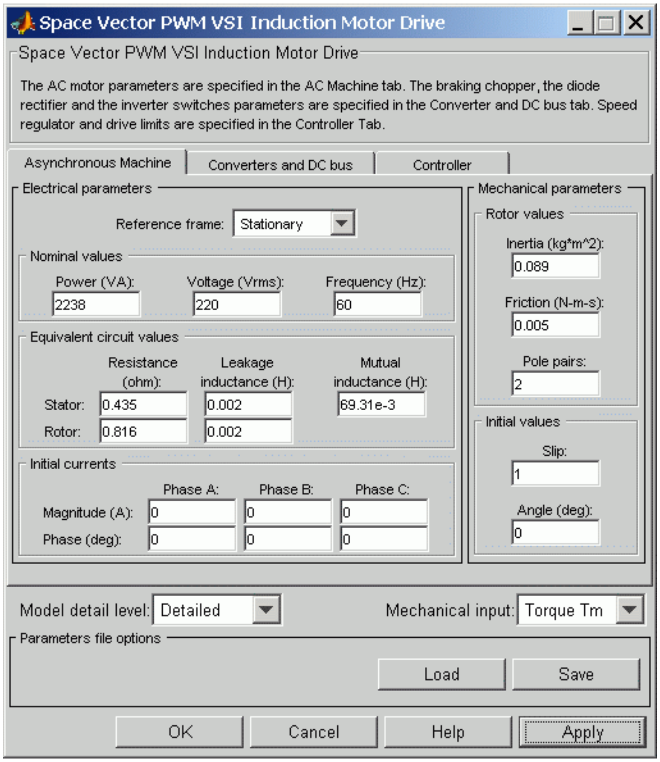
The simulation step size must be chosen in accordance with the inverter's switching frequency. A rule of thumb is to choose a simulation step size 100 times smaller than the switching period. If the simulation step size is set too high, the simulation results can be erroneous. The average-value inverter 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



Space Vector PWM VSI Induction Motor Drive

The AC motor parameters are specified in the AC Machine tab. The braking chopper, the diode rectifier and the inverter switches parameters are specified in the Converter and DC bus tab. Speed regulator and drive limits are specified in the Controller Tab.

Electrical parameters

Reference frame: Stationary

Nominal values

Power (VA): 2238

Voltage (Vrms): 220

Frequency (Hz): 60

Equivalent circuit values

	Resistance (ohm):	Leakage inductance (H):	Mutual inductance (H):
Stator:	0.435	0.002	69.31e-3
Rotor:	0.816	0.002	

Initial currents

	Phase A:	Phase B:	Phase C:
Magnitude (A):	0	0	0
Phase (deg):	0	0	0

Mechanical parameters

Rotor values

Inertia (kg*m^2): 0.089

Friction (N-m-s): 0.005

Pole pairs: 2

Initial values

Slip: 1

Angle (deg): 0

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

The asynchronous machine tab displays the parameters of the asynchronous machine block of the powerlib library. Refer to Asynchronous Machine for more information on the asynchronous machine parameters.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Allows you to select either the load torque or the motor speed as mechanical input. Note that if you select and apply a load torque, you will obtain as output the motor speed according to the following differential equation that describes the mechanical system dynamics:

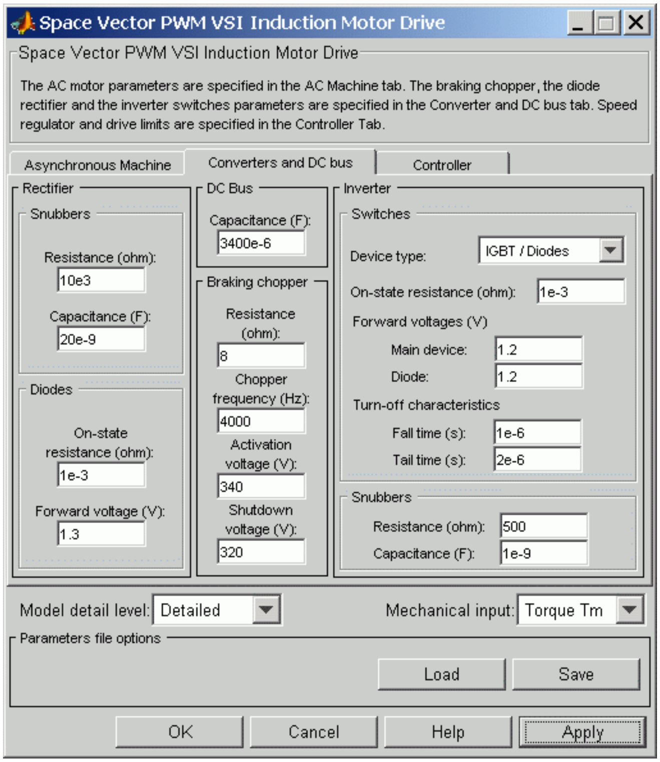
$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

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

See for example “Mechanical Coupling of Two Motor Drives”.

Converters and DC Bus Tab



Space Vector PWM VSI Induction Motor Drive

The AC motor parameters are specified in the AC Machine tab. The braking chopper, the diode rectifier and the inverter switches parameters are specified in the Converter and DC bus tab. Speed regulator and drive limits are specified in the Controller Tab.

Rectifier

Snubbers

Resistance (ohm): 10e3

Capacitance (F): 20e-9

Diodes

On-state resistance (ohm): 1e-3

Forward voltage (V): 1.3

DC Bus

Capacitance (F): 3400e-6

Braking chopper

Resistance (ohm): 8

Chopper frequency (Hz): 4000

Activation voltage (V): 340

Shutdown voltage (V): 320

Inverter

Switches

Device type: IGBT / Diodes

On-state resistance (ohm): 1e-3

Forward voltages (V)

Main device: 1.2

Diode: 1.2

Turn-off characteristics

Fall time (s): 1e-6

Tail time (s): 2e-6

Snubbers

Resistance (ohm): 500

Capacitance (F): 1e-9

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

Rectifier section

The rectifier section of the Converters and DC bus tab displays the parameters of the Universal Bridge block of the 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 Brige block of the 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

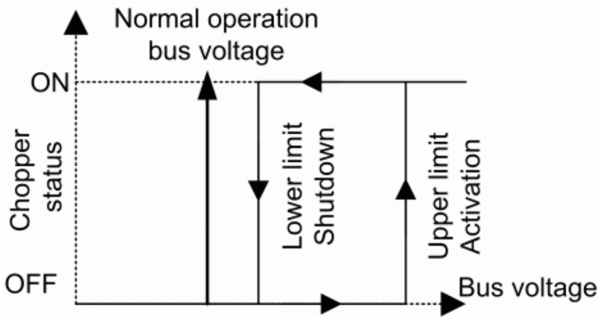
The braking chopper resistance used to avoid bus over-voltage during motor deceleration or when the load torque tends to accelerate the motor (Ω).

Frequency

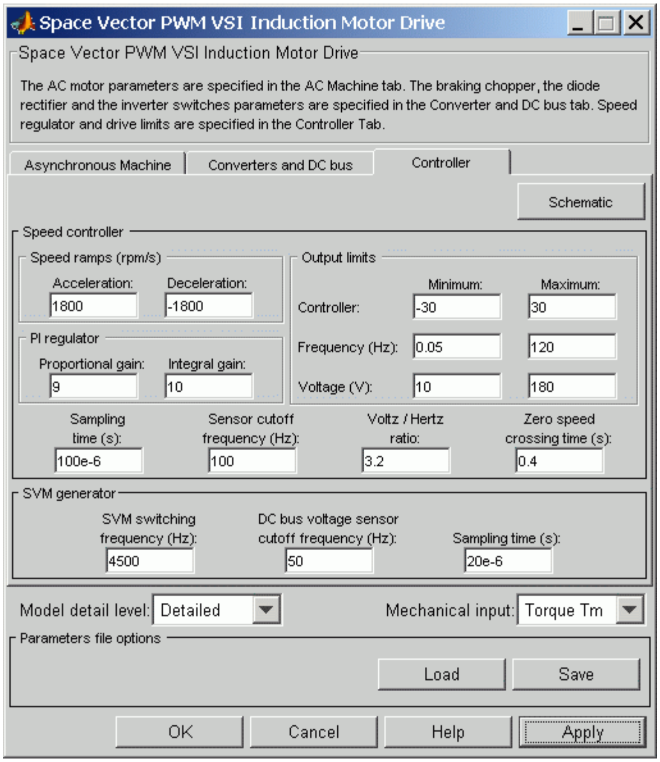
The braking chopper frequency (Hz).

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



Space Vector PWM VSI Induction Motor Drive

The AC motor parameters are specified in the AC Machine tab. The braking chopper, the diode rectifier and the inverter switches parameters are specified in the Converter and DC bus tab. Speed regulator and drive limits are specified in the Controller Tab.

Speed controller

Speed ramps (rpm/s)

Acceleration: 1800

Deceleration: -1800

PI regulator

Proportional gain: 9

Integral gain: 10

Output limits

	Minimum:	Maximum:
Controller:	-30	30
Frequency (Hz):	0.05	120
Voltage (V):	10	180

Sampling time (s): 100e-6

Sensor cutoff frequency (Hz): 100

Voltz / Hertz ratio: 3.2

Zero speed crossing time (s): 0.4

SVM generator

SVM switching frequency (Hz): 4500

DC bus voltage sensor cutoff frequency (Hz): 50

Sampling time (s): 20e-6

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

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. Note that 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).

`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

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

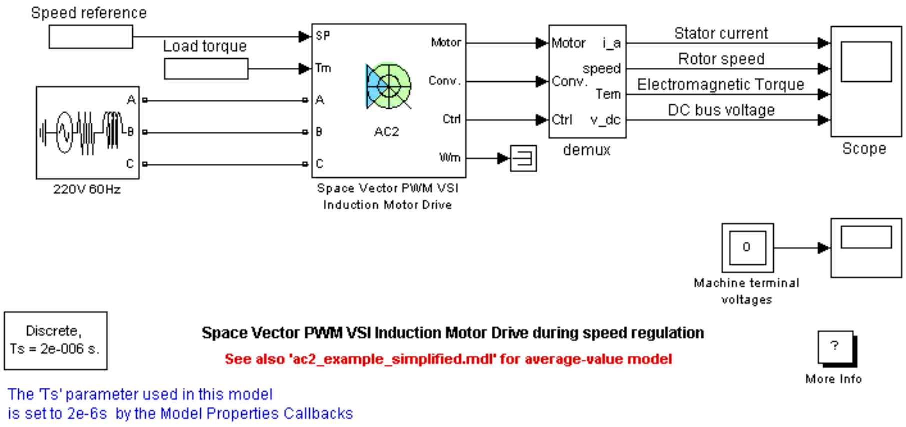
		3 HP Drive	**200 HP Drive**
Drive Input Voltage			
	Amplitude	220 V	575 V
	Frequency	60 Hz	60 Hz

3 HP and 200 HP Drive Specifications (Continued)

Drive Input Voltage		**3 HP Drive**	**200 HP Drive**
Motor Nominal Values			
	Power	3 hp	200 hp
	Speed	1705 rpm	1785 rpm
	Voltage	220 V	575 V

Example

The `ac2_example` demo illustrates an AC2 induction motor drive simulation with standard load conditions. At time t = 0 s, the speed set point is 1000 rpm.

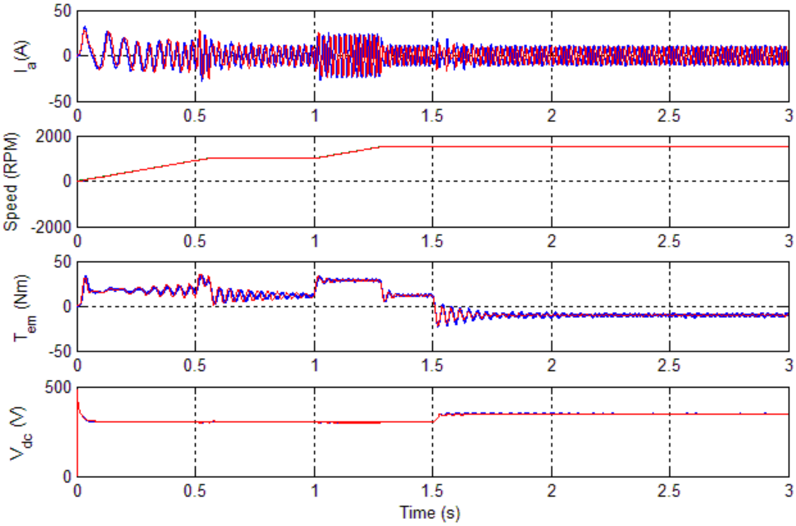


Space Vector PWM VSI Induction Motor Drive during speed regulation

See also 'ac2_example_simplified.mdl' for average-value model

The 'Ts' parameter used in this model is set to 2e-6s by the Model Properties Callbacks

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.

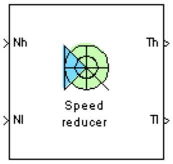
Purpose

Implement speed reducer

Library

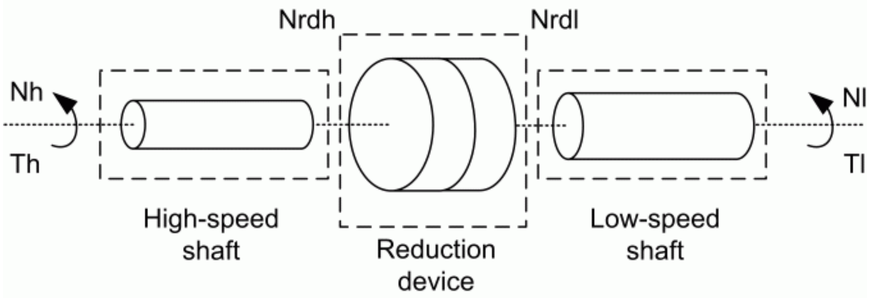
Electric Drives/Shafts and Speed Reducers

Description



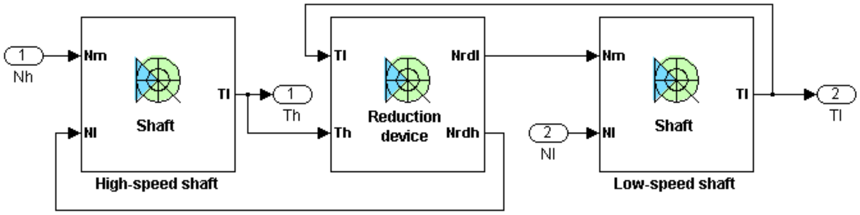
The high-level schematic shown below is built from three main blocks: a high-speed shaft, a reduction device, and a low-speed shaft. More details on the shaft model are included in the Mechanical Shaft reference pages.

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:

$$J_{rdh} \cdot \ddot{\theta}_{rdh} = T_h - \frac{T_l}{(\eta \cdot i)}$$

where J_{rdh} is the inertia of the reduction device with respect to the high-speed side, $\ddot{\theta}_{rdh}$ 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 ($i \geq 1$).

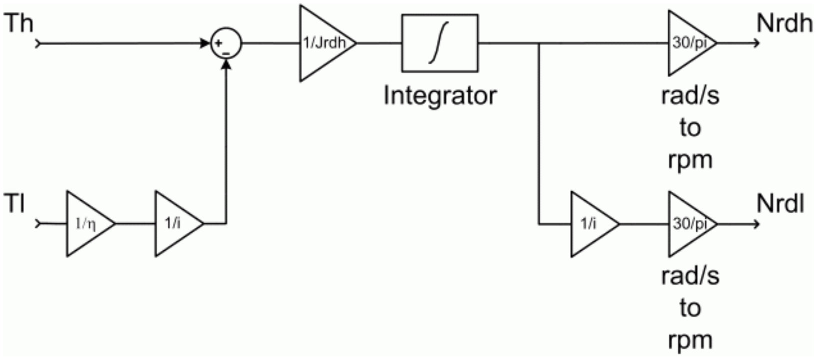
For reduction devices composed of gears, the efficiency varies according to the type of gears, the number of stages (thus the reduction ratio), the lubricant, etc. For small reduction ratios, the efficiency can climb up to 95%. For higher reduction ratios, the efficiency can be as low as 75%. However, 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:

$$N_{rdl} = \frac{N_{rdh}}{i}$$

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

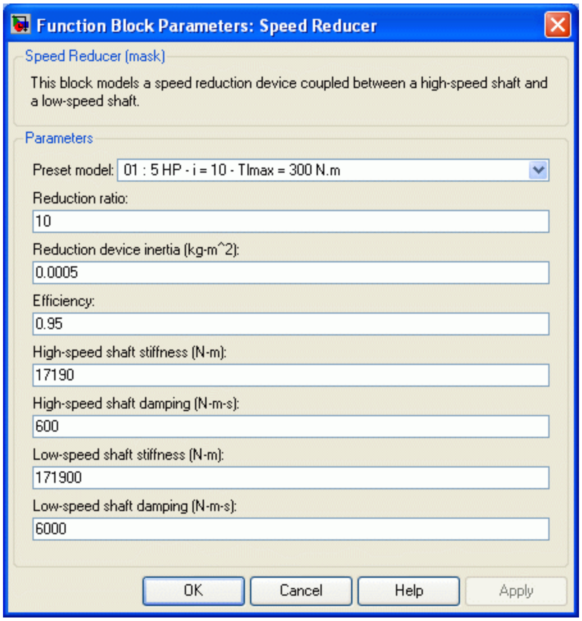
The stiffness of the shafts must be high enough to avoid large angular deflections that could cause misalignment inside the bearings and damage.

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



Speed Reducer (mask)

This block models a speed reduction device coupled between a high-speed shaft and a low-speed shaft.

Parameters

Preset model: 01 : 5 HP - i = 10 - Tlmax = 300 N.m

Reduction ratio: 10

Reduction device inertia (kg-m^2): 0.0005

Efficiency: 0.95

High-speed shaft stiffness (N-m): 17190

High-speed shaft damping (N-m-s): 600

Low-speed shaft stiffness (N-m): 171900

Low-speed shaft damping (N-m-s): 6000

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.

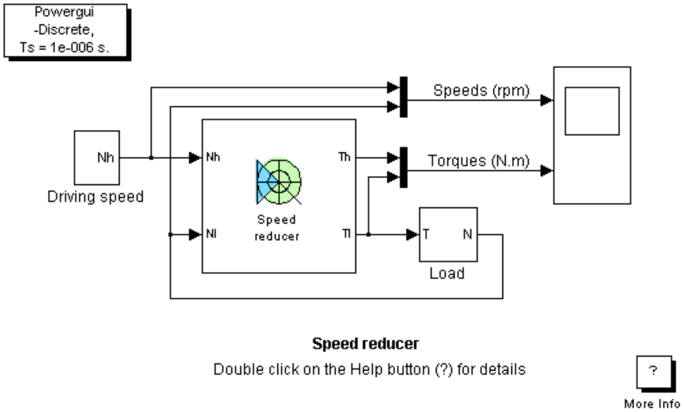
Preset Speed Reducer Models

	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` demo illustrates the speed reducer model.



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.

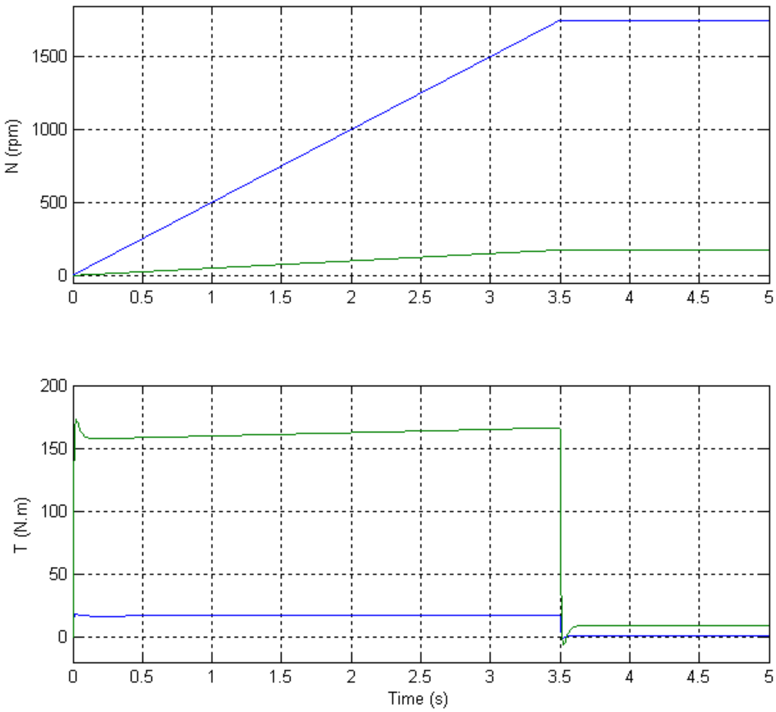
The high-speed shaft has a stiffness of 17190 N.m and an internal damping factor of 600 N.m.s. This shaft is designed to have 0.1 degree of angular deflection for a 30 N.m load torque. The low-speed shaft, having a higher torque to transmit, has a stiffness of 171900 N.m and an internal damping factor 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.

Static Synchronous Compensator (Phasor Type)

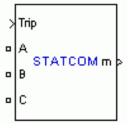
Purpose

Implement phasor model of three-phase static synchronous compensator

Library

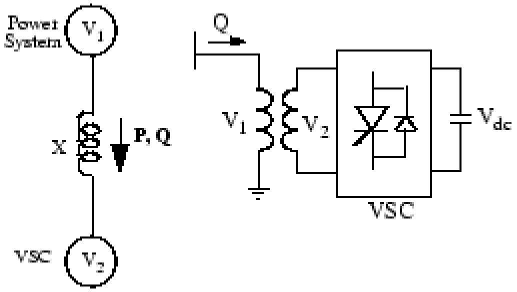
Flexible AC Transmission Systems (FACTS)/Power-Electronics Based FACTS

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.



$$P = \frac{V_1 V_2 \sin\delta}{X}$$

$$Q = \frac{V_1(V_1 - V_2\cos\delta)}{X}$$

where:

V_1 = line to line voltage of source V_1

V_2 = line to line voltage V_2

X = Reactance of interconnection transformer and filters

δ = 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

$$Q = \frac{V_1(V_1 - V_2)}{X}$$

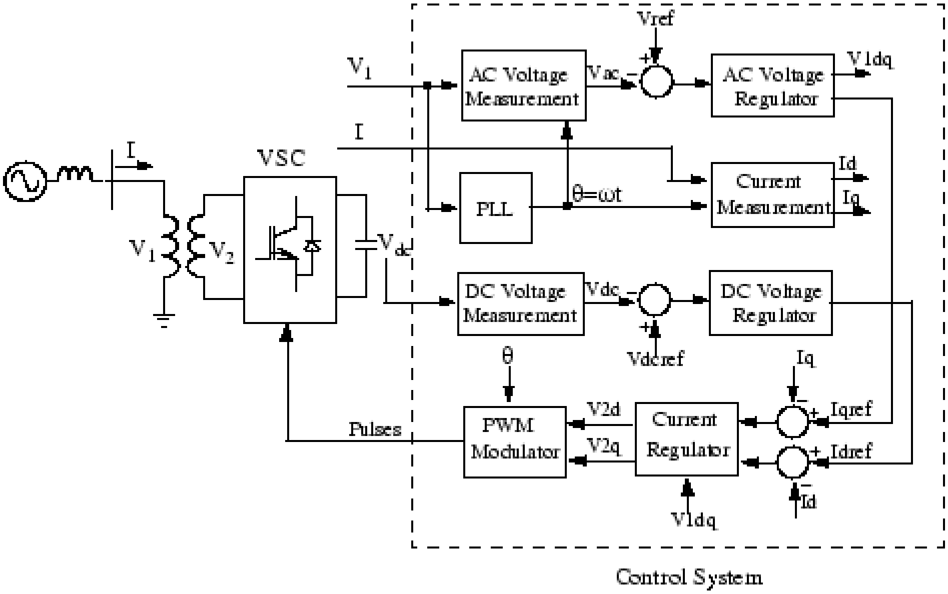
A capacitor connected on the DC side of the VSC acts as a DC voltage source. In steady state the voltage V2 has to be phase shifted slightly behind V1 in order to compensate for transformer and VSC losses and to keep the capacitor charged. Two VSC technologies can be used for the VSC:

- 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 demo library (`power_statcom_gto48p` demo).

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.

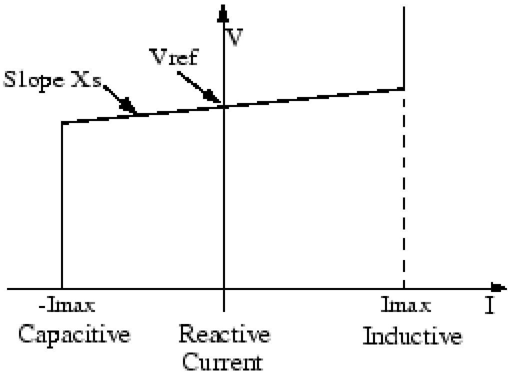
The STACOM block is a phasor model which does not include detailed representations of the power electronics. You must use it with the phasor simulation method, activated with the Powergui block. It can be used in three-phase power systems together with synchronous generators, motors, dynamic loads and other FACTS and DR 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:

$$V = Vref + Xs \cdot I$$

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

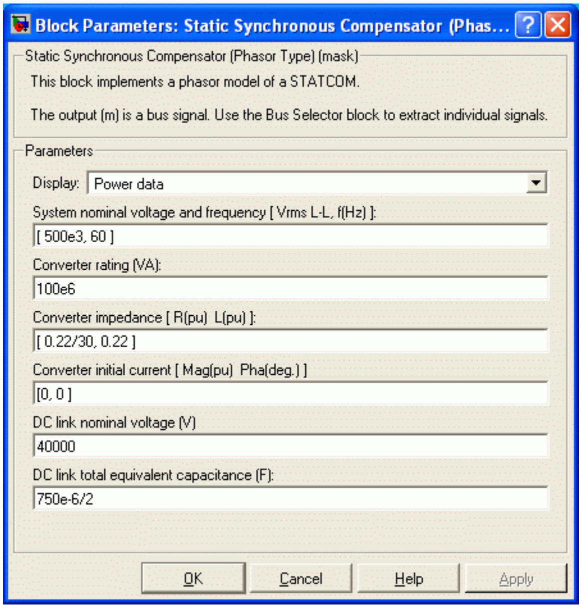
STATCOM vs SVC

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 Data Parameters



Block Parameters: Static Synchronous Compensator (Phas...

Static Synchronous Compensator (Phasor Type) (mask)

This block implements a phasor model of a STATCOM.

The output (m) is a bus signal. Use the Bus Selector block to extract individual signals.

Parameters

Display: Power data

System nominal voltage and frequency [Vrms L-L, f(Hz)]: [500e3, 60]

Converter rating (VA): 100e6

Converter impedance [R(pu) L(pu)]: [0.22/30, 0.22]

Converter initial current [Mag(pu) Pha(deg.)]: [0, 0]

DC link nominal voltage (V): 40000

DC link total equivalent capacitance (F): 750e-6/2

System nominal voltage and frequency [Vrms f]

The nominal line-to-line voltage in Vrms and the nominal system frequency in hertz.

Converter rating Snom

The nominal power of the converter in VA.

Converter impedance [R L]

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 [Mag Phase]

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.

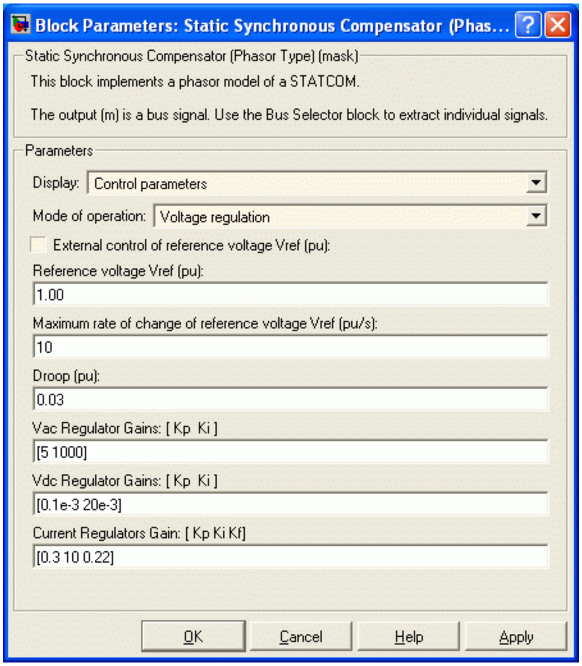
DC link nominal voltage

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 $(1/2 \times C \times Vdc^2)/(Snom)$ 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.

Control Parameters



Static Synchronous Compensator (Phasor Type) (mask)

This block implements a phasor model of a STATCOM.

The output (m) is a bus signal. Use the Bus Selector block to extract individual signals.

Parameters

Display: Control parameters

Mode of operation: Voltage regulation

☐ External control of reference voltage Vref (pu):

Reference voltage Vref (pu): 1.00

Maximum rate of change of reference voltage Vref (pu/s): 10

Droop (pu): 0.03

Vac Regulator Gains: [Kp Ki] [5 1000]

Vdc Regulator Gains: [Kp Ki] [0.1e-3 20e-3]

Current Regulators Gain: [Kp Ki Kf] [0.3 10 0.22]

Mode of operation

Specifies the STATCOM mode of operation. Select either `Voltage regulation` or `Var Control`.

External control of reference voltage Vref

If this parameter is checked, a Simulink input named Vref appears on the block, allowing to control the reference voltage from an external signal (in pu). Otherwise a fixed reference voltage is used, as specified by the parameter below.

Reference voltage Vref

This parameter is not visible when the **Mode of operation** parameter is set to `Var Control` or when the **External control of reference voltage Vref** parameter is checked.

Reference voltage, in pu, used by the voltage regulator.

Maximum rate of change of reference voltage Vref

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.
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.

Signal	Signal Group	Signal Names	Definition
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` demo which illustrates the steady-state and dynamic performance of a STATCOM regulating voltage on a 500 kV, 60 Hz, system. The demo 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)

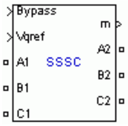
Purpose

Implement phasor model of three-phase static synchronous series compensator

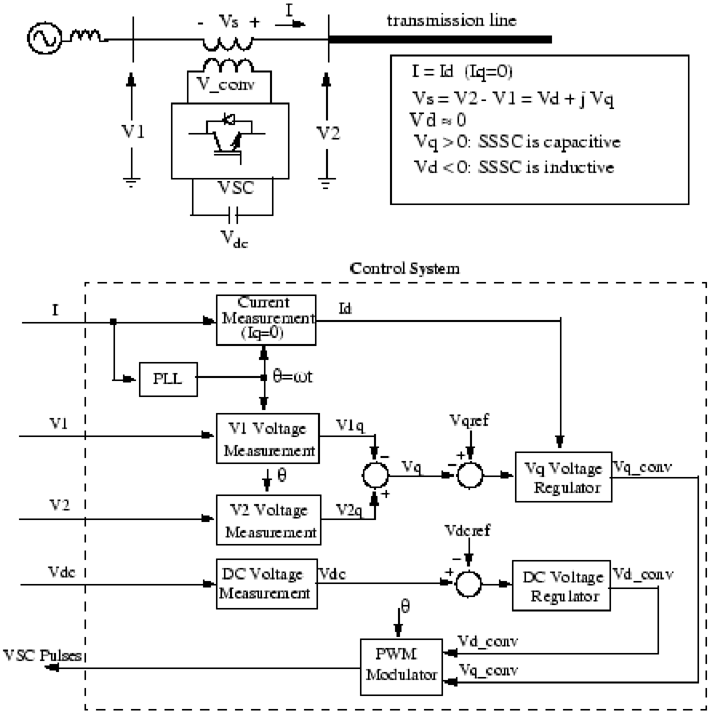
Library

Flexible AC Transmission Systems (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:

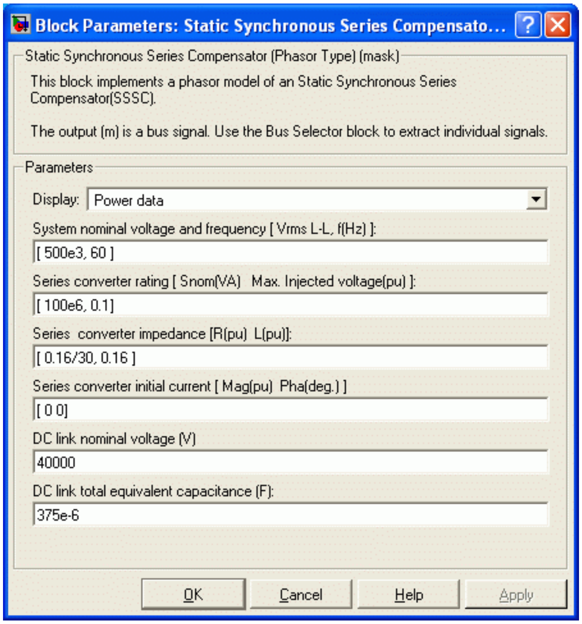
- A phase-locked loop (PLL) which synchronizes on the positive-sequence component of the current I. The output of the PLL (angle Θ=ωt) is used to compute the direct-axis and quadrature-axis components of the AC three-phase voltages and currents (labeled as Vd, Vq or Id, Iq on the diagram).
- Measurement 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 DR 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 Data Parameters



Static Synchronous Series Compensator (Phasor Type) (mask)

This block implements a phasor model of an Static Synchronous Series Compensator(SSSC).

The output (m) is a bus signal. Use the Bus Selector block to extract individual signals.

Parameters

Display: Power data

System nominal voltage and frequency [Vrms L-L, f(Hz)]:
[500e3, 60]

Series converter rating [Snom(VA) Max. Injected voltage(pu)]:
[100e6, 0.1]

Series converter impedance [R(pu) L(pu)]:
[0.16/30, 0.16]

Series converter initial current [Mag(pu) Pha(deg.)]
[0 0]

DC link nominal voltage (V)
40000

DC link total equivalent capacitance (F):
375e-6

System nominal voltage and frequency [Vrms f]

The nominal line-to-line voltage in Vrms and the nominal system frequency in hertz.

Series converter rating [Snom, Max. Injected voltage]

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 [R L]

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 [Mag Phase]

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.

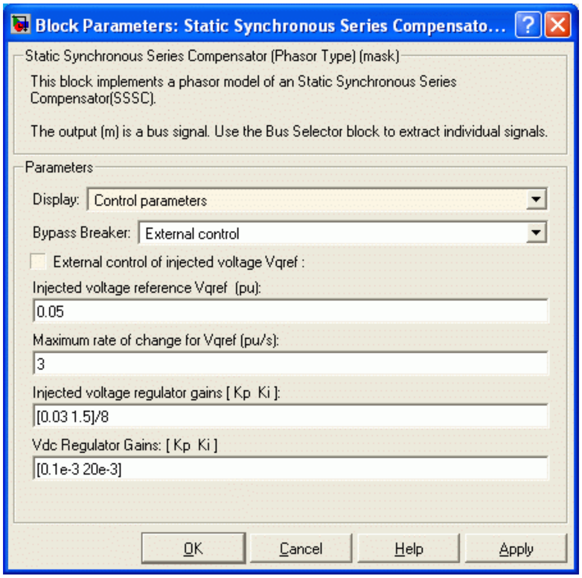
DC link nominal voltage

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 $(1/2 \times C \cdot Vdc^2)/(Snom)$ 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.

Control Parameters



Static Synchronous Series Compensator (Phasor Type) (mask)

This block implements a phasor model of an Static Synchronous Series Compensator(SSSC).

The output (m) is a bus signal. Use the Bus Selector block to extract individual signals.

Parameters

Display: Control parameters

Bypass Breaker: External control

☐ External control of injected voltage Vqref :

Injected voltage reference Vqref (pu): 0.05

Maximum rate of change for Vqref (pu/s): 3

Injected voltage regulator gains [Kp Ki]: [0.03 1.5]/8

Vdc Regulator Gains: [Kp Ki] [0.1e-3 20e-3]

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).

External control of injected voltage Vqref

If this parameter is checked, a Simulink input named Vqref appears on the block, allowing to control the injected voltage from an external signal (in pu). Otherwise a fixed reference voltage is used, as specified by the parameter below.

Injected voltage reference Vqref

This parameter is not visible when the **External control of injected voltage Vqref** parameter is checked.

Specify the quadrature-axis component of the voltage injected on the VSC side of the series transformer, in pu.

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:

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)

Signal	Signal Group	Signal Names	Definition
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` demo 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)

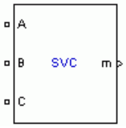
Purpose

Implement phasor model of three-phase static var compensator

Library

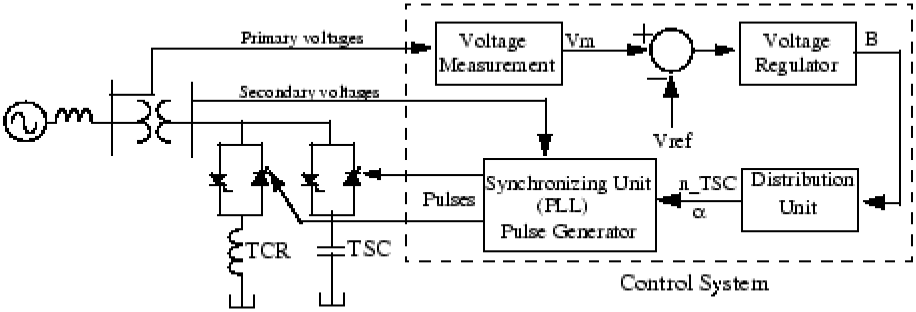
Flexible AC Transmission Systems (FACTS)/Power-Electronics Based FACTS

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.

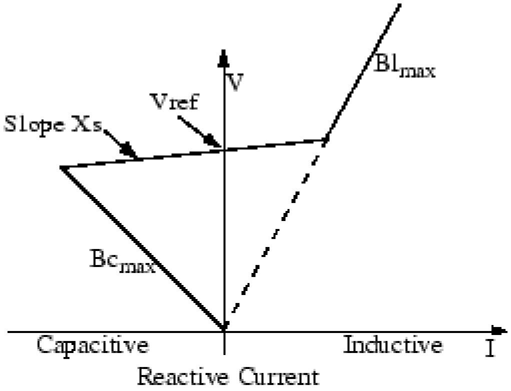
A detailed model of a SVC using three TSCs and one TCR is provided in the `power_svc_1tcr3tsc` demo.

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:

$$V = Vref + Xs \cdot I$$ SVC is in regulation range ($-Bc_{max} < B < Bl_{max}$)

$$V = -\frac{I}{Bc_{max}}$$ SVC is fully capacitive ($B = Bc_{max}$)

$$V = \frac{I}{Bl_{max}}$$ SVC is fully inductive ($B = Bl_{max}$)

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:

$$T_c = \frac{1}{Ki \cdot (Xs + Xn)}$$

where

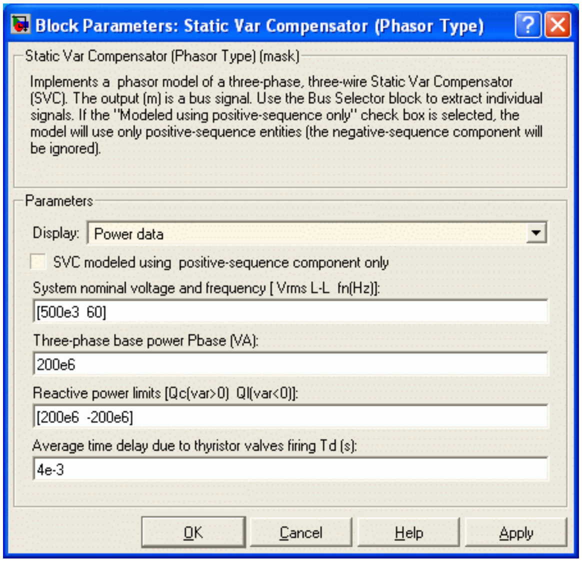
Tc	Closed loop time constant
Ki	Proportional gain of the voltage regulator (pu_B/pu_V/s)
Xs	Slope reactance pu/Pbase
Xn	Equivalent power system reactance (pu/Pbase)

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 Data Parameters



Block Parameters: Static Var Compensator (Phasor Type)

Static Var Compensator (Phasor Type) (mask)

Implements a phasor model of a three-phase, three-wire Static Var Compensator (SVC). The output (m) is a bus signal. Use the Bus Selector block to extract individual signals. If the "Modeled using positive-sequence only" check box is selected, the model will use only positive-sequence entities (the negative-sequence component will be ignored).

Parameters

Display: Power data

☐ SVC modeled using positive-sequence component only

System nominal voltage and frequency [Vrms L-L fn(Hz)]: [500e3 60]

Three-phase base power Pbase (VA): 200e6

Reactive power limits [Qc(var>0) Ql(var<0)]: [200e6 -200e6]

Average time delay due to thyristor valves firing Td (s): 4e-3

SVC modeled using positive-sequence only

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.

System nominal voltage and frequency [Vrms f]

The nominal line-to-line voltage in Vrms and the nominal system frequency in hertz.

Three-phase base power Pbase

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.

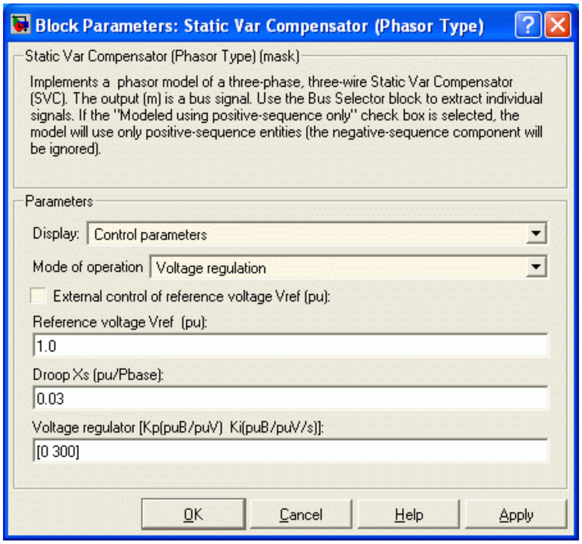
Reactive power limits [Qc Ql]

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 Td

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.

Control Parameters



Block Parameters: Static Var Compensator (Phasor Type)

Static Var Compensator (Phasor Type) (mask)

Implements a phasor model of a three-phase, three-wire Static Var Compensator (SVC). The output (m) is a bus signal. Use the Bus Selector block to extract individual signals. If the "Modeled using positive-sequence only" check box is selected, the model will use only positive-sequence entities (the negative-sequence component will be ignored).

Parameters

Display: Control parameters

Mode of operation: Voltage regulation

☐ External control of reference voltage Vref (pu):

Reference voltage Vref (pu): 1.0

Droop Xs (pu/Pbase): 0.03

Voltage regulator [Kp(puB/puV) Ki(puB/puV/s)]: [0 300]

Mode of operation

Specifies the SVC mode of operation. Select either `Voltage regulation` or `Var control (Fixed susceptance Bref)`.

External control of reference voltage Vref

If this parameter is checked, a Simulink input named Vref appears on the block, allowing to control the reference voltage from an external signal (in pu). Otherwise a fixed reference voltage is used, as specified by the parameter below.

Reference voltage Vref

This parameter is not visible when the **Mode of operation** parameter is set to `Var Control` or when the **External control of reference voltage Vref** parameter is checked

Reference voltage, in pu, used by the voltage regulator.

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 [Kp Ki]

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.

Bref for var control mode

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.

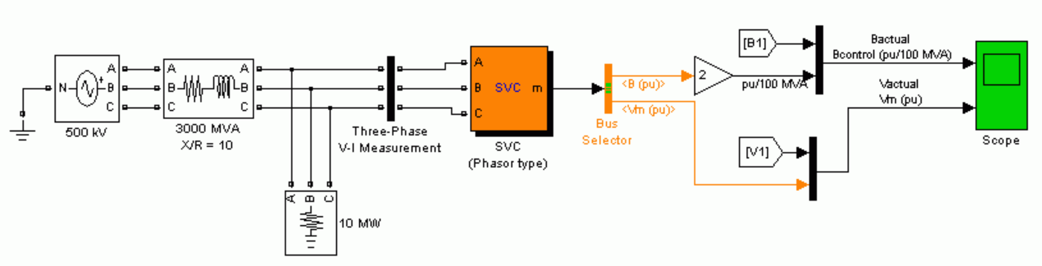
`m`

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)
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

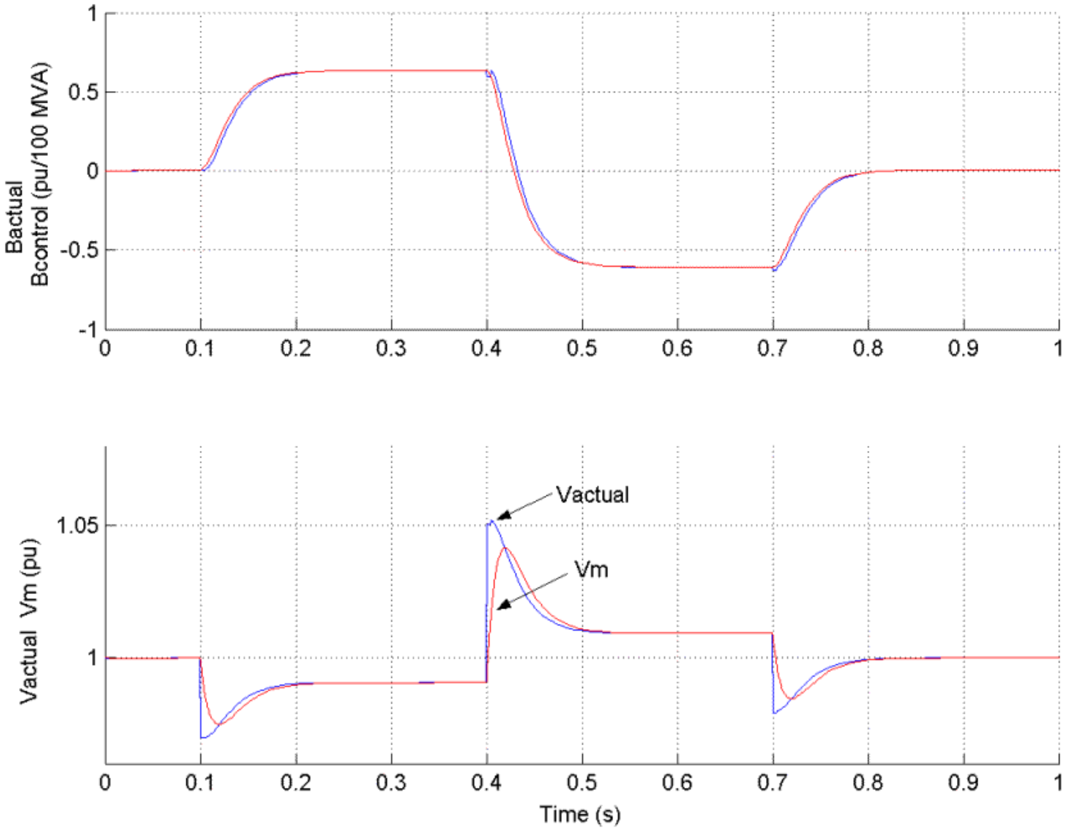
The `power_svc` demo illustrates the steady-state and dynamic performance of a +200 Mvar/- 100 Mvar SVC regulating voltage on a 500 kV, 60 Hz, system.



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.



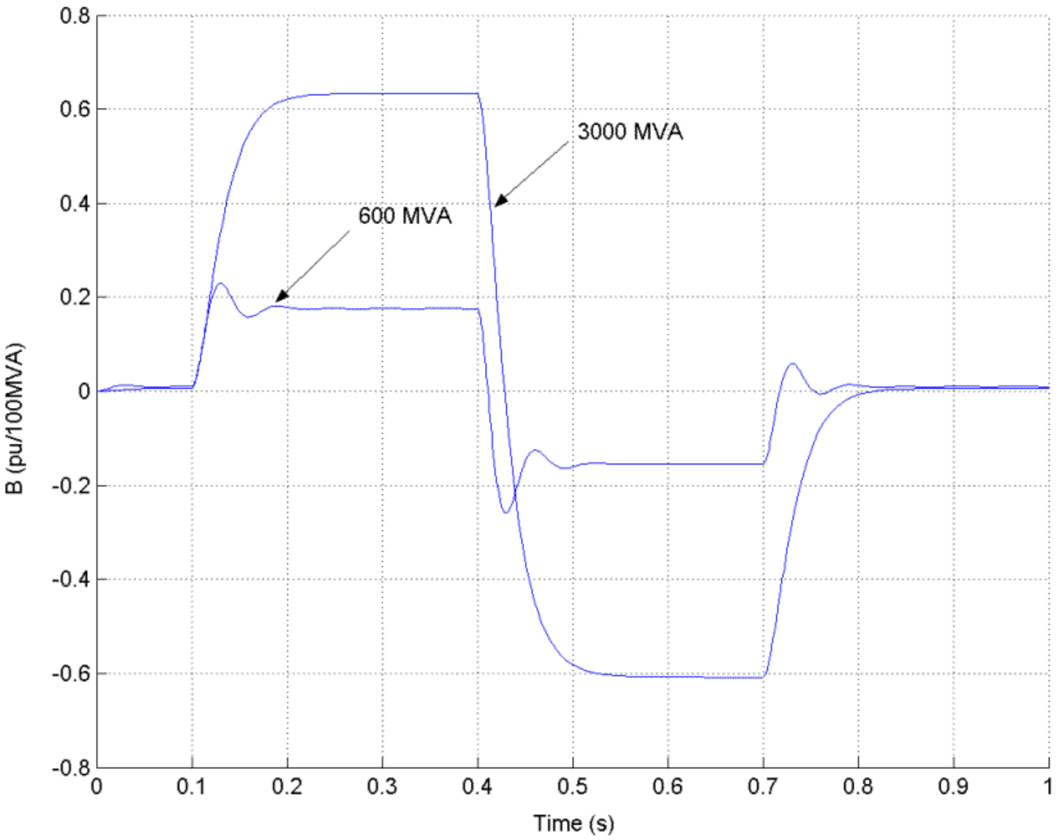
The SVC response speed depends on the voltage regulator integral gain Ki (proportional gain Kp is set to zero), system strength (reactance Xn), and droop (reactance Xs).

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:

$$T_c = \frac{1}{Ki \cdot (Xs + Xn)}$$

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

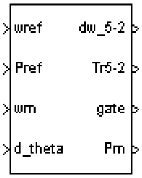
Purpose

Model the dynamics of speed governing system, steam turbine, and multimass shaft

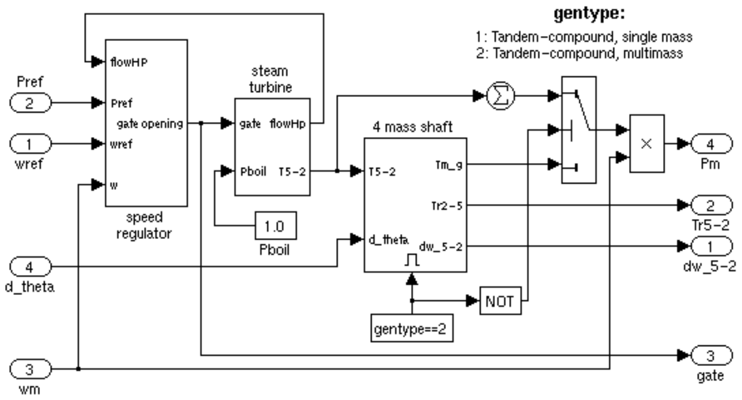
Library

Machines

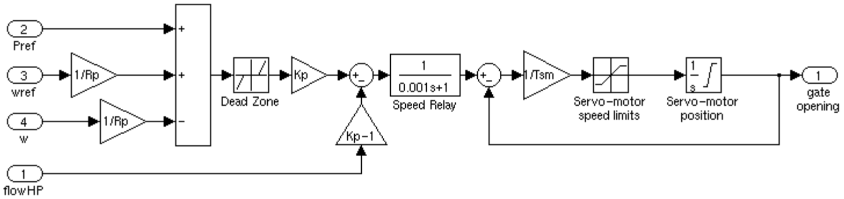
Description



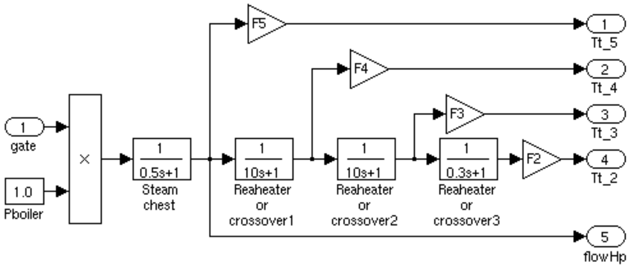
The Steam Turbine and Governor block implements a complete tandem-compound steam prime mover, including a speed governing system, a four-stage steam turbine, and a shaft with up to four masses.



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].

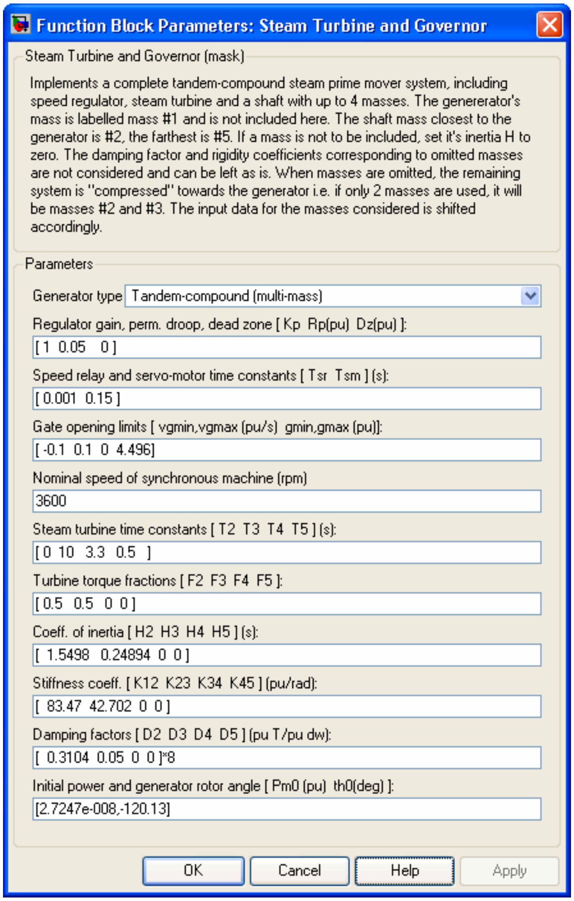


The steam turbine has four stages, each modeled by a first-order transfer function. The first stage represents the steam chest while the three other stages represent either reheaters or crossover piping. The boiler is not modeled and boiler pressure is constant at 1.0 pu. Fractions F2 to F5 are used 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



Steam Turbine and Governor (mask)

Implements a complete tandem-compound steam prime mover system, including speed regulator, steam turbine and a shaft with up to 4 masses. The genererator's mass is labelled mass #1 and is not included here. The shaft mass closest to the generator is #2, the farthest is #5. If a mass is not to be included, set it's inertia H to zero. The damping factor and rigidity coefficients corresponding to omitted masses are not considered and can be left as is. When masses are omitted, the remaining system is "compressed" towards the generator i.e. if only 2 masses are used, it will be masses #2 and #3. The input data for the masses considered is shifted accordingly.

Parameters

Generator type: Tandem-compound (multi-mass)

Regulator gain, perm. droop, dead zone [Kp Rp(pu) Dz(pu)]: [1 0.05 0]

Speed relay and servo-motor time constants [Tsr Tsm] (s): [0.001 0.15]

Gate opening limits [vgmin,vgmax (pu/s) gmin,gmax (pu)]: [-0.1 0.1 0 4.496]

Nominal speed of synchronous machine (rpm): 3600

Steam turbine time constants [T2 T3 T4 T5] (s): [0 10 3.3 0.5]

Turbine torque fractions [F2 F3 F4 F5]: [0.5 0.5 0 0]

Coeff. of inertia [H2 H3 H4 H5] (s): [1.5498 0.24894 0 0]

Stiffness coeff. [K12 K23 K34 K45] (pu/rad): [83.47 42.702 0 0]

Damping factors [D2 D3 D4 D5] (pu T/pu dw): [0.3104 0.05 0 0]*8

Initial power and generator rotor angle [Pm0 (pu) th0(deg)]: [2.7247e-008,-120.13]

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.

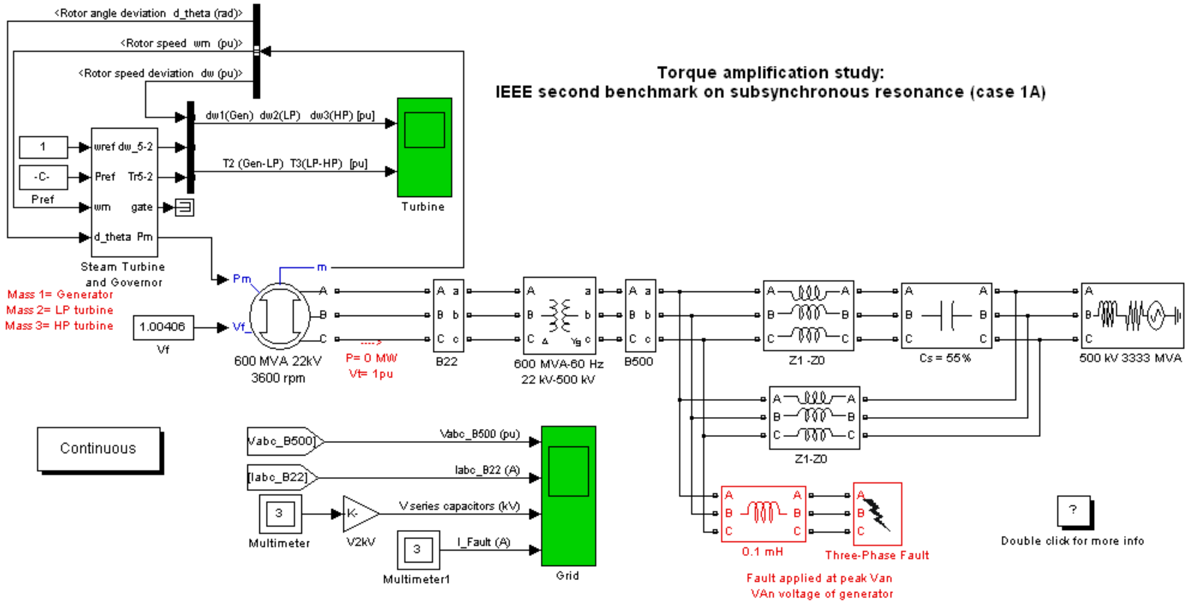
`gate`
Gate opening in pu.

`Pm`
The mechanical power, in pu, that you connect to the first input of a Synchronous Machine block.

Example

The `power_thermal` demo 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`.

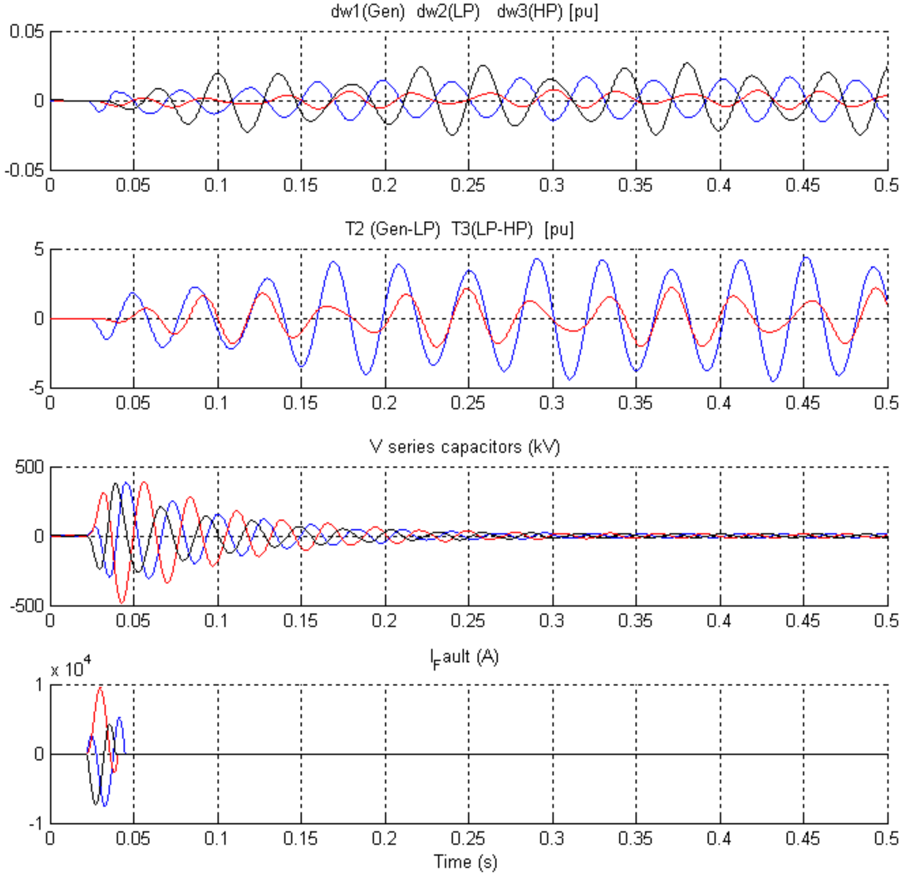
This system is slightly different from the one presented in [2]. Since we are using the Synchronous Machine mass as the first mass, we cannot model the exciter's mass as is done in [2]. Therefore, our system has only three masses, representing the generator's rotor (mass #1) and the turbine's low and 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 **Load Flow and Machine Initialization** utility 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

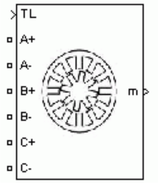
Purpose

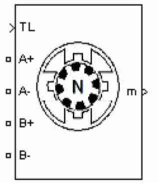
Implement stepper motor model

Library

Machines

Description



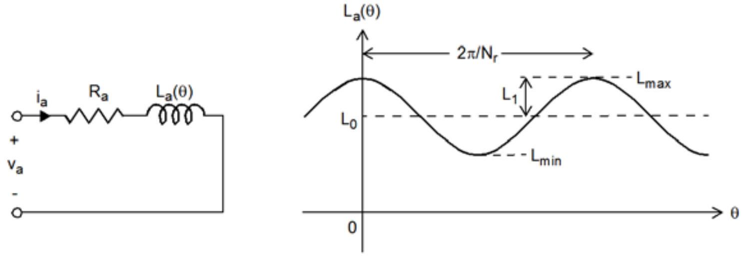


The Stepper Motor (STM) block implements a generic model that represents two most popular families of stepper motors:

- 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.

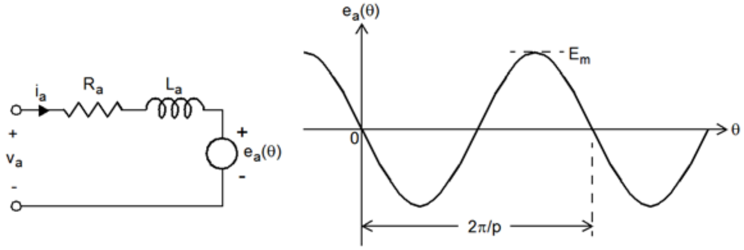
Note that at the reference position ($\Theta = 0$), the rotor tooth is fully aligned with A-axis pole so that the A-phase winding inductance is then maximum.

The total electromagnetic torque produced by the motor is the sum of the torques produced by the motor phases:

$$T_e = \sum_{x=1}^{m} 0.5 i_x^2 \frac{dL_x}{d\theta}$$

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:

$$e_a(\theta) = -p\psi_m \sin(p\theta)\frac{d\theta}{dt}$$

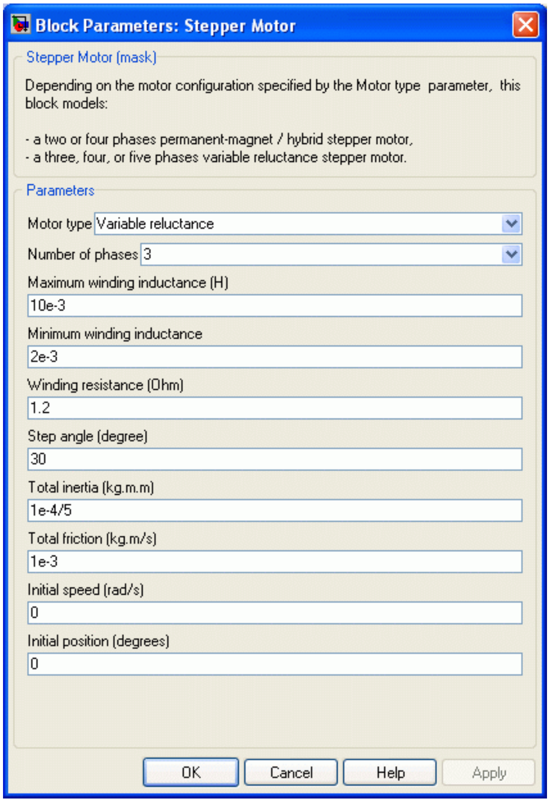
where p is the number of pole pairs and ψ_m is the motor maximum magnetic flux.

