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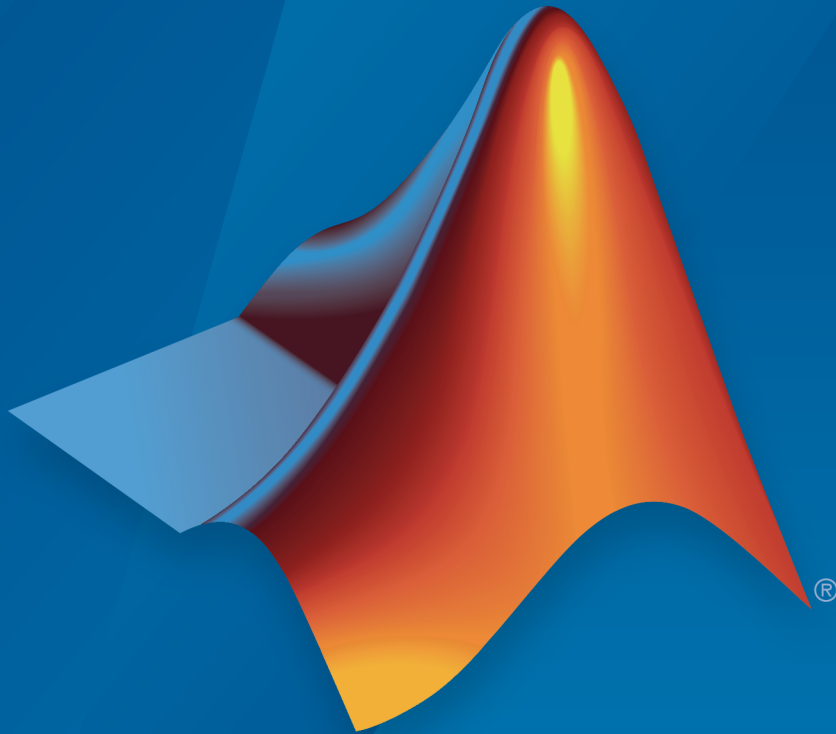
Reference (Simscape™ Components)

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Description

The Asynchronous Machine Measurement block outputs a per-unit measurement associated with a connected Asynchronous Machine Squirrel Cage or Asynchronous Machine Wound Rotor block. The input of the Asynchronous Machine Measurement block connects to the pu output port of the asynchronous machine block.

You set the **Output** parameter to a per-unit measurement associated with the asynchronous machine. Based on the value you select, the Asynchronous Machine Measurement block:

- Directly outputs the value of an element in the input signal vector
- Calculates the per-unit measurement by using values of elements in the input signal vector in mathematical expressions

The Asynchronous Machine Measurement block outputs a per-unit measurement from the asynchronous machine according to the output value expressions in the table. For example, when you set **Output** to Stator d-axis voltage, the block directly outputs the value of the pu_vds element in the input signal vector. However, when you set **Output** to Slip, the block calculates the slip value by subtracting the value of the pu_velocity element from 1.

Output Parameter Setting	Output Value Expression
Electrical torque	pu_torque

Output Parameter Setting	Output Value Expression
Rotor velocity	pu_velocity
Stator d-axis voltage	pu_vds
Stator q-axis voltage	pu_vqs
Stator zero-sequence voltage	pu_v0s
Stator d-axis current	pu_ids
Stator q-axis current	pu_iqs
Stator zero-sequence current	pu_i0s
Slip	1-pu_velocity
Apparent power	$\sqrt{pu\_Pt^2 + pu\_Qt^2}$
Real power	pu_Pt = (pu_vds*pu_ids) + (pu_vqs*pu_iqs) + 2(pu_v0s*pu_i0s)
Reactive power	pu_Qt = (pu_vqs*pu_ids) − (pu_vds*pu_iqs)
Terminal voltage	$\sqrt{pu\_vds^2 + pu\_vqs^2}$
Terminal current	$\sqrt{pu\_ids^2 + pu\_iqs^2}$
Power factor angle (rad)	power_factor_angle = atan2(pu_Qt, pu_Pt)
Power factor	cos(power_factor_angle)

Parameters

Output

Per-unit measurement from asynchronous machine. The default value is
`Electrical torque`.

Ports

The block has the following ports:

pu

Physical signal vector port associated with per-unit measurements from a connected asynchronous machine. The vector elements are:

- pu_torque
- pu_velocity
- pu_vds
- pu_vqs
- pu_v0s
- pu_ids
- pu_iqs
- pu_i0s

o

    Per-unit measurement output port.

See Also

Asynchronous Machine Squirrel Cage (fundamental)

Asynchronous Machine Wound Rotor (fundamental)

Introduced in R2013b

Asynchronous Machine Squirrel Cage (fundamental)

Squirrel-cage-rotor asynchronous machine with fundamental parameterization
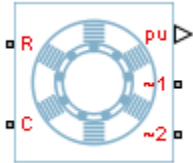
Library

Machines / Asynchronous Machine (Squirrel Cage)

Description

The Asynchronous Machine Squirrel Cage (fundamental) block models a squirrel-cage-rotor asynchronous machine using fundamental parameters. A squirrel-cage-rotor asynchronous machine is a type of induction machine. All stator connections are accessible on the block. Therefore, you can model soft-start regimes using a switch between wye and delta configurations. If you need access to the rotor windings, use the `Asynchronous Machine Wound Rotor (fundamental)` or the `Asynchronous Machine Wound Rotor (fundamental, SI)` block instead.

Connect port ~1 to a three-phase circuit. To connect the stator in delta configuration, connect a Phase Permute block between ports ~1 and ~2. To connect the stator in wye configuration, connect port ~2 to a Grounded Neutral or a Floating Neutral block.

Electrical Defining Equations

The asynchronous machine equations are expressed with respect to a synchronous reference frame, defined by

$$\theta_e(t) = \int_0^t 2\pi f_{rated}\, dt,$$

where f_{rated} is the value of the **Rated electrical frequency** parameter.

Park's transformation maps stator equations to a reference frame that is stationary with respect to the rated electrical frequency. Park's transformation is defined by

$$
P_s = \frac{2}{3}
\begin{bmatrix}
\cos\theta_e & \cos(\theta_e - \frac{2\pi}{3}) & \cos(\theta_e + \frac{2\pi}{3}) \\
-\sin\theta_e & -\sin(\theta_e - \frac{2\pi}{3}) & -\sin(\theta_e + \frac{2\pi}{3}) \\
\frac{1}{2} & \frac{1}{2} & \frac{1}{2}
\end{bmatrix},
$$

where θ_e is the electrical angle.

Park's transformation is used to define the per-unit asynchronous machine equations. The stator voltage equations are defined by

$$
v_{ds} = \frac{1}{\omega_{base}} \frac{d\psi_{ds}}{dt} - \omega\psi_{qs} + R_s i_{ds},
$$

$$
v_{qs} = \frac{1}{\omega_{base}} \frac{d\psi_{qs}}{dt} + \omega\psi_{ds} + R_s i_{qs},
$$

and

$$
v_{0s} = \frac{1}{\omega_{base}} \frac{d\psi_{0s}}{dt} + R_s i_{0s},
$$

where:

- v_{ds}, v_{qs}, and v_{0s} are the d-axis, q-axis, and zero-sequence stator voltages, defined by

$$
\begin{bmatrix}
v_{ds} \\
v_{qs} \\
v_{0s}
\end{bmatrix}
= P_s
\begin{bmatrix}
v_a \\
v_b \\
v_c
\end{bmatrix}.
$$

v_a, v_b, and v_c are the stator voltages across ports ~1 and ~2.

- ω_{base} is the per-unit base electrical speed.
- ψ_{ds}, ψ_{qs}, and ψ_{0s} are the d-axis, q-axis, and zero-sequence stator flux linkages.
- R_s is the stator resistance.
- i_{ds}, i_{qs}, and i_{0s} are the d-axis, q-axis, and zero-sequence stator currents defined by

$$\begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{0s} \end{bmatrix} = P_s \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}.$$

i_a, i_b, and i_c are the stator currents flowing from port ~1 to port ~2.

The rotor voltage equations are defined by

$$v_{dr} = \frac{1}{\omega_{base}} \frac{d\psi_{dr}}{dt} - (\omega - \omega_r)\psi_{qr} + R_{rd}i_{dr} = 0$$

and

$$v_{qr} = \frac{1}{\omega_{base}} \frac{d\psi_{qr}}{dt} + (\omega - \omega_r)\psi_{dr} + R_{rd}i_{qr} = 0,$$

where:

- v_{dr} and v_{qr} are the d-axis and q-axis rotor voltages.
- ψ_{dr} and ψ_{qr} are the d-axis and q-axis rotor flux linkages.
- ω is the per-unit synchronous speed. For a synchronous reference frame, the value is 1.
- ω_r is the per-unit mechanical rotational speed.
- R_{rd} is the rotor resistance referred to the stator.
- i_{dr} and i_{qr} are the d-axis and q-axis rotor currents.

The stator flux linkage equations are defined by

$$\psi_{ds} = L_{ss}i_{ds} + L_m i_{dr},$$

$$\psi_{qs} = L_{ss}i_{qs} + L_m i_{qr},$$

and

$$\psi_{0s} = L_{ss}i_{0s},$$

where L_{ss} is the stator self-inductance and L_m is the magnetizing inductance.

The rotor flux linkage equations are defined by

$$\psi_{dr} = L_{rrd}i_{dr} + L_m i_{ds}$$

and

$$\psi_{qr} = L_{rrd}i_{qr} + L_m i_{qs},$$

where L_{rrd} is the rotor self-inductance referred to the stator.

The rotor torque is defined by

$$T = \psi_{ds}i_{qs} - \psi_{qs}i_{ds}.$$

The stator self-inductance L_{ss}, stator leakage inductance L_{ls}, and magnetizing inductance L_m are related by

$$L_{ss} = L_{ls} + L_m.$$

The rotor self-inductance L_{rrd}, rotor leakage inductance L_{lrd}, and magnetizing inductance L_m are related by

$$L_{rrd} = L_{lrd} + L_m.$$

Plotting and Display Options

You can perform plotting and display actions using the **Power Systems** menu on the block context menu.

Right-click the block and, from the **Power Systems** menu, select an option:

- **Display Base Values** displays the machine per-unit base values in the MATLAB® Command Window.
- **Plot Torque Speed (SI)** plots torque versus speed (both measured in SI units) in a MATLAB figure window using the current machine parameters.
- **Plot Torque Speed (pu)** plots torque versus speed, both measured in per-unit, in a MATLAB figure window using the current machine parameters.

Parameters

All default parameter values are based on a machine delta-winding configuration.

- "Main Tab" on page 1-9
- "Impedances Tab" on page 1-9
- "Initial Conditions Tab" on page 1-10

Main Tab

Rated apparent power

Rated apparent power of the asynchronous machine. The default value is `15e3 V*A`.

Rated voltage

RMS line-line voltage. The default value is `220 V`.

Rated electrical frequency

Nominal electrical frequency corresponding to the rated apparent power. The default value is `60 Hz`.

Number of pole pairs

Number of machine pole pairs. The default value is `1`.

Impedances Tab

Stator resistance, Rs (pu)

Stator resistance. The default value is `0.0258`.

Stator leakage inductance, Lls (pu)

Stator leakage inductance. The default value is `0.0930`.

Referred rotor resistance, Rr' (pu)

Rotor resistance referred to the stator. The default value is `0.0145`.

Referred rotor leakage inductance, Llr' (pu)

Rotor leakage inductance referred to the stator. The default value is `0.0424`.

Magnetizing inductance, Lm (pu)

Magnetizing inductance, that is, the peak value of stator-rotor mutual inductance. The default value is `1.7562`.

Stator zero-sequence inductance, L0 (pu)

Stator zero-sequence inductance. The default value is `0.0930`.

Initial Conditions Tab

Initial rotor angle

Initial rotor angle. The default value is `0` deg.

Initial stator d-axis magnetic flux linkage

Initial stator d-axis flux linkage. The default value is `0` pu.

Initial stator q-axis magnetic flux linkage

Initial stator q-axis flux linkage. The default value is `0` pu.

Initial stator zero-sequence magnetic flux linkage

Initial stator zero-sequence flux linkage. The default value is `0` pu.

Initial rotor d-axis magnetic flux linkage

Initial rotor d-axis flux linkage. The default value is `0` pu.

Initial rotor q-axis magnetic flux linkage

Initial stator q-axis flux linkage. The default value is `0` pu.

Ports

The block has the following ports:

`R`

Mechanical rotational conserving port associated with the machine rotor.

`C`

Mechanical rotational conserving port associated with the machine case.

~1

Expandable three-phase port associated with the stator positive-end connections.

~2

Expandable three-phase port associated with the stator negative-end connections.

pu

Physical signal vector port associated with the machine per-unit measurements. The vector elements are:

- pu_torque
- pu_velocity
- pu_vds
- pu_vqs
- pu_v0s
- pu_ids
- pu_iqs
- pu_i0s

References

[1] Kundur, P. *Power System Stability and Control.* New York, NY: McGraw Hill, 1993.

[2] Lyshevski, S. E. *Electromechanical Systems, Electric Machines and Applied Mechatronics.* Boca Raton, FL: CRC Press, 1999.

See Also

See Also
Asynchronous Machine Measurement | Asynchronous Machine Squirrel Cage (fundamental, SI) | Asynchronous Machine Wound Rotor (fundamental, SI) | Asynchronous Machine Wound Rotor (fundamental)

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Three-Phase Asynchronous Machine Starting

Introduced in R2013b

Asynchronous Machine Squirrel Cage (fundamental, SI)

Squirrel-cage-rotor asynchronous machine with fundamental parameterization in SI units
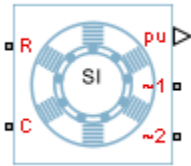
Library

Machines / Asynchronous Machine (Squirrel Cage)

Description

The Asynchronous Machine Squirrel Cage (fundamental, SI) block models a squirrel-cage-rotor asynchronous machine using fundamental parameters expressed in the International System of Units (SI). A squirrel-cage asynchronous machine is a type of induction machine. All stator connections are accessible on the block. Therefore, you can model soft-start regimes using a switch between wye and delta configurations. If you need access to the rotor windings, use the `Asynchronous Machine Wound Rotor (fundamental, SI)` block or the `Asynchronous Machine Wound Rotor (fundamental)` block instead.

Connect port ~1 to a three-phase circuit. To connect the stator in delta configuration, connect a Phase Permute block between ports ~1 and ~2. To connect the stator in wye configuration, connect port ~2 to a Grounded Neutral or a Floating Neutral block.

Electrical Defining Equations

The Asynchronous Machine Squirrel Cage (fundamental, SI) converts the SI values that you enter in the dialog box to per-unit values for simulation. For information on the

relationship between SI and per-unit machine parameters, see "Per-Unit Conversion for Machine Parameters". For information on per-unit parameterization, see "Per-Unit System of Units".

The asynchronous machine equations are expressed with respect to a synchronous reference frame, defined by

$$\theta_e(t) = \int\limits_0^t 2\pi\, f_{rated}\, dt,$$

where f_{rated} is the value of the **Rated electrical frequency** parameter.

Park's transformation maps stator equations to a reference frame that is stationary with respect to the rated electrical frequency. Park's transformation is defined by

$$P_s = \frac{2}{3} \begin{bmatrix} \cos\theta_e & \cos(\theta_e - \dfrac{2\pi}{3}) & \cos(\theta_e + \dfrac{2\pi}{3}) \\ -\sin\theta_e & -\sin(\theta_e - \dfrac{2\pi}{3}) & -\sin(\theta_e + \dfrac{2\pi}{3}) \\ \dfrac{1}{2} & \dfrac{1}{2} & \dfrac{1}{2} \end{bmatrix},$$

where θ_e is the electrical angle.

Park's transformation is used to define the per-unit asynchronous machine equations. The stator voltage equations are defined by

$$v_{ds} = \frac{1}{\omega_{base}} \frac{d\psi_{ds}}{dt} - \omega\psi_{qs} + R_s i_{ds},$$

$$v_{qs} = \frac{1}{\omega_{base}} \frac{d\psi_{qs}}{dt} + \omega\psi_{ds} + R_s i_{qs},$$

and

$$v_{0s} = \frac{1}{\omega_{base}} \frac{d\psi_{0s}}{dt} + R_s i_{0s},$$

where:

- v_{ds}, v_{qs}, and v_{0s} are the d-axis, q-axis, and zero-sequence stator voltages, defined by

$$\begin{bmatrix} v_{ds} \\ v_{qs} \\ v_{0s} \end{bmatrix} = P_s \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}.$$

v_a, v_b, and v_c are the stator voltages across ports ~1 and ~2.

- ω_{base} is the per-unit base electrical speed.
- ψ_{ds}, ψ_{qs}, and ψ_{0s} are the d-axis, q-axis, and zero-sequence stator flux linkages.
- R_s is the stator resistance.
- i_{ds}, i_{qs}, and i_{0s} are the d-axis, q-axis, and zero-sequence stator currents defined by

$$\begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{0s} \end{bmatrix} = P_s \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}.$$

i_a, i_b, and i_c are the stator currents flowing from port ~1 to port ~2.

The rotor voltage equations are defined by

$$v_{dr} = \frac{1}{\omega_{base}} \frac{d\psi_{dr}}{dt} - (\omega - \omega_r)\psi_{qr} + R_{rd}i_{dr} = 0$$

and

$$v_{qr} = \frac{1}{\omega_{base}} \frac{d\psi_{qr}}{dt} + (\omega - \omega_r)\psi_{dr} + R_{rd}i_{qr} = 0,$$

where:

- v_{dr} and v_{qr} are the d-axis and q-axis rotor voltages.
- ψ_{dr} and ψ_{qr} are the d-axis and q-axis rotor flux linkages.

- ω is the per-unit synchronous speed. For a synchronous reference frame, the value is 1.
- ω_r is the per-unit mechanical rotational speed.
- R_{rd} is the rotor resistance referred to the stator.
- i_{dr} and i_{qr} are the d-axis and q-axis rotor currents.

The stator flux linkage equations are defined by

$$\psi_{ds} = L_{ss}i_{ds} + L_m i_{dr},$$

$$\psi_{qs} = L_{ss}i_{qs} + L_m i_{qr},$$

and

$$\psi_{0s} = L_{ss}i_{0s},$$

where L_{ss} is the stator self-inductance and L_m is the magnetizing inductance.

The rotor flux linkage equations are defined by

$$\psi_{dr} = L_{rrd}i_{dr} + L_m i_{ds}$$

and

$$\psi_{qr} = L_{rrd}i_{qr} + L_m i_{qs},$$

where L_{rrd} is the rotor self-inductance referred to the stator.

The rotor torque is defined by

$$T = \psi_{ds}i_{qs} - \psi_{qs}i_{ds}.$$

The stator self-inductance L_{ss}, stator leakage inductance L_{ls}, and magnetizing inductance L_m are related by

$$L_{ss} = L_{ls} + L_m.$$

The rotor self-inductance L_{rrd}, rotor leakage inductance L_{lrd}, and magnetizing inductance L_m are related by

$$L_{rrd} = L_{lrd} + L_m.$$

Plotting and Display Options

You can perform plotting and display actions using the **Power Systems** menu on the block context menu.

Right-click the block and, from the **Power Systems** menu, select an option:

- **Display Base Values** displays the machine per-unit base values in the MATLAB Command Window.
- **Plot Torque Speed (SI)** plots torque versus speed (both measured in SI units) in a MATLAB figure window using the current machine parameters.
- **Plot Torque Speed (pu)** plots torque versus speed, both measured in per-unit, in a MATLAB figure window using the current machine parameters.

Parameters

All default parameter values are based on a machine delta-winding configuration.

- "Main Tab" on page 1-17
- "Impedances Tab" on page 1-18
- "Initial Conditions Tab" on page 1-18

Main Tab

Rated apparent power

  Rated apparent power of the asynchronous machine. The default value is `15e3 V*A`.

Rated voltage

  RMS line-line voltage. The default value is `220 V`.

Rated electrical frequency

Nominal electrical frequency corresponding to the rated apparent power. The default value is 60 Hz.

Number of pole pairs

Number of machine pole pairs. The default value is 1.

Impedances Tab

Stator resistance, Rs

Stator resistance. The default value is 0.25 Ohm.

Stator leakage reactance, Xls

Stator leakage reactance. The default value is 0.9 Ohm.

Referred rotor resistance, Rr'

Rotor resistance referred to the stator. The default value is 0.14 Ohm.

Referred rotor leakage reactance, Xlr'

Rotor leakage reactance referred to the stator. The default value is 0.41 Ohm.

Magnetizing reactance, Xm

Magnetizing reactance The default value is 17 Ohm.

Stator zero-sequence reactance, X0

Stator zero-sequence reactance. The default value is 0.9 Ohm.

Initial Conditions Tab

Initial rotor angle

Initial rotor angle. The default value is 0 deg.

Initial stator d-axis magnetic flux linkage

Initial stator d-axis flux linkage. The default value is 0 Wb.

Initial stator q-axis magnetic flux linkage

Initial stator q-axis flux linkage. The default value is 0 Wb.

Initial stator zero-sequence magnetic flux linkage

Initial stator zero-sequence flux linkage. The default value is 0 Wb.

Initial rotor d-axis magnetic flux linkage

Initial rotor *d*-axis flux linkage. The default value is `0 Wb`.

Initial rotor q-axis magnetic flux linkage

Initial stator *q*-axis flux linkage. The default value is `0 Wb`.

Ports

The block has the following ports:

`R`

Mechanical rotational conserving port associated with the machine rotor.

`C`

Mechanical rotational conserving port associated with the machine case.

`~1`

Expandable three-phase port associated with the stator positive-end connections.

`~2`

Expandable three-phase port associated with the stator negative-end connections.

`pu`

Physical signal vector port associated with the machine per-unit measurements. The vector elements are:

- pu_torque
- pu_velocity
- pu_vds
- pu_vqs
- pu_v0s
- pu_ids
- pu_iqs
- pu_i0s

References

[1] Kundur, P. *Power System Stability and Control.* New York, NY: McGraw Hill, 1993.

[2] Lyshevski, S. E. *Electromechanical Systems, Electric Machines and Applied Mechatronics.* Boca Raton, FL: CRC Press, 1999.

See Also

See Also
```
Asynchronous Machine Measurement | Asynchronous Machine Squirrel
Cage (fundamental) | Asynchronous Machine Wound Rotor (fundamental) |
Asynchronous Machine Wound Rotor (fundamental, SI)
```

Topics
"Expand and Collapse Three-Phase Ports on a Block"
Three-Phase Asynchronous Machine Starting

Introduced in R2015a

Asynchronous Machine Wound Rotor (fundamental)

Wound-rotor asynchronous machine with fundamental parameterization
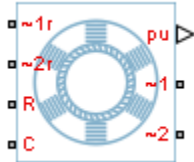
Library

Machines / Asynchronous Machine (Wound Rotor)

Description

The Asynchronous Machine Wound Rotor (fundamental) block models a wound-rotor asynchronous machine using fundamental parameters. A wound-rotor asynchronous machine is a type of induction machine. All stator and rotor connections are accessible on the block. Therefore, you can model soft-start regimes using a switch between wye and delta configurations or by increasing rotor resistance. If you do not need access to the rotor windings, use the `Asynchronous Machine Squirrel Cage (fundamental)` block instead.

Connect port ~1 to a three-phase circuit. To connect the stator in delta configuration, connect a Phase Permute block between ports ~1 and ~2. To connect the stator in wye configuration, connect port ~2 to a Grounded Neutral or a Floating Neutral block. If you do not need to vary rotor resistance, connect rotor port ~1r to a Floating Neutral block and rotor port ~2r to a Grounded Neutral block.

The rotor circuit is referred to the stator. Therefore, when you use the block in a circuit, refer any additional circuit parameters to the stator.

Electrical Defining Equations

The asynchronous machine equations are expressed with respect to a synchronous reference frame, defined by

$$\theta_e(t) = \int_0^t 2\pi f_{rated}\, dt,$$

where f_{rated} is the value of the **Rated electrical frequency** parameter.

Park's transformation maps stator equations to a reference frame that is stationary with respect to the rated electrical frequency. Park's transformation is defined by

$$P_s = \frac{2}{3}\begin{bmatrix} \cos\theta_e & \cos(\theta_e - \frac{2\pi}{3}) & \cos(\theta_e + \frac{2\pi}{3}) \\ -\sin\theta_e & -\sin(\theta_e - \frac{2\pi}{3}) & -\sin(\theta_e + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix},$$

where θ_e is the electrical angle.

The rotor equations are mapped to another reference frame, defined by the difference between the electrical angle and the product of rotor angle θ_r and number of pole pairs N:

$$P_r = \frac{2}{3}\begin{bmatrix} \cos(\theta_e - N\theta_r) & \cos(\theta_e - N\theta_r - \frac{2\pi}{3}) & \cos(\theta_e - N\theta_r + \frac{2\pi}{3}) \\ -\sin(\theta_e - N\theta_r) & -\sin(\theta_e - N\theta_r - \frac{2\pi}{3}) & -\sin(\theta_e - N\theta_r + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}.$$

Park's transformation is used to define the per-unit asynchronous machine equations. The stator voltage equations are defined by

$$v_{ds} = \frac{1}{\omega_{base}} \frac{d\psi_{ds}}{dt} - \omega\psi_{qs} + R_s i_{ds},$$

$$v_{qs} = \frac{1}{\omega_{base}} \frac{d\psi_{qs}}{dt} + \omega\psi_{ds} + R_s i_{qs},$$

and

$$v_{0s} = \frac{1}{\omega_{base}} \frac{d\psi_{0s}}{dt} + R_s i_{0s},$$

where:

- v_{ds}, v_{qs}, and v_{0s} are the d-axis, q-axis, and zero-sequence stator voltages, defined by

$$\begin{bmatrix} v_{ds} \\ v_{qs} \\ v_{0s} \end{bmatrix} = P_s \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}.$$

v_a, v_b, and v_c are the stator voltages across ports ~1 and ~2.

- ω_{base} is the per-unit base electrical speed.
- ψ_{ds}, ψ_{qs}, and ψ_{0s} are the d-axis, q-axis, and zero-sequence stator flux linkages.
- R_s is the stator resistance.
- i_{ds}, i_{qs}, and i_{0s} are the d-axis, q-axis, and zero-sequence stator currents, defined by

$$\begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{0s} \end{bmatrix} = P_s \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}.$$

i_a, i_b, and i_c are the stator currents flowing from port ~1 to port ~2.

The rotor voltage equations are defined by

$$v_{dr} = \frac{1}{\omega_{base}} \frac{d\psi_{dr}}{dt} - (\omega - \omega_r)\psi_{qr} + R_{rd}i_{dr},$$

$$v_{qr} = \frac{1}{\omega_{base}} \frac{d\psi_{qr}}{dt} + (\omega - \omega_r)\psi_{dr} + R_{rd}i_{qr},$$

and

$$v_{0r} = \frac{1}{\omega_{base}} \frac{d\psi_{0r}}{dt} + R_{rd} i_{0s},$$

where:

- v_{dr}, v_{qr}, and v_{0r} are the d-axis, q-axis, and zero-sequence rotor voltages, defined by

$$\begin{bmatrix} v_{dr} \\ v_{qr} \\ v_{0r} \end{bmatrix} = P_r \begin{bmatrix} v_{ar} \\ v_{br} \\ v_{cr} \end{bmatrix}.$$

  v_{ar}, v_{br}, and v_{cr} are the rotor voltages across ports ~1r and ~2r.

- ψ_{dr}, ψ_{qr}, and ψ_{0r} are the d-axis, q-axis, and zero-sequence rotor flux linkages.
- ω is the per-unit synchronous speed. For a synchronous reference frame, the value is 1.
- ω_r is the per-unit mechanical rotational speed.
- R_{rd} is the rotor resistance referred to the stator.
- i_{dr}, i_{qr}, and i_{0r} are the d-axis, q-axis, and zero-sequence rotor currents, defined by

$$\begin{bmatrix} i_{dr} \\ i_{qr} \\ i_{0r} \end{bmatrix} = P_r \begin{bmatrix} i_{ar} \\ i_{br} \\ i_{cr} \end{bmatrix}.$$

  i_{ar}, i_{br}, and i_{cr} are the rotor currents flowing from port ~1r to port ~2r.

The stator flux linkage equations are defined by

$$\psi_{ds} = L_{ss} i_{ds} + L_m i_{dr},$$

$$\psi_{qs} = L_{ss} i_{qs} + L_m i_{qr},$$

and

$$\psi_{0s} = L_{ss} i_{0s},$$

where L_{ss} is the stator self-inductance and L_m is the magnetizing inductance.

The rotor flux linkage equations are defined by

$$\psi_{dr} = L_{rrd}i_{dr} + L_m i_{ds}$$

$$\psi_{qr} = L_{rrd}i_{qr} + L_m i_{qs},$$

and

$$\psi_{0r} = L_{rrd}i_{0r},$$

where L_{rrd} is the rotor self-inductance referred to the stator.