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:

$$T_e = -p\psi_m i_a \sin(p\theta) - p\psi_m i_b \sin\left(p\theta - \frac{\pi}{2}\right) - T_{dm}\sin(2p\theta)$$

Dialog Box and Parameters



Block Parameters: Stepper Motor

Stepper Motor (mask)

Depending on the motor configuration specified by the Motor type parameter, this block models:

- a two or four phases permanent-magnet / hybrid stepper motor,
- a three, four, or five phases variable reluctance stepper motor.

Parameters

Motor type: Variable reluctance

Number of phases: 3

Maximum winding inductance (H): 10e-3

Minimum winding inductance: 2e-3

Winding resistance (Ohm): 1.2

Step angle (degree): 30

Total inertia (kg.m.m): 1e-4/5

Total friction (kg.m/s): 1e-3

Initial speed (rad/s): 0

Initial position (degrees): 0

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

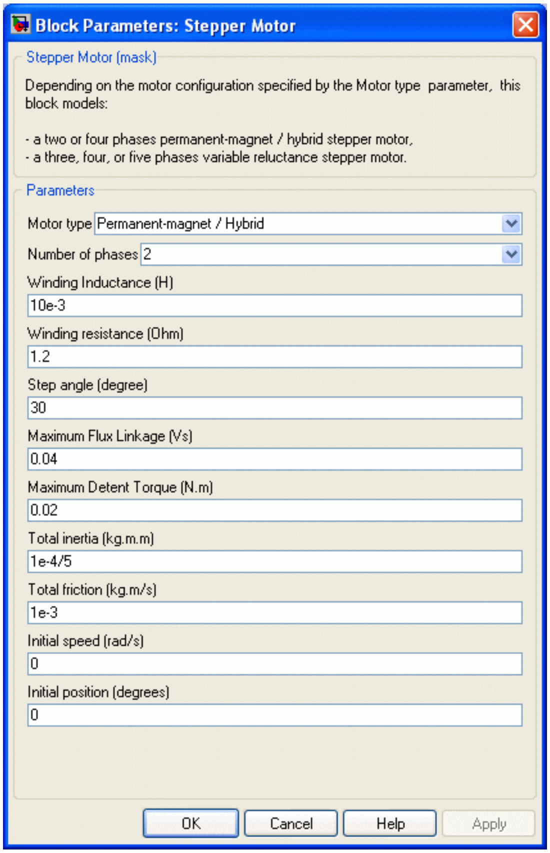
The total viscous friction coefficient B (N.m.s) of the motor and the load.

Initial speed

The initial rotation speed ω_0 (rad/s).

Initial position

The initial rotor position Θ_0 (degrees).



Stepper Motor (mask)

Depending on the motor configuration specified by the Motor type parameter, this block models:

- a two or four phases permanent-magnet / hybrid stepper motor,
- a three, four, or five phases variable reluctance stepper motor.

Parameters

Motor type: Permanent-magnet / Hybrid

Number of phases: 2

Winding Inductance (H): 10e-3

Winding resistance (Ohm): 1.2

Step angle (degree): 30

Maximum Flux Linkage (Vs): 0.04

Maximum Detent Torque (N.m): 0.02

Total inertia (kg.m.m): 1e-4/5

Total friction (kg.m/s): 1e-3

Initial speed (rad/s): 0

Initial position (degrees): 0

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}

Signal	Definition	Units	Symbol
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).

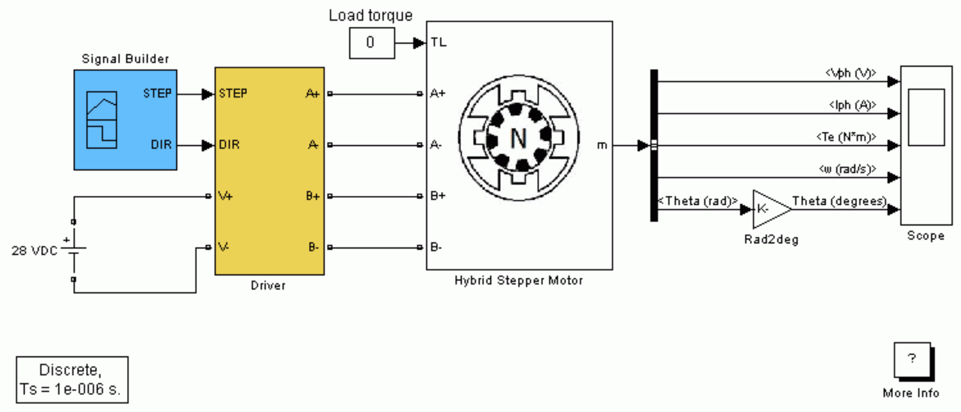
The parameter ψ_m is then computed by the following relation:

$$\psi_m = (30/p\pi)(E_m/N)$$

where p is the number of pole pairs given by $p = \frac{360}{2m \times step}$ (m = phase number, $step$ = step angle in degrees).

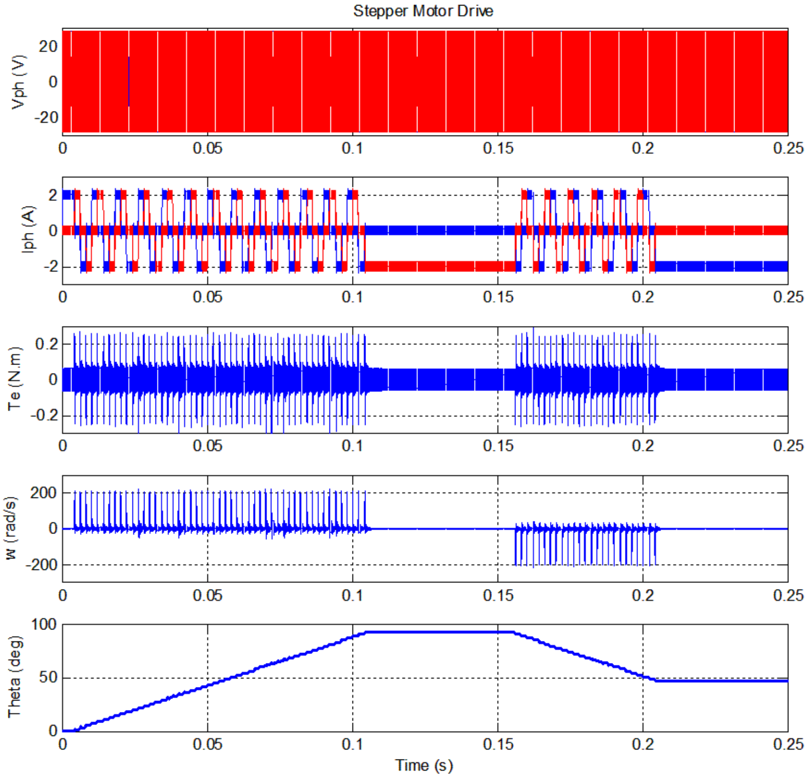
Example

The `power_steppermotor` demo illustrates the operation of a stepper motor drive using a two-phase hybrid stepper motor model.

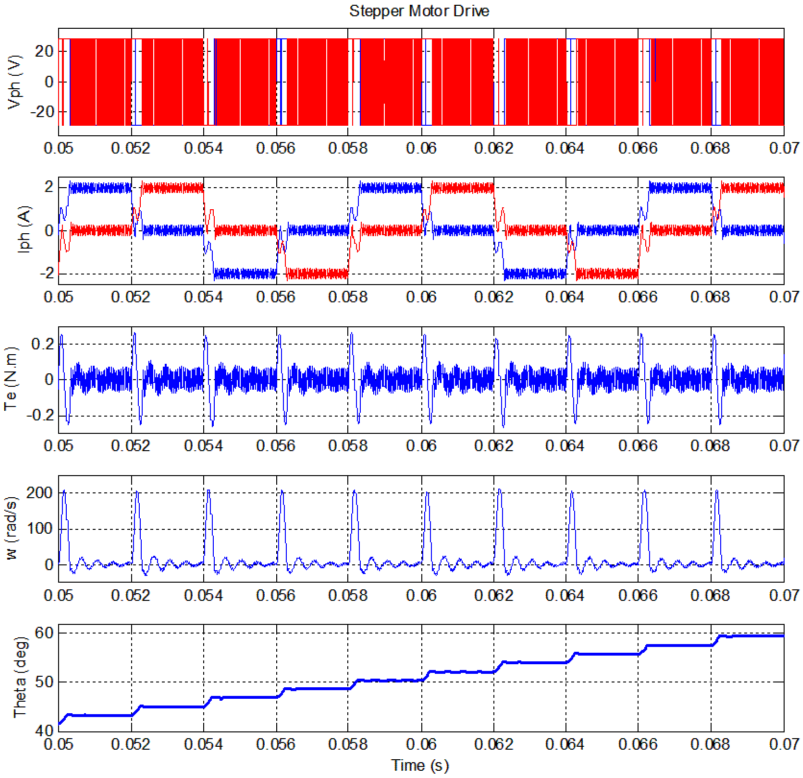


The motor phases are fed by two H-bridge MOSFET PWM converters connected to a 28 V DC voltage source. The motor phase currents are independently controlled by two hysteresis-based controllers which generate the MOSFET drive signals by comparing the measured currents with their references. Square-wave 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.



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.

Surge Arrester

Purpose Implement metal-oxide surge arrester

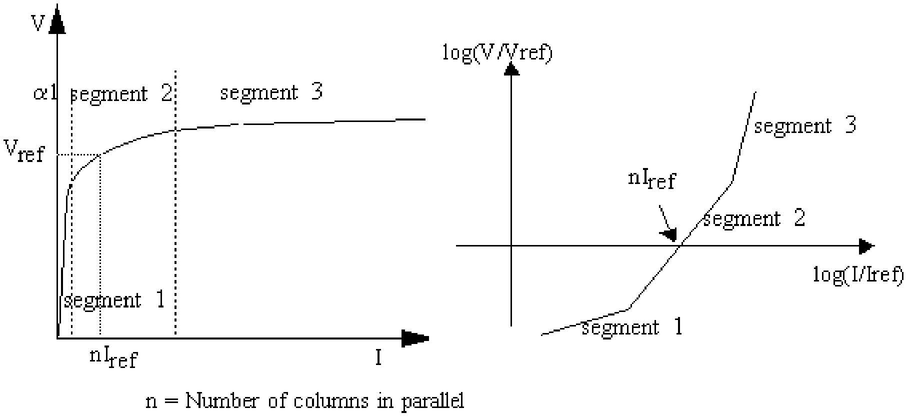
Library Elements

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

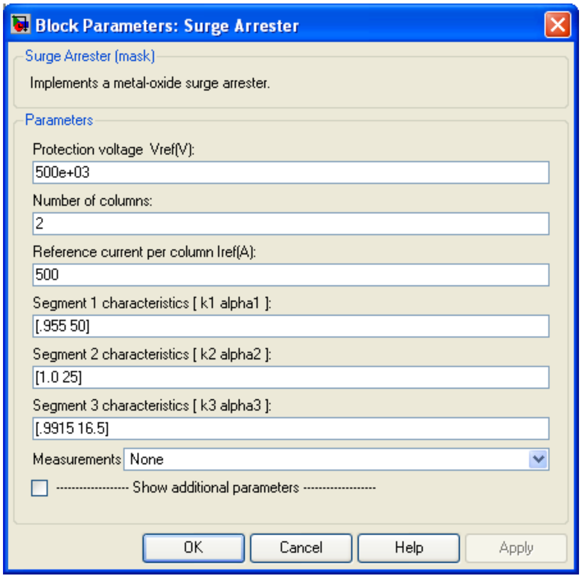
$$\frac{V}{V_{ref}} = k_i\left(\frac{I}{I_{ref}}\right)^{1/\alpha_i}$$

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).



Dialog Box and Parameters



Surge Arrester (mask)

Implements a metal-oxide surge arrester.

Parameters

Protection voltage Vref(V): 500e+03

Number of columns: 2

Reference current per column Iref(A): 500

Segment 1 characteristics [k1 alpha1]: [.955 50]

Segment 2 characteristics [k2 alpha2]: [1.0 25]

Segment 3 characteristics [k3 alpha3]: [.9915 16.5]

Measurements None

☐ ------------------ Show additional 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:`

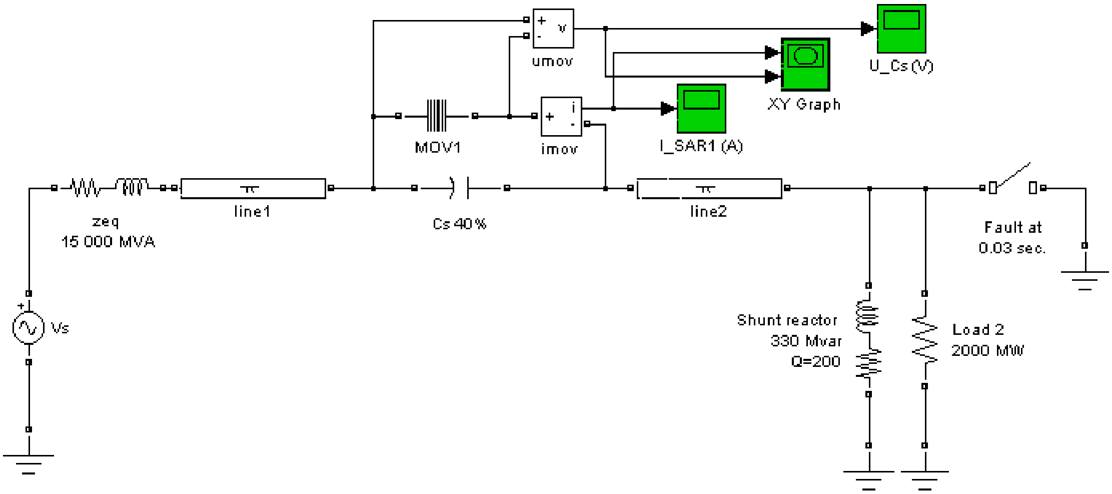
Limitations

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.

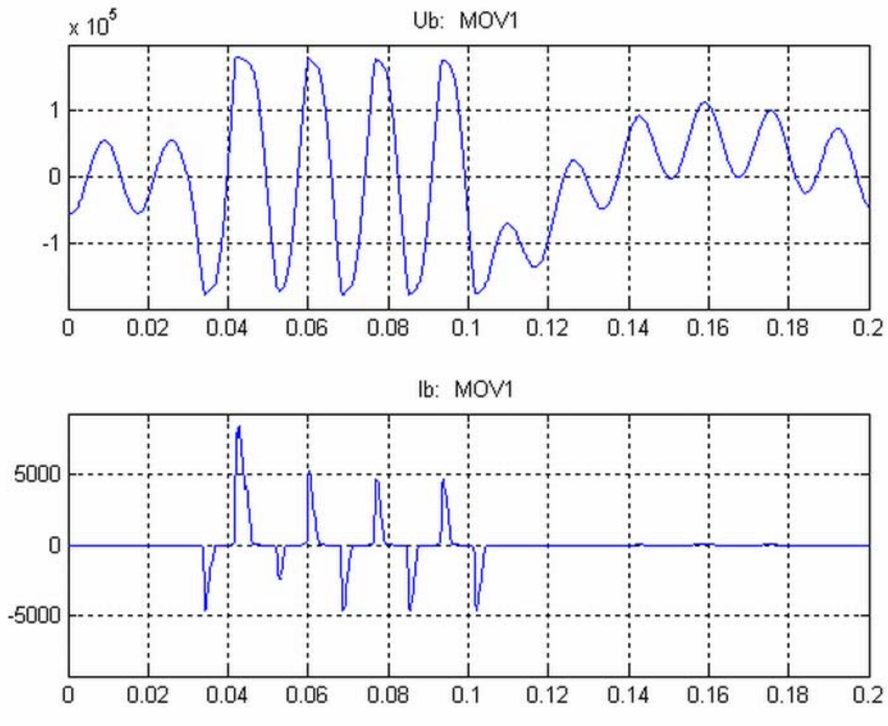
When you use the Surge Arrester block in a discrete system, you will get an algebraic loop. This algebraic loop, which is required in most cases to get an accurate solution, tends to slow down the simulation. However, to speed up the simulation, in some circumstances, you can disable the algebraic loop 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.

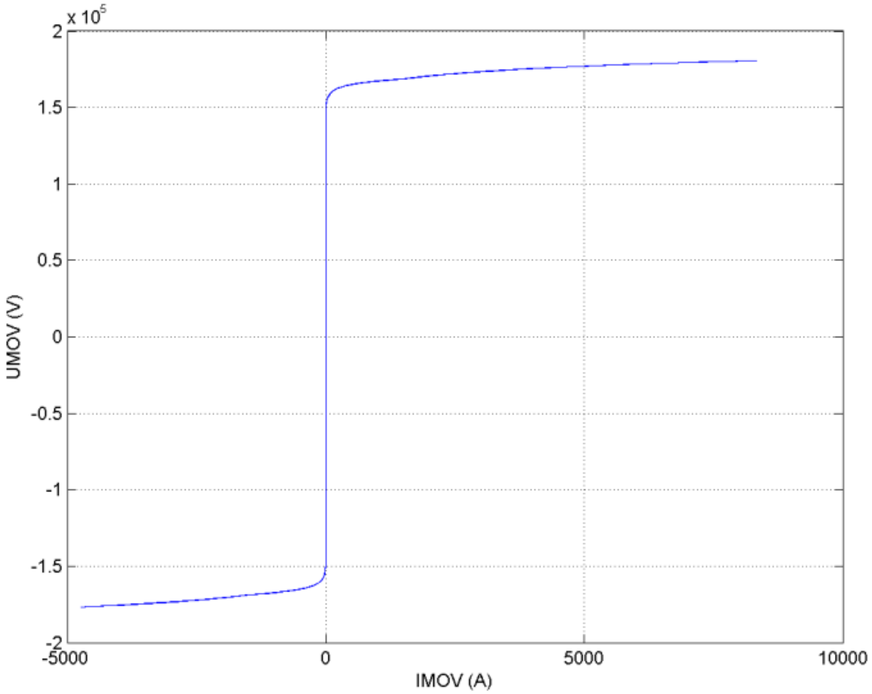
Example

The `power_arrester` demo 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. The waveforms displayed by Umov and Imov measurements as well as the V-I characteristic plotted by the X-Y scope are shown below:


x 10^5
Ub: MOV1
1
0
-1
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
Ib: MOV1
5000
0
-5000
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2



See Also Multimeter

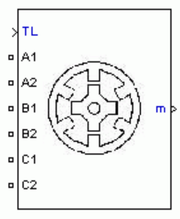
Purpose

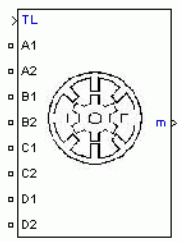
Model the dynamics of switched reluctance motor

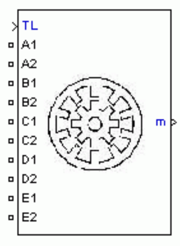
Library

Machines

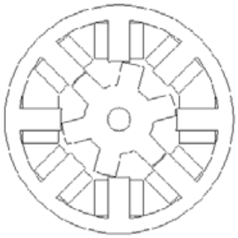
Description





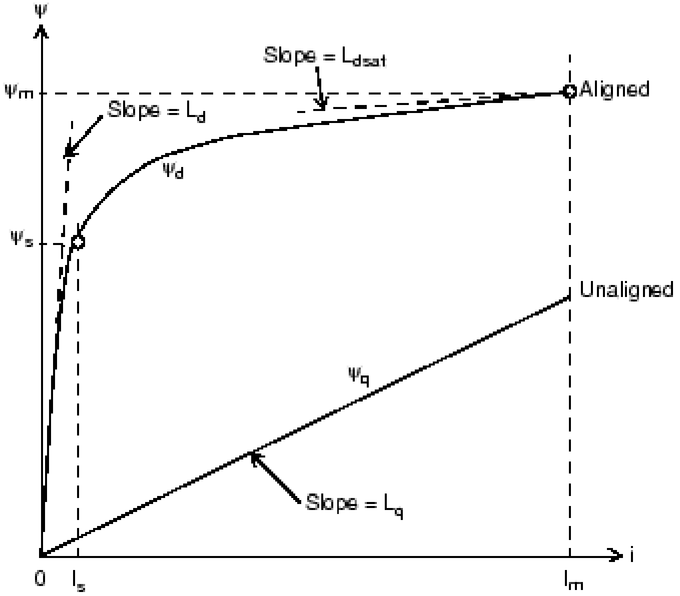


The Switched Reluctance Motor (SRM) block represents three most common switched reluctance motors: three-phase 6/4 SRM, four-phase 8/6 SRM, five-phase 10/8 SRM, as shown in the following figure.



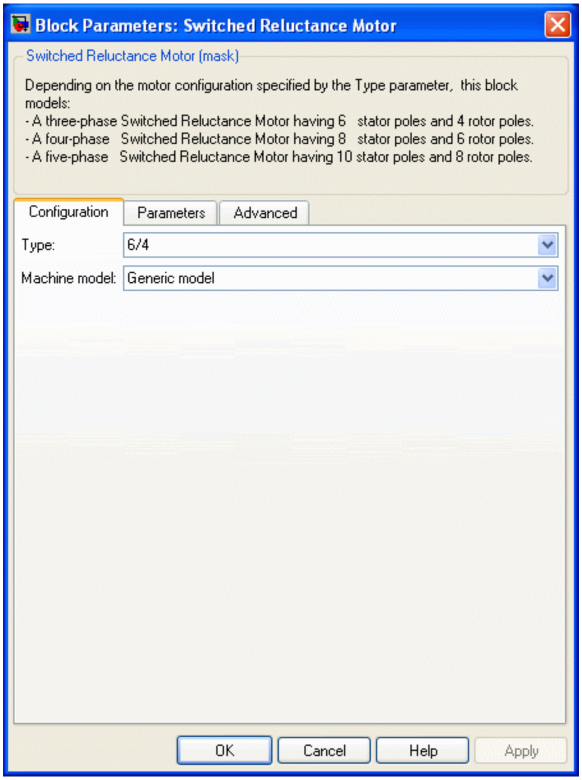
The electric part of the motor is represented by a nonlinear model based on the magnetization characteristic composed of several magnetizing curves and on the torque characteristic computed from the magnetization curves. The mechanic part is represented by a state-space model based on inertia moment 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.


ψ
ψm
ψs
Slope = L_{dsat}
Slope = L_d
Aligned
ψd
Unaligned
ψq
Slope = L_q
0
Is
Im
i

Dialog Box and Parameters

Configuration Tab



Block Parameters: Switched Reluctance Motor

Switched Reluctance Motor (mask)

Depending on the motor configuration specified by the Type parameter, this block models:
- A three-phase Switched Reluctance Motor having 6 stator poles and 4 rotor poles.
- A four-phase Switched Reluctance Motor having 8 stator poles and 6 rotor poles.
- A five-phase Switched Reluctance Motor having 10 stator poles and 8 rotor poles.

Type: 6/4

Machine model: Generic model

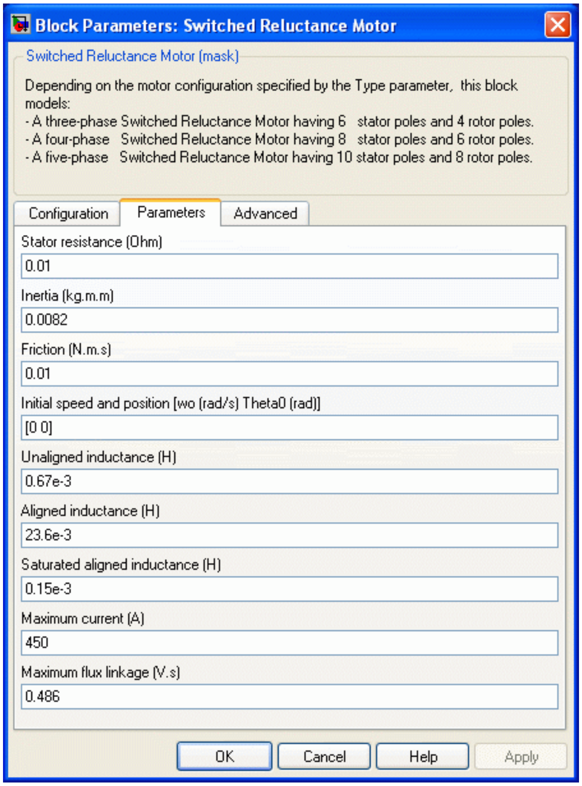
Type

Specifies a three-phase 6/4 motor, four-phase 8/6 motor, or a five-phase 10/8 motor.

Machine model

Select `Generic model` or `Specific model`. The **Parameters** tab is modified accordingly.

Parameters Tab: Generic Model



Switched Reluctance Motor (mask)

Depending on the motor configuration specified by the Type parameter, this block models:
- A three-phase Switched Reluctance Motor having 6 stator poles and 4 rotor poles.
- A four-phase Switched Reluctance Motor having 8 stator poles and 6 rotor poles.
- A five-phase Switched Reluctance Motor having 10 stator poles and 8 rotor poles.

Stator resistance (Ohm): 0.01

Inertia (kg.m.m): 0.0082

Friction (N.m.s): 0.01

Initial speed and position [wo (rad/s) Theta0 (rad)]: [0 0]

Unaligned inductance (H): 0.67e-3

Aligned inductance (H): 23.6e-3

Saturated aligned inductance (H): 0.15e-3

Maximum current (A): 450

Maximum flux linkage (V.s): 0.486

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).

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).

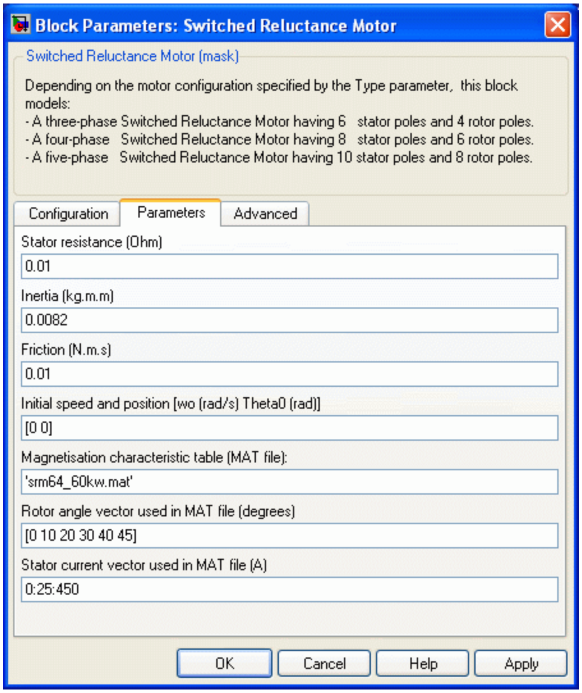
Maximum current

The stator maximum current I_m (A).

Maximum flux linkage

The maximum flux linkage ψ_m (Wb or V.s) corresponding to I_m.

Parameters Tab: Specific Model



Depending on the motor configuration specified by the Type parameter, this block models:
- A three-phase Switched Reluctance Motor having 6 stator poles and 4 rotor poles.
- A four-phase Switched Reluctance Motor having 8 stator poles and 6 rotor poles.
- A five-phase Switched Reluctance Motor having 10 stator poles and 8 rotor poles.

Stator resistance (Ohm): 0.01

Inertia (kg.m.m): 0.0082

Friction (N.m.s): 0.01

Initial speed and position [wo (rad/s) Theta0 (rad)]: [0 0]

Magnetisation characteristic table (MAT file): 'srm64_60kw.mat'

Rotor angle vector used in MAT file (degrees): [0 10 20 30 40 45]

Stator current vector used in MAT file (A): 0:25:450

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

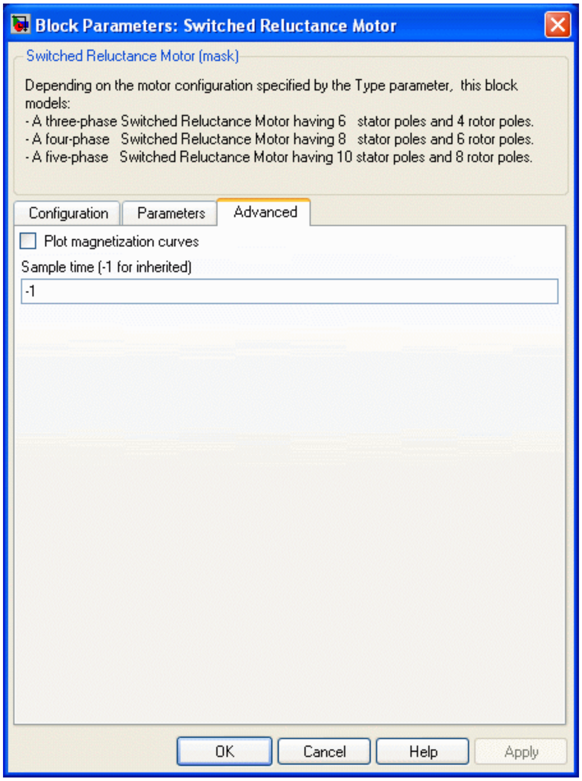
The initial rotation speed w0 (rad/s) and initial rotor position Theta0 (rad).

Rotor angle vector
The rotor position Θ (deg) for which the flux linkage is specified.

Stator current vector
The stator current I_s (A) for which the flux linkage is specified.

Magnetization characteristic
The 2-D lookup table containing the flux linkage as a function of stator current and rotor position.

Advanced Tab



Block Parameters: Switched Reluctance Motor

Switched Reluctance Motor (mask)

Depending on the motor configuration specified by the Type parameter, this block models:
- A three-phase Switched Reluctance Motor having 6 stator poles and 4 rotor poles.
- A four-phase Switched Reluctance Motor having 8 stator poles and 6 rotor poles.
- A five-phase Switched Reluctance Motor having 10 stator poles and 8 rotor poles.

☐ Plot magnetization curves

Sample time (-1 for inherited)

-1

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.

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

`TL`

The block input is the mechanical load torque (in N.m). TL is positive in motor operation and negative in generator operation.

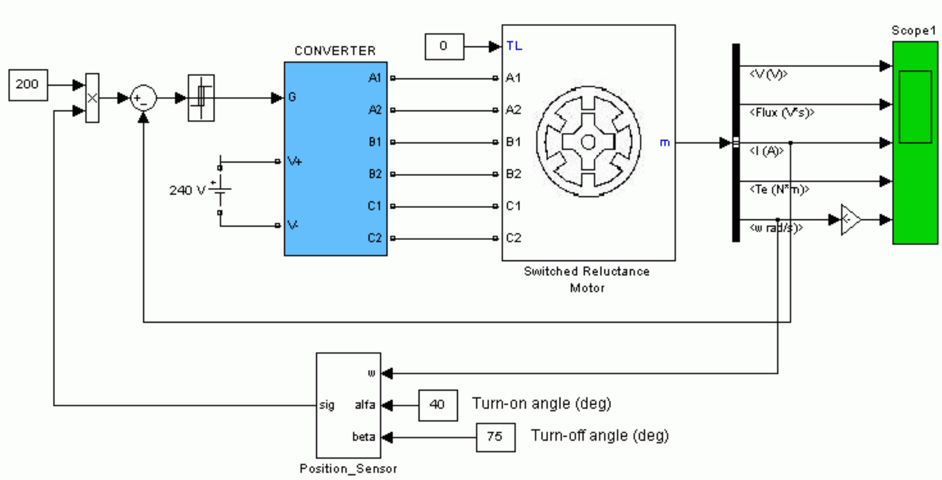
`m`

The block output m is a vector containing several signals. You can demultiplex these signals by using the Bus Selector block from Simulink library.

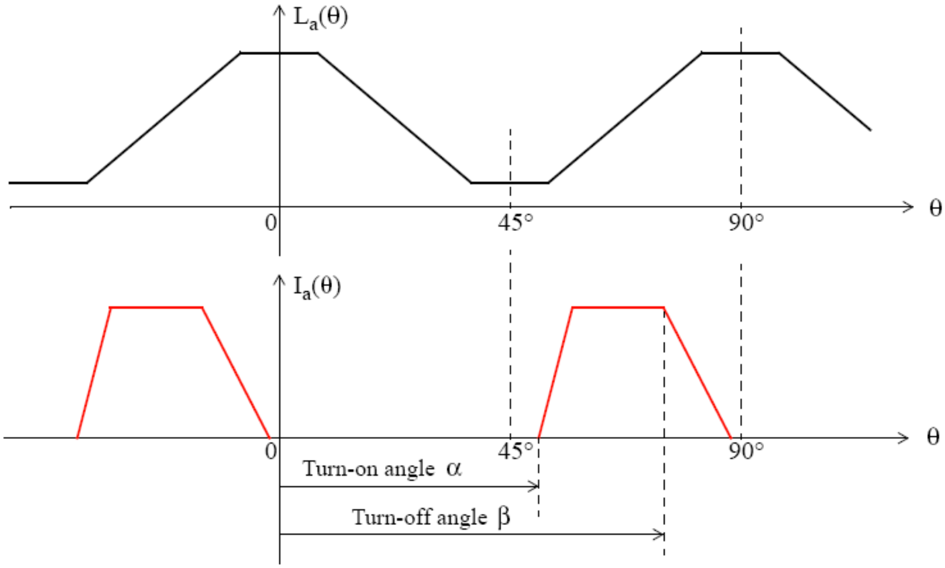
Signal	Definition	Units
V	Stator voltages	V
flux	Flux linkage	V.s
I	Stator currents	A
Te	Electromagnetic torque	N.m
w	Rotor speed	rad/s
teta	Rotor position	rad

Example

The `power_SwitchedReluctanceMotor` demo illustrates the simulation of the Switched Reluctance Motor.



To develop positive torque, the currents in the phases of a SRM must be synchronized 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

Purpose

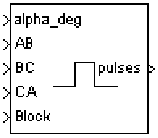
Implement synchronized pulse generator to fire thyristors of six-pulse converter

Library

Extras/Control Blocks

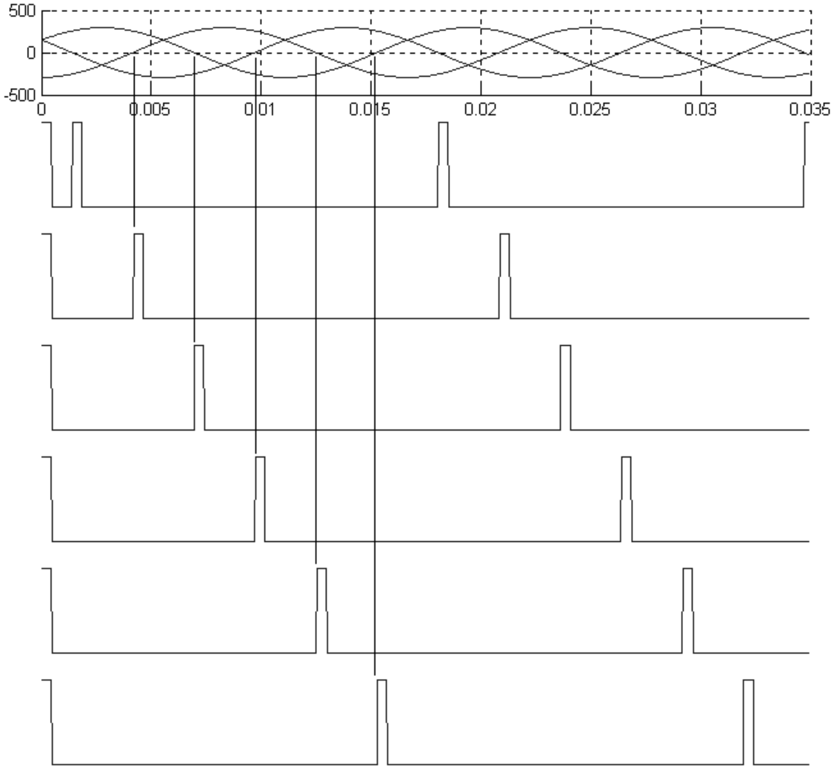
A discrete version of this block is available in the Extras/Discrete Control Blocks library.

Description



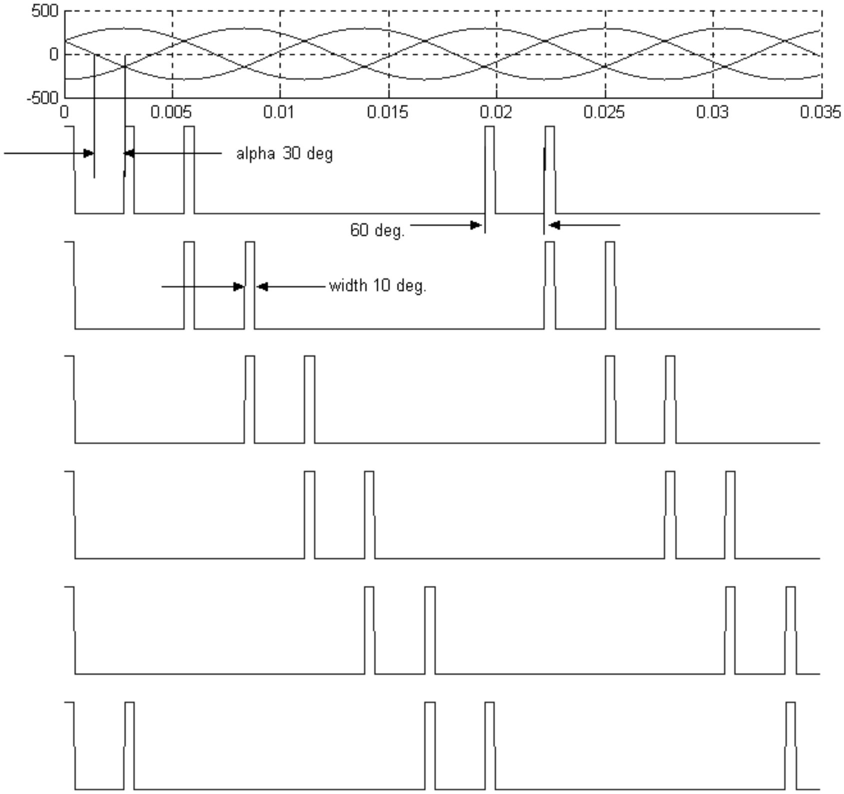
The Synchronized 6-Pulse Generator block can be used to fire the six thyristors of a six-pulse converter. The output of the block is a vector of six pulses individually synchronized on the six thyristor voltages. The pulses are generated alpha degrees after the increasing zero crossings of the thyristor 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.

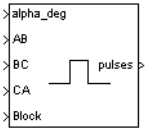


The Synchronized 6-Pulse Generator block can be configured to work in double-pulsing mode. In this mode two pulses are sent to each thyristor: a first pulse when the alpha angle is reached, then a second pulse 60 degrees later, when the next thyristor is fired.

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.

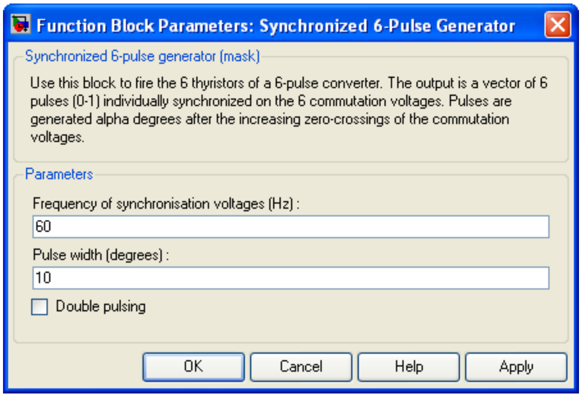


The pulse ordering at the output of the block corresponds to the natural order of commutation of a three-phase thyristor bridge. When you connect the Synchronized 6-Pulse Generator block to the pulses input of the Universal Bridge block (with the thyristors as the power electronic device), the pulses 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



Synchronized 6-pulse generator (mask)

Use this block to fire the 6 thyristors of a 6-pulse converter. The output is a vector of 6 pulses (0-1) individually synchronized on the 6 commutation voltages. Pulses are generated alpha degrees after the increasing zero-crossings of the commutation voltages.

Parameters

Frequency of synchronisation voltages (Hz) : 60

Pulse width (degrees) : 10

☐ Double pulsing

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`

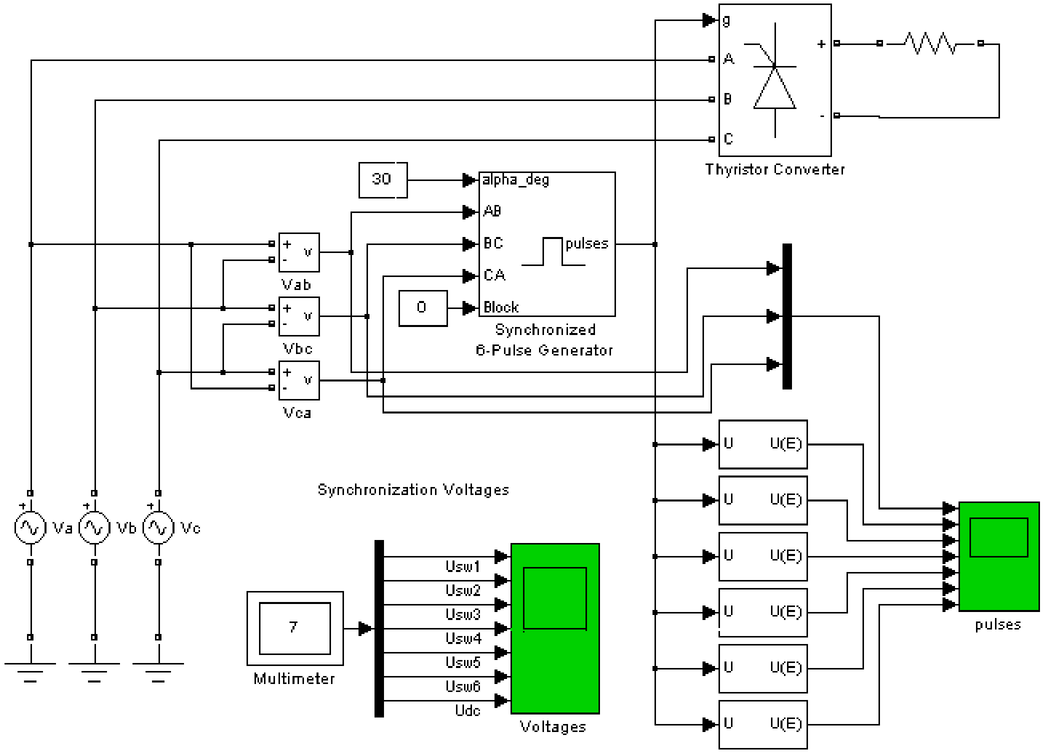
Input 5 allows you to block the operation of the generator. The pulses are disabled when the applied signal is greater than zero.

`pulses`

The output contains the six pulse signals.

Example

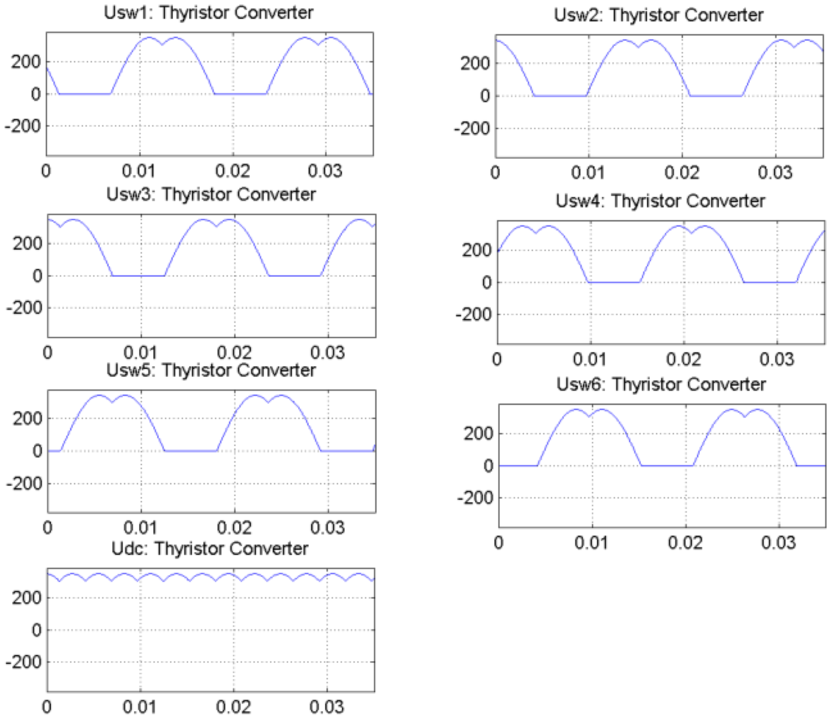
The `power_sixpulses` demo uses a Synchronized 6-Pulse Generator block to fire the thyristors of a six-pulse thyristor bridge. The bridge is fed by a three-phase voltage source (200 V peak line-to-ground or 245 V RMS line-to-line) and it is connected to a resistive load.



A first simulation is performed with an alpha angle of 0 degrees. Open the Constant block connected at input 1 of the Synchronized 6-Pulse Generator block and set its value to 0. Start the simulation. The average voltage is

$$V_{dc} = \frac{3\sqrt{2}}{\pi}E = \frac{3\sqrt{2}}{\pi}245 = 331 \text{ volts}$$

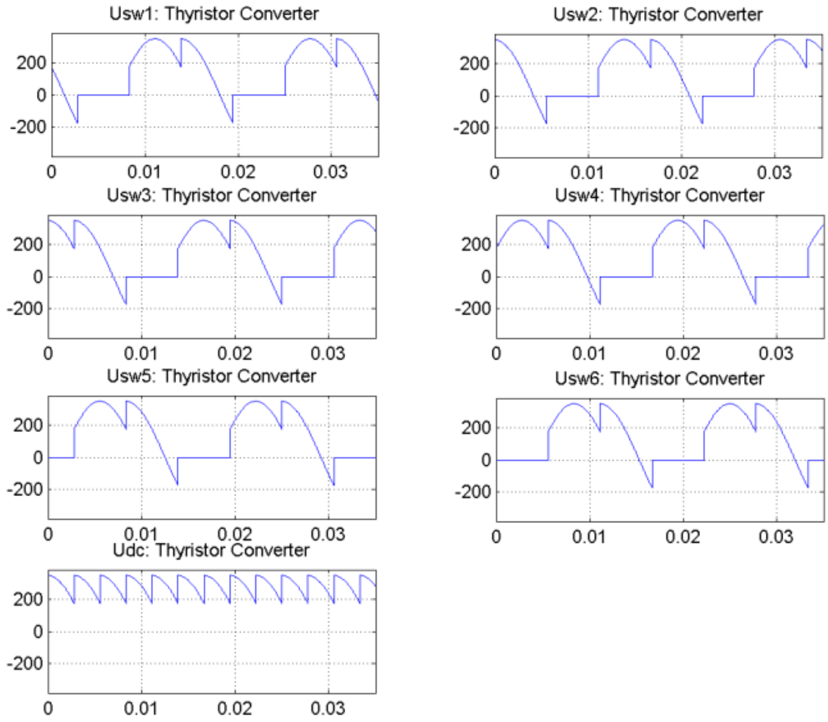
The six thyristor voltages are displayed in the next figure. The resulting DC voltage at the output of the rectifier is also displayed (average value of 331 V).



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 Synchronized 6-Pulse Generator block.

See Also

The `power_hvdc` demo illustrates the use of the Discrete Synchronized 6-Pulse Generator block.

Synchronized 12-Pulse Generator

Purpose

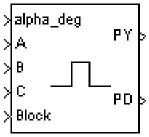
Implement synchronized pulse generator to fire thyristors of twelve-pulse converter

Library

Extras/Control Blocks

A discrete version of this block is available in the Extras/Discrete Control Blocks library.

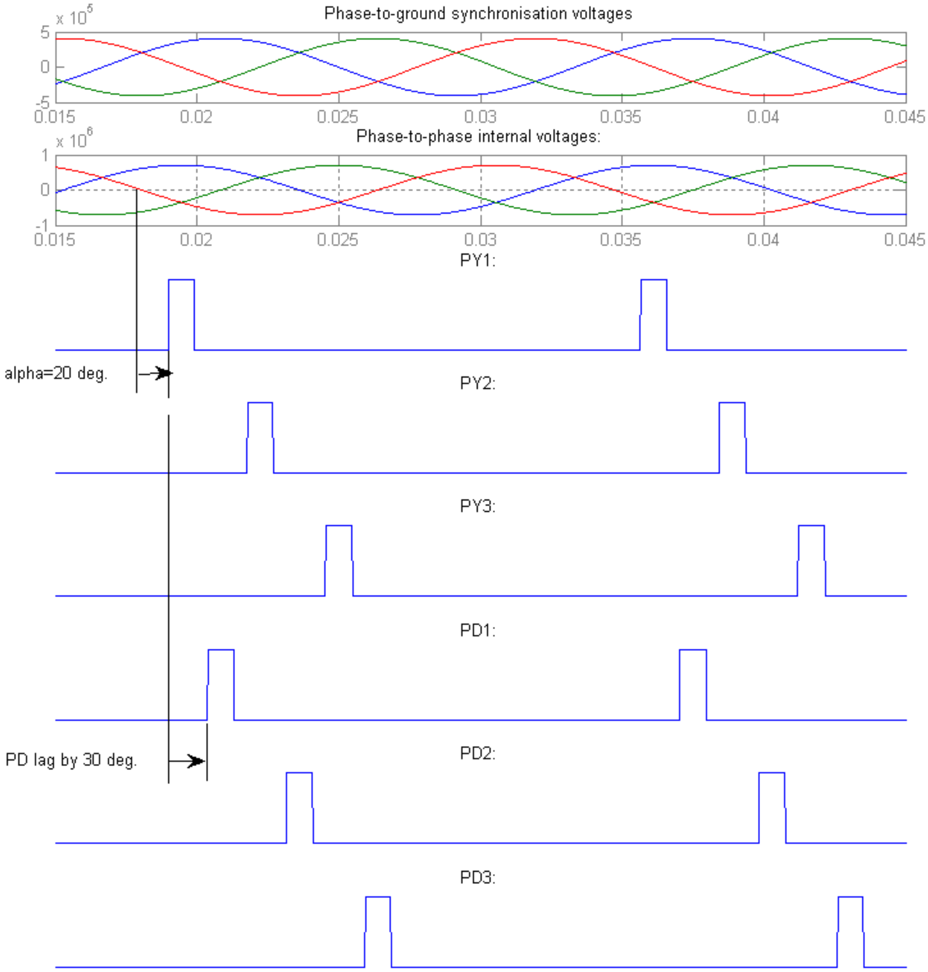
Description



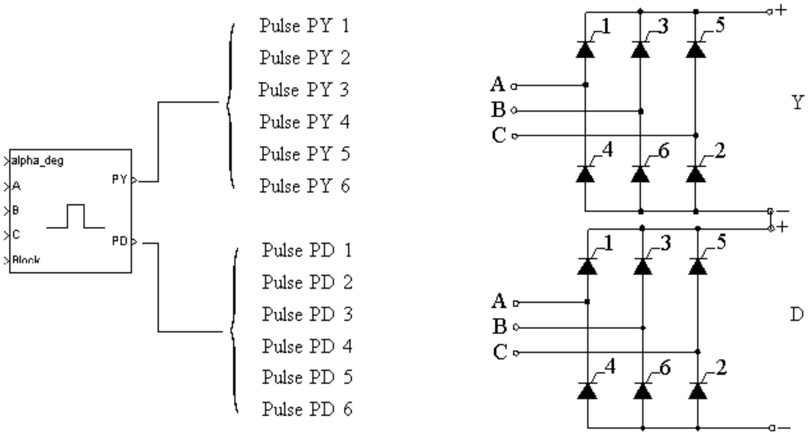
The Synchronized 12-Pulse Generator block generates two vectors of six pulses synchronized on the twelve thyristor commutation voltages. The first set of pulses, denoted PY, is sent to the six-pulse bridge connected to the wye (Y) secondary winding of the Y/Y/Delta converter transformer. The second set 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.

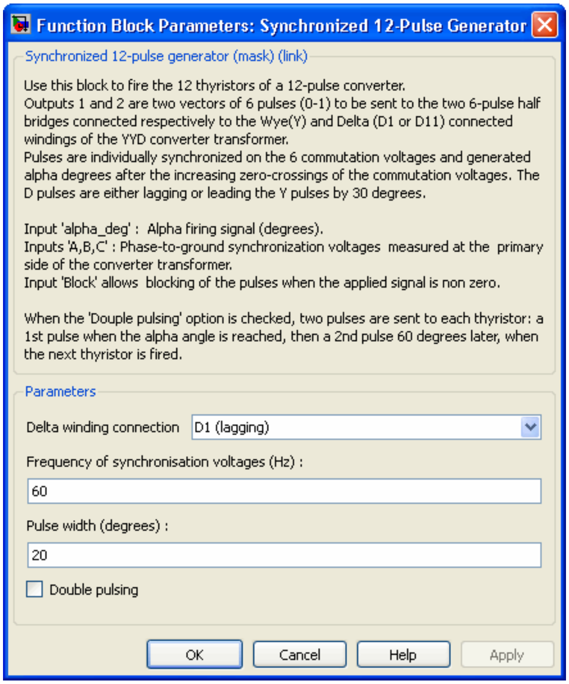
The following figure shows the synchronization and internal phase-to-phase voltages plus the first three pulses of the PY and PD output vectors. In this example the PY pulses are generated 20 degrees (alpha angle) after the zero crossing of the phase-to-phase voltages and the PD pulses lag the PY pulses 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



Synchronized 12-pulse generator (mask) (link)

Use this block to fire the 12 thyristors of a 12-pulse converter.
Outputs 1 and 2 are two vectors of 6 pulses (0-1) to be sent to the two 6-pulse half bridges connected respectively to the Wye(Y) and Delta (D1 or D11) connected windings of the YYD converter transformer.
Pulses are individually synchronized on the 6 commutation voltages and generated alpha degrees after the increasing zero-crossings of the commutation voltages. The D pulses are either lagging or leading the Y pulses by 30 degrees.

Input 'alpha_deg' : Alpha firing signal (degrees).
Inputs 'A,B,C' : Phase-to-ground synchronization voltages measured at the primary side of the converter transformer.
Input 'Block' allows blocking of the pulses when the applied signal is non zero.

When the 'Douple pulsing' option is checked, two pulses are sent to each thyristor: a 1st pulse when the alpha angle is reached, then a 2nd pulse 60 degrees later, when the next thyristor is fired.

Parameters

Delta winding connection: D1 (lagging)

Frequency of synchronisation voltages (Hz) : 60

Pulse width (degrees) : 20

☐ Double pulsing

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 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.

`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`

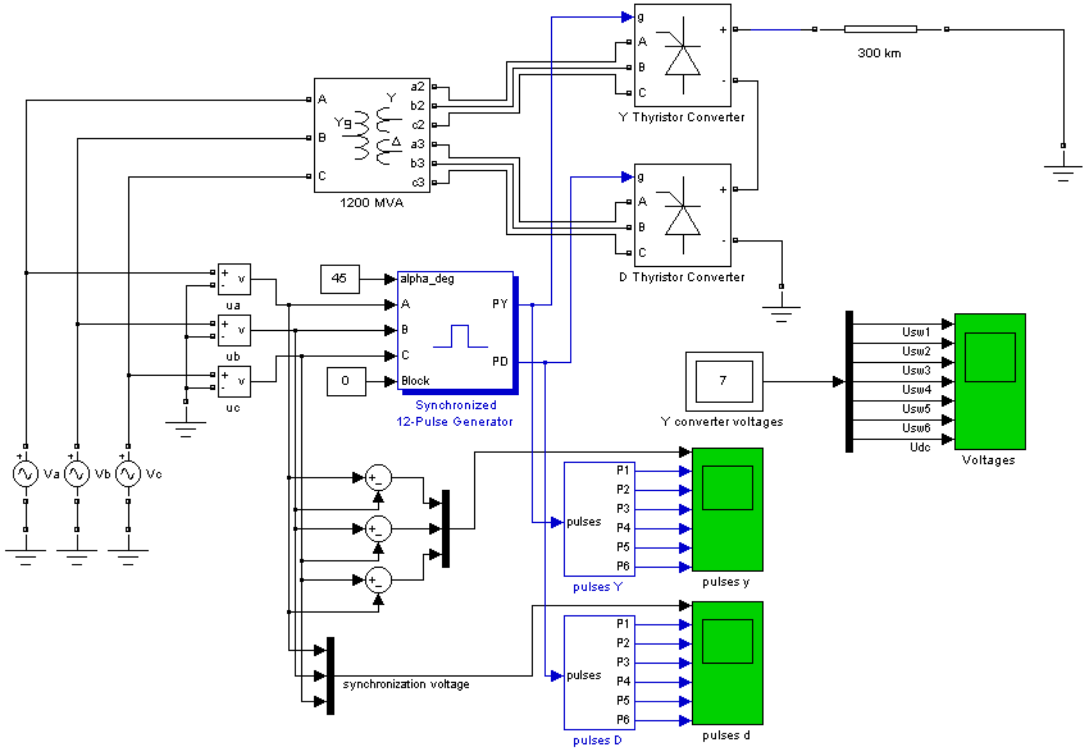
Output 2 contains the six-pulse signals to be sent to the six-pulse thyristor converter connected to the Delta (D) secondary winding of the converter transformer.

Example

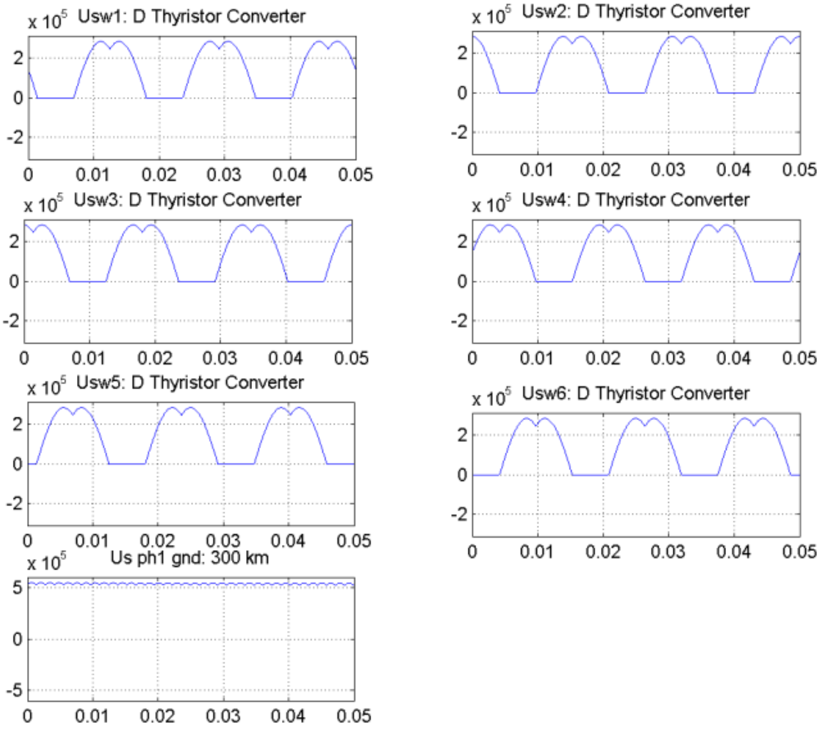
In the `power_twelvepulses` demo a Synchronized 12-Pulse Generator block is used to fire the thyristors of a twelve-pulse thyristor bridge built with two six-pulse bridges. The bridge is fed by a three-winding three-phase transformer (500 kV / 200 kV / 200 kV). The Y-connected secondary feeds the first 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

$$V_{dc} = 2\frac{3\sqrt{2}}{\pi}200\ \mathrm{kV} = 540\ \mathrm{kV}$$

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 Synchronized 12-Pulse Generator 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 Synchronized 12-Pulse Generator with the DC voltage you obtained with the Synchronized 6-Pulse Generator. Notice that the ripple in the DC voltage waveform is lower. The rectifier voltage contains the harmonics 12*k (k = 1,2,...).

See Also

The `power_hvdc12pulse` demo illustrates the use of the Discrete Synchronized 12-Pulse Generator block.

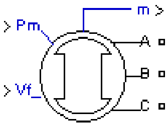
Synchronized 6-Pulse Generator

Synchronous Machine

Purpose Model the dynamics of three-phase round-rotor or salient-pole synchronous machine

Library Machines

Description

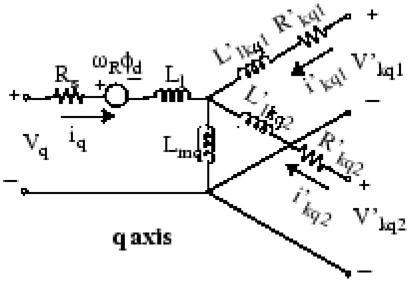


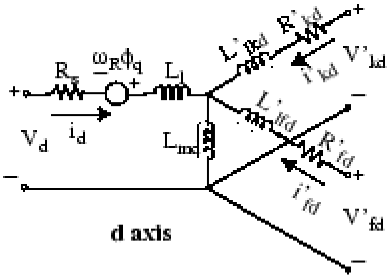
The Synchronous Machine block operates in generator or motor modes. The operating mode is dictated by the sign of the mechanical power (positive for generator mode, negative for motor mode). The electrical part of the machine is represented by a sixth-order state-space model and the mechanical part is 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





with the following equations.

$$
\begin{aligned}
V_d &= R_s i_d + \frac{d}{dt}\varphi_d - \omega_R \varphi_q \\
V_q &= R_s i_q + \frac{d}{dt}\varphi_q + \omega_R \varphi_d \\
V'_{fd} &= R'_{fd} i'_{fd} + \frac{d}{dt}\varphi'_{fd} \\
V'_{kd} &= R'_{kd} i'_{kd} + \frac{d}{dt}\varphi'_{kd} \\
V'_{kq1} &= R'_{kq1} i'_{kq1} + \frac{d}{dt}\varphi'_{kq1} \\
V'_{kq2} &= R'_{kq2} i'_{kq2} + \frac{d}{dt}\varphi'_{kq2}
\end{aligned}
$$

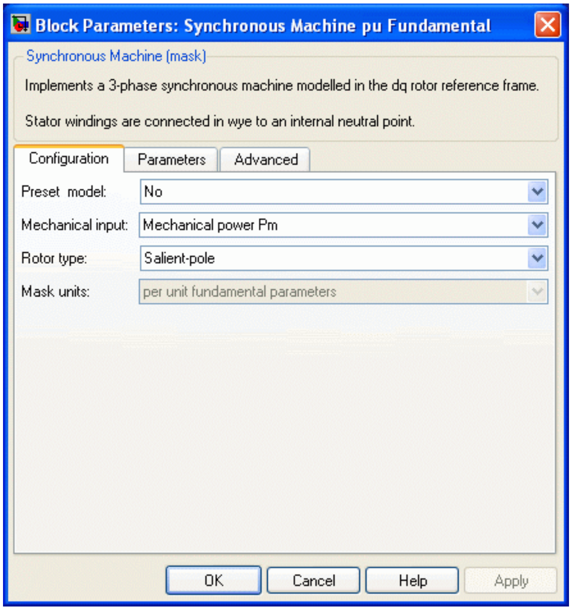
$$
\begin{aligned}
\varphi_d &= L_d i_d + L_{md}(i'_{fd} + i'_{kd}) \\
\varphi_q &= L_q i_q + L_{mq} i'_{kq} \\
\varphi'_{fd} &= L'_{fd} i'_{fd} + L_{md}(i_d + i'_{kd}) \\
\varphi'_{kd} &= L'_{kd} i'_{kd} + L_{md}(i_d + i'_{fd}) \\
\varphi'_{kq1} &= L'_{kq1} i'_{kq1} + L_{mq} i_q \\
\varphi'_{kq2} &= L'_{kq2} i'_{kq2} + L_{mq} i_q
\end{aligned}
$$

Note that 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.

Dialog Box and Parameters

In the **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 of entering the parameter units in the **Parameters** tab.

Configuration Tab



Synchronous Machine (mask)

Implements a 3-phase synchronous machine modelled in the dq rotor reference frame.

Stator windings are connected in wye to an internal neutral point.

Preset model: No

Mechanical input: Mechanical power Pm

Rotor type: Salient-pole

Mask units: per unit fundamental parameters

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 unmodifiable (grayed out). To start from a given preset model and then modify machine parameters, you have to do the following:

1. Select the desired preset model to initialize the parameters.
2. Change the **Preset model** parameter value to `No`. This will 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 wish, then click **Apply**.