The rotor torque is defined by

$$T = \psi_{ds}i_{qs} - \psi_{qs}i_{ds}.$$

The stator self-inductance L_{ss}, stator leakage inductance L_{ls}, and magnetizing inductance L_m are related by

$$L_{ss} = L_{ls} + L_m.$$

The rotor self-inductance L_{rrd}, rotor leakage inductance L_{lrd}, and magnetizing inductance L_m are related by

$$L_{rrd} = L_{lrd} + L_m.$$

Plotting and Display Options

You can perform plotting and display actions using the **Power Systems** menu on the block context menu.

Right-click the block and, from the **Power Systems** menu, select an option:

- **Display Base Values** displays the machine per-unit base values in the MATLAB Command Window.
- **Plot Torque Speed (SI)** plots torque versus speed (both measured in SI units) in a MATLAB figure window using the current machine parameters.

- **Plot Torque Speed (pu)** plots torque versus speed, both measured in per-unit, in a MATLAB figure window using the current machine parameters.

Parameters

All default parameter values are based on a machine delta-winding configuration.

- "Main Tab" on page 1-26
- "Impedances Tab" on page 1-26
- "Initial Conditions Tab" on page 1-27

Main Tab

Rated apparent power

Rated apparent power of the asynchronous machine. The default value is 15e3 V*A.

Rated voltage

RMS line-line voltage. The default value is 220 V.

Rated electrical frequency

Nominal electrical frequency corresponding to the rated apparent power. The default value is 60 Hz.

Number of pole pairs

Number of machine pole pairs. The default value is 1.

Impedances Tab

Stator resistance, Rs (pu)

Stator resistance. The default value is 0.0258.

Stator leakage inductance, Lls (pu)

Stator leakage inductance. The default value is 0.0930.

Referred rotor resistance, Rr' (pu)

Rotor resistance referred to the stator. The default value is 0.0145.

Referred rotor leakage inductance, Llr' (pu)

Rotor leakage inductance referred to the stator. The default value is 0.0424.

Magnetizing inductance, Lm (pu)

Magnetizing inductance, that is, the peak value of stator-rotor mutual inductance. The default value is `1.7562`.

Stator zero-sequence inductance, L0 (pu)

Stator zero-sequence inductance. The default value is `0.0930`.

Initial Conditions Tab

Initial rotor angle

Initial rotor angle. The default value is `0 deg`.

Initial stator d-axis magnetic flux linkage

Initial stator d-axis flux linkage. The default value is `0` pu.

Initial stator q-axis magnetic flux linkage

Initial stator q-axis flux linkage. The default value is `0` pu.

Initial stator zero-sequence magnetic flux linkage

Initial stator zero-sequence flux linkage. The default value is `0` pu.

Initial rotor d-axis magnetic flux linkage

Initial rotor d-axis flux linkage. The default value is `0` pu.

Initial rotor q-axis magnetic flux linkage

Initial stator q-axis flux linkage. The default value is `0` pu.

Initial rotor zero-sequence magnetic flux linkage

Initial rotor zero-sequence flux linkage. The default value is `0` pu.

Ports

The block has the following ports:

`R`

Mechanical rotational conserving port associated with the machine rotor.

`C`

Mechanical rotational conserving port associated with the machine case.

`~1`

Expandable three-phase port associated with the stator positive-end connections.

~2

Expandable three-phase port associated with the stator negative-end connections.

~1r

Expandable three-phase port associated with the rotor positive-end connections.

~2r

Expandable three-phase port associated with the rotor negative-end connections.

pu

Physical signal vector port associated with the machine per-unit measurements. The vector elements are:

- pu_torque
- pu_velocity
- pu_vds
- pu_vqs
- pu_v0s
- pu_ids
- pu_iqs
- pu_i0s

References

[1] Kundur, P. *Power System Stability and Control.* New York, NY: McGraw Hill, 1993.

[2] Lyshevski, S. E. *Electromechanical Systems, Electric Machines and Applied Mechatronics.* Boca Raton, FL: CRC Press, 1999.

See Also

See Also
Asynchronous Machine Measurement | Asynchronous Machine Squirrel Cage (fundamental) | Asynchronous Machine Squirrel Cage (fundamental, SI) | Asynchronous Machine Wound Rotor (fundamental, SI)

Topics

"Expand and Collapse Three-Phase Ports on a Block"
Three-Phase Asynchronous Machine Starting

Introduced in R2013b

Asynchronous Machine Wound Rotor (fundamental, SI)

Wound-rotor asynchronous machine with fundamental parameterization in SI units
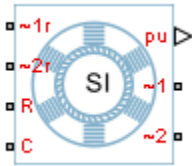
Library

Machines / Asynchronous Machine (Wound Rotor)

Description

The Asynchronous Machine Wound Rotor (fundamental, SI) block models a wound-rotor asynchronous machine using fundamental parameters expressed in the International System of Units (SI). A wound-rotor asynchronous machine is a type of induction machine. All stator and rotor connections are accessible on the block. Therefore, you can model soft-start regimes using a switch between wye and delta configurations or by increasing rotor resistance. If you do not need access to the rotor windings, use the `Asynchronous Machine Squirrel Cage (fundamental)` or `Asynchronous Machine Squirrel Cage (fundamental,SI)` block instead.

Connect port ~1 to a three-phase circuit. To connect the stator in delta configuration, connect a Phase Permute block between ports ~1 and ~2. To connect the stator in wye configuration, connect port ~2 to a Grounded Neutral or a Floating Neutral block. If you do not need to vary rotor resistance, connect rotor port ~1r to a Floating Neutral block and rotor port ~2r to a Grounded Neutral block.

The rotor circuit is referred to the stator. Therefore, when you use the block in a circuit, refer any additional circuit parameters to the stator.

Electrical Defining Equations

The Asynchronous Machine Wound Rotor (fundamental, SI) converts the SI values that you enter in the dialog box to per-unit values for simulation. For information on the relationship between SI and per-unit machine parameters, see "Per-Unit Conversion for Machine Parameters". For information on per-unit parameterization, see "Per-Unit System of Units".

The asynchronous machine equations are expressed with respect to a synchronous reference frame, defined by

$$\theta_e(t) = \int\limits_0^t 2\pi f_{rated}\, dt,$$

where f_{rated} is the value of the **Rated electrical frequency** parameter.

Park's transformation maps stator equations to a reference frame that is stationary with respect to the rated electrical frequency. Park's transformation is defined by

$$P_s = \frac{2}{3} \begin{bmatrix} \cos\theta_e & \cos(\theta_e - \dfrac{2\pi}{3}) & \cos(\theta_e + \dfrac{2\pi}{3}) \\ -\sin\theta_e & -\sin(\theta_e - \dfrac{2\pi}{3}) & -\sin(\theta_e + \dfrac{2\pi}{3}) \\ \dfrac{1}{2} & \dfrac{1}{2} & \dfrac{1}{2} \end{bmatrix},$$

where θ_e is the electrical angle.

The rotor equations are mapped to another reference frame, defined by the difference between the electrical angle and the product of rotor angle θ_r and number of pole pairs N:

$$P_r = \frac{2}{3} \begin{bmatrix} \cos(\theta_e - N\theta_r) & \cos(\theta_e - N\theta_r - \dfrac{2\pi}{3}) & \cos(\theta_e - N\theta_r + \dfrac{2\pi}{3}) \\ -\sin(\theta_e - N\theta_r) & -\sin(\theta_e - N\theta_r - \dfrac{2\pi}{3}) & -\sin(\theta_e - N\theta_r + \dfrac{2\pi}{3}) \\ \dfrac{1}{2} & \dfrac{1}{2} & \dfrac{1}{2} \end{bmatrix}.$$

Park's transformation is used to define the per-unit asynchronous machine equations. The stator voltage equations are defined by

$$v_{ds} = \frac{1}{\omega_{base}} \frac{d\psi_{ds}}{dt} - \omega\psi_{qs} + R_s i_{ds},$$

$$v_{qs} = \frac{1}{\omega_{base}} \frac{d\psi_{qs}}{dt} + \omega\psi_{ds} + R_s i_{qs},$$

and

$$v_{0s} = \frac{1}{\omega_{base}} \frac{d\psi_{0s}}{dt} + R_s i_{0s},$$

where:

- v_{ds}, v_{qs}, and v_{0s} are the d-axis, q-axis, and zero-sequence stator voltages, defined by

$$\begin{bmatrix} v_{ds} \\ v_{qs} \\ v_{0s} \end{bmatrix} = P_s \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}.$$

  v_a, v_b, and v_c are the stator voltages across ports ~1 and ~2.
- ω_{base} is the per-unit base electrical speed.
- ψ_{ds}, ψ_{qs}, and ψ_{0s} are the d-axis, q-axis, and zero-sequence stator flux linkages.
- R_s is the stator resistance.
- i_{ds}, i_{qs}, and i_{0s} are the d-axis, q-axis, and zero-sequence stator currents, defined by

$$\begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{0s} \end{bmatrix} = P_s \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}.$$

  i_a, i_b, and i_c are the stator currents flowing from port ~1 to port ~2.

The rotor voltage equations are defined by

$$v_{dr} = \frac{1}{\omega_{base}} \frac{d\psi_{dr}}{dt} - (\omega - \omega_r)\psi_{qr} + R_{rd}i_{dr},$$

$$v_{qr} = \frac{1}{\omega_{base}} \frac{d\psi_{qr}}{dt} + (\omega - \omega_r)\psi_{dr} + R_{rd}i_{qr},$$

and

$$v_{0r} = \frac{1}{\omega_{base}} \frac{d\psi_{0r}}{dt} + R_{rd}i_{0s},$$

where:

- v_{dr}, v_{qr}, and v_{0r} are the d-axis, q-axis, and zero-sequence rotor voltages, defined by

$$\begin{bmatrix} v_{dr} \\ v_{qr} \\ v_{0r} \end{bmatrix} = P_r \begin{bmatrix} v_{ar} \\ v_{br} \\ v_{cr} \end{bmatrix}.$$

  v_{ar}, v_{br}, and v_{cr} are the rotor voltages across ports ~1r and ~2r.

- ψ_{dr}, ψ_{qr}, and ψ_{0r} are the d-axis, q-axis, and zero-sequence rotor flux linkages.
- ω is the per-unit synchronous speed. For a synchronous reference frame, the value is 1.
- ω_r is the per-unit mechanical rotational speed.
- R_{rd} is the rotor resistance referred to the stator.
- i_{dr}, i_{qr}, and i_{0r} are the d-axis, q-axis, and zero-sequence rotor currents, defined by

$$\begin{bmatrix} i_{dr} \\ i_{qr} \\ i_{0r} \end{bmatrix} = P_r \begin{bmatrix} i_{ar} \\ i_{br} \\ i_{cr} \end{bmatrix}.$$

  i_{ar}, i_{br}, and i_{cr} are the rotor currents flowing from port ~1r to port ~2r.

The stator flux linkage equations are defined by

$$\psi_{ds} = L_{ss}i_{ds} + L_m i_{dr},$$

$$\psi_{qs} = L_{ss}i_{qs} + L_m i_{qr},$$

and

$$\psi_{0s} = L_{ss}i_{0s},$$

where L_{ss} is the stator self-inductance and L_m is the magnetizing inductance.

The rotor flux linkage equations are defined by

$$\psi_{dr} = L_{rrd}i_{dr} + L_m i_{ds}$$

$$\psi_{qr} = L_{rrd}i_{qr} + L_m i_{qs},$$

and

$$\psi_{0r} = L_{rrd}i_{0r},$$

where L_{rrd} is the rotor self-inductance referred to the stator.

The rotor torque is defined by

$$T = \psi_{ds}i_{qs} - \psi_{qs}i_{ds}.$$

The stator self-inductance L_{ss}, stator leakage inductance L_{ls}, and magnetizing inductance L_m are related by

$$L_{ss} = L_{ls} + L_m.$$

The rotor self-inductance L_{rrd}, rotor leakage inductance L_{lrd}, and magnetizing inductance L_m are related by

$$L_{rrd} = L_{lrd} + L_m.$$

Plotting and Display Options

You can perform display and plotting actions using the **Power Systems** menu on the block context menu.

Right-click the block and, from the **Power Systems** menu, select an option:

- **Display Base Values** displays the machine per-unit base values in the MATLAB Command Window.
- **Plot Torque Speed (SI)** plots torque versus speed (both measured in SI units) in a MATLAB figure window using the current machine parameters.
- **Plot Torque Speed (pu)** plots torque versus speed, both measured in per-unit, in a MATLAB figure window using the current machine parameters.

Parameters

All default parameter values are based on a machine delta-winding configuration.

- "Main Tab" on page 1-35
- "Impedances Tab" on page 1-36
- "Initial Conditions Tab" on page 1-36

Main Tab

Rated apparent power

Rated apparent power of the asynchronous machine. The default value is 15e3 V*A.

Rated voltage

RMS line-line voltage. The default value is 220 V.

Rated electrical frequency

Nominal electrical frequency corresponding to the rated apparent power. The default value is 60 Hz.

Number of pole pairs

Number of machine pole pairs. The default value is 1.

Impedances Tab

Stator resistance, Rs

> Stator resistance. The default value is `0.25 Ohm`.

Stator leakage reactance, Xls

> Stator leakage reactance. The default value is `0.9 Ohm`.

Referred rotor resistance, Rr'

> Rotor resistance referred to the stator. The default value is `0.14 Ohm`.

Referred rotor leakage reactance, Xlr'

> Rotor leakage reactance referred to the stator. The default value is `0.41 Ohm`.

Magnetizing reactance, Xm

> Magnetizing reactance The default value is `17 Ohm`.

Stator zero-sequence reactance, X0

> Stator zero-sequence reactance. The default value is `0.9 Ohm`.

Initial Conditions Tab

Initial rotor angle

> Initial rotor angle. The default value is `0 deg`.

Initial stator d-axis magnetic flux linkage

> Initial stator d-axis flux linkage. The default value is `0 Wb`.

Initial stator q-axis magnetic flux linkage

> Initial stator q-axis flux linkage. The default value is `0 Wb`.

Initial stator zero-sequence magnetic flux linkage

> Initial stator zero-sequence flux linkage. The default value is `0 Wb`.

Initial rotor d-axis magnetic flux linkage

> Initial rotor d-axis flux linkage. The default value is `0 Wb`.

Initial rotor q-axis magnetic flux linkage

> Initial rotor q-axis flux linkage. The default value is `0 Wb`.

Initial rotor zero-sequence magnetic flux linkage

> Initial rotor zero-sequence flux linkage. The default value is `0 Wb`.

Ports

The block has the following ports:

R

Mechanical rotational conserving port associated with the machine rotor.

C

Mechanical rotational conserving port associated with the machine case.

~1

Expandable three-phase port associated with the stator positive-end connections.

~2

Expandable three-phase port associated with the stator negative-end connections.

~1r

Expandable three-phase port associated with the rotor positive-end connections.

~2r

Expandable three-phase port associated with the rotor negative-end connections.

pu

Physical signal vector port associated with the machine per-unit measurements. The vector elements are:

- pu_torque
- pu_velocity
- pu_vds
- pu_vqs
- pu_v0s
- pu_ids
- pu_iqs
- pu_i0s

References

[1] Kundur, P. *Power System Stability and Control.* New York, NY: McGraw Hill, 1993.

[2] Lyshevski, S. E. *Electromechanical Systems, Electric Machines and Applied Mechatronics.* Boca Raton, FL: CRC Press, 1999.

See Also

See Also

Asynchronous Machine Measurement | Asynchronous Machine Squirrel Cage (fundamental) | Asynchronous Machine Squirrel Cage (fundamental, SI) | Asynchronous Machine Wound Rotor (fundamental)

Topics

"Expand and Collapse Three-Phase Ports on a Block"
Three-Phase Asynchronous Machine Starting

Introduced in R2015a

Average-Value Inverter

Convert DC voltage to three-phase AC voltage with fixed power loss
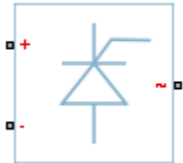
Library

Semiconductors

Description

The Average-Value Inverter block models an average-value, full-wave inverter. It converts DC voltage to three-phase AC voltages and converts three-phase AC power demand to DC power demand. The corresponding DC power demand is equal to the sum of the fixed power loss and the AC power demand.

You can use the Average-Value Inverter block only as a full-wave inverter. It behaves as a DC-voltage-controlled AC voltage source. The ratio you specify determines the ratio between the DC voltage and the AC voltage.

The figure shows the equivalent circuit for the inverter as a full-wave inverter. The Average-Value Inverter block does not yield the harmonics that are typically associated with the detailed representation, however, because it performs an average-value power conversion.
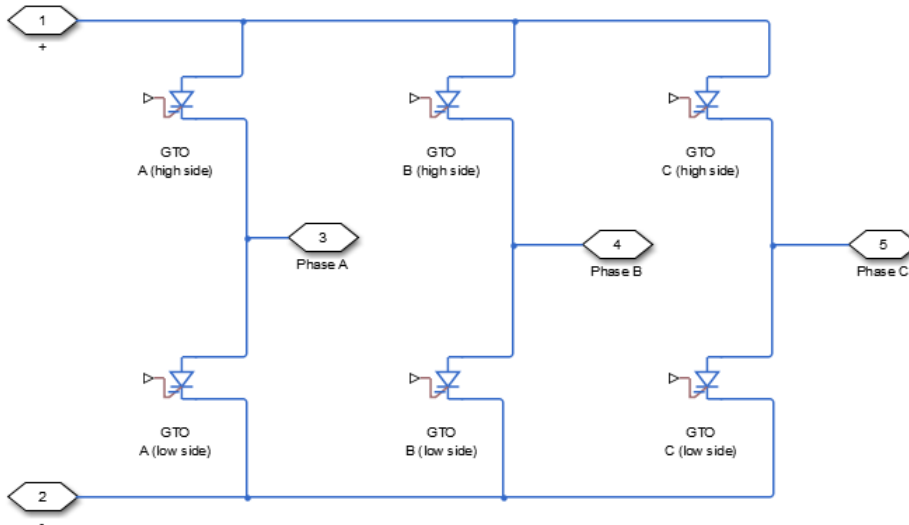
Electrical Defining Equations

The voltages are defined by

$$v_{DC} = v_p - v_n,$$

$$v_{ref} = \frac{v_p + v_n}{2},$$

$$v_{RMS} = v_{ratio}v_{DC},$$

$$V_0 = \frac{\sqrt{2}}{\sqrt{3}}V_{RMS},$$

$$v_a = V_0 \sin(2\pi ft + \varphi) + v_{ref},$$

$$v_b = V_0 \sin(2\pi ft + \varphi - 120^\circ) + v_{ref},$$

and

$$v_c = V_0 \sin(2\pi f t + \varphi + 120°) + v_{ref} ,$$

where:

- v_p, v_n are the voltages at the positive and negative terminals of the inverter.
- v_{DC} is the voltage difference between the positive and negative terminals of the inverter.
- v_{ref} is the DC offset.
- V_{ratio} is the ratio of rated AC voltage to rated DC voltage for the inverter. See the **Ratio of rated AC voltage to rated DC voltage** parameter in "Parameters" on page 1-42for the V_{ratio} values for common inverter control modes.
- V_{RMS} is the RMS AC line-line voltage.
- V_0 is the peak phase voltage.
- f is the frequency.
- t is the time.
- φ is the phase shift.
- v_a, v_b, v_c are the respective AC phase voltages.

The power, resistance, and currents are defined by

$$P_{AC} = -v_a i_a - v_b i_b - v_c i_c ,$$

$$R_{DC} = \frac{v_{DC}^2}{P_{AC} + P_{fixed}} ,$$

and

$$i = \frac{v_{DC}}{R_{DC}} ,$$

where:

- i_a, i_b, i_c are the respective AC phase currents flowing into the inverter.
- P_{AC} is the power output on the AC side. P_{AC} has a minimum limit of 0 W.
- P_{fixed} is the fixed power loss that you specify on the block.
- R_{DC} is the resistance on the DC side.
- i is the current flowing from the positive to the negative terminals of the inverter.

Assumptions and Limitations

For simulation, the block implements an assertion that

$$i_s \leq i_{\max},$$

where:

- i_s is the supply-side current.
- i_{max} is the maximum expected supply-side current.

If the supply-side current exceeds the maximum expected supply-side current, then simulation terminates. Set the value for the **Maximum expected supply-side current** parameter (i_{max}) larger than the expected maximum current.

Parameters

Rated AC voltage

Rated voltage of the AC system. The default value is 4160 V.

Phase shift

Phase shift in angular units. The default value is 0 deg.

Rated AC frequency

AC frequency, specified in Hz (where Hz is defined as $1/s$). For example, kHz and MHz are valid units, but rad/s is not. The default value is 60 Hz.

Ratio of rated AC voltage to rated DC voltage

The table shows ratios for common three-phase two-level inverter control modes. The default value is $\sqrt{6}/\pi$.

For 180° and 120° conduction modes, the listed voltages are the fundamental RMS values of line-line voltages. For other methods, the listed voltages are the maximum fundamental RMS values of line-line voltages.

You can control the output voltage of the inverter according to specific requirements. DPWM includes 30° DPWM, 60° DPWM, and 120° DPWM. For details, see references [3] and [4].

Control Method	V_{RMS} (line-line)	Ratio of V_{RMS} (line-line) to v_{DC}
180° conduction mode [1]	$\dfrac{\sqrt{6}}{\pi} V_{DC}$	0.7797
120° conduction mode [1]	$\dfrac{3}{\sqrt{2}\pi} V_{DC}$	0.6752
Hysteresis current control [2]	$\left(\dfrac{\sqrt{3}}{\sqrt{2}}\right)\left(\dfrac{2V_{DC}}{\pi}\right)$	0.7797
Sinusoidal PWM (SPMW) [2]	$\left(\dfrac{\sqrt{3}}{\sqrt{2}}\right)\left(\dfrac{V_{DC}}{2}\right)$	0.6124
Space vector modulation (SVM) [2]	$\left(\dfrac{\sqrt{3}}{\sqrt{2}}\right)\left(\dfrac{V_{DC}}{\sqrt{3}}\right)$	0.7071
Discontinuous PWM (DPWM) [3], [4]	$\left(\dfrac{\sqrt{3}}{\sqrt{2}}\right)\left(\dfrac{V_{DC}}{\sqrt{3}}\right)$	0.7071
Convert to the original AC voltage of the average-value rectifier	$\left(\dfrac{\pi}{\sqrt{2}}\right)\left(\dfrac{V_{DC}}{3}\right)$	0.7405

Fixed power loss

Minimum power drawn on the DC side. The default value is `1e3` W.

Maximum expected supply-side current

Set this value to a value greater than the maximum expected supply-side current in your model. Using twice the expected maximum current is generally sufficient. For

more information, see "Assumptions and Limitations" on page 1-42. The default value is `10e3` A.

Ports

The block has the following ports:

+

Electrical conserving port associated with the positive terminal

-

Electrical conserving port associated with the negative terminal

~

Expandable three-phase port

References

[1] Rashid, M. H. *Pulse-Width-Modulation Inverters.* Upper Saddle River, NJ: Prentice-Hall, 2004, pp. 237–248.

[2] Krause, P. C., O. Wasynczuk, and S. D. Sudhoff. *Analysis of Electric Machinery and Drive Systems*. Piscataway, NJ: IEEE Press, 2002.

[3] Chung, D. W., J. S. Kim, and S. K. Kul. "Unified voltage modulation technique for real-time three-phase power conversion." *IEEE Transactions on Industry Applications*. Vol. 34, no. 2, 1998, pp. 374–380.

[4] Hava, A. M., R. J. Kerkman, and T. A. Lipo. "Simple analytical and graphical methods for carrier-based PWM-VSI drives." *IEEE Transactions on Power Electronics*. Vol. 14, 1999, no. 1, pp. 49–61.

See Also

See Also
`Average-Value Rectifier` | `Converter` | `Rectifier` | `Three-Level Converter`

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2015a

Average-Value Rectifier

Convert three-phase AC voltage to DC voltage with fixed power loss

Library

Semiconductors

Description

The Average-Value Rectifier block models an average-value, full-wave, six-pulse rectifier. It converts instantaneous three-phase AC voltages to DC voltage and DC power demand to three-phase AC power demand. The corresponding AC power demand is equal to the sum of the fixed power loss and the DC power demand.

You can use the Average-Value Rectifier block only as a six-pulse rectifier. You cannot combine two Average-Value Rectifier blocks to represent a twelve-pulse rectifier.

The figure shows the equivalent circuit for the rectifier as a full-wave, six-pulse rectifier. The Average-Value Rectifier block does not yield the harmonics that are typically associated with the detailed representation, however, because it performs an average-value power conversion.
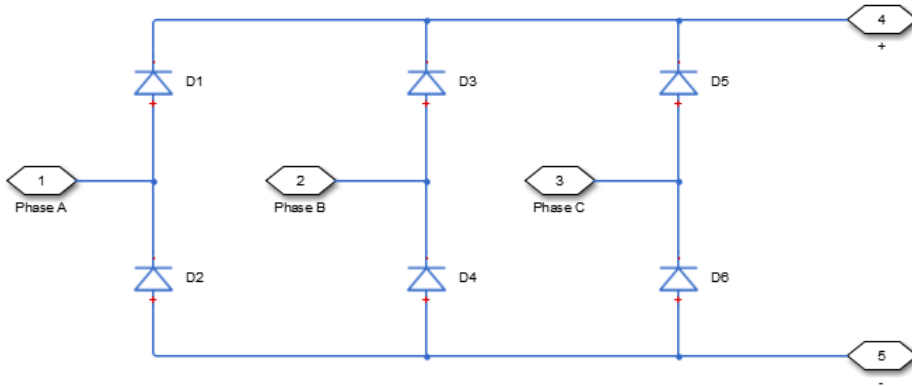
Electrical Defining Equations

The voltages are defined by:

$$v_{ref} = \frac{v_a + v_b + v_c}{3},$$

$$V_{RMS} = \sqrt{\frac{\left(v_a - v_b\right)^2 + \left(v_b - v_c\right)^2 + \left(v_c - v_a\right)^2}{3}},$$

$$v_{DC} = 3\frac{\sqrt{2}}{\pi}V_{RMS},$$

$$v_p = v_{ref} + \frac{v_{DC}}{2},$$

and

$$v_n = v_{ref} - \frac{v_{DC}}{2},$$

where:

- v_a, v_b, v_c are the respective AC phase voltages.
- v_{ref} is the DC offset on the AC side. In a balanced AC power system with no DC bias, v_{DC} is 0 V.
- V_{RMS} is the RMS AC line-line voltage.
- v_{DC} is the voltage difference between the positive and negative terminals of the rectifier.
- $3\sqrt{2}/\pi$ is the v_{DC}/V_{RMS} ratio for a full-wave, six-pulse rectifier.
- v_p, v_n are the voltages at the positive and negative terminals of the rectifier.

The resistance, power, and currents are defined by

$$R_{fixed} = \frac{V_{Rated}^2}{P_{fixed}},$$

$$P_{DC} = -v_p i_p - v_n i_n,$$

$$R_{AC} = \frac{V_{RMS}^2}{P_{DC} + \dfrac{V_{RMS}^2}{R_{fixed}}},$$

and

$$\begin{bmatrix} i_a & i_b & i_c \end{bmatrix} = \frac{\begin{bmatrix} v_a & v_b & v_c \end{bmatrix} - v_{ref}}{R_{AC}},$$

where:

- V_{Rated} is the rated AC voltage that you specify on the block mask.
- P_{fixed} is the fixed power loss that you specify on the block mask.
- R_{fixed} is the fixed per-phase series resistance in an equivalent wye-connected load.
- i_p, i_n are the currents flowing into the positive and negative terminals of the rectifier.

- P_{DC} is the power output on the DC side. P_{DC} has a minimum limit of 0 W.
- R_{AC} is the per-phase series resistance in an equivalent wye-connected load.
- i_a, i_b, i_c are the respective AC phase currents flowing into the rectifier.

Parameters

Rated AC voltage

Rated voltage of the AC system. The default value is 4160 V.

Fixed power loss

Minimum power drawn on the AC side at rated AC voltage. When the instantaneous AC voltage is equal to the value you specify for the **Rated AC voltage**, the AC power demand equals the value you specify for the **Fixed power loss** plus DC power demand. The default value is 1e3 W.

Ports

The block has the following ports:

~

Expandable three-phase port

+

Electrical conserving port associated with the positive terminal

-

Electrical conserving port associated with the negative terminal

See Also

See Also
Average-Value Inverter | Converter | Rectifier | Three-Level Converter

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2014b

Battery

Simple battery model
Library: Sources

Description

The Battery block represents a simple battery model. For information on how you can create a detailed battery model, see the (Simscape).

The Battery block has four modeling variants, accessible by right-clicking the block in your block diagram and then selecting the appropriate option from the context menu, under **Simscape** > **Block choices**:

- **Uninstrumented | No thermal port** (default) — Basic model that does not output battery charge level or simulate thermal effects.

- **Uninstrumented | Show thermal port** — Model with exposed thermal port. This model does not measure internal charge level of the battery.

- **Instrumented | No thermal port** — Model with exposed charge output port. This model does not simulate thermal effects.

- **Instrumented | Show thermal port** — Model that lets you measure internal charge level of the battery and simulate thermal effects. Both the thermal port and the charge output port are exposed.