Mechanical input

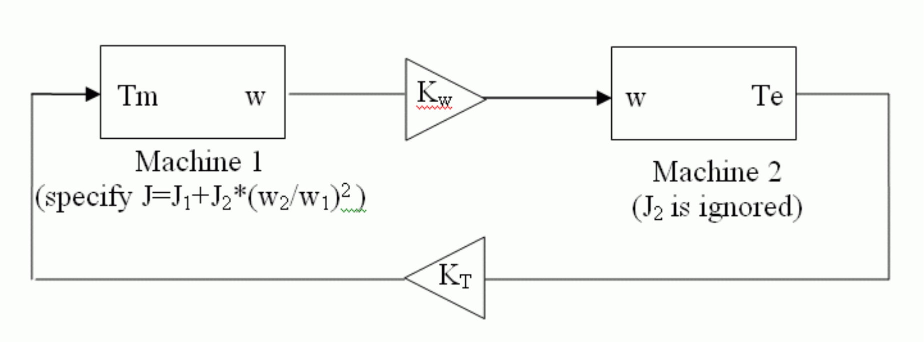
Allows you to select either the torque applied to the shaft or the rotor speed as the Simulink signal applied to the block's input.

Select **Mechanical power Pm** to specify a mechanical power input, in W or in pu, and change labeling of the block's 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 the applied mechanical power Pm, and the internal electromagnetic torque Te. The sign convention for the mechanical power is the following: 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's 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 and interfacing with SimMechanics and SimDriveline models.

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.



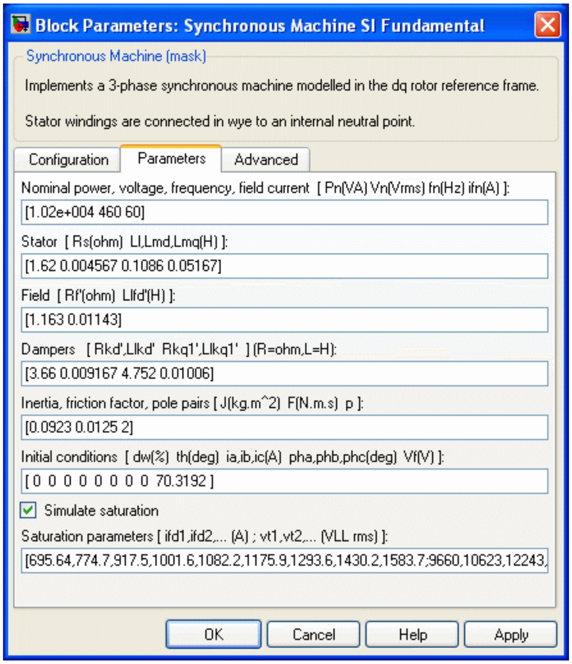
Rotor type

Specify rotor type: `Salient-pole` or `Round` (cylindrical). This choice affects the number of rotor circuits in the q-axis (damper windings).

Mask units

Specifies the units of the electrical and mechanical parameters of the model. This parameter is not modifiable; it is provided for information purposes only.

Parameters Tab for Synchronous Machine SI Fundamental



Synchronous Machine (mask)

Implements a 3-phase synchronous machine modelled in the dq rotor reference frame.

Stator windings are connected in wye to an internal neutral point.

Nominal power, voltage, frequency, field current [Pn(VA) Vn(Vrms) fn(Hz) ifn(A)]:
[1.02e+004 460 60]

Stator [Rs(ohm) Ll,Lmd,Lmq(H)]:
[1.62 0.004567 0.1086 0.05167]

Field [Rf'(ohm) Llfd'(H)]:
[1.163 0.01143]

Dampers [Rkd',Llkd' Rkq1',Llkq1'] (R=ohm,L=H):
[3.66 0.009167 4.752 0.01006]

Inertia, friction factor, pole pairs [J(kg.m^2) F(N.m.s) p]:
[0.0923 0.0125 2]

Initial conditions [dw(%) th(deg) ia,ib,ic(A) pha,phb,phc(deg) Vf(V)]:
[0 0 0 0 0 0 0 0 70.3192]

☑ Simulate saturation

Saturation parameters [ifd1,ifd2,... (A) ; vt1,vt2,... (VLL rms)]:
[695.64,774.7,917.5,1001.6,1082.2,1175.9,1293.6,1430.2,1583.7;9660,10623,12243,

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. 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. This 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 and 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 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 number of pole pairs p. The friction torque Tf is proportional to the rotor speed ω (Tf = F.ω, where 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 specify the initial field voltage in one of two ways. If you know the nominal field current (first line, last parameter), enter in the dialog box the initial field voltage in volts DC referred to the rotor. Otherwise, enter a zero as nominal field current, as explained earlier, 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 at the bottom of the dialog box.

Simulate saturation

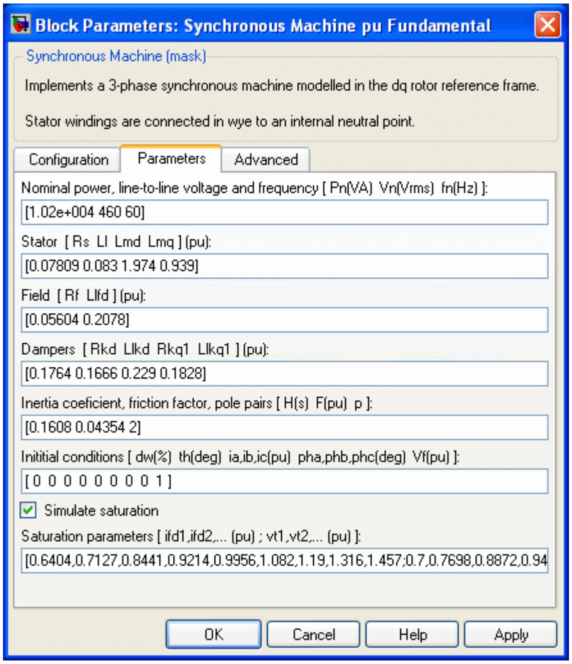
Specifies whether magnetic saturation of rotor and stator iron is to be simulated or not.

Saturation parameters

The no-load saturation curve parameters. Magnetic saturation of stator and rotor iron is modeled by a nonlinear function (in this case a polynomial) using points on the no-load saturation curve. You must enter a 2-by-n matrix, where n is the number of points taken from the saturation curve. The first row of this matrix contains the values of field currents, while the second row contains values of corresponding terminal voltages. The first point (first column of the matrix) must correspond to the point where the effect of saturation begins.

You must select the **Simulate saturation** check box to simulate saturation. 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 ifd and Vt obtained is linear (no saturation).

Parameters Tab for Synchronous Machine pu Fundamental



Block Parameters: Synchronous Machine pu Fundamental

Synchronous Machine (mask)

Implements a 3-phase synchronous machine modelled in the dq rotor reference frame.

Stator windings are connected in wye to an internal neutral point.

Nominal power, line-to-line voltage and frequency [Pn(VA) Vn(Vrms) fn(Hz)]: [1.02e+004 460 60]

Stator [Rs Ll Lmd Lmq] (pu): [0.07809 0.083 1.974 0.939]

Field [Rf Llfd] (pu): [0.05604 0.2078]

Dampers [Rkd Llkd Rkq1 Llkq1] (pu): [0.1764 0.1666 0.229 0.1828]

Inertia coeficient, friction factor, pole pairs [H(s) F(pu) p]: [0.1608 0.04354 2]

Inititial conditions [dw(%) th(deg) ia,ib,ic(pu) pha,phb,phc(deg) Vf(pu)]: [0 0 0 0 0 0 0 0 1]

☑ Simulate saturation

Saturation parameters [ifd1,ifd2,... (pu) ; vt1,vt2,... (pu)]: [0.6404,0.7127,0.8441,0.9214,0.9956,1.082,1.19,1.316,1.457;0.7,0.7698,0.8872,0.94

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.

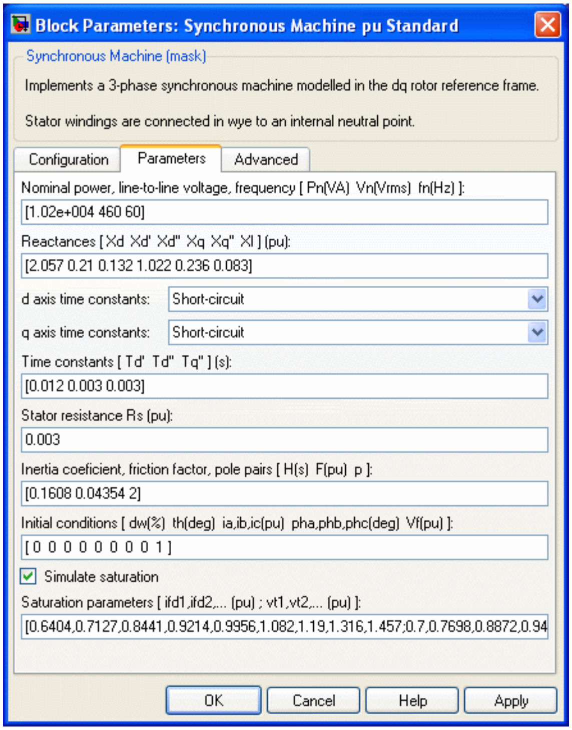
Inertia coefficient, friction factor, pole pairs

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 multiplied by the d-axis magnetizing inductance 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



Synchronous Machine (mask)

Implements a 3-phase synchronous machine modelled in the dq rotor reference frame.

Stator windings are connected in wye to an internal neutral point.

Nominal power, line-to-line voltage, frequency [Pn(VA) Vn(Vrms) fn(Hz)]: [1.02e+004 460 60]

Reactances [Xd Xd' Xd" Xq Xq" Xl] (pu): [2.057 0.21 0.132 1.022 0.236 0.083]

d axis time constants: Short-circuit

q axis time constants: Short-circuit

Time constants [Td' Td" Tq"] (s): [0.012 0.003 0.003]

Stator resistance Rs (pu): 0.003

Inertia coeficient, friction factor, pole pairs [H(s) F(pu) p]: [0.1608 0.04354 2]

Initial conditions [dw(%) th(deg) ia,ib,ic(pu) pha,phb,phc(deg) Vf(pu)]: [0 0 0 0 0 0 0 0 1]

☑ Simulate saturation

Saturation parameters [ifd1,ifd2,... (pu) ; vt1,vt2,... (pu)]: [0.6404,0.7127,0.8441,0.9214,0.9956,1.082,1.19,1.316,1.457;0.7,0.7698,0.8872,0.94

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.

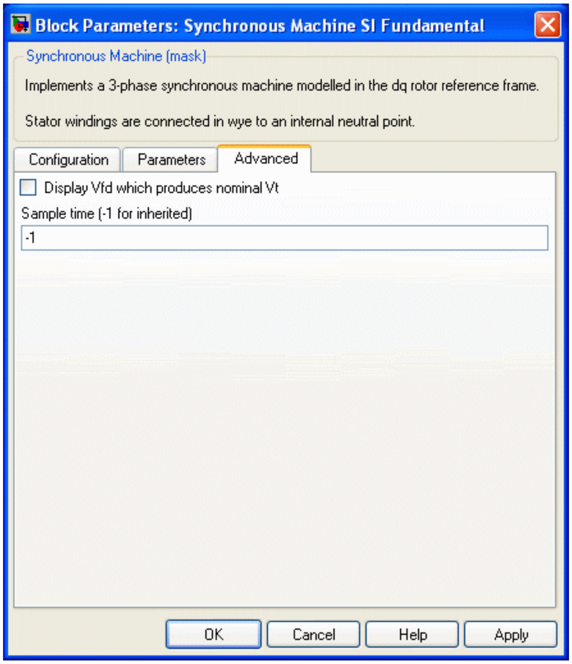
Stator resistance

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



Block Parameters: Synchronous Machine SI Fundamental

Synchronous Machine (mask)

Implements a 3-phase synchronous machine modelled in the dq rotor reference frame.

Stator windings are connected in wye to an internal neutral point.

☐ Display Vfd which produces nominal Vt

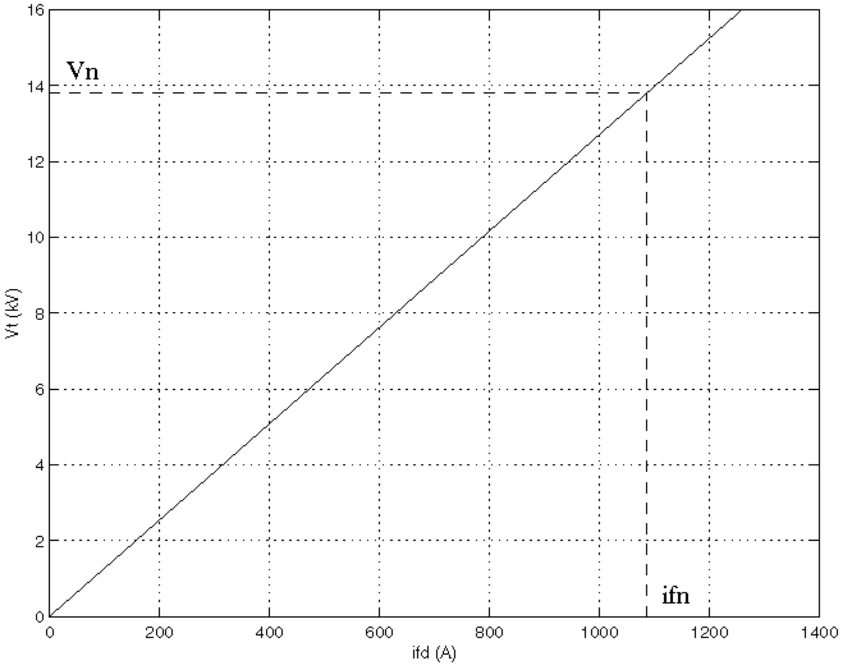
Sample time (-1 for inherited)

-1

Display Vfd which produces a nominal Vt

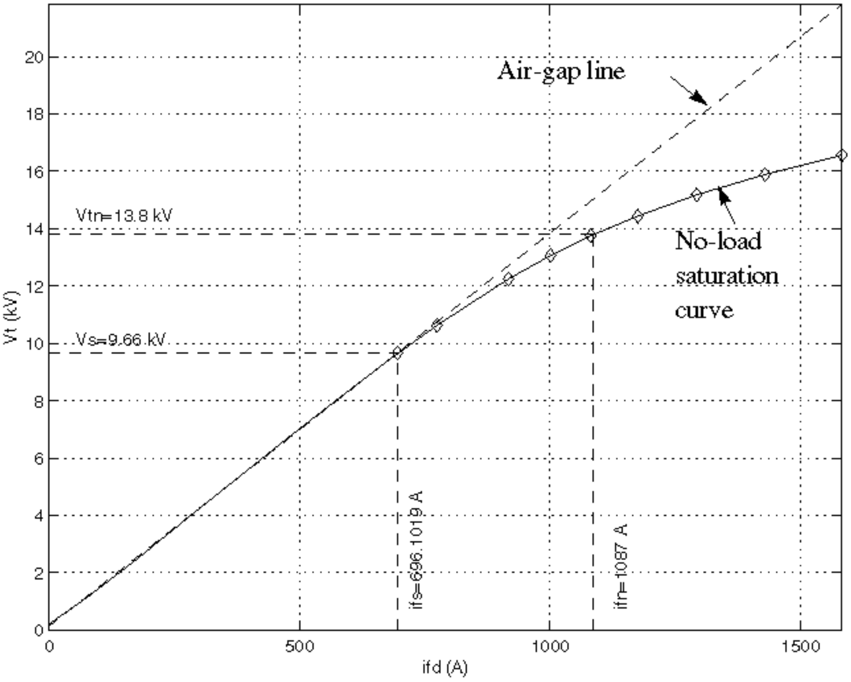
Select to determine the nominal field voltage viewed from the stator. This parameter is visible only for the Synchronous Machine SI Fundamental block.

As an example, without saturation, a typical curve might be as shown below. Here 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 by fitting a polynomial to the curve corresponding to the matrix of points you enter. The more points you enter, the better the fit to the original curve.

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 were 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`.

Inputs and Outputs

The units of inputs and outputs vary according to which dialog box was used 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 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 should 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 last check box of the dialog box. If you use the model in pu Standard or in pu Fundamental units, Vf should 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 22 signals. You can demultiplex these signals by using the Bus Selector block provided in the Simulink library.

Signal	Definition	Units
1	Stator current is_a	A or pu
2	Stator current is_b	A or pu
3	Stator current is_c	A or pu
4	Stator current is_q	A or pu
5	Stator current is_d	A or pu
6	Field current ifd	A or pu
7	Damper winding current ikq1	A or pu
8	Damper winding current ikq2	A or pu
9	Damper winding current ikd	A or pu
10	Mutual flux phimq	V.s or pu
11	Mutual flux phimd	V.s or pu
12	Stator voltage vq	V or pu
13	Stator voltage vd	V or pu
14	Rotor angle deviation d_theta	rad
15	Rotor speed wm	rad/s.
16	Electrical power Pe	VA or pu
17	Rotor speed deviation dw	rad/s
18	Rotor mechanical angle theta	rad
19	Electromagnetic torque Te	N.m or pu
20	Load angle delta	N.m or pu

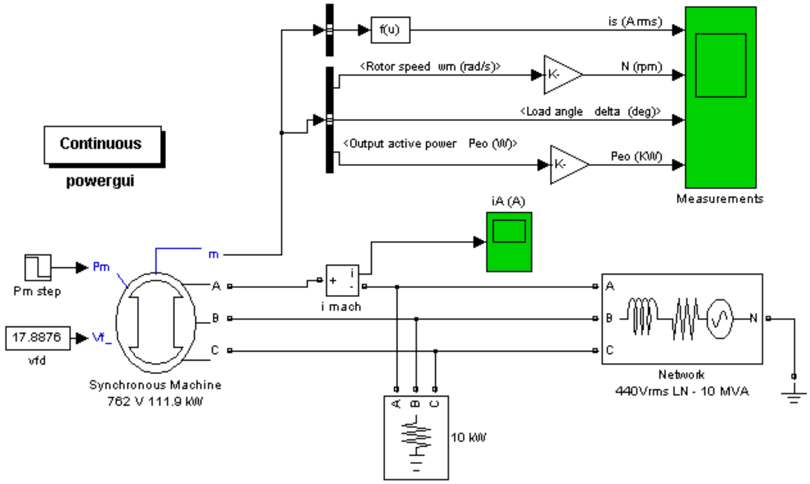
Signal	Definition	Units
21	Output active power Peo	rad
22	Output reactive power Qeo	rad

Limitations

When you use Synchronous Machine blocks in discrete systems, you might have to use a small parasitic resistive load, connected at the machine terminals, in order 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.

Example

The `power_syncmachine` demo 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. In order to start simulation in steady state, the machine is initialized using the **Load Flow and Machine Initialization** option of the Powergui. 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 have been automatically entered by the **Load Flow** analysis into the Pm Step block and in the Vf Constant block. The Pm Step block has been programmed in order to apply a sudden increase of mechanical power from -48.9 kW to -60 kW at time t = 0.1 s.



Run the simulation and observe the RMS current, RMS voltage, speed, load angle δ, and output electrical power of the motor.

Since this is a four-pole machine, the nominal speed is 1800 rpm. The initial speed is 1800 rpm as prescribed. After the load has increased from 48.9 kW to 100 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.

See Also

Excitation System, Hydraulic Turbine and Governor, Powergui, Simplified Synchronous Machine, Steam Turbine and Governor

Three-Level Bridge

Purpose

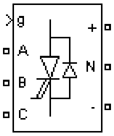
Implement three-level neutral point clamped (NPC) power converter with selectable topologies and power switching devices

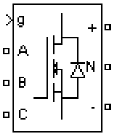
Library

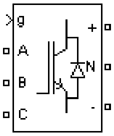
Power Electronics

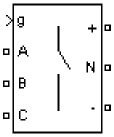
Description

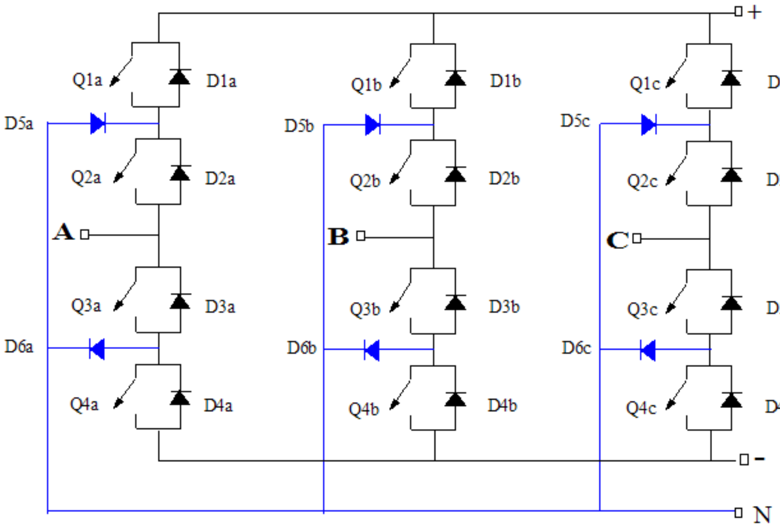
The Three-Level Bridge block implements a three-level power converter that consists of one, two, or three arms of power switching devices. Each arm consists of four switching devices along with their antiparallel diodes and two neutral clamping diodes as shown in the figure below.



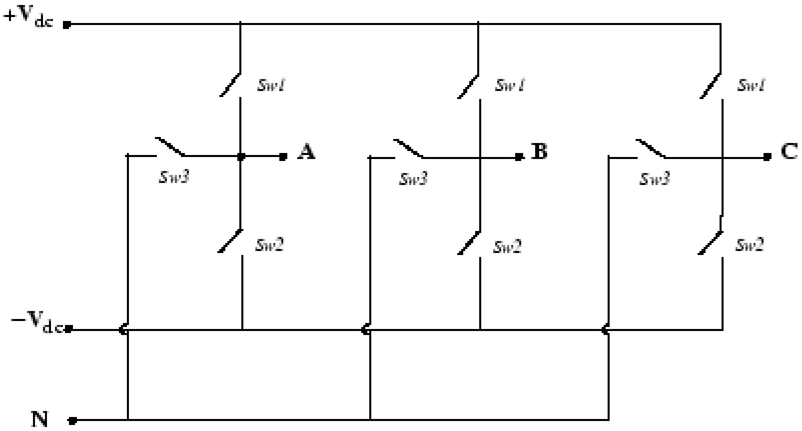




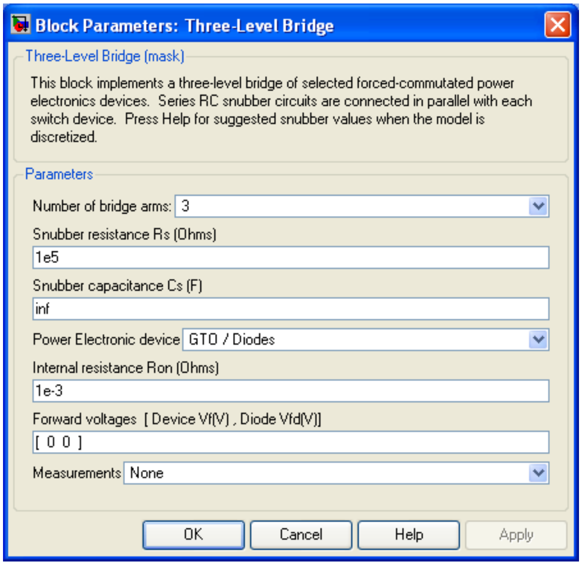




The type of power switching device (IGBT, GTO, MOSFET, or ideal switch) and the number of arms (one, two, or three) are selectable from the dialog box. When the ideal switch is used as the switching device, the Three-Level Bridge block implements an ideal switch bridge having a three-level topology as shown in the following figure.



Dialog Box and Parameters



Three-Level Bridge (mask)

This block implements a three-level bridge of selected forced-commutated power electronics devices. Series RC snubber circuits are connected in parallel with each switch device. Press Help for suggested snubber values when the model is discretized.

Parameters

Number of bridge arms: 3

Snubber resistance Rs (Ohms)
1e5

Snubber capacitance Cs (F)
inf

Power Electronic device GTO / Diodes

Internal resistance Ron (Ohms)
1e-3

Forward voltages [Device Vf(V) , Diode Vfd(V)]
[0 0]

Measurements None

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.

For forced-commutated devices (GTO, IGBT, or MOSFET) the Three-Level Bridge block operates satisfactorily with resistive snubbers as long as the firing pulses are sent to the switching devices.

If the firing pulses to forced-commutated devices are blocked, the bridge operates as a diode rectifier. In this condition, you must use appropriate values of Rs and Cs. If the model is discretized, 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

P_n = Nominal power of single- or three-phase converter (VA)

Vn = Nominal line-to-line AC voltage (Vrms)

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.

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]`

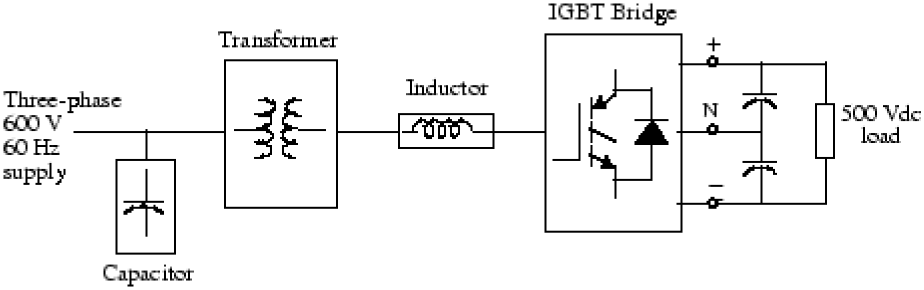
Note In the case of the ideal switch converter, the Q1 pulse is sent to Sw1, the Q4 pulse to Sw2, and a logical AND operation is performed on the Q2 and Q3 pulses and the result sent to Sw3.

Assumptions and Limitations

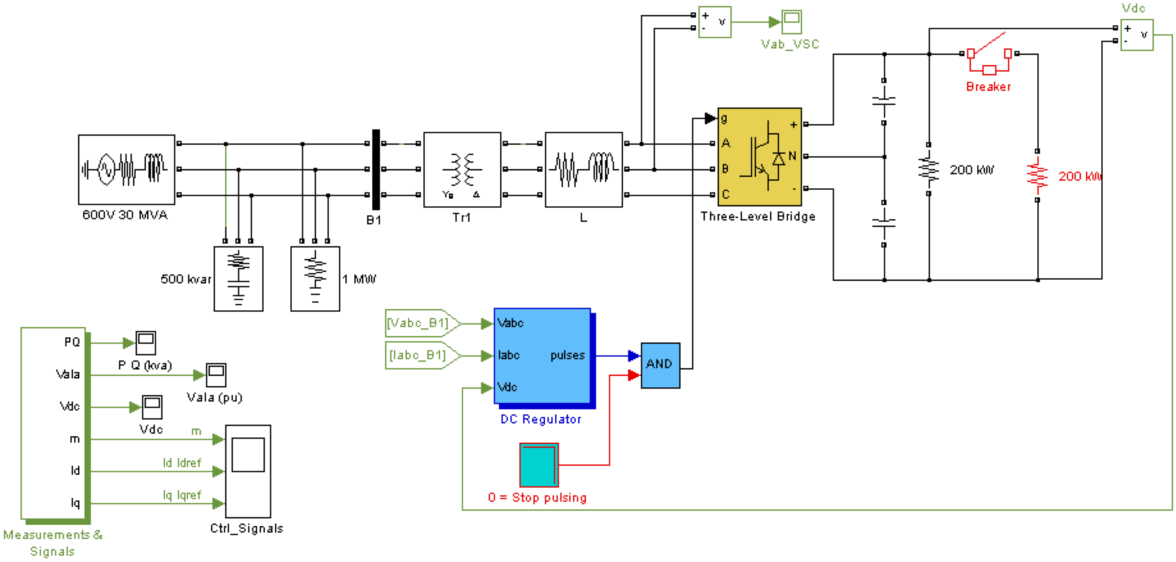
Turn-on and turn-off times (Fall time, Tail time) of power switching devices are not modeled in the Three-Level Bridge block.

Example

The `power_3levelVSC` demo 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:

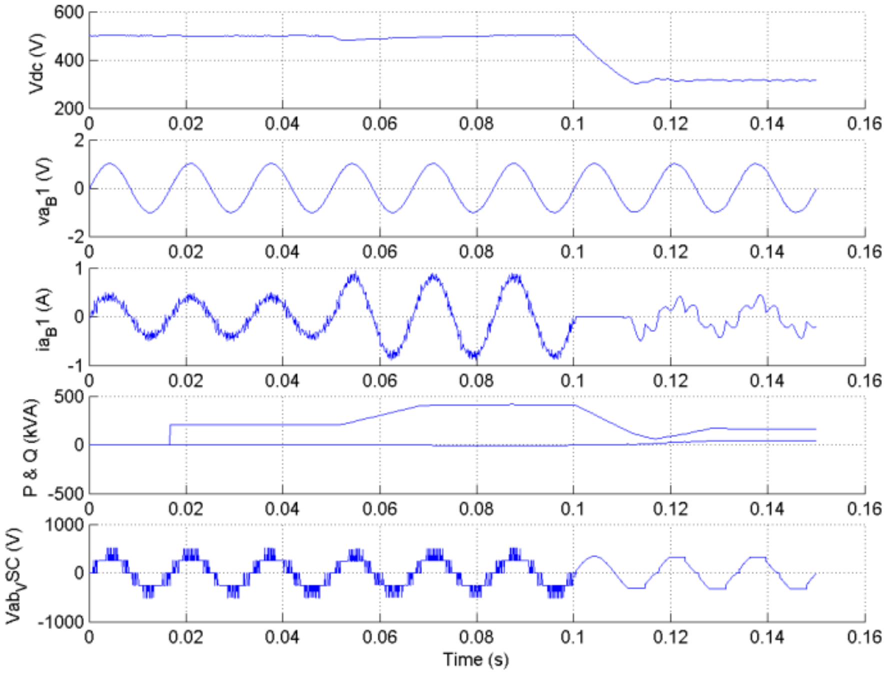
- The DC voltage (Vdc Scope block)
- The primary voltage and current of phase A of the AC supply (VaIa Scope block)

- 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)

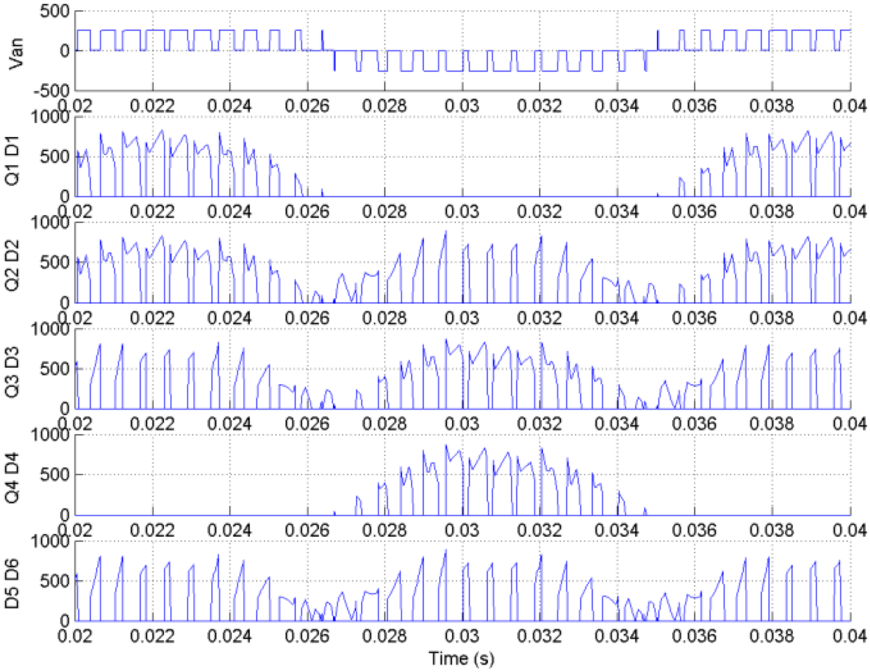
At 50 ms, a 200 kW load is switched in. You can see that the dynamic response of the DC regulator to the sudden load variation from 200 kW to 400 kW is satisfactory. The DC voltage reverts to 500 V within 2 cycles and the unity power factor on the AC side is maintained.

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

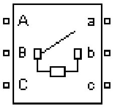
Purpose

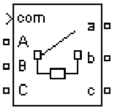
Implement three-phase circuit breaker opening at current zero crossing

Library

Elements

Description





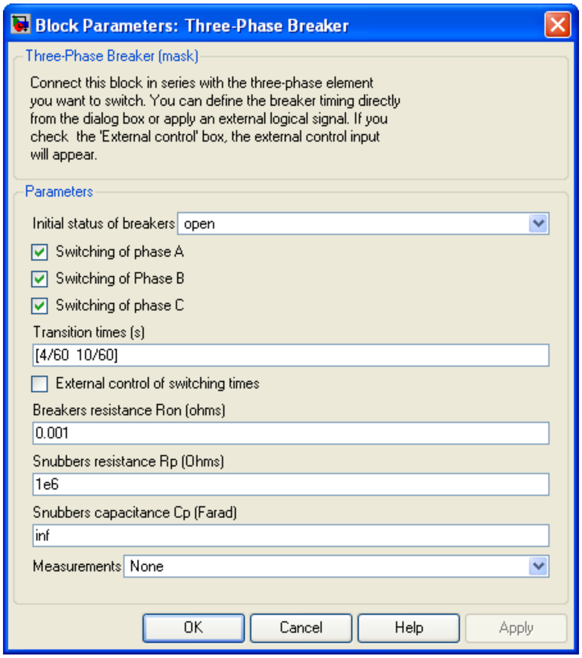
The Three-Phase Breaker block implements a three-phase circuit breaker where the opening and closing times can be controlled either from an external Simulink signal (external control mode), or from an internal control timer (internal control mode).

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. 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



Three-Phase Breaker (mask)

Connect this block in series with the three-phase element you want to switch. You can define the breaker timing directly from the dialog box or apply an external logical signal. If you check the 'External control' box, the external control input will appear.

Parameters

Initial status of breakers: open

☑ Switching of phase A

☑ Switching of Phase B

☑ Switching of phase C

Transition times (s): [4/60 10/60]

☐ External control of switching times

Breakers resistance Ron (ohms): 0.001

Snubbers resistance Rp (Ohms): 1e6

Snubbers capacitance Cp (Farad): inf

Measurements: None

Initial status of breakers

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 of breakers** 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 of breakers** 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 of breakers** parameter.

Transition times(s)

The **Transition times(s)** parameter is not visible in the dialog box if the **External control of switching times** parameter is 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 control of switching times

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 Rp

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

Snubbers capacitance Cp

The snubber capacitances, in farads (F). Set the **Snubber capacitance Cp** 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: 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` demos for circuits using the Three-Phase Breaker block.

See Also

Breaker, Multimeter, Three-Phase Fault

Three-Phase Dynamic Load

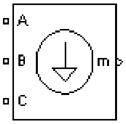
Purpose

Implement three-phase dynamic load with active power and reactive power as function of voltage or controlled from external input

Library

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:

$$P(s) = P_o\left(\frac{V}{V_o}\right)^{n_p}\frac{(1+T_{p1}s)}{(1+T_{p2}s)}$$

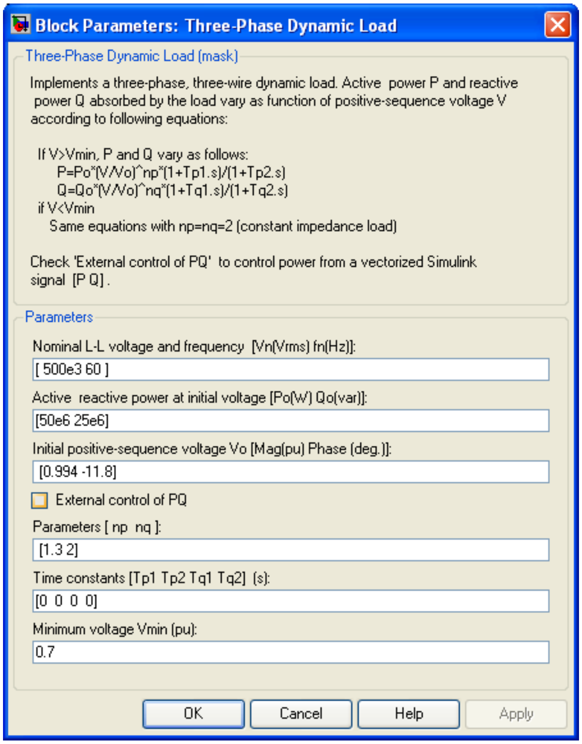
$$Q(s) = Q_o\left(\frac{V}{V_o}\right)^{n_q}\frac{(1+T_{q1}s)}{(1+T_{q2}s)}$$

where

- V_o is the initial positive sequence voltage.
- P_o 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)

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 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

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. If the load flow utility of the Powergui is used 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.

Initial positive-sequence voltage Vo

Specifies the magnitude and phase of the initial positive-sequence voltage of the load. If the load flow utility of the Powergui is used 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.

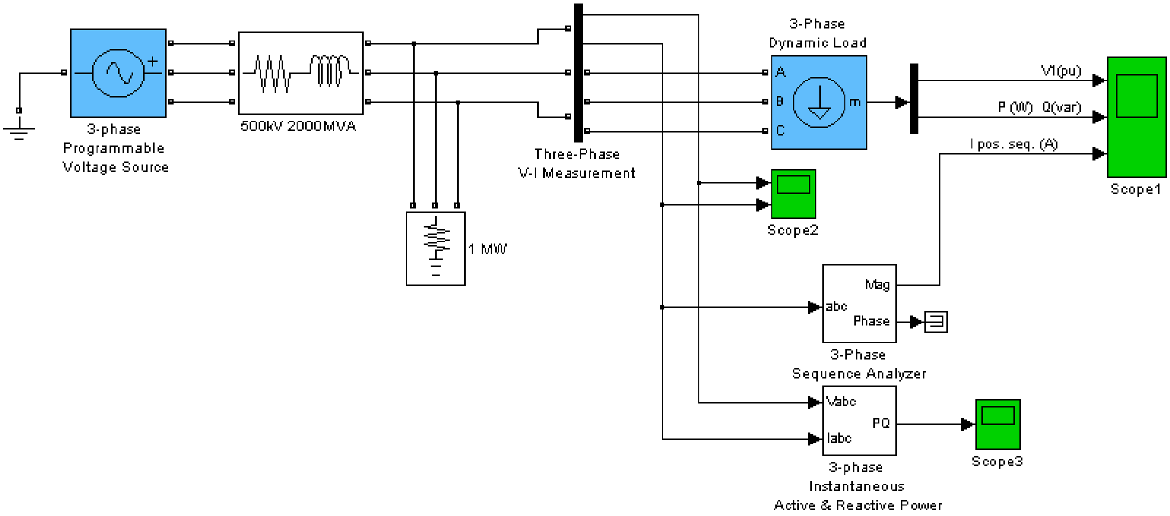
Inputs and Outputs

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 **Load Flow and Machine Initialization**. Specify the desired active power and reactive powers for the dynamic load (50 MW, 25 Mvar):

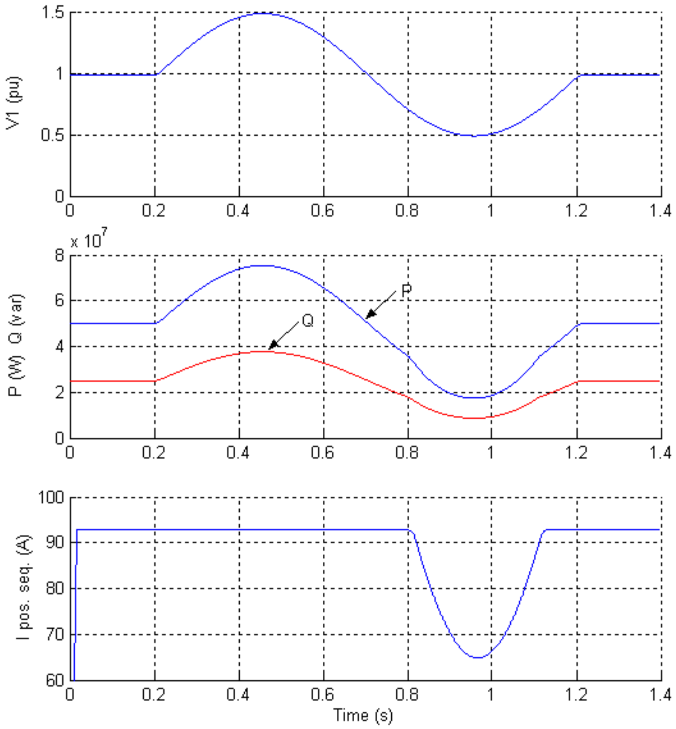
Active Power = 50e6; Reactive Power = 25e6

Then press the **Update Load Flow** 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

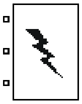
Purpose

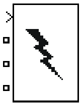
Implement programmable phase-to-phase and phase-to-ground fault breaker system

Library

Elements

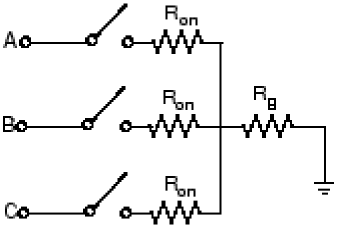
Description





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.

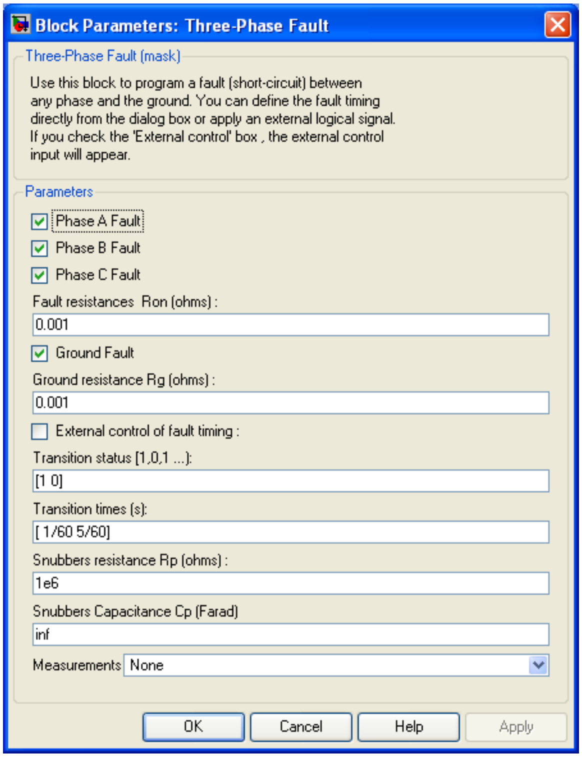


The ground resistance Rg is automatically set to 10^6 ohms when the ground fault option is not programmed. For example, to program a fault between the phases A and B you need to select the **Phase A Fault** and **Phase B Fault** block parameters only. To program a fault between the phase A and the ground, you need to select the **Phase A Fault** and **Ground Fault** 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 Rp-Cp 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



Block Parameters: Three-Phase Fault

Three-Phase Fault (mask)

Use this block to program a fault (short-circuit) between any phase and the ground. You can define the fault timing directly from the dialog box or apply an external logical signal. If you check the 'External control' box , the external control input will appear.

Parameters

☑ Phase A Fault

☑ Phase B Fault

☑ Phase C Fault

Fault resistances Ron (ohms) : 0.001

☑ Ground Fault

Ground resistance Rg (ohms) : 0.001

☐ External control of fault timing :

Transition status [1,0,1 ...]: [1 0]

Transition times (s): [1/60 5/60]

Snubbers resistance Rp (ohms) : 1e6

Snubbers Capacitance Cp (Farad) inf

Measurements None

Phase A Fault

If selected, the fault switching of phase A is activated. If not selected, the breaker of phase A stays in its initial status. The initial status of the phase A breaker corresponds to the complement of the first value specified in the vector of **Transition status**. The initial status of the fault breaker is usually 0 (open). However, it is possible to start a simulation in steady state with the fault initially applied on the system. For example, if the first value in the **Transition status** vector is 0, the phase A breaker is initially closed. It opens at the first time specified in the **Transition time(s)** vector.

Phase B Fault

If selected, the fault switching of phase B is activated. If not selected, the breaker of phase B stays in its initial status. The initial status of the phase B breaker corresponds to the complement of the first value specified in the vector of **Transition status**.

Phase C Fault

If selected, the fault switching of phase C is activated. If not selected, the breaker of phase C stays in its initial status. The initial status of the phase C breaker corresponds to the complement of the first value specified in the vector of **Transition status**.

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 Fault

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 Fault** and **Ground Fault** 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 Fault** parameter is not selected.

Ground resistance Rg

The **Ground resistance Rg (ohms)** parameter is not visible if the **Ground Fault** parameter is not selected. The ground resistance, in ohms (Ω). The **Ground resistance Rg (ohms)** parameter cannot be set to 0.

External control of fault timing

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.

Transition status

Specify the vector of switching status when using the Three-Phase Breaker block in internal control mode. The selected fault breakers open (0) or close (1) at each transition time according to the **Transition status** parameter values.

The initial status of the breakers corresponds to the complement of the first value specified in the vector of switching status.

Transition 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 state. The **Transition times (s)** parameter is not visible in the dialog box if the **External control of switching times** parameter is selected.

Snubbers resistance Rp

The snubber resistances, in ohms (Ω). Set the **Snubbers resistance Rp** parameter to `inf` to eliminate the snubbers from the model.

Snubbers capacitance Cp

The snubber capacitances, in farads (F). Set the **Snubbers capacitance Cp** 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` demo for a circuit using the Three-Phase Fault block.

See Also

Breaker, Multimeter, and Three-Phase Breaker

Three-Phase Harmonic Filter

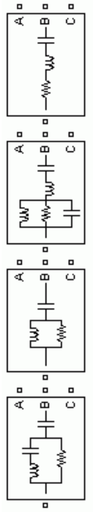
Purpose

Implement four types of three-phase harmonic filters using RLC components

Library

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

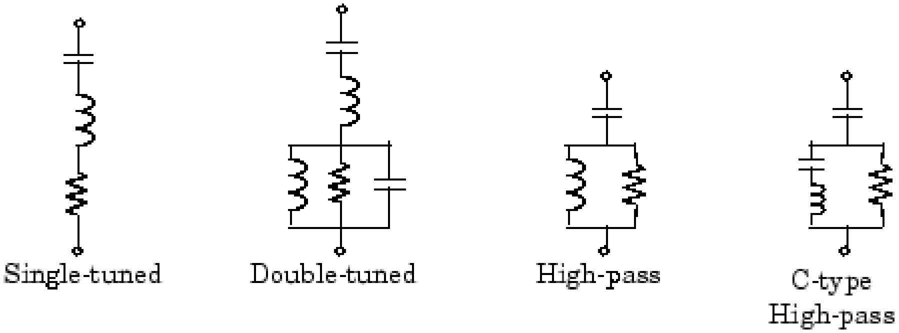
- Band-pass filters, which are used to filter lowest order harmonics such as 5th, 7th, 11th, 13th, etc. Band-pass filters can be tuned at a single frequency (single-tuned filter) or at two frequencies (double-tuned filter).
- High-pass filters, which are used to filter high-order harmonics and cover 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:

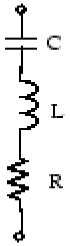
- Reactive power at nominal voltage
- Tuning frequencies

- 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:



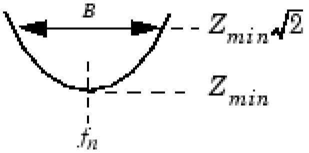
The simplest filter type is the single-tuned filter. The following figure gives the definition of the quality factor Q and practical formulae for computing the reactive power Q_C and losses (active power P). The quality factor Q of the filter is the quality factor of the reactance at the tuning frequency $Q = (n.X_L)/R$. 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 $n = \frac{f_n}{f_1} = \sqrt{\frac{X_C}{X_L}}$

Quality factor $Q = \frac{n \cdot X_L}{R} = \frac{X_C}{n \cdot R}$

Bandwidth $B = \frac{f_n}{Q}$



Reactive power at f_1 $Q_C = \frac{V^2}{X_C} \cdot \frac{n^2}{(n^2-1)}$

Active power at f_1 (losses) $P \cong Q_C \cdot \frac{n}{n^2-1} \cdot \frac{1}{Q}$

where:

f_1 = fundamental frequency
$\omega = 2\pi f_1$ = angular frequency
f_n = tuning frequency
n = harmonic order f_n / f_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:

$$Q = \frac{R}{L \times 2\pi f_m}.$$

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.

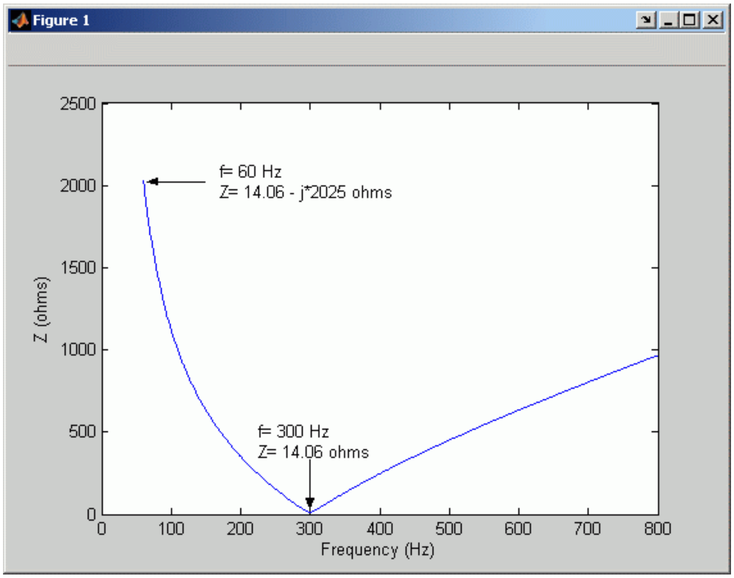
The quality factor of the high-pass filter is the quality factor of the parallel RL circuit at the tuning frequency: $Q = \frac{R}{L \times 2\pi f_n}$.

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.

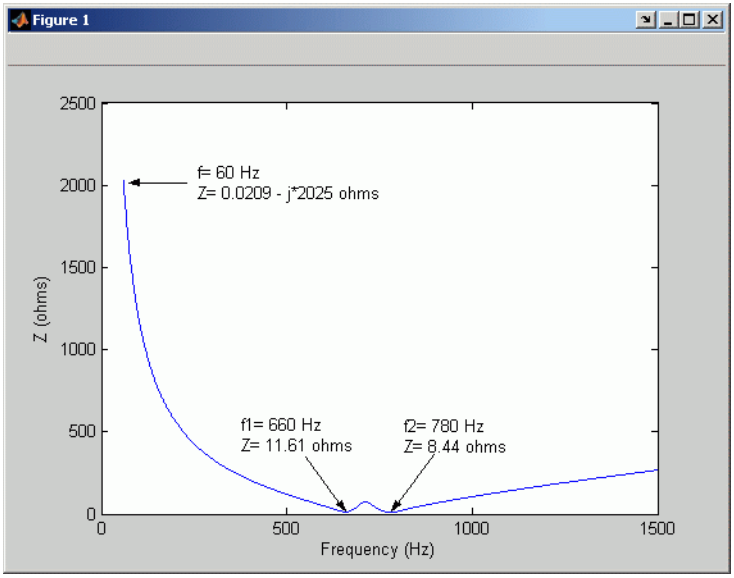
The quality factor of the C-type filter is still given by the ratio:

$$Q = \frac{R}{L \times 2\pi f_n}.$$

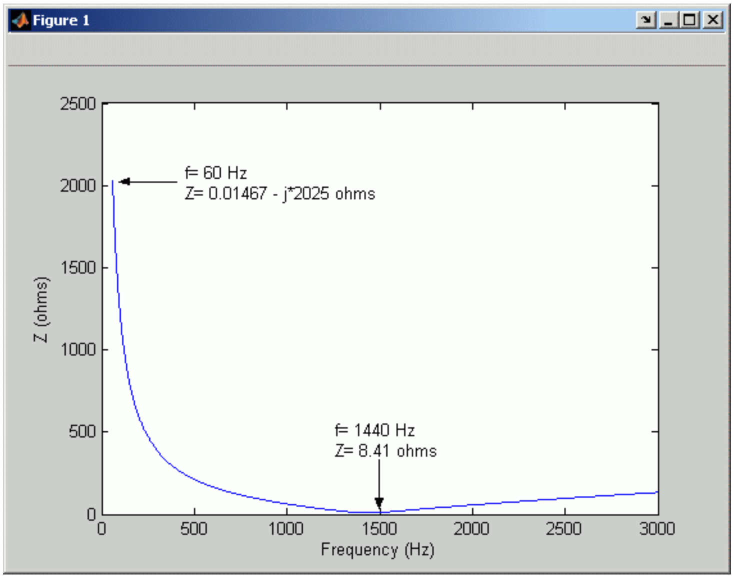
The following figures give R, L, C values and typical impedance versus frequency curves obtained for the four types of filters applied on a 60 Hz network. Each filter is rated 315 kV, 49 Mvar.



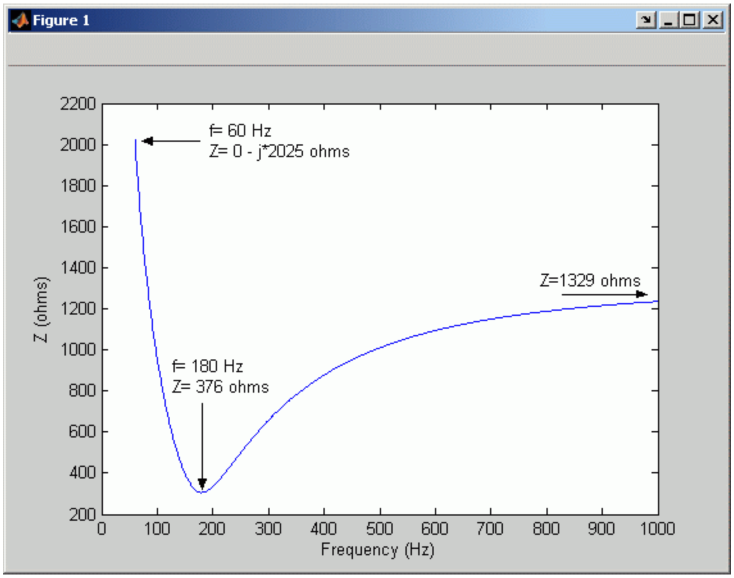
Single-Tuned, 315 kV, 49 Mvar, 5th Harmonic Filter; Q = 30



Double-Tuned, 315 kV, 49 Mvar, 11th and 13th Harmonics Filter; Q = 16

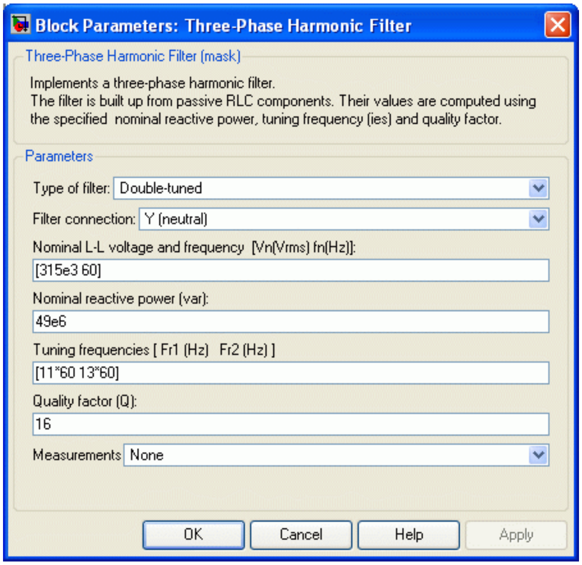


High-Pass, 315 kV, 49 Mvar, 24th Harmonic Filter; Q = 10



C-Type High-Pass, 315 kV, 49 Mvar, 3rdHharmonic Filter; Q = 1.75

Dialog Box and Parameters



Block Parameters: Three-Phase Harmonic Filter

Three-Phase Harmonic Filter (mask)

Implements a three-phase harmonic filter.
The filter is built up from passive RLC components. Their values are computed using the specified nominal reactive power, tuning frequency (ies) and quality factor.

Parameters

Type of filter: Double-tuned

Filter connection: Y (neutral)

Nominal L-L voltage and frequency [Vn(Vrms) fn(Hz)]: [315e3 60]

Nominal reactive power (var): 49e6

Tuning frequencies [Fr1 (Hz) Fr2 (Hz)] [11*60 13*60]

Quality factor (Q): 16

Measurements None

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.

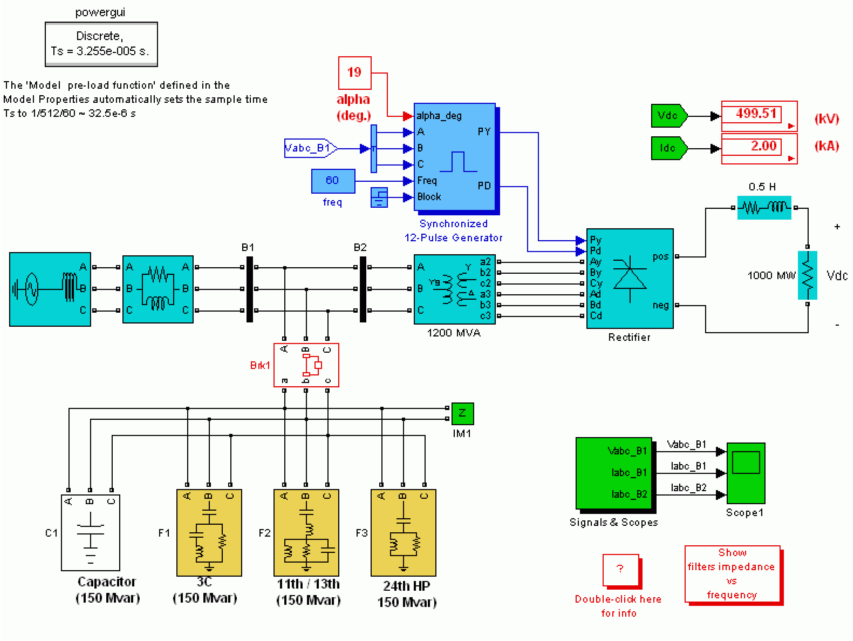
Place a Multimeter block in your model to display the selected measurements during the simulation. In the **Available Measurements** list box of the Multimeter block, the measurements are identified by a label followed by the block name.

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` demo 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:

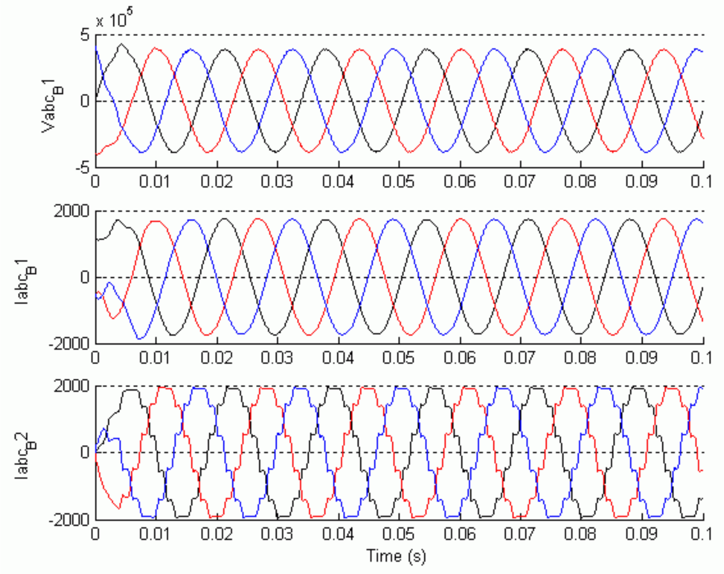
- One 150 Mvar C-type high-pass filter tuned to the 3rd harmonic (F1)
- One 150 Mvar double-tuned filter tuned to the 11/13th (F2)
- One 150 Mvar high-pass filter tuned to the 24th (F3)
- One 150 Mvar capacitor bank



The 'Model pre-load function' defined in the Model Properties automatically sets the sample time Ts to 1/512/60 ~ 32.5e-6 s

Time-domain simulation

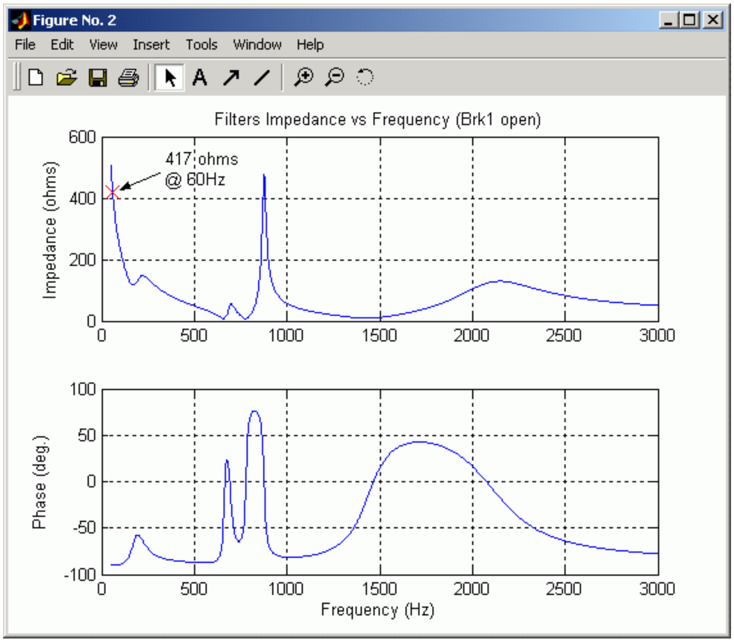
Run the simulation with an alpha firing angle of 19 degrees. You should get a DC voltage level of 500 kV. Now, look inside Scope1. Compare the currents flowing into Bus B1 (Iabc_B1, axis 2) with those flowing into Bus B2 (Iabc_B2, axis 3). You can see that the harmonic filters almost eliminate the harmonics 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

$$Q_c = \frac{V^2}{X_c} = \frac{(500 \times 10^3)^2}{417} = 600 \text{ Mvar}$$

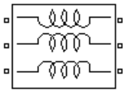
Purpose

Implement three-phase impedance with mutual coupling among phases

Library

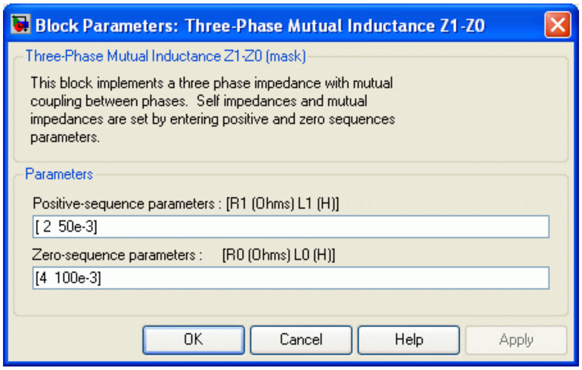
Elements

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



Block Parameters: Three-Phase Mutual Inductance Z1-Z0

Three-Phase Mutual Inductance Z1-Z0 (mask)

This block implements a three phase impedance with mutual coupling between phases. Self impedances and mutual impedances are set by entering positive and zero sequences parameters.

Parameters

Positive-sequence parameters : [R1 (Ohms) L1 (H)]

[2 50e-3]

Zero-sequence parameters : [R0 (Ohms) L0 (H)]

[4 100e-3]

Positive-sequence parameters

The positive-sequence resistance R1, in ohms (Ω), and the positive-sequence inductance L1, in henries (H).

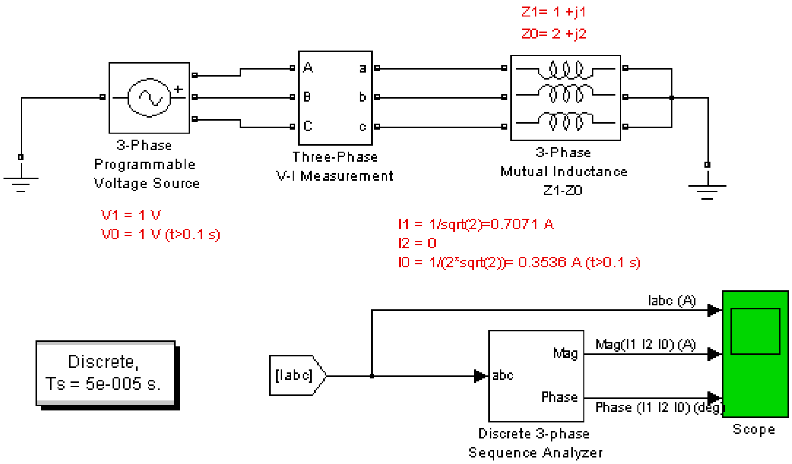
Zero-sequence parameters

The zero-sequence resistance R0, in ohms (Ω), and the zero-sequence inductance L0, in henries (H).

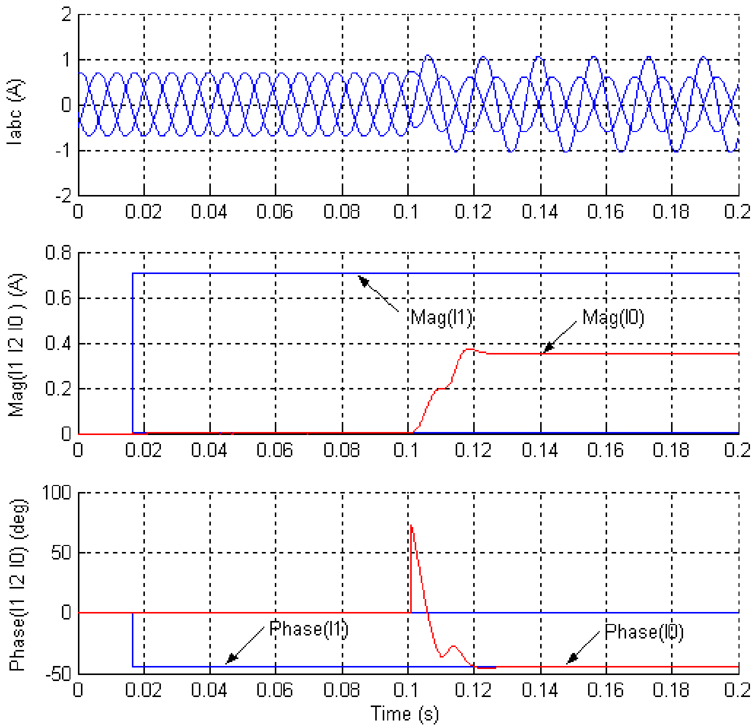
Example

The `power_3phmutseq10` demo 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 $Z1 = \sqrt{2}\angle 45°\ \Omega$ and $Z0 = 2\sqrt{2}\angle 45°\ \Omega$

Therefore, the positive- and zero-sequence currents displayed on the scope are

$$I1 = V1/Z1 = 1/(\sqrt{2}\angle 45°) = 0.7071\ \mathrm{A}\angle{-45°}$$

$$I0 = V0/Z0 = 1/(2\sqrt{2}\angle 45°) = 0.3536\ \mathrm{A}\angle{-45°}$$

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)

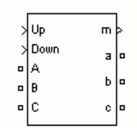
Purpose

Implement phasor model of three-phase OLTC phase-shifting transformer using delta hexagonal connection

Library

Flexible AC Transmission Systems (FACTS)/Transformers

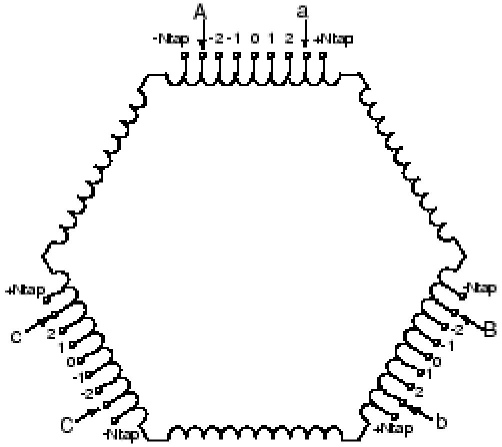
Description



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.

Three-Phase OLTC Phase Shifting Transformer Delta-Hexagonal (Phasor Type)



$$\psi = 2 \times \operatorname{atan}\left(\frac{-k}{\sqrt{3}}\right)$$

where:

ψ = phase shift of abc output voltages with respect to ABC input voltages

k = relative tap position = N/Ntap

N = tap position

$$-Ntap \le N \le Ntap$$

$$-1 \le k \le 1$$

$$-60° \le \psi \le 60°$$

Delta-Hexagonal Phase-Shifting Transformer Connections

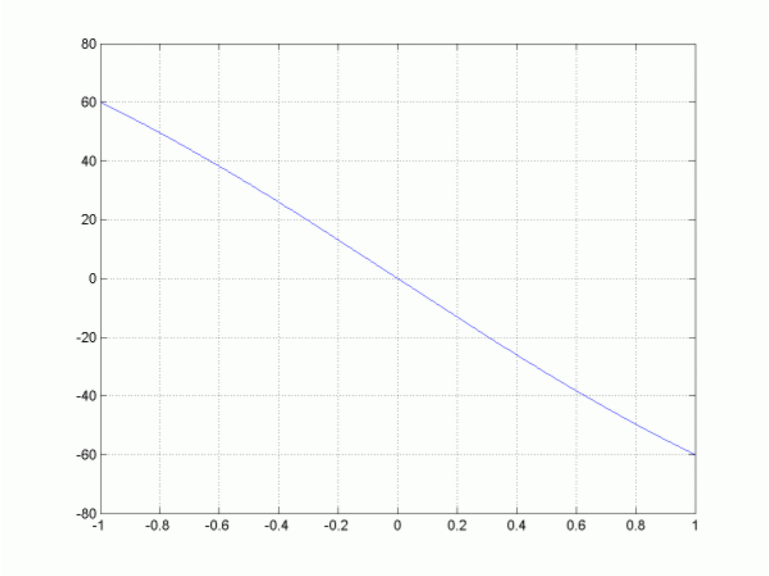
Each phase consists of two coupled windings drawn in parallel on the figure: one tapped winding with two OLTCs and one winding without taps. All windings have the same number of turns. The two OLTCs vary phase shift by moving transformer input terminals (A, B, C) and outputs terminals (a, b, c) symmetrically 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 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.

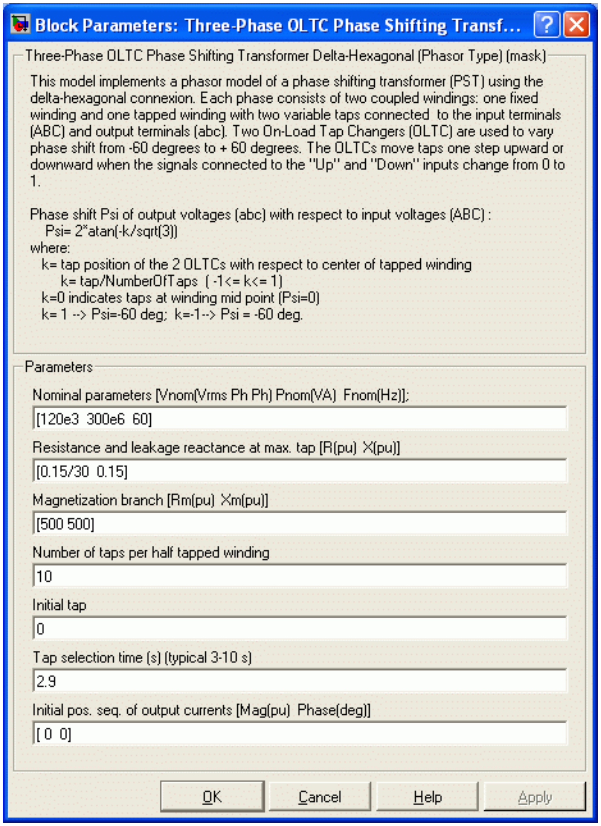


Variation of phase shift as function of tap position

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` demo.



Block Parameters: Three-Phase OLTC Phase Shifting Transf...

Three-Phase OLTC Phase Shifting Transformer Delta-Hexagonal (Phasor Type) (mask)

This model implements a phasor model of a phase shifting transformer (PST) using the delta-hexagonal connexion. Each phase consists of two coupled windings: one fixed winding and one tapped winding with two variable taps connected to the input terminals (ABC) and output terminals (abc). Two On-Load Tap Changers (OLTC) are used to vary phase shift from -60 degrees to + 60 degrees. The OLTCs move taps one step upward or downward when the signals connected to the "Up" and "Down" inputs change from 0 to 1.

```
Phase shift Psi of output voltages (abc) with respect to input voltages (ABC) :
   Psi= 2*atan(-k/sqrt(3))
where:
  k= tap position of the 2 OLTCs with respect to center of tapped winding
      k= tap/NumberOfTaps  ( -1<= k<= 1)
  k=0 indicates taps at winding mid point (Psi=0)
  k= 1 --> Psi=-60 deg;  k=-1--> Psi = -60 deg.
```

Parameters

Nominal parameters [Vnom(Vrms Ph Ph) Pnom(VA) Fnom(Hz)]: [120e3 300e6 60]

Resistance and leakage reactance at max. tap [R(pu) X(pu)]: [0.15/30 0.15]

Magnetization branch [Rm(pu) Xm(pu)]: [500 500]

Number of taps per half tapped winding: 10

Initial tap: 0

Tap selection time (s) (typical 3-10 s): 2.9

Initial pos. seq. of output currents [Mag(pu) Phase(deg)]: [0 0]

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:

$$Z_1 = (R + jX) \times \frac{|k|(-3k^2 + 2|k| + 9)}{2(k^2 + 3)}$$

$$Z_0 = \frac{R_m \times jX_m}{R_m + jX_m} \times k^2$$

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 Rm, Xm 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
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` demo 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)

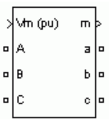
Purpose

Implement phasor model of three-phase OLTC regulating transformer

Library

Flexible AC Transmission Systems (FACTS)/Transformers

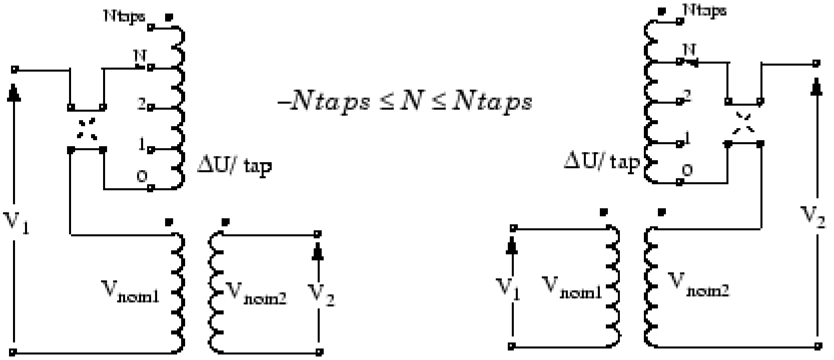
Description



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.

Three-Phase OLTC Regulating Transformer (Phasor Type)



$$-Ntaps \le N \le Ntaps$$

OLTC on winding 1

$$\frac{V_2}{V_1} = \frac{1}{(1 + N \cdot \Delta U)} \times \frac{V_{nom2}}{V_{nom1}}$$

OLTC on winding 2

$$\frac{V_2}{V_1} = (1 + N \cdot \Delta U) \times \frac{V_{nom2}}{V_{nom1}}$$

One Phase of the Regulating Transformer

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 on the figure is the voltage correction factor. It is given by:

$$1/(1 + N \cdot \Delta U) \quad \text{for OLTC on winding 1}$$

$$(1 + N \cdot \Delta U) \quad \text{for OLTC on winding 2}$$

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` demo.

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

$abs(Vm - Vref) > DeadBand/2$ during a time $t > \mathrm{Delay}$

where Vref, Deadband and Delay are parameters of the voltage regulator.

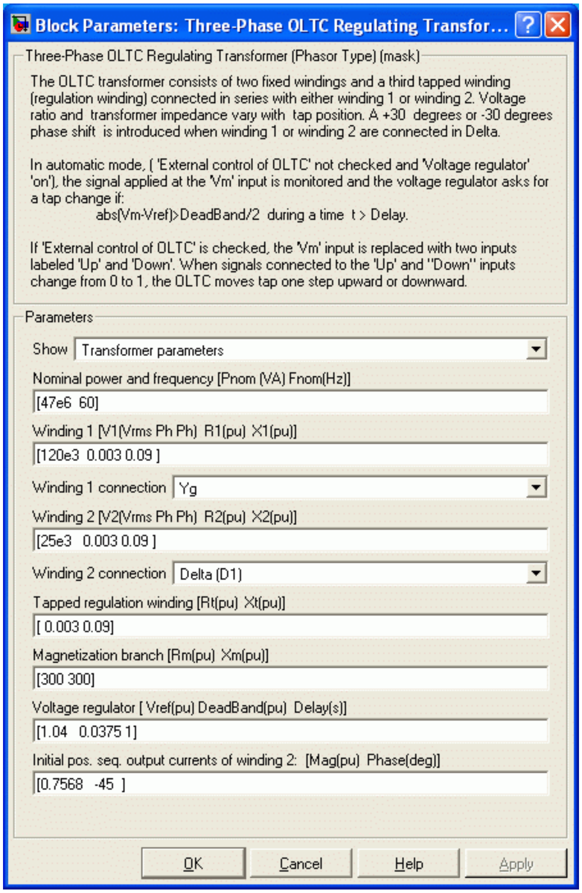
External control of OLTC

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 Parameters



Three-Phase OLTC Regulating Transformer (Phasor Type) (mask)

The OLTC transformer consists of two fixed windings and a third tapped winding (regulation winding) connected in series with either winding 1 or winding 2. Voltage ratio and transformer impedance vary with tap position. A +30 degrees or -30 degrees phase shift is introduced when winding 1 or winding 2 are connected in Delta.

In automatic mode, ('External control of OLTC' not checked and 'Voltage regulator' 'on'), the signal applied at the 'Vm' input is monitored and the voltage regulator asks for a tap change if:

abs(Vm-Vref)>DeadBand/2 during a time t > Delay.

If 'External control of OLTC' is checked, the 'Vm' input is replaced with two inputs labeled 'Up' and 'Down'. When signals connected to the 'Up' and "Down" inputs change from 0 to 1, the OLTC moves tap one step upward or downward.

Parameters

Show: Transformer parameters

Nominal power and frequency [Pnom (VA) Fnom(Hz)]: [47e6 60]

Winding 1 [V1(Vrms Ph Ph) R1(pu) X1(pu)]: [120e3 0.003 0.09]

Winding 1 connection: Yg

Winding 2 [V2(Vrms Ph Ph) R2(pu) X2(pu)]: [25e3 0.003 0.09]

Winding 2 connection: Delta (D1)

Tapped regulation winding [Rt(pu) Xt(pu)]: [0.003 0.09]

Magnetization branch [Rm(pu) Xm(pu)]: [300 300]

Voltage regulator [Vref(pu) DeadBand(pu) Delay(s)]: [1.04 0.0375 1]

Initial pos. seq. output currents of winding 2: [Mag(pu) Phase(deg)]: [0.7568 -45]

Nominal Power and frequency [Pnom Fnom]

The three-phase nominal power, in VA and the nominal frequency, in hertz.

Winding 1 [V1 R1 X1]

The nominal line to line voltage of winding 1, in volts rms, winding resistance, in pu, and leakage reactance, in pu.

Winding 1 connection

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 [V2 R2 X2]

The nominal line to line voltage of winding 2, in volts rms, winding resistance in pu, and leakage reactance, in pu.

Winding 2 connection

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.

Tapped regulation winding [Rt Xt]

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.

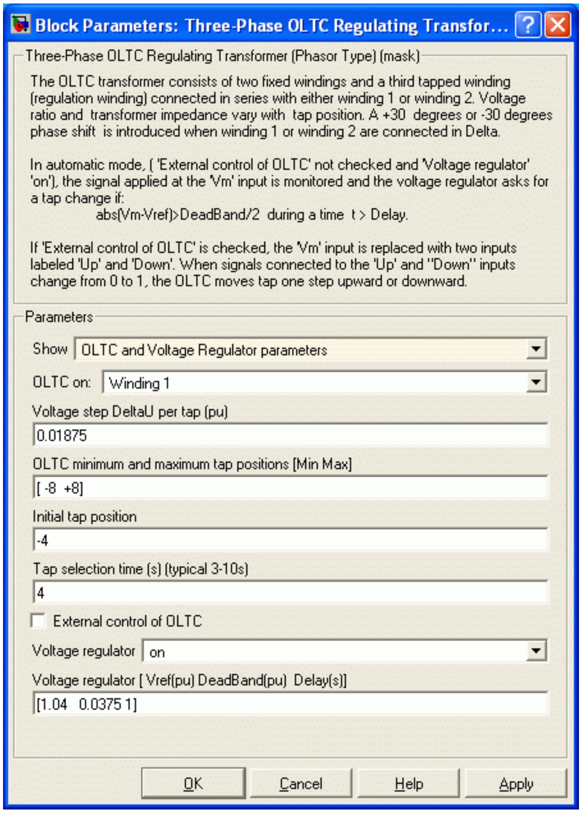
Magnetizing branch [Rm Xm]

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.

Initial pos. seq. output currents of winding 2 [Mag Phase]

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.

OLTC and Voltage Regulation Parameters



Block Parameters: Three-Phase OLTC Regulating Transfor...

Three-Phase OLTC Regulating Transformer (Phasor Type) (mask)

The OLTC transformer consists of two fixed windings and a third tapped winding (regulation winding) connected in series with either winding 1 or winding 2. Voltage ratio and transformer impedance vary with tap position. A +30 degrees or -30 degrees phase shift is introduced when winding 1 or winding 2 are connected in Delta.

In automatic mode, ('External control of OLTC' not checked and 'Voltage regulator' 'on'), the signal applied at the 'Vm' input is monitored and the voltage regulator asks for a tap change if:

abs(Vm-Vref)>DeadBand/2 during a time t > Delay.

If 'External control of OLTC' is checked, the 'Vm' input is replaced with two inputs labeled 'Up' and 'Down'. When signals connected to the 'Up' and "Down" inputs change from 0 to 1, the OLTC moves tap one step upward or downward.

Parameters

Show: OLTC and Voltage Regulator parameters

OLTC on: Winding 1

Voltage step DeltaU per tap (pu): 0.01875

OLTC minimum and maximum tap positions [Min Max]: [-8 +8]

Initial tap position: -4

Tap selection time (s) (typical 3-10s): 4

☐ External control of OLTC

Voltage regulator: on

Voltage regulator [Vref(pu) DeadBand(pu) Delay(s)]: [1.04 0.0375 1]

OLTC on

Select either `Winding 1` or `Winding 2`.

Voltage Step DeltaU per tap

The voltage step per tap, in pu of the nominal voltage of winding 1 or winding 2.

OLTC minimum and maximum tap [MinTap MaxTap]

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.

Voltage regulator [Vref DeadBand Delay]

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
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)

Signal	Signal Group	Signal Names	Definition
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` demo 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)

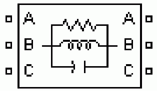
Purpose

Implement three-phase parallel RLC branch

Library

Elements

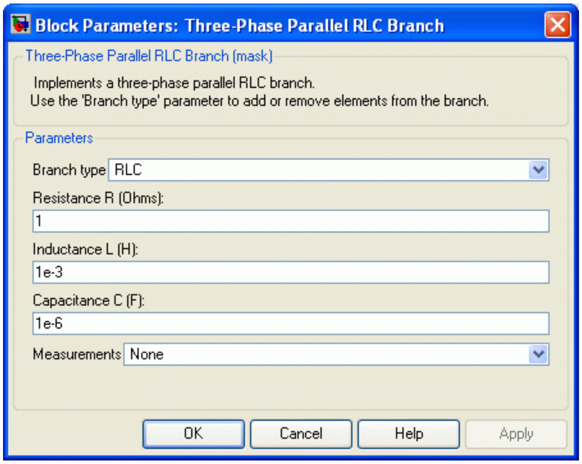
Description



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. If you eliminate either the resistance, inductance, or capacitance of each branch, the R, L, and C values are automatically set respectively to infinity (`inf`), infinity (`inf`), and `0` and the corresponding parameters no longer appear in the block dialog box. Only existing elements are displayed in the block icon.

Negative values are allowed for resistance, inductance, and capacitance.

Dialog Box and Parameters



Three-Phase Parallel RLC Branch (mask)

Implements a three-phase parallel RLC branch.
Use the 'Branch type' parameter to add or remove elements from the branch.

Parameters

Branch type: RLC

Resistance R (Ohms): 1

Inductance L (H): 1e-3

Capacitance C (F): 1e-6

Measurements: None

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).

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

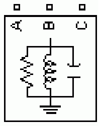
Purpose

Implement three-phase parallel RLC load with selectable connection

Library

Elements

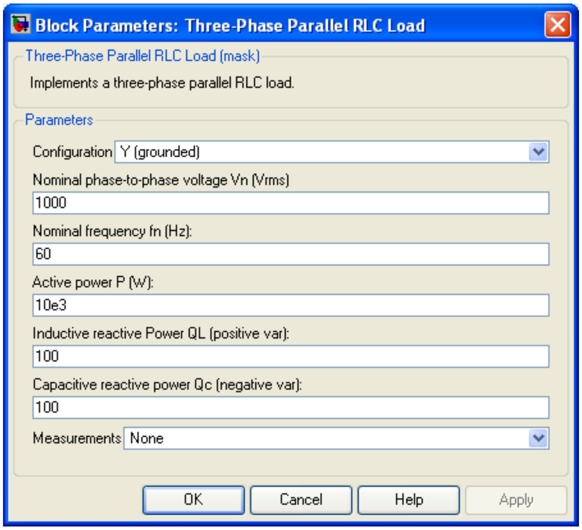
Description



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



Implements a three-phase parallel RLC load.

Configuration: Y (grounded)

Nominal phase-to-phase voltage Vn (Vrms): 1000

Nominal frequency fn (Hz): 60

Active power P (W): 10e3

Inductive reactive Power QL (positive var): 100

Capacitive reactive power Qc (negative var): 100

Measurements: None

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).

Active power P

The three-phase active power of the load, in watts (W).

Inductive reactive power QL

The three-phase inductive reactive power QL, in vars. Specify a positive value, or 0.

Capacitive reactive power QC

The three-phase capacitive reactive power QC, in vars. Specify a positive value, or 0.

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:`

See Also

Multimeter, Three-Phase Dynamic Load, Three-Phase Parallel RLC Branch, Three-Phase Series RLC Branch, Three-Phase Series RLC Load

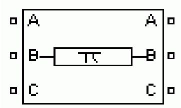
Purpose

Implement three-phase transmission line section with lumped parameters

Library

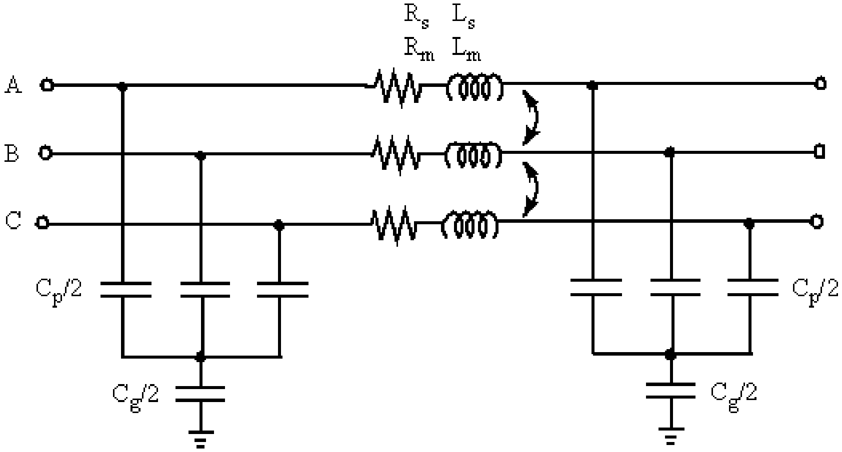
Elements

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:

$$\begin{aligned} R_1 &= r_1 \cdot l\sec \cdot k_{r1} \\ L_1 &= l_1 \cdot l\sec \cdot k_{l1} \\ C_1 &= c_1 \cdot l\sec \cdot k_{c1} \\ R_0 &= r_0 \cdot l\sec \cdot k_{r0} \\ L_0 &= l_0 \cdot l\sec \cdot k_{l0} \\ C_0 &= c_0 \cdot l\sec \cdot k_{c0} \end{aligned}$$

where

k_{r1}, k_{l1}, k_{c1}, k_{r0}, k_{l0}, k_{c0} — hyperbolic correction factors

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.

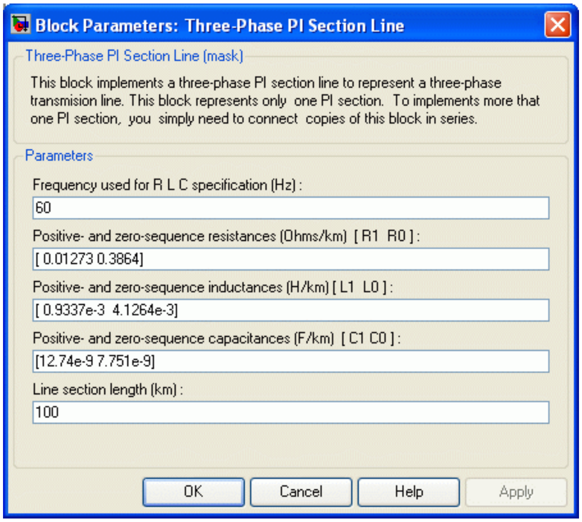
The RLC line section parameters are then computed as follows:

$$Rs = (2R_1 + R_0)/3$$
$$Ls = (2L_1 + L_0)/3$$
$$R_m = (R_0 - R_1)/3$$
$$L_m = (L_0 - L_1)/3$$
$$C_p = C_1$$
$$C_g = 3C_1C_0/(C_1 - C_0)$$

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 the resistance, inductance, and capacitance per unit length based on the line geometry and the conductor characteristics. See the Powergui to learn how to use this tool.

Dialog Box and Parameters



Block Parameters: Three-Phase PI Section Line

Three-Phase PI Section Line (mask)

This block implements a three-phase PI section line to represent a three-phase transmision line. This block represents only one PI section. To implements more that one PI section, you simply need to connect copies of this block in series.

Parameters

Frequency used for R L C specification (Hz) : 60

Positive- and zero-sequence resistances (Ohms/km) [R1 R0] : [0.01273 0.3864]

Positive- and zero-sequence inductances (H/km) [L1 L0] : [0.9337e-3 4.1264e-3]

Positive- and zero-sequence capacitances (F/km) [C1 C0] : [12.74e-9 7.751e-9]

Line section length (km) : 100

Frequency used for R L C specification
The frequency used for specification of 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` demo 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

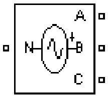
Purpose

Implement three-phase voltage source with programmable time variation of amplitude, phase, frequency, and harmonics

Library

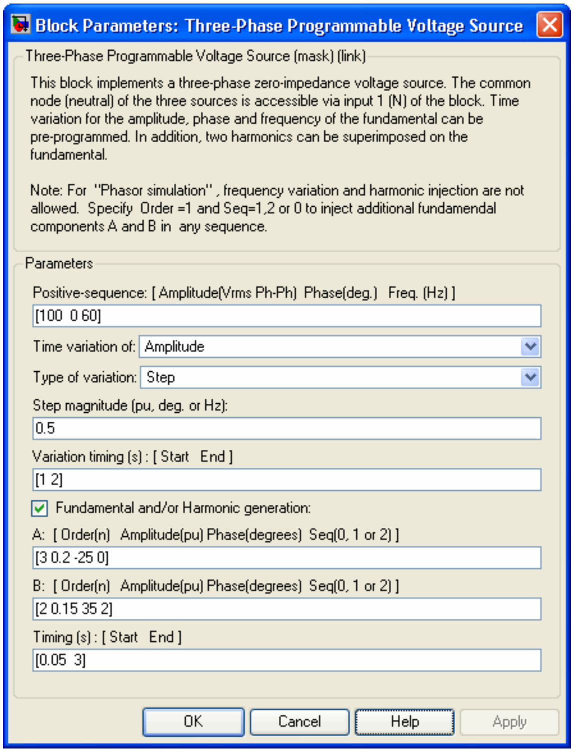
Electrical Sources

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



Three-Phase Programmable Voltage Source (mask) (link)

This block implements a three-phase zero-impedance voltage source. The common node (neutral) of the three sources is accessible via input 1 (N) of the block. Time variation for the amplitude, phase and frequency of the fundamental can be pre-programmed. In addition, two harmonics can be superimposed on the fundamental.

Note: For "Phasor simulation" , frequency variation and harmonic injection are not allowed. Specify Order =1 and Seq=1,2 or 0 to inject additional fundamendal components A and B in any sequence.

Parameters

Positive-sequence: [Amplitude(Vrms Ph-Ph) Phase(deg.) Freq. (Hz)]
[100 0 60]

Time variation of: Amplitude

Type of variation: Step

Step magnitude (pu, deg. or Hz):
0.5

Variation timing (s) : [Start End]
[1 2]

☑ Fundamental and/or Harmonic generation:

A: [Order(n) Amplitude(pu) Phase(degrees) Seq(0, 1 or 2)]
[3 0.2 -25 0]

B: [Order(n) Amplitude(pu) Phase(degrees) Seq(0, 1 or 2)]
[2 0.15 35 2]

Timing (s) : [Start End]
[0.05 3]

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.

Note that the time variation applies on the three phases of the source except when the **Type of variation** parameter is set to `Table of amplitude-pairs`, in which case you can apply a variation on phase A only.

Type of variation

Specify the type of variation that is applied on 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.

Step magnitude

This parameter is only visible 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 only visible 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 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 only visible 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.

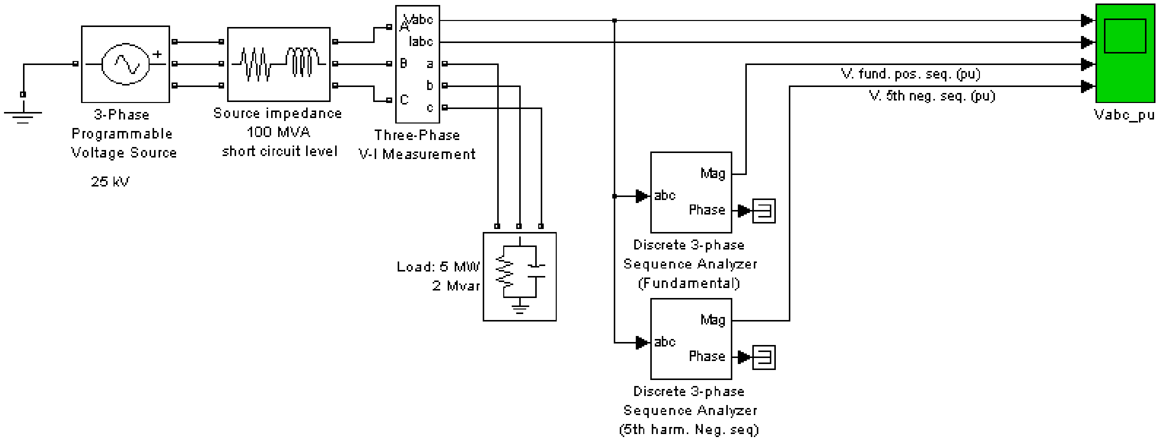
Example

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 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.

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

Purpose

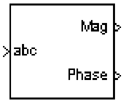
Measure positive-, negative-, and zero-sequence components of three-phase signal

Library

Extras/Measurements

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

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:

$$V_1 = \frac{1}{3}(V_a + a \cdot V_b + a^2 \cdot V_c)$$

$$V_2 = \frac{1}{3}(V_a + a^2 \cdot V_b + a \cdot V_c)$$

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

where

V_a, V_b, V_c = three voltage phasors at specified frequency

$a = e^{j2\pi/3} = 1\angle 120$degree complex operator

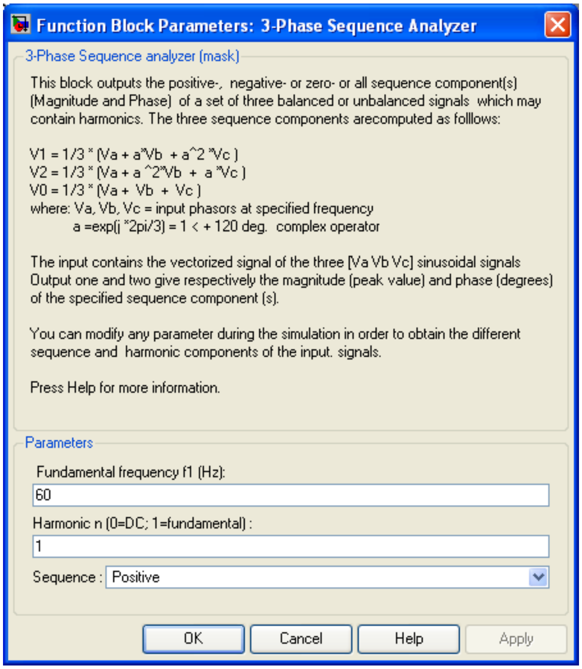
A Fourier analysis over a sliding window of one cycle of the specified frequency is first applied to the three input signals. It evaluates the phasor values Va, Vb, and Vc at the specified fundamental or harmonic frequency. Then the transformation is applied to obtain the positive sequence, negative sequence, and zero sequence.

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 V1 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



This block outputs the positive-, negative- or zero- or all sequence component(s) (Magnitude and Phase) of a set of three balanced or unbalanced signals which may contain harmonics. The three sequence components arecomputed as folllows:

V1 = 1/3 * (Va + a*Vb + a^2 *Vc)
V2 = 1/3 * (Va + a ^2*Vb + a *Vc)
V0 = 1/3 * (Va + Vb + Vc)
where: Va, Vb, Vc = input phasors at specified frequency
a =exp(j *2pi/3) = 1 < + 120 deg. complex operator

The input contains the vectorized signal of the three [Va Vb Vc] sinusoidal signals Output one and two give respectively the magnitude (peak value) and phase (degrees) of the specified sequence component (s).

You can modify any parameter during the simulation in order to obtain the different sequence and harmonic components of the input. signals.

Press Help for more information.

Fundamental frequency f1 (Hz): 60

Harmonic n (0=DC; 1=fundamental) : 1

Sequence : Positive

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.

`Phase`

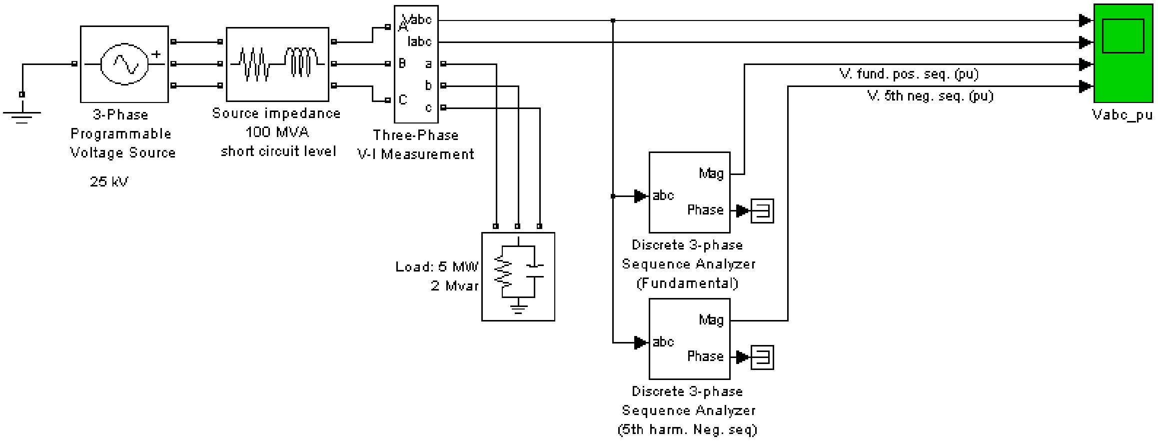
The second output gives the phase in degrees of the specified component(s).

Example

The `power_3phsignalseq` demo illustrates the use of the Discrete 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 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 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 Discrete Three-Phase 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 Three-Phase Sequence Analyzer blocks use Fourier analysis, their response time is delayed by one cycle of the fundamental frequency.

Three-Phase Series RLC Branch

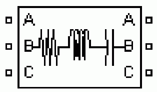
Purpose

Implement three-phase series RLC branch

Library

Elements

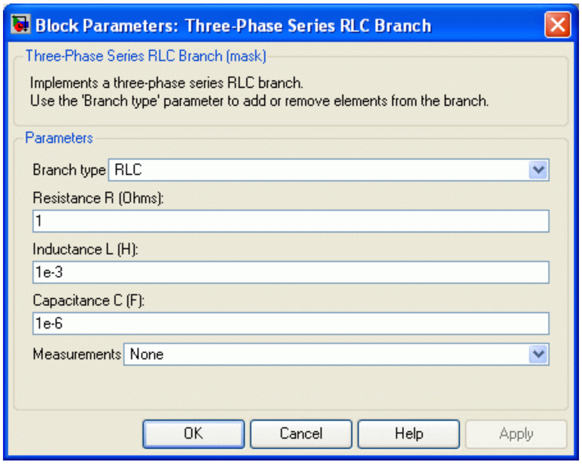
Description



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. If you eliminate either the resistance, inductance, or capacitance of each branch, the R, L, and C values are automatically set respectively to 0, 0, and infinity (inf) and the corresponding parameters no longer appear in the block dialog box. Only existing elements are displayed in the block icon.

Negative values are allowed for resistance, inductance, and capacitance.

Dialog Box and Parameters



Implements a three-phase series RLC branch.
Use the 'Branch type' parameter to add or remove elements from the branch.

Branch type: RLC

Resistance R (Ohms): 1

Inductance L (H): 1e-3

Capacitance C (F): 1e-6

Measurements: None

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).

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

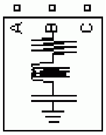
Purpose

Implement three-phase series RLC load with selectable connection

Library

Elements

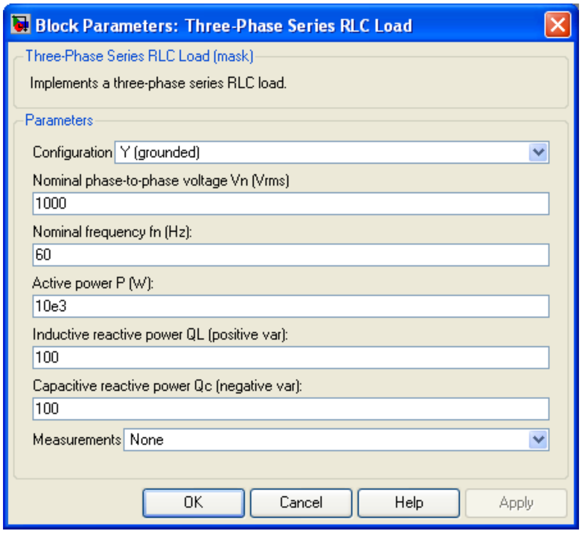
Description



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


Block Parameters: Three-Phase Series RLC Load

Three-Phase Series RLC Load (mask)

Implements a three-phase series RLC load.

Parameters

Configuration: Y (grounded)

Nominal phase-to-phase voltage Vn (Vrms): 1000

Nominal frequency fn (Hz): 60

Active power P (W): 10e3

Inductive reactive power QL (positive var): 100

Capacitive reactive power Qc (negative var): 100

Measurements: None

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).

Active power P

The three-phase active power of the load, in watts (W).

Inductive reactive power QL

The three-phase inductive reactive power QL, in vars. Specify a positive value, or 0.

Capacitive reactive power Qc

The three-phase capacitive reactive power QC, in vars. Specify a positive value, or 0.

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:`

See Also

Multimeter, Three-Phase Dynamic Load, Three-Phase Parallel RLC Branch, Three-Phase Parallel RLC Load, Three-Phase Series RLC Branch

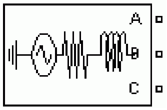
Purpose

Implement three-phase source with internal R-L impedance

Library

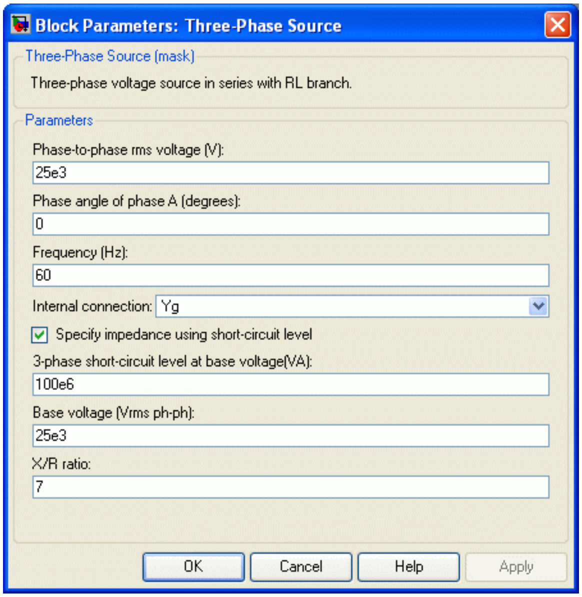
Electrical Sources

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



Block Parameters: Three-Phase Source

Three-Phase Source (mask)

Three-phase voltage source in series with RL branch.

Parameters

Phase-to-phase rms voltage (V): 25e3

Phase angle of phase A (degrees): 0

Frequency (Hz): 60

Internal connection: Yg

☑ Specify impedance using short-circuit level

3-phase short-circuit level at base voltage(VA): 100e6

Base voltage (Vrms ph-ph): 25e3

X/R ratio: 7

Phase-to-phase rms voltage

The internal phase-to-phase voltage in volts RMS (Vrms)

Phase angle of phase A

The phase angle of the internal voltage generated by phase A, in degrees. The three voltages are generated in positive sequence. Thus, phase B and phase C internal voltages are lagging phase A respectively by 120 degrees and 240 degrees.

Frequency

The source frequency in hertz (Hz).

Internal connection

The internal connection of the three internal voltage sources. The block icon is updated according to the source connection.

Select one of the following three 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 impedance using short-circuit level

Select to specify internal impedance using the inductive short-circuit level and X/R ratio.

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 **Specify impedance using short-circuit level** is 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:

$$L = \frac{(Vbase)^2}{Psc} \cdot \frac{1}{2\pi f}$$

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 **Specify impedance using short-circuit level** is 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 **Specify impedance using short-circuit level** is 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:

$$R = \frac{X}{(X/R)} = \frac{2\pi f L}{(X/R)}$$

Source resistance

This parameter is available only if **Specify impedance using short-circuit level** is not selected.

The source internal resistance in ohms (Ω).

Source inductance

This parameter is available only if **Specify impedance using short-circuit level** is not selected.

The source internal inductance in henries (H).

Note Either resistance or inductance of the source can be set to zero, but not both at the same time. The block icon is updated accordingly.

Example

See the `power_3phseriescomp` demo, 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

Purpose

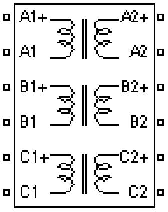
Implement three single-phase, two-winding transformers where all terminals are accessible

Library

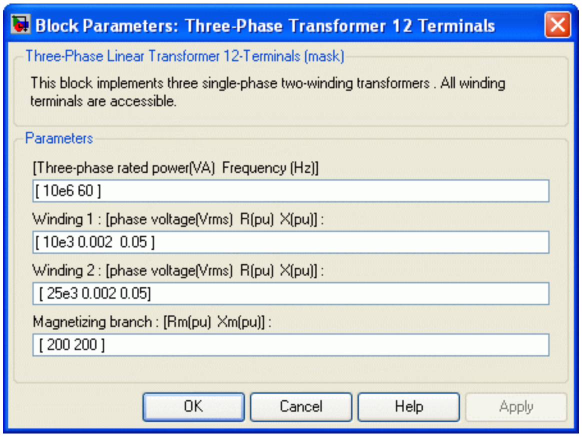
Elements

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



Block Parameters: Three-Phase Transformer 12 Terminals

Three-Phase Linear Transformer 12-Terminals (mask)

This block implements three single-phase two-winding transformers . All winding terminals are accessible.

Parameters

[Three-phase rated power(VA) Frequency (Hz)]

[10e6 60]

Winding 1 : [phase voltage(Vrms) R(pu) X(pu)] :

[10e3 0.002 0.05]

Winding 2 : [phase voltage(Vrms) R(pu) X(pu)] :

[25e3 0.002 0.05]

Magnetizing branch : [Rm(pu) Xm(pu)] :

[200 200]

[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 the `power_3phPWM` demo 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)

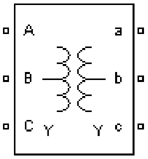
Purpose

Implement three-phase transformer with configurable winding connections

Library

Elements

Description



The Three-Phase Transformer (Two Windings) block implements a three-phase transformer using three single-phase transformers. You can simulate the saturable core or not simply by setting the appropriate check box in the parameter menu of the block. See the Linear Transformer block and Saturable Transformer block sections for a detailed description of the electrical model of a single-phase transformer.

The two 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).

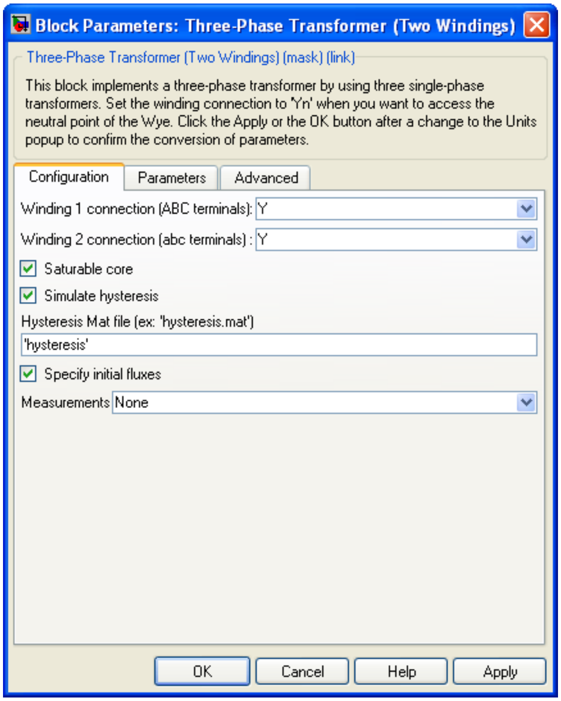
The block takes into account the connection type you have selected, and the icon of the block is automatically updated. An input port labeled N is added to the block if you select the Y connection with accessible neutral for winding 1. If you ask for an accessible neutral on winding 2, an extra output port labeled n is generated.

The saturation characteristic, when activated, is the same as the one described for the Saturable Transformer block, and the icon of the block is automatically updated. 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 an explanation of per units, refer to the Linear Transformer and to the Saturable Transformer.

Dialog Box and Parameters

Configuration Tab



Block Parameters: Three-Phase Transformer (Two Windings)

Three-Phase Transformer (Two Windings) (mask) (link)

This block implements a three-phase transformer by using three single-phase transformers. Set the winding connection to 'Yn' when you want to access the neutral point of the Wye. Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

Winding 1 connection (ABC terminals): Y

Winding 2 connection (abc terminals) : Y

☑ Saturable core

☑ Simulate hysteresis

Hysteresis Mat file (ex: 'hysteresis.mat')

'hysteresis'

☑ Specify initial fluxes

Measurements None

Winding 1 connection (ABC terminals)
The winding connections for winding 1.

Winding 2 connection (abc terminals)
The winding connections for winding 2.

Saturable core
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 (for saturable transformers only).

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 (for saturable transformers only).

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:`

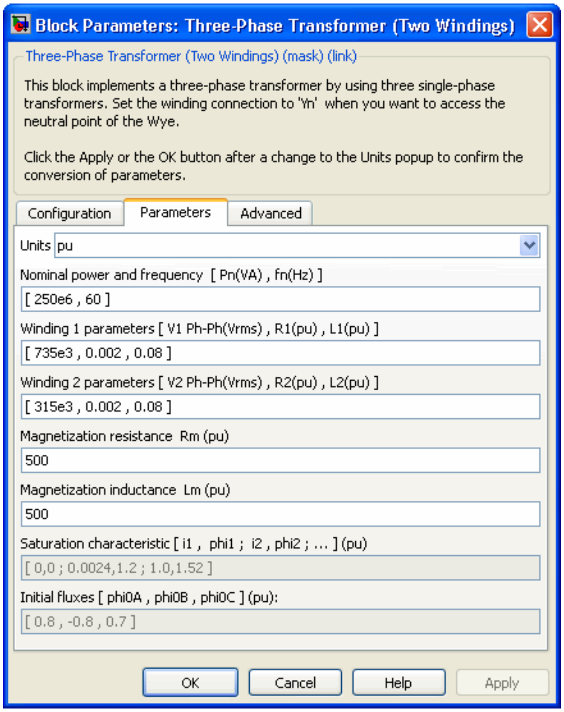
Fluxes	`Flux_A:`, `Flux_B:`, `Flux_C:`
Magnetization currents	`Imag_A:`, `Imag_B:`, `Imag_C:`
Excitation currents	`Iexc_A:`, `Iexc_B:`, `Iexc_C:`

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



Block Parameters: Three-Phase Transformer (Two Windings)

Three-Phase Transformer (Two Windings) (mask) (link)

This block implements a three-phase transformer by using three single-phase transformers. Set the winding connection to 'Yn' when you want to access the neutral point of the Wye.

Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

Units pu

Nominal power and frequency [Pn(VA) , fn(Hz)]
[250e6 , 60]

Winding 1 parameters [V1 Ph-Ph(Vrms) , R1(pu) , L1(pu)]
[735e3 , 0.002 , 0.08]

Winding 2 parameters [V2 Ph-Ph(Vrms) , R2(pu) , L2(pu)]
[315e3 , 0.002 , 0.08]

Magnetization resistance Rm (pu)
500

Magnetization inductance Lm (pu)
500

Saturation characteristic [i1 , phi1 ; i2 , phi2 ; ...] (pu)
[0,0 ; 0.0024,1.2 ; 1.0,1.52]

Initial fluxes [phi0A , phi0B , phi0C] (pu):
[0.8 , -0.8 , 0.7]

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.

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.

Saturation characteristic

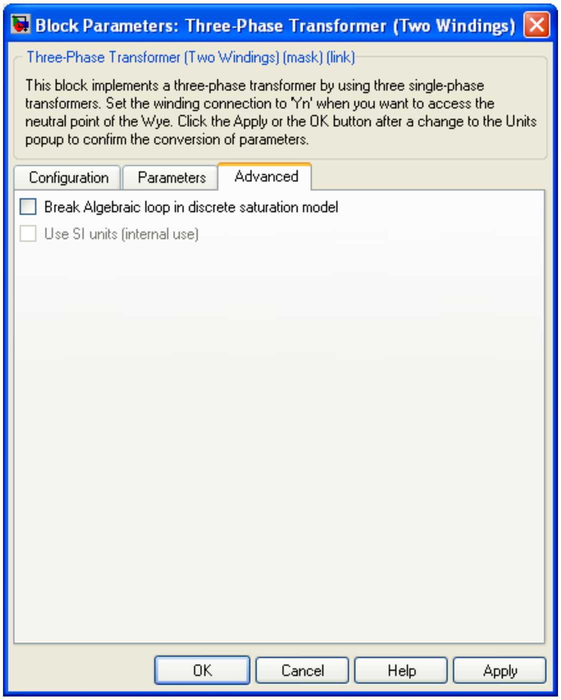
The saturation characteristic for the saturable core. Specify a series of current/ flux pairs (in pu) starting with the pair (0,0). This parameter is accessible only if the **Saturable core** parameter on the Configuration tab is selected.

Initial fluxes

Specify initial fluxes for each phase of the transformer. This parameter is accessible 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 will overwrite any previous values.

Advanced Tab



Three-Phase Transformer (Two Windings) (mask) (link)

This block implements a three-phase transformer by using three single-phase transformers. Set the winding connection to 'Yn' when you want to access the neutral point of the Wye. Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

☐ Break Algebraic loop in discrete saturation model

☐ Use SI units (internal use)

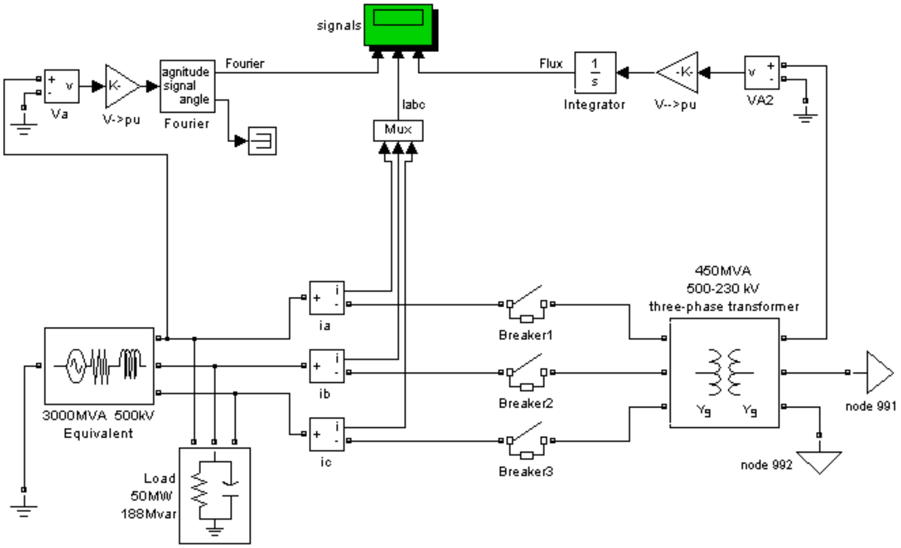
Break Algebraic loop in discrete saturation model

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.

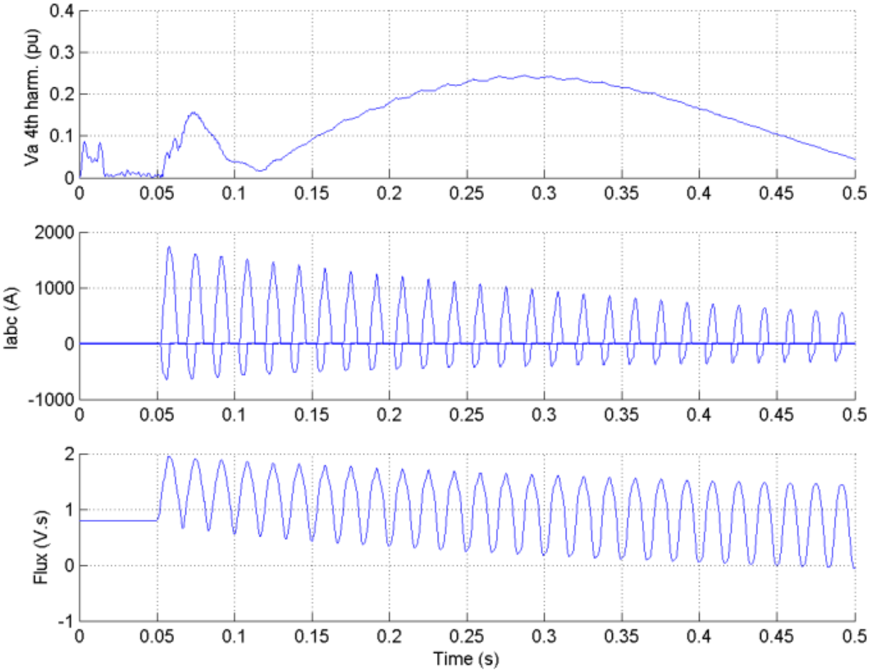
Example

The `power_transfo3ph` circuit uses the Three-Phase Transformer block where the saturable core is simulated. Both windings are connected in a Y grounded configuration. Note that 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

Linear Transformer, Multimeter, Saturable Transformer, Three-Phase Transformer (Three Windings), Three-Phase Transformer Inductance Matrix Type (Two Windings)

Three-Phase Transformer (Three Windings)

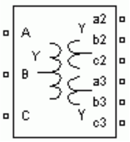
Purpose

Implement three-phase transformer with configurable winding connections

Library

Elements

Description



This block implements a three-phase transformer by using three single-phase transformers with three windings. You can simulate the saturable core or not simply by setting the appropriate check box in the parameter menu of the block. See the Linear Transformer and Saturable Transformer block sections for a detailed description of the electrical model of a single-phase 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

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).

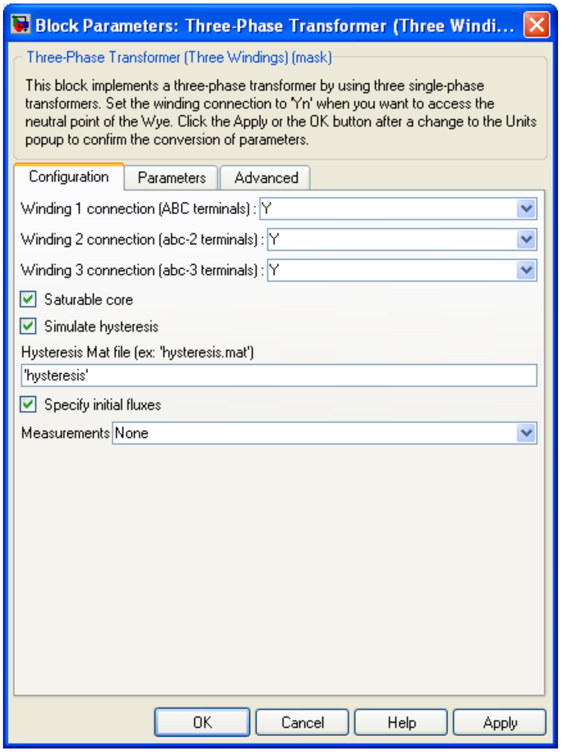
The block takes into account the connection type you select, and the icon of the block is automatically updated. An input port labeled `N` is added to the block if you select the Y connection with accessible neutral for winding 1. If you ask for an accessible neutral on winding 3, an extra outport port labeled `n3` is generated.

The saturation characteristic, when activated, is the same as the one described for the Saturable Transformer block, and the icon of the block is automatically updated. 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.

Dialog Box and Parameters

Configuration Tab


Block Parameters: Three-Phase Transformer (Three Windi...

Three-Phase Transformer (Three Windings) (mask)

This block implements a three-phase transformer by using three single-phase transformers. Set the winding connection to 'Yn' when you want to access the neutral point of the Wye. Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

Winding 1 connection (ABC terminals) : Y

Winding 2 connection (abc-2 terminals) : Y

Winding 3 connection (abc-3 terminals) : Y

☑ Saturable core

☑ Simulate hysteresis

Hysteresis Mat file (ex: 'hysteresis.mat')

'hysteresis'

☑ Specify initial fluxes

Measurements None

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.

Saturable core
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 (for saturable transformers only).

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 (for saturable transformers only).

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:`

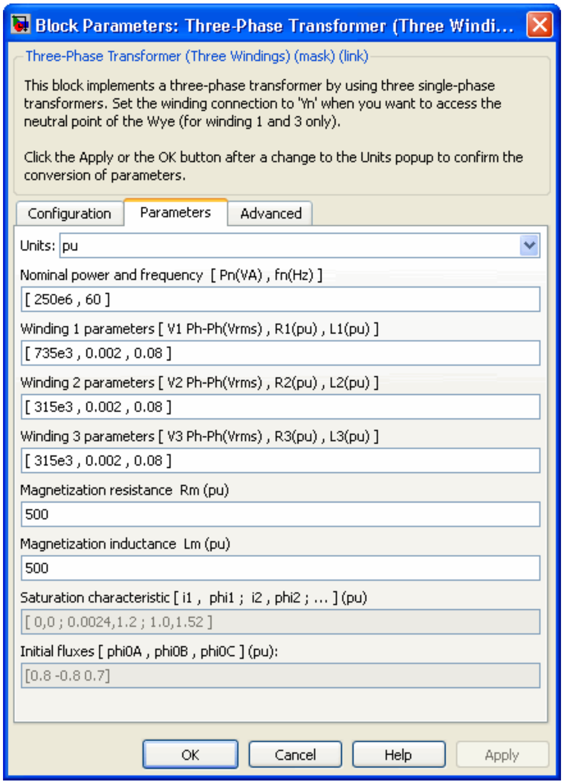
Flux linkages	`Flux_A:, Flux_B:, Flux_C:`
Magnetization currents	`Imag_A:, Imag_B:, Imag_C:`
Excitation currents	`Iexc_A:, Iexc_B:, Iexc_C:`

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



Three-Phase Transformer (Three Windings) (mask) (link)

This block implements a three-phase transformer by using three single-phase transformers. Set the winding connection to 'Yn' when you want to access the neutral point of the Wye (for winding 1 and 3 only).

Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

Units: pu

Nominal power and frequency [Pn(VA) , fn(Hz)]
[250e6 , 60]

Winding 1 parameters [V1 Ph-Ph(Vrms) , R1(pu) , L1(pu)]
[735e3 , 0.002 , 0.08]

Winding 2 parameters [V2 Ph-Ph(Vrms) , R2(pu) , L2(pu)]
[315e3 , 0.002 , 0.08]

Winding 3 parameters [V3 Ph-Ph(Vrms) , R3(pu) , L3(pu)]
[315e3 , 0.002 , 0.08]

Magnetization resistance Rm (pu)
500

Magnetization inductance Lm (pu)
500

Saturation characteristic [i1 , phi1 ; i2 , phi2 ; ...] (pu)
[0,0 ; 0.0024,1.2 ; 1.0,1.52]

Initial fluxes [phi0A , phi0B , phi0C] (pu):
[0.8 -0.8 0.7]

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.

Saturation characteristic

This parameter is accessible only if the **Saturable core** parameter is selected.

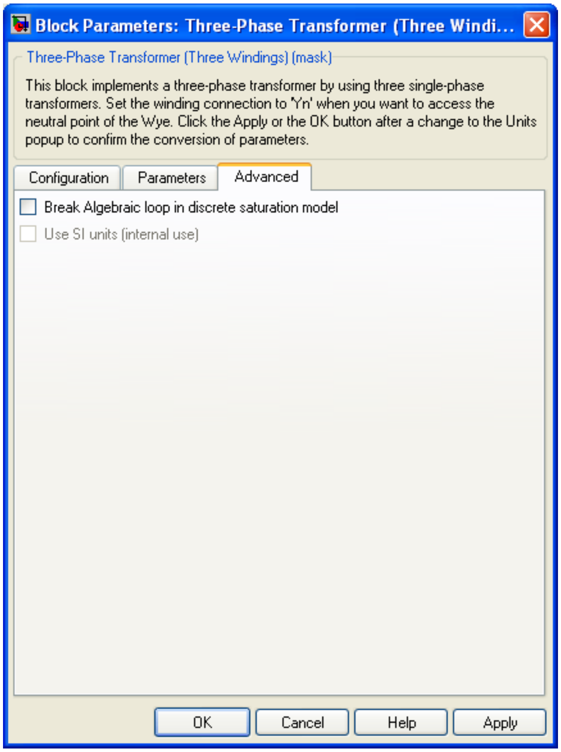
The saturation characteristic for the saturable core. Specify a series of current/ flux pairs (in pu) starting with the pair (0,0).

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



This block implements a three-phase transformer by using three single-phase transformers. Set the winding connection to 'Yn' when you want to access the neutral point of the Wye. Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

☐ Break Algebraic loop in discrete saturation model

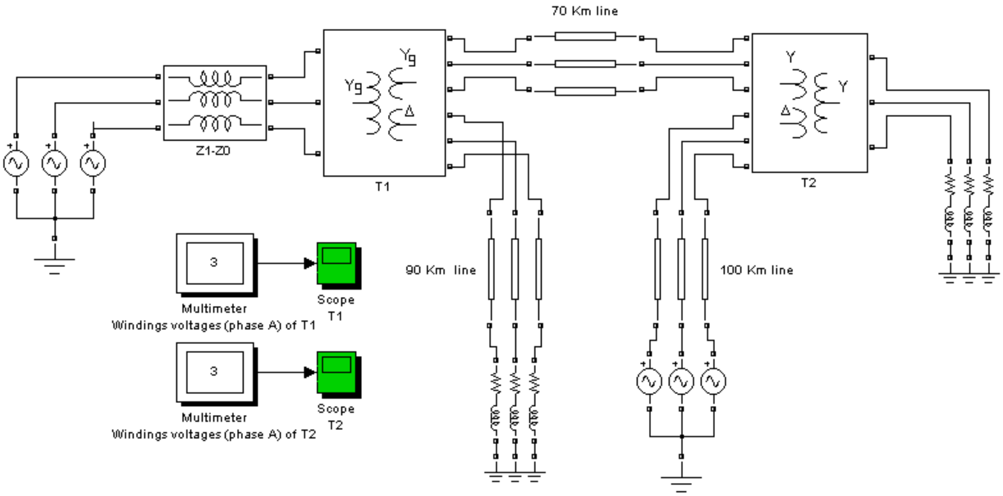
☐ Use SI units (internal use)

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)

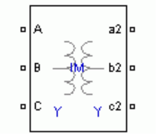
Purpose

Implement three-phase two-winding transformer with configurable winding connections and core geometry

Library

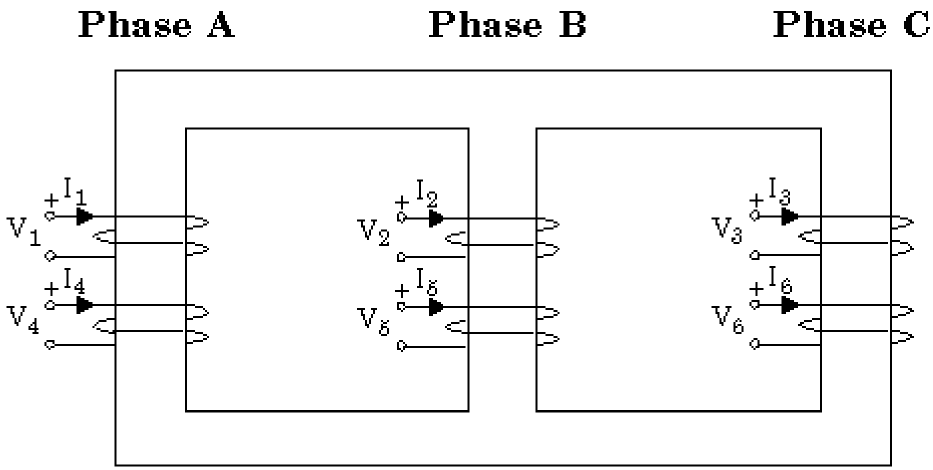
Elements

Description



The standard Three-Phase Transformer (Two Windings) block uses three single-phase transformers to implement a three-phase model. When a three-phase transformer is built with a three-limb core or a five-limb core this model does not represent the couplings between windings of different phases.