The instrumented variants have an extra physical signal port that outputs the internal state of charge. Use this functionality to change load behavior as a function of state of charge, without the complexity of building a charge state estimator.

The thermal port variants expose a thermal port, which represents the battery thermal mass. When you select this option, provide additional parameters to define battery behavior at a second temperature. For more information, see "Modeling Thermal Effects" on page 1-54.

Battery Model

If you select `Infinite` for the **Battery charge capacity** parameter, the block models the battery as a series resistor and a constant voltage source. If you select `Finite` for the **Battery charge capacity** parameter, the block models the battery as a series resistor and a charge-dependent voltage source whose voltage as a function of charge has the following reciprocal relationship:

$$V = V_0 \left[1 - \frac{\alpha(1-x)}{1 - \beta(1-x)} \right]$$

where:

- x is the ratio of current charge to rated battery capacity in ampere-hours (AH).
- V_0 is the voltage when the battery is fully charged, as defined by the **Nominal voltage** parameter.
- The block calculates the constants α and β to satisfy these battery conditions:
  - The battery voltage is zero when the charge is zero, that is, when $x = 0$.
  - When $x = AH1/AH$, that is, when the charge is the value of the **Charge AH1 when no-load volts are V1** parameter, the battery voltage is $V1$ (the **Voltage V1 < Vnom when charge is AH1** parameter value).

The equation defines a reciprocal relationship between voltage and remaining charge. It approximates a real battery, but it does replicate the increasing rate of voltage drop at low charge values. It also ensures that the battery voltage becomes zero when the charge level is zero. This simple model has the advantage of requiring few parameters, and these parameters are readily available on most datasheets.

Modeling Battery Fade

For battery models with finite battery charge capacity, you can model battery performance deterioration depending on the number of discharge cycles, which is sometimes referred to as battery fade. To enable battery fade, set the **Model battery fade?** parameter to `Include`. This setting exposes additional parameters in the **Fade** section.

The block implements battery fade by scaling certain battery parameter values that you specify in the **Main** section, depending on the number of completed discharge cycles.

The block uses multipliers λ_{AH}, λ_{R1}, and λ_{V1} on the **Ampere-hour rating**, **Internal resistance**, and **Voltage V1 < Vnom when charge is AH1** parameter values, respectively. These multipliers, in turn, depend on the number of discharge cycles:

$$\lambda_{AH} = 1 - k_1 N^{0.5}$$

$$\lambda_{R1} = 1 + k_2 N^{0.5}$$

$$\lambda_{V1} = 1 - k_3 N$$

$$N = N_0 + \frac{1}{AH} \int_0^t \frac{i(t) \cdot H\left(i(t)\right)}{\lambda_{AH}(t)} dt$$

where:

- λ_{AH} is the multiplier for battery nominal capacity.
- λ_{R1} is the multiplier for battery series resistance.
- λ_{V1} is the multiplier for voltage *V1* to scale for a number of discharge cycles when the charge is *AH1*.
- *N* is the number of discharge cycles completed.
- N_0 is the number of full discharge cycles completed before the start of the simulation.
- *AH* is the rated battery capacity in AH.
- *i(t)* is the instantaneous battery output current.
- *H(i(t))* is the Heaviside function of the instantaneous battery output current. This function returns 0 if the argument is negative, and 1 if the argument is positive.

The block calculates the coefficients k_1, k_2, and k_3 by substituting the parameter values you provide in the **Fade** section into these battery equations. For example, the default set of block parameters corresponds to the following coefficient values:

- k_1 = 1e-2
- k_2 = 1e-3
- k_3 = 1e-3

You can also define a starting point for a simulation based on the previous charge-discharge history by using the high-priority variable **Discharge cycles**. For more information, see "Variables" on page 1-55.

Modeling Thermal Effects

For thermal variants of the block, you provide additional parameters to define battery behavior at a second temperature. The extended equations for the voltage when the thermal port is exposed are:

$$V = V_{0T} \left[1 - \left(\frac{\alpha_T (1-x)}{1 - \beta_T (1-x)} \right) \right]$$

$$\alpha_T = \alpha \left(1 + \lambda_\alpha \left(T - T_1 \right) \right)$$

$$\beta_T = \beta \left(1 + \lambda_\beta \left(T - T_1 \right) \right)$$

$$V_{0T} = V_0 \left(1 + \lambda_V \left(T - T_1 \right) \right)$$

where:

- T is the battery temperature.
- T_1 is the temperature at which nominal values for α and β are provided.
- λ_α, λ_β, and λ_V are the parameter temperature dependence coefficients for α, β, and V_0, respectively.

The internal series resistance (R_1) and self-discharge resistance (R_2) also become functions of temperature:

$$R_{1T} = R_1 \left(1 + \lambda_{R1} \left(T - T_1 \right) \right)$$
$$R_{2T} = R_2 \left(1 + \lambda_{R2} \left(T - T_1 \right) \right)$$

where λ_{R1} and λ_{R2} are the parameter temperature dependence coefficients. All the temperature dependence coefficients are determined from the corresponding values you provide at the nominal and second measurement temperatures.

The battery temperature is determined from:

$$M_{th}\dot{T} = i^2 R_{1T} + V^2 / R_{2T}$$

where:

- M_{th} is the battery thermal mass.
- i is the battery output current.

Variables

Use the **Variables** tab to set the priority and initial target values for the block variables before simulation. For more information, see "Set Priority and Initial Target for Block Variables" (Simscape) .

Unlike block parameters, variables do not have conditional visibility. The **Variables** tab lists all the existing block variables. If a variable is not used in the set of equations corresponding to the selected block configuration, the values specified for this variable are ignored.

When you model battery fade, the **Discharge cycles** variable lets you specify the number of charge-discharge cycles completed before the start of simulation. For more information, see "Modeling Battery Fade" on page 1-52. If you omit battery fade modeling, this variable is not used by the block.

Assumptions and Limitations

- The self-discharge resistance is assumed not to depend strongly on the number of discharge cycles.
- For the thermal variant of the battery, you provide fade data only for the reference temperature operation. The block applies the same derived λ_{AH}, λ_{R1}, and λ_{V1} multipliers to parameter values corresponding to the second temperature.
- When using the thermal block variants, use caution when operating at temperatures outside of the temperature range bounded by the **Measurement temperature** and **Second temperature measurement** values. The block uses linear interpolation for the derived equation coefficients, and simulation results might become nonphysical outside of the specified range. The block checks that the internal series resistance,

self-discharge resistance, and nominal voltage always remain positive, and issues error messages if there is a violation.

Ports

Output

q — Battery charge level, C
physical signal

Physical signal port that outputs the internal state of charge, in the units of coulomb (C). Use this output port to change load behavior as a function of state of charge, without the complexity of building a charge state estimator.

Dependencies

Enabled for the instrumented variants of the block: **Instrumented | No thermal port** and **Instrumented | Show thermal port**.

Conserving

+ — Positive terminal
electrical

Electrical conserving port associated with the battery positive terminal.

- — Negative terminal
electrical

Electrical conserving port associated with the battery negative terminal.

H — Battery thermal mass
thermal

Thermal conserving port representing the battery thermal mass. When you expose this port, provide additional parameters to define battery behavior at a second temperature. For more information, see "Modeling Thermal Effects" on page 1-54.

Dependencies

Enabled for the thermal variants of the block: **Uninstrumented | Show thermal port** and **Instrumented | Show thermal port**.

Parameters

Main

`Nominal voltage` — Output voltage when battery is fully charged
12 V (default)

No-load voltage across the battery when it is fully charged.

`Internal resistance` — Battery internal resistance
2 Ω (default)

Internal connection resistance of the battery.

`Battery charge capacity` — Select battery model
`Infinite` (default) | `Finite`

Select one of the options for modeling the charge capacity of the battery:

- `Infinite` — The battery voltage is independent of the charge drawn from the battery.
- `Finite` — The battery voltage decreases as the charge decreases.

`Ampere-hour rating` — Nominal battery capacity when fully charged
50 hr*A (default)

This parameter is the maximum (nominal) battery charge in AH. To specify a target value for the initial battery charge at the start of simulation, use the high-priority **Charge** variable. For more information, see "Variables" on page 1-55.

Dependencies

Enabled when the **Battery charge capacity** parameter is set to `Finite`.

Voltage V1 < Vnom when charge is AH1 — Output voltage at charge level AH1
11.5 V (default)

Battery output voltage when the charge level is AH1, as specified by the **Charge AH1 when no-load volts are V1** parameter.

Dependencies

Enabled when the **Battery charge capacity** parameter is set to Finite.

Charge AH1 when no-load volts are V1 — Charge level when the no-load output voltage is V1
25 hr*A (default)

Battery charge level, in AH, corresponding to the no-load output voltage specified by the **Voltage V1 < Vnom when charge is AH1** parameter.

Dependencies

Enabled when the **Battery charge capacity** parameter is set to Finite.

Model self-discharge resistance? — Select whether to model the self-discharge resistance of the battery
Omit (default) | Include

Select whether to model the self-discharge resistance of the battery:

- Omit — Do not include resistance across the battery output terminals in the model.
- Include — Include resistance R2 across the battery output terminals in the model.

Dependencies

Enabled when the **Battery charge capacity** parameter is set to Finite.

Self-discharge resistance — Resistance that represents battery self-discharge
2000 Ω (default)

Resistance across the battery output terminals that represents battery self-discharge.

Dependencies

Enabled when the **Model self-discharge resistance?** parameter is set to `Include`.

`Measurement temperature` — Temperature at which the block parameters are measured
298.15 K (default)

Temperature T_1, at which the block parameters in the **Main** section are measured. For more information, see "Modeling Thermal Effects" on page 1-54.

Dependencies

Enabled for blocks with exposed thermal port.

Fade

`Model battery fade?` — Select whether to model battery performance deterioration with aging
`Omit` (default) | `Include`

Select whether to include battery fade modeling:

- `Omit` — The battery performance is not age-dependent.
- `Include` — The battery performance changes depending on the number of completed charge-discharge cycles. Selecting this option exposes additional parameters in this section, which define the battery performance after a specified number of discharge cycles. The block uses these parameter values to calculate the scaling coefficients k_1, k_2, and k_3. For more information, see "Modeling Battery Fade" on page 1-52.

Dependencies

Enabled when the **Battery charge capacity** parameter in the **Main** section is set to `Finite`. If **Battery charge capacity** is `Infinite`, the **Fade** section is empty.

`Number of discharge cycles, N` — **Number of cycles that defines a second set of data points**
100 (default)

Number of charge-discharge cycles after which the other parameters in this section are measured. This second set of data points defines the scaling coefficients k_1, k_2, and k_3, used in modeling battery fade.

Dependencies

Enabled when the **Model battery fade?** parameter is set to `Include`.

`Ampere-hour rating after N discharge cycles` — **Maximum battery capacity after N discharge cycles**
45 hr*A (default)

Maximum battery charge, in AH, after the number of discharge cycles specified by the **Number of discharge cycles, N** parameter.

Dependencies

Enabled when the **Model battery fade?** parameter is set to `Include`.

`Internal resistance after N discharge cycles` — **Battery internal resistance after N discharge cycles**
2.02 Ω (default)

Battery internal resistance after the number of discharge cycles specified by the **Number of discharge cycles, N** parameter.

Dependencies

Enabled when the **Model battery fade?** parameter is set to `Include`.

`Voltage V1 at charge AH1 after N discharge cycles` — **Output voltage at charge level AH1 after N discharge cycles**
10.35 V (default)

Battery output voltage, at charge level in AH is *AH1*, after the number of discharge cycles specified by the **Number of discharge cycles, N** parameter.

Dependencies

Enabled when the **Model battery fade?** parameter is set to `Include`.

Temperature Dependence

This section appears only for blocks with exposed thermal port. For more information, see "Modeling Thermal Effects" on page 1-54.

Nominal voltage at second measurement temperature — Output voltage when battery is fully charged
12 V (default)

No-load voltage across the battery when it is fully charged.

Internal resistance at second measurement temperature — Battery internal resistance
2.2 Ω (default)

Internal connection resistance of the battery.

Voltage V1 at second measurement temperature — Output voltage at charge level AH1
11.4 V (default)

Battery output voltage when the charge level is AH1, as specified by the **Charge AH1 when no-load volts are V1** parameter.

Dependencies

Enabled when the **Battery charge capacity** parameter in the **Main** section is set to `Finite`.

Self-discharge resistance at second measurement temperature — Resistance that represents battery self-discharge
2200 Ω (default)

Resistance across the battery output terminals that represents battery self-discharge.

Dependencies

Enabled when the **Model self-discharge resistance?** parameter in the **Main** section is set to `Include`.

`Second measurement temperature` — Temperature at which the block parameters in this section are measured
273.15 K (default)

Temperature T_2, at which the block parameters in the **Temperature Dependence** section are measured. For more information, see "Modeling Thermal Effects" on page 1-54.

To specify the initial temperature at the start of simulation, use the high-priority **Temperature** variable. For more information, see "Variables" on page 1-55.

Thermal Port

This section appears only for blocks with exposed thermal port. For more information, see "Modeling Thermal Effects" on page 1-54.

`Thermal mass` — Thermal mass associated with the thermal port
30000 J/K (default)

Thermal mass associated with the thermal port H. It represents the energy required to raise the temperature of the thermal port by one degree.

Model Examples

References

[1] Ramadass, P., B. Haran, R. E. White, and B. N. Popov. "Mathematical modeling of the capacity fade of Li-ion cells." *Journal of Power Sources*. 123 (2003), pp. 230–240.

[2] Ning, G., B. Haran, and B. N. Popov. "Capacity fade study of lithium-ion batteries cycled at high discharge rates." *Journal of Power Sources*. 117 (2003), pp. 160–169.

See Also

See Also
Current Source | Voltage Source

Introduced in R2013b

Brushless DC Motor

Three-winding brushless DC motor with trapezoidal flux distribution
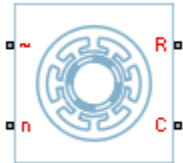
Library

Machines / Permanent Magnet Rotor

Description

The Brushless DC Motor block models a permanent magnet synchronous machine with a three-phase wye-wound stator. The block has four options for defining the permanent magnet flux distribution as a function of rotor angle. Two options allow for simple parameterization by assuming a perfect trapezoid for the back emf. For simple parameterization, you specify either the flux linkage or the rotor-induced back emf. The other two options give more accurate results using tabulated data that you specify. For more accurate results, you specify either the flux linkage partial derivative or the measured back emf constant for a given rotor speed.

The figure shows the equivalent electrical circuit for the stator windings.
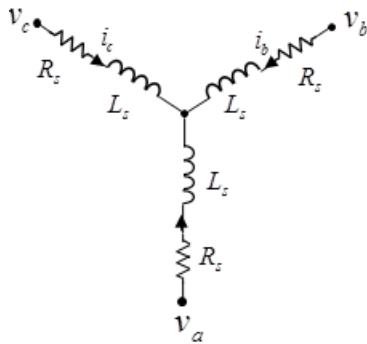
Motor Construction

This figure shows the motor construction with a single pole-pair on the rotor.
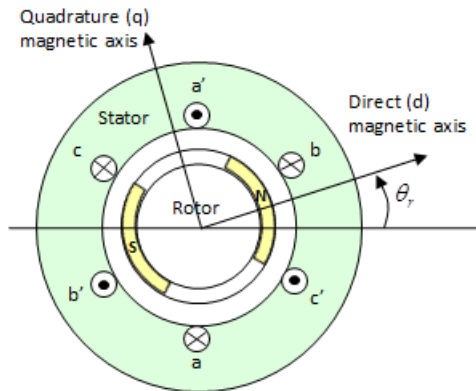
For the axes convention in the preceding figure, the a-phase and permanent magnet fluxes are aligned when rotor angle θ_r is zero. The block supports a second rotor-axis definition. For the second definition, the rotor angle is the angle between the a-phase magnetic axis and the rotor q-axis.

Trapezoidal Rate of Change of Flux

The rotor magnetic field due to the permanent magnets create a trapezoidal rate of change of flux with rotor angle. The figure shows this rate of change of flux.
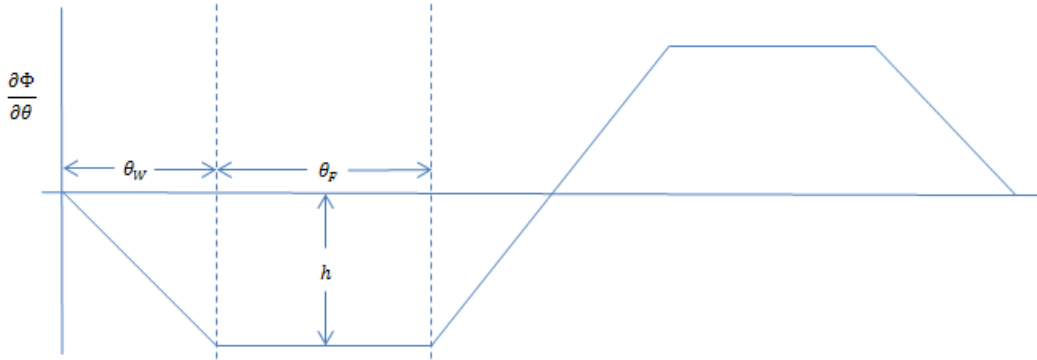
Back emf is the rate of change of flux, defined by

$$\frac{d\Phi}{dt} = \frac{\partial\Phi}{\partial\theta}\frac{d\theta}{dt} = \frac{\partial\Phi}{\partial\theta}\omega,$$

where:

- Φ is the permanent magnet flux linkage.
- θ is the rotor angle.
- ω is the mechanical rotational speed.

The height h of the trapezoidal rate of change of flux profile is derived from the permanent magnet peak flux.

Integrating $\dfrac{\partial\Phi}{\partial\theta}$ over the range 0 to п/2,

$$\Phi_{max} = \frac{h}{2}(\theta_F + \theta_W),$$

where:

- Φ_{max} is the permanent magnet flux linkage.
- h is the rate of change of flux profile height.
- θ_F is the rotor angle range over which the back emf that the permanent magnet flux induces in the stator is constant.

- θ_W is the rotor angle range over which back emf increases or decreases linearly when the rotor moves at constant speed.

Rearranging the preceding equation,

$$h = 2\Phi_{max} / (\theta_F + \theta_W).$$

Electrical Defining Equations

Voltages across the stator windings are defined by

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} \dfrac{d\psi_a}{dt} \\ \dfrac{d\psi_b}{dt} \\ \dfrac{d\psi_c}{dt} \end{bmatrix},$$

where:

- v_a, v_b, and v_c are the external voltages applied to the three motor electrical connections.
- R_s is the equivalent resistance of each stator winding.
- i_a, i_b, and i_c are the currents flowing in the stator windings.
- $\dfrac{d\psi_a}{dt}$, $\dfrac{d\psi_b}{dt}$, and $\dfrac{d\psi_c}{dt}$

  are the rates of change of magnetic flux in each stator winding.

The permanent magnet and the three windings contribute to the total flux linking each winding. The total flux is defined by

$$\begin{bmatrix} \psi_a \\ \psi_b \\ \psi_c \end{bmatrix} = \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} \psi_{am} \\ \psi_{bm} \\ \psi_{cm} \end{bmatrix},$$

where:

- ψ_a, ψ_b, and ψ_c are the total fluxes linking each stator winding.
- L_{aa}, L_{bb}, and L_{cc} are the self-inductances of the stator windings.
- L_{ab}, L_{ac}, L_{ba}, etc. are the mutual inductances of the stator windings.
- ψ_{am}, ψ_{bm}, and ψ_{cm} are the permanent magnet fluxes linking the stator windings.

The inductances in the stator windings are functions of rotor angle, defined by

$$L_{aa} = L_s + L_m \cos(2\theta_r),$$

$$L_{bb} = L_s + L_m \cos(2(\theta_r - 2\pi/3)),$$

$$L_{cc} = L_s + L_m \cos(2(\theta_r + 2\pi/3)),$$

$$L_{ab} = L_{ba} = -M_s - L_m \cos(2(\theta_r + \pi/6)),$$

$$L_{bc} = L_{cb} = -M_s - L_m \cos(2(\theta_r + \pi/6 - 2\pi/3)),$$

and

$$L_{ca} = L_{ac} = -M_s - L_m \cos(2(\theta_r + \pi/6 + 2\pi/3)),$$

where:

- L_s is the stator self-inductance per phase — The average self-inductance of each of the stator windings.
- L_m is the stator inductance fluctuation — The amplitude of the fluctuation in self-inductance and mutual inductance with changing rotor angle.
- M_s is the stator mutual inductance — The average mutual inductance between the stator windings.

The permanent magnet flux linking each stator winding follows the trapezoidal profile shown in the figure. The block implements the trapezoidal profile using lookup tables to calculate permanent magnet flux values.

Simplified Equations

The defining voltage and torque equations for the block are

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = P \left(\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} - N\omega \begin{bmatrix} \dfrac{\partial \psi_a}{\partial \theta_r} \\ \dfrac{\partial \psi_b}{\partial \theta_r} \\ \dfrac{\partial \psi_c}{\partial \theta_r} \end{bmatrix} \right),$$

$$v_d = R_s i_d + L_d \frac{di_d}{dt} - N\omega i_q L_q,$$

$$v_q = R_s i_q + L_q \frac{di_q}{dt} + N\omega i_d L_d,$$

$$v_0 = R_s i_0 + L_0 \frac{di_0}{dt},$$

and

$$T = \frac{3}{2} N \left(i_q i_d L_d - i_d i_q L_q \right) + \begin{bmatrix} i_a & i_b & i_c \end{bmatrix} \begin{bmatrix} \dfrac{\partial \psi_a}{\partial \theta_r} \\ \dfrac{\partial \psi_b}{\partial \theta_r} \\ \dfrac{\partial \psi_c}{\partial \theta_r} \end{bmatrix},$$

where:

- v_d, v_q, and v_0 are the d-axis, q-axis, and zero-sequence voltages.

- P is Park's Transformation, defined by

$$P = 2/3 \begin{bmatrix} \cos\theta_e & \cos(\theta_e - 2\pi/3) & \cos(\theta_e + 2\pi/3) \\ -\sin\theta_e & -\sin(\theta_e - 2\pi/3) & -\sin(\theta_e + 2\pi/3) \\ 0.5 & 0.5 & 0.5 \end{bmatrix}.$$

- N is the number of rotor permanent magnet pole pairs.

- ω is the rotor mechanical rotational speed.

- $$\frac{\partial\psi_a}{\partial\theta_r}, \frac{\partial\psi_b}{\partial\theta_r}, \text{ and } \frac{\partial\psi_c}{\partial\theta_r}$$

  are the partial derivatives of instantaneous permanent magnet flux linking each phase winding.

- i_d, i_q, and i_0 are the d-axis, q-axis, and zero-sequence currents, defined by

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = P \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}.$$

- $L_d = L_s + M_s + 3/2\ L_m$. L_d is the stator d-axis inductance.

- $L_q = L_s + M_s - 3/2\ L_m$. L_q is the stator q-axis inductance.

- $L_0 = L_s - 2M_s$. L_0 is the stator zero-sequence inductance.

- T is the rotor torque. Torque flows from the motor case (block physical port C) to the motor rotor (block physical port R).

Parameters

Rotor Tab

Back EMF profile

Parameterization for defining the permanent magnet flux distribution as a function of rotor angle. Choose:

- `Perfect trapezoid - specify maximum flux linkage` to specify the maximum flux linkage for the permanent magnet and the rotor angle where the back emf is constant. The block assumes a perfect trapezoid for the back emf. This is the default value.

- `Perfect trapezoid - specify maximum rotor-induced back emf` to specify the maximum rotor-induced back emf and the corresponding rotor speed. The block assumes a perfect trapezoid for the back emf.

- `Tabulated - specify flux partial derivative with respect to rotor angle` to specify values for the partial derivative of flux linkage and the corresponding rotor angles.

- `Tabulated - specify rotor-induced back emf as a function of rotor angle` to specify the measured back emf constant and the corresponding rotor speed and angles.

Maximum permanent magnet flux linkage

Peak permanent magnet flux linkage with any of the stator windings. This parameter is visible only when **Back EMF profile** is set to `Perfect trapezoid - specify maximum flux linkage`. The default value is `0.03` Wb.

Rotor angle over which back emf is constant

Rotor angle range over which the permanent magnet flux linking the stator winding is constant. This angle is θ_F in the figure that shows the "Trapezoidal Rate of Change of Flux" on page 1-65. This parameter is visible only when **Back EMF profile** is set to `Perfect trapezoid - specify maximum flux linkage`. The default value is `pi / 12` rad.

Maximum rotor-induced back emf

Peak rotor-induced back emf into the stator windings. This parameter is visible only when **Back EMF profile** is set to `Perfect trapezoid - specify maximum rotor-induced back emf`. The default value is `9.6` V.

Rotor-induced back emf

Vector of values for the rotor-induced back emf as a function of rotor angle. The first and last values must be the same, and are normally both zero. For more information, see the **Corresponding rotor angles** parameter. First and last values are the same because flux is cyclic with period $2\pi / N$, where N is the number of permanent magnet pole pairs. This parameter is visible only when **Back EMF profile** is set to `Tabulated - specify rotor-induced back emf as a function of rotor angle`. The default value is `[0.0, -9.6, -9.6, 9.6, 9.6, 0.0]` V.

Flux linkage partial derivative with respect to rotor angle

Vector of values for the partial derivative of flux linkage (where flux linkage is flux times number of winding turns) with respect to rotor angle. The first and last values must be the same, and are normally both zero. For more information, see the **Corresponding rotor angles** parameter. First and last values are the same because flux is cyclic with period $2\pi/N$, where N is the number of permanent magnet pole pairs. This parameter is visible only when **Back EMF profile** is set to `Tabulated - specify flux partial derivative with respect to rotor angle`. The default value is `[0.0, -0.1528, -0.1528, 0.1528, 0.1528, 0.0] Wb/rad`.

Corresponding rotor angles

Vector of rotor angles where the flux linkage partial derivative or rotor-induced back emf is defined. Rotor angle is defined as the angle between the a-phase magnetic axis and the d-axis. That is, when the angel is zero, the magnetic fields due to the rotor and the a-phase winding align. This definition is used regardless of your block setting for rotor angle definition. The first value is zero, and the last value is $2\pi/N$, where N is the number of permanent magnet pole pairs. This parameter is visible only when **Back EMF profile** is set to `Tabulated - specify flux partial derivative with respect to rotor angle` or to `Tabulated - specify rotor-induced back emf as a function of rotor angle`. The default value is `[0, 7.5, 22.5, 37.5, 52.5, 60] deg`.

Rotor speed used for back emf measurement

Specify the rotor speed used when quotoring the maximum rotor-induced back emf. This parameter is visible only when **Back EMF profile** is set to `Perfect trapezoid - specify maximum rotor-induced back emf` or `Tabulated - specify rotor-induced back emf as a function of rotor angle`. The default value is `600 rpm`.

Number of pole pairs

Number of permanent magnet pole pairs on the rotor. The default value is `6`.

Stator Tab

Stator parameterization

Choose `Specify Ld, Lq, and L0`, the default value, or `Specify Ls, Lm, and Ms`.

Stator d-axis inductance, Ld

D-axis inductance. This parameter is visible only if you set **Stator parameterization** to `Specify Ld, Lq, and L0`. The default value is `0.00022` H.

Stator q-axis inductance, Lq

Q-axis inductance. This parameter is visible only if you set **Stator parameterization** to `Specify Ld, Lq, and L0`. The default value is `0.00022` H.

Stator zero-sequence inductance, L0

Zero-sequence inductance. This parameter is visible only if you set **Stator parameterization** to `Specify Ld, Lq, and L0`. The default value is `0.00016` H.

Stator self-inductance per phase, Ls

Average self-inductance of each of the three stator windings. This parameter is visible only if you set **Stator parameterization** to `Specify Ls, Lm, and Ms`. The default value is `0.00002` H.

Stator inductance fluctuation, Lm

Amplitude of the fluctuation in self-inductance and mutual inductance of the stator windings with rotor angle. This parameter is visible only if you set **Stator parameterization** to `Specify Ls, Lm, and Ms`. The default value is `0` H.

Stator mutual inductance, Ms

Average mutual inductance between the stator windings. This parameter is visible only if you set **Stator parameterization** to `Specify Ls, Lm, and Ms`. The default value is `0.00002` H.

Stator resistance per phase, Rs

Resistance of each of the stator windings. The default value is `0.013` Ohm.

Initial Conditions Tab

Initial currents, [i_d i_q i_0]

Initial d-axis, q-axis, and zero-sequence currents. The default value is `[0, 0, 0]` A.

Rotor angle definition

Reference point for the rotor angle measurement. The default value is `Angle between the a-phase magnetic axis and the d-axis`. This definition is shown in the "Motor Construction" on page 1-65 figure. When you select this value, the rotor and a-phase fluxes are aligned when the rotor angle is zero.

The other value you can choose for this parameter is `Angle between the a-phase magnetic axis and the q-axis`. When you select this value, the a-phase current generates maximum torque when the rotor angle is zero.

Initial rotor angle

> Initial angle of the rotor. The default value is `0 deg`.

Ports

~

> Expandable three-phase port

n

> Electrical conserving port associated with the neutral phase

R

> Mechanical rotational conserving port associated with the motor rotor

C

> Mechanical rotational conserving port associated with the motor case

References

[1] Kundur, P. *Power System Stability and Control.* New York, NY: McGraw Hill, 1993.

[2] Anderson, P. M. *Analysis of Faulted Power Systems.* Hoboken, NJ: Wiley-IEEE Press, 1995.

See Also

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Cauer Thermal Model Element

Heat transfer through an individual layer of a semiconductor module

Library

Semiconductors / Fundamental Components / Thermal

Description

The Cauer Thermal Model Element block represents heat transfer through an individual layer of a semiconductor module. The figure shows an equivalent circuit for a Cauer Thermal Model Element block.
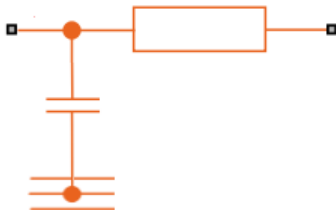
A Cauer thermal model represents the multiple layers that constitute the packaging of a semiconductor. Layers include chip, solder, substrate, solder, and base. Other terms that describe a Cauer thermal model are:

- Continued fraction circuit
- T model
- Ladder network

To create a Cauer thermal model, connect multiple instances of the Cauer Thermal Model Element block in series. In the figure of the Cauer thermal model, T_j is the junction temperature and T_c is the base plate temperature.
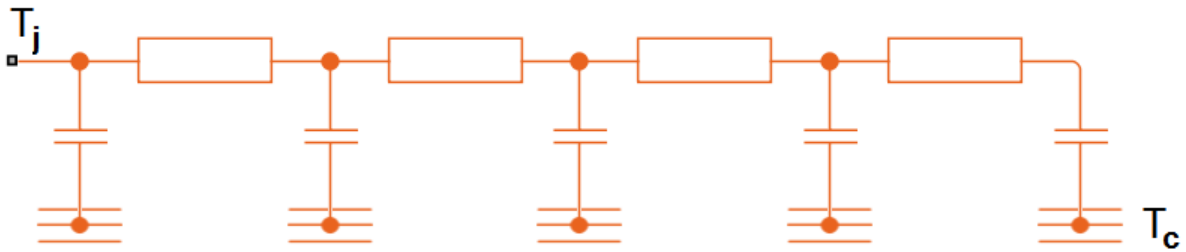
The defining equations for the Cauer Thermal Model Element block are:

$$C_{thermal} = \frac{\tau}{R_{thermal}},$$

$$Q_{AB} = \frac{T_{AB}}{R_{thermal}},$$

and

$$Q_{AR} = C_{thermal} \frac{dT_{AR}}{dt},$$

where:

- $C_{thermal}$ is the thermal capacity.
- τ is the thermal time constant.
- $R_{thermal}$ is the thermal resistance.
- Q_{AB} is the heat flow through the material.
- T_{AB} is the temperature difference between the material layers.
- Q_{AR} is the heat flow through the thermal capacity.
- T_{AR} is the temperature drop across the thermal capacity.

Parameters

- "Parameters Tab" on page 1-77
- "Variables Tab" on page 1-77

Parameters Tab

Thermal resistance

The default value for the thermal resistance, $R_{thermal}$, is `5e-3 K/W`.

Thermal time constant

The default value for the thermal time constant, τ, is `0.1 s`.

Variables Tab

Use the **Variables** tab to set the priority and initial target values for the block variables before simulation. For more information, see "Set Priority and Initial Target for Block Variables" (Simscape) .

Unlike block parameters, variables do not have conditional visibility. The **Variables** tab lists all the existing block variables. If a variable is not used in the set of equations corresponding to the selected block configuration, the values specified for this variable are ignored.

Ports

The block has the following ports:

A

Thermal conserving port associated with the first surface of the individual layer of the semiconductor.

R

Thermal conserving port associated with the chosen thermal reference.

B

Thermal conserving port associated with the second surface of the individual layer of the semiconductor.

References

[1] Schütze, T. *AN2008-03: Thermal equivalent circuit models.* Application Note. V1.0. Germany: Infineon Technologies AG, 2008.

See Also

See Also
```
Foster Thermal Model | Thermal Resistor
```

Topics

Introduced in R2016a

Commutation Diode

Piecewise linear diode with charge dynamics and junction capacitance

Library

Semiconductors / Fundamental Components

Description

The Commutation Diode block augments the Diode block with a model of charge dynamics. For a description of the piecewise linear diode operation that the Commutation Diode block uses, see Diode.

Use the Commutation Diode block in place of the Diode block when you want to specify precisely the charge dynamics of the device as it operates in reverse mode. For example, suppose that your model uses the diode to divert inductive currents from a motor drive or inverter. In this case, precise reverse-mode operation is important and an appropriate time to use the Commutation Diode block.

The Commutation Diode uses a charge model proposed by Lauritzen and Ma [1]. The defining expressions for this charge model are:

$$i = \frac{q_E - q_M}{T_M}$$

$$\frac{dq_M}{dt} + \frac{q_M}{\tau} - \frac{q_E - q_M}{T_M} = 0$$

$$\begin{aligned} q_E &= (\tau + T_M)(v_D - v_F(1 - RG))/R) \quad &if \quad v_D > v_F \\ q_E &= (\tau + T_M)Gv_D \quad &if \quad v_D \le v_F \end{aligned}$$

where:

- i is the diode current.
- q_E is the junction charge.
- q_M is the total stored charge.
- T_M is the transit time.
- τ is the carrier lifetime.
- v_D is the voltage across the diode.
- v_F is the diode forward voltage.
- R is the diode on resistance.
- G is the diode off conductance.

This graphic shows a typical reverse-mode current characteristic for a diode device.
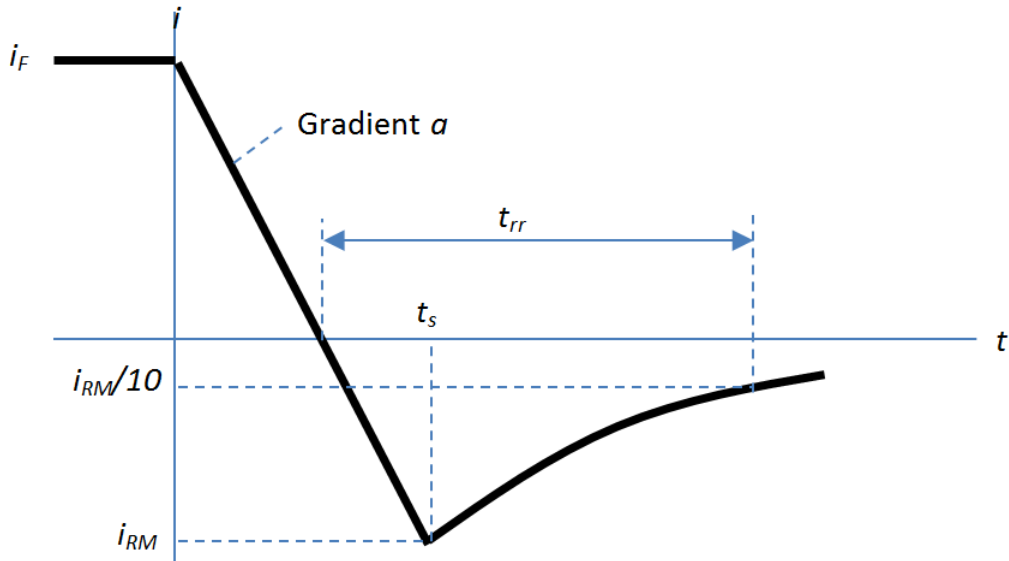
where:

- i_{RM} is the peak reverse current.
- i_F is the starting forward current when measuring i_{RM}.

- a is the rate of change of current when measuring i_{RM}.

- t_{rr} is the reverse recovery time.

On the Charge Dynamics tab of the block, you specify characteristics of your diode device. The block uses these values to calculate the diode charge dynamics expressed in equations 1–1, 1–2, and 1–3.

Data sheets for diodes quote values for peak reverse current for an initial forward current and a steady rate of change of current. The data sheet might also provide values for reverse recovery time and total recovery charge.

How the Block Calculates T_M and Tau

The block calculates transit time T_M and carrier lifetime τ based on the values you enter on the Charge Dynamics tab of the block dialog box. The block uses T_M and τ to solve the charge dynamics equations 1–1, 1–2, and 1–3.

During initial current drop in reverse mode, the diode is still on, and the rate of change of current is determined by an external test circuit.

Using Equation 1–1,

$$i_F + at = \frac{q_E - q_M}{T_M}.$$

Substituting Equation 1–4 into Equation 1–2,

$$\frac{dq_M}{dt} + \frac{q_M}{\tau} = i_F + at.$$

Solving Equation 1–5 for q_M,

$$q_M = i_F \tau - a\tau^2 + \frac{k}{\exp\left(\dfrac{t}{\tau}\right)} + a\tau t,$$

where k is a constant.

When t is zero, $i = i_F$ and $q_M = \tau i_F$ because the system is in steady state.

Substituting these relationships into Equation 1–6 and solving the equation gives $k = a\tau^2$.

Therefore,

$$q_M = i_F\tau + a\tau^2 \left(\frac{1}{\exp\left(\dfrac{t}{\tau}\right)} - 1 \right) + a\tau t.$$

At time $t = t_s$, the current is i_{RM} and the junction charge q_E is zero.

Substituting these values into Equation 1–1,

$$i_{RM} = \frac{-q_M}{T_M}.$$

Rearranging Equation 1–8 to solve for q_M and substituting the result into Equation 1–7,

$$-T_M i_{RM} = i_F\tau + a\tau^2 \left(\frac{1}{\exp\left(\dfrac{t_s}{\tau}\right)} - 1 \right) + a\tau t_s.$$

Expressing time t_s in terms of i_{RM}, i_F, and a,

$$t_s = \frac{i_{RM} - i_F}{a}.$$

Consider the diode recovery, that is, when $t > t_s$. The diode is reverse biased, and current and junction charge are effectively zero.

The current is defined by

$$i = i_{RM}\exp[\frac{-(t - t_s)}{\tau_{rr}}],$$

where

$$\frac{1}{\tau_{rr}} = \frac{1}{\tau} + \frac{1}{T_M}.$$

The block now relates the expression in Equation 1–12 to the reverse recovery time t_{rr}.

When $t = \frac{i_{RM}}{a} + t_{rr}$, the current is $\frac{i_{RM}}{10}$.

Therefore,

$$\exp\left(-\frac{t - t_s}{\tau_{rr}}\right) = 0.1$$

and

$$t_{rr} = \tau_{rr} \log(10) + \frac{i_{RM}}{a}.$$

The block uses equations 1–9 and 1–14 to calculate values for T_M and τ. The calculation uses an iterative scheme because of the exponential term in Equation 1–9.

Alternatives to Specifying t_{rr} Directly

In addition to allowing you to specify reverse recovery time t_{rr} directly, the block supports two alternative parameterizations. The block can derive t_{rr} from either of these parameters:

- Reverse recovery time stretch factor λ
- Reverse recovery charge Q_{rr}, when the data sheet specifies this value instead of the reverse recovery time.

The relationship between reverse recovery time stretch factor λ and t_{rr} is expressed by the equation

$$\lambda = \frac{t_{rr}\,a}{i_{RM}}.$$

Reverse recovery time must be greater than $\frac{i_{RM}}{a}$ and a typical value is $3\left(\frac{i_{RM}}{a}\right).$

Therefore, a typical value for λ is 3. λ must be greater than 1.

Reverse recovery charge Q_{rr} is the integral over time of the reverse current from the point where the current goes negative until it decays back to zero.

The initial charge, to time t_s (as shown in the figure), is expressed by the equation

$$Q_s = \frac{1}{2}\left(-i_{RM}\right)\frac{i_{RM}}{a}.$$

Integrating Equation 1–11 gives the charge between times t_s and inf. This charge is equal to

$$\tau_{rr}\,i_{RM}.$$

Therefore, total reverse recovery charge is given by the equation

$$Q_{rr} = -\frac{i_{RM}^2}{2a} + \tau_{rr}\,i_{RM}.$$

Rearranging Equation 1–16 to solve for τ_{rr} and substituting the result into Equation 1–14 gives an equation that expresses t_{rr} in terms of Q_{rr}:

$$t_{rr} = \left(\frac{Q_{rr}}{i_{RM}} + \frac{i_{RM}}{2a}\right)\log\left(10\right) + \frac{i_{RM}}{a}.$$

Modeling Variants

The block provides a thermal modeling variant. To select a variant, right-click the block in your model. From the context menu, select **Simscape** > **Block choices**, and then one of these variants:

- **No thermal port** — This variant does not simulate heat generation in the device. This variant is the default.
- **Show thermal port** — This variant contains a thermal port that allows you to model the heat that conduction losses generate. For numerical efficiency, the thermal state does not affect the electrical behavior of the block. The thermal port is hidden by default. When you select a thermal variant of the block, the thermal port appears.

Ports

+

Electrical conserving port associated with the diode positive terminal

-

Electrical conserving port associated with the diode negative terminal

H

Thermal conserving port. The thermal port is optional and is hidden by default. To enable this port, select a variant that includes a thermal port.

Parameters

- "Main Tab" on page 1-85
- "Charge Dynamics Tab" on page 1-86

Main Tab

Forward voltage

Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is `0.8 V`.

On resistance

Rate of change of voltage versus current above the **Forward voltage**. The default value is `0.001 Ohm`.

Off conductance

Conductance of the reverse-biased diode. The default value is `1e-5 1/Ohm`.

Number of series diodes

The number of diodes connected in series between the + and - block ports. Each diode has the **Forward voltage**, **On resistance**, and **Off conductance** that you specify. The default value is `1`.

Number of parallel diodes

The number of parallel diodes, or number of parallel paths formed by series-connected diodes, between the + and - block ports. Each diode has the **Forward voltage**, **On resistance**, and **Off conductance** that you specify. The default value is `1`.

Charge Dynamics Tab

Junction capacitance

Diode junction capacitance. The default value is `50 nF`.

Peak reverse current, iRM

Peak reverse current measured by an external test circuit. This value must be less than zero. The default value is `-235 A`.

Initial forward current when measuring iRM

Initial forward current when measuring peak reverse current. This value must be greater than zero. The default value is `300 A`.

Rate of change of current when measuring iRM

Rate of change of current when measuring peak reverse current. This value must be less than zero. The default value is `-50 A/`μ`s`.

Reverse recovery time parameterization

Determines how you specify reverse recovery time in the block. The default value is `Specify reverse recovery time directly`.

If you select `Specify stretch factor` or `Specify reverse recovery charge`, you specify a value that the block uses to derive the reverse recovery time. For more information on these options, see "Alternatives to Specifying t_{rr} Directly" on page 1-83.

Reverse recovery time, trr

Interval between the time when the current initially goes to zero (when the diode turns off) and the time when the current falls to less than 10% of the peak reverse current. The default value is `15` μ`s`.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery time directly`.

The value of the **Reverse recovery time, trr** parameter must be greater than the value of the **Peak reverse current, iRM** parameter divided by the value of the **Rate of change of current when measuring iRM** parameter.

Reverse recovery time stretch factor

Value that the block uses to calculate **Reverse recovery time, trr**. This value must be greater than 1. The default value is 3.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify stretch factor`.

Specifying the stretch factor is an easier way to parameterize the reverse recovery time than specifying the reverse recovery charge. The larger the value of the stretch factor, the longer it takes for the reverse recovery current to dissipate.

Reverse recovery charge, Qrr

Value that the block uses to calculate **Reverse recovery time, trr**. Use this parameter if the data sheet for your diode device specifies a value for the reverse recovery charge instead of a value for the reverse recovery time.

The reverse recovery charge is the total charge that continues to dissipate when the diode turns off. The value must be less than $-\dfrac{i^2_{RM}}{2a}$,

where:

- i_{RM} is the value specified for **Peak reverse current, iRM**.
- a is the value specified for **Rate of change of current when measuring iRM**.

The default value is 1500 μAs.

The parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery charge`.

References

[1] Lauritzen, P.O. & C.L. Ma, "A Simple Diode Model with Reverse Recovery." *IEEE*® *Transactions on Power Electronics*. Vol. 6, No. 2, 1991, pp. 188–191.

See Also

See Also
Diode | GTO | Ideal Semiconductor Switch | IGBT | MOSFET | Thyristor

Topics
"Simulate Thermal Losses in Semiconductors"

Introduced in R2013b

Converter

Connect three-phase AC network to DC network

Library

Semiconductors

Description

The Converter block models a three-arm converter circuit that connects a three-phase AC network to a DC network.

Each component in the three-arm circuit is the same switching device, which you specify using an option on the Converter block dialog box. The switching devices that you can specify are in the Semiconductors / Fundamental Components library.

The figure shows the equivalent circuit for a converter with fully controlled switching devices (e.g. IGBTs, GTOs).
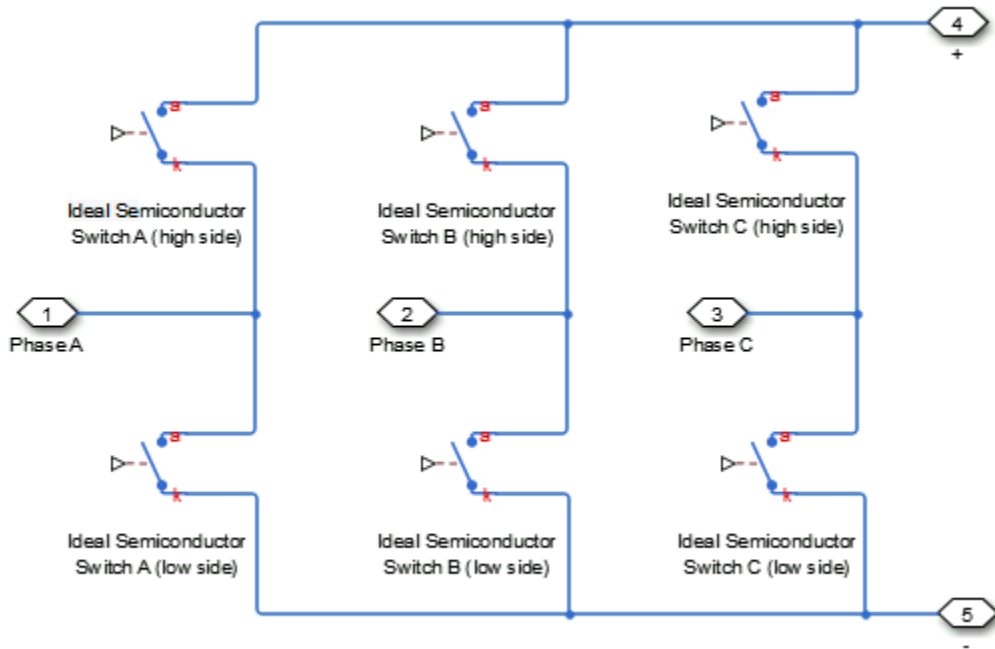
The figure shows the equivalent circuit for a converter with partially controlled switching devices (e.g. thyristors).
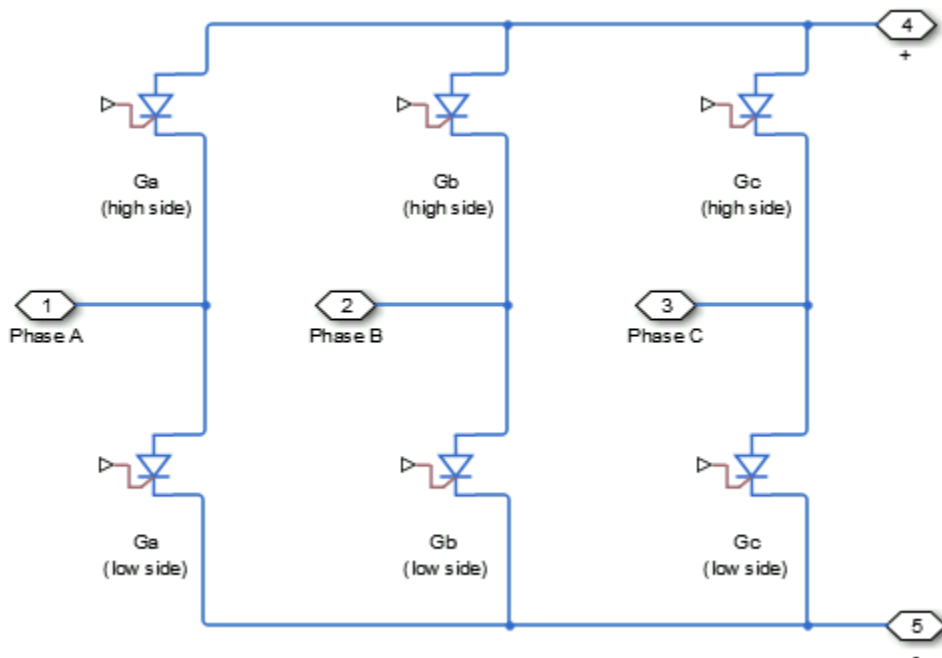
Control the gate ports of the six switching devices via an input to port G on the Converter block:

1 Multiplex all six gate signals into a single vector with a `Six-Pulse Gate Multiplexer` block.

2 Connect the output of the Six-Pulse Gate Multiplexer block to the Converter block `G` port.

You can specify an integral protection diode for each switching device. An integral diode protects the semiconductor device by providing a conduction path for reverse current. An inductive load can produce a high reverse-voltage spike when the semiconductor device suddenly switches off the voltage supply to the load.

The table shows you how to set the **Integral protection diode** parameter based on your goals.

Goal	Value to Select	Block Behavior
Prioritize simulation speed.	`Protection diode with no dynamics`	The block includes an integral copy of the `Diode` block. The block dialog box shows parameters relating to the Diode block.
Precisely specify reverse-mode charge dynamics.	`Protection diode with charge dynamics`	The block includes an integral copy of the `Commutation Diode` block. The block dialog box shows parameters relating to the Commutation Diode block.

You can include a snubber circuit, consisting of a resistor and capacitor connected in series, for each switching device. Snubber circuits protect switching devices against high voltages that inductive loads produce when the device turns off the voltage supply to the load. Snubber circuits also prevent excessive rates of change of current when a switching device turns on.

Parameters

- "Switching Devices Tab" on page 1-92
- "Protection Diodes Tab" on page 1-95
- "Snubbers Tab" on page 1-98

Switching Devices Tab

Switching device

Converter switching device. The default value is `Ideal Semiconductor Switch`.

The switching devices you can select are:

- `GTO`
- `Ideal Semiconductor Switch`
- `IGBT`
- `MOSFET`

- Thyristor

GTO Parameters

When you select GTO, parameters for the GTO block appear.

Additional GTO Parameters

Forward voltage, Vf

Minimum voltage required across the anode and cathode block ports for the gradient of the device i-v characteristic to be $1/R_{on}$, where R_{on} is the value of **On-state resistance**. The default value is 0.8 V.

On-state resistance

Rate of change of voltage versus current above the forward voltage. The default value is 0.001 Ohm.

Off-state conductance

Anode-cathode conductance when the device is off. The value must be less than $1/R$, where R is the value of **On-state resistance**. The default value is 1e-6 1/Ohm.

Gate trigger voltage, Vgt

Gate-cathode voltage threshold. The device turns on when the gate-cathode voltage is above this value. The default value is 1 V.

Gate turn-off voltage, Vgt_off

Gate-cathode voltage threshold. The device turns off when the gate-cathode voltage is below this value. The default value is -1 V.

Holding current

Current threshold. The device stays on when the current is above this value, even when the gate-cathode voltage falls below the gate trigger voltage. The default value is 1 A.

For more information, see GTO.

Ideal Semiconductor Switch Parameters

When you select Ideal Semiconductor Switch, parameters for the Ideal Semiconductor Switch block appear.

Additional Ideal Semiconductor Switch Parameters

On-state resistance

Anode-cathode resistance when the device is on. The default value is `0.001 1/Ohm`.

Off-state conductance

Anode-cathode conductance when the device is off. The value must be less than 1/R, where R is the value of **On-state resistance**. The default value is `1e-6 1/Ohm`.

Threshold voltage, Vth

Gate-cathode voltage threshold. The device turns on when the gate-cathode voltage is above this value. The default value is `6 V`.

For more information, see `Ideal Semiconductor Switch`.

IGBT Parameters

When you select `IGBT`, parameters for the IGBT block appear.

Additional IGBT Parameters

Forward voltage, Vf

Minimum voltage required across the collector and emitter block ports for the gradient of the diode i-v characteristic to be $1/R_{on}$, where R_{on} is the value of **On-state resistance**. The default value is `0.8 V`.

On-state resistance

Collector-emitter resistance when the device is on. The default value is `0.001 Ohm`.

Off-state conductance

Collector-emitter conductance when the device is off. The value must be less than 1/R, where R is the value of **On-state resistance**. The default value is `1e-6 1/Ohm`.

Threshold voltage, Vth

Collector-emitter voltage at which the device turns on. The default value is `6 V`.

For more information, see `IGBT`.

MOSFET Parameters

When you select `MOSFET`, parameters for the MOSFET block appear.

Additional MOSFET Parameters

On-state resistance, R_DS(on)

Drain-source resistance when the device is on. The default value is `0.001 Ohm`.

Off-state conductance

Drain-source conductance when the device is off. The value must be less than 1/R, where R is the value of **On-state resistance**. The default value is `1e-6 1/Ohm`.

Threshold voltage, Vth

Gate-source voltage threshold. The device turns on when the gate-source voltage is above this value. The default value is `6 V`.

For more information, see `MOSFET`.

Thyristor Parameters

When you select `Thyristor`, parameters for the Thyristor block appear.

Additional Thyristor Parameters

Forward voltage, Vf

Forward voltage at which the device turns on. The default value is `0.8 V`.

On-state resistance

Anode-cathode resistance when the device is on. The default value is `0.001 Ohm`.

Off-state conductance

Anode-cathode conductance when the device is off. The value must be less than 1/R, where R is the value of **On-state resistance**. The default value is `1e-6 1/Ohm`.

Gate trigger voltage, Vgt

Gate-cathode voltage threshold. The device turns on when the gate-cathode voltage is above this value. The default value is `1 V`.

Holding current

Current threshold. The device stays on when the current is above this value, even when the gate-cathode voltage falls below the gate trigger voltage. The default value is `1 A`.

For more information, see `Thyristor`.

Protection Diodes Tab

Integral protection diode

Integral protection diode for each switching device. The default value is `None`.

The diodes you can select are:

- `Protection diode with no dynamics`
- `Protection diode with charge dynamics`

Parameters for Protection Diode with No Dynamics

When you select `Protection diode with no dynamics`, additional parameters appear.

Additional Parameters for Protection Diode with No Dynamics

Forward voltage

   Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is `0.8 V`.

On resistance

   Rate of change of voltage versus current above the **Forward voltage**. The default value is `0.001 Ohm`.

Off conductance

   Conductance of the reverse-biased diode. The default value is `1e-5 1/Ohm`.

For more information on these parameters, see `Diode`.

Parameters for Protection Diode with Charge Dynamics

When you select `Protection diode with charge dynamics`, additional parameters appear.

Additional Parameters for Protection Diode with Charge Dynamics

Forward voltage

   Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is `0.8 V`.

On resistance

   Rate of change of voltage versus current above the **Forward voltage**. The default value is `0.001 Ohm`.

Off conductance

Conductance of the reverse-biased diode. The default value is `1e-5 1/Ohm`.

Junction capacitance

Diode junction capacitance. The default value is `50 nF`.

Peak reverse current, iRM

Peak reverse current measured by an external test circuit. This value must be less than zero. The default value is `-235 A`.

Initial forward current when measuring iRM

Initial forward current when measuring peak reverse current. This value must be greater than zero. The default value is `300 A`.

Rate of change of current when measuring iRM

Rate of change of current when measuring peak reverse current. This value must be less than zero. The default value is `-50 A/`μ`s`.

Reverse recovery time parameterization

Determines how you specify reverse recovery time in the block. The default value is `Specify reverse recovery time directly`.

If you select `Specify stretch factor` or `Specify reverse recovery charge`, you specify a value that the block uses to derive the reverse recovery time. For more information on these options, see "Alternatives to Specifying t_{rr} Directly" on page 1-83.

Reverse recovery time, trr

Interval between the time when the current initially goes to zero (when the diode turns off) and the time when the current falls to less than 10% of the peak reverse current. The default value is `15 `μ`s`.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery time directly`.

The value of the **Reverse recovery time, trr** parameter must be greater than the value of the **Peak reverse current, iRM** parameter divided by the value of the **Rate of change of current when measuring iRM** parameter.

Reverse recovery time stretch factor

Value that the block uses to calculate **Reverse recovery time, trr**. This value must be greater than `1`. The default value is `3`.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify stretch factor`.

Specifying the stretch factor is an easier way to parameterize the reverse recovery time than specifying the reverse recovery charge. The larger the value of the stretch factor, the longer it takes for the reverse recovery current to dissipate.

Reverse recovery charge, Qrr

Value that the block uses to calculate **Reverse recovery time, trr**. Use this parameter if the data sheet for your diode device specifies a value for the reverse recovery charge instead of a value for the reverse recovery time.