A three-phase transformer using a three-limb core and two windings per phase is shown in the following figure. Windings are numbered as follows: 1, 4 for phase A, 2, 5 for phase B and 3, 6 for phase C.



This core geometry implies that winding 1 is coupled to all other windings (2 to 6), whereas in a three-phase transformer using three independent cores (as in the Three-Phase Transformer (Two Windings) block) winding 1 is coupled only with winding 4.

Transformer Model

The Three-Phase Transformer Inductance Matrix Type (Two Windings) block implements the following matrix relationship:

$$\begin{bmatrix} V_1 \\ V_2 \\ \dots \\ V_6 \end{bmatrix} = \begin{bmatrix} R_1 & 0 & \dots & 0 \\ 0 & R_2 & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & R_6 \end{bmatrix} \cdot \begin{bmatrix} I_1 \\ I_2 \\ \dots \\ I_6 \end{bmatrix} + \begin{bmatrix} L_{11} & L_{12} & \dots & L_{16} \\ L_{21} & L_{22} & \dots & L_{16} \\ \dots & \dots & \dots & \dots \\ L_{61} & L_{62} & \dots & L_{66} \end{bmatrix} \cdot \frac{d}{dt} \begin{bmatrix} I_1 \\ I_2 \\ \dots \\ I_6 \end{bmatrix}$$

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 transformer shown in the previous figure has 2 three-phase windings:

- Three-phase winding 1 consists of windings 1,2,3
- Three-phase winding 2 consists of windings 4,5,6

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:

$$X_1(1,1) = \frac{Vnom_1^{\;2}}{Q1_1}$$

$$X_1(2,2) = \frac{Vnom_2^{\;2}}{Q1_2}$$

$$X_1(1,2) = X_1(2,1) = \sqrt{X_1(1,1) \cdot X_1(2,2) - X1_{12}^2}$$

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

$$\begin{bmatrix} X_1(1,1) & X_1(1,2) \\ X_1(2,1) & X_1(2,2) \end{bmatrix} \qquad \begin{bmatrix} X_0(1,1) & X_0(1,2) \\ X_0(2,1) & X_0(2,2) \end{bmatrix}$$

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:

$$X_s = \frac{1}{3}(X_0 + 2X_1)$$

$$X_m = \frac{1}{3}(X_0 - X_1)$$

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:

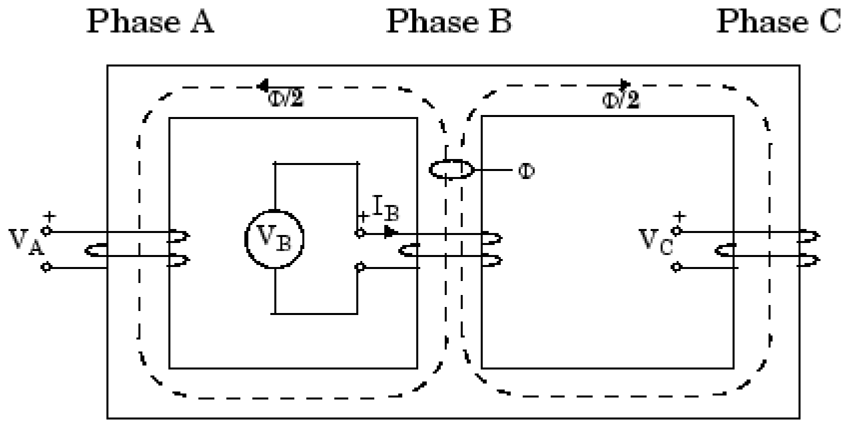
$$R1_1 = \frac{Vnom_1^{\ 2}}{P1_1} \qquad R0_1 = \frac{Vnom_1^{\ 2}}{P0_1}$$

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 figure below shows a 3-limb core with a 3-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

$$V_B = Z_s I_B$$

$$V_A = Z_m I_B = -V_B/2$$

$$V_C = Z_m I_B = -V_B/2$$

$$Z_s = \frac{(2Z_1 + Z_0)}{3}$$

$$Z_m = \frac{(Z_0 - Z_1)}{3}$$

$$V_A = V_C = \frac{Zm}{Zs} V_B = -\frac{\frac{Z_1}{Z_0} - 1}{2\frac{Z_1}{Z_0} + 1} V_B = -\frac{\frac{I_0}{I_1} - 1}{2\frac{I_0}{I_1} + 1} V_B = -kV_B$$

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

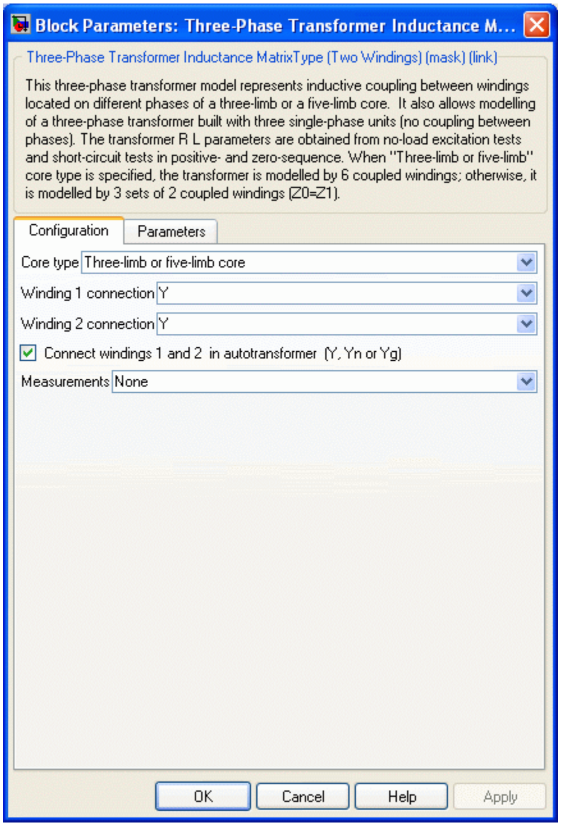
The two windings of the transformer can be connected in the following manner:

- 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



Three-Phase Transformer Inductance MatrixType (Two Windings) (mask) (link)

This three-phase transformer model represents inductive coupling between windings located on different phases of a three-limb or a five-limb core. It also allows modelling of a three-phase transformer built with three single-phase units (no coupling between phases). The transformer R L parameters are obtained from no-load excitation tests and short-circuit tests in positive- and zero-sequence. When "Three-limb or five-limb" core type is specified, the transformer is modelled by 6 coupled windings; otherwise, it is modelled by 3 sets of 2 coupled windings (Z0=Z1).

Core type Three-limb or five-limb core

Winding 1 connection Y

Winding 2 connection Y

☑ Connect windings 1 and 2 in autotransformer (Y, Yn or Yg)

Measurements None

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 winding 1.

Winding 2 connection
The winding connection for winding 2.

Connect windings 1 and 2 in autotransformer
Check this parameter to connect windings 1 and 2 in autotransformer.

Specifying this connection connects 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). If you select this option you must specify the same winding connections for windings 1 and 2. If you select `Yn` for both winding 1 and winding 2, the common neutral N connector is displayed on the left side.

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:`

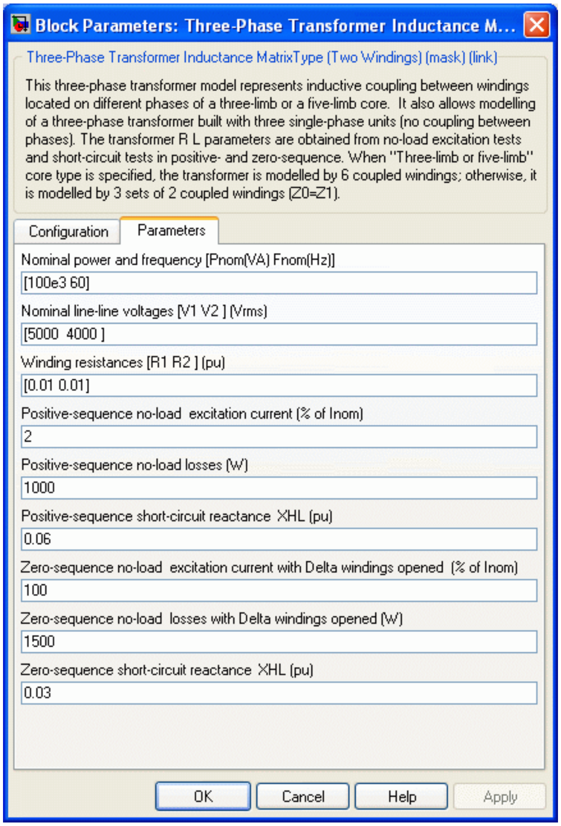
Winding 1 currents	`Ian_w1:, Ibn_w1:, Icn_w1:`
	or
	`Iag_w1:, Ibg_w1:, Icg_w1:`

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 winding 2, except that `1` is replaced by `2` in the labels.

Parameters Tab



Block Parameters: Three-Phase Transformer Inductance M...

Three-Phase Transformer Inductance MatrixType (Two Windings) (mask) (link)

This three-phase transformer model represents inductive coupling between windings located on different phases of a three-limb or a five-limb core. It also allows modelling of a three-phase transformer built with three single-phase units (no coupling between phases). The transformer R L parameters are obtained from no-load excitation tests and short-circuit tests in positive- and zero-sequence. When "Three-limb or five-limb" core type is specified, the transformer is modelled by 6 coupled windings; otherwise, it is modelled by 3 sets of 2 coupled windings (Z0=Z1).

Nominal power and frequency [Pnom(VA) Fnom(Hz)]
[100e3 60]

Nominal line-line voltages [V1 V2] (Vrms)
[5000 4000]

Winding resistances [R1 R2] (pu)
[0.01 0.01]

Positive-sequence no-load excitation current (% of Inom)
2

Positive-sequence no-load losses (W)
1000

Positive-sequence short-circuit reactance XHL (pu)
0.06

Zero-sequence no-load excitation current with Delta windings opened (% of Inom)
100

Zero-sequence no-load losses with Delta windings opened (W)
1500

Zero-sequence short-circuit reactance XHL (pu)
0.03

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 group of 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 group of winding terminals (ABC or abc2).

Positive-sequence short-circuit reactance

The positive-sequence short-circuit reactances X12 in pu, where 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, where 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 group of winding terminals (ABC or abc2).

If you want to measure this excitation current, you must connect the excited winding in Yg or Yn in order to provide a return path for the source zero-sequence currents. Also, the Delta connection of the other winding must be open; otherwise, this Delta connection would produce a short-circuit for zero sequence. You must therefore temporarily change the open winding connection from D1 or D11 to Y, Yg, Yn.

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). The Delta winding must be temporarily open in order to measure these losses.

Zero-sequence short-circuit reactance
The zero-sequence short-circuit reactance X12 in pu, where 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, where 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 same connection (Yg, D1 or D11) and same winding resistance for the two windings connected in parallel. Specify Y or Yg connection for the secondary winding and leave it open. Specify appropriate voltage, power ratings and desired saturation characteristics. The saturation characteristic is the characteristic obtained when then 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.

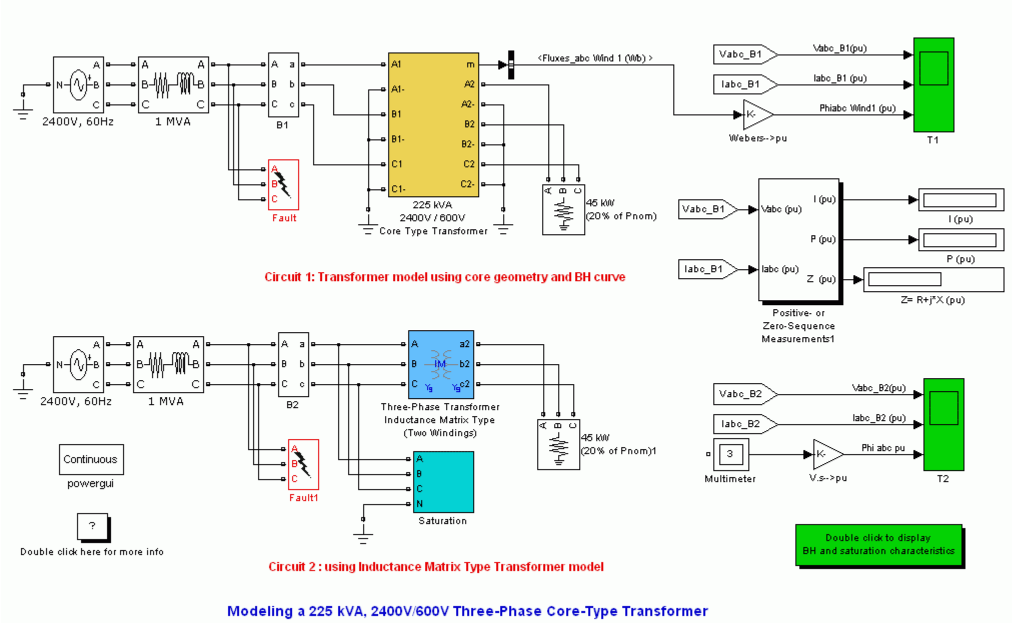
For a three-limb core, it is less evident that this saturation model also gives acceptable results because zero-sequence flux circulates outside of the core and returns through the air and the transformer tank surrounding the iron core. However, as the zero-sequence flux circulates in the air, the magnetic 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 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` demo 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.

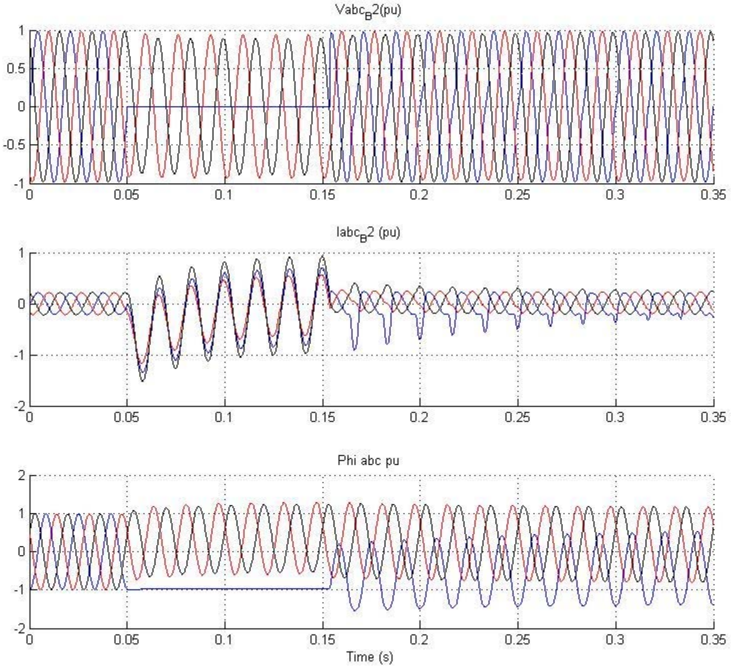


The model shows two identical circuits with a three-phase transformer rated 225 kVA, 2400 V/600V, 60Hz, connected to a 1 MVA, 2400 V power network. A 45 kW resistive load (20 % of transformer nominal power) is connected on the 600 V side. Each phase of the transformer consists of two windings, both connected 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 demo 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

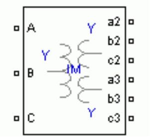
Linear Transformer, Multimeter, Three-Phase Transformer (Two Windings), Three-Phase Transformer (Three Windings), Three-Phase Transformer Inductance Matrix Type (Three Windings)

Three-Phase Transformer Inductance Matrix Type (Three Windings)

Purpose Implement three-phase three-winding transformer with configurable winding connections and core geometry

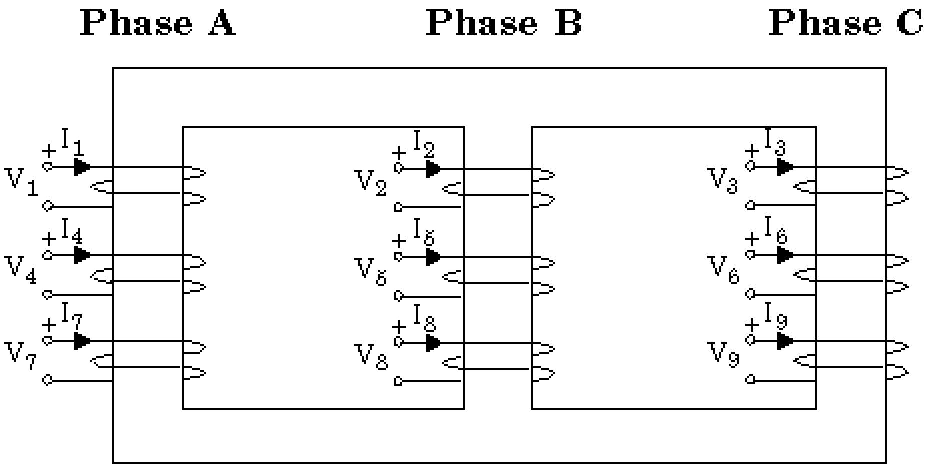
Library Elements

Description



The standard Three-Phase Transformer (Three Windings) block uses three single-phase transformers to implement a three-phase model. When a three-phase transformer is built with a three-limb core or a five-limb core this model does not represent the couplings between windings of different phases.

A three-phase transformer using a three-limb core and three windings per phase is shown in the following figure. Windings are numbered as follows: 1, 4, 7 for phase A, 2,5,8 for phase B and 3, 6, 9 for phase C.



This core geometry implies that winding 1 is coupled to all other windings (2 to 9), whereas in a three-phase transformer using three independent cores (as in Three-Phase Transformer (Three Windings) block) winding 1 is coupled only with windings 4 and 7.

Three-Phase Transformer Inductance Matrix Type (Three Windings)

Transformer Model

The Three-Phase Transformer Inductance Matrix Type (Three-Windings) block implements the following matrix relationship:

$$\begin{bmatrix} V_1 \\ V_2 \\ \dots \\ V_9 \end{bmatrix} = \begin{bmatrix} R_1 & 0 & \dots & 0 \\ 0 & R_2 & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & R_9 \end{bmatrix} \cdot \begin{bmatrix} I_1 \\ I_2 \\ \dots \\ I_9 \end{bmatrix} + \begin{bmatrix} L_{11} & L_{12} & \dots & L_{19} \\ L_{21} & L_{22} & \dots & L_{29} \\ \dots & \dots & \dots & \dots \\ L_{91} & L_{92} & \dots & L_{99} \end{bmatrix} \cdot \frac{d}{dt} \begin{bmatrix} I_1 \\ I_2 \\ \dots \\ I_9 \end{bmatrix}$$

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 transformer shown in the previous figure has 3 three-phase windings:

- Three-phase winding 1 consists of windings 1,2,3
- Three-phase winding 2 consists of windings 4,5,6
- Three-phase winding 3 consists of windings 7,8,9

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):

$Q_{1\mathrm{i}}$= Three-phase reactive power absorbed by winding i at no load when winding i is
excited by a positive-sequence voltage $Vnom_\mathrm{i}$ with winding j open

$Q_{1\mathrm{j}}$= Three-phase reactive power absorbed by winding j at no load when winding j is
excited by a positive-sequence voltage $Vnom_\mathrm{j}$ with winding i open

$X_{1\mathrm{ij}}$ = positive-sequence short-circuit reactance seen from winding i when winding j is short-circuited

$Vnom_\mathrm{i}$, $Vnom_\mathrm{j}$ = nominal line-line voltages of windings i and j

The positive-sequence self and mutual reactances are given by:

$$X_1(i,i) = \frac{Vnom_i^{\ 2}}{Q_{1_i}}$$

$$X_1(j,j) = \frac{Vnom_j^{\ 2}}{Q_{1_j}}$$

$$X_1(i,j) = X_1(j,i) = \sqrt{X_1(i,i)\cdot X_1(j,j) - X_{1ij}^2}$$

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:

$$X_s = \frac{1}{3}(X_0 + 2X_1)$$
$$X_m = \frac{1}{3}(X_0 - X_1)$$

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:

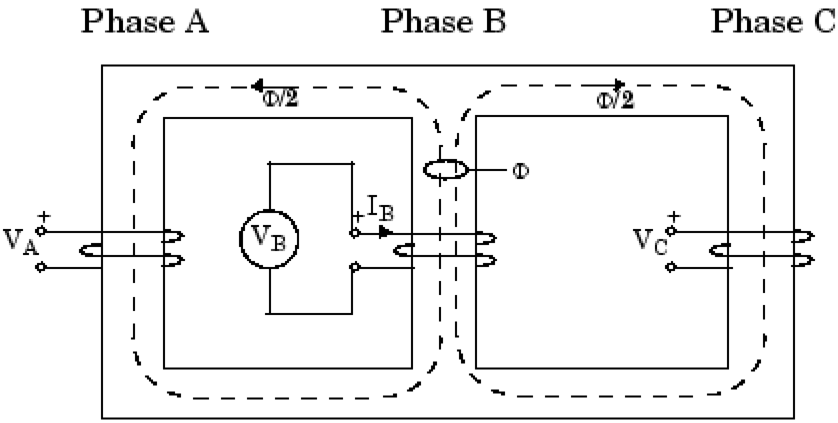
$$R1_i = \frac{Vnom_i^{\;2}}{P_{1_i}} \qquad\qquad R0_i = \frac{Vnom_i^{\;2}}{P_{0_i}}$$

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 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 figure below shows a 3-limb core with a 3-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

$$V_B = Z_s I_B$$

$$V_A = Z_m I_B = -V_B/2$$

$$V_C = Z_m I_B = -V_B/2$$

$$Z_s = \frac{(2Z_1 + Z_0)}{3}$$

$$Z_m = \frac{(Z_0 - Z_1)}{3}$$

$$V_A = V_C = \frac{Zm}{Zs} V_B = -\frac{\frac{Z_1}{Z_0} - 1}{2\frac{Z_1}{Z_0} + 1} V_B = -\frac{\frac{I_0}{I_1} - 1}{2\frac{I_0}{I_1} + 1} V_B = -k V_B$$

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 windings of the transformer can be connected in the following manner:

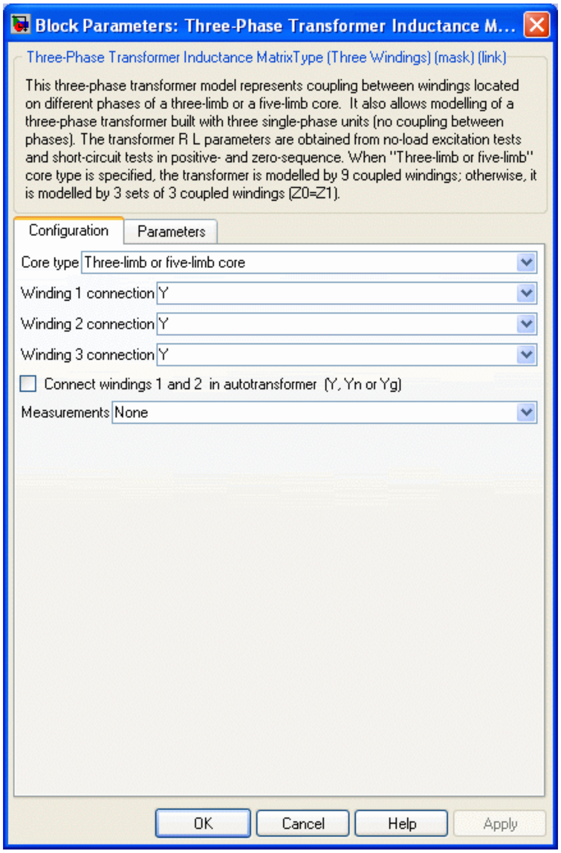
- Y
- Y with accessible neutral
- Grounded Y
- Delta (D1), delta lagging Y by 30 degrees
- Delta (D11), delta leading Y by 30 degrees

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).

Three-Phase Transformer Inductance Matrix Type (Three Windings)

Dialog Box and Parameters

Configuration Tab



This three-phase transformer model represents coupling between windings located on different phases of a three-limb or a five-limb core. It also allows modelling of a three-phase transformer built with three single-phase units (no coupling between phases). The transformer R L parameters are obtained from no-load excitation tests and short-circuit tests in positive- and zero-sequence. When "Three-limb or five-limb" core type is specified, the transformer is modelled by 9 coupled windings; otherwise, it is modelled by 3 sets of 3 coupled windings (Z0=Z1).

Core type: Three-limb or five-limb core

Winding 1 connection: Y

Winding 2 connection: Y

Winding 3 connection: Y

☐ Connect windings 1 and 2 in autotransformer (Y, Yn or Yg)

Measurements: None

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 winding 1.

Winding 2 connection

The winding connection for winding 2.

Winding 3 connection

The winding connection for winding 3.

Connect windings 1 and 2 in autotransformer

Check this parameter to connect windings 1 and 2 in autotransformer.

Specifying this connection connects 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). If you select this option you must specify the same winding connections for windings 1 and 2. If you select `Yn` for both winding 1 and winding 2, the common neutral N connector is displayed on the left side.

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:`

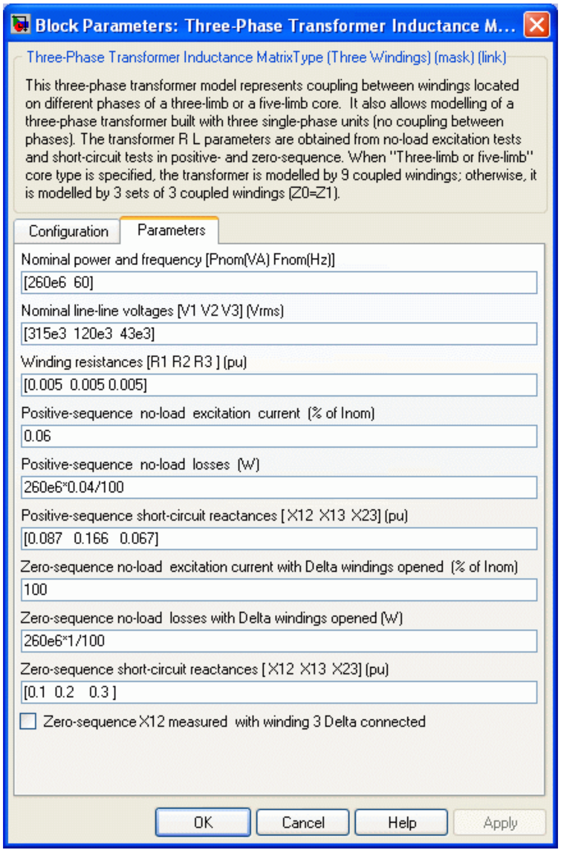
Winding 1 currents	`Ian_w1:`, `Ibn_w1:`, `Icn_w1:`
	or
	`Iag_w1:`, `Ibg_w1:`, `Icg_w1:`

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 windings 2 and 3, except that `1` is replaced by `2 or 3` in the labels.

Parameters Tab



Three-Phase Transformer Inductance MatrixType (Three Windings) (mask) (link)

This three-phase transformer model represents coupling between windings located on different phases of a three-limb or a five-limb core. It also allows modelling of a three-phase transformer built with three single-phase units (no coupling between phases). The transformer R L parameters are obtained from no-load excitation tests and short-circuit tests in positive- and zero-sequence. When "Three-limb or five-limb" core type is specified, the transformer is modelled by 9 coupled windings; otherwise, it is modelled by 3 sets of 3 coupled windings (Z0=Z1).

Nominal power and frequency [Pnom(VA) Fnom(Hz)]
[260e6 60]

Nominal line-line voltages [V1 V2 V3] (Vrms)
[315e3 120e3 43e3]

Winding resistances [R1 R2 R3] (pu)
[0.005 0.005 0.005]

Positive-sequence no-load excitation current (% of Inom)
0.06

Positive-sequence no-load losses (W)
260e6*0.04/100

Positive-sequence short-circuit reactances [X12 X13 X23] (pu)
[0.087 0.166 0.067]

Zero-sequence no-load excitation current with Delta windings opened (% of Inom)
100

Zero-sequence no-load losses with Delta windings opened (W)
260e6*1/100

Zero-sequence short-circuit reactances [X12 X13 X23] (pu)
[0.1 0.2 0.3]

☐ Zero-sequence X12 measured with winding 3 Delta connected

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 group of 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 group of winding terminals (ABC, abc2 or abc3).

Positive-sequence short-circuit reactances

The positive-sequence short-circuit reactances X12, X23 and X13 in pu, where 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 checked, the short-circuit reactances are labeled XHL, XHT and XLT, where 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 group of winding terminals (ABC, abc2 or abc3).

If you want to measure this excitation current, you must connect the excited winding in Yg or Yn in order to provide a return path for the source zero-sequence currents. Also, the Delta connections of the other windings must be open; otherwise, these Delta connections would produce a short-circuit for zero sequence. You must therefore temporarily change the open winding connections from D1 or D11 to Y, Yg, Yn.

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, abc2 or abc3). The Delta windings must be temporarily open in order to measure these losses.

Zero-sequence short-circuit reactances

The zero-sequence short-circuit reactances X12, X23 and X13 in pu, where 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, where 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 were 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 same connection (Yg, D1 or D11) and same winding resistance for the two windings connected in parallel. Specify Y or Yg connection for the secondary winding and leave it open. Specify appropriate voltage, power ratings and desired saturation characteristics. The saturation characteristic is the characteristic obtained when then 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, it is less evident that this saturation model also gives acceptable results because zero-sequence flux circulates outside of the core and returns through the air and the transformer tank surrounding the iron core. However, 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 the iron core. This model will give acceptable results whether the three-limb transformer has a delta or not.

See the `power_Transfo3phCoreType` demo 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)

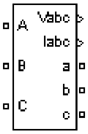
Purpose

Measure three-phase currents and voltages in circuit

Library

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:

$$V_{\text{abc}}\,(pu) = \frac{V_{\text{phase to ground}}\,(V)}{V_{\text{base}}\,(V)}$$

where

$$V_{\text{base}} = \frac{V_{\text{nom}}\,(Vrms)}{\sqrt{3}} \cdot \sqrt{2}$$

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:

$$I_{\text{abc}}\,(pu) = \frac{I_{\text{abc}}\,(A)}{I_{\text{base}}\,(A)}$$

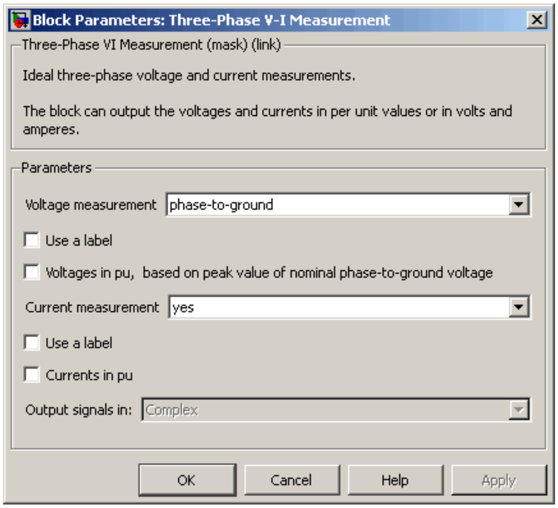
where

$$I_{\text{base}} = \frac{P_{\text{base}}\,(VA)}{\frac{V_{\text{nom}}\,(Vrms)}{\sqrt{3}} \cdot \sqrt{2}}$$

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



Block Parameters: Three-Phase V-I Measurement

Three-Phase VI Measurement (mask) (link)

Ideal three-phase voltage and current measurements.

The block can output the voltages and currents in per unit values or in volts and amperes.

Parameters

Voltage measurement: phase-to-ground

☐ Use a label

☐ Voltages in pu, based on peak value of nominal phase-to-ground voltage

Current measurement: yes

☐ Use a label

☐ Currents in pu

Output signals in: Complex

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

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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` demo (blocks B1, B2, and B3) for a typical application using the Three-Phase V-I Measurement block.

Thyristor

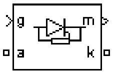
Purpose

Implement thyristor model

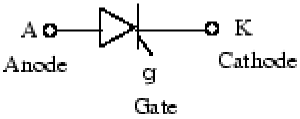
Library

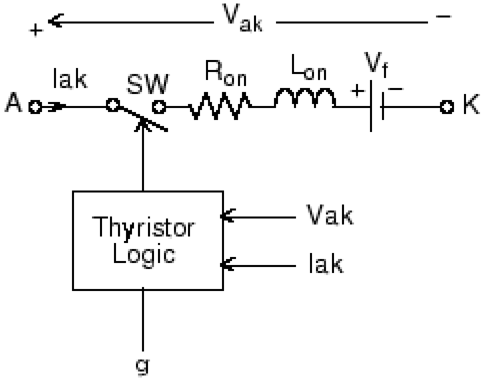
Power Electronics

Description



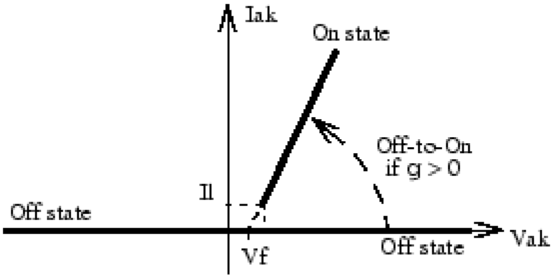
The thyristor is a semiconductor device that can be turned on via a gate signal. The thyristor model is simulated as a resistor Ron, an inductor Lon, and a DC voltage source representing the forward voltage Vf, connected in series with a switch. The switch is controlled by a logical signal depending 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*.

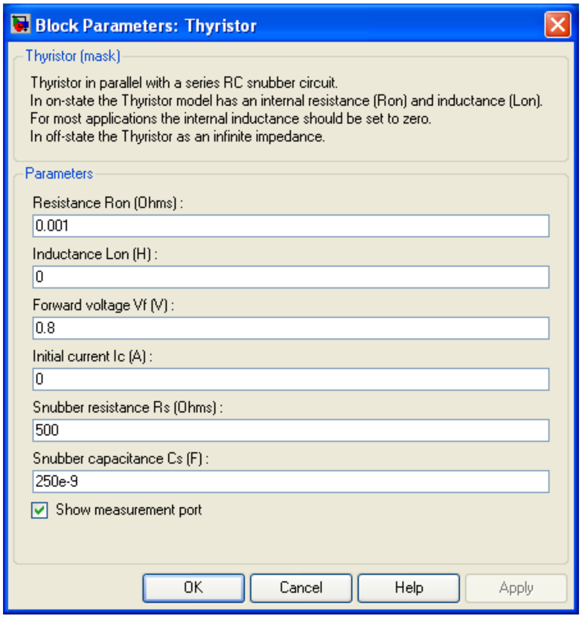
The thyristor device turns off when the current flowing in the device becomes 0 (Iak = 0) and a negative voltage appears across the anode and cathode for at least a period of time equal to the turnoff time Tq. If the voltage across the device becomes positive within a period of time less than Tq, the 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.



Thyristor (mask)

Thyristor in parallel with a series RC snubber circuit.
In on-state the Thyristor model has an internal resistance (Ron) and inductance (Lon).
For most applications the internal inductance should be set to zero.
In off-state the Thyristor as an infinite impedance.

Parameters

Resistance Ron (Ohms) : 0.001

Inductance Lon (H) : 0

Forward voltage Vf (V) : 0.8

Initial current Ic (A) : 0

Snubber resistance Rs (Ohms) : 500

Snubber capacitance Cs (F) : 250e-9

☑ Show measurement port

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

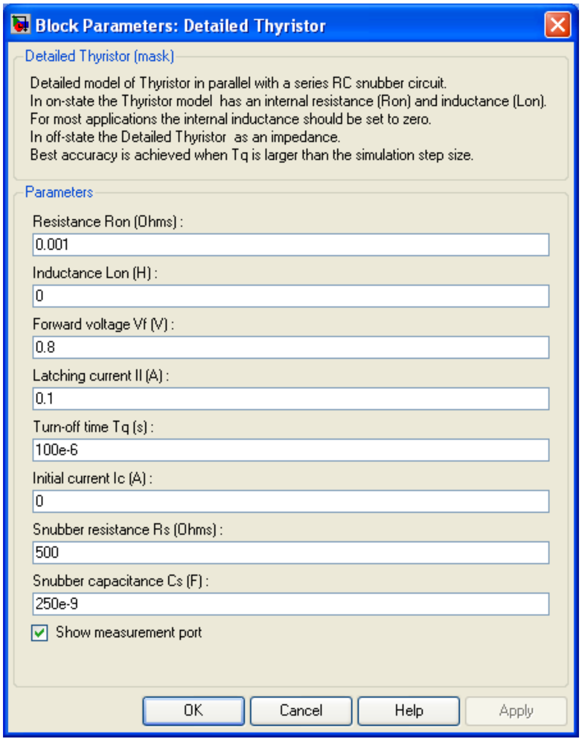
The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to `inf` to eliminate the snubber from the model.

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.



Detailed Thyristor (mask)

Detailed model of Thyristor in parallel with a series RC snubber circuit.
In on-state the Thyristor model has an internal resistance (Ron) and inductance (Lon).
For most applications the internal inductance should be set to zero.
In off-state the Detailed Thyristor as an impedance.
Best accuracy is achieved when Tq is larger than the simulation step size.

Parameters

Resistance Ron (Ohms) : 0.001

Inductance Lon (H) : 0

Forward voltage Vf (V) : 0.8

Latching current Il (A) : 0.1

Turn-off time Tq (s) : 100e-6

Initial current Ic (A) : 0

Snubber resistance Rs (Ohms) : 500

Snubber capacitance Cs (F) : 250e-9

☑ Show measurement port

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. See Improving Simulation Performance for more details on this topic.

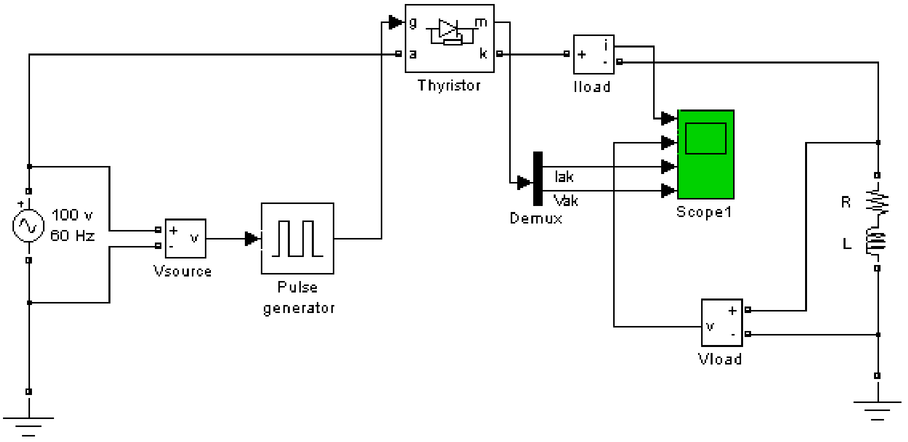
Use the Powergui block to specify either continuous simulation or discretization of your electrical circuit containing Thyristor blocks. When using a continuous model, the `ode23tb` solver with a relative tolerance of 1e-4 is recommended for best accuracy and simulation speed.

The inductance Lon is forced to 0 if you choose to discretize your circuit.

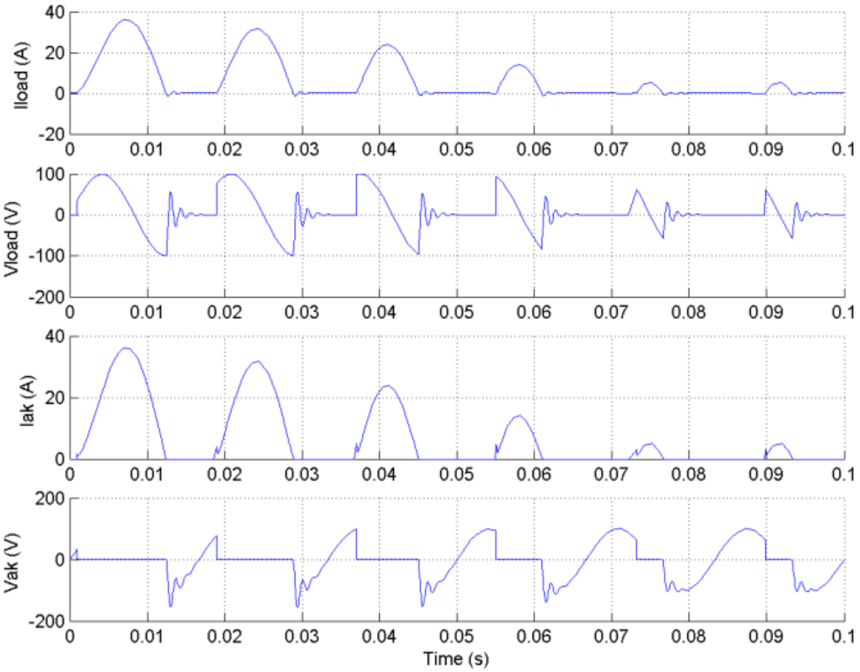
Example

In the `power_thyristor` demo 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 W
	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

Timer

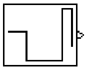
Purpose

Generate signal changing at specified transition times

Library

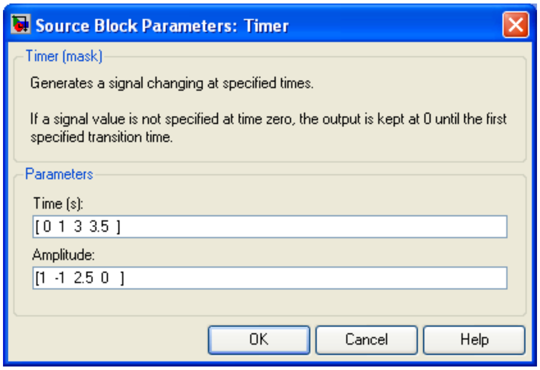
Extras/Control Blocks, Extras/Discrete Control Blocks

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



Timer (mask)

Generates a signal changing at specified times.

If a signal value is not specified at time zero, the 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]

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.

Example

See the `power_breaker` model for a circuit using the Timer block to control a circuit breaker.

Total Harmonic Distortion

Purpose

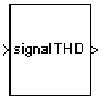
Measure total harmonic distortion (THD) of signal

Library

Extras/Measurements

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

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

$$\text{total harmonic distortion (THD)} = \frac{I_H}{I_F}$$

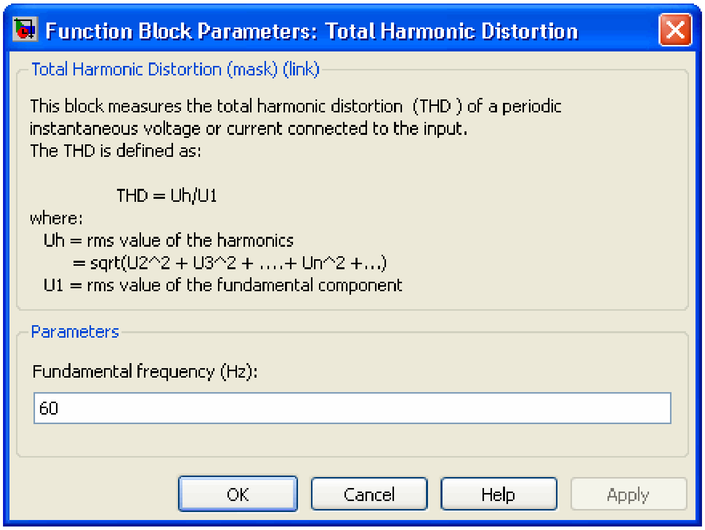
where

$$I_H = \sqrt{{I_2}^2 + {I_3}^2 + \ldots + {I_n}^2} \qquad I_n : \text{RMS value of the harmonic } n$$

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



Function Block Parameters: Total Harmonic Distortion

Total Harmonic Distortion (mask) (link)

This block measures the total harmonic distortion (THD) of a periodic instantaneous voltage or current connected to the input.
The THD is defined as:

THD = Uh/U1

where:
Uh = rms value of the harmonics
= sqrt(U2^2 + U3^2 + ...+ Un^2 +...)
U1 = rms value of the fundamental component

Parameters

Fundamental frequency (Hz): 60

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.

Two-Quadrant Chopper DC Drive

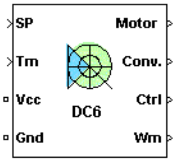
Purpose

Implement two-quadrant chopper (buck-boost converter topology) DC drive

Library

Electric Drives/DC drives

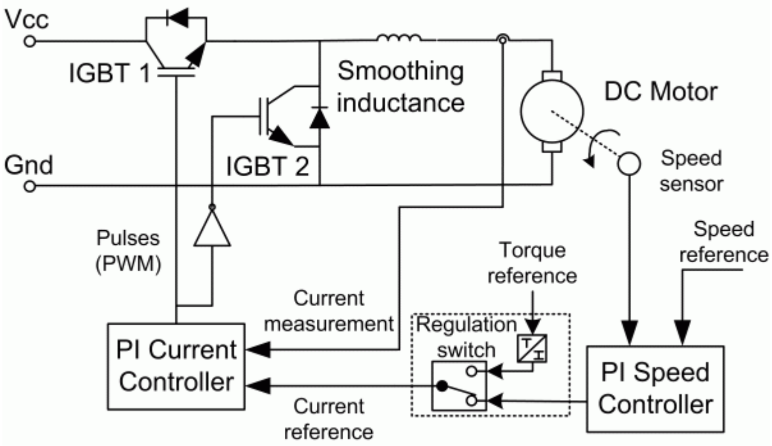
Description



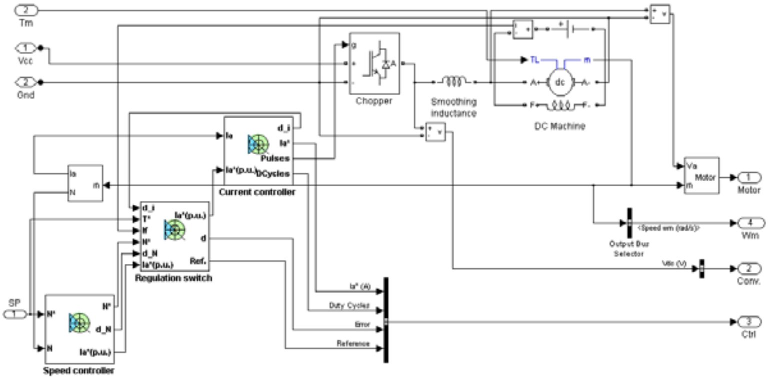
The high-level schematic shown below is built from four main blocks. The DC motor and the IGBT/Diode devices (within the Universal Bridge block) are provided with the SimPowerSystems library. More details are available in the reference pages for these blocks. The two other blocks are specific to the 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



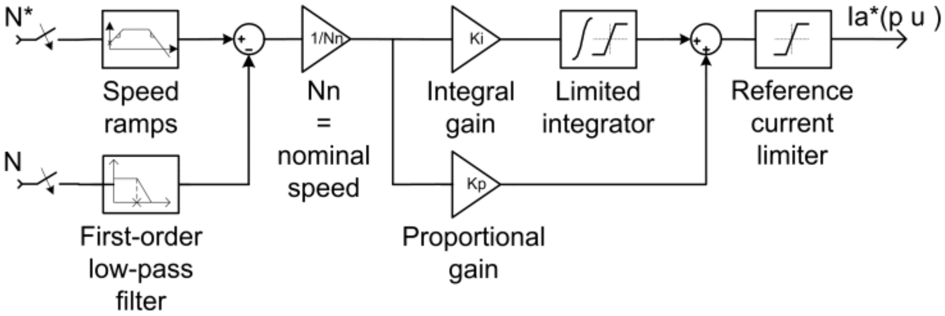
Speed Controller

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.

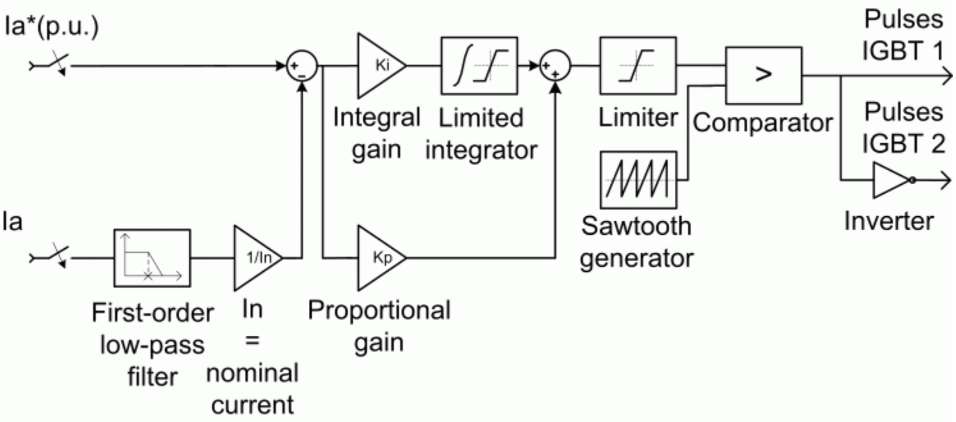


Current Controller

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.

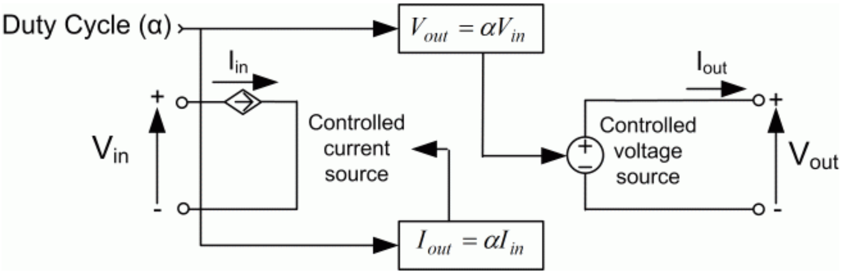
The controller takes the current reference (in pu) and the armature current flowing through the motor as inputs. The current reference is either provided by the speed controller during speed regulation or computed from the torque reference provided by the user during torque regulation. This is managed 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) on page 2-815).



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:

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

with α 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:

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

with V_{in} being the input voltage.

Remarks

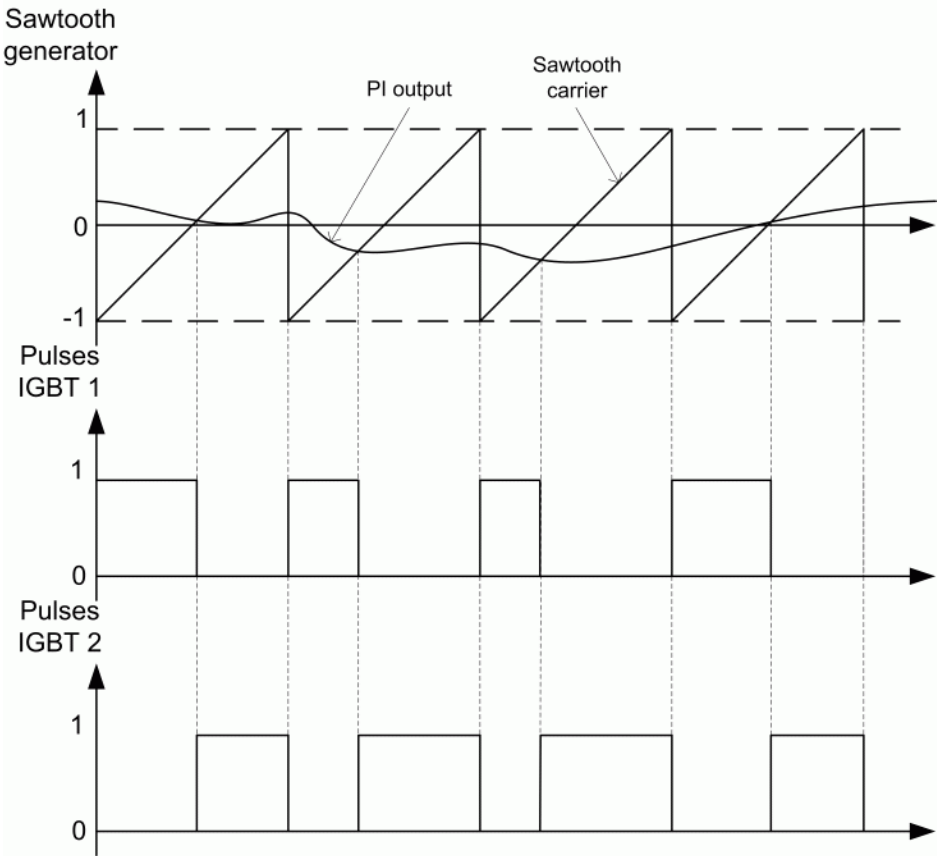
The machine is separately excited with a constant DC field voltage source. There is thus no field voltage control. By default, the field current is set to its steady-state value when a simulation is started.

The armature voltage is provided by an IGBT 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

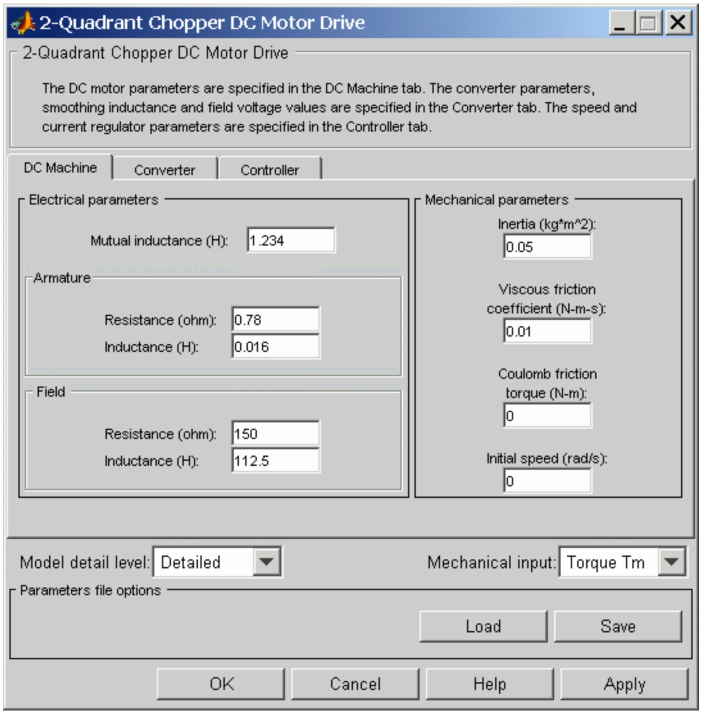
The speed controller sampling time has to be a multiple of the current sampling time. The latter sampling time has to be a multiple of the simulation time step.



Pulse Width Modulation (PWM)

Dialog Box

DC Machine Tab



2-Quadrant Chopper DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The speed and current regulator parameters are specified in the Controller tab.

Electrical parameters

Mutual inductance (H): 1.234

Armature

Resistance (ohm): 0.78

Inductance (H): 0.016

Field

Resistance (ohm): 150

Inductance (H): 112.5

Mechanical parameters

Inertia (kg*m^2): 0.05

Viscous friction coefficient (N-m-s): 0.01

Coulomb friction torque (N-m): 0

Initial speed (rad/s): 0

Model detail level: Detailed

Mechanical input: Torque Tm

The DC Machine tab displays the parameters of the DC machine block of the powerlib library. Refer to the DC Machine for more information on the DC machine block parameters.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Allows you to select either the load torque or the motor speed as mechanical input. Note that if you select and apply a load torque, you will obtain as output the motor speed according to the following differential equation that describes the mechanical system dynamics:

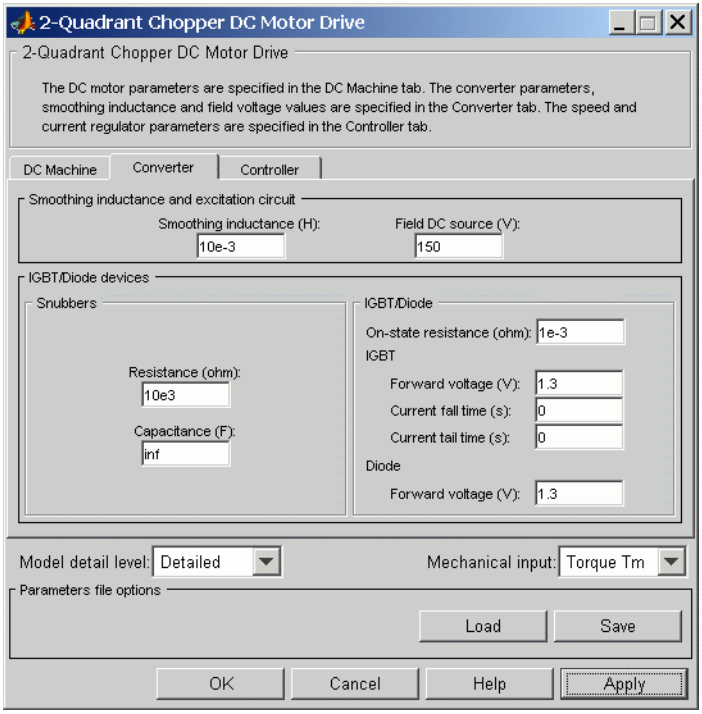
$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

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

See for example “Mechanical Coupling of Two Motor Drives”.

Converter Tab



2-Quadrant Chopper DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The speed and current regulator parameters are specified in the Controller tab.

Smoothing inductance and excitation circuit

Smoothing inductance (H): 10e-3

Field DC source (V): 150

IGBT/Diode devices

Snubbers

Resistance (ohm): 10e3

Capacitance (F): inf

IGBT/Diode

On-state resistance (ohm): 1e-3

IGBT

Forward voltage (V): 1.3

Current fall time (s): 0

Current tail time (s): 0

Diode

Forward voltage (V): 1.3

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

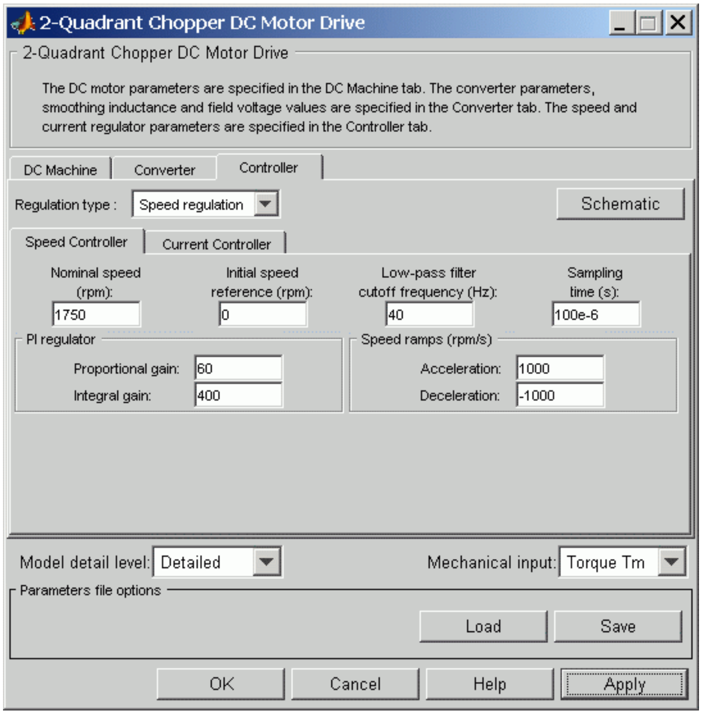
IGBT/Diode Devices Section

The IGBT/Diode section of the Converter tab displays the parameters of the Universal Bridge block of the 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



2-Quadrant Chopper DC Motor Drive

2-Quadrant Chopper DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The speed and current regulator parameters are specified in the Controller tab.

Regulation type : Speed regulation

Nominal speed (rpm): 1750

Initial speed reference (rpm): 0

Low-pass filter cutoff frequency (Hz): 40

Sampling time (s): 100e-6

PI regulator

Proportional gain: 60

Integral gain: 400

Speed ramps (rpm/s)

Acceleration: 1000

Deceleration: -1000

Model detail level: Detailed

Mechanical input: Torque Tm

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.

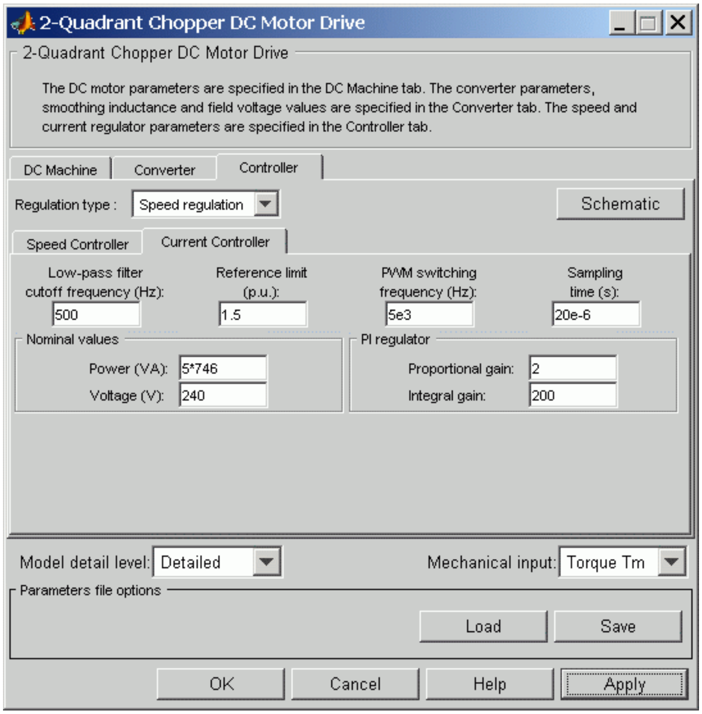
Proportional Gain
The proportional gain of the PI speed controller.

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



2-Quadrant Chopper DC Motor Drive

2-Quadrant Chopper DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The speed and current regulator parameters are specified in the Controller tab.

Regulation type : Speed regulation

Low-pass filter cutoff frequency (Hz): 500

Reference limit (p.u.): 1.5

PWM switching frequency (Hz): 5e3

Sampling time (s): 20e-6

Nominal values

Power (VA): 5*746

Voltage (V): 240

PI regulator

Proportional gain: 2

Integral gain: 200

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

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. Note that 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).

`Vcc, Gnd`

The DC voltage source electric connections. The voltage must be adequate for the motor size.

`Wm` or `Te`

The mechanical output: motor speed (Wm) or electromagnetic torque (Te).

`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

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

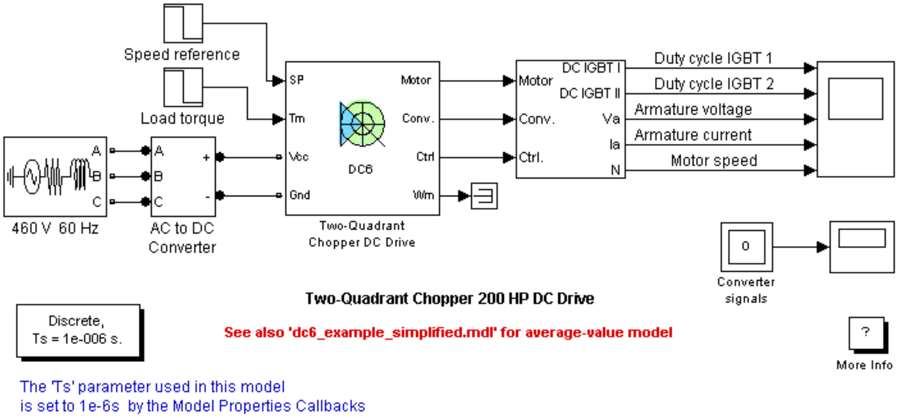
		5 HP Drive	200 HP Drive
Drive Input Voltage			
	Amplitude	280 V	550 V
Motor Nominal Values			
	Power	5 hp	200 hp

5 HP and 200 HP Drive Specifications (Continued)

		5 HP Drive	200 HP Drive
Drive Input Voltage			
	Speed	1750 rpm	1750 rpm
	Voltage	240 V	500 V

Example

The `dc6_example` demo 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.

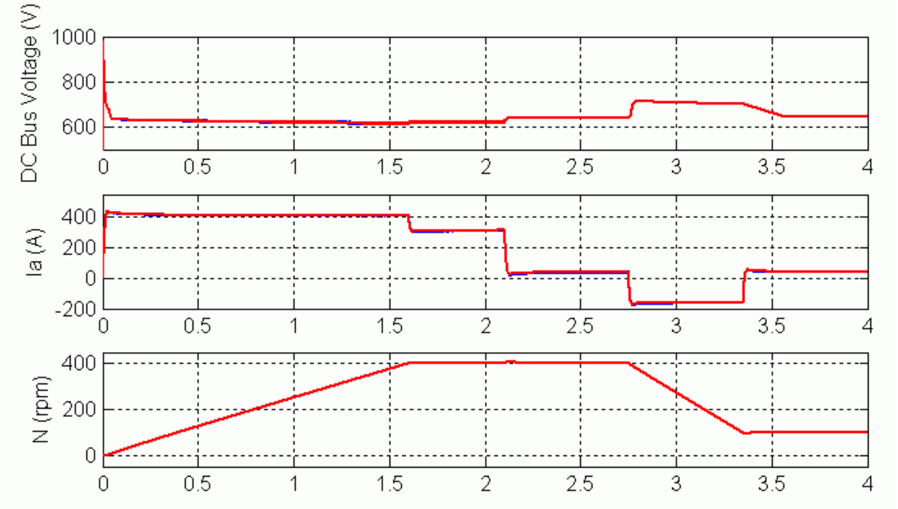
At t = 2.1 s, the load torque passes from 814 N.m to 100 N.m. The motor speed recovers fast and is back at 400 rpm at t = 2.75 s. The current reference lowers to about 40 A to generate a smaller electromagnetic torque, the load torque being reduced. As observed before, the armature current follows its 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.

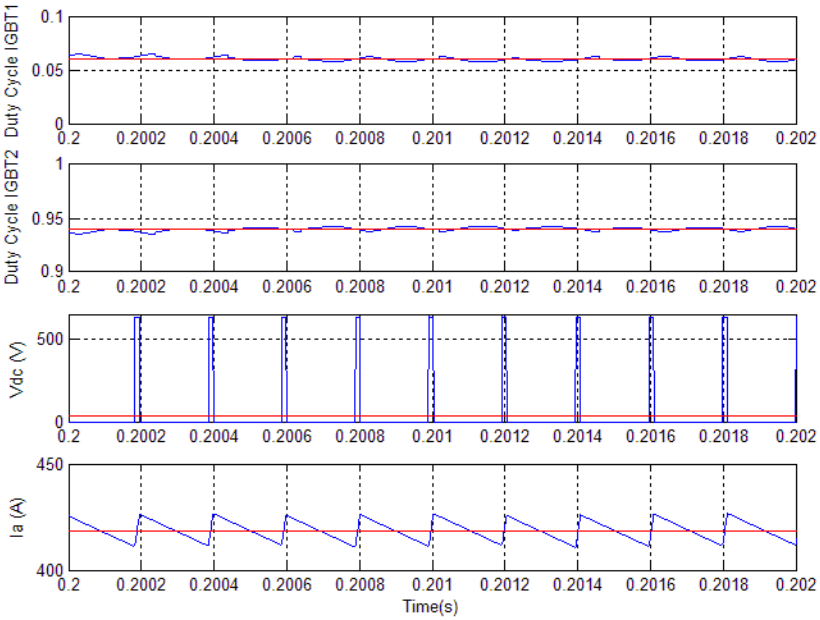
At t = 4 s, the speed stabilizes around its reference.

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.

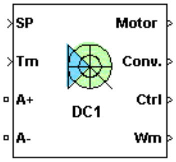
[2] Séguier, Guy, *Electronique de puissance*, Dunod, 1999.

Two-Quadrant Single-Phase Rectifier DC Drive

Purpose Implement two-quadrant single-phase rectifier DC drive

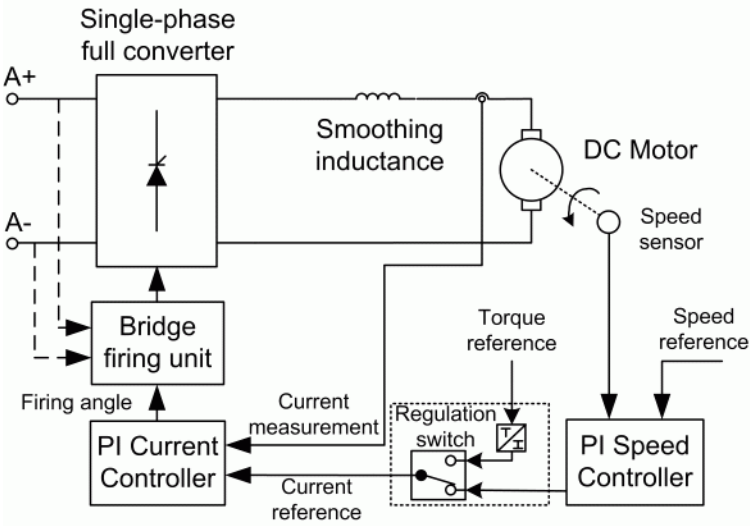
Library Electric Drives/DC drives

Description



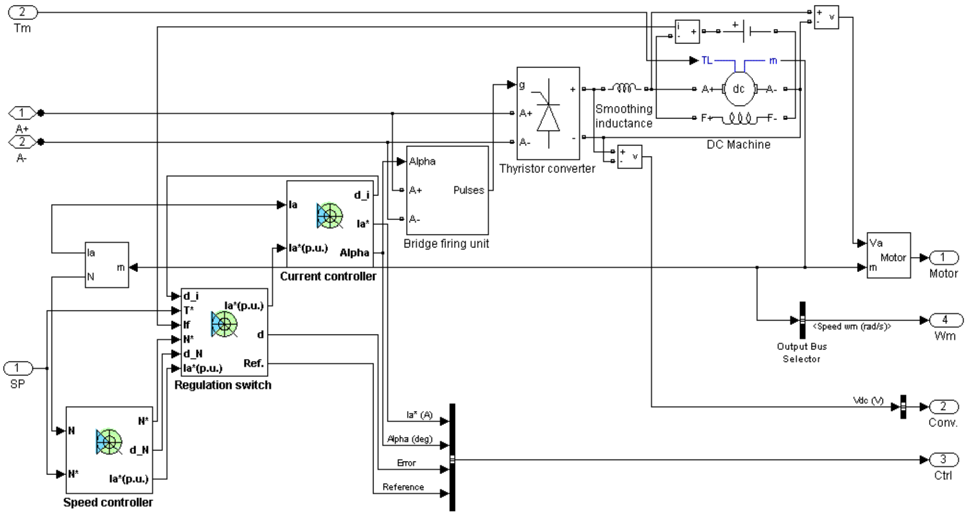
The high-level schematic shown below is built from five main blocks. The DC motor, the single-phase full converter, and the bridge firing unit are provided with the SimPowerSystems library. More details are available in the reference pages for these blocks. The two other blocks are specific to the Electric 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

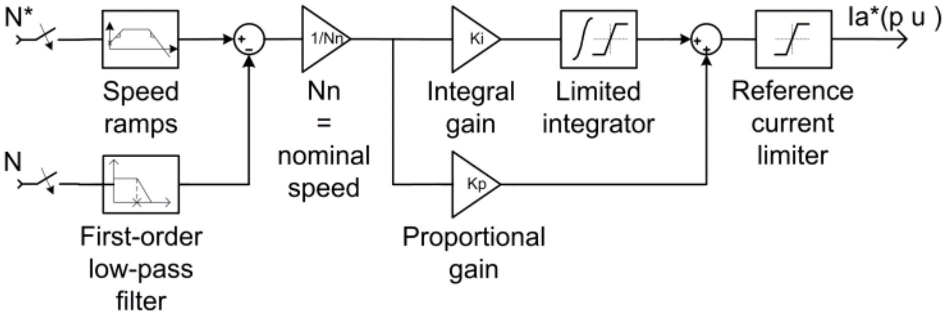


Speed Controller

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.

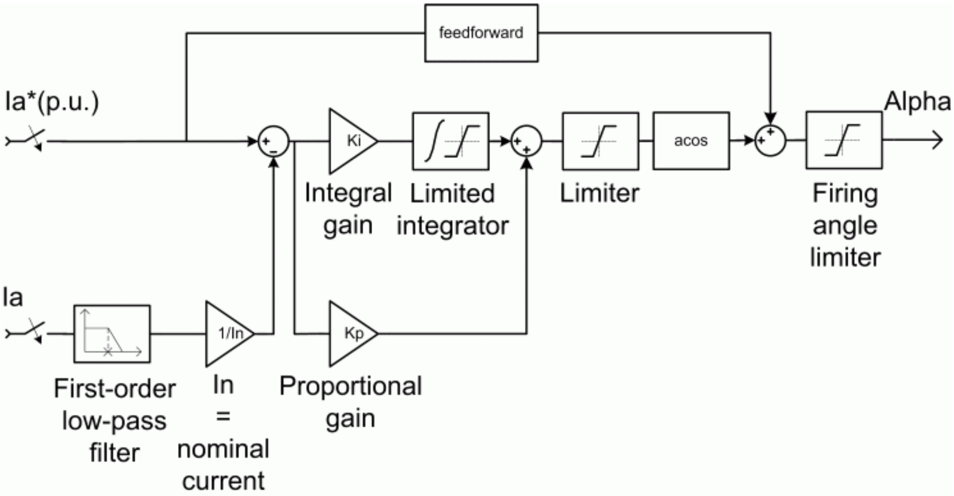


Current Controller

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.

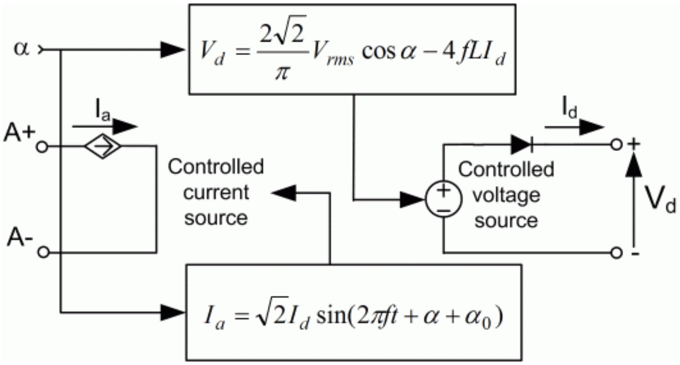
The controller takes the current reference (in pu) and the armature current flowing through the motor as inputs. The current reference is either provided by the speed controller during speed regulation or computed from the torque reference provided by the user during torque regulation. This is managed 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:

$$I_a = \sqrt{2} I_d \sin(2\pi ft + \alpha + \alpha_0)$$

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 following the next equation:

$$V_d = \frac{2\sqrt{2}}{\pi} V_{rms} \cos\alpha - 4fLI_d$$

with V_{rms} being the input RMS voltage value and L being the source inductance value.

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.

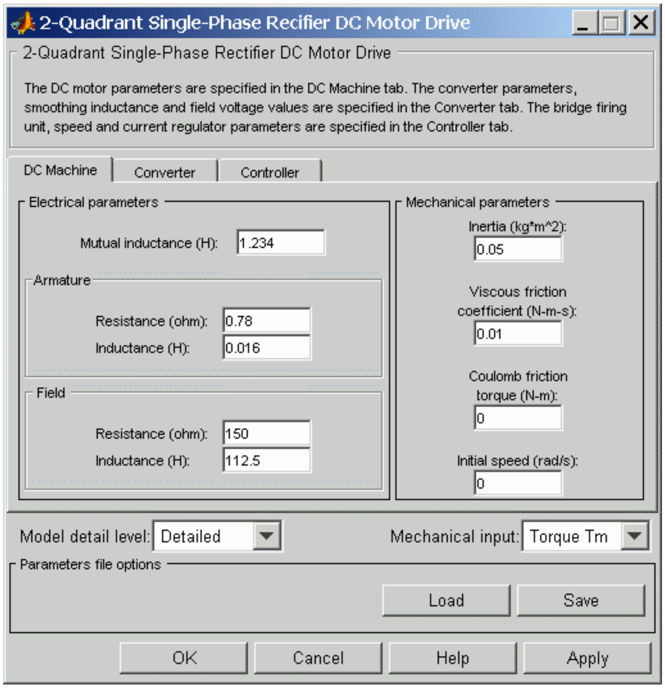
The average-value converter represents the average behavior of a single-phase rectifier for continuous armature current. This model is thus not suitable for simulating DC drives under discontinuous armature current conditions.The converter outputs a continuous voltage value equal to the average-value 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 motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulator parameters are specified in the Controller tab.

Mutual inductance (H): 1.234

Armature Resistance (ohm): 0.78

Armature Inductance (H): 0.016

Field Resistance (ohm): 150

Field Inductance (H): 112.5

Inertia (kg*m^2): 0.05

Viscous friction coefficient (N-m-s): 0.01

Coulomb friction torque (N-m): 0

Initial speed (rad/s): 0

Model detail level: Detailed

Mechanical input: Torque Tm

The DC Machine tab displays the parameters of the DC machine block of the powerlib library. Refer to the DC Machine for more information on the DC machine block parameters.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Allows you to select either the load torque or the motor speed as mechanical input. Note that if you select and apply a load torque, you will obtain as output the motor speed according to the following differential equation that describes the mechanical system dynamics:

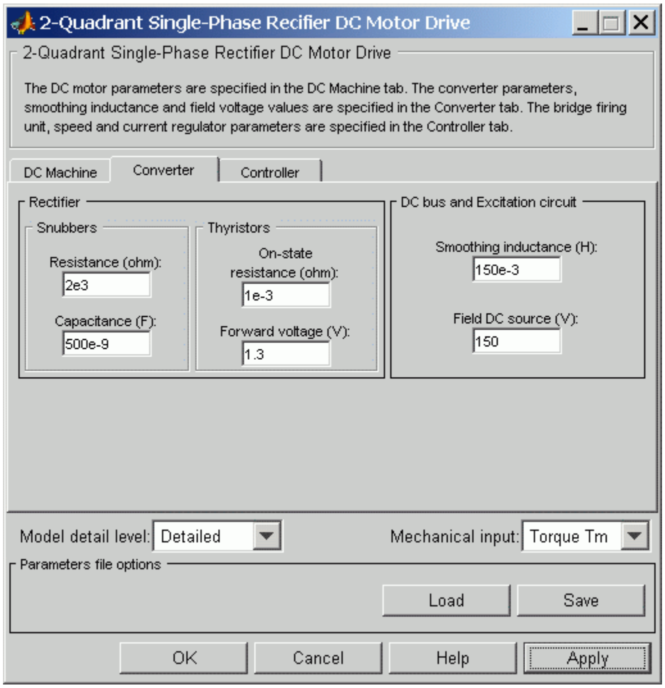
$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

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

See for example “Mechanical Coupling of Two Motor Drives”.

Converter Tab



2-Quadrant Single-Phase Recifier DC Motor Drive

2-Quadrant Single-Phase Rectifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulator parameters are specified in the Controller tab.

Rectifier

Snubbers

Resistance (ohm): 2e3

Capacitance (F): 500e-9

Thyristors

On-state resistance (ohm): 1e-3

Forward voltage (V): 1.3

DC bus and Excitation circuit

Smoothing inductance (H): 150e-3

Field DC source (V): 150

Model detail level: Detailed

Mechanical input: Torque Tm

Rectifier section

The Rectifier section of the Converter tab displays the parameters of the Universal Bridge block of the 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.

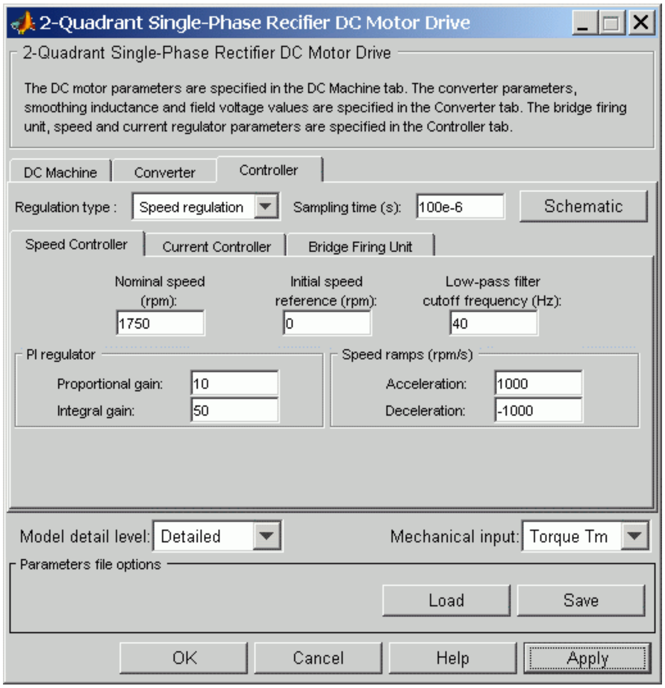
Source Inductance

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



2-Quadrant Single-Phase Rectifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulator parameters are specified in the Controller tab.

Regulation type : Speed regulation

Sampling time (s): 100e-6

Nominal speed (rpm): 1750

Initial speed reference (rpm): 0

Low-pass filter cutoff frequency (Hz): 40

Proportional gain: 10

Integral gain: 50

Acceleration: 1000

Deceleration: -1000

Model detail level: Detailed

Mechanical input: Torque Tm

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).

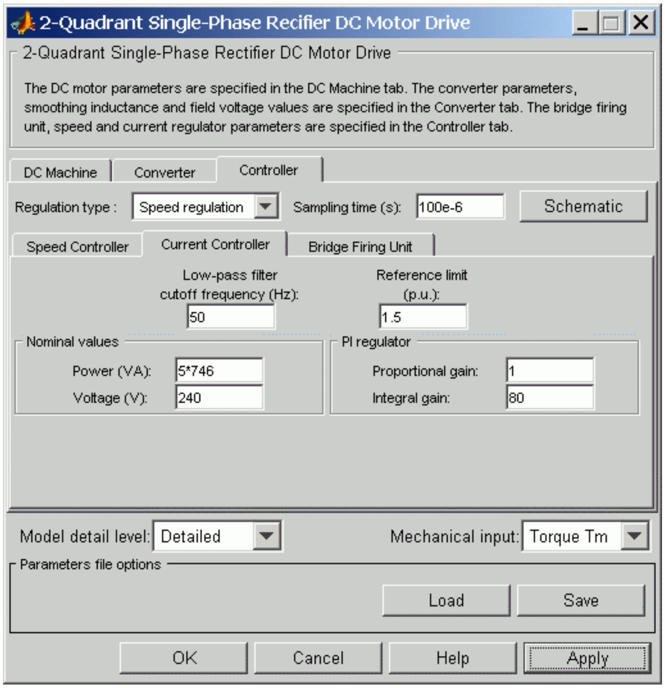
Proportional Gain
The proportional gain of the PI speed controller.

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



2-Quadrant Single-Phase Recifier DC Motor Drive

2-Quadrant Single-Phase Rectifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulator parameters are specified in the Controller tab.

Regulation type : Speed regulation

Sampling time (s): 100e-6

Low-pass filter cutoff frequency (Hz): 50

Reference limit (p.u.): 1.5

Nominal values

Power (VA): 5*746

Voltage (V): 240

PI regulator

Proportional gain: 1

Integral gain: 80

Model detail level: Detailed

Mechanical input: Torque Tm

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.

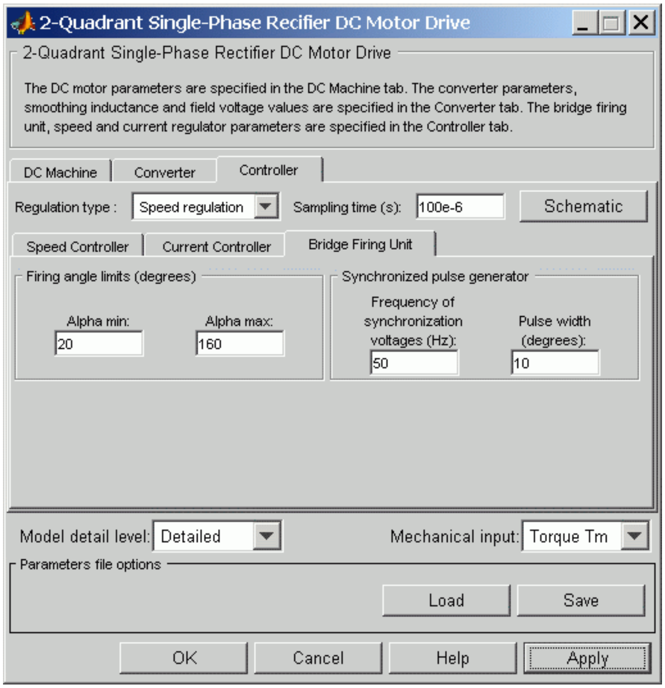
Integral Gain
The integral gain of the PI current controller.

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



2-Quadrant Single-Phase Recifier DC Motor Drive

2-Quadrant Single-Phase Rectifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulator parameters are specified in the Controller tab.

Regulation type : Speed regulation

Sampling time (s): 100e-6

Firing angle limits (degrees)

Alpha min: 20

Alpha max: 160

Synchronized pulse generator

Frequency of synchronization voltages (Hz): 50

Pulse width (degrees): 10

Model detail level: Detailed

Mechanical input: Torque Tm

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. Note that 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+, A-`

The single-phase electric connections. The applied voltage must be adequate for the motor size.

`Wm` or `Te`

The mechanical output: motor speed (Wm) or electromagnetic torque (Te).

`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

Model Specifications

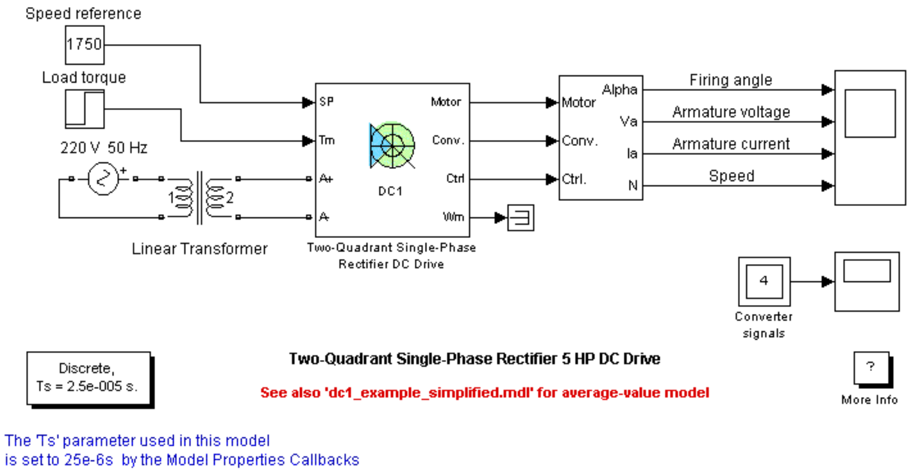
The library contains a 5 hp drive parameter set. The specifications of the 5 hp drive are shown in the following table.

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` demo illustrates the single-phase rectifier drive used with the 5 hp drive parameter set during speed regulation.



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.

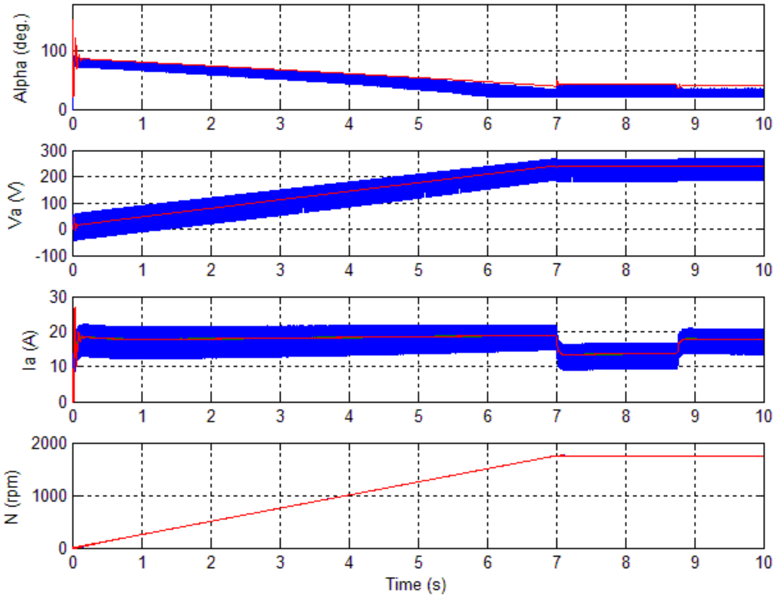
The speed reference is set at 1750 rpm at t = 0 s. Initial load torque is 15 N.m.

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.

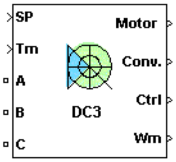
[2] Nondahl, Thomas A., *Microprocessor Control of Motor Drives and Power Converters*, *tutorial course*, IEEE Industry Application Society, October 1993, pp. 7.1-7.26.

Two-Quadrant Three-Phase Rectifier DC Drive

Purpose Implement two-quadrant three-phase rectifier DC drive

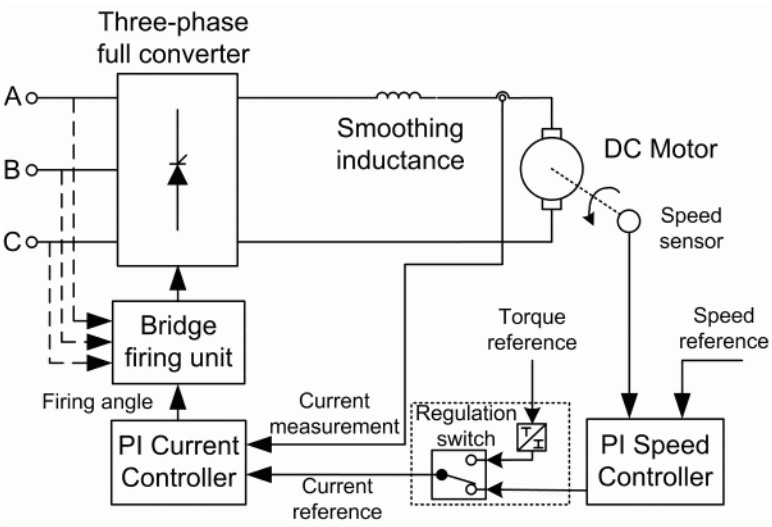
Library Electric Drives/DC drives

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.

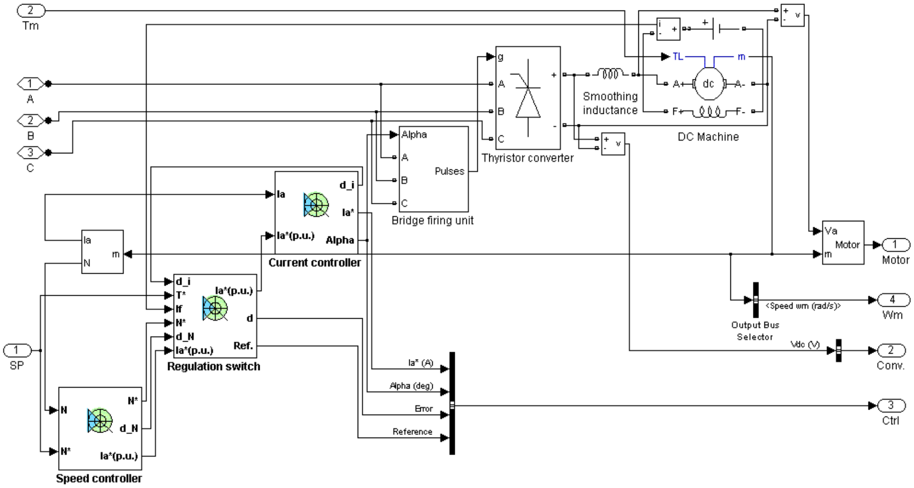


Note In SimPowerSystems software, the Two-Quadrant Three-Phase Rectifier DC Drive block is commonly called the `DC3` motor drive.

High-Level Schematic



Simulink Schematic

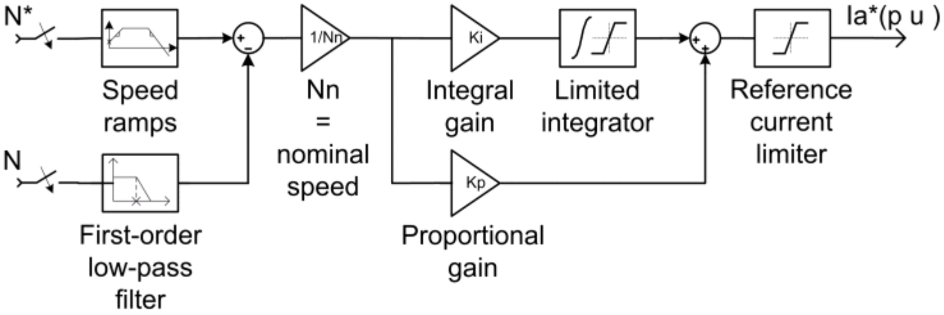


Speed Controller

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.

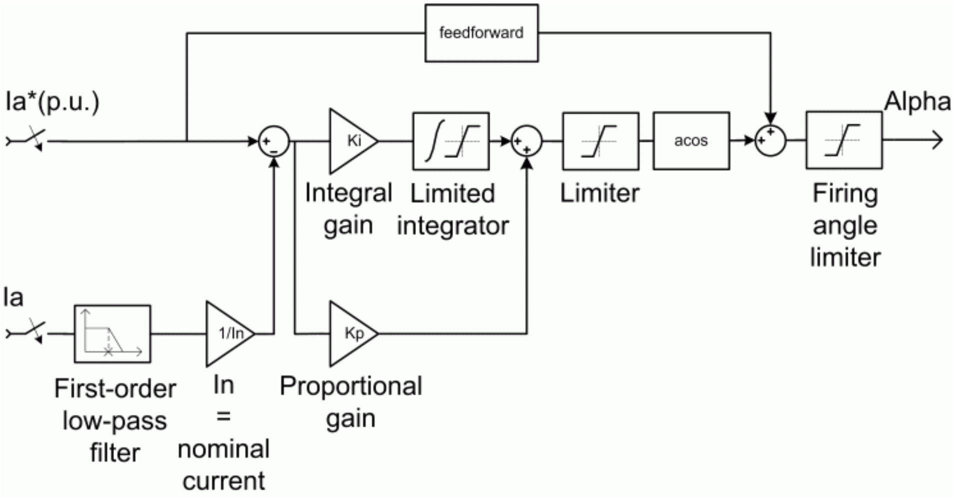


Current Controller

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.

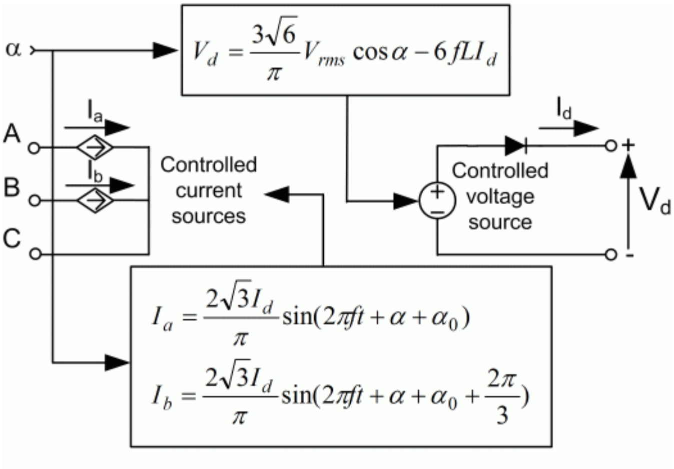
The controller takes the current reference (in pu) and the armature current flowing through the motor as inputs. The current reference is either provided by the speed controller during speed regulation or computed from the torque reference provided by the user during torque regulation. This is managed 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:

$$I_a = \frac{2\sqrt{3}}{\pi} I_d \sin(2\pi ft + \alpha + \alpha_0)$$

$$I_b = \frac{2\sqrt{3}}{\pi} I_d \sin\left(2\pi ft + \alpha + \alpha_0 + \frac{2\pi}{3}\right)$$

with αbeing 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:

$$V_d = \frac{3\sqrt{6}}{\pi} V_{rms} \cos\alpha - 6fLI_d$$

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.

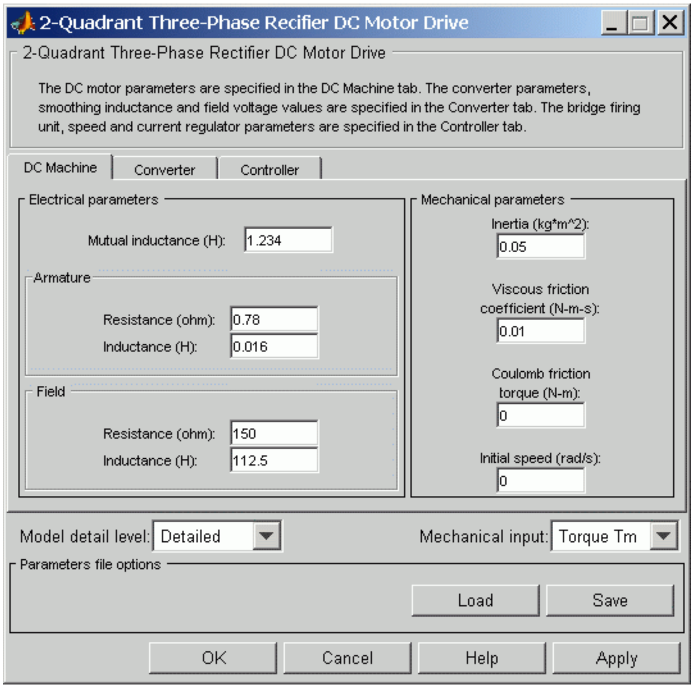
The average-value converter represents the average behavior of a three-phase rectifier for continuous armature current. This model is thus not suitable for simulating DC drives under discontinuous armature current conditions. The converter outputs a continuous voltage value equal to the average-value 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



2-Quadrant Three-Phase Recifier DC Motor Drive

2-Quadrant Three-Phase Rectifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulator parameters are specified in the Controller tab.

Electrical parameters

Mutual inductance (H): 1.234

Armature

Resistance (ohm): 0.78

Inductance (H): 0.016

Field

Resistance (ohm): 150

Inductance (H): 112.5

Mechanical parameters

Inertia (kg*m^2): 0.05

Viscous friction coefficient (N-m-s): 0.01

Coulomb friction torque (N-m): 0

Initial speed (rad/s): 0

Model detail level: Detailed

Mechanical input: Torque Tm

Parameters file options

The DC Machine tab displays the parameters of the DC machine block of the powerlib library. Refer to the DC Machine for more information on the DC machine block parameters.

Model detail level

Select between the detailed and the average-value inverter.

Mechanical input

Allows you to select either the load torque or the motor speed as mechanical input. Note that if you select and apply a load torque, you will obtain as output the motor speed according to the following differential equation that describes the mechanical system dynamics:

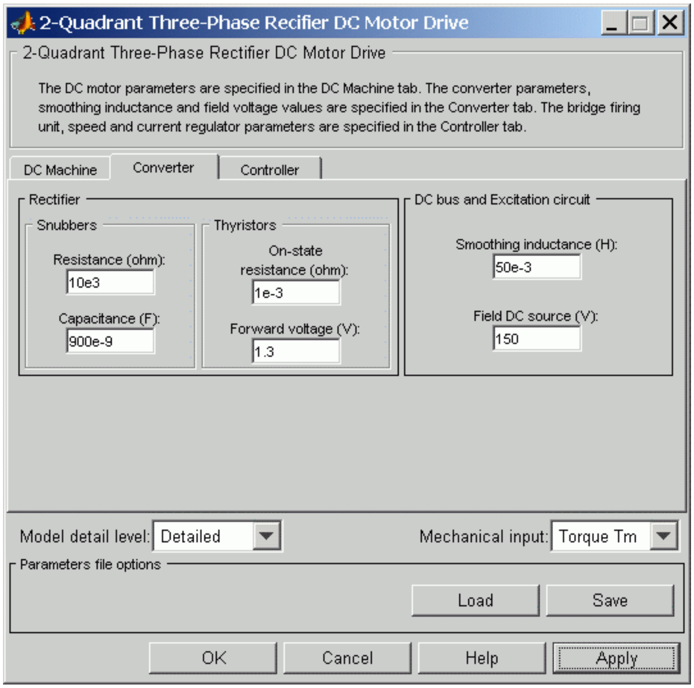
$$T_e = J\frac{d}{dt}\omega_r + F\omega_r + T_m$$

This mechanical system is included in the motor model.

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

See for example “Mechanical Coupling of Two Motor Drives”.

Converter Tab



2-Quadrant Three-Phase Recifier DC Motor Drive

2-Quadrant Three-Phase Rectifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulator parameters are specified in the Controller tab.

Rectifier

Snubbers

Resistance (ohm): 10e3

Capacitance (F): 900e-9

Thyristors

On-state resistance (ohm): 1e-3

Forward voltage (V): 1.3

DC bus and Excitation circuit

Smoothing inductance (H): 50e-3

Field DC source (V): 150

Model detail level: Detailed

Mechanical input: Torque Tm

Rectifier section

The Rectifier section of the Converter tab displays the parameters of the Universal Bridge block of the 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).

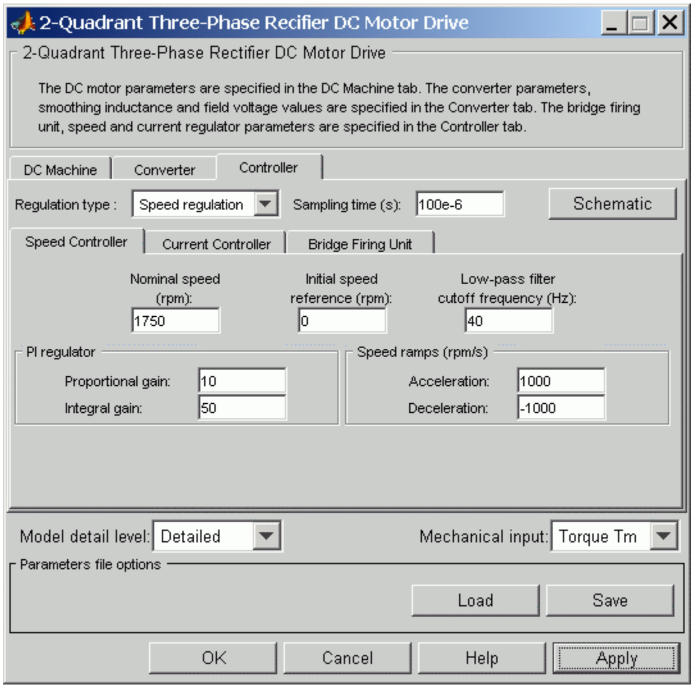
Phase-to-Phase RMS Voltage
Phase-to-phase rms voltage of the three-phase voltage source connected to the A,B,C terminals of the drive (V). This parameter is not used when using the detailed rectifier.

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



2-Quadrant Three-Phase Rectifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulator parameters are specified in the Controller tab.

Regulation type : Speed regulation
Sampling time (s): 100e-6
Nominal speed (rpm): 1750
Initial speed reference (rpm): 0
Low-pass filter cutoff frequency (Hz): 40

PI regulator
Proportional gain: 10
Integral gain: 50

Speed ramps (rpm/s)
Acceleration: 1000
Deceleration: -1000

Model detail level: Detailed
Mechanical input: Torque Tm

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).

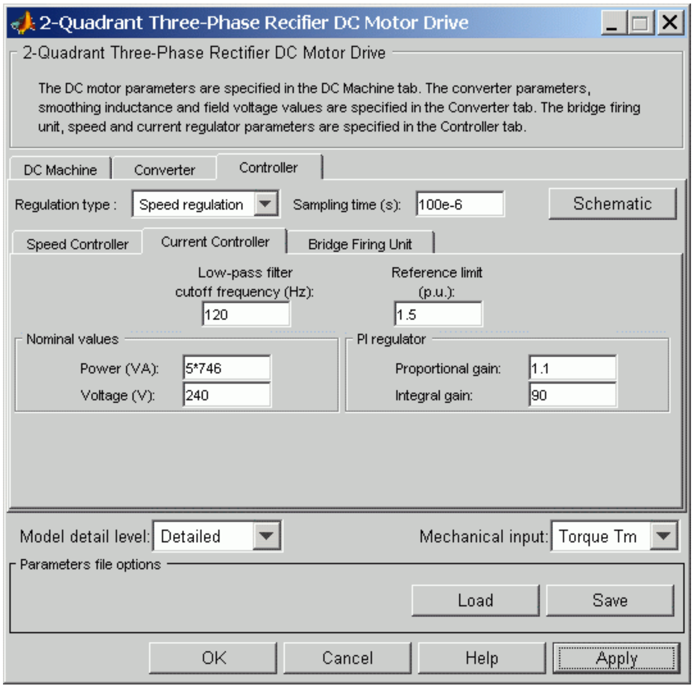
Proportional Gain
The proportional gain of the PI speed controller.

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



The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulator parameters are specified in the Controller tab.

Regulation type : Speed regulation

Sampling time (s): 100e-6

Low-pass filter cutoff frequency (Hz): 120

Reference limit (p.u.): 1.5

Nominal values

Power (VA): 5*746

Voltage (V): 240

PI regulator

Proportional gain: 1.1

Integral gain: 90

Model detail level: Detailed

Mechanical input: Torque Tm

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).

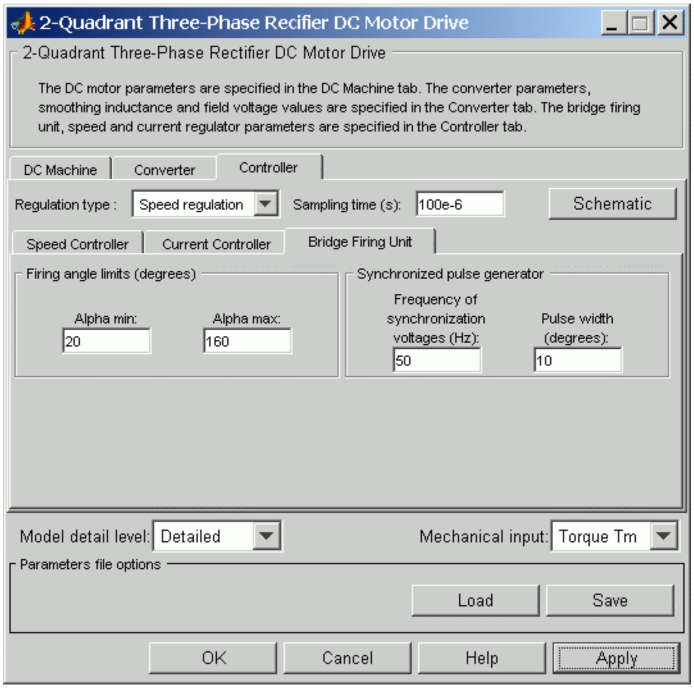
Proportional Gain
The proportional gain of the PI current controller.

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



2-Quadrant Three-Phase Rectifier DC Motor Drive

The DC motor parameters are specified in the DC Machine tab. The converter parameters, smoothing inductance and field voltage values are specified in the Converter tab. The bridge firing unit, speed and current regulator parameters are specified in the Controller tab.

Regulation type : Speed regulation

Sampling time (s): 100e-6

Alpha min: 20

Alpha max: 160

Frequency of synchronization voltages (Hz): 50

Pulse width (degrees): 10

Model detail level: Detailed

Mechanical input: Torque Tm

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. Note that 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).

`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

Model Specifications

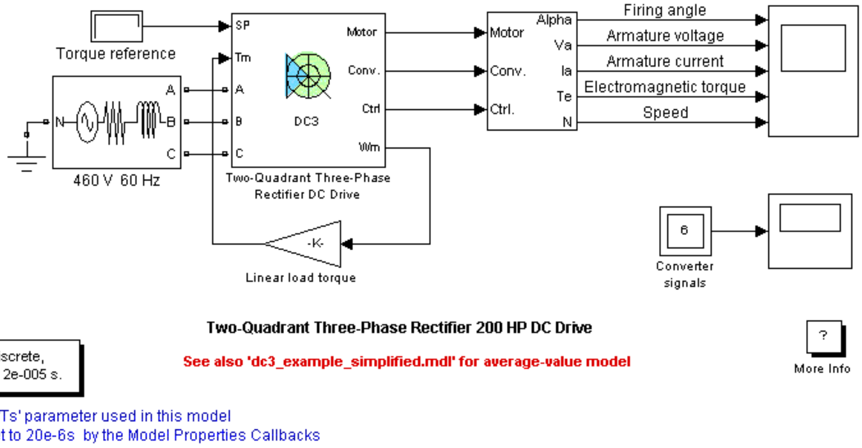
The library contains a 5 hp and a 200 hp drive parameter set. The specifications of these two drives are shown in the following table.

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` demo 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 'Ts' parameter used in this model
is set to 20e-6s by the Model Properties Callbacks

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.

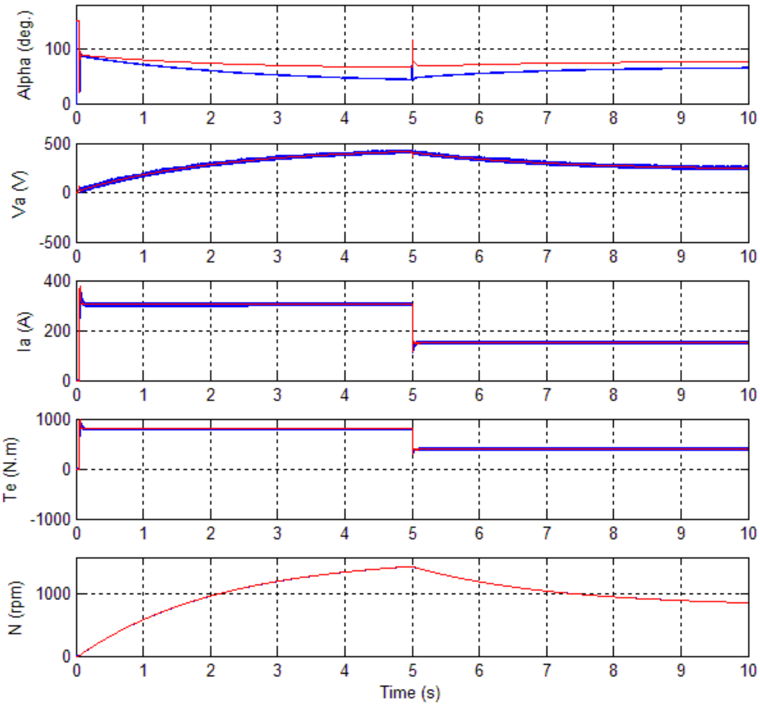
At t = 0.05 s, the torque reference jumps to 800 N.m. This causes the armature current to rise to about 305 A. Notice that the armature current follows the reference quite accurately, with fast response time and small overshooting. The 15 mH smoothing inductance keeps the current oscillations quite small. 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

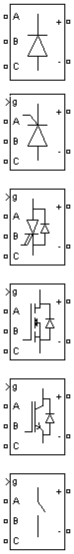
Purpose

Implement universal power converter with selectable topologies and power electronic devices

Library

Power Electronics

Description

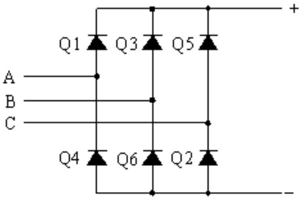


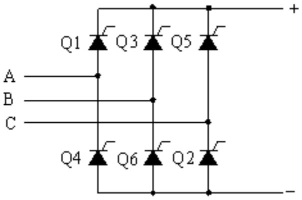
The Universal Bridge block implements a universal three-phase power converter that consists of up to six power switches connected in a bridge configuration. The type of power switch and converter configuration are selectable from the dialog box.

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).

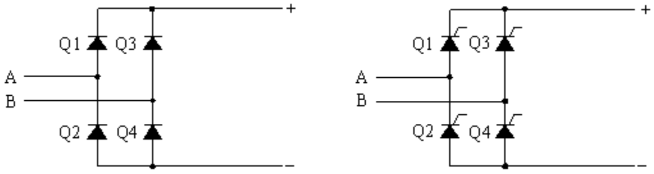
The Universal Bridge block is the basic block for building two-level voltage-sourced converters (VSC).

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:

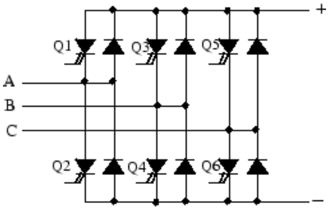




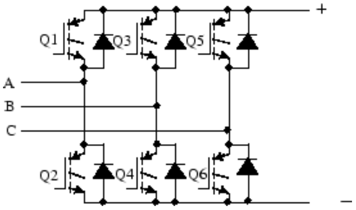
For the case of a two-phase diode or thyristor bridge, and for any other bridge configuration, the order of commutation is the following:



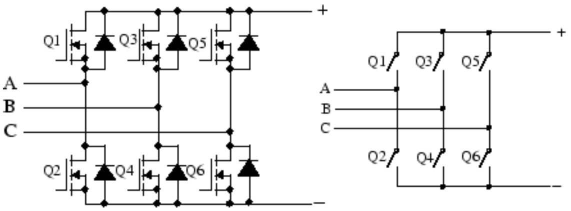
GTO-Diode bridge:



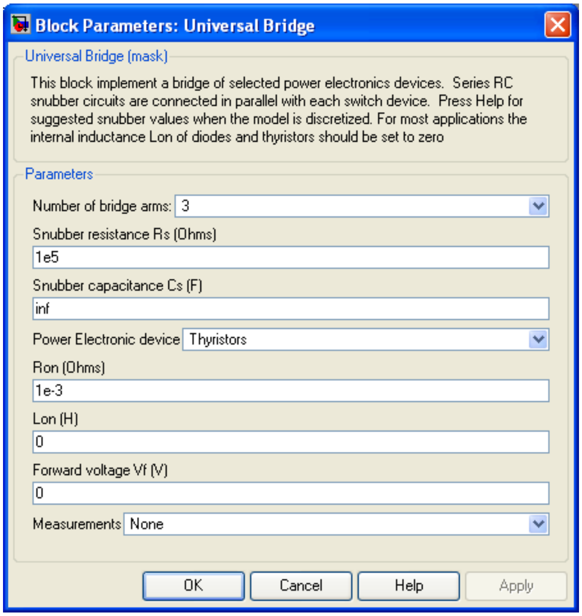
IGBT-Diode bridge:



MOSFET-Diode and Ideal Switch bridges:



Dialog Box and Parameters



Universal Bridge (mask)

This block implement a bridge of selected power electronics devices. Series RC snubber circuits are connected in parallel with each switch device. Press Help for suggested snubber values when the model is discretized. For most applications the internal inductance Lon of diodes and thyristors should be set to zero

Parameters

Number of bridge arms: 3

Snubber resistance Rs (Ohms): 1e5

Snubber capacitance Cs (F): inf

Power Electronic device: Thyristors

Ron (Ohms): 1e-3

Lon (H): 0

Forward voltage Vf (V): 0

Measurements: None

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.

In order to avoid numerical oscillations when your system is discretized, you need to specify Rs and Cs snubber values for diode and thyristor 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, 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

P_n = Nominal power of single or three phase converter (VA)

Vn = Nominal line-to-line AC voltage (Vrms)

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 the `power_sfavg` demo 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

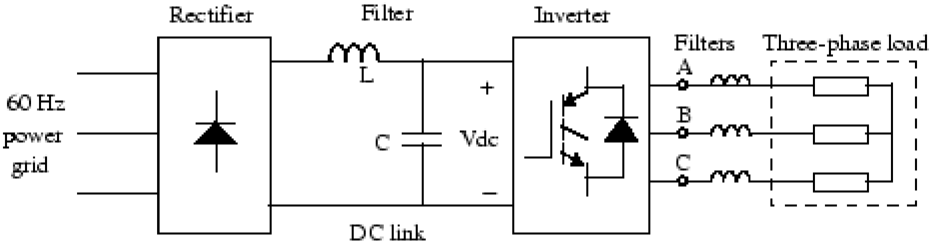
`g`

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]`

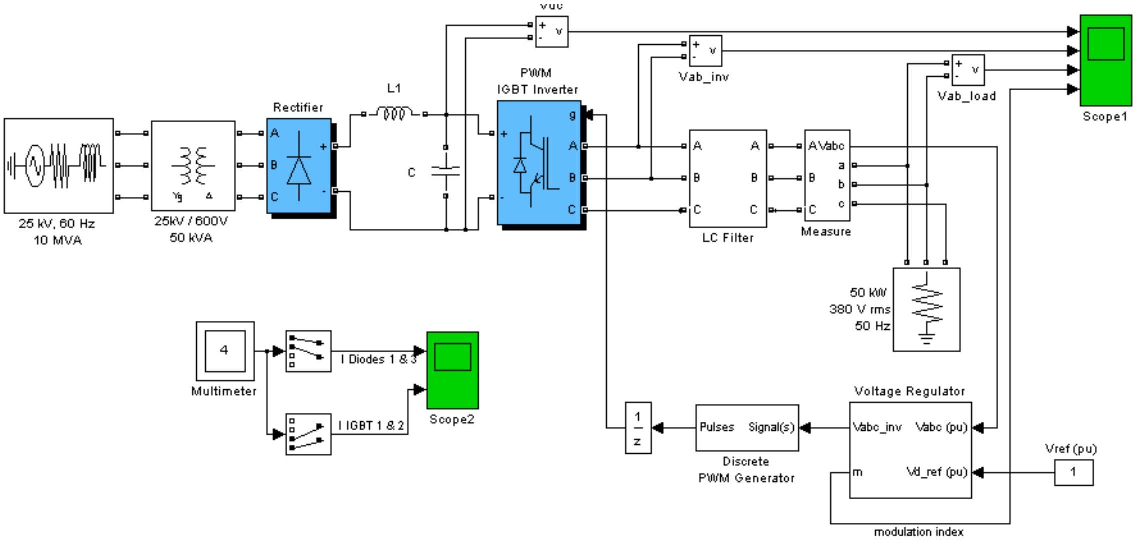
Example

The `power_bridges` demo 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.

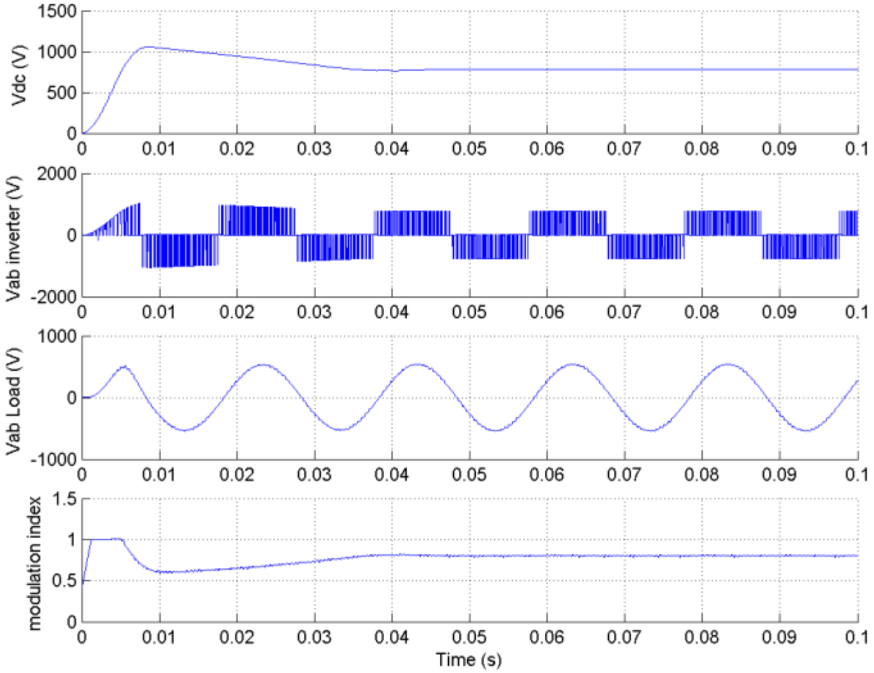


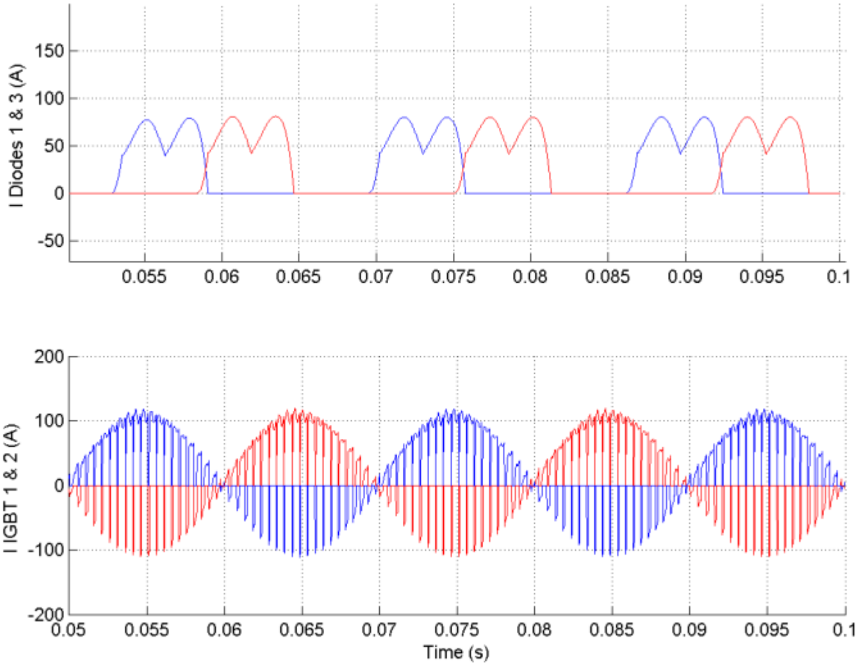
Start simulation. After a transient period of approximately 40 ms, the system reaches a steady state. Observe voltage waveforms at DC bus, inverter output, and load on Scope1. The harmonics generated by the inverter around multiples of 2 kHz are filtered by the LC filter. As expected the peak value of 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)

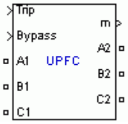
Purpose

Implement phasor model of three-phase unified power flow controller

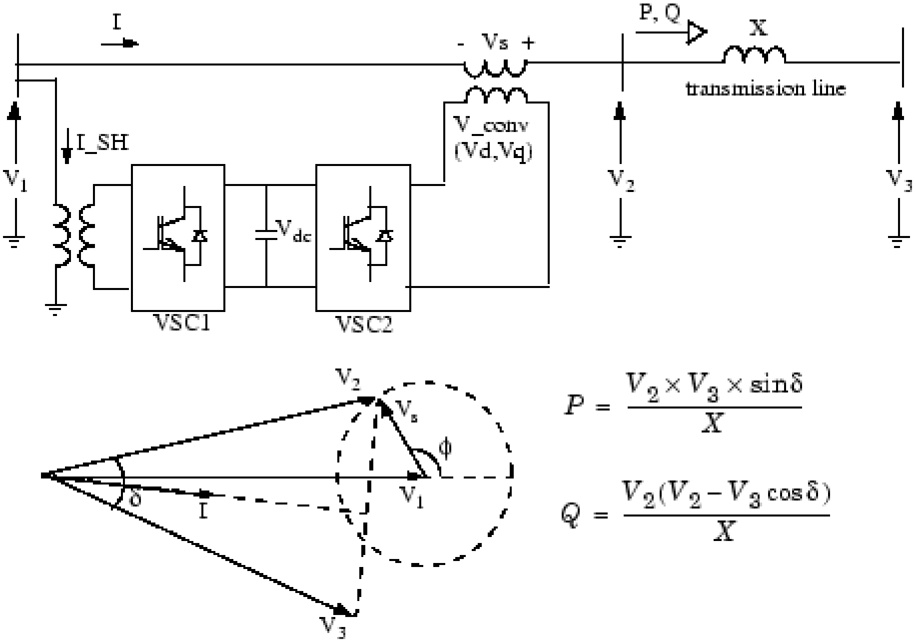
Library

Flexible AC Transmission Systems (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.

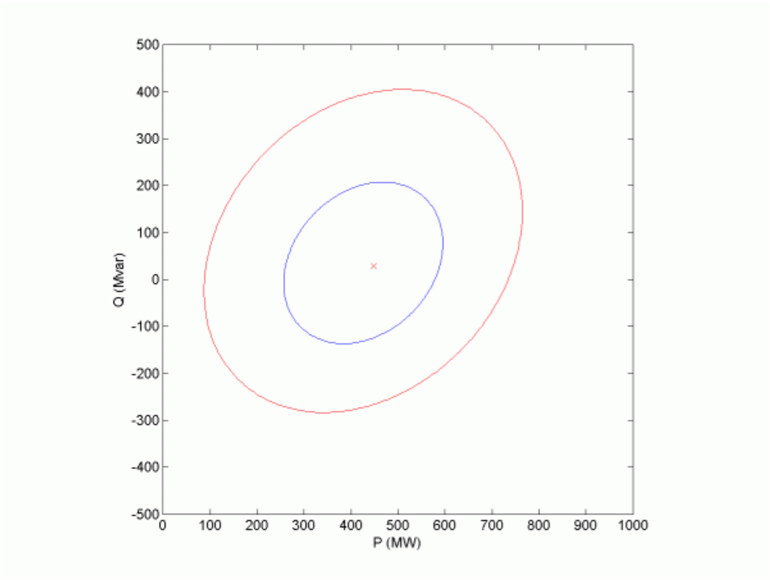


$$P = \frac{V_2 \times V_3 \times \sin\delta}{X}$$

$$Q = \frac{V_2(V_2 - V_3\cos\delta)}{X}$$

Single-line Diagram of a UPFC and Phasor Diagram of Voltages and Currents

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 [[PHI]] 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 [[PHI]] 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.

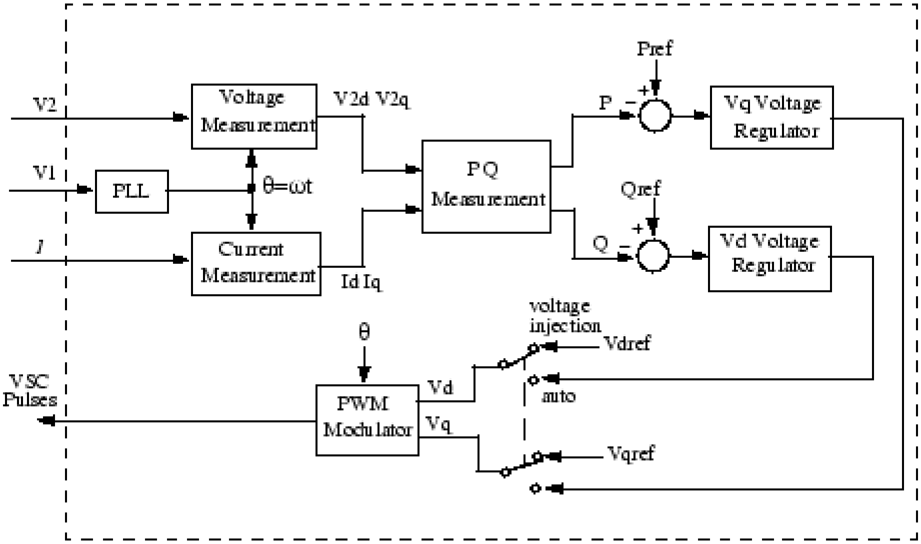
- VSC using IGBT-based PWM inverters. This type of inverter uses Pulse-Width Modulation (PWM) technique to synthesize a sinusoidal waveform from a DC voltage with a typical chopping frequency of a few kilohertz. Harmonics are cancelled by connecting filters at the AC side of the VSC. This type of VSC 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

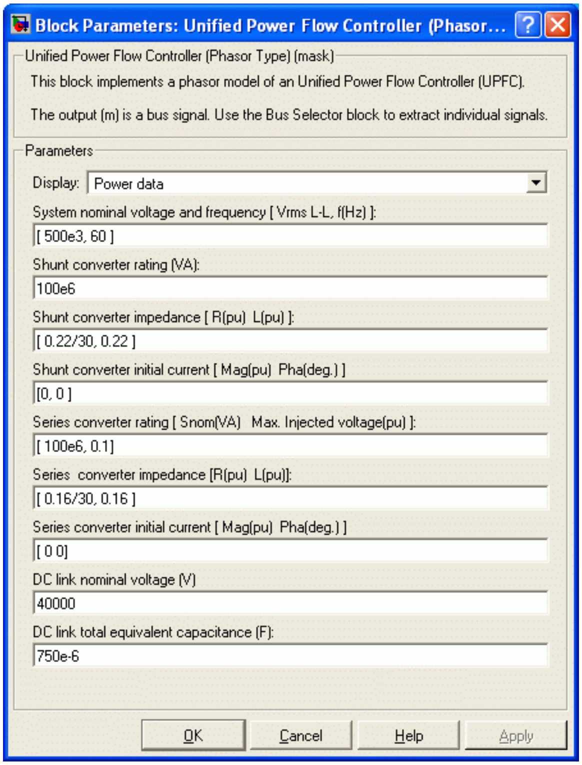
The series converter can operate either in power flow control (automatic mode) or in manual voltage injection mode. In power control mode, the measured active power and reactive power are compared with reference values to produce P and Q errors. The P error and the Q error are used by two PI regulators 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 DR 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 Data Parameters



Unified Power Flow Controller (Phasor Type) (mask)

This block implements a phasor model of an Unified Power Flow Controller (UPFC).