The reverse recovery charge is the total charge that continues to dissipate when the diode turns off. The value must be less than $-\dfrac{i^2_{RM}}{2a}$,

where:

- i_{RM} is the value specified for **Peak reverse current, iRM**.
- a is the value specified for **Rate of change of current when measuring iRM**.

The default value is `1500` μAs.

The parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery charge`.

For more information on these parameters, see `Commutation Diode`.

Snubbers Tab

Snubber

Snubber for each switching device. The default value is `None`.

Snubber resistance

Snubber resistance. This parameter is visible only if you set **Snubber** to `RC snubber`. The default value is `0.1 Ohm`.

Snubber capacitance

Snubber capacitance. This parameter is visible only if you set **Snubber** to `RC snubber`. The default value is `1e-7 F`.

Ports

The block has the following ports:

G

> Vector input port associated with the gate terminals of the switching devices. Connect this port to a Six-Pulse Gate Multiplexer block.

~

> Expandable three-phase port

+

> Electrical conserving port associated with the DC positive terminal

-

> Electrical conserving port associated with the DC negative terminal

See Also

See Also
```
Average-Value Inverter | Average-Value Rectifier | Rectifier | Six-
Pulse Gate Multiplexer | Three-Level Converter
```

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Current Sensor

Measure phase currents in three-phase system
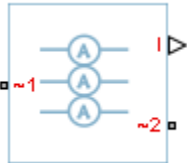
Library

Sensors

Description

The Current Sensor block represents an ideal three-phase current sensor. The block measures each of the three currents flowing from port ~1 to port ~2 and outputs a single three-element, physical signal vector. Each element of the physical signal output vector is proportional to the current in its respective phase.

Ports

The block has the following ports:

~1

    Expandable three-phase port.

~2

    Expandable three-phase port.

I

    Three-element physical signal vector output port associated with the phase currents.

See Also

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Current Source

Ideal three-phase current source
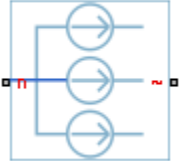
Library

Sources

Description

The Current Source block models an ideal three-phase current source that maintains sinusoidal currents of the specified magnitude through its terminals, independent of the voltage across the source.

The output current is defined by the following equations:

$$I_0 = \sqrt{2}i_{phase\_rms}$$

$$i_a = I_0 \sin(2\pi ft + \varphi)$$

$$i_b = I_0 \sin(2\pi ft + \varphi - 120°)$$

$$i_c = I_0 \sin(2\pi ft + \varphi + 120°),$$

where:

- I_0 is the peak phase current.
- i_{phase_rms} is the RMS phase current.

- i_a, i_b, i_c are the respective phase currents.
- f is the frequency.
- φ is the phase shift.
- t is the time.

The arrow indicates the positive direction of the current flow. The source has a wye configuration, and port n provides a connection to the center of the wye. Port ~ is an expandable three-phase port representing the three phases, a, b, and c.

Parameters

Current (phase RMS)

RMS phase current. The default value is `100/sqrt(2)`, or 70.7107, `A`.

Phase shift

Phase shift in angular units. The default value is `0 deg`.

Frequency

Current frequency, specified in Hz or units directly convertible to Hz (where Hz is defined as 1/s). For example, `kHz` and `MHz` are valid units, but `rad/s` is not. The default value is `60 Hz`.

Ports

The block has the following ports:

~

Expandable three-phase port

n

Electrical conserving port associated with the center of the wye

See Also

See Also
`Voltage Source`

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Circuit Breaker

Three-phase circuit breaker controlled by external signal
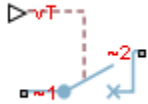
Library

Switches & Breakers

Description

The Circuit Breaker block models a three-phase circuit breaker that uses an external signal and phase current information to break an electrical circuit.

The table shows how the external signal vT controls the block behavior.

Condition	Block Behavior	Resistance Parameter Used
vT < **Threshold**	The breaker is closed. Each phase in the composite three-phase port ~1 connects to the corresponding phase in the port ~2.	**Closed Resistance**
vT ≥ **Threshold**	When the current in any phase of the composite port ~1 crosses zero, the phase disconnects from the corresponding phase at port ~2. The breaker is open.	**Open Conductance**

Parameters

Closed resistance

Resistance between ports ~1 and ~2 when the breaker is closed. The default value is 0.001 Ohm.

Open conductance

Conductance between ports ~1 and ~2 when the breaker is open. The default value is 1e-6 1/Ohm.

Threshold

Threshold voltage for the control port vT. The block uses the threshold voltage and the value of vT at the start of the simulation to determine whether the breaker is initially open or closed. When the voltage rises above the threshold, the breaker opens each phase as its current crosses zero. When the control port voltage falls below the threshold, the breaker closes. The default value is 0 V.

Ports

The block has the following ports:

~1

Expandable three-phase port

~2

Expandable three-phase port

vT

Scalar control port, which is either a physical signal or an electrical port.

See Also

See Also
Single-Phase Circuit Breaker | Single-Phase Circuit Breaker (with arc)

Topics
"Switch Between Physical Signal and Electrical Ports"
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Delta-Connected Load

Three-phase load wired in delta configuration

Library

Passive Devices

Description

The Delta-Connected Load block models a three-phase load wired in a delta configuration. Each limb of the load can include any combination of a resistor (R), capacitor (C), and inductor (L), connected in series or in parallel.

You can specify values for the R, L, and C components directly in terms of resistance, inductance, and capacitance, or by rated powers at a rated voltage and frequency.

- If you parameterize the block directly in terms or R, L, and C values, then for initialization provide a three-element row vector of initial voltages for a capacitor, and a three-element row vector of initial currents for an inductor.

- If you parameterize the block in terms of rated powers, then specify initial conditions in terms of an initial voltage, initial voltage phase, and initial frequency. For example, if the load is connected directly to a three-phase voltage source, then the initial conditions are identical to the source values for RMS line voltage, frequency, and phase shift. To specify zero initial voltage magnitude, set the initial voltage to 0.

For certain combinations of R, L, and C, for some circuit topologies, specify parasitic resistance or conductance values that help the simulation to converge numerically. These parasitic terms ensure that an inductor has a small parallel resistive path and that a capacitor has a small series resistance. When you parameterize the block in terms of

rated powers, the rated power values do not account for these small parasitic terms. The rated powers represent only the R, L, and C values of the load itself.

Parameters

Main Tab

Parameterization

Select one of these values:

- `Specify by rated power` — Specify values for the R, L, and C components by rated powers at a rated voltage and frequency. This is the default.
- `Specify component values directly` — Specify values for the R, L, and C components directly in terms of resistance, inductance, and capacitance.

Switching the **Parameterization** value resets the **Component structure** value. Select the component parameterization option first, and then the component structure. If you later switch the **Parameterization** value, check the **Component structure** value and reselect it, if necessary.

Component structure

Select the desired combination of a resistor (R), capacitor (C), and inductor (L), connected in series or in parallel. The default is `R`, resistor.

Rated voltage

Voltage for which load powers are specified. This parameter is visible only when you specify values by rated power. The default value is `2.4e4` V.

Real power

Total real power dissipated by three-phase load when supplied at the rated voltage. This parameter is visible only when you specify values by rated power and select a component structure that includes a resistor. The value must be greater than 0. The default value is `1000` W.

Rated electrical frequency

Frequency for which reactive load powers are specified. This parameter is visible only when you specify values by rated power. The default value is 60 Hz.

Inductive reactive power

Total inductive reactive power taken by the three-phase load when supplied at the rated voltage. This parameter is visible only when you specify values by rated power and select a component structure that includes an inductor. The value must be greater than 0. The default value is 100 V*A.

Capacitive reactive power

Total capacitive reactive power taken by the three-phase load when supplied at the rated voltage. This parameter is visible only when you specify values by rated power and select a component structure that includes a capacitor. The value must be less than 0. The default value is -100 V*A.

Resistance

The resistance of each of the load limbs. This parameter is visible only when you specify component values directly and select a component structure that includes a resistor. The default value is 1 Ohm.

Inductance

Inductance of each of the load limbs. This parameter is visible only when you specify component values directly and select a component structure that includes an inductor. The default value is 0.001 H.

Capacitance

Capacitance in each of the load limbs. This parameter is visible only when you specify component values directly and select a component structure that includes a capacitor. The default value is 1e-6 F.

Parasitics Tab

Parasitic series resistance

Represents small parasitic effects. The parameter value corresponds to the series resistance value added to all instances of capacitors in the load. The default value is 1e-6 Ohm.

Parasitic parallel conductance

Represents small parasitic effects. The parameter value corresponds to the parallel conductance value added across all instances of inductors in the load. The default value is 1e-6 1/Ohm.

Initial Conditions Tab

Terminal voltage magnitude

Expected initial RMS line voltage at the load. This parameter is visible only when you specify values by rated power. The default value is `2.4e4` V.

Terminal voltage angle

Expected initial phase of the voltage at the load. This parameter is visible only when you specify values by rated power. The default value is `0 deg`.

Frequency

Expected initial frequency at the load. This parameter is visible only when you specify values by rated power. The default value is `60 Hz`.

Initial inductor current [Ia Ib Ic]

Initial current in the a, b, and c phase inductors, respectively. This parameter is visible only when you specify component values directly and select a component structure that includes an inductor. The default value is `[0 0 0]` A.

Initial capacitor voltage [Va Vb Vc]

Initial voltage across the a, b, and c phase capacitors, respectively. This parameter is visible only when you specify component values directly and select a component structure that includes a capacitor. The default value is `[0 0 0]` V.

Block Parameterization

The following two tables list the block parameters for each **Component structure**, based on the selected **Parameterization** option:

- Specify by rated power
- Specify component values directly

Specify by Rated Power

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
R	Rated voltage Real power	None	None
L	Rated voltage Rated electrical frequency	Parasitic parallel conductance	Terminal voltage magnitude

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
	Inductive reactive power		Terminal voltage angle Frequency
C	Rated voltage Rated electrical frequency Capacitive reactive power	Parasitic series resistance	Terminal voltage magnitude Terminal voltage angle Frequency
Series RL	Rated voltage Rated electrical frequency Real power Inductive reactive power	Parasitic parallel conductance	Terminal voltage magnitude Terminal voltage angle Frequency
Series RC	Rated voltage Rated electrical frequency Real power Capacitive reactive power	None	Terminal voltage magnitude Terminal voltage angle Frequency
Series LC	Rated voltage Rated electrical frequency Inductive reactive power Capacitive reactive power	Parasitic parallel conductance	Terminal voltage magnitude Terminal voltage angle Frequency

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
Series RLC	Rated voltage Rated electrical frequency Real power Inductive reactive power Capacitive reactive power	Parasitic parallel conductance	Terminal voltage magnitude Terminal voltage angle Frequency
Parallel RL	Rated voltage Rated electrical frequency Real power Inductive reactive power	None	Terminal voltage magnitude Terminal voltage angle Frequency
Parallel RC	Rated voltage Rated electrical frequency Real power Capacitive reactive power	Parasitic series resistance	Terminal voltage magnitude Terminal voltage angle Frequency
Parallel LC	Rated voltage Rated electrical frequency Inductive reactive power	Parasitic series resistance	Terminal voltage magnitude Terminal voltage angle Frequency

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
	Capacitive reactive power		
Parallel RLC	Rated voltage Rated electrical frequency Real power Inductive reactive power Capacitive reactive power	Parasitic series resistance	Terminal voltage magnitude Terminal voltage angle Frequency

Specify Component Values Directly

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
R	Resistance	None	None
L	Inductance	Parasitic parallel conductance	Initial inductor current [Ia Ib Ic]
C	Capacitance	Parasitic series resistance	Initial capacitor voltage [Va Vb Vc]
Series RL	Resistance Inductance	Parasitic parallel conductance	Initial inductor current [Ia Ib Ic]
Series RC	Resistance Capacitance	None	Initial capacitor voltage [Va Vb Vc]
Series LC	Inductance Capacitance	Parasitic parallel conductance	Initial inductor current [Ia Ib Ic] Initial capacitor voltage [Va Vb Vc]
Series RLC	Resistance Inductance	Parasitic parallel conductance	Initial inductor current [Ia Ib Ic]

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
	Capacitance		Initial capacitor voltage [Va Vb Vc]
Parallel RL	Resistance Inductance	None	Initial inductor current [Ia Ib Ic]
Parallel RC	Resistance Capacitance	Parasitic series resistance	Initial capacitor voltage [Va Vb Vc]
Parallel LC	Inductance Capacitance	Parasitic series resistance	Initial inductor current [Ia Ib Ic] Initial capacitor voltage [Va Vb Vc]
Parallel RLC	Resistance Inductance Capacitance	Parasitic series resistance	Initial inductor current [Ia Ib Ic] Initial capacitor voltage [Va Vb Vc]

Ports

The block has one expandable three-phase port, ~.

See Also

See Also
RLC | Wye-Connected Load

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Delta-Delta Transformer

Linear nonideal delta-delta transformer with three-limb core

Library

Passive Devices / Transformers

Description

The Delta-Delta Transformer block models a linear, nonideal transformer with a three-limb core, in which both the primary and the secondary windings are configured in a delta connection. The block includes linear winding leakage and linear core magnetization effects.

The figure shows the equivalent circuit diagram for the delta-delta transformer.
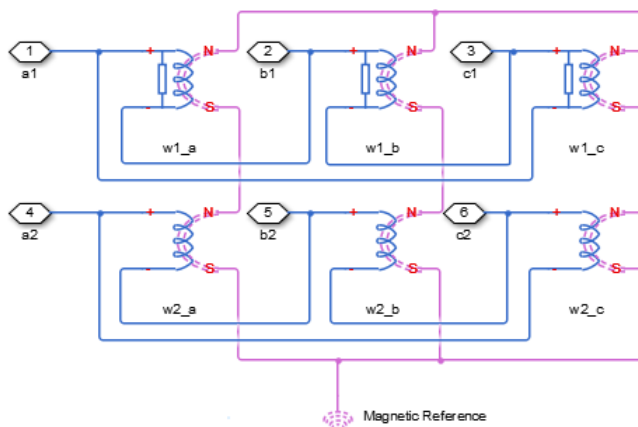
- w1$_a$ is the primary winding connected between the a-phase and the b-phase.
- w1$_b$ is the primary winding connected between the b-phase and the c-phase.
- w1$_c$ is the primary winding connected between the c-phase and the a-phase.
- w2$_a$ is the secondary winding connected between the a-phase and the b-phase.
- w2$_b$ is the secondary winding connected between the b-phase and the c-phase.
- w2$_c$ is the secondary winding connected between the c-phase and the a-phase.

Display Options

You can display the transformer per-unit base values in the MATLAB command window using the block context menu. To display the values, right-click the block and select **Power Systems** > **Display Base Values**.

Parameters

- "Main Tab" on page 1-116
- "Impedances Tab" on page 1-117
- "Initial Conditions Tab" on page 1-117

Main Tab

Rated apparent power

Apparent power flowing through the transformer when operating at rated capacity. The default value is 100e6 V*A.

Primary rated voltage

RMS line voltage applied to the primary winding under normal operating conditions. The default value is 4160 V.

Secondary rated voltage

RMS line voltage applied to the secondary winding under normal operating conditions. The default value is 24e3 V.

Rated electrical frequency

Rated or nominal frequency of the AC network to which the transformer is connected. The default value is 60 Hz.

Impedances Tab

Parameters in this tab are expressed in per-unit (pu). For more information, see "Per-Unit System of Units".

Primary leakage resistance (pu)

Power loss in the primary winding. The default value is `0.01`.

Primary leakage reactance (pu)

Magnetic flux loss in the primary winding. The default value is `0.001`.

Secondary leakage resistance (pu)

Power loss in the secondary winding. The default value is `0.01`.

Secondary leakage reactance (pu)

Magnetic flux loss in the secondary winding. The default value is `0.001`.

Shunt magnetizing resistance (pu)

Magnetic losses in transformer core. The default value is `500`.

Shunt magnetizing reactance (pu)

Magnetic effects of the transformer core when operating in its linear region. The default value is `500`.

Initial Conditions Tab

Initial primary currents

Current through the primary leakage inductors at time zero. The default value is `[0 0 0]` A.

Initial secondary currents

Current through the secondary leakage inductors at time zero. The default value is `[0 0 0]` A.

Initial magnetizing currents

Current through the shunt magnetization inductors at time zero. The default value is `[0 0 0]` A.

Initial fluxes

Magnetic fluxes in the limbs of the core at time zero. The default value is `[0 0 0]` Wb.

Ports

The block has the following ports:

~1

    Expandable three-phase port for primary winding

~2

    Expandable three-phase port for secondary winding

See Also

See Also

`Delta1-Delta1-Wye Transformer` | `Delta11-Delta11-Wye Transformer` | `Wye-Delta1 Transformer` | `Wye-Delta1-Wye Transformer` | `Wye-Delta11 Transformer` | `Wye-Delta11-Wye Transformer` | `Wye-Wye Transformer` | `Zigzag-Delta1-Wye Transformer` | `Zigzag-Delta11-Wye Transformer`

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Delta1-Delta1-Wye Transformer

Linear nonideal delta1-delta1-wye transformer with three-limb core

Library

Passive Devices / Transformers

Description

The Delta1-Delta1-Wye Transformer block models a linear, nonideal transformer with a three-limb core, in which the primary windings are configured in a delta connection and there are delta secondary windings and wye secondary windings. The delta voltages lag the wye voltages by 30 degrees, hence the name 1 o'clock delta. The block includes linear winding leakage and linear core magnetization effects.

The figure shows the equivalent circuit diagram for the delta1-delta1-wye transformer.
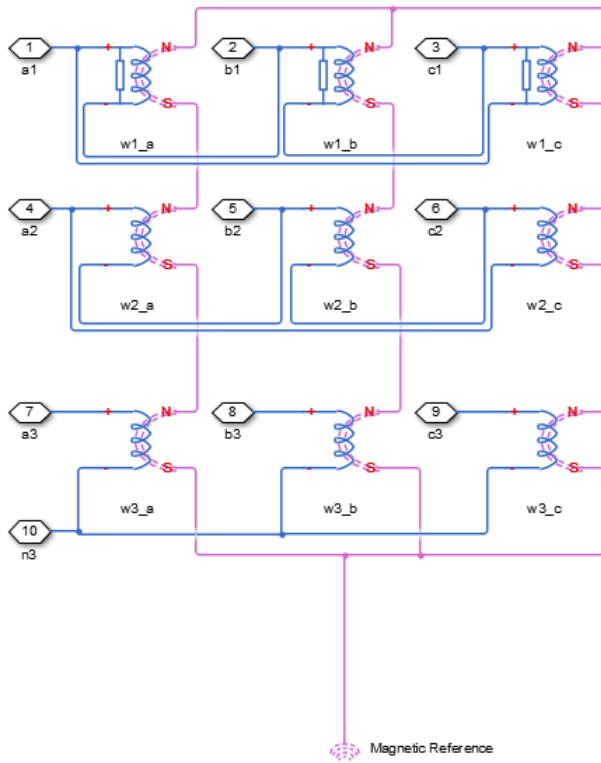
- w1$_a$ is the primary winding connected between the a-phase and the b-phase.
- w1$_b$ is the primary winding connected between the b-phase and the c-phase.
- w1$_c$ is the primary winding connected between the c-phase and the a-phase.
- w2$_a$ is the delta secondary winding connected between the a-phase and the b-phase.
- w2$_b$ is the delta secondary winding connected between the b-phase and the c-phase.
- w2$_c$ is the delta secondary winding connected between the c-phase and the a-phase.
- w3$_a$ is the wye secondary winding connected between the a-phase and the secondary neutral point.
- w3$_b$ is the wye secondary winding connected between the b-phase and the secondary neutral point.
- w3$_c$ is the wye secondary winding connected between the c-phase and the secondary neutral point.

Display Options

You can display the transformer per-unit base values in the MATLAB command window using the block context menu. To display the values, right-click the block and select **Power Systems** > **Display Base Values**.

Parameters

- "Main Tab" on page 1-121
- "Impedances Tab" on page 1-121
- "Initial Conditions Tab" on page 1-122

Main Tab

Rated apparent power

Apparent power flowing through the transformer when operating at rated capacity. The default value is `100e6 V*A`.

Primary rated voltage

RMS line voltage applied to the primary winding under normal operating conditions. The default value is `4160 V`.

Delta secondary rated voltage

RMS line voltage applied to the delta secondary winding under normal operating conditions. The default value is `24e3 V`.

Wye secondary rated voltage

RMS line voltage applied to the wye secondary winding under normal operating conditions. The default value is `24e3 V`.

Rated electrical frequency

Rated or nominal frequency of the AC network to which the transformer is connected. The default value is `60 Hz`.

Impedances Tab

Parameters in this tab are expressed in per-unit (pu). For more information, see "Per-Unit System of Units".

Primary leakage resistance (pu)

Power loss in the primary winding. The default value is `0.01`.

Primary leakage reactance (pu)

Magnetic flux loss in the primary winding. The default value is `0.001`.

Delta secondary leakage resistance (pu)

Power loss in the delta secondary winding. The default value is `0.01`.

Delta secondary leakage reactance (pu)

Magnetic flux loss in the delta secondary winding. The default value is `0.001`.

Wye secondary leakage resistance (pu)

Power loss in the wye secondary winding. The default value is `0.01`.

Wye secondary leakage reactance (pu)

Magnetic flux loss in the wye secondary winding. The default value is `0.001`.

Shunt magnetizing resistance (pu)

Magnetic losses in transformer core. The default value is `500`.

Shunt magnetizing reactance (pu)

Magnetic effects of the transformer core when operating in its linear region. The default value is `500`.

Initial Conditions Tab

Initial primary currents

Current through the primary leakage inductors at time zero. The default value is `[0 0 0]` A.

Initial delta secondary currents

Current through the delta secondary leakage inductors at time zero. The default value is `[0 0 0]` A.

Initial wye secondary currents

Current through the wye secondary leakage inductors at time zero. The default value is `[0 0 0]` A.

Initial magnetizing currents

Current through the shunt magnetization inductors at time zero. The default value is `[0 0 0]` A.

Initial fluxes

Magnetic fluxes in the limbs of the core at time zero. The default value is `[0 0 0]` Wb.

Ports

The block has the following ports:

~1

Expandable three-phase port for primary winding

~2

Expandable three-phase port for delta secondary winding

~3

Expandable three-phase port for wye secondary winding

n3

Electrical conserving port associated with the wye secondary winding neutral point

See Also

See Also

`Delta-Delta Transformer` | `Delta11-Delta11-Wye Transformer` | `Wye-Delta1 Transformer` | `Wye-Delta1-Wye Transformer` | `Wye-Delta11 Transformer` | `Wye-Delta11-Wye Transformer` | `Wye-Wye Transformer` | `Zigzag-Delta1-Wye Transformer` | `Zigzag-Delta11-Wye Transformer`

Topics

"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Delta11-Delta11-Wye Transformer

Linear nonideal delta11-delta11-wye transformer with three-limb core

Library

Passive Devices / Transformers

Description

The Delta11-Delta11-Wye Transformer block models a linear, nonideal transformer with a three-limb core, in which the primary windings are configured in a delta connection and there are delta secondary windings and wye secondary windings. The delta voltages lead the wye voltages by 30 degrees, hence the name 11 o'clock delta. The block includes linear winding leakage and linear core magnetization effects.

The figure shows the equivalent circuit diagram for the delta11-delta11-wye transformer.

Magnetic Reference
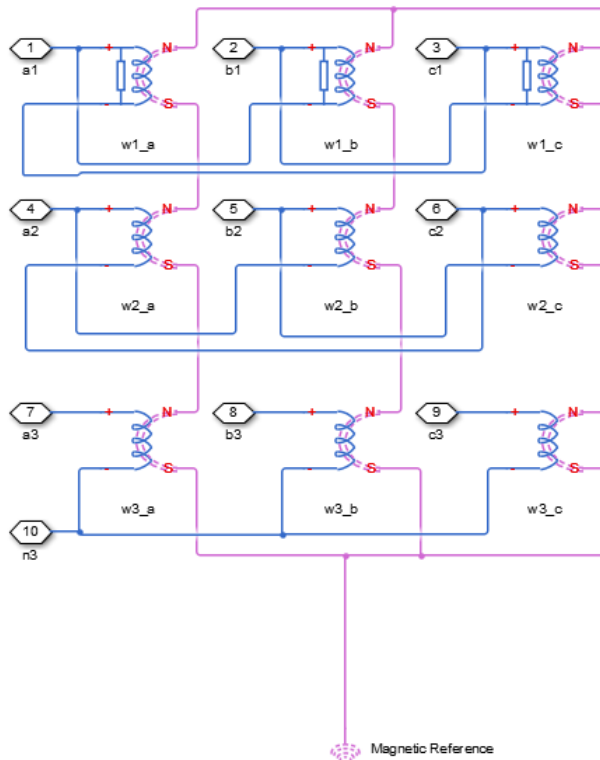
- $w1_a$ is the primary winding connected between the a-phase and the c-phase.
- $w1_b$ is the primary winding connected between the b-phase and the a-phase.
- $w1_c$ is the primary winding connected between the c-phase and the b-phase.
- $w2_a$ is the delta secondary winding connected between the a-phase and the c-phase.
- $w2_b$ is the delta secondary winding connected between the b-phase and the a-phase.
- $w2_c$ is the delta secondary winding connected between the c-phase and the b-phase.
- $w3_a$ is the wye secondary winding connected between the a-phase and the secondary neutral point.
- $w3_b$ is the wye secondary winding connected between the b-phase and the secondary neutral point.

- w3$_c$ is the wye secondary winding connected between the c-phase and the secondary neutral point.

Display Options

You can display the transformer per-unit base values in the MATLAB command window using the block context menu. To display the values, right-click the block and select **Power Systems** > **Display Base Values**.

Parameters

- "Main Tab" on page 1-126
- "Impedances Tab" on page 1-127
- "Initial Conditions Tab" on page 1-127

Main Tab

Rated apparent power

Apparent power flowing through the transformer when operating at rated capacity. The default value is `100e6 V*A`.

Primary rated voltage

RMS line voltage applied to the primary winding under normal operating conditions. The default value is `4160 V`.

Delta secondary rated voltage

RMS line voltage applied to the delta secondary winding under normal operating conditions. The default value is `24e3 V`.

Wye secondary rated voltage

RMS line voltage applied to the wye secondary winding under normal operating conditions. The default value is `24e3 V`.

Rated electrical frequency

Rated or nominal frequency of the AC network to which the transformer is connected. The default value is `60 Hz`.

Impedances Tab

Parameters in this tab are expressed in per-unit (pu). For more information, see "Per-Unit System of Units".

Primary leakage resistance (pu)

Power loss in the primary winding. The default value is `0.01`.

Primary leakage reactance (pu)

Magnetic flux loss in the primary winding. The default value is `0.001`.

Delta secondary leakage resistance (pu)

Power loss in the delta secondary winding. The default value is `0.01`.

Delta secondary leakage reactance (pu)

Magnetic flux loss in the delta secondary winding. The default value is `0.001`.

Wye secondary leakage resistance (pu)

Power loss in the wye secondary winding. The default value is `0.01`.

Wye secondary leakage reactance (pu)

Magnetic flux loss in the wye secondary winding. The default value is `0.001`.

Shunt magnetizing resistance (pu)

Magnetic losses in transformer core. The default value is `500`.

Shunt magnetizing reactance (pu)

Magnetic effects of the transformer core when operating in its linear region. The default value is `500`.

Initial Conditions Tab

Initial primary currents

Current through the primary leakage inductors at time zero. The default value is `[0 0 0]` A.

Initial delta secondary currents

Current through the delta secondary leakage inductors at time zero. The default value is `[0 0 0]` A.

Initial wye secondary currents

Current through the wye secondary leakage inductors at time zero. The default value is `[0 0 0]` A.

Initial magnetizing currents

Current through the shunt magnetization inductors at time zero. The default value is [0 0 0] A.

Initial fluxes

Magnetic fluxes in the limbs of the core at time zero. The default value is [0 0 0] Wb.

Ports

The block has the following ports:

~1

Expandable three-phase port for primary winding

~2

Expandable three-phase port for delta secondary winding

~3

Expandable three-phase port for wye secondary winding

n3

Electrical conserving port associated with the wye secondary winding neutral point

See Also

See Also

Delta-Delta Transformer | Delta1-Delta1-Wye Transformer | Wye-Delta1 Transformer | Wye-Delta1-Wye Transformer | Wye-Delta11 Transformer | Wye-Delta11-Wye Transformer | Wye-Wye Transformer | Zigzag-Delta1-Wye Transformer | Zigzag-Delta11-Wye Transformer

Topics

"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Delta Reference

Reference point for delta-connected network

Library

Connections

Description

In a Simscape™ Power Systems™ Simscape Components model, connect a Delta Reference block to any part of the three-phase system that is connected in a delta winding configuration. The block provides a reference point for the delta winding, representing the center of the line-line vector voltage triangle. The software calculates absolute node voltages relative to the voltage at this reference point.

For example, suppose you model a transmission system that consists of a generator connected in a wye configuration, a wye-delta transformer, a delta-wye transformer, and a load connected in wye. Connect a Delta Reference block to the part of the circuit between the two transformers.

Ports

The block has the following ports:

~

Expandable three-phase port

See Also

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Diode

Piecewise linear diode

Library

Semiconductors / Fundamental Components

Description

The Diode block models a piecewise linear diode.