The output (m) is a bus signal. Use the Bus Selector block to extract individual signals.

Parameters

Display: Power data

System nominal voltage and frequency [Vrms L-L, f(Hz)]: [500e3, 60]

Shunt converter rating (VA): 100e6

Shunt converter impedance [R(pu) L(pu)]: [0.22/30, 0.22]

Shunt converter initial current [Mag(pu) Pha(deg.)]: [0, 0]

Series converter rating [Snom(VA) Max. Injected voltage(pu)]: [100e6, 0.1]

Series converter impedance [R(pu) L(pu)]: [0.16/30, 0.16]

Series converter initial current [Mag(pu) Pha(deg.)]: [0 0]

DC link nominal voltage (V): 40000

DC link total equivalent capacitance (F): 750e-6

System nominal voltage and frequency [Vrms f]

The nominal line-to-line voltage in Vrms and the nominal system frequency in hertz.

Shunt converter ratings

The nominal rating of the shunt converter in VA.

Shunt converter impedance [R L]

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 [Mag Phase]

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 ratings [Snom, Max. Injected voltage]

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 [R L]

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 [Mag Phase]

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.

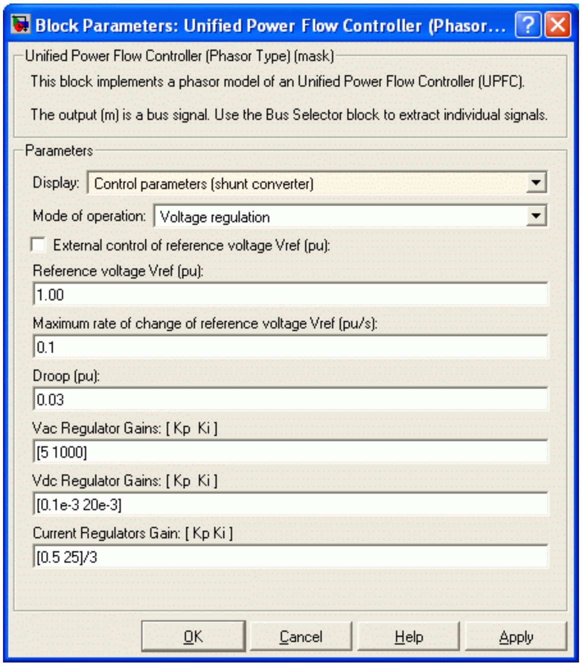
DC link nominal voltage

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 $(1/2 \times C \times Vdc^2)/(Snom)$ 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.

Control Parameters (shunt converter)



This block implements a phasor model of an Unified Power Flow Controller (UPFC).

The output (m) is a bus signal. Use the Bus Selector block to extract individual signals.

Display: Control parameters (shunt converter)

Mode of operation: Voltage regulation

☐ External control of reference voltage Vref (pu):

Reference voltage Vref (pu): 1.00

Maximum rate of change of reference voltage Vref (pu/s): 0.1

Droop (pu): 0.03

Vac Regulator Gains: [Kp Ki] [5 1000]

Vdc Regulator Gains: [Kp Ki] [0.1e-3 20e-3]

Current Regulators Gain: [Kp Ki] [0.5 25]/3

Mode of operation

Specifies the shunt converter mode of operation. Select either `Voltage regulation` or `Var Control`.

External control of reference voltage Vref

If this parameter is checked, a Simulink input named Vref appears on the block, allowing to control the reference voltage from an external signal (in pu). Otherwise a fixed reference voltage is used, as specified by the parameter below.

Reference voltage Vref

This parameter is not visible when the **Mode of operation** parameter is set to `Var Control` or when the **External control of reference voltage Vref** parameter is checked.

Reference voltage, in pu, used by the voltage regulator.

Maximum rate of change of reference voltage Vref

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

This parameter is not visible when the **Mode of operation** 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 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 shunt converter 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.

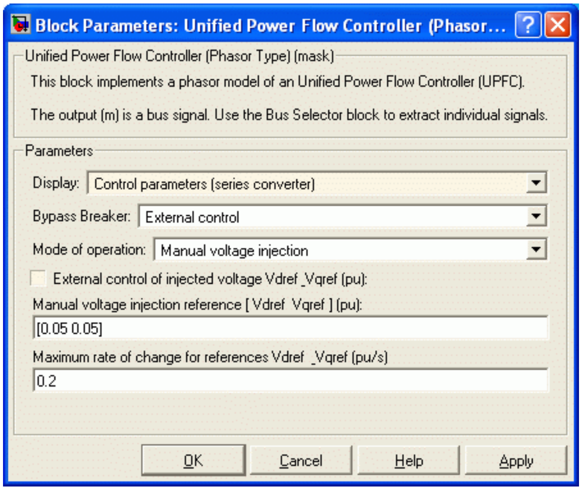
Current Regulators Gains: [Kp Ki]

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.

Control Parameters (series converter)



Unified Power Flow Controller (Phasor Type) (mask)

This block implements a phasor model of an Unified Power Flow Controller (UPFC).

The output (m) is a bus signal. Use the Bus Selector block to extract individual signals.

Parameters

Display: Control parameters (series converter)

Bypass Breaker: External control

Mode of operation: Manual voltage injection

☐ External control of injected voltage Vdref _Vqref (pu):

Manual voltage injection reference [Vdref Vqref] (pu): [0.05 0.05]

Maximum rate of change for references Vdref _Vqref (pu/s) 0.2

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 of operation

Specifies the series converter mode of operation. Select either `Power flow control` or `Manual voltage injection`.

External control of power references

This parameter is not visible when the **Mode of operation** parameter is set to `Manual voltage injection`.

If this parameter is checked, a Simulink input named PQref appears on the block, allowing to control the active and reactive powers from an external signal (in pu). Otherwise, fixed reference power are used, as specified by the parameter below.

Reference active and reactive powers [Pref Qref]

This parameter is not visible when the **Mode of operation** parameter is set to `Manual voltage injection`.

Specify references values, in pu.

Maximum rate of change for references Pref _Qref

This parameter is not visible when the **Mode of operation** 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 of operation** 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.

External control of injected voltage [Vdref Vqref]

This parameter is not visible when the **Mode of operation** parameter is set to `Power flow control`.

If this parameter is checked, a Simulink input named Vdqref appears on the block, allowing to control the injected voltage from an external signal (in pu). Otherwise a fixed reference voltage is used, as specified by the parameter below.

Manual voltage injection reference [Vdref Vqref]

This parameter is not visible when the **External control of injected voltage [Vdref Vqref]** parameter is checked or when the **Mode of operation** 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.

Maximum rate of change for references Vdref _Vqref

This parameter is not visible when the **Mode of operation** 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)

Signal	Signal Group	Signal Names	Definition
14_16	Power Iabc_SE (cmplx)	Ia_SE (pu) Ib_SE (pu) Ic_SE (pu)	Phasor currents Ia, Ib, Ic flowing in the series 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.

Signal	Signal Group	Signal Names	Definition
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)
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.

Signal	Signal Group	Signal Names	Definition
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)

Signal	Signal Group	Signal Names	Definition
33	Control (Series)	Vqref (pu)	Reference value of quadrature-axis injected voltage (pu)
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` demo 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)

Voltage Measurement

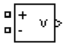
Purpose

Measure voltage in circuit

Library

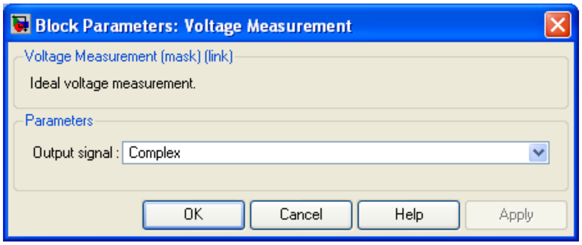
Measurements

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


Block Parameters: Voltage Measurement

Voltage Measurement (mask) (link)

Ideal voltage measurement.

Parameters

Output signal : Complex

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.

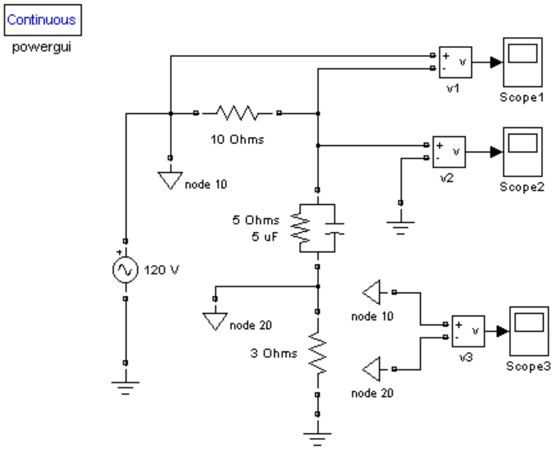
Set to `Real-Imag` to output the real and imaginary parts of the measured current. The output is a vector of two elements.

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_voltmeasure` demo uses three Voltage Measurement blocks to read voltages.



See Also

Current Measurement, Powergui, Three-Phase V-I Measurement

Wind Turbine

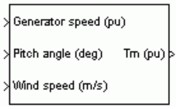
Purpose

Implement model of variable pitch wind turbine

Library

Distributed Resources/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.

$$P_m = c_p(\lambda, \beta)\frac{\rho A}{2}v_{wind}^3 \tag{2-1}$$

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 2-1 can be normalized. In the per unit (pu) system we have:

$$P_{m\_pu} = k_p c_{p\_pu} v_{wind\_pu}^3 \tag{2-2}$$

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

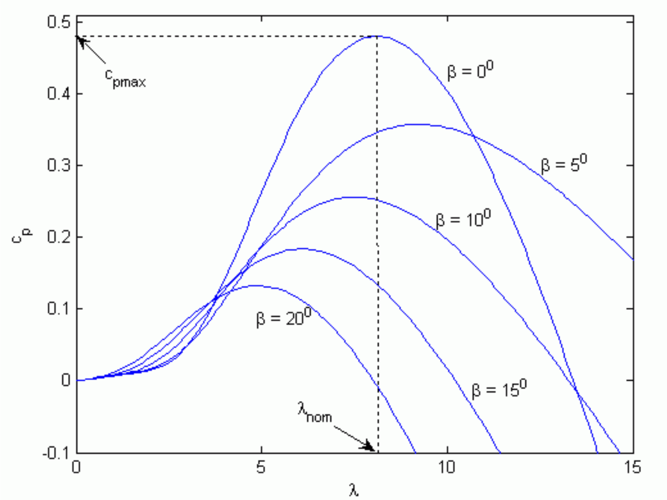
A generic equation is used to model c_p(λ,ß). This equation, based on the modeling turbine characteristics of [1], is:

$$c_p(\lambda, \beta) = c_1\left(\frac{c_2}{\lambda_i} - c_3\beta - c_4\right)e^{\frac{-c_5}{\lambda_i}} + c_6\lambda \qquad \textbf{(2-3)}$$

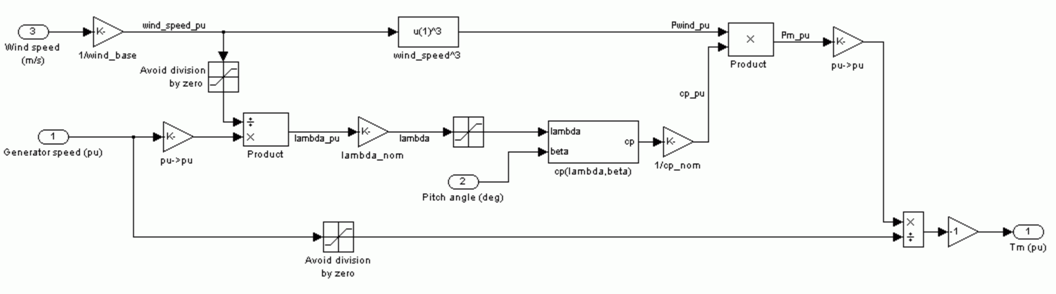
with

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \qquad \textbf{(2-4)}$$

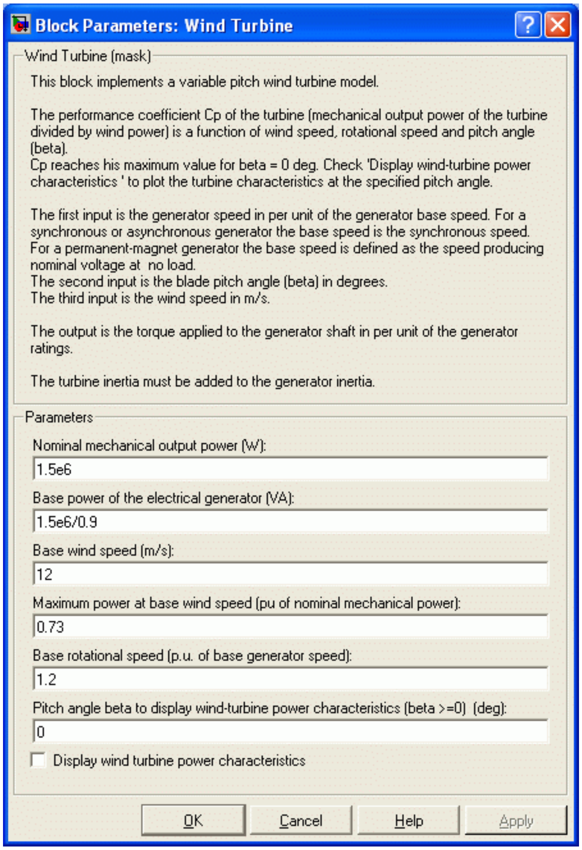
The coefficients c_1 to c_6 are: $c_1 = 0.5176$, $c_2 = 116$, $c_3 = 0.4$, $c_4 = 5$, $c_5 = 21$ and $c_6 = 0.0068$. The c_p-λ characteristics, for different values of the pitch angle ß, are illustrated below. The maximum value of c_p ($c_{pmax} = 0.48$) is achieved for ß = 0 degree and for λ = 8.1. 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



Wind Turbine (mask)

This block implements a variable pitch wind turbine model.

The performance coefficient Cp of the turbine (mechanical output power of the turbine divided by wind power) is a function of wind speed, rotational speed and pitch angle (beta).
Cp reaches his maximum value for beta = 0 deg. Check 'Display wind-turbine power characteristics ' to plot the turbine characteristics at the specified pitch angle.

The first input is the generator speed in per unit of the generator base 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.
The second input is the blade pitch angle (beta) in degrees.
The third input is the wind speed in m/s.

The output is the torque applied to the generator shaft in per unit of the generator ratings.

The turbine inertia must be added to the generator inertia.

Parameters

Nominal mechanical output power (W): 1.5e6

Base power of the electrical generator (VA): 1.5e6/0.9

Base wind speed (m/s): 12

Maximum power at base wind speed (pu of nominal mechanical power): 0.73

Base rotational speed (p.u. of base generator speed): 1.2

Pitch angle beta to display wind-turbine power characteristics (beta >=0) (deg): 0

☐ Display wind turbine power characteristics

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.

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

If this parameter is checked, the turbine power characteristics are displayed 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)`

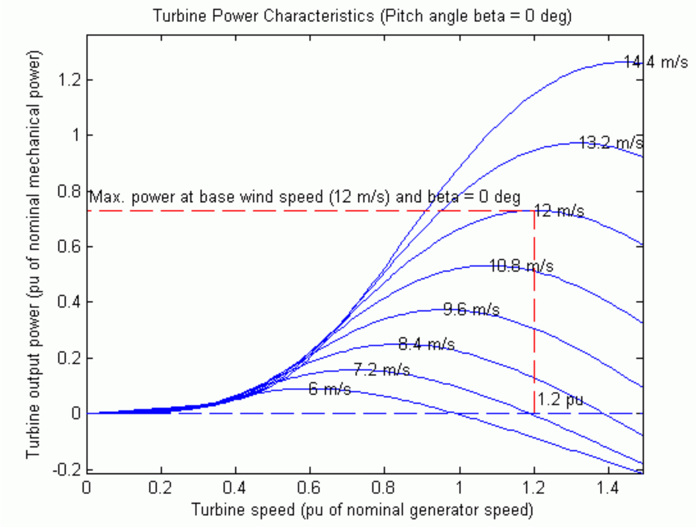
Simulink input of the wind speed in m/s.

`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 β = 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)

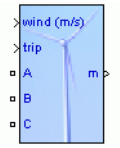
Purpose

Implement phasor model of variable speed doubly-fed induction generator driven by wind turbine

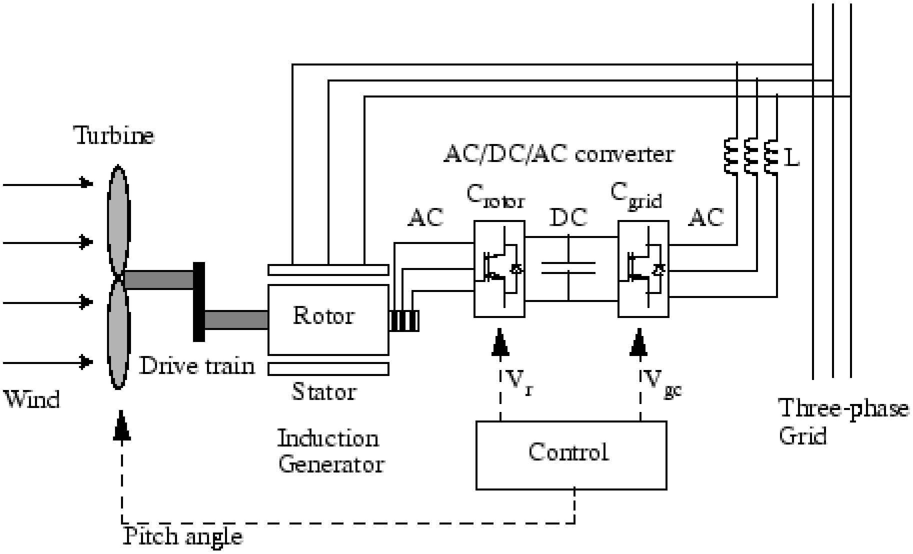
Library

Distributed Resources/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 on page 2-901. 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 on page 2-903, 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 loss less generator the mechanical equation is:

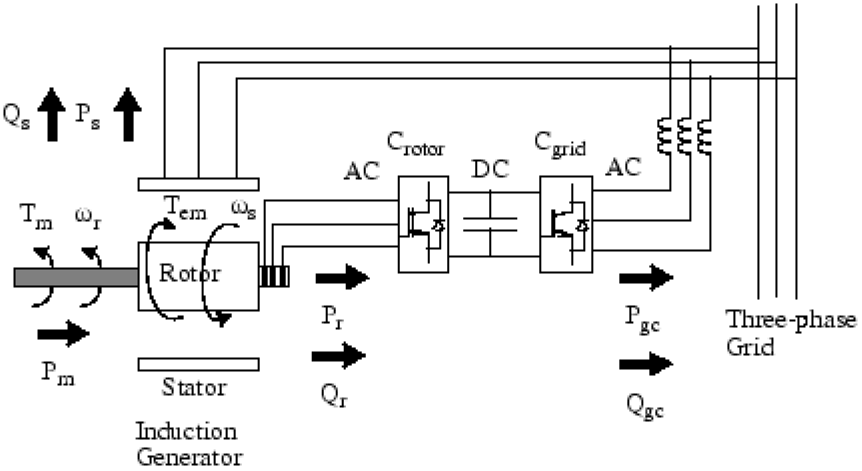
$$J\frac{d\omega_r}{dt} = T_m - T_{em}$$

In steady-state at fixed speed for a loss less generator $T_m = T_{em}$ and $P_m = P_s + P_r$

It follows that:

$$P_r = P_m - P_s = T_m\omega_r - T_{em}\omega_s = -T_m\left(\frac{\omega_s - \omega_r}{\omega_s}\right)\omega_s = -sT_m\omega_s = -sP_s$$

where s is defined as the slip of the generator: $s = \frac{\omega_s - \omega_r}{\omega_s}$



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 loss less 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.

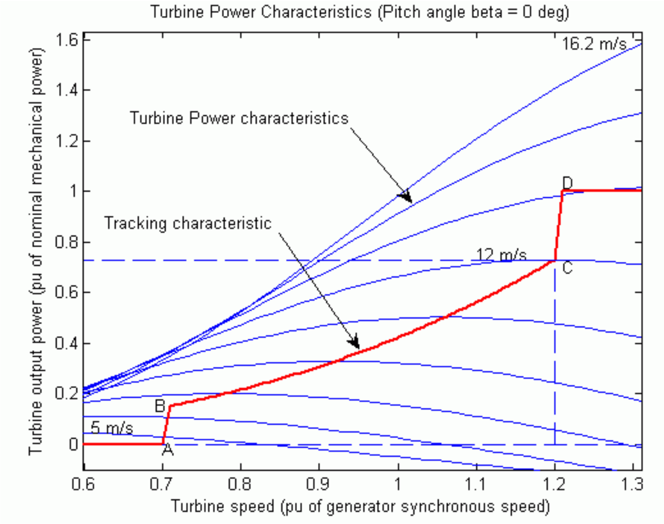
C_{rotor} and C_{grid} have the capability of generating or absorbing reactive power and could be used to control the reactive power or the voltage at the grid terminals.

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.

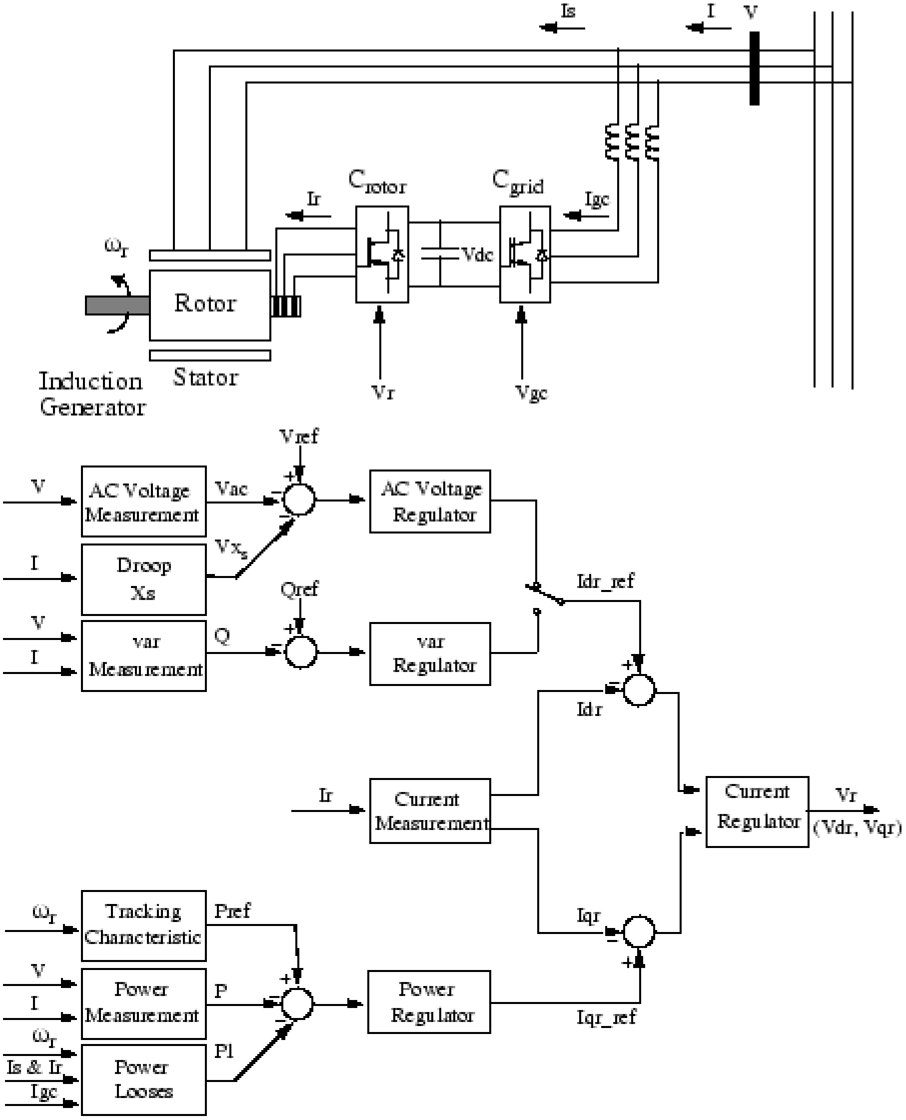
Power Control

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 on page 2-905, 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 on page 2-906. 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.

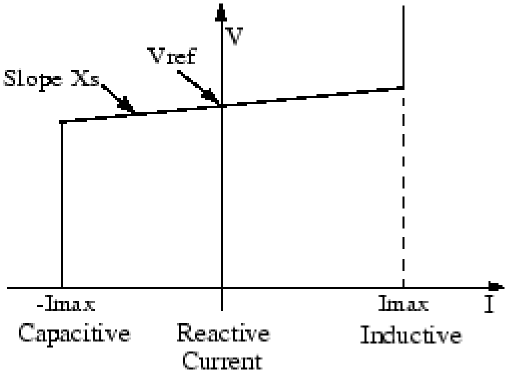


Rotor-Side Converter Control System

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 on page 2-906.

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 on page 2-907. In the voltage regulation mode, the V-I characteristic is described by the following equation:

$$V = Vref + Xs \cdot I$$

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

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 $\sqrt{Idr\_ref^2 + Iqr\_ref^2}$. 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.

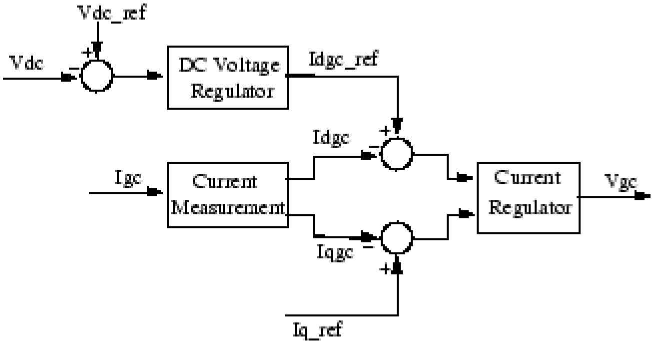
C_grid Control System

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 on page 2-910, 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.

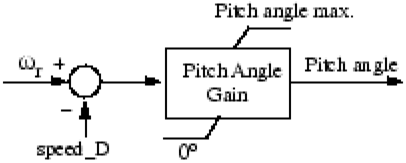
The magnitude of the reference grid converter current Igc_ref is equal to $\sqrt{Idgc\_ref^2 + Iq\_ref^2}$. The maximum value of this current is limited to a value defined by the converter maximum power at nominal voltage. When Idgc_ref and Iq_ref are such that the magnitude is higher than this maximum 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 Distributed Resources/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:

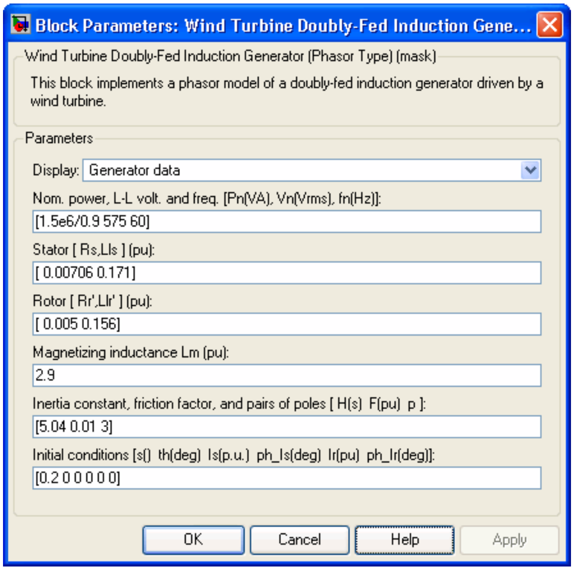
1. Only the positive-sequence is taken into account, the negative-sequence has been eliminated.

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 Data Parameters



This block implements a phasor model of a doubly-fed induction generator driven by a wind turbine.

Display: Generator data

Nom. power, L-L volt. and freq. [Pn(VA), Vn(Vrms), fn(Hz)]: [1.5e6/0.9 575 60]

Stator [Rs,Lls] (pu): [0.00706 0.171]

Rotor [Rr',Llr'] (pu): [0.005 0.156]

Magnetizing inductance Lm (pu): 2.9

Inertia constant, friction factor, and pairs of poles [H(s) F(pu) p]: [5.04 0.01 3]

Initial conditions [s() th(deg) Is(p.u.) ph_Is(deg) Ir(pu) ph_Ir(deg)]: [0.2 0 0 0 0 0]

WTDFIG modeled using positive-sequence only

The WTDFIG is modeled by a three-wire system using two current sources. The WTDFIG does not generate any zero-sequence current, but it can generate negative-sequence currents during unbalanced system operation.

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 rating.

Rotor [Rr', Llr']

The rotor resistance Rr' and leakage inductance Llr', both referred to the stator, in pu based on the generator rating.

Magnetizing inductance Lm

The magnetizing inductance Lm in pu based on the generator rating.

Inertia constant, friction factor and pairs of poles

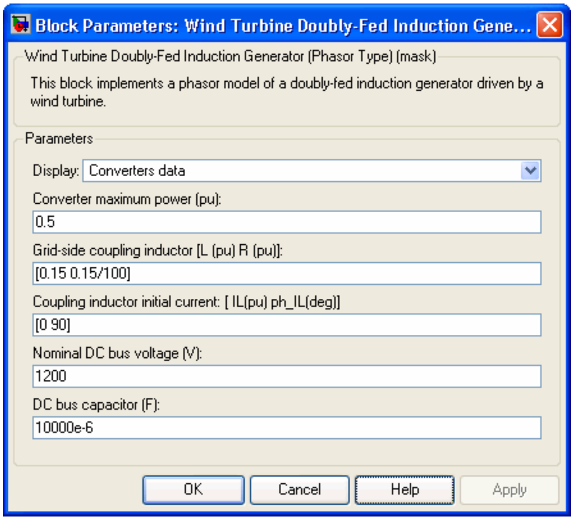
Combined generator and turbine inertia constant H in seconds, combined viscous friction factor F in pu based on the generator rating and number of pole pairs p.

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.

Converters Data Parameters



Wind Turbine Doubly-Fed Induction Generator (Phasor Type) (mask)

This block implements a phasor model of a doubly-fed induction generator driven by a wind turbine.

Parameters

Display: Converters data

Converter maximum power (pu):
0.5

Grid-side coupling inductor [L (pu) R (pu)]:
[0.15 0.15/100]

Coupling inductor initial current: [IL(pu) ph_IL(deg)]
[0 90]

Nominal DC bus voltage (V):
1200

DC bus capacitor (F):
10000e-6

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 [L R]

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.

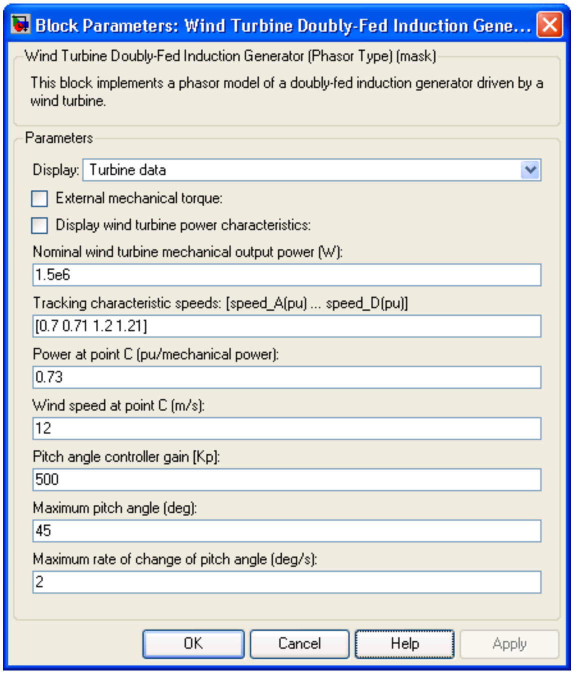
Nominal DC bus voltage

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 $(1/2 \times C \times Vdc^2)/(Pn)$ 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.

Turbine Data Parameters



Wind Turbine Doubly-Fed Induction Generator (Phasor Type) (mask)

This block implements a phasor model of a doubly-fed induction generator driven by a wind turbine.

Display: Turbine data

☐ External mechanical torque:

☐ Display wind turbine power characteristics:

Nominal wind turbine mechanical output power (W): 1.5e6

Tracking characteristic speeds: [speed_A(pu) ... speed_D(pu)]: [0.7 0.71 1.2 1.21]

Power at point C (pu/mechanical power): 0.73

Wind speed at point C (m/s): 12

Pitch angle controller gain [Kp]: 500

Maximum pitch angle (deg): 45

Maximum rate of change of pitch angle (deg/s): 2

External mechanical torque

If this parameter is checked, 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.

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.

Display wind turbine power characteristics

If this parameter is checked, the turbine power characteristics at zero degree of pitch angle are displayed for different wind speeds. The tracking characteristic is also displayed on the same figure.

This parameter is not visible when the **External mechanical torque** parameter is checked.

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.

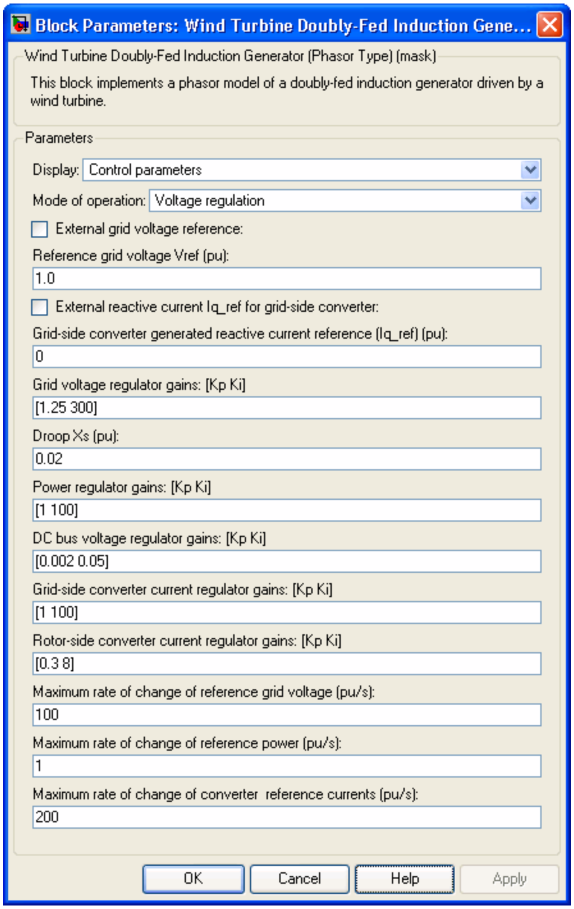
The maximum pitch angle in degrees.

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.

Control Parameters



Wind Turbine Doubly-Fed Induction Generator (Phasor Type) (mask)

This block implements a phasor model of a doubly-fed induction generator driven by a wind turbine.

Parameters

Display: Control parameters

Mode of operation: Voltage regulation

☐ External grid voltage reference:

Reference grid voltage Vref (pu): 1.0

☐ External reactive current Iq_ref for grid-side converter:

Grid-side converter generated reactive current reference (Iq_ref) (pu): 0

Grid voltage regulator gains: [Kp Ki]: [1.25 300]

Droop Xs (pu): 0.02

Power regulator gains: [Kp Ki]: [1 100]

DC bus voltage regulator gains: [Kp Ki]: [0.002 0.05]

Grid-side converter current regulator gains: [Kp Ki]: [1 100]

Rotor-side converter current regulator gains: [Kp Ki]: [0.3 8]

Maximum rate of change of reference grid voltage (pu/s): 100

Maximum rate of change of reference power (pu/s): 1

Maximum rate of change of converter reference currents (pu/s): 200

Mode of operation

Specifies the **WTDFIG** mode of operation. Select either `Voltage regulation` or `Var regulation`.

External grid voltage reference

This parameter is not visible when the **Mode of operation** parameter is set to `Var regulation.`

If this parameter is checked, a Simulink input named Vref appears on the block, allowing to control the reference voltage from an external signal in pu. Otherwise a fixed reference voltage is used, as specified by the parameter below.

Reference grid voltage Vref

This parameter is not visible when the **Mode of operation** parameter is set to `Var regulation` or when the **External grid voltage reference** parameter is checked.

Reference voltage, in pu, used by the voltage regulator.

External generated reactive power reference

This parameter is not visible when the **Mode of operation** parameter is set to `Voltage regulation.`

If this parameter is checked, a Simulink input named Qref appears on the block, allowing to control the reference reactive power, at grid terminals, from an external signal in pu. Otherwise a fixed reference reactive power is used, as specified by the parameter below.

Generated reactive power Qref

This parameter is not visible when the **Mode of operation** parameter is set to `Voltage regulation` or when the **External generated reactive power reference** parameter is checked.

Reference generated reactive power at grid terminals, in pu, used by the var regulator.

External reactive current Iq_ref for grid-side converter reference

If this parameter is checked, a Simulink input named Iq_ref appears on the block, allowing to control the grid-side converter reactive current from an external signal in pu. Specify a positive value for Iq_ref for generated reactive power. Otherwise a fixed reactive current is used, as specified by the parameter below.

Grid-side converter generated reactive current reference (Iq_ref)

This parameter is not visible when the **External reactive current Iq_ref for grid-side converter reference** parameter is checked.

Reference grid-side converter reactive current, in pu, used by the current regulator. Specify a positive value of Iq_ref for generated reactive power.

Grid voltage regulator gains [Kp Ki]

This parameter is not visible when the **Mode of operation** 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 of operation** 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 of operation** 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 of operation** 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 of operation** 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.

Signal	Signal Group	Signal Names	Definition
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.

Signal	Signal Group	Signal Names	Definition
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.
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.

Signal	Signal Group	Signal Names	Definition
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` demo 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)

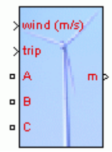
Purpose

Implement phasor model of squirrel-cage induction generator driven by variable pitch wind turbine

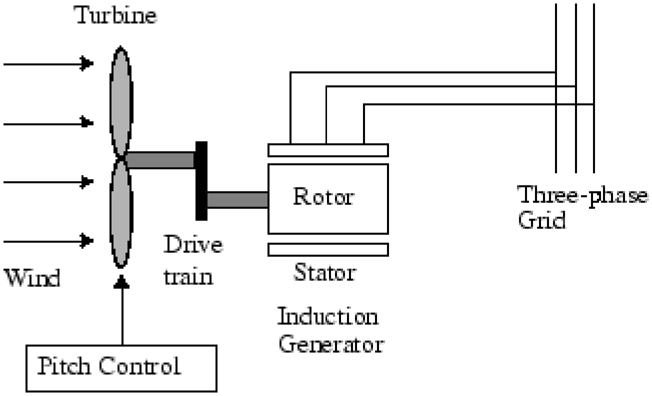
Library

Distributed Resources/Wind Generation

Description



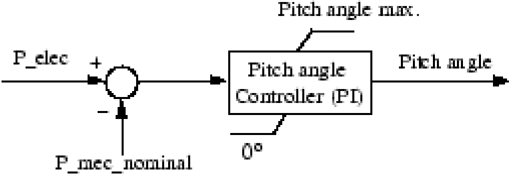
The wind turbine and the induction generator (WTIG) are shown below. The stator winding is connected directly to the grid and the rotor is driven by the wind turbine. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by 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 Distributed Resources/Wind Generation library. See documentation of this block for details.

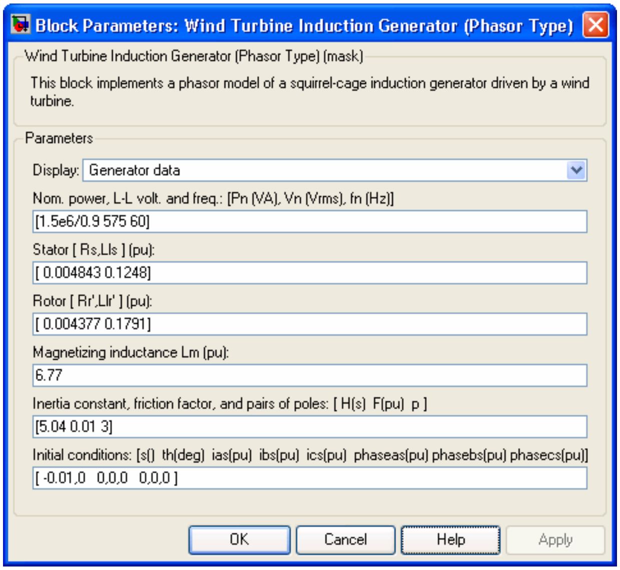
A Proportional-Integral (PI) controller is used to control the blade pitch angle in order to limit the electric output power to the nominal mechanical power. The pitch angle is kept constant at zero degree when the measured electric output power is under its nominal value. When it increases above its 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 Data Parameters



Wind Turbine Induction Generator (Phasor Type) (mask)

This block implements a phasor model of a squirrel-cage induction generator driven by a wind turbine.

Parameters

Display: Generator data

Nom. power, L-L volt. and freq.: [Pn (VA), Vn (Vrms), fn (Hz)]
[1.5e6/0.9 575 60]

Stator [Rs,Lls] (pu):
[0.004843 0.1248]

Rotor [Rr',Llr'] (pu):
[0.004377 0.1791]

Magnetizing inductance Lm (pu):
6.77

Inertia constant, friction factor, and pairs of poles: [H(s) F(pu) p]
[5.04 0.01 3]

Initial conditions: [s() th(deg) ias(pu) ibs(pu) ics(pu) phaseas(pu) phasebs(pu) phasecs(pu)]
[-0.01,0 0,0,0 0,0,0]

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

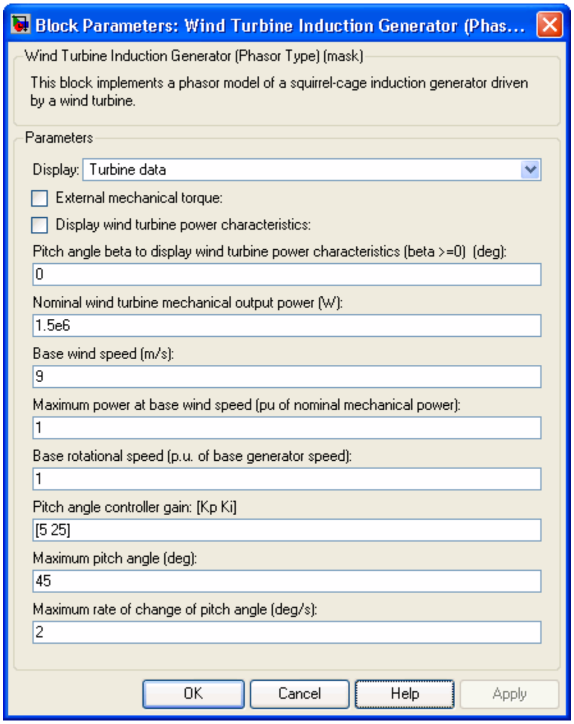
Combined generator and turbine inertia constant H in seconds, combined viscous friction factor F in pu based on the generator ratings and number of pole pairs p.

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.

Turbine Data Parameters



Wind Turbine Induction Generator (Phasor Type) (mask)

This block implements a phasor model of a squirrel-cage induction generator driven by a wind turbine.

Parameters

Display: Turbine data

☐ External mechanical torque:

☐ Display wind turbine power characteristics:

Pitch angle beta to display wind turbine power characteristics (beta >=0) (deg): 0

Nominal wind turbine mechanical output power (W): 1.5e6

Base wind speed (m/s): 9

Maximum power at base wind speed (pu of nominal mechanical power): 1

Base rotational speed (p.u. of base generator speed): 1

Pitch angle controller gain: [Kp Ki] [5 25]

Maximum pitch angle (deg): 45

Maximum rate of change of pitch angle (deg/s): 2

Refer to the Wind Turbine for a detailed documentation.

External mechanical torque

If this parameter is checked, 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.

Display wind turbine power characteristics

If this parameter is checked, the turbine power characteristics at the specified pitch angle are displayed for different wind speeds.

This parameter is not visible when the **External mechanical torque** parameter is checked.

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.
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` demo 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

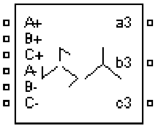
Purpose

Implement zigzag phase-shifting transformer with configurable secondary winding connection

Library

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).

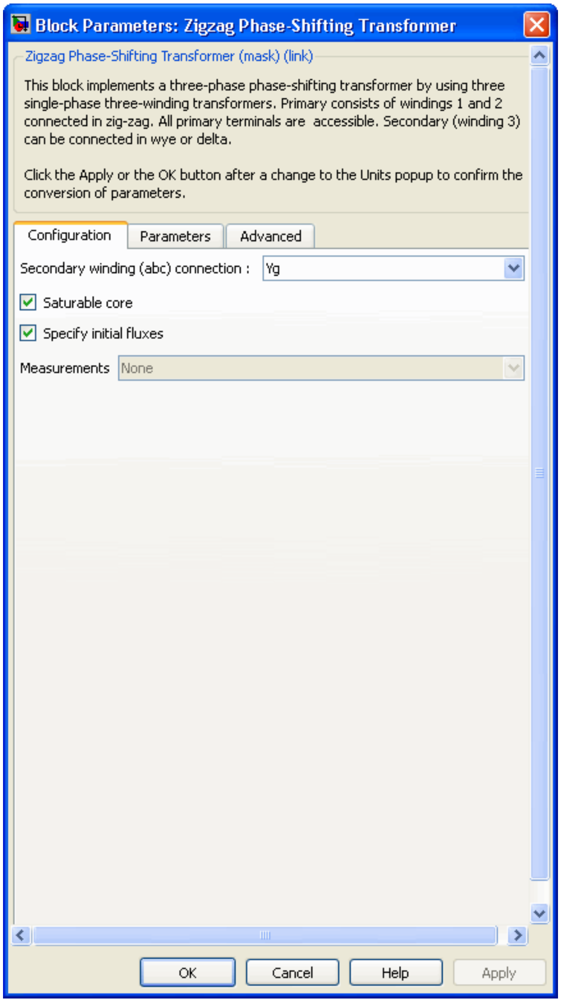
If the secondary winding is connected in Y, the secondary phase voltages are leading or lagging the primary voltages by the Phi phase angle specified in the parameters of the block. If the secondary winding is connected in delta (D11), an additional phase shift of +30 degrees is added to the phase angle. 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



Block Parameters: Zigzag Phase-Shifting Transformer

Zigzag Phase-Shifting Transformer (mask) (link)

This block implements a three-phase phase-shifting transformer by using three single-phase three-winding transformers. Primary consists of windings 1 and 2 connected in zig-zag. All primary terminals are accessible. Secondary (winding 3) can be connected in wye or delta.

Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

Secondary winding (abc) connection : Yg

☑ Saturable core

☑ Specify initial fluxes

Measurements None

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 (for saturable transformers only).

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 (for saturable transformers only).

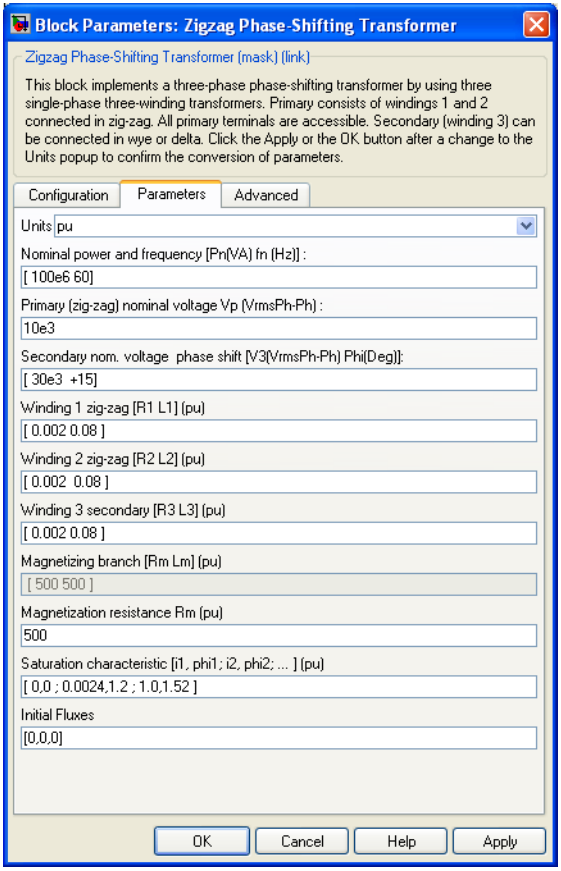
Select `All measurements (V, I, Flux)` to measure the winding voltages, currents, magnetization currents, and the flux linkages. Note that the magnetization currents and the flux linkages signals are measured only if the **Saturable core** parameter is selected.

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:`
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



Zigzag Phase-Shifting Transformer (mask) (link)

This block implements a three-phase phase-shifting transformer by using three single-phase three-winding transformers. Primary consists of windings 1 and 2 connected in zig-zag. All primary terminals are accessible. Secondary (winding 3) can be connected in wye or delta. Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

Units pu

Nominal power and frequency [Pn(VA) fn (Hz)] : [100e6 60]

Primary (zig-zag) nominal voltage Vp (VrmsPh-Ph) : 10e3

Secondary nom. voltage phase shift [V3(VrmsPh-Ph) Phi(Deg)]: [30e3 +15]

Winding 1 zig-zag [R1 L1] (pu): [0.002 0.08]

Winding 2 zig-zag [R2 L2] (pu): [0.002 0.08]

Winding 3 secondary [R3 L3] (pu): [0.002 0.08]

Magnetizing branch [Rm Lm] (pu): [500 500]

Magnetization resistance Rm (pu): 500

Saturation characteristic [i1 , phi1 ; i2, phi2 ; ...] (pu): [0,0 ; 0.0024,1.2 ; 1.0,1.52]

Initial Fluxes: [0,0,0]

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.

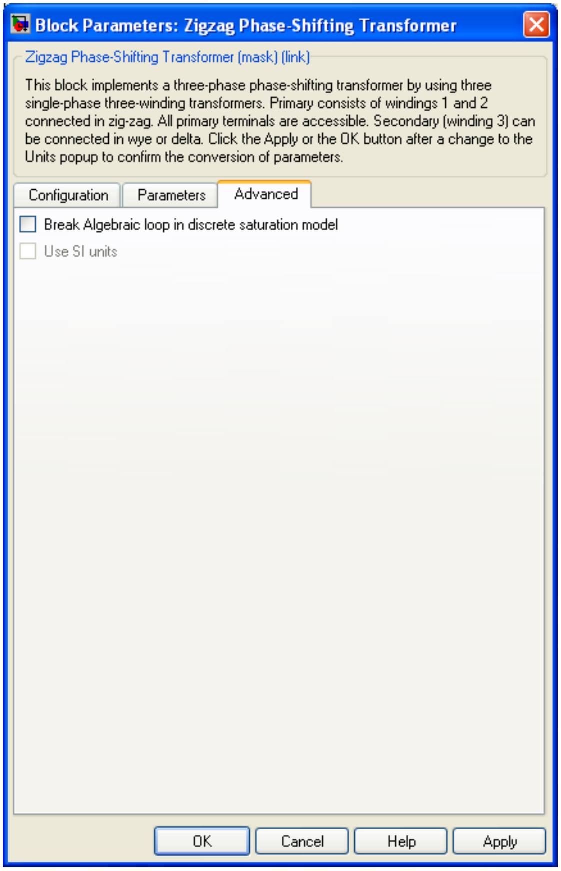
The saturation characteristic for the saturable core. Specify a series of current/ flux pairs (in pu) starting with the pair (0,0).

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



Block Parameters: Zigzag Phase-Shifting Transformer

Zigzag Phase-Shifting Transformer (mask) (link)

This block implements a three-phase phase-shifting transformer by using three single-phase three-winding transformers. Primary consists of windings 1 and 2 connected in zig-zag. All primary terminals are accessible. Secondary (winding 3) can be connected in wye or delta. Click the Apply or the OK button after a change to the Units popup to confirm the conversion of parameters.

☐ Break Algebraic loop in discrete saturation model

☐ Use SI units

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` demo.

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)

Function Reference

This table indicates the tasks performed by the commands described in this chapter.

`power_analyze`	Analyze electric circuit
`power_cableparam`	Compute RLC parameters of radial copper cables with single screen, based on conductor and insulator characteristics
`power_fftscope`	Perform Fourier analysis of signals stored in Structure with Time format
`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 machine load flow and initialization for models containing three-phase machines and dynamic load blocks

`power_ltiview`	Create state-space object of model for use with LTI Viewer tools
`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

Purpose

Analyze electric circuit

Syntax

```
sps = power_analyze('sys','structure')
sps = power_analyze('sys','sort')
sps = power_analyze('sys','ss')
[A,B,C,D,x0,states,inputs,outputs,uss,xss,yss,freqyss,Hlin]=
power_analyze('sys');
power_analyze('sys','net')
```

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 3-90for 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.

Field	**Description**
`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
`x0switch`	Vector of initial values of switch currents
`Hlin`	`nfreq`-by-`noutput`-by-`ninput` 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,x0,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
`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

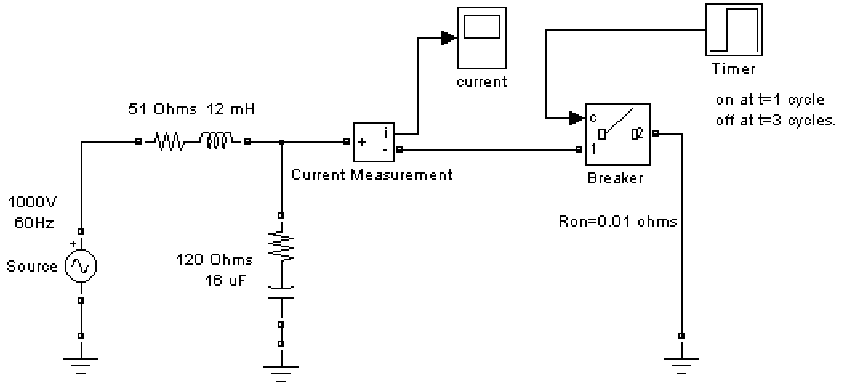
`sps = power_analyze('sys','`**`ss`**`')` creates a continuous state-space model of the model `sys` with matrices A, B, C, D. You must have Control System Toolbox software installed for this option. The output is a state-space object.

Output Arguments: Net

`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.

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_cableparam

Purpose

Compute RLC parameters of radial copper cables with single screen, based on conductor and insulator characteristics

Syntax

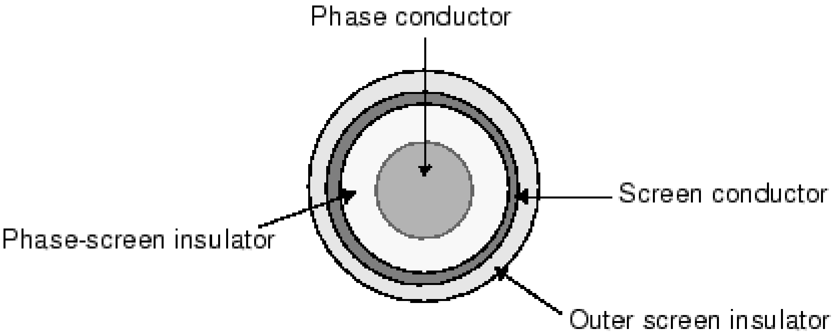
Description

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

μr: the relative permittivity 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

$$Z_{aa} = R_{\phi} + R_e + jk_1 \log\left(\frac{D_e}{GMR_{\phi}}\right) \qquad \Omega/\mathrm{km}$$

The DC resistance of phase conductor is given by

$$R_{\phi} = \rho_{Cu}\frac{1000}{S_{Cu}} = (17.8e-9)\frac{1000}{n\pi(d/2)^2} \qquad \Omega/\mathrm{km}$$

The resistance of earth return is given by

$$R_e = \pi^2 \cdot 10^{-4} \cdot f \qquad \Omega/\mathrm{km}$$

The frequency factor is given by

$$k_1 = 0.0529 \cdot \frac{f}{0.3048 \cdot 60} \qquad units(\Omega/\mathrm{km})$$

The distance to equivalent earth return path is given by

$$D_e = 1650\sqrt{\rho_{Cu}/(2\pi f)} \qquad m$$
$$\rho_{Cu} = 17.8e-9 \qquad \Omega/\mathrm{m}$$

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

$$Z_{xx} = R_N + R_e + jk_1 \log\left(\frac{D_e}{GMR_N}\right) \qquad \Omega/\mathrm{km}$$

The DC resistance of phase-screen insulator is given by

$$R_N = \rho\frac{1000}{S} \qquad \Omega/\mathrm{km}$$

The geometric mean radius of phase-screen insulator is given by

$$GMR_N = \frac{r_{ext} - r_{int}}{2}$$

Mutual Impedance Between the Phase and Screen Conductors

The mutual impedance between the phase conductor and its corresponding screen conductor is calculated as follow

$$Z_{ax} = R_e + jk_1 \log\left(\frac{D_e}{D_n}\right) \qquad \Omega/\mathrm{km}$$

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

$$Z_{ab} = R_e + jk_1 \log\left(\frac{D_e}{GMD}\right) \qquad \Omega/\mathrm{km}$$

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

$$C_{ax} = \frac{1}{0.3048}\left(\frac{0.00736\varepsilon_{rax}}{\log(D_{ax}/d_{ax})}\right) \qquad \mu F/km$$

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

$$C_{xe} = \frac{1}{0.3048}\left(\frac{0.00736\varepsilon_{rxe}}{\log(D_{xe}/d_{xe})}\right) \qquad \mu F/km$$

Capacitance Between the Phase Conductor

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 permittivity 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)
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 phase and screen conductor, in Henries/Km
l.ax	Mutual inductance between the phase conductors, in Ohm/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
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.mdl` demo for an example on how to build a block that represents a 4-Cables with Screen block.

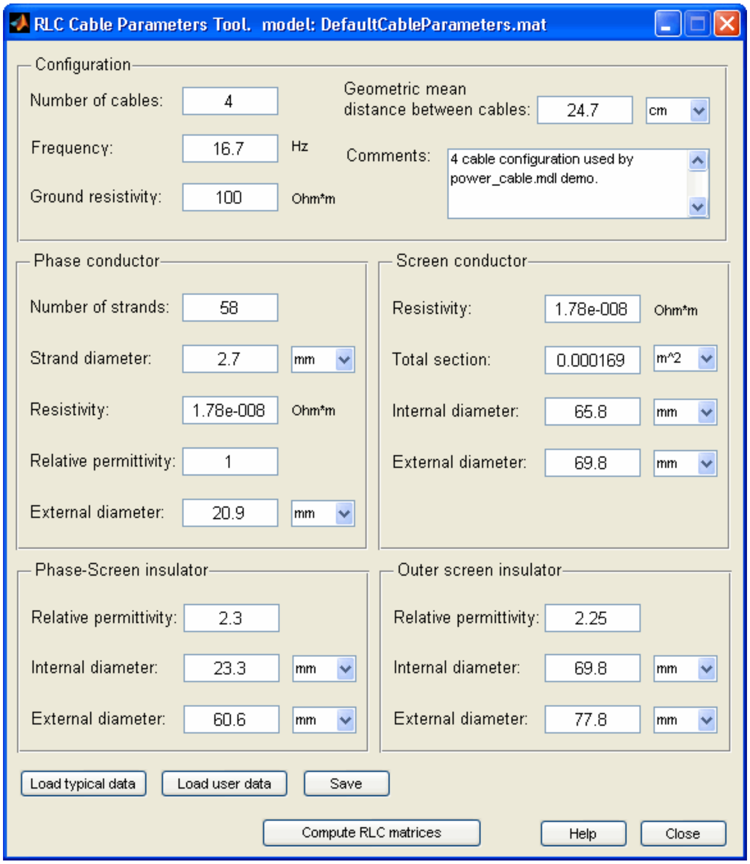
The RLC matrices are defined as follow (the example is given for a 3-cables configuration):

$$R = \begin{bmatrix} r_{aa} & r_{ax} & r_{ab} & r_{ab} & r_{ab} & r_{ab} \\ r_{ax} & r_{xx} & r_{ab} & r_{ab} & r_{ab} & r_{ab} \\ r_{ab} & r_{ab} & r_{aa} & r_{ax} & r_{ab} & r_{ab} \\ r_{ab} & r_{ab} & r_{ax} & r_{xx} & r_{ab} & r_{ab} \\ r_{ab} & r_{ab} & r_{ab} & r_{ab} & r_{aa} & r_{ax} \\ r_{ab} & r_{ab} & r_{ab} & r_{ab} & r_{ax} & r_{xx} \end{bmatrix} \qquad L = \begin{bmatrix} l_{aa} & l_{ax} & l_{ab} & l_{ab} & l_{ab} & l_{ab} \\ l_{ax} & l_{xx} & l_{ab} & l_{ab} & l_{ab} & l_{ab} \\ l_{ab} & l_{ab} & l_{aa} & l_{ax} & l_{ab} & l_{ab} \\ l_{ab} & l_{ab} & l_{ax} & r_{xx} & l_{ab} & l_{ab} \\ l_{ab} & l_{ab} & l_{ab} & r_{ab} & l_{aa} & l_{ax} \\ l_{ab} & l_{ab} & l_{ab} & l_{ab} & l_{ax} & l_{xx} \end{bmatrix}$$

$$C = \begin{bmatrix} c_{ax} & -c_{ax} & 0 & 0 & 0 & 0 \\ -c_{ax} & c_{xe} & 0 & 0 & 0 & 0 \\ 0 & 0 & c_{ax} & -c_{ax} & 0 & 0 \\ 0 & 0 & -c_{ax} & c_{xe} & 0 & 0 \\ 0 & 0 & 0 & 0 & c_{ax} & -c_{ax} \\ 0 & 0 & 0 & 0 & -c_{ax} & c_{xe} \end{bmatrix}$$

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.


RLC Cable Parameters Tool. model: DefaultCableParameters.mat

Configuration
Number of cables: 4
Frequency: 16.7 Hz
Ground resistivity: 100 Ohm*m
Geometric mean distance between cables: 24.7 cm
Comments: 4 cable configuration used by power_cable.mdl demo.

Phase conductor
Number of strands: 58
Strand diameter: 2.7 mm
Resistivity: 1.78e-008 Ohm*m
Relative permittivity: 1
External diameter: 20.9 mm

Screen conductor
Resistivity: 1.78e-008 Ohm*m
Total section: 0.000169 m^2
Internal diameter: 65.8 mm
External diameter: 69.8 mm

Phase-Screen insulator
Relative permittivity: 2.3
Internal diameter: 23.3 mm
External diameter: 60.6 mm

Outer screen insulator
Relative permittivity: 2.25
Internal diameter: 69.8 mm
External diameter: 77.8 mm

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 ohms/m.

Relative permittivity
Specify the relative permittivity 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 ohms/m.

Total section
Total section of screen conductor (in mm^2, cm^2, or m^2)

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 conducting 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 conducting 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.mdl` demo.

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" on page 3-50 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.mdl` demo.

Example

See the `power_cable` demo for an example using the `power_cableparam` function.

See Also

`power_lineparam`

power_fftscope

Purpose

Perform Fourier analysis of signals stored in Structure with Time format

Syntax

```
power_fftscope
sps = power_fftscope('sys')
```

Description

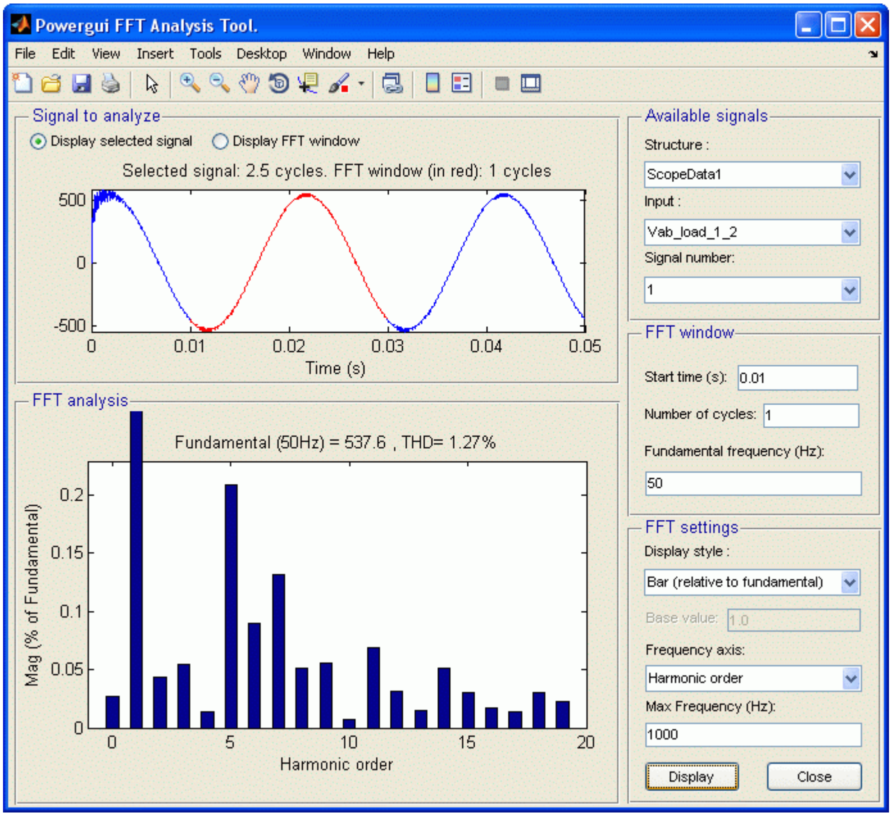
`power_fftscope` opens the FFT Analysis Tool dialog box to perform Fourier analysis of signals stored in a Structure with Time format. The dialog box provides an easy access to all the Structure with Time variables defined in your workspace. This tool can also be activated from the Powergui block dialog box by selecting **FFT Analysis**.