If the voltage across the diode exceeds the value specified in the block **Forward voltage** parameter, then the diode behaves like a linear resistor plus a series voltage source. The value of the **On resistance** parameter specifies the resistance of the linear resistor.

If the voltage across the diode is less than the forward voltage, the diode behaves like a linear resistor with low conductance specified by the value of the **Off conductance** parameter.

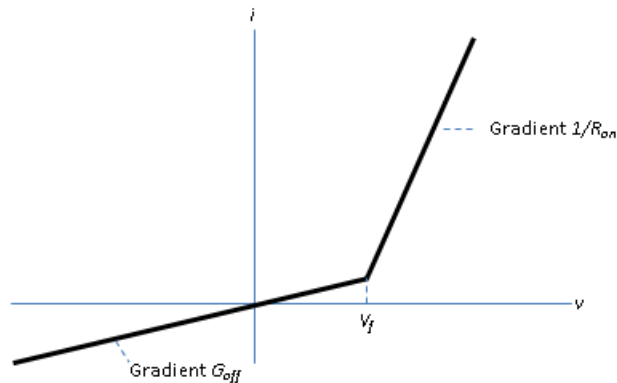When forward biased, the series voltage source is given by

$$V = V_f (1 - R_{on} G_{off}),$$

where:

- V is the voltage supplied by the series voltage source.
- V_f is the forward voltage.
- R_{on} is the on resistance.
- G_{off} is the off conductance.

The $R_{on}*G_{off}$ term ensures that the diode current is exactly zero when the voltage across it is zero.

The figure shows a typical I-V characteristic for a diode device.

Modeling Variants

The block provides a thermal modeling variant. To select a variant, right-click the block in your model. From the context menu, select **Simscape** > **Block choices**, and then one of these variants:

- **No thermal port** — This variant does not simulate heat generation in the device. This variant is the default.
- **Show thermal port** — This variant contains a thermal port that allows you to model the heat that conduction losses generate. For numerical efficiency, the thermal state does not affect the electrical behavior of the block. The thermal port is hidden by default. When you select a thermal variant of the block, the thermal port appears.

Ports

+

    Electrical conserving port associated with the diode positive terminal

-

    Electrical conserving port associated with the diode negative terminal

H

    Thermal conserving port. The thermal port is optional and is hidden by default. To enable this port, select a variant that includes a thermal port.

Parameters

Forward voltage

Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is 0.8 V.

On resistance

Rate of change of voltage versus current above the **Forward voltage**. The default value is 0.001 Ohm.

Off conductance

Conductance of the reverse-biased diode. The default value is 1e-5 1/Ohm.

Number of series diodes

The number of diodes connected in series between the + and - block ports. Each diode has the **Forward voltage**, **On resistance**, and **Off conductance** that you specify. The default value is 1.

Number of parallel diodes

The number of parallel diodes, or number of parallel paths formed by series-connected diodes, between the + and - block ports. Each diode has the **Forward voltage**, **On resistance**, and **Off conductance** that you specify. The default value is 1.

See Also

See Also
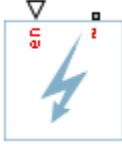Commutation Diode | GTO | Ideal Semiconductor Switch | IGBT | MOSFET | Thyristor

Topics
"Simulate Thermal Losses in Semiconductors"

Introduced in R2013b

Enabled Fault

Signal-enabled single-phase, two-phase, or three-phase grounded or ungrounded fault

Library
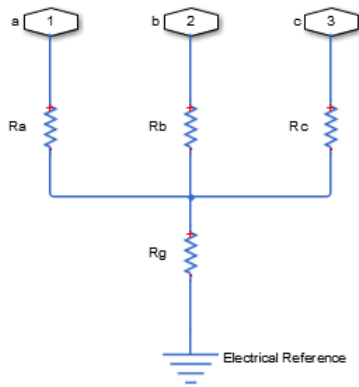
Passive Devices / Faults

Description

The Enabled Fault models any permutation of a single-phase, two-phase, or three-phase grounded or ungrounded fault. You specify the fault activation threshold using the block **Threshold** parameter. An external control signal *en* enables the fault. The fault is active when *en* is greater than the threshold. The fault is inactive when *en* is less than or equal to the threshold.

You can set the Enabled Fault block to represent any of these permutations:

- Single-phase-to-ground fault (a-g, b-g, or c-g)
- Two-phase fault (a-b, b-c, or c-a)
- Two-phase-to-ground fault (a-b-g, b-c-g, or c-a-g)
- Three-phase fault (a-b-c)
- Three-phase-to-ground fault (a-b-c-g)

The figure shows the equivalent circuit diagram for the Enabed Fault block.

You can determine the resistance in the equivalent circuit using the equations in the table.

Fault type	Value of R_a	Value of R_b	Value of R_c	Value of R_g
None / inactive	$\dfrac{1}{G_{pn}}$	$\dfrac{1}{G_{pn}}$	$\dfrac{1}{G_{pn}}$	Infinity / open circuit
a-g	R_{pn}	$\dfrac{1}{G_{pn}}$	$\dfrac{1}{G_{pn}}$	R_{ng}
b-g	$\dfrac{1}{G_{pn}}$	R_{pn}	$\dfrac{1}{G_{pn}}$	R_{ng}
c-g	$\dfrac{1}{G_{pn}}$	$\dfrac{1}{G_{pn}}$	R_{pn}	R_{ng}
a-b	R_{pn}	R_{pn}	$\dfrac{1}{G_{pn}}$	Infinity / open circuit
b-c	$\dfrac{1}{G_{pn}}$	R_{pn}	R_{pn}	Infinity / open circuit

Fault type	Value of R_a	Value of R_b	Value of R_c	Value of R_g
c-a	R_{pn}	$\dfrac{1}{G_{pn}}$	R_{pn}	Infinity / open circuit
a-b-g	R_{pn}	R_{pn}	$\dfrac{1}{G_{pn}}$	R_{ng}
b-c-g	$\dfrac{1}{G_{pn}}$	R_{pn}	R_{pn}	R_{ng}
c-a-g	R_{pn}	$\dfrac{1}{G_{pn}}$	R_{pn}	R_{ng}
a-b-c	R_{pn}	R_{pn}	R_{pn}	Infinity / open circuit
a-b-c-g	R_{pn}	R_{pn}	R_{pn}	R_{ng}

where:

- R_a is the resistance between the a-phase and the neutral point of a wye connection.
- R_b is the resistance between the b-phase and the neutral point of a wye connection.
- R_c is the resistance between the c-phase and the neutral point of a wye connection.
- R_g is the resistance between the neutral point of a wye connection and electrical reference.
- R_{pn} is the value of the **Faulted phase-neutral resistance** parameter.
- R_{ng} is the value of the **Faulted neutral-ground resistance** parameter.
- G_{pn} is the value of the **Unfaulted phase-neutral conductance** parameter.

Parameters

- "Main Tab" on page 1-137
- "Parasitics Tab" on page 1-137

Main Tab

Fault type

Select one of the following:

- None — Specifies that the fault is not active. This is the default value.
- Single-phase to ground (a-g)
- Single-phase to ground (b-g)
- Single-phase to ground (c-g)
- Two-phase (a-b)
- Two-phase (b-c)
- Two-phase (c-a)
- Two-phase to ground (a-b-g)
- Two-phase to ground (b-c-g)
- Two-phase to ground (c-a-g)
- Three-phase (a-b-c)
- Three-phase to ground (a-b-c-g)

Faulted phase-neutral resistance

Resistance between the phase connection and the neutral point when the fault is active. This parameter is visible if the **Fault type** parameter is set to anything other than None. The default value is 1e-3 Ohm.

Faulted neutral-ground resistance

Resistance between the neutral point and the electrical reference when fault is active. This parameter is visible if the **Fault type** parameter is set to any fault which includes a ground connection. The default value is 1e-3 Ohm.

Threshold

Threshold for activating the fault. If the input *en* is above the value for the **Threshold** parameter, then the fault is active. If the input *en* is equal to or less than the value for the **Threshold** parameter, then the fault is not active. This parameter is visible if the **Fault type** parameter is set to anything other than None. The default value is 0.

Parasitics Tab

Unfaulted phase-neutral conductance

Conductance between the phase connections and the neutral point when a phase is not involved in the fault. The default value is `1e-6 1/Ohm`.

Ports

The block has the following ports:

~

Expandable three-phase port for connecting the fault to the system

en

Physical signal scalar control input port for enabling the fault

See Also

See Also
`Time-Based Fault`

Introduced in R2014a

Floating Neutral

Floating neutral point for phases of three-phase system

Library

Connections

Description

The Floating Neutral block connects the individual phases of a three-phase system to form a floating neutral point.

Note: If you want to create a neutral point that you can connect to other blocks, use the Neutral Port block. If you want to create a neutral point that is connected to ground, use the Grounded Neutral block.

Ports

The block has the following ports:

~

    Expandable three-phase port

See Also

See Also
`Grounded Neutral | Neutral Port`

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Foster Thermal Model

Heat transfer through a semiconductor module


Library

Semiconductors / Fundamental Components / Thermal

Description

The Foster Thermal Model block represents heat transfer through a semiconductor module. The figure shows an equivalent circuit for a fourth-order Foster Thermal Model block. T_j is the junction temperature and T_c is the base plate temperature.
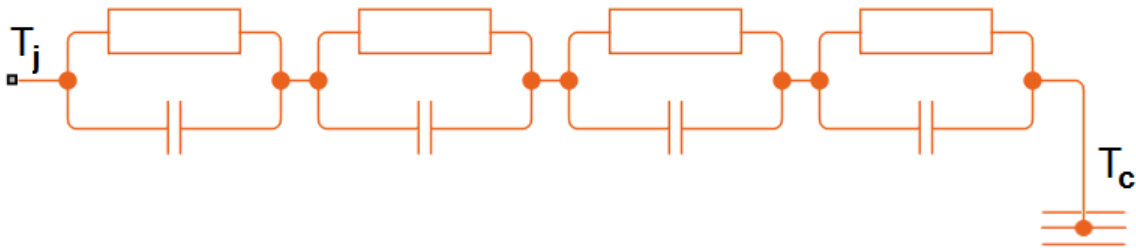
A Foster thermal model contains one or more instances of Foster thermal model elements. The figure shows an equivalent circuit for a Foster thermal model element.
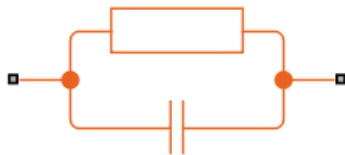
The number of thermal elements is equal to the order of representation. For a first order model, use scalar block parameters. For an nth order model, use row vectors of length n. Other terms that describe a Foster thermal model are:

- Partial fraction circuit
- Pi model

The defining equations for a first-order Foster thermal model element are:

$$C_{thermal} = \frac{\tau}{R_{thermal}}$$

and

$$Q_{AB} = \frac{T_{AB}}{R_{thermal}} + C_{thermal}\,\frac{dT_{AB}}{dt},$$

where:

- $C_{thermal}$ is the thermal capacity.
- τ is the thermal time constant.
- $R_{thermal}$ is the thermal resistance.
- Q_{AB} is the heat flow through the material.
- T_{AB} is the temperature difference between the material layers.

Parameters

Thermal resistance data

Thermal resistance values, $R_{thermal}$, of the semiconductor module, specified as a vector. The default value is [0.0016 0.0043 0.0013 0.0014] K/W.

Thermal time constant data

Thermal time constant values, τ, of the semiconductor module, specified as a vector. The default value is [0.0068 0.064 0.32 2] s.

Ports

The block has the following ports:

A

    Thermal conserving port associated with the semiconductor junction.

B

    Thermal conserving port associated with the base plate junction.

References

[1] Schütze, T. *AN2008-03: Thermal equivalent circuit models.* Application Note. V1.0. Germany: Infineon Technologies AG, 2008.

See Also

See Also
| Cauer Thermal Model Element | Thermal Resistor

Introduced in R2016a

Grounded Neutral

Ground connection for phases of three-phase system

Library

Connections

Description

The Grounded Neutral block connects the phases of a three-phase system to ground.

Note: If you want to connect the neutral point of the three-phase system to other blocks, use the Neutral Port block instead. If you want to create a floating neutral point, use the Floating Neutral block.

Ports

The block has the following ports:

~

 Expandable three-phase port

See Also

See Also
Floating Neutral | Neutral Port

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

GTO

Gate Turn-Off Thyristor

Library

Semiconductors / Fundamental Components

Description

The GTO block models a gate turn-off thyristor (GTO). The I-V characteristic of a GTO is such that if the gate-cathode voltage exceeds the specified gate trigger voltage, the GTO turns on. If the gate-cathode voltage falls below the specified gate turn-off voltage value, or if the load current falls below the specified holding-current value, the device turns off .
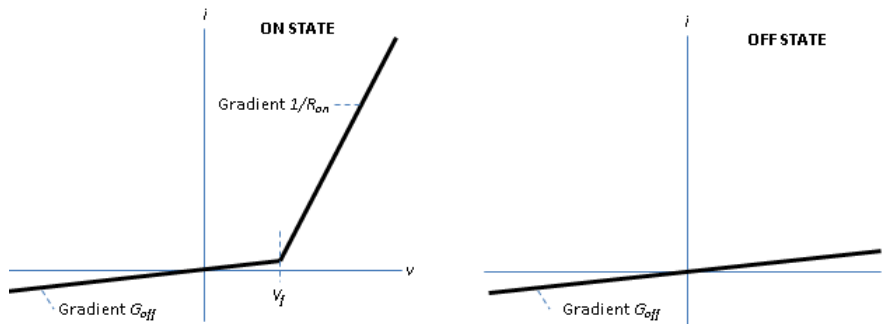
In the on state, the anode-cathode path behaves like a linear diode with forward-voltage drop, V_f, and on-resistance, R_{on}.

In the off state, the anode-cathode path behaves like a linear resistor with a low off-state conductance value, G_{off}.

The defining Simscape equations for the block are:

```
if ((v > Vf)&&((G>Vgt)||(i>Ih)))&&(G>Vgt_off)
    i == (v - Vf*(1-Ron*Goff))/Ron;
else
    i == v*Goff;
end
```

where:

- *v* is the anode-cathode voltage.
- *Vf* is the forward voltage.
- *G* is the gate voltage.
- *Vgt* is the gate trigger voltage.
- *i* is the anode-cathode current.
- *Ih* is the holding current.
- *Vgt_off* is the gate turn-off voltage.
- *Ron* is the on-state resistance.
- *Goff* is the off-state conductance.

Using the Integral Diode tab of the block dialog box, you can include an integral cathode-anode diode. A GTO that includes an integral cathode-anode diode is known as an asymmetrical GTO (A-GTO) or reverse-conducting GTO (RCGTO). An integral diode protects the semiconductor device by providing a conduction path for reverse current. An inductive load can produce a high reverse-voltage spike when the semiconductor device suddenly switches off the voltage supply to the load.

The table shows you how to set the **Integral protection diode** parameter based on your goals.

Goal	Value to Select	Block Behavior
Prioritize simulation speed.	`Protection diode with no dynamics`	The block includes an integral copy of the `Diode` block. The block dialog box shows parameters relating to the Diode block.
Precisely specify reverse-mode charge dynamics.	`Protection diode with charge dynamics`	The block includes an integral copy of the

Goal	Value to Select	Block Behavior
		`Commutation Diode` block. The block dialog box shows parameters relating to the Commutation Diode block.

Modeling Variants

The block provides four modeling variants. To select the desired variant, right-click the block in your model. From the context menu, select **Simscape** > **Block choices**, and then one of these variants:
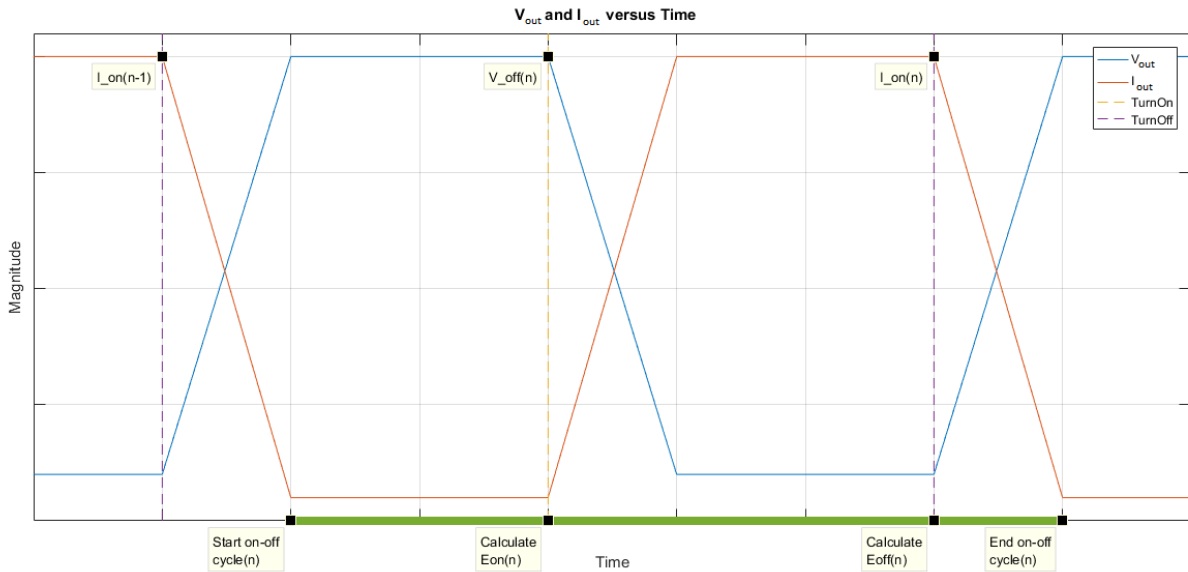
- **PS Control Port** — Contains a physical signal port that is associated with the gate terminal. This variant is the default.
- **Electrical Control Port** — Contains an electrical conserving port that is associated with the gate terminal.
- **PS Control Port | Thermal Port** — Contains a thermal port and a physical signal port that is associated with the gate terminal.
- **Electrical Control Port | Thermal Port** — Contains a thermal port and an electrical conserving port that is associated with the gate terminal.

The variants of this block without the thermal port do not simulate heat generation in the device.

The variants with the thermal port allow you to model the heat that switching events and conduction losses generate. For numerical efficiency, the thermal state does not affect the electrical behavior of the block. The thermal port is hidden by default. To enable the thermal port, select a thermal block variant.

Thermal Loss Equations

The figure shows an idealized representation of the output voltage, V_{out}, and the output current, I_{out}, of the semiconductor device. The interval shown includes the entire nth switching cycle, during which the block turns off and then on.

Vout and Iout versus Time

Heat Loss Due to a Switch-On Event

When the semiconductor turns on during the nth switching cycle, the amount of thermal energy that the device dissipates increments by a discrete amount. If you select Voltage, current, and temperature for the **Thermal loss dependent on** parameter, the equation for the incremental change is

$$E_{on(n)} = \frac{V_{off(n)}}{V_{off\_data}} fcn(T, I_{on(n-1)}),$$

where:

- $E_{on(n)}$ is the switch-on loss at the nth switch-on event.
- $V_{off(n)}$ is the off-state output voltage, V_{out}, just before the device switches on during the nth switching cycle.
- V_{off_data} is the **Off-state voltage for losses data** parameter value.
- T is the device temperature.
- $I_{on(n-1)}$ is the on-state output current, I_{out}, just before the device switches off during the cycle that precedes the nth switching cycle.

1-149

The function *fcn* is a 2-D lookup table with linear interpolation and linear extrapolation:

$$E = tablelookup(T_{j\_data}, I_{out\_data}, E_{on\_data}, T, I_{on(n-1)}),$$

where:

- T_{j_data} is the **Temperature vector, Tj** parameter value.
- I_{out_data} is the **Output current vector, Iout** parameter value.
- E_{on_data} is the **Switch-on loss, Eon=fcn(Tj,Iout)** parameter value.

If you select `Voltage and current` for the **Thermal loss dependent on** parameter, when the semiconductor turns on during the *n*th switching cycle, the equation that the block uses to calculate the incremental change in the discrete amount of thermal energy that the device dissipates is

$$E_{on(n)} = \left(\frac{V_{off(n)}}{V_{off\_data}} \right) \left(\frac{I_{on(n-1)}}{I_{out\_scalar}} \right) (E_{on\_scalar})$$

where:

- I_{out_scalar} is the **Output current, Iout** parameter value.
- E_{on_scalar} is the **Switch-on loss** parameter value.

Heat Loss Due to a Switch-Off Event

When the semiconductor turns off during the *n*th switching cycle, the amount of thermal energy that the device dissipates increments by a discrete amount. If you select `Voltage, current, and temperature` for the **Thermal loss dependent on** parameter, the equation for the incremental change is

$$E_{off(n)} = \frac{V_{off(n)}}{V_{off\_data}} fcn(T, I_{on(n)}),$$

where:

- $E_{off(n)}$ is the switch-off loss at the *n*th switch-off event.
- $V_{off(n)}$ is the off-state output voltage, V_{out}, just before the device switches on during the *n*th switching cycle.

- V_{off_data} is the **Off-state voltage for losses data** parameter value.
- T is the device temperature.
- $I_{on(n)}$ is the on-state output current, I_{out}, just before the device switches off during the nth switching cycle.

The function *fcn* is a 2-D lookup table with linear interpolation and linear extrapolation:

$$E = tablelookup(T_{j\_data}, I_{out\_data}, E_{off\_data}, T, I_{on(n)}),$$

where:

- T_{j_data} is the **Temperature vector, Tj** parameter value.
- I_{out_data} is the **Output current vector, Iout** parameter value.
- E_{off_data} is the **Switch-off loss, Eoff=fcn(Tj,Iout)** parameter value.

If you select `Voltage and current` for the **Thermal loss dependent on** parameter, when the semiconductor turns off during the nth switching cycle, the equation that the block uses to calculate the incremental change in the discrete amount of thermal energy that the device dissipates is

$$E_{off(n)} = \left(\frac{V_{off(n)}}{V_{off\_data}} \right) \left(\frac{I_{on(n-1)}}{I_{out\_scalar}} \right) (E_{off\_scalar})$$

where:

- I_{out_scalar} is the **Output current, Iout** parameter value.
- E_{off_scalar} is the **Switch-off loss** parameter value.

Heat Loss Due to Electrical Conduction

If you select `Voltage, current, and temperature` for the **Thermal loss dependent on** parameter, then, for both the on state and the off state, the heat loss due to electrical conduction is

$$E_{conduction} = \int fcn(T, I_{out}) \, dt,$$

where:

- $E_{conduction}$ is the heat loss due to electrical conduction.
- T is the device temperature.
- I_{out} is the device output current.

The function *fcn* is a 2-D lookup table:

$$Q_{conduction} = tablelookup(T_{j\_data}, I_{out\_data}, I_{out\_data\_repmat} .*V_{on\_data}, T, I_{out}),$$

where:

- T_{j_data} is the **Temperature vector, Tj** parameter value.
- I_{out_data} is the **Output current vector, Iout** parameter value.
- $I_{out\_data\_repmat}$ is a matrix that contains length, T_{j_data}, copies of I_{out_data}.
- V_{on_data} is the **On-state voltage, Von=fcn(Tj,Iout)** parameter value.

If you select `Voltage and current` for the **Thermal loss dependent on** parameter, then, for both the on state and the off state, the heat loss due to electrical conduction is

$$E_{conduction} = \int (I_{out} * V_{on\_scalar}) dt,$$

where V_{on_scalar} is the **On-state voltage** parameter value.

Heat Flow

The block uses the **Energy dissipation time constant** parameter to filter the amount of heat flow that the block outputs. The filtering allows the block to:

- Avoid discrete increments for the heat flow output

- Handle a variable switching frequency

The filtered heat flow is

$$Q = \frac{1}{\tau} \left(\sum_{i=1}^{n} E_{on(i)} + \sum_{i=1}^{n} E_{off(i)} + E_{conduction} - \int Q \, dt \right),$$
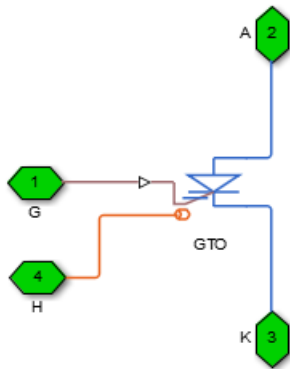
where:

- Q is the heat flow from the component.

- τ is the **Energy dissipation time constant** parameter value.
- n is the number of switching cycles.
- $E_{on(i)}$ is the switch-on loss at the ith switch-on event.
- $E_{off(i)}$ is the switch-off loss at the ith switch-off event.
- $E_{conduction}$ is the heat loss due to electrical conduction.
- $\int Q dt$ is the total heat previously dissipated from the component.

Ports

The figure shows the block port names.

G

Port associated with the gate terminal. You can set the port to either a physical signal or electrical port.

A

Electrical conserving port associated with the anode terminal.

K

Electrical conserving port associated with the cathode terminal.

H

Thermal conserving port. The thermal port is optional and is hidden by default. To enable this port, select a variant that includes a thermal port.

Parameters

- "Main Tab" on page 1-154
- "Integral Diode Tab" on page 1-154
- "Thermal Model Tab" on page 1-157

Main Tab

Forward voltage, Vf

Minimum voltage required across the anode and cathode block ports for the gradient of the device I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On-state resistance**. The default value is `0.8` V.

On-state resistance

Rate of change of voltage versus current above the forward voltage. The default value is `0.001` Ohm.

Off-state conductance

Anode-cathode conductance when the device is off. The value must be less than 1/R, where R is the value of **On-state resistance**. The default value is `1e-5` 1/Ohm.

Gate trigger voltage, Vgt

Gate-cathode voltage threshold. The device turns on when the gate-cathode voltage is above this value. The default value is `1` V.

Gate turn-off voltage, Vgt_off

Gate-cathode voltage threshold. The device turns off when the gate-cathode voltage is below this value. The default value is `-1` V.

Holding current

Current threshold. The device stays on when the current is above this value, even when the gate-cathode voltage falls below the gate trigger voltage. The default value is `1` A.

Integral Diode Tab

Integral protection diode

Block integral protection diode. The default value is `None`.

The diodes you can select are:

- Protection diode with no dynamics
- Protection diode with charge dynamics

Parameters for Protection diode with no dynamics

When you select Protection diode with no dynamics, additional parameters appear.

Additional Parameters for Protection diode with no dynamics

Forward voltage

Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is 0.8 V.

On resistance

Rate of change of voltage versus current above the **Forward voltage**. The default value is 0.001 Ohm.

Off conductance

Conductance of the reverse-biased diode. The default value is 1e-5 1/Ohm.

For more information on these parameters, see Diode.

Parameters for Protection diode with charge dynamics

When you select Protection diode with charge dynamics, additional parameters appear.

Additional Parameters for Protection diode with charge dynamics

Forward voltage

Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is 0.8 V.

On resistance

Rate of change of voltage versus current above the **Forward voltage**. The default value is 0.001 Ohm.

Off conductance

Conductance of the reverse-biased diode. The default value is 1e-5 1/Ohm.

Junction capacitance

Diode junction capacitance. The default value is `50 nF`.

Peak reverse current, iRM

Peak reverse current measured by an external test circuit. This value must be less than zero. The default value is `-235 A`.

Initial forward current when measuring iRM

Initial forward current when measuring peak reverse current. This value must be greater than zero. The default value is `300 A`.

Rate of change of current when measuring iRM

Rate of change of current when measuring peak reverse current. This value must be less than zero. The default value is `-50 A/`μ`s`.

Reverse recovery time parameterization

Determines how you specify reverse recovery time in the block. The default value is `Specify reverse recovery time directly`.

If you select `Specify stretch factor` or `Specify reverse recovery charge`, you specify a value that the block uses to derive the reverse recovery time. For more information on these options, see "Alternatives to Specifying t_{rr} Directly" on page 1-83.

Reverse recovery time, trr

Interval between the time when the current initially goes to zero (when the diode turns off) and the time when the current falls to less than 10% of the peak reverse current. The default value is `15 `μ`s`.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery time directly`.

The value of the **Reverse recovery time, trr** parameter must be greater than the value of the **Peak reverse current, iRM** parameter divided by the value of the **Rate of change of current when measuring iRM** parameter.

Reverse recovery time stretch factor

Value that the block uses to calculate **Reverse recovery time, trr**. This value must be greater than 1. The default value is `3`.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify stretch factor`.

Specifying the stretch factor is an easier way to parameterize the reverse recovery time than specifying the reverse recovery charge. The larger the value of the stretch factor, the longer it takes for the reverse recovery current to dissipate.

Reverse recovery charge, Qrr

Value that the block uses to calculate **Reverse recovery time, trr**. Use this parameter if the data sheet for your diode device specifies a value for the reverse recovery charge instead of a value for the reverse recovery time.

The reverse recovery charge is the total charge that continues to dissipate when the diode turns off. The value must be less than $-\dfrac{i^2_{RM}}{2a}$,

where:

- i_{RM} is the value specified for **Peak reverse current, iRM**.

- a is the value specified for **Rate of change of current when measuring iRM**.

The default value is `1500` μ`As`.

The parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery charge`.

For more information on these parameters, see `Commutation Diode`.

Thermal Model Tab

The **Thermal Model** tab is enabled only when you select a block variant that includes a thermal port.

Thermal loss dependent on

Select a parameterization method. The option that you select determines which other parameters are enabled. Options are:

- `Voltage and current` — Use scalar values to specify the output current, switch-on loss, switch-off loss, and on-state voltage data.

- `Voltage, current, and temperature` — Use vectors to specify the output current, switch-on loss, switch-off loss, on-state voltage, and temperature data. This is the default parameterization method.

Off-state voltage for losses data

The output voltage of the device during the off state. This is the blocking voltage at which the switch-on loss and switch-off loss data are defined. The default value is 300 V.

Energy dissipation time constant

Time constant used to average the switch-on losses, switch-off losses, and conduction losses. This value is equal to the period of the minimum switching frequency. The default value is 1e-4 s.

Additional Parameters for Parameterizing by Voltage, Current, and Temperature

Temperature vector, Tj

Temperature values at which the switch-on loss, switch-off loss, and on-state voltage are specified. Specify this parameter using a vector quantity. The default value is [298.15 398.15] K.

Output current vector, Iout

Output currents for which the switch-on loss, switch-off- loss and on-state voltage are defined. The first element must be zero. Specify this parameter using a vector quantity. The default value is [0 10 50 100 200 400 600] A.

Switch-on loss, Eon=fcn(Tj,Iout)

Energy dissipated during a single swtich on event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a vector quantity. The default value is [0 2.9e-4 0.00143 0.00286 0.00571 0.01314 0.02286; 0 5.7e-4 0.00263 0.00514 0.01029 0.02057 0.03029] J.

Switch-off loss, Eoff=fcn(Tj,Iout)

Energy dissipated during a single switch-off event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a vector quantity. The default value is [0 2.1e-4 0.00107 0.00214 0.00429 0.009859999999999999 0.01714; 0 4.3e-4 0.00197 0.00386 0.00771 0.01543 0.02271] J.

On-state voltage, Von=fcn(Tj,Iout)

Voltage drop across the device while it is in a triggered conductive state.. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a vector quantity. The default value is [0 1.1 1.3 1.45 1.75 2.25 2.7; 0 1 1.15 1.35 1.7 2.35 3] V.

Additional Parameters for Parameterizing by Voltage and Current

Output current, Iout

Output currents for which the switch-on loss, switch-off loss, and on-state voltage are defined. The first element must be zero. Specify this parameter using a scalar quantity. The default value is 600 A.

Switch-on loss

Energy dissipated during a single switch-on event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a scalar quantity. The default value is 0.02286 J.

Switch-off loss

Energy dissipated during a single switch-off event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a scalar quantity. The default value is 0.01714 J.

On-state voltage

Voltage drop across the block while it is in a triggered conductive state. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a scalar quantity. The default value is 2.7 V.

See Also

See Also

Commutation Diode | Diode | Ideal Semiconductor Switch | IGBT | MOSFET | Thyristor

Topics

"Simulate Thermal Losses in Semiconductors"
"Switch Between Physical Signal and Electrical Ports"

Introduced in R2013b

Ideal Semiconductor Switch
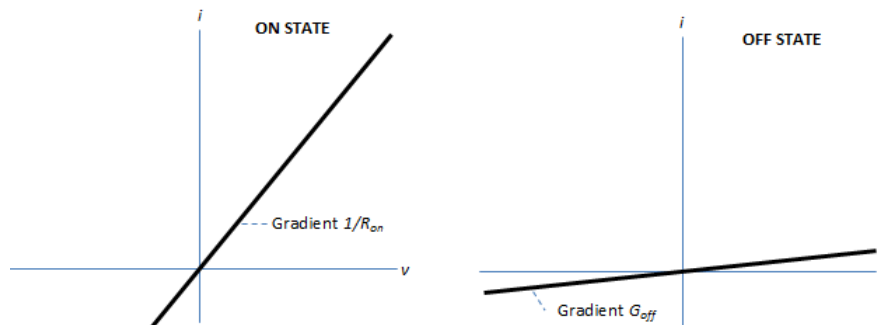
Ideal Semiconductor Switch

Library

Semiconductors / Fundamental Components

Description

The Ideal Semiconductor Switch block models an ideal semiconductor switching device.

The figure shows a typical *i-v characteristic* for an ideal semiconductor switch.

If the gate-cathode voltage exceeds the specified threshold voltage, the ideal semiconductor switch is in the on state. Otherwise the device is in the off state.

In the on state, the anode-cathode path behaves like a linear resistor with on-resistance R_{on}.

In the off state, the anode-cathode path behaves like a linear resistor with a low off-state conductance G_{off}.

Using the Integral Diode tab of the block dialog box, you can include an integral cathode-anode diode. An integral diode protects the semiconductor device by providing a conduction path for reverse current. An inductive load can produce a high reverse-voltage spike when the semiconductor device suddenly switches off the voltage supply to the load.

The table shows you how to set the **Integral protection diode** parameter based on your goals.

Goal	Value to Select	Block Behavior
Prioritize simulation speed.	`Protection diode with no dynamics`	The block includes an integral copy of the `Diode` block. The block dialog box shows parameters relating to the Diode block.
Precisely specify reverse-mode charge dynamics.	`Protection diode with charge dynamics`	The block includes an integral copy of the `Commutation Diode` block. The block dialog box shows parameters relating to the Commutation Diode block.

Parameters

- "Main Tab" on page 1-161
- "Integral Diode Tab" on page 1-162

Main Tab

On-state resistance

Anode-cathode resistance when the device is on. The default value is `0.001 Ohm`.

Off-state conductance

Anode-cathode conductance when the device is off. The value must be less than 1/R, where R is the value of **On-state resistance**. The default value is `1e-6 1/Ohm`.

Threshold voltage, Vth

Gate-cathode voltage threshold. The device turns on when the gate-cathode voltage is above this value. The default value is `0.5 V`.

Integral Diode Tab

Integral protection diode

Specify whether the block includes an integral protection diode. The default value is `None`.

If you want to include an integral protection diode, there are two options:

- `Protection diode with no dynamics`
- `Protection diode with charge dynamics`

Parameters for Protection diode with no dynamics

When you select `Protection diode with no dynamics`, additional parameters appear.

Additional Parameters for Protection diode with no dynamics

Forward voltage

Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is `0.8 V`.

On resistance

Rate of change of voltage versus current above the **Forward voltage**. The default value is `0.001 Ohm`.

Off conductance

Conductance of the reverse-biased diode. The default value is `1e-5 1/Ohm`.

For more information on these parameters, see `Diode`.

Parameters for Protection diode with charge dynamics

When you select `Protection diode with charge dynamics`, additional parameters appear.

Additional Parameters for Protection diode with charge dynamics

Forward voltage

Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is 0.8 V.

On resistance

Rate of change of voltage versus current above the **Forward voltage**. The default value is 0.001 Ohm.

Off conductance

Conductance of the reverse-biased diode. The default value is 1e-5 1/Ohm.

Junction capacitance

Diode junction capacitance. The default value is 50 nF.

Peak reverse current, iRM

Peak reverse current measured by an external test circuit. This value must be less than zero. The default value is -235 A.

Initial forward current when measuring iRM

Initial forward current when measuring peak reverse current. This value must be greater than zero. The default value is 300 A.

Rate of change of current when measuring iRM

Rate of change of current when measuring peak reverse current. This value must be less than zero. The default value is -50 A/μs.

Reverse recovery time parameterization

Determines how you specify reverse recovery time in the block. The default value is Specify reverse recovery time directly.

If you select Specify stretch factor or Specify reverse recovery charge, you specify a value that the block uses to derive the reverse recovery time. For more information on these options, see "Alternatives to Specifying t_{rr} Directly" on page 1-83.

Reverse recovery time, trr

Interval between the time when the current initially goes to zero (when the diode turns off) and the time when the current falls to less than 10% of the peak reverse current. The default value is 15 μs.

This parameter is visible only if you set **Reverse recovery time parameterization** to Specify reverse recovery time directly.

The value of the **Reverse recovery time, trr** parameter must be greater than the value of the **Peak reverse current, iRM** parameter divided by the value of the **Rate of change of current when measuring iRM** parameter.

Reverse recovery time stretch factor

Value that the block uses to calculate **Reverse recovery time, trr**. This value must be greater than 1. The default value is 3.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify stretch factor`.

Specifying the stretch factor is an easier way to parameterize the reverse recovery time than specifying the reverse recovery charge. The larger the value of the stretch factor, the longer it takes for the reverse recovery current to dissipate.

Reverse recovery charge, Qrr

Value that the block uses to calculate **Reverse recovery time, trr**. Use this parameter if the data sheet for your diode device specifies a value for the reverse recovery charge instead of a value for the reverse recovery time.

The reverse recovery charge is the total charge that continues to dissipate when the diode turns off. The value must be less than $-\dfrac{i^2_{RM}}{2a}$,

where:

- i_{RM} is the value specified for **Peak reverse current, iRM**.
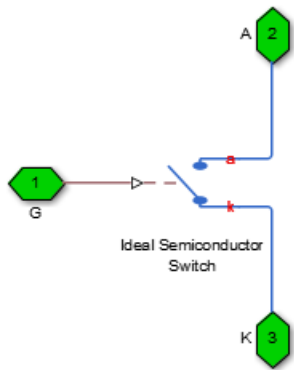- a is the value specified for **Rate of change of current when measuring iRM**.

The default value is 1500 μAs.

The parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery charge`.

For more information on these parameters, see `Commutation Diode`.

Ports

This figure shows the block port names.

G

Port associated with the gate terminal. You can set the port to either a physical signal or electrical port.

A

Electrical conserving port associated with the anode terminal.

K

Electrical conserving port associated with the cathode terminal.

See Also

Topics
"Switch Between Physical Signal and Electrical Ports"

Introduced in R2013b

IGBT

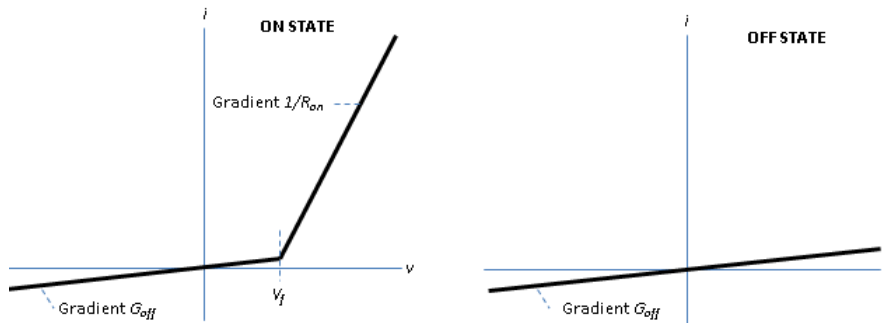Insulated-Gate Bipolar Transistor

Library

Semiconductors / Fundamental Components

Description

The IGBT block models an insulated-gate bipolar transistor (IGBT). The I-V characteristic of an IGBT is such that if the gate-emitter voltage exceeds the specified threshold voltage, V_{th}, the IGBT is in the on state. Otherwise, the device is in the off state.

In the on state, the collector-emitter path behaves like a linear diode with forward-voltage drop, V_f, and on-resistance, R_{on}.

In the off state, the collector-emitter path behaves like a linear resistor with a low off-state conductance value, G_{off}.

The defining Simscape equations for the block are:

```
if (v>Vf)&&(G>Vth)
    i == (v - Vf*(1-Ron*Goff))/Ron;
else
    i == v*Goff;
end
```

where:

- v is the collector-emitter voltage.
- Vf is the forward voltage.
- G is the gate-emitter voltage.
- Vth is the threshold voltage.
- i is the collector-emitter current.
- Ron is the on-state resistance.
- $Goff$ is the off-state conductance.

Integral Protection Diode Option

Using the Integral Diode tab of the block dialog box, you can include an integral emitter-collector diode. An integral diode protects the semiconductor device by providing a conduction path for reverse current. An inductive load can produce a high reverse-voltage spike when the semiconductor device suddenly switches off the voltage supply to the load.

Set the **Integral protection diode** parameter based on your goal.

Goal	Value to Select	Block Behavior
Prioritize simulation speed.	`Protection diode with no dynamics`	The block includes an integral copy of the `Diode` block. The block dialog box shows parameters relating to the Diode block.
Precisely specify reverse-mode charge dynamics.	`Protection diode with charge dynamics`	The block includes an integral copy of the `Commutation Diode` block. The block dialog box shows

Goal	Value to Select	Block Behavior
		parameters relating to the Commutation Diode block.

Modeling Variants

The block provides four modeling variants. To select the desired variant, right-click the block in your model. From the context menu, select **Simscape** > **Block choices**, and then one of these variants:
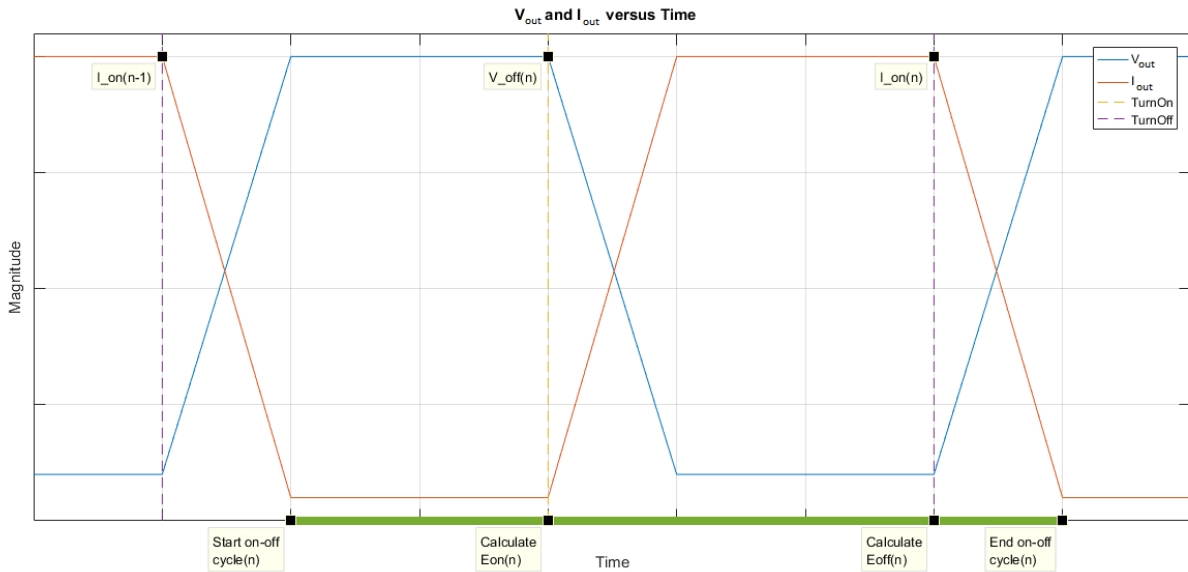
- **PS Control Port** — Contains a physical signal port that is associated with the gate terminal. This variant is the default.

- **Electrical Control Port** — Contains an electrical conserving port that is associated with the gate terminal.

- **PS Control Port | Thermal Port** — Contains a thermal port and a physical signal port that is associated with the gate terminal.

- **Electrical Control Port | Thermal Port** — Contains a thermal port and an electrical conserving port that is associated with the gate terminal.

The variants of this block without the thermal port do not simulate heat generation in the device.

The variants with the thermal port allow you to model the heat that switching events and conduction losses generate. For numerical efficiency, the thermal state does not affect the electrical behavior of the block. The thermal port is hidden by default. To enable the thermal port, select a thermal block variant.

Thermal Loss Equations

The figure shows an idealized representation of the output voltage, V_{out}, and the output current, I_{out}, of the semiconductor device. The interval shown includes the entire nth switching cycle, during which the block turns off and then on.

V_{out} and I_{out} versus Time

Heat Loss Due to a Switch-On Event

When the semiconductor turns on during the nth switching cycle, the amount of thermal energy that the device dissipates increments by a discrete amount. If you select `Voltage, current, and temperature` for the **Thermal loss dependent on** parameter, the equation for the incremental change is

$$E_{on(n)} = \frac{V_{off(n)}}{V_{off\_data}} \, fcn(T, I_{on(n-1)}),$$

where:

- $E_{on(n)}$ is the switch-on loss at the nth switch-on event.
- $V_{off(n)}$ is the off-state output voltage, V_{out}, just before the device switches on during the nth switching cycle.
- V_{off_data} is the **Off-state voltage for losses data** parameter value.
- T is the device temperature.
- $I_{on(n-1)}$ is the on-state output current, I_{out}, just before the device switches off during the cycle that precedes the nth switching cycle.

The function *fcn* is a 2-D lookup table with linear interpolation and linear extrapolation:

$$E = tablelookup(T_{j\_data}, I_{out\_data}, E_{on\_data}, T, I_{on(n-1)}),$$

where:

- T_{j_data} is the **Temperature vector, Tj** parameter value.
- I_{out_data} is the **Output current vector, Iout** parameter value.
- E_{on_data} is the **Switch-on loss, Eon=fcn(Tj,Iout)** parameter value.

If you select `Voltage and current` for the **Thermal loss dependent on** parameter, when the semiconductor turns on during the *n*th switching cycle, the equation that the block uses to calculate the incremental change in the discrete amount of thermal energy that the device dissipates is

$$E_{on(n)} = \left(\frac{V_{off(n)}}{V_{off\_data}} \right) \left(\frac{I_{on(n-1)}}{I_{out\_scalar}} \right) (E_{on\_scalar})$$

where:

- I_{out_scalar} is the **Output current, Iout** parameter value.
- E_{on_scalar} is the **Switch-on loss** parameter value.

Heat Loss Due to a Switch-Off Event

When the semiconductor turns off during the *n*th switching cycle, the amount of thermal energy that the device dissipates increments by a discrete amount. If you select `Voltage, current, and temperature` for the **Thermal loss dependent on** parameter, the equation for the incremental change is

$$E_{off(n)} = \frac{V_{off(n)}}{V_{off\_data}} fcn(T, I_{on(n)}),$$

where:

- $E_{off(n)}$ is the switch-off loss at the *n*th switch-off event.

- $V_{off(n)}$ is the off-state output voltage, V_{out}, just before the device switches on during the nth switching cycle.

- V_{off_data} is the **Off-state voltage for losses data** parameter value.

- T is the device temperature.

- $I_{on(n)}$ is the on-state output current, I_{out}, just before the device switches off during the nth switching cycle.

The function *fcn* is a 2-D lookup table with linear interpolation and linear extrapolation:

$$E = tablelookup(T_{j\_data}, I_{out\_data}, E_{off\_data}, T, I_{on(n)}),$$

where:

- T_{j_data} is the **Temperature vector, Tj** parameter value.

- I_{out_data} is the **Output current vector, Iout** parameter value.

- E_{off_data} is the **Switch-off loss, Eoff=fcn(Tj,Iout)** parameter value.

If you select `Voltage and current` for the **Thermal loss dependent on** parameter, when the semiconductor turns off during the nth switching cycle, the equation that the block uses to calculate the incremental change in the discrete amount of thermal energy that the device dissipates is

$$E_{off(n)} = \left(\frac{V_{off(n)}}{V_{off\_data}} \right) \left(\frac{I_{on(n-1)}}{I_{out\_scalar}} \right) (E_{off\_scalar})$$

where:

- I_{out_scalar} is the **Output current, Iout** parameter value.

- E_{off_scalar} is the **Switch-off loss** parameter value.

Heat Loss Due to Electrical Conduction

If you select `Voltage, current, and temperature` for the **Thermal loss dependent on** parameter, then, for both the on state and the off state, the heat loss due to electrical conduction is

$$E_{conduction} = \int fcn(T, I_{out}) \, dt,$$

where:

- $E_{conduction}$ is the heat loss due to electrical conduction.
- T is the device temperature.
- I_{out} is the device output current.

The function *fcn* is a 2-D lookup table:

$$Q_{conduction} = tablelookup(T_{j\_data}, I_{out\_data}, I_{out\_data\_repmat} \cdot {}^* V_{on\_data}, T, I_{out}),$$

where:

- T_{j_data} is the **Temperature vector, Tj** parameter value.
- I_{out_data} is the **Output current vector, Iout** parameter value.
- $I_{out\_data\_repmat}$ is a matrix that contains length, T_{j_data}, copies of I_{out_data}.
- V_{on_data} is the **On-state voltage, Von=fcn(Tj,Iout)** parameter value.

If you select `Voltage and current` for the **Thermal loss dependent on** parameter, then, for both the on state and the off state, the heat loss due to electrical conduction is

$$E_{conduction} = \int \left(I_{out} {}^* V_{on\_scalar} \right) dt,$$

where V_{on_scalar} is the **On-state voltage** parameter value.

Heat Flow

The block uses the **Energy dissipation time constant** parameter to filter the amount of heat flow that the block outputs. The filtering allows the block to:

- Avoid discrete increments for the heat flow output

- Handle a variable switching frequency
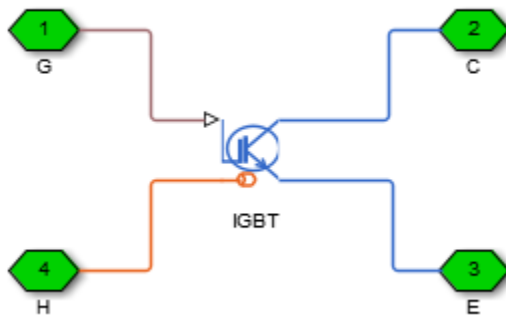
The filtered heat flow is

$$Q = \frac{1}{\tau}\left(\sum_{i=1}^{n} E_{on(i)} + \sum_{i=1}^{n} E_{off(i)} + E_{conduction} - \int Q\, dt \right),$$

where:

- Q is the heat flow from the component.
- τ is the **Energy dissipation time constant** parameter value.
- n is the number of switching cycles.
- $E_{on(i)}$ is the switch-on loss at the ith switch-on event.
- $E_{off(i)}$ is the switch-off loss at the ith switch-off event.
- $E_{conduction}$ is the heat loss due to electrical conduction.
- $\int Q\, dt$ is the total heat previously dissipated from the component.

Ports

The figure shows the block port names.

G

    Port associated with the gate terminal. You can set the port to either a physical signal or electrical port

C

Electrical conserving port associated with the collector terminal

E

Electrical conserving port associated with the emitter terminal

H

Thermal conserving port. The thermal port is optional and is hidden by default. To enable this port, select a variant that includes a thermal port.

Parameters

- "Main Tab" on page 1-174
- "Integral Diode Tab" on page 1-174
- "Thermal Model Tab" on page 1-157

Main Tab

Forward voltage, Vf

Minimum voltage required across the collector and emitter block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On-state resistance**. The default value is `0.8` V.

On-state resistance

Collector-emitter resistance when the device is on. The default value is `0.001 Ohm`.

Off-state conductance

Collector-emitter conductance when the device is off. The value must be less than $1/R$, where R is the value of **On-state resistance**. The default value is `1e-5 1/Ohm`.

Threshold voltage, Vth

Collector-emitter voltage at which the device turns on. The default value is `6` V.

Integral Diode Tab

Integral protection diode

Block integral protection diode. The default value is `None`.

The diodes you can select are:

- Protection diode with no dynamics
- Protection diode with charge dynamics

Parameters for Protection diode with no dynamics

When you select `Protection diode with no dynamics`, additional parameters appear.

Additional Parameters for Protection diode with no dynamics

Forward voltage

Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is `0.8 V`.

On resistance

Rate of change of voltage versus current above the **Forward voltage**. The default value is `0.001 Ohm`.

Off conductance

Conductance of the reverse-biased diode. The default value is `1e-5 1/Ohm`.

For more information on these parameters, see `Diode`.

Parameters for Protection diode with charge dynamics

When you select `Protection diode with charge dynamics`, additional parameters appear.

Additional Parameters for Protection diode with charge dynamics

Forward voltage

Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is `0.8 V`.

On resistance

Rate of change of voltage versus current above the **Forward voltage**. The default value is `0.001 Ohm`.

Off conductance

Conductance of the reverse-biased diode. The default value is `1e-5 1/Ohm`.

Junction capacitance

Diode junction capacitance. The default value is `50 nF`.

Peak reverse current, iRM

Peak reverse current measured by an external test circuit. This value must be less than zero. The default value is `-235 A`.

Initial forward current when measuring iRM

Initial forward current when measuring peak reverse current. This value must be greater than zero. The default value is `300 A`.

Rate of change of current when measuring iRM

Rate of change of current when measuring peak reverse current. This value must be less than zero. The default value is `-50 A/`μ`s`.

Reverse recovery time parameterization

Determines how you specify reverse recovery time in the block. The default value is `Specify reverse recovery time directly`.

If you select `Specify stretch factor` or `Specify reverse recovery charge`, you specify a value that the block uses to derive the reverse recovery time. For more information on these options, see "Alternatives to Specifying t_{rr} Directly" on page 1-83.

Reverse recovery time, trr

Interval between the time when the current initially goes to zero (when the diode turns off) and the time when the current falls to less than 10% of the peak reverse current. The default value is `15` μ`s`.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery time directly`.

The value of the **Reverse recovery time, trr** parameter must be greater than the value of the **Peak reverse current, iRM** parameter divided by the value of the **Rate of change of current when measuring iRM** parameter.

Reverse recovery time stretch factor

Value that the block uses to calculate **Reverse recovery time, trr**. This value must be greater than 1. The default value is `3`.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify stretch factor`.

Specifying the stretch factor is an easier way to parameterize the reverse recovery time than specifying the reverse recovery charge. The larger the value of the stretch factor, the longer it takes for the reverse recovery current to dissipate.

Reverse recovery charge, Qrr

Value that the block uses to calculate **Reverse recovery time, trr**. Use this parameter if the data sheet for your diode device specifies a value for the reverse recovery charge instead of a value for the reverse recovery time.

The reverse recovery charge is the total charge that continues to dissipate when the diode turns off. The value must be less than $-\dfrac{i^2_{RM}}{2a}$,

where:

- i_{RM} is the value specified for **Peak reverse current, iRM**.
- a is the value specified for **Rate of change of current when measuring iRM**.

The default value is `1500 μAs`.

The parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery charge`.

For more information on these parameters, see `Commutation Diode`.

Thermal Model Tab

The **Thermal Model** tab is enabled only when you select a block variant that includes a thermal port.

Thermal loss dependent on

Select a parameterization method. The option that you select determines which other parameters are enabled. Options are:

- `Voltage and current` — Use scalar values to specify the output current, switch-on loss, switch-off loss, and on-state voltage data.
- `Voltage, current, and temperature` — Use vectors to specify the output current, switch-on loss, switch-off loss, on-state voltage, and temperature data. This is the default parameterization method.

1-177

Off-state voltage for losses data

The output voltage of the device during the off state. This is the blocking voltage at which the switch-on loss and switch-off loss data are defined. The default value is 300 V.

Energy dissipation time constant

Time constant used to average the switch-on losses, switch-off losses, and conduction losses. This value is equal to the period of the minimum switching frequency. The default value is 1e-4 s.

Additional Parameters for Parameterizing by Voltage, Current, and Temperature

Temperature vector, Tj

Temperature values at which the switch-on loss, switch-off loss, and on-state voltage are specified. Specify this parameter using a vector quantity. The default value is [298.15 398.15] K.

Output current vector, Iout

Output currents for which the switch-on loss, switch-off- loss and on-state voltage are defined. The first element must be zero. Specify this parameter using a vector quantity. The default value is [0 10 50 100 200 400 600] A.

Switch-on loss, Eon=fcn(Tj,Iout)

Energy dissipated during a single swtich on event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a vector quantity. The default value is [0 2.9e-4 0.00143 0.00286 0.00571 0.01314 0.02286; 0 5.7e-4 0.00263 0.00514 0.01029 0.02057 0.03029] J.

Switch-off loss, Eoff=fcn(Tj,Iout)

Energy dissipated during a single switch-off event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a vector quantity. The default value is [0 2.1e-4 0.00107 0.00214 0.00429 0.009859999999999999 0.01714; 0 4.3e-4 0.00197 0.00386 0.00771 0.01543 0.02271] J.

On-state voltage, Von=fcn(Tj,Iout)

Voltage drop across the device while it is in a triggered conductive state.. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a vector quantity. The default value is [0 1.1 1.3 1.45 1.75 2.25 2.7; 0 1 1.15 1.35 1.7 2.35 3] V.

Additional Parameters for Parameterizing by Voltage and Current

Output current, Iout

>   Output currents for which the switch-on loss, switch-off loss, and on-state voltage are defined. The first element must be zero. Specify this parameter using a scalar quantity. The default value is 600 A.

Switch-on loss

>   Energy dissipated during a single switch-on event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a scalar quantity. The default value is 0.02286 J.

Switch-off loss

>   Energy dissipated during a single switch-off event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a scalar quantity. The default value is 0.01714 J.

On-state voltage

>   Voltage drop across the block while it is in a triggered conductive state. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a scalar quantity. The default value is 2.7 V.