`sps = power_fftscope('sys')` returns the current FFT settings and results for the signal displayed in the dialog box. `fftdata` is a structure with the fields:

Field	Description
`structure`	The name of the Structure with Time variable that contains the analyzed signal
`input`	The input signal of the selected Structure with Time variable
`signal`	The index of the selected input signal specified by the input field
`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
`FFTdata`	The analyzed signal (FFT window data)

Field	Description
`mag`	Computed magnitude of FFT
`phase`	Computed phase of FFT
`freq`	Frequency vector
`THD`	The computed Total Harmonic Distortion for the analyzed signal

Dialog Box



Signal to analyze: ● Display selected signal ○ Display FFT window

Structure : ScopeData1

Input : Vab_load_1_2

Signal number: 1

Start time (s): 0.01

Number of cycles: 1

Fundamental frequency (Hz): 50

Display style : Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Harmonic order

Max Frequency (Hz): 1000

Display selected signal
If selected, display in the upper plot the signal selected by the **Structure**, **Input**, and **Signal number** parameters.

Display FFT window
If selected, display in the upper plot the portion of the selected signal where the FFT analysis is performed.

Structure
Lists the structures with time variables that are present in your workspace. You first need to run a simulation of your model. These structures are generated by the Scope or To Workspace blocks in your model. The signals must be sampled at a fixed rate, by using the Scope block settings. Use the pull-down menu to select the variable you want to analyze.

Input
Select the input signal of the selected structure with time variables specified in the **Structure** field. Structures with time variables with multiple inputs can be generated by a Scope block having multiple input ports.

Signal Number
Specify 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.

Start time(s)
Specify the start times for the FFT analysis. The FFT analysis will be performed on the portion of the signal starting at the specified time and for the specified number of cycles.

Number of cycles
Specify the number of cycles of the selected signal to analyze for the FFT analysis.

Fundamental frequency
Specify the fundamental frequency, in hertz (Hz), as a reference frequency for the FFT analysis.

Display style

In the pull-down menu, 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 **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.

Base value

Enter a base value for the display of harmonics.

Frequency axis

In the pull-down menu, 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.

Max Frequency

Specify the maximum frequency, in hertz (Hz), for the FFT analysis.

Display

Display in the lower plot the FFT analysis results for the selected measurement.

Close

Close the FFT Analysis Tool window.

power_hysteresis

Purpose

View and edit hysteresis characteristic for saturable core of Saturable Transformer blocks

Syntax

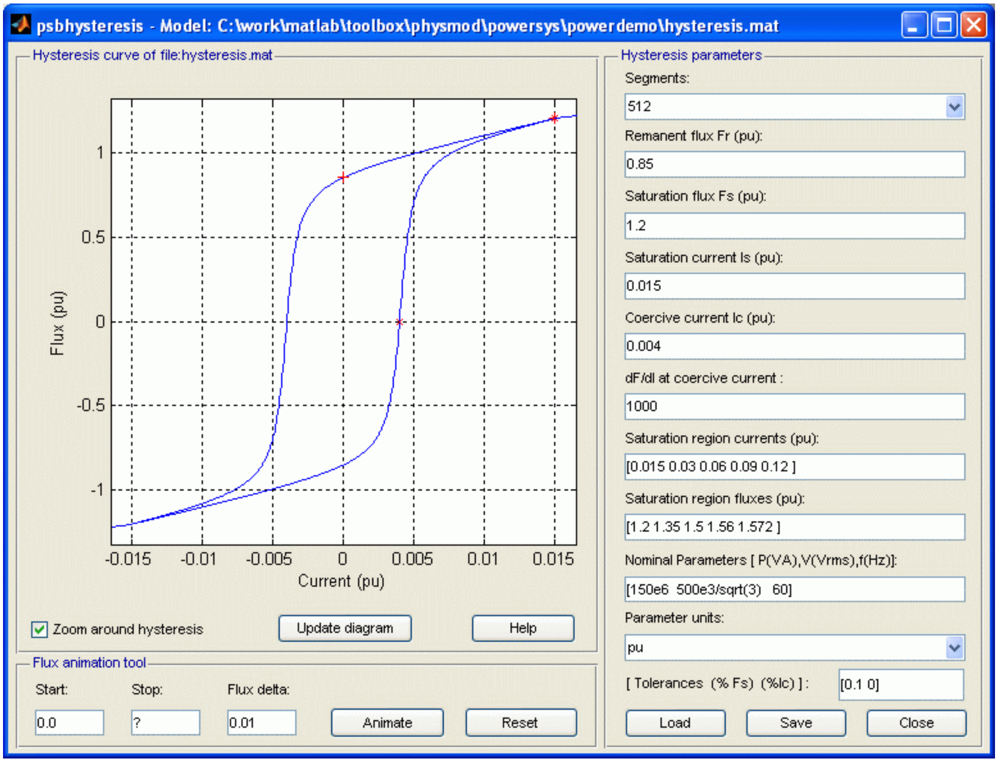
```
power_hysteresis
hparam = power_hysteresis(matfile)
```

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.



psbhysteresis - Model: C:\work\matlab\toolbox\physmod\powersys\powerdemo\hysteresis.mat

Hysteresis curve of file:hysteresis.mat

Hysteresis parameters

Segments: 512

Remanent flux Fr (pu): 0.85

Saturation flux Fs (pu): 1.2

Saturation current Is (pu): 0.015

Coercive current Ic (pu): 0.004

dF/dI at coercive current : 1000

Saturation region currents (pu): [0.015 0.03 0.06 0.09 0.12]

Saturation region fluxes (pu): [1.2 1.35 1.5 1.56 1.572]

Nominal Parameters [P(VA),V(Vrms),f(Hz)]: [150e6 500e3/sqrt(3) 60]

Parameter units: pu

[Tolerances (% Fs) (%Ic)]: [0.1 0]

☑ Zoom around hysteresis

Flux animation tool

Start: 0.0

Stop: ?

Flux delta: 0.01

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 then `TOL_I`, then evolution within these two points will follow a line segment instead of a loop.

See Also

Powergui

Purpose

Set initial state values of model built with Simulink and SimPowerSystems software

Syntax

```
[x0,states] = power_init(sys)
[x0,states] = power_init(sys,'look')
power_init(sys,'states')
power_init(sys,'ForceToZero')
power_init(sys,'ResetToDefault')
power_init(sys,'x0',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.

`power_init(sys,'`**`states`**`')` displays in a two-column format the initial state values and names of your model.

`power_init(sys,'`**`ForceToZero`**`')` sets to zero the initial states your model. It uses the **Data import/export initial state** option of the Simulink **Configuration Parameters** menu to specify the initial state values. Use the **`ResetToDefault`** option of power_init to reset the Simulink configuration parameters to its previous settings.

`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.

`power_init(sys,'`**`x0`**`',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 of the Simulink **Configuration Parameters** menu 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 thesteady state.

See Also

`power_analyze`, Powergui

Purpose

Compute and modify initial values of voltages and currents of model

Syntax

```
power_initstates('sys')
sps = initstates('sys')
```

Description

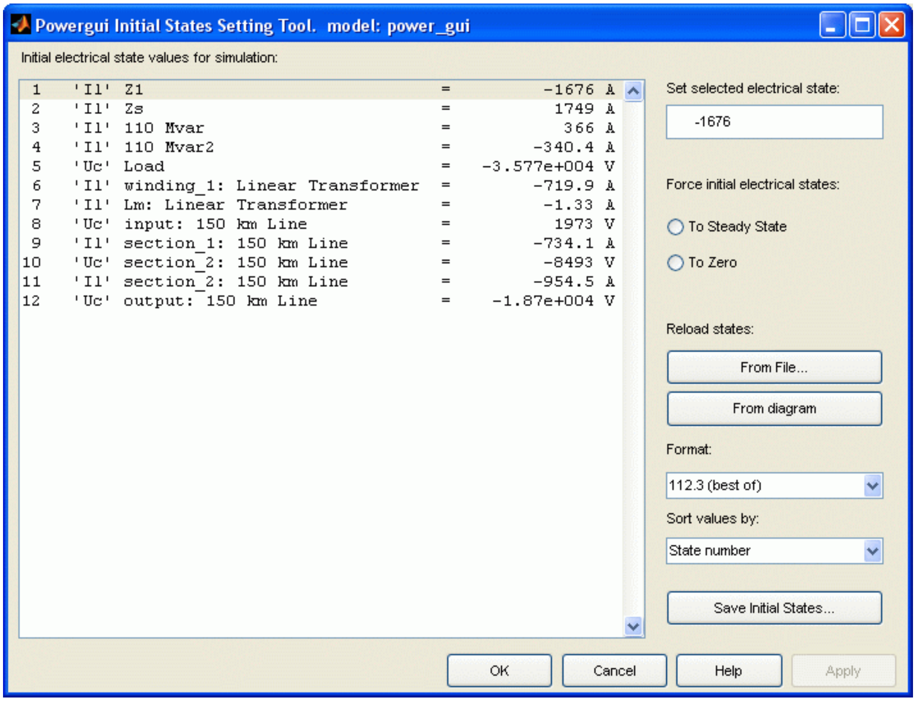
`power_initstates('sys')` opens the Initial States Setting Tool dialog box that lets you display the initial values of the electrical state variables (inductor currents and capacitor voltages) of a model, as well as modify the initial electrical states in order to start the simulation from any initial conditions. This tool can also be activated from the Powergui block dialog box by selecting **Initial States Setting**.

`sps = 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

Field	Description
`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'`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



Powergui Initial States Setting Tool. model: power_gui

Initial electrical state values for simulation:

```
 1    'Il' Z1                            =         -1676 A
 2    'Il' Zs                            =          1749 A
 3    'Il' 110 Mvar                      =           366 A
 4    'Il' 110 Mvar2                     =        -340.4 A
 5    'Uc' Load                          =    -3.577e+004 V
 6    'Il' winding_1: Linear Transformer =        -719.9 A
 7    'Il' Lm: Linear Transformer        =         -1.33 A
 8    'Uc' input: 150 km Line            =          1973 V
 9    'Il' section_1: 150 km Line        =        -734.1 A
10    'Uc' section_2: 150 km Line        =         -8493 V
11    'Il' section_2: 150 km Line        =        -954.5 A
12    'Uc' output: 150 km Line           =     -1.87e+004 V
```

Set selected electrical state: -1676

Force initial electrical states:

○ To Steady State

○ To Zero

Format: 112.3 (best of)

Sort values by: State number

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

Purpose

Compute RLC parameters of overhead transmission line from its conductor characteristics and tower geometry

Syntax

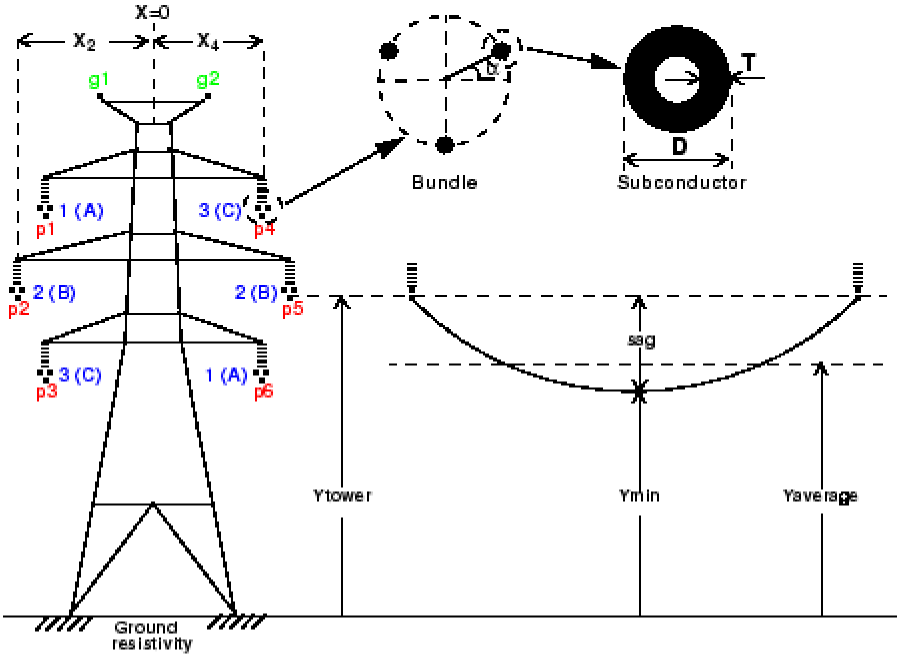
```
power_lineparam
```

Description

`power_lineparam` opens a graphical user interface (GUI) that is used to enter the line parameters and return the electrical R, L, C line parameters. This GUI can also be activated from the Powergui block dialog box by selecting **Compute RLC Line Parameters**.

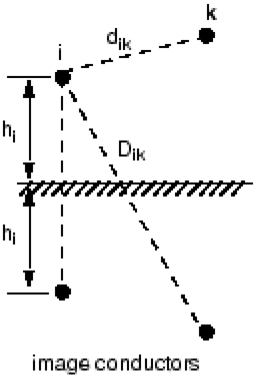
The `power_lineparam` function computes the resistance, inductance, and capacitance matrices of an arbitrary arrangement of conductors of an overhead transmission line. For a three-phase line, the symmetrical component RLC values are also computed.

The following figure shows a typical conductor arrangement for a three-phase double-circuit line. This line configuration is used as an example to illustrate the various line parameters to be entered 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]



Self and mutual resistance terms:

$$R_{ii} = R_{int} + \Delta R_{ii} \quad \Omega/\mathrm{km}$$
$$R_{ik} = \Delta R_{ik} \quad \Omega/\mathrm{km}$$

Self and mutual inductance terms:

$$L_{ii} = L_{int} + \frac{\mu_0}{2\pi} \cdot \log\frac{2h_i}{r_i} + \Delta L_{ii} \quad H/\mathrm{km}$$
$$L_{ik} = \frac{\mu_0}{2\pi} \cdot \log\frac{D_{ik}}{d_{ik}} + \Delta L_{ik} \quad H/\mathrm{km}$$

Self and mutual potential coefficient terms:

$$P_{ii} = \frac{1}{2\pi\varepsilon_o} \cdot \log\frac{2h_i}{r_i} \quad \mathrm{km/F}$$
$$P_{ik} = \frac{1}{2\pi\varepsilon_o} \cdot \log\frac{D_{ik}}{d_{ik}} \quad \mathrm{km/F}$$
$$[C] = [P]^{-1} \quad F/\mathrm{km}$$

where:

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 so called internal inductance Lint, which is dependant 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 named Configuration of a Three-Phase Double-Circuit Line on page 3-39). 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 so called "Reactance at one-foot spacing."

The GMR is the radius of the equivalent hollow conductor with zero thickness, thus producing no internal flux, giving the same self inductance. The conductor self inductance is then derived from the GMR using the following equation.

$$L_{ii} = \frac{\mu_0}{2\pi} \cdot \log\frac{2h_i}{GMR} + \Delta L_{ii} \quad H/\mathrm{km}$$

For a solid conductor (T/D=0.5), the GMR is given by

$$GMR = r \cdot e^{-\mu_r/4}$$

where: r = radius of conductor
μ_r = relative permeability of conducting material

The GMR obtained from the above 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).

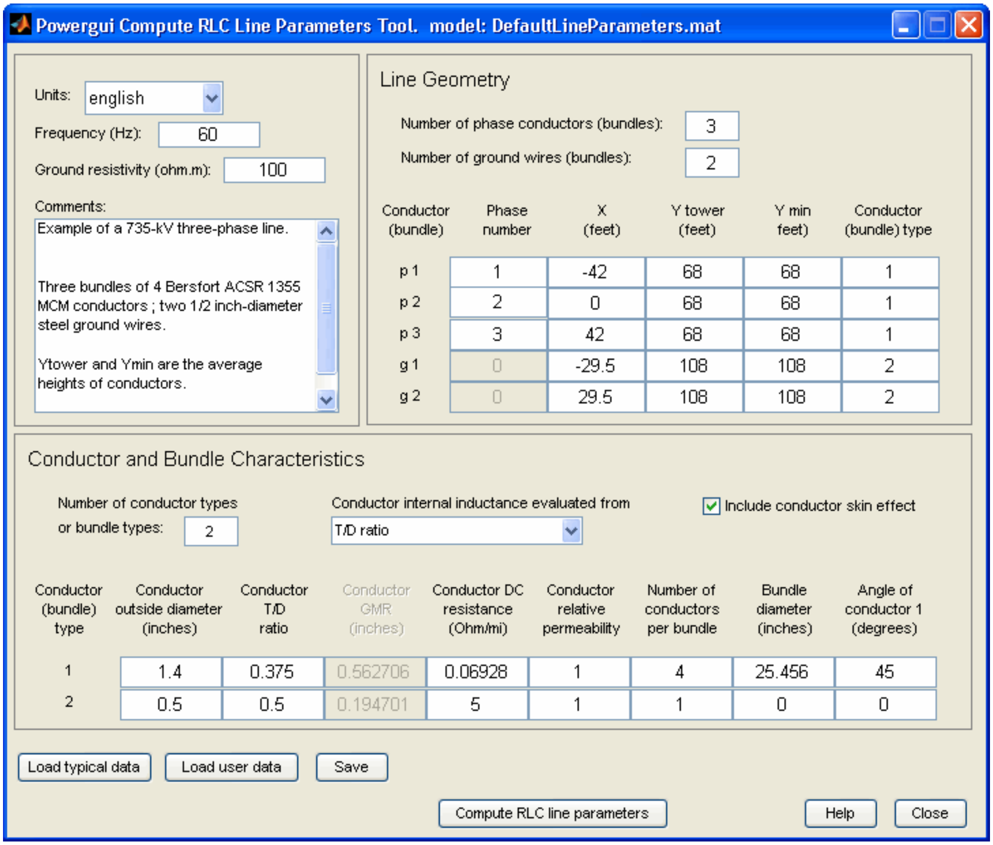
The reactance X_a at 1-foot spacing (or 1-meter spacing if metric units are used) is the positive-sequence reactance of a three-phase line having one foot (or one meter) spacing between the three phases and infinite conductor heights. The reactance at one-foot spacing (or 1-meter spacing) at frequency f is related to the GMR by the following equation

$$X_a = \omega \cdot \frac{\mu_0}{2\pi} \cdot \log\frac{1}{GMR} \quad \Omega/\text{km}$$

where: GMR = Geometric Mean Radius in feet or meters
$\omega = 2\pi.f$ 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. In fact, 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`.

When you type the `power_lineparam` command, the GUI is displayed as shown below.



Powergui Compute RLC Line Parameters Tool. model: DefaultLineParameters.mat

Units: english

Frequency (Hz): 60

Ground resistivity (ohm.m): 100

Comments:

Example of a 735-kV three-phase line.

Three bundles of 4 Bersfort ACSR 1355 MCM conductors ; two 1/2 inch-diameter steel ground wires.

Ytower and Ymin are the average heights of conductors.

Line Geometry

Number of phase conductors (bundles): 3

Number of ground wires (bundles): 2

Conductor (bundle)	Phase number	X (feet)	Y tower (feet)	Y min feet)	Conductor (bundle) type
p 1	1	-42	68	68	1
p 2	2	0	68	68	1
p 3	3	42	68	68	1
g 1	0	-29.5	108	108	2
g 2	0	29.5	108	108	2

Conductor and Bundle Characteristics

Number of conductor types or bundle types: 2

Conductor internal inductance evaluated from: T/D ratio

☑ Include conductor skin effect

Conductor (bundle) type	Conductor outside diameter (inches)	Conductor T/D ratio	Conductor GMR (inches)	Conductor DC resistance (Ohm/mi)	Conductor relative permeability	Number of conductors per bundle	Bundle diameter (inches)	Angle of conductor 1 (degrees)
1	1.4	0.375	0.562706	0.06928	1	4	25.456	45
2	0.5	0.5	0.194701	5	1	1	0	0

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)

General Parameters

Units

In the pull-down menu, 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 be used to evaluate RLC parameters.

Ground resistivity

Specify the ground resistivity in ohm.meters. A zero value (perfectly conducting ground) is allowed.

Comments

Use this window to type comments that you want to save with the line parameters, for example, voltage level, conductor types and characteristics, etc.

Conductor and Bundle Characteristics

Number of conductor types or bundle types

Specify the number of conductor types (single conductor or bundle of subconductors) to be used. 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 above, 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. More than two types will be necessary for several lines in the same corridor, DC bipolar lines or distribution feeders where neutral and sheaths of TV and telephone cables are represented.

In the table of conductor types, two rows are visible at a time. If more than two conductor types are specified, a scroll bar appears at the right side of the table to give you access to the different rows of the table.

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, where D is the conductor diameter and T is the thickness of the conducting material (see the figure named Configuration of a Three-Phase Double-Circuit Line on page 3-39). 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 is used to evaluate the internal inductance. When the conductor inductance is evaluated from the GMR, the specified frequency does not affect the conductor inductance. You have therefore to 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 checked, 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 is used to evaluate 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 or bundle 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, where 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 checked. 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 explained below.

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 checked.

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 together 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.

Line Geometry

Number of phase conductors (bundles)

Specify the number of phase conductors (single conductors or bundles of subconductors) to be used. This parameter, together with the **Number of ground wires (bundles)** parameter**,** determines the number of rows of the table of conductors.

Number of ground wires (bundles)

Specify the number of ground wires (single conductors or bundles of subconductors) to be used. Ground wires are usually not bundled. This parameter, together with the **Number of phase conductors (bundles)** parameter, determines the number of rows of the table of conductors.

In the table of conductors, five rows are visible at a time. If more than five conductors (phase conductors plus ground wires) are specified, a scroll bar appears at the right side of the table to give you access to the different rows of the table.

Conductor (bundle)

Lists the conductor or bundle identifiers. Phase conductors are identified p1, p2,..., pn. Ground wires are identified g1,g2,..., gn.

Phase number

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 will be considered as a single equivalent conductor in the R L 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 named Configuration of a Three-Phase Double-Circuit Line on page 3-39, 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 would rather 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, 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 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 connect them to the ground by yourself.

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 named Configuration of a Three-Phase Double-Circuit Line on page 3-39) is given by

$$Y_{average} = Y_{min} + \frac{sag}{3} = \frac{2Y_{min} + Y_{tower}}{3}$$

where: 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.

Conductor (bundle) type
Specify one of the conductor or bundle type numbers listed in the first column of the table of conductor characteristics.

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

The frequency and ground resistivity used for evaluation of the RLC matrices are first displayed. Then come the computed RLC parameters.

Note The R, L, C parameters are always displayed respectively in ohms/km, henries/km, and farads/km, even if the english units have been used to 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: 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.

The **Display RLC Values** window also allows you to download parameters into your workspace and/or into your transmission line models.

Send RLC parameters to workspace
Sends the three RLC matrices as well as the symmetrical component parameters in 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 have 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
Clicking this button 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.

Load/Save

You can save and reload your line data. You can also load typical line data provided with SimPowerSystems software.

Load typical data

Opens a browser window where you can select examples of line configurations provided with SimPowerSystems software. Select the desired `.mat` file.

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.

Typical Line Data

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.

Examples

The following two examples illustrate the inputs and outputs of the `power_lineparam` GUI.

Example 1

The first case is an academic example. It 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 $\rho_c = 28.3\ 10^{-9}\ \Omega.\text{m}$ at 20° C) having a 15-mm diameter.

The DC resistance per km of each conductors is

$$r = \frac{\rho_c \cdot l}{A} = \frac{28.3 \times 10^{-9} \times 1000}{\pi \cdot \left(\frac{15 \times 10^{-3}}{2}\right)^2} = 0.1601\ \Omega/\text{km}$$

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

$$GMR = r \cdot e^{-\mu_r/4} = \frac{1.5}{2} e^{-1/4} = 0.5841\ \text{cm}$$

The self and mutual inductances are computed as follows. The ΔL correction terms are ignored because ground resistivity is zero.

$$L_{11} = L_{22} = \frac{\mu_0}{2\pi} \cdot \log\frac{2h_i}{GMR} = 2\times 10^{-4}\log\frac{2\times 8}{0.5841\times 10^{-2}} = 1.583\times 10^{-3}\ H/\mathrm{km}$$

$$L_{12} = L_{21} = \frac{\mu_0}{2\pi} \cdot \log\frac{D_{12}}{d_{12}} = 2\times 10^{-4}\log\frac{\sqrt{16^2+1}}{1} = 0.5549\times 10^{-3}\ H/\mathrm{km}$$

$$L = \begin{bmatrix} L_{11} & L_{12} \\ L_{21} & L_{22} \end{bmatrix} = \begin{bmatrix} 1.583\times 10^{-3} & 0.5549\times 10^{-3} \\ 0.5549\times 10^{-3} & 1.583\times 10^{-3} \end{bmatrix} \mathrm{H/km}$$

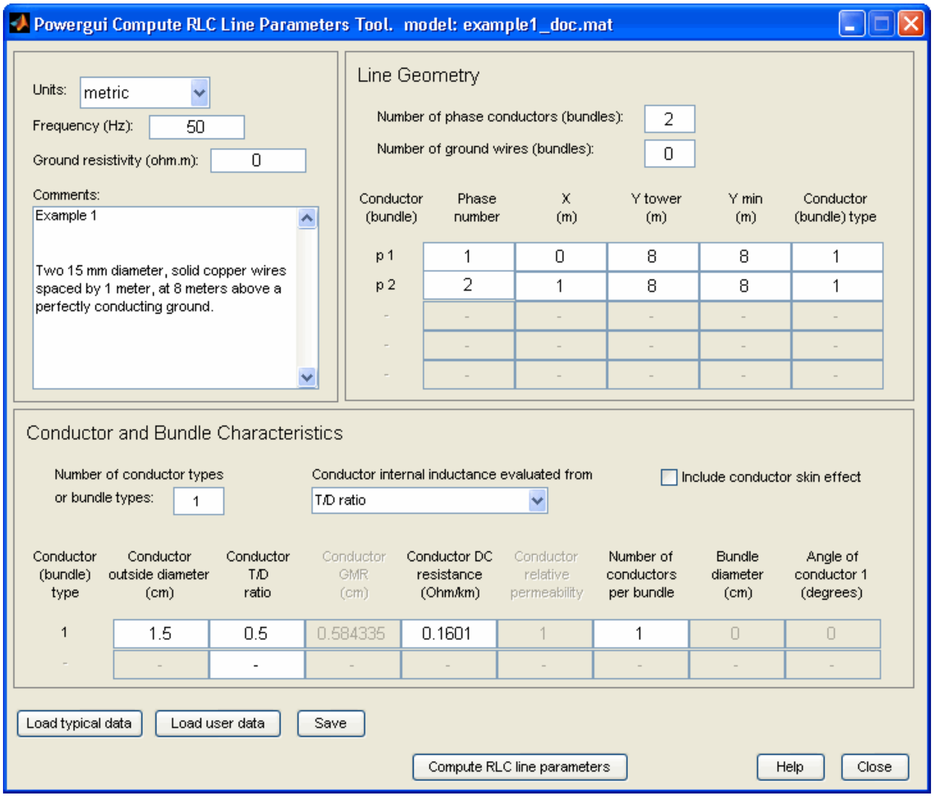
The self and mutual capacitances are computed as follows:

$$P_{11} = P_{22} = \frac{1}{2\pi\varepsilon_o}\log\frac{2h}{r_i} = 1.7975\times 10^{7}\log\frac{2\times 8}{0.75\times 10^{-2}} = 1.3779\times 10^{8}\ km/F$$

$$P_{12} = P_{21} = \frac{1}{2\pi\varepsilon_o}\log\frac{D_{12}}{d_{12}} = 1.7975\times 10^{7}\log\frac{\sqrt{16^2+1}}{1} = 4.9872\times 10^{7}\ km/F$$

$$C = \begin{bmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{bmatrix}^{-1} = \begin{bmatrix} 8.352\times 10^{-9} & -3.023\times 10^{-9} \\ -3.023\times 10^{-9} & 8.352\times 10^{-9} \end{bmatrix} \mathrm{F/km}$$

Enter the line parameters in the `power_lineparam` GUI as shown below. Make sure that the specified frequency is 50 Hz and select `T/D ratio` for computing the line inductance. Do not check **Include conductor skin effect**.



Powergui Compute RLC Line Parameters Tool. model: example1_doc.mat

Units: metric

Frequency (Hz): 50

Ground resistivity (ohm.m): 0

Comments:

Example 1

Two 15 mm diameter, solid copper wires spaced by 1 meter, at 8 meters above a perfectly conducting ground.

Line Geometry

Number of phase conductors (bundles): 2

Number of ground wires (bundles): 0

Conductor (bundle)	Phase number	X (m)	Y tower (m)	Y min (m)	Conductor (bundle) type
p 1	1	0	8	8	1
p 2	2	1	8	8	1
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-

Conductor and Bundle Characteristics

Number of conductor types or bundle types: 1

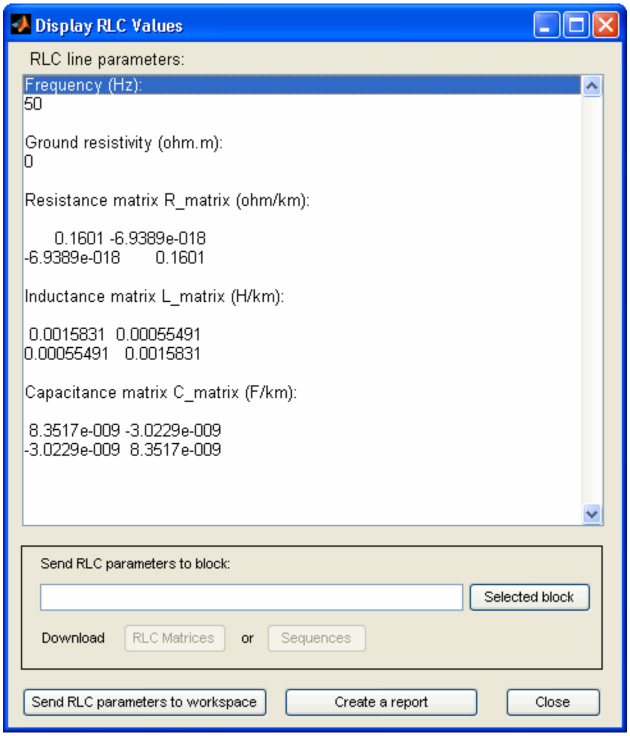
Conductor internal inductance evaluated from: T/D ratio

☐ Include conductor skin effect

Conductor (bundle) type	Conductor outside diameter (cm)	Conductor T/D ratio	Conductor GMR (cm)	Conductor DC resistance (Ohm/km)	Conductor relative permeability	Number of conductors per bundle	Bundle diameter (cm)	Angle of conductor 1 (degrees)
1	1.5	0.5	0.584335	0.1601	1	1	0	0
-	-	-	-	-	-	-	-	-

Notice that the displayed GMR value (0.58433 cm) is the GMR value that should be used 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 non uniform current distribution. In our case, the line parameters will be 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.



RLC line parameters:

```
Frequency (Hz):
50

Ground resistivity (ohm.m):
0

Resistance matrix R_matrix (ohm/km):

     0.1601 -6.9389e-018
-6.9389e-018       0.1601

Inductance matrix L_matrix (H/km):

 0.0015831  0.00055491
0.00055491   0.0015831

Capacitance matrix C_matrix (F/km):

 8.3517e-009 -3.0229e-009
-3.0229e-009  8.3517e-009
```

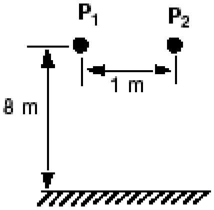
The PI model for a 1-km line is obtained from the RLC matrices. The PI RLC values are deduced from the self and mutual terms of the RLC matrices, as explained below. Subscript s and m designate the self and mutual terms in the RLC matrices.

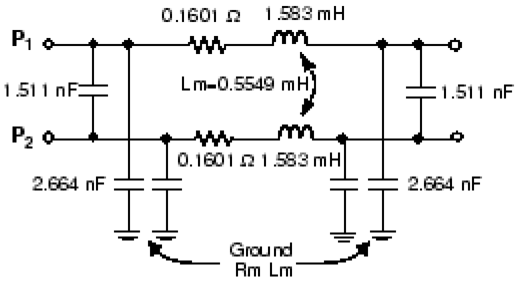
$R_{p1}=R_{p2}=R_s=0.1601$ Ω/km; $L_{p1}=L_{p2}=L_s=1.583$ mH/km

$C_{p1}=C_{p2}=C_s+C_m=8.352-3.023=5.329$ nF/km

(2.664 nF at each end of PI section)

$C_{p1p2}=-C_m=3.023$ nF/km (1.511 nF at each end of PI section)





You can also vary the ground resistivity and the frequency and 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 table below. 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 (•.m)	Conductor Rs-Rm (•/km)	Ground Rm (•/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 a humid soil and 10 000 Ω.m for a 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 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 .m; with Conductor Skin Effect)

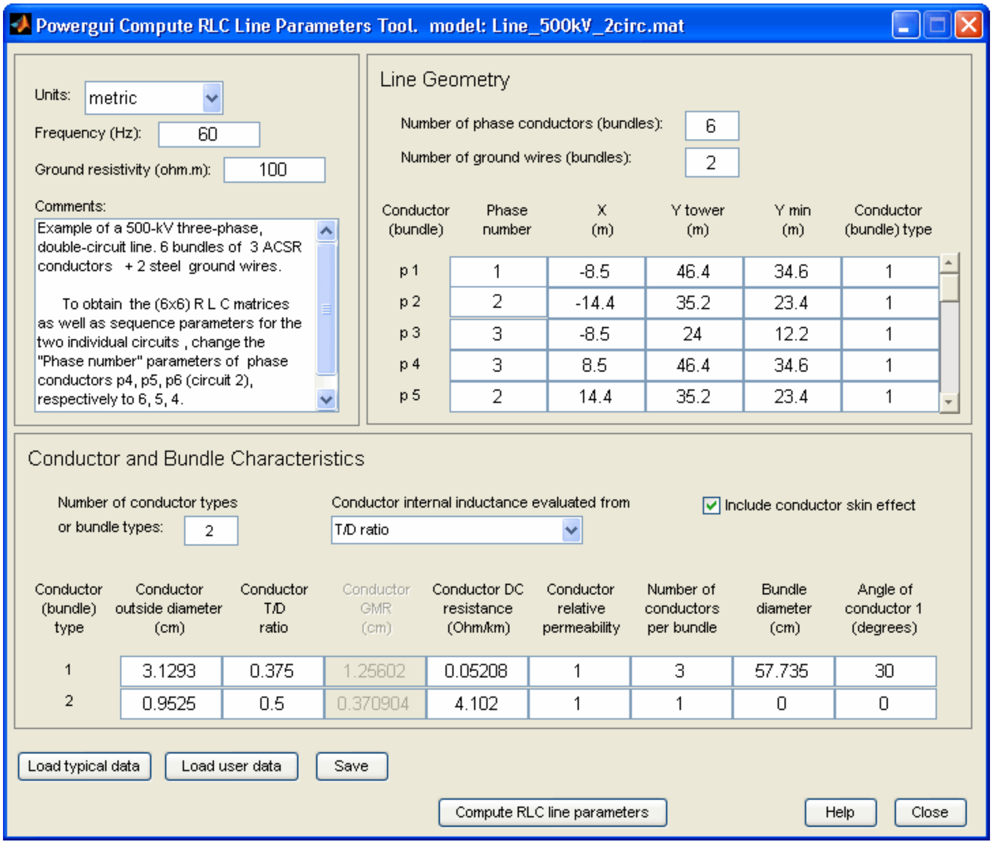
Frequency (Hz)	Conductor Rs-Rm (•/km)	Ground Rm (•/km)	Conductor Ls-Lm (mH/km)	Ground Lm (mH/km)
0.05	0.1601	4.93e-5	1.029	2.058
50	0.1606	0.04844	1.029	1.370
500	0.2012	0.4666	1.022	1.147
5000	0.5442	4.198	0.9944	0.9351
50 000	1.641	32.14	0.9836	0.7559

This table shows that frequency has a very large impact on ground resistance and 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 thus increasing its resistance. As ground current travels at a lower depth at high frequencies, this also means that 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%.

Example 2

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 `power_lineparam` GUI is shown below:



Powergui Compute RLC Line Parameters Tool. model: Line_500kV_2circ.mat

Units: metric

Frequency (Hz): 60

Ground resistivity (ohm.m): 100

Comments:

Example of a 500-kV three-phase, double-circuit line. 6 bundles of 3 ACSR conductors + 2 steel ground wires.

To obtain the (6x6) R L C matrices as well as sequence parameters for the two individual circuits , change the "Phase number" parameters of phase conductors p4, p5, p6 (circuit 2), respectively to 6, 5, 4.

Line Geometry

Number of phase conductors (bundles): 6

Number of ground wires (bundles): 2

Conductor (bundle)	Phase number	X (m)	Y tower (m)	Y min (m)	Conductor (bundle) type
p 1	1	-8.5	46.4	34.6	1
p 2	2	-14.4	35.2	23.4	1
p 3	3	-8.5	24	12.2	1
p 4	3	8.5	46.4	34.6	1
p 5	2	14.4	35.2	23.4	1

Conductor and Bundle Characteristics

Number of conductor types or bundle types: 2

Conductor internal inductance evaluated from: T/D ratio

☑ Include conductor skin effect

Conductor (bundle) type	Conductor outside diameter (cm)	Conductor T/D ratio	Conductor GMR (cm)	Conductor DC resistance (Ohm/km)	Conductor relative permeability	Number of conductors per bundle	Bundle diameter (cm)	Angle of conductor 1 (degrees)
1	3.1293	0.375	1.25602	0.05208	1	3	57.735	30
2	0.9525	0.5	0.370904	4.102	1	1	0	0

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 named Configuration of a Three-Phase Double-Circuit Line on page 3-39.

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 RLC 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 listed below:

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, PI Section Line, Three-Phase PI Section Line

power_loadflow

Purpose

Perform machine load flow and initialization for models containing three-phase machines and dynamic load blocks

Syntax

```
power_loadflow('sys')
lfparam = power_loadflow('sys')
lf = power_loadflow('sys',lfparam)
lf = power_loadflow('sys','default')
```

Description

`power_loadflow('sys')` opens the Machine Load Flow Tool dialog box to perform machine load flow and initialization. This tool can also be activated from the Powergui block dialog box by selecting **Load Flow and Machine Initialization**.

`lfparam = power_loadflow('sys')` returns the most recent load flow parameter values of a model. `lfparam` can be used as a template variable to compute new machine load flow.

`lf = power_loadflow('sys',lfparam)` computes the machine load flow using the load flow parameters given in `lfparam`. The MathWorks recommends that you create an instance of `lfparam` using `lfparam = power_loadflow('sys')`, and edit the load flow parameter values based on this template.

`lf = power_loadflow('sys','default')` computes the machine load flow using the default load flow parameter values. The default load flow parameters are returned by `lfparam = power_loadflow('sys')`.

Load Flow Parameters

Load flow 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`

Field	Description
	`Machine'`, `'Synchronous Machine'`, and/or `'Three Phase Dynamic Load'`) defining the mask type of the machine and load blocks
`set`	Structure with variable fields defining the load flow parameters specific to each machine or dynamic load (Bus Type, Terminal Voltage, Active Power, Reactive Power, Mechanical Power) parameter defining the desired load flow frequency, in hertz. The frequency is specified only in the first element of the load flow parameters structure.
`LoadFlowFrequency`	Parameter defining the desired load flow frequency, in hertz. The frequency is specified only in the first element of the load flow parameters structure.
`InitialConditions`	String value defining the load flow initial condition type (`'Auto'`,`'Start from previous solution'`). The initial condition status is specified only in the first element of load flow parameter structure.
`DisplayWarnings`	String value (`'on'`,`'off'`) controlling the display of warning messages during the load flow computation.

For example, you obtain the load flow parameters for the `power_machines` demo by doing:

```
lfparam = power_loadflow('power_machines');
lfparam(1)
                 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 `lfparam = power_loadflow('sys')` command to create the load flow 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 load flow parameter values, `lfparam(1).LoadFlowFrequency` is where you defined the load flow frequency, and `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 blocks, `lfparam` returns an empty variable.

Load Flow Parameters of Asynchronous Machine Block

For the Asynchronous Machine blocks, you can only specify the desired mechanical power of the machine. The `set` field is a structure with the field:

Field	Description
`MechanicalPower`	The desired mechanical power, in watts, of the machine

For example, the mechanical power of the Asynchronous Machine in the `power_machines` demo is given by:

```
lfparam = power_loadflow('power_machines');
lfparam(2).set
ans =
    MechanicalPower: 1492000
```

Load Flow Parameters of Synchronous Machine Blocks

For the Simplified Synchronous Machine and Synchronous Machine blocks, the `set` field is a structure with the fields:

Field	Description
`BusType`	A string (`'P & V generator'`, `'P & Q generator'`, or `'Swing bus'`) defining the desired bus type of the machine
`TerminalVoltage`	Parameter defining the desired terminal voltage, in volts rms
`ActivePower`	Parameter defining the desired active power, in watts
`ReactivePower`	Parameter defining the desired reactive power, in vars
`PhaseUan`	Parameter defining the desired phase voltage, in degrees, of the Uan voltage

For example, the load flow parameter values of the Synchronous Machine block in the `power_machines` demo are given by:

```
lfparam = power_loadflow('power_machines');
lfparam(1).set
ans =
            BusType: 'P & V generator'
    TerminalVoltage: 2400
        ActivePower: 0
      ReactivePower: 0
           PhaseUan: 0
```

Load Flow Parameters of Three-Phase Dynamic Load Block

For the Three-Phase Dynamic Load blocks, the `set` field is a structure with the fields:

Field	Description
`ActivePower`	Parameter defining the desired active power, in watts
`ReactivePower`	Parameter defining the desired reactive power, in vars

Load Flow Solution

The load flow results are organized in a structure with the fields:

Field	Description
`status`	The load flow status returns `1` when a solution is found, and returns `0` when no solution is found. Note that the load flow status is given only in the first element of the load flow 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

Field	Description
`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
`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 pu 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 pu 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 pu 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 pu based on the nominal power of the machine

Field	Description
`Pmec`	The mechanical power of the machine is returned in a 1-by-2 vector, representing the mechanical power in watts and in pu 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 pu 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.
`Slip`	The computed slip of Asynchronous Machine blocks. This parameter is set to an empty value for the other types of machines and loads.

Example

The `power_machines` demo 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 want to change its mechanical power to -1.0 MW (generator mode) and perform a new machine load flow to initialize the machine initial currents and start the simulation in steady-state:

```
lfparam = power_loadflow('power_machines');
lfparam(2).set
ans =
```

```
    MechanicalPower: 1492000
lfparam(2).set.MechanicalPower = -1e6;
lf = power_loadflow('power_machines',lfparam);
lf(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: []
lf(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]
```

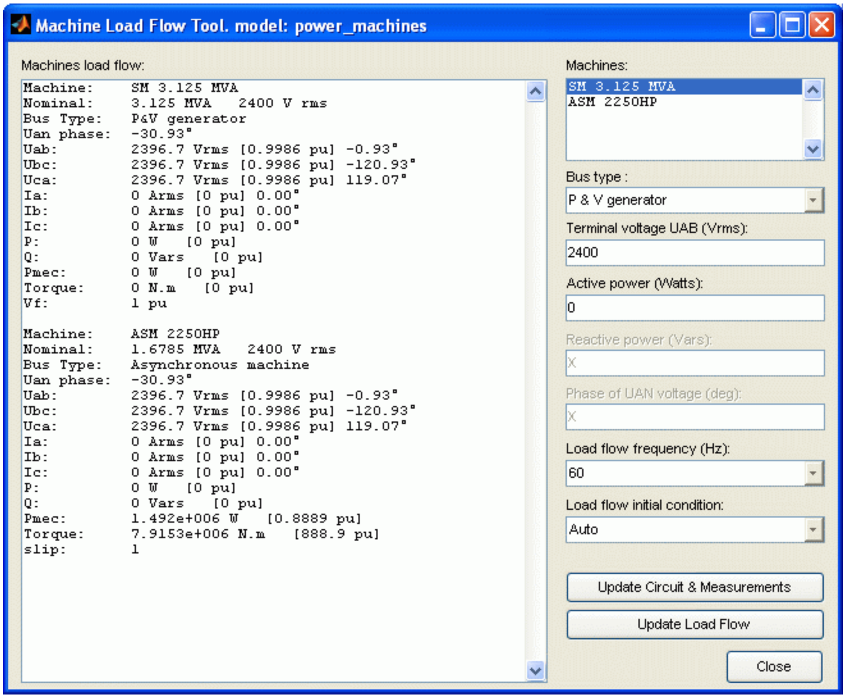
```
     Pmec: [-1000000 -0.5958]
   Torque: [-5.2844e+003 -0.5934]
       Vf: []
     Slip: -0.0039
```

First, note that `lf(1).status` is set to `1`, meaning that `power_loadflow` has found a solution for the given load flow parameters.

Take a look a the model and note that the mechanical torque reference input for the Asynchronous machine 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.

Dialog Box

An alternative way to compute machine load flow is to specify the load flow parameters using the Machine Load Flow Tool dialog box. This tool can be activated by entering the `power_loadflow('sys')` command, or from the Powergui block dialog box by selecting **Load Flow and Machine Initialization**.



Machines load flow:

```
Machine:     SM 3.125 MVA
Nominal:     3.125 MVA   2400 V rms
Bus Type:    P&V generator
Uan phase:   -30.93°
Uab:         2396.7 Vrms [0.9986 pu] -0.93°
Ubc:         2396.7 Vrms [0.9986 pu] -120.93°
Uca:         2396.7 Vrms [0.9986 pu] 119.07°
Ia:          0 Arms [0 pu] 0.00°
Ib:          0 Arms [0 pu] 0.00°
Ic:          0 Arms [0 pu] 0.00°
P:           0 W   [0 pu]
Q:           0 Vars   [0 pu]
Pmec:        0 W   [0 pu]
Torque:      0 N.m   [0 pu]
Vf:          1 pu

Machine:     ASM 2250HP
Nominal:     1.6785 MVA   2400 V rms
Bus Type:    Asynchronous machine
Uan phase:   -30.93°
Uab:         2396.7 Vrms [0.9986 pu] -0.93°
Ubc:         2396.7 Vrms [0.9986 pu] -120.93°
Uca:         2396.7 Vrms [0.9986 pu] 119.07°
Ia:          0 Arms [0 pu] 0.00°
Ib:          0 Arms [0 pu] 0.00°
Ic:          0 Arms [0 pu] 0.00°
P:           0 W   [0 pu]
Q:           0 Vars   [0 pu]
Pmec:        1.492e+006 W   [0.8889 pu]
Torque:      7.9153e+006 N.m   [888.9 pu]
slip:        1
```

Machines:
SM 3.125 MVA
ASM 2250HP

Bus type : P & V generator

Terminal voltage UAB (Vrms): 2400

Active power (Watts): 0

Reactive power (Vars): X

Phase of UAN voltage (deg): X

Load flow frequency (Hz): 60

Load flow initial condition: Auto

Machines

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 in order to set its parameters for the load flow.

Bus type

If **Bus type** is set to `P&V Generator`, you can set the desired terminal voltage and active power of the machine. If **Bus type** is set to `PQ generator`, you can set the desired active and reactive powers. If **Bus type** is set to `Swing Bus`, you can set the desired 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 only have to enter the desired mechanical power delivered by the machine. If you select a Three-Phase Dynamic Load block, you have to 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 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.

Load flow frequency

Specify the frequency to be used in the load flow calculations (normally 60 Hz or 50 Hz).

Load flow initial condition

Normally, you should keep the default setting **Auto** to let the load flow automatically adjust the initial conditions before starting iterations. If you select **Start from previous solution**, the load flow 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 Circuit & Measurements

Update the list of machines, voltage and current phasors, as well as the powers in the load flow window if you have made a change in your model while the load flow window is open. The new voltages and powers displayed in the load flow window are computed by using the machine currents obtained from the last load flow (the three currents stored in the **Initial conditions** parameter of the machine blocks).

Update Load Flow

Executes the load flow calculations for the given load flow parameters.

power_ltiview

Purpose

Create state-space object of model for use with LTI Viewer tools

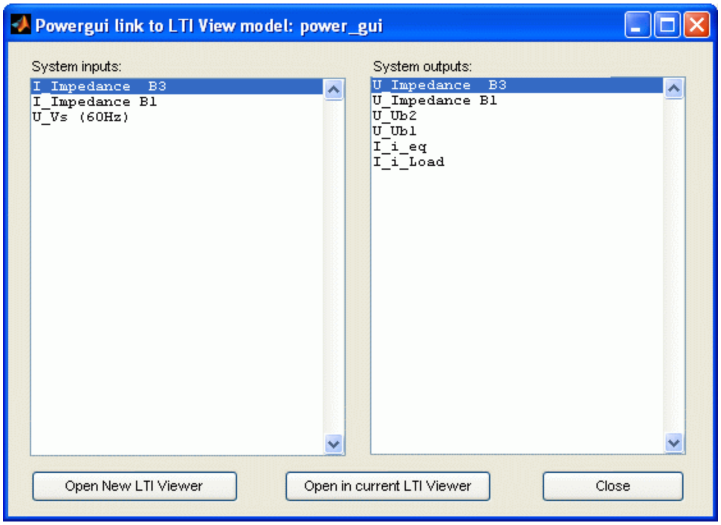
Syntax

```
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 LTI Viewer tools. The command opens the LTI View dialog box. This tool can also be activated from the Powergui block dialog box by selecting **Use LTI Viewer**. The LTI Viewer functionality is provided with Control System Toolbox software.

Dialog Box



Powergui link to LTI View model: power_gui

System inputs:

I_Impedance B3
I_Impedance B1
U_Vs (60Hz)

System outputs:

U_Impedance B3
U_Impedance B1
U_Ub2
U_Ub1
I_i_eq
I_i_Load

System inputs

Lists the inputs of the state-space model of your circuit. Select the inputs to be used by the LTI Viewer.

System outputs

Lists the outputs of the state-space model of your circuit. Select the outputs to be used by the LTI Viewer.

Open New LTI Viewer

Generates the state-space model of the circuit and opens the LTI Viewer for the selected system inputs and outputs.

Open in current LTI Viewer

Generates the state-space model of the circuit for the selected system inputs and outputs in the current LTI Viewer.

power_report

Purpose

Generate report of steady state variables, initial states, and machine load flow for model

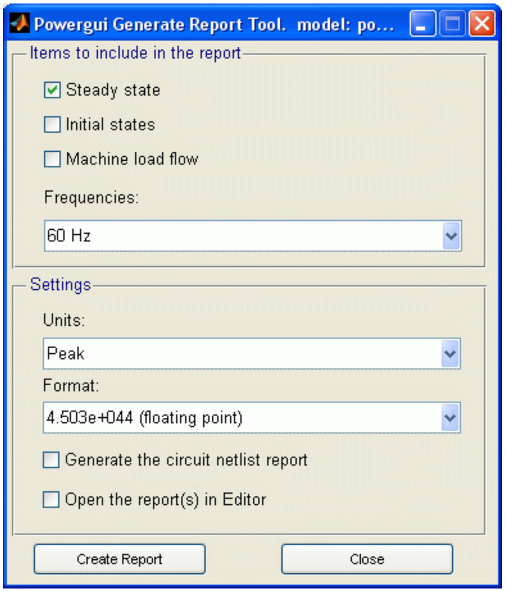
Syntax

```
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

☑ Steady state

☐ Initial states

☐ Machine load flow

Frequencies: 60 Hz

Settings

Units: Peak

Format: 4.503e+044 (floating point)

☐ Generate the circuit netlist report

☐ Open the report(s) in Editor

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

Purpose Compute state-space model of linear electrical circuit

Synopsis 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

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx + Du \end{aligned}$$

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 blocks of the **powerlib** library, `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 block modeling interface and to access options that are not available through **powerlib**. 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 "Example" on page 3-91). 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 **powerlib_models** library (see Improving Simulation Performance).

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:

- `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 **powerlib_models/Continuous** 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 "Example" on page 3-91.

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 **powerlib_models** 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)
`Rm`	Vector of the nphase modal series resistances (Ω/km)

Parameter	Description
`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

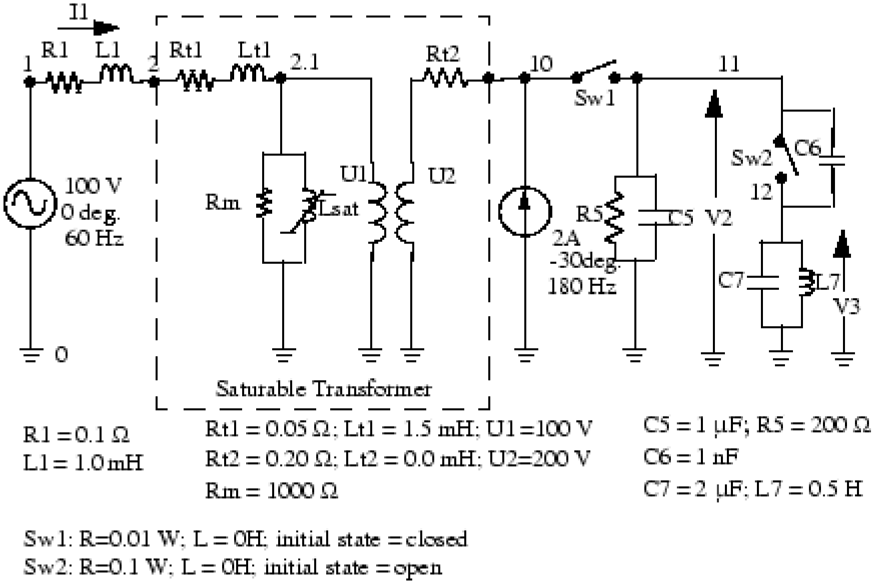
2. The currents of all switches that have a null inductance (Lon = 0), if any, in the same order as the voltages above

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.

Example

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.



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=0 Hz :
y_u1= 0Volts
y_u2= 0Volts
y_i3= 0Amperes
y_i4= 0Amperes
y_u5= 0Volts
y_i6= 0Amperes
y_u7= 0Volts
y_u8= 0Volts
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.

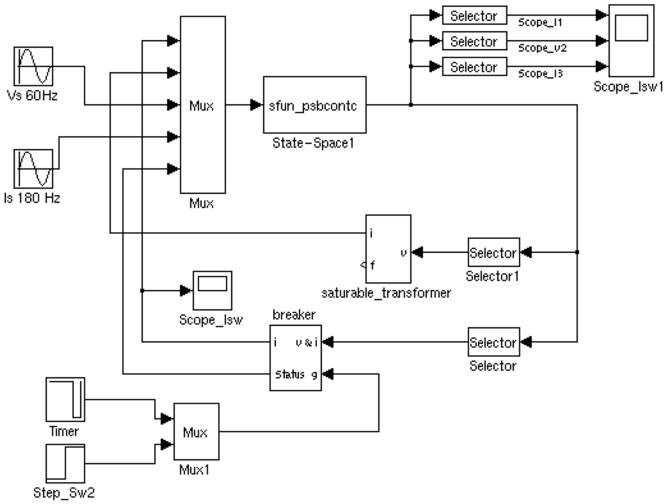
```
x0
x0 =
 2.3302
 14.111
 14.07
 3.1391e-05
```

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.

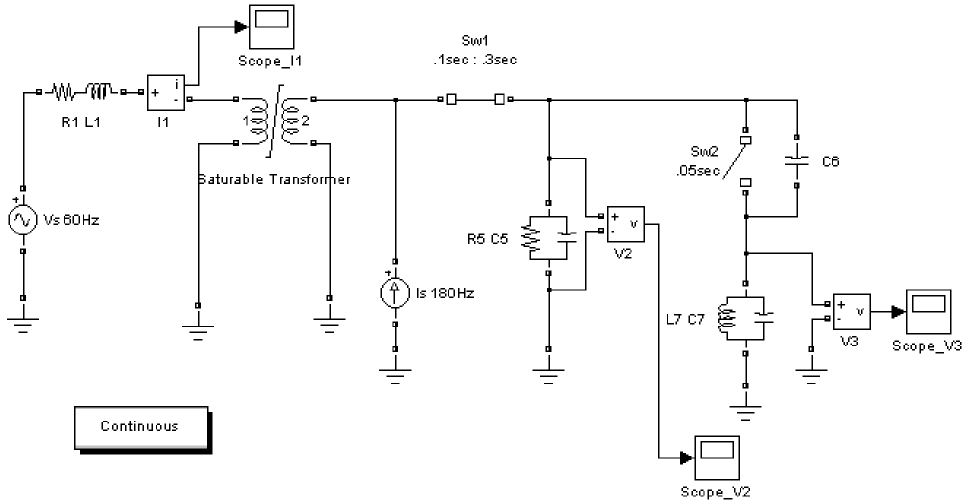
```
x0sw
x0sw =
   0.16155
   0
```

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 **powerlib_models/Continuous** 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 **powerlib** library to build your circuit, the same Simulink system is generated automatically by the `power_analyze` command. The **powerlib** version of this system is also available in the `power_circ2ss_sps` model and is shown below.



power_circ2ss_slk.mdl Example Diagram



power_circ2ss_sps.mdl Example Diagram

See Also

`power_analyze`

power_steadystate

Purpose 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**.

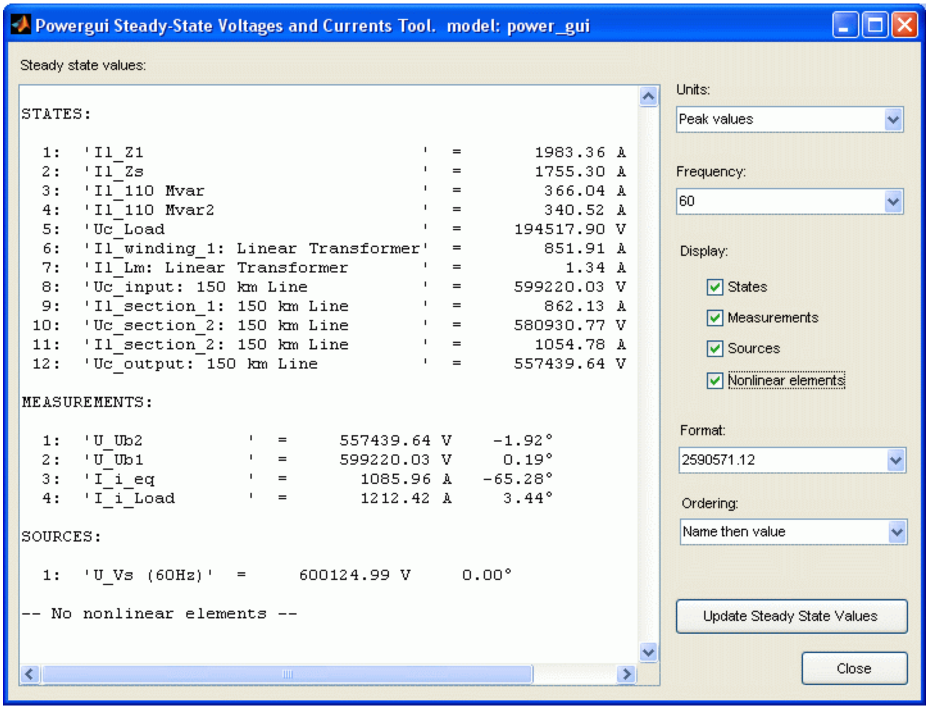
`sps = power_steadystate('sys')` returns a structure with the fields:

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
`Yss_Measurements`	The steady-state values of measurement blocks of the model
`Sources`	The names of the electrical source blocks of the model

Field	Description
`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:

```
STATES:

  1:  'Il_Z1                          '  =       1983.36 A
  2:  'Il_Zs                          '  =       1755.30 A
  3:  'Il_110 Mvar                    '  =        366.04 A
  4:  'Il_110 Mvar2                   '  =        340.52 A
  5:  'Uc_Load                        '  =     194517.90 V
  6:  'Il_winding_1: Linear Transformer'  =        851.91 A
  7:  'Il_Lm: Linear Transformer      '  =          1.34 A
  8:  'Uc_input: 150 km Line          '  =     599220.03 V
  9:  'Il_section_1: 150 km Line      '  =        862.13 A
 10:  'Uc_section_2: 150 km Line      '  =     580930.77 V
 11:  'Il_section_2: 150 km Line      '  =       1054.78 A
 12:  'Uc_output: 150 km Line         '  =     557439.64 V

MEASUREMENTS:

  1:  'U_Ub2           '  =     557439.64 V    -1.92°
  2:  'U_Ub1           '  =     599220.03 V     0.19°
  3:  'I_i_eq          '  =       1085.96 A   -65.28°
  4:  'I_i_Load        '  =       1212.42 A     3.44°

SOURCES:

  1:  'U_Vs (60Hz)'  =     600124.99 V     0.00°

-- No nonlinear elements --
```

Units: Peak values

Frequency: 60

Display:

☑ States

☑ Measurements

☑ Sources

☑ Nonlinear elements

Format: 2590571.12

Ordering: Name then value

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.

Purpose

Compute impedance versus frequency of Impedance Measurement blocks of model

Syntax

```
power_zmeter('sys')
Zdata = power_zmeter('sys',freq)
```

Description

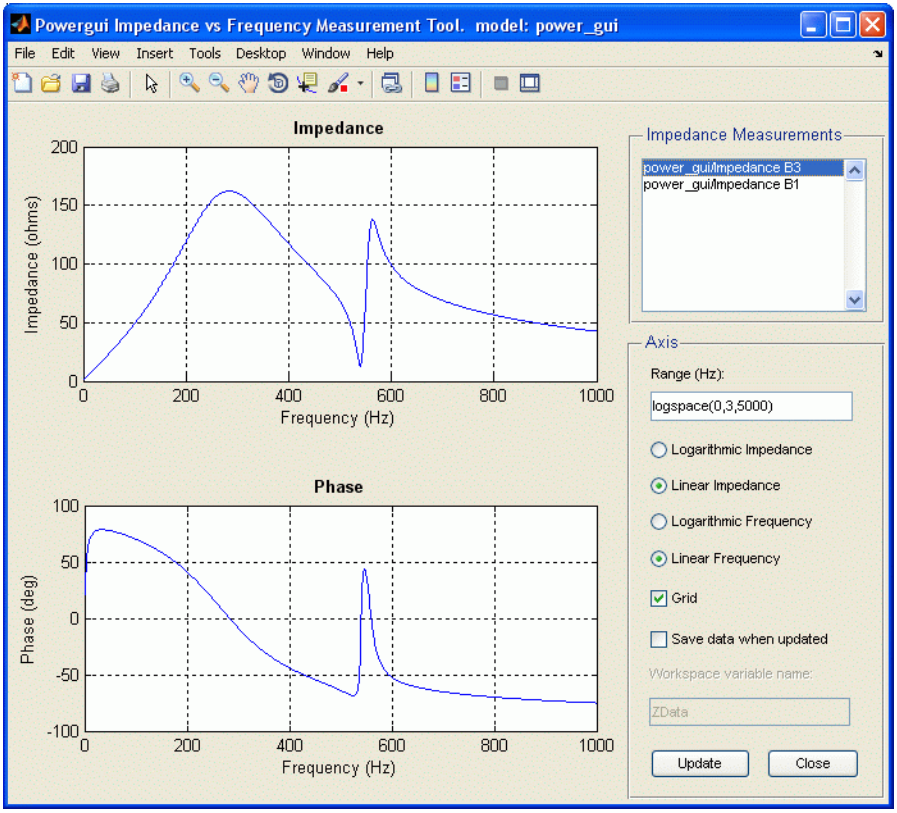
`power_zmeter('sys')` opens the Impedance vs Frequency Measurement Tool dialog box to display the impedance versus frequency defined by the Impedance Measurement blocks. This tool can also be activated from the Powergui block dialog box by selecting **Impedance vs Frequency Measurement**.

`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



power_gui/Impedance B3
power_gui/Impedance B1

Range (Hz): logspace(0,3,5000)

○ Logarithmic Impedance
● Linear Impedance
○ Logarithmic Frequency
● Linear Frequency
☑ Grid
☐ Save data when updated

Workspace variable name: ZData

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

This appendix describes the two units of measurement used in this manual.

- “International System of Units” on page A-2
- “Per Unit” on page A-3

International System of Units

This guide 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
Torque	newton-meter	N.m
Inertia	kilogram-meter^2	kg.m^2
Friction factor	newton-meter-second	N.m.s

Per Unit

In this section...

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 **powerlib**. 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 **powerlib**, 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.

B

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