See Also

See Also
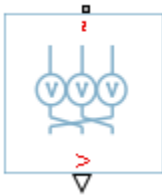Commutation Diode | Diode | GTO | Ideal Semiconductor Switch | MOSFET | Thyristor

Topics
"Simulate Thermal Losses in Semiconductors"
"Switch Between Physical Signal and Electrical Ports"

Introduced in R2013b

Line Voltage Sensor

Measure line voltages in three-phase system

Library

Sensors

Description

The Line Voltage Sensor block represents an ideal three-phase line voltage sensor. The block measures the line-line voltages of a three-phase system and outputs a three-element physical signal vector. Each element of the physical signal output vector is proportional to the voltage between the phases as follows:

- Element 1: $V_{ab} = V_a - V_b$
- Element 2: $V_{bc} = V_b - V_c$
- Element 3: $V_{ca} = V_c - V_a$

where V_a, V_b and V_c are the absolute phase voltages.

Ports

The block has the following ports:

~1

 Expandable three-phase port

V

Three-element physical signal vector output port associated with the voltages between the phases

See Also

See Also
Phase Voltage Sensor

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b
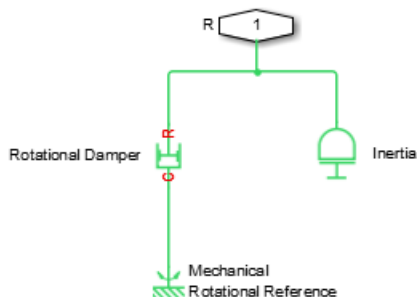
Machine Inertia

Machine inertia

Library

Machines

Description

The Machine Inertia block models inertia and damping that you connect to the mechanical rotational R port of a three-phase machine. The block has an internal connection to a mechanical rotational reference. The figure shows an equivalent configuration to the Machine Inertia block using Simscape mechanical rotational components.

Based on the value you select for the `Specify inertia parameterization by` parameter, you specify inertia J directly or using the machine inertia constant H.

If you specify the inertia constant, the block calculates inertia by

$$J = \frac{2HS_{rated}}{(2\pi F_{rated} \ / \ N)^2},$$

where:

- J is inertia in kg·m^2.
- H is the inertia constant in sW/VA.
- S_{rated} is the machine rated apparent power in VA.
- F_{rated} is the machine rated electrical frequency in Hz.
- N is the number of machine pole pairs.

You specify damping that represents viscous friction between the machine rotor and mechanical rotational reference. Based on the value you select for the `Specify damper parameterization by` parameter, you specify a damping coefficient in SI units or in per-unit. If you specify the damping coefficient in per-unit, the block calculates the damping coefficient in SI units by

$$\omega_{base} = \frac{2\pi F_{rated}}{N},$$

$$T_{base} = \frac{S_{rated}}{\omega_{base}},$$

$$D_{base} = \frac{T_{base}}{\omega_{base}},$$

and

$$D = D_{pu}D_{base},$$

where:

- ω_{base} is the base mechanical speed in rad/s.
- T_{base} is the base damping torque in Nm.

- D_{base} is the base damping coefficient in Nm/(rad/s).
- D_{pu} is the damping coefficient in per-unit.
- D is the damping coefficient in SI units of Nm/(rad/s).

Display Option

You can display machine parameters using the **Power Systems** menu on the block context menu.

Right-click the block and, from the **Power Systems** menu, select **Display Parameters** to display the machine per-unit base values and inertia parameters in the MATLAB Command Window.

Parameters

Main Tab

Rated apparent power

Machine rated apparent power. The default value is `555e6 V*A`.

Rated electrical frequency

Nominal electrical frequency corresponding to the machine rated apparent power. The default value is `60 Hz`.

Number of pole pairs

Number of machine pole pairs. The default value is `1`.

Inertia Tab

Specify inertia parameterization by

Inertia specification. The default value is `Inertia constant, H`.

Inertia constant, H

Inertia constant. This parameter is visible only if you set **Specify inertia parameterization by** to `Inertia constant, H`. The default value is `3.525 sW/ VA`.

Actual inertia, J

Inertia. This parameter is visible only if you set **Specify inertia parameterization by** to `Actual inertia, J`. The default value is `27548` kg·m^2.

Specify damper parameterization by

Damping specification. The default value is `Per-unit damping coefficient, pu_D`.

Per-unit damping coefficient

Damping coefficient in per-unit. This parameter is visible only if you set **Specify damper parameterization by** to `Per-unit damping coefficient, pu_D`. The default value is `0.01`.

SI damping coefficient

Damping coefficient in SI units. This parameter is visible only if you set **Specify damper parameterization by** to `SI damping coefficient, D`. The default value is `39.0509` Nm/(rad/s).

Initial Conditions Tab

Specify initialization by

Frequency initialization. The default value is `Initial electrical frequency`.

Initial electrical frequency

Initial electrical frequency. This parameter is visible only if you set **Specify initialization by** to `Initial electrical frequency`. The default value is `60 Hz`.

Initial mechanical frequency

Initial mechanical frequency. This parameter is visible only if you set **Specify initialization by** to `Initial mechanical frequency`. The default value is `60 Hz`.

Ports

The block has the following ports:

R

Mechanical rotational conserving port associated with the machine rotor
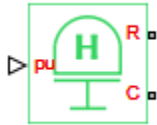
References

[1] Kundur, P. *Power System Stability and Control.* New York, NY: McGraw Hill, 1993.

Introduced in R2013b

Machine Mechanical Power (pu)

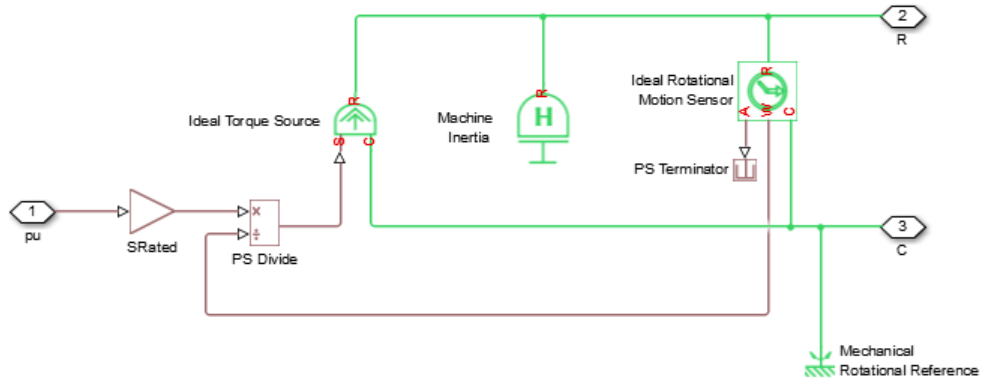Machine mechanical power defined in the per-unit system

Library

Machines

Description

The Machine Mechanical Power (pu) block supplies specified power to, or draws specified power from, the machine that it connects to. It includes a representation of machine inertia and a mechanical rotational reference. In generator mode, the physical signal input pu defines the per-unit mechanical power that is input to the machine. In motor mode, it defines the mechanical power output from the machine. The pu input must always be positive.

The figure shows an equivalent configuration to the Machine Mechanical Power (pu) block using Simscape mechanical rotational components.

Electrical Defining Equations

To calculate the torque that it applies to the inertia, the block divides the power demand by the present speed. To set the peak torque limit, specify a value for the **Peak torque to rated torque ratio** parameter. Use the **Specify inertia parameterization by** parameter to specify inertia, J, directly or indirectly, with the inertia constant for the machine, H.

If you specify the inertia constant for the machine, the block calculates inertia as

$$J = \frac{2HS_{rated}}{(2\pi F_{rated} / N)^2},$$

where:

- J is inertia in $kg \cdot m^2$.
- H is the inertia constant in sW/VA.
- S_{rated} is the rated apparent power of the connected machine in VA.
- F_{rated} is the rated electrical frequency of the connected machine in Hz.
- N is the number of machine pole pairs.

Damping represents viscous friction between the machine rotor and mechanical rotational reference. Based on the value you select for the **Specify damper**

parameterization by parameter, you specify a damping coefficient in per-unit or in SI units. If you specify the damping coefficient in per-unit, the block calculates the damping coefficient in SI units using these equations:

$$\omega_{base} = \frac{2\pi F_{rated}}{N},$$

$$T_{base} = \frac{S_{rated}}{\omega_{base}},$$

$$D_{base} = \frac{T_{base}}{\omega_{base}},$$

and

$$D = D_{pu}D_{base},$$

where:

- ω_{base} is the base mechanical speed in rad/s.
- T_{base} is the base damping torque in Nm.
- D_{base} is the base damping coefficient in Nm/(rad/s).
- D_{pu} is the damping coefficient in per-unit.
- D is the damping coefficient in SI units of Nm/(rad/s).

Parameters

- "Main Tab" on page 1-189
- "Inertia Tab" on page 1-190
- "Initial Conditions Tab" on page 1-191

Main Tab

Input power sign convention

Machine type specification. The choices are `Generator` and `Motor`. The default value is `Generator`.

Rated apparent power

Rated apparent power of the connected machine. The default value is `555e6 V*A`.

Rated electrical frequency

Nominal electrical frequency corresponding to the rated apparent power of the connected machine. The default value is `60 Hz`.

Number of pole pairs

Number of pole pairs of the connected machine. The default value is `1`.

Peak torque to rated torque ratio

Ratio that the block multiplies by the base torque to provide the upper limit for the torque that accelerates the inertia. The default value is `2`.

Inertia Tab

Specify inertia parameterization by

Inertia specification. The choices are between `Actual Inertia, J` and `Inertia constant, H`. The default value is `Inertia constant, H`.

Inertia constant, H

Inertia constant. This parameter is visible only if you set **Specify inertia parameterization by** to `Inertia constant, H`. The default value is `3.525 s*W/VA`.

Actual inertia, J

Inertia. This parameter is visible only if you set **Specify inertia parameterization by** to `Actual Inertia, J`. The default value is `27548 kg·m`^{2}.

Specify damper parameterization by

Damping specification. The choices are `Per-unit damping coefficient, pu_D` and `SI damping coefficient, D`. The default value is `Per-unit damping coefficient, pu_D`.

Per-unit damping coefficient

Damping coefficient in per-unit. This parameter is visible only if you set **Specify damper parameterization by** to `Per-unit damping coefficient, pu_D`. The default value is `0.01`.

SI damping coefficient

> Damping coefficient in SI units. This parameter is visible only if you set **Specify damper parameterization by** to `SI damping coefficient, D`. The default value is `39.0509` Nm/(rad/s).

Initial Conditions Tab

Specify initialization by

> Frequency initialization. The choices are `Initial electrical frequency` and `Initial mechanical frequency`. The default value is `Initial electrical frequency`.

Initial electrical frequency

> Initial electrical frequency. This parameter is visible only if you set **Specify initialization by** to `Initial electrical frequency`. The default value is `60 Hz`.

Initial mechanical frequency

> Initial mechanical frequency. This parameter is visible only if you set **Specify initialization by** to `Initial mechanical frequency`. The default value is `60 Hz`.

Ports

The block has the following ports:

`pu`

> Physical signal input port associated with mechanical power, per-unit

`R`

> Mechanical rotational conserving port associated with the machine rotor

`C`

> Mechanical rotational conserving port associated with the machine case

See Also

`Machine Inertia | Machine Mechanical Power (SI)`

Introduced in R2014b

Machine Mechanical Power (SI)
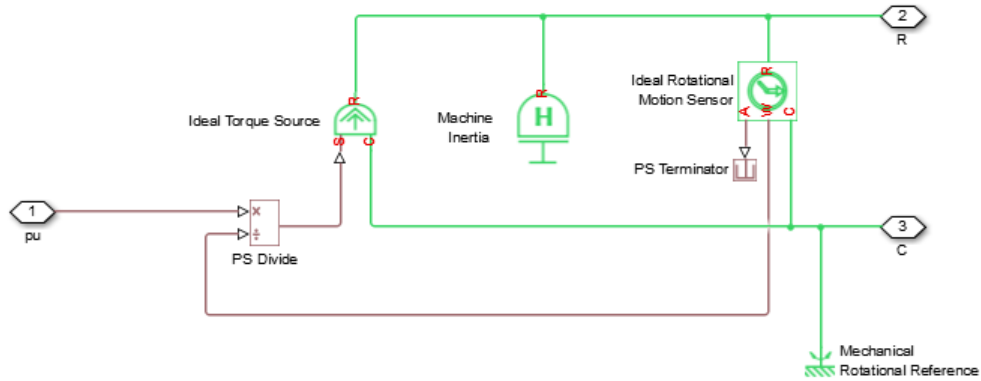
Machine mechanical power defined in SI units

Library

Machines

Description

The Machine Mechanical Power (SI) block supplies specified power to, or draws specified power from, the machine that it connects to. It includes a representation of machine inertia and a mechanical rotational reference. In generator mode, the physical signal input Pm defines the mechanical power in SI units that is input to the machine. In motor mode, it defines the mechanical power output from the machine. The Pm input must always be positive.

The figure shows an equivalent configuration to the Machine Mechanical Power (SI) block using Simscape mechanical rotational components.

Electrical Defining Equations

To calculate the torque that it applies to the inertia, the block divides the power demand by the present speed. To set the peak torque limit, specify a value for the **Peak torque to rated torque ratio** parameter. Use the **Specify inertia parameterization by** parameter to specify inertia, J, directly or indirectly, with the inertia constant for the machine, H.

If you specify the inertia constant for the machine, the block calculates inertia as

$$J = \frac{2HS_{rated}}{(2\pi F_{rated} / N)^2},$$

where:

- J is inertia in kg·m^2.
- H is the inertia constant in sW/VA.
- S_{rated} is the rated apparent power of the connected machine in VA.
- F_{rated} is the rated electrical frequency of the connected machine in Hz.
- N is the number of pole pairs in the connected machine.

Damping represents viscous friction between the machine rotor and mechanical rotational reference. Based on the value you select for the **Specify damper**

parameterization by parameter, you specify a damping coefficient in per-unit or in SI units. If you specify the damping coefficient in per-unit, the block calculates the damping coefficient in SI units using these equations:

$$\omega_{base} = \frac{2\pi F_{rated}}{N},$$

$$T_{base} = \frac{S_{rated}}{\omega_{base}},$$

$$D_{base} = \frac{T_{base}}{\omega_{base}},$$

and

$$D = D_{pu}D_{base},$$

where:

- ω_{base} is the base mechanical speed in rad/s.
- T_{base} is the base damping torque in Nm.
- D_{base} is the base damping coefficient in Nm/(rad/s).
- D_{pu} is the damping coefficient in per-unit.
- D is the damping coefficient in SI units of Nm/(rad/s).

Parameters

- "Main Tab" on page 1-195
- "Inertia Tab" on page 1-196
- "Initial Conditions Tab" on page 1-197

Main Tab

Input power sign convention

Machine type specification. The choices are `Generator` and `Motor`. The default value is `Generator`.

Rated apparent power

Rated apparent power of the connected machine. The default value is `555e6 V*A`.

Rated electrical frequency

Nominal electrical frequency corresponding to the rated apparent power of the connected machine. The default value is `60 Hz`.

Number of pole pairs

Number of pole pairs of the connected machine. The default value is `1`.

Peak torque to rated torque ratio

Ratio that the block multiplies by the base torque to provide the upper limit for the torque that accelerates the inertia. The default value is `2`.

Inertia Tab

Specify inertia parameterization by

Inertia specification. The choices are `Actual Inertia, J` and `Inertia constant, H`. The default value is `Inertia constant, H`.

Inertia constant, H

Inertia constant. This parameter is visible only if you set **Specify inertia parameterization by** to `Inertia constant, H`. The default value is `3.525 s*W/VA`.

Actual inertia, J

Inertia. This parameter is visible only if you set **Specify inertia parameterization by** to `Actual Inertia, J`. The default value is `27548 kg·m`^{2}.

Specify damper parameterization by

Damping specification. The choices are `Per-unit damping coefficient, pu_D` and `SI damping coefficient, D`. The default value is `Per-unit damping coefficient, pu_D`.

Per-unit damping coefficient

Damping coefficient in per-unit. This parameter is visible only if you set **Specify damper parameterization by** to `Per-unit damping coefficient, pu_D`. The default value is `0.01`.

SI damping coefficient

Damping coefficient in SI units. This parameter is visible only if you set **Specify damper parameterization by** to `SI damping coefficient, D`. The default value is `39.0509` Nm/(rad/s).

Initial Conditions Tab

Specify initialization by

Frequency initialization. The choices are `Initial electrical frequency` and `Initial mechanical frequency`. The default value is `Initial electrical frequency`.

Initial electrical frequency

Initial electrical frequency. This parameter is visible only if you set **Specify initialization by** to `Initial electrical frequency`. The default value is `60 Hz`.

Initial mechanical frequency

Initial mechanical frequency. This parameter is visible only if you set **Specify initialization by** to `Initial mechanical frequency`. The default value is `60 Hz`.

Ports

The block has the following ports:

`Pm`

Physical signal input port associated with mechanical power, W

`R`

Mechanical rotational conserving port associated with the machine rotor

`C`

Mechanical rotational conserving port associated with the machine case

See Also

See Also
`Machine Inertia | Machine Mechanical Power (pu)`

Topics

Three-Phase Asynchronous Machine Starting

**Introduced in R2014b**

MOSFET

N-channel MOSFET

Library

Semiconductors / Fundamental Components

Description

The MOSFET block models an n-channel metal-oxide-semiconductor field-effect transistor (MOSFET).

The I-V characteristic of an n-channel MOSFET is such that if the gate-source voltage exceeds the specified threshold voltage, the MOSFET is in the on state. Otherwise, the device is in the off state.
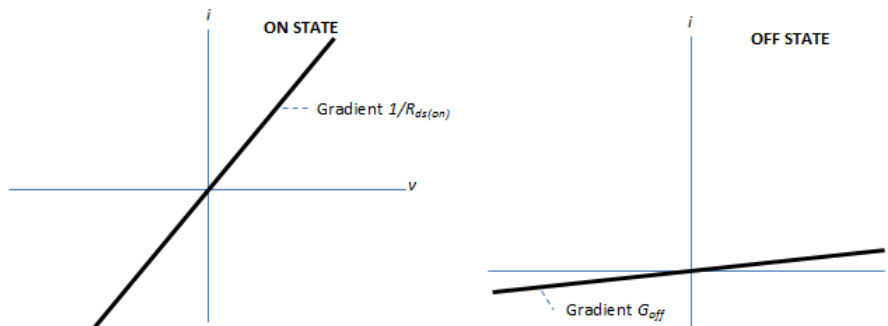
In the on state, the drain-source path behaves like a linear resistor with resistance, R_{ds_on}.

In the off state, the drain-source path behaves like a linear resistor with low off-state conductance, G_{off}.

The defining Simscape equations for the block are:

```
if G > Vth
  v == i*Rds_on;
else
  v == i/Goff;
end
```

where:

- G is the gate-source voltage.
- Vth is the threshold voltage.
- v is the drain-source voltage.
- i is the drain-source current.
- Rds_on is the on-state resistance.
- $Goff$ is the off-state conductance.

Using the Integral Diode tab of the block dialog box, you can include an integral source-drain diode. An integral diode protects the semiconductor device by providing a conduction path for reverse current. An inductive load can produce a high reverse-voltage spike when the semiconductor device suddenly switches off the voltage supply to the load.

Set the **Integral protection diode** parameter based on your goal.

Goal	Value to Select	Block Behavior
Prioritize simulation speed.	`Protection diode with no dynamics`	The block includes an integral copy of the `Diode` block. The block dialog box shows parameters relating to the Diode block.
Precisely specify reverse-mode charge dynamics.	`Protection diode with charge dynamics`	The block includes an integral copy of the `Commutation Diode` block. The block dialog box shows parameters relating to the Commutation Diode block.

Modeling Variants

The block provides four modeling variants. To select the desired variant, right-click the block in your model. From the context menu, select **Simscape** > **Block choices**, and then one of these variants:
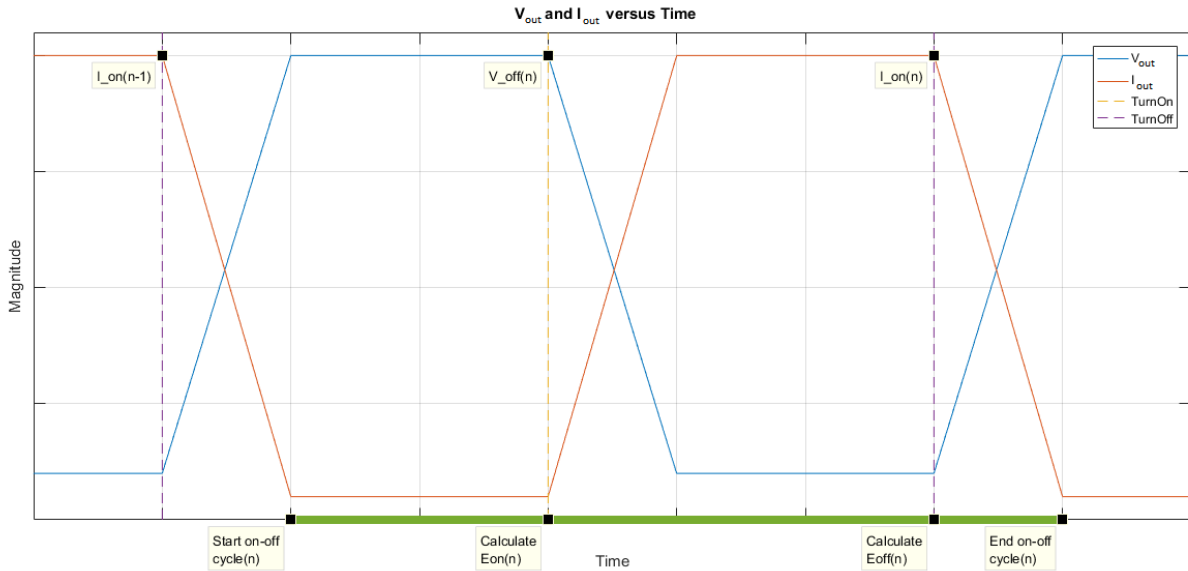
- **PS Control Port** — Contains a physical signal port that is associated with the gate terminal. This variant is the default.
- **Electrical Control Port** — Contains an electrical conserving port that is associated with the gate terminal.
- **PS Control Port | Thermal Port** — Contains a thermal port and a physical signal port that is associated with the gate terminal.
- **Electrical Control Port | Thermal Port** — Contains a thermal port and an electrical conserving port that is associated with the gate terminal.

The variants of this block without the thermal port do not simulate heat generation in the device.

The variants with the thermal port allow you to model the heat that switching events and conduction losses generate. For numerical efficiency, the thermal state does not affect the electrical behavior of the block. The thermal port is hidden by default. To enable the thermal port, select a thermal block variant.

Thermal Loss Equations

The figure shows an idealized representation of the output voltage, V_{out}, and the output current, I_{out}, of the semiconductor device. The interval shown includes the entire nth switching cycle, during which the block turns off and then on.

Heat Loss Due to a Switch-On Event

When the semiconductor turns on during the nth switching cycle, the amount of thermal energy that the device dissipates increments by a discrete amount. If you select `Voltage, current, and temperature` for the **Thermal loss dependent on** parameter, the equation for the incremental change is

$$E_{on(n)} = \frac{V_{off(n)}}{V_{off\_data}} fcn(T, I_{on(n-1)}),$$

where:

- $E_{on(n)}$ is the switch-on loss at the nth switch-on event.
- $V_{off(n)}$ is the off-state output voltage, V_{out}, just before the device switches on during the nth switching cycle.
- V_{off_data} is the **Off-state voltage for losses data** parameter value.
- T is the device temperature.
- $I_{on(n-1)}$ is the on-state output current, I_{out}, just before the device switches off during the cycle that precedes the nth switching cycle.

The function *fcn* is a 2-D lookup table with linear interpolation and linear extrapolation:

$$E = tablelookup(T_{j\_data}, I_{out\_data}, E_{on\_data}, T, I_{on(n-1)}),$$

where:

- T_{j_data} is the **Temperature vector, Tj** parameter value.
- I_{out_data} is the **Output current vector, Iout** parameter value.
- E_{on_data} is the **Switch-on loss, Eon=fcn(Tj,Iout)** parameter value.

If you select `Voltage and current` for the **Thermal loss dependent on** parameter, when the semiconductor turns on during the *n*th switching cycle, the equation that the block uses to calculate the incremental change in the discrete amount of thermal energy that the device dissipates is

$$E_{on(n)} = \left(\frac{V_{off(n)}}{V_{off\_data}} \right) \left(\frac{I_{on(n-1)}}{I_{out\_scalar}} \right) (E_{on\_scalar})$$

where:

- I_{out_scalar} is the **Output current, Iout** parameter value.
- E_{on_scalar} is the **Switch-on loss** parameter value.

Heat Loss Due to a Switch-Off Event

When the semiconductor turns off during the *n*th switching cycle, the amount of thermal energy that the device dissipates increments by a discrete amount. If you select `Voltage, current, and temperature` for the **Thermal loss dependent on** parameter, the equation for the incremental change is

$$E_{off(n)} = \frac{V_{off(n)}}{V_{off\_data}} fcn(T, I_{on(n)}),$$

where:

- $E_{off(n)}$ is the switch-off loss at the *n*th switch-off event.

- $V_{off(n)}$ is the off-state output voltage, V_{out}, just before the device switches on during the nth switching cycle.
- V_{off_data} is the **Off-state voltage for losses data** parameter value.
- T is the device temperature.
- $I_{on(n)}$ is the on-state output current, I_{out}, just before the device switches off during the nth switching cycle.

The function *fcn* is a 2-D lookup table with linear interpolation and linear extrapolation:

$$E = tablelookup(T_{j\_data}, I_{out\_data}, E_{off\_data}, T, I_{on(n)}),$$

where:

- T_{j_data} is the **Temperature vector, Tj** parameter value.
- I_{out_data} is the **Output current vector, Iout** parameter value.
- E_{off_data} is the **Switch-off loss, Eoff=fcn(Tj,Iout)** parameter value.

If you select `Voltage and current` for the **Thermal loss dependent on** parameter, when the semiconductor turns off during the nth switching cycle, the equation that the block uses to calculate the incremental change in the discrete amount of thermal energy that the device dissipates is

$$E_{off(n)} = \left(\frac{V_{off(n)}}{V_{off\_data}} \right) \left(\frac{I_{on(n-1)}}{I_{out\_scalar}} \right) (E_{off\_scalar})$$

where:

- I_{out_scalar} is the **Output current, Iout** parameter value.
- E_{off_scalar} is the **Switch-off loss** parameter value.

Heat Loss Due to Electrical Conduction

If you select `Voltage, current, and temperature` for the **Thermal loss dependent on** parameter, then, for both the on state and the off state, the heat loss due to electrical conduction is

$$E_{conduction} = \int fcn(T, I_{out}) \, dt,$$

where:

- $E_{conduction}$ is the heat loss due to electrical conduction.
- T is the device temperature.
- I_{out} is the device output current.

The function *fcn* is a 2-D lookup table:

$$Q_{conduction} = tablelookup(T_{j\_data}, I_{out\_data}, I_{out\_data\_repmat} \cdot * V_{on\_data}, T, I_{out}),$$

where:

- T_{j_data} is the **Temperature vector, Tj** parameter value.
- I_{out_data} is the **Output current vector, Iout** parameter value.
- $I_{out\_data\_repmat}$ is a matrix that contains length, T_{j_data}, copies of I_{out_data}.
- V_{on_data} is the **On-state voltage, Von=fcn(Tj,Iout)** parameter value.

If you select `Voltage and current` for the **Thermal loss dependent on** parameter, then, for both the on state and the off state, the heat loss due to electrical conduction is

$$E_{conduction} = \int \left(I_{out} * V_{on\_scalar} \right) dt,$$

where V_{on_scalar} is the **On-state voltage** parameter value.

Heat Flow

The block uses the **Energy dissipation time constant** parameter to filter the amount of heat flow that the block outputs. The filtering allows the block to:

- Avoid discrete increments for the heat flow output
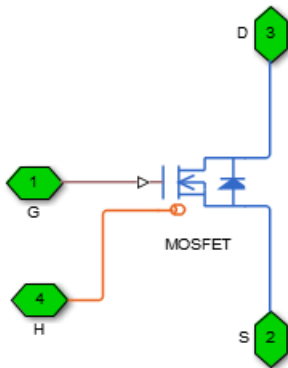- Handle a variable switching frequency

The filtered heat flow is

$$Q = \frac{1}{\tau}\left(\sum_{i=1}^{n} E_{on(i)} + \sum_{i=1}^{n} E_{off(i)} + E_{conduction} - \int Q\,dt\right),$$

where:

- Q is the heat flow from the component.
- τ is the **Energy dissipation time constant** parameter value.
- n is the number of switching cycles.
- $E_{on(i)}$ is the switch-on loss at the ith switch-on event.
- $E_{off(i)}$ is the switch-off loss at the ith switch-off event.
- $E_{conduction}$ is the heat loss due to electrical conduction.
- $\int Q\,dt$ is the total heat previously dissipated from the component.

Ports

The figure shows the block port names.

G

Port associated with the gate terminal. You can set the port to either a physical signal or electrical port.

S

Electrical conserving port associated with the source terminal.

D

Electrical conserving port associated with the drain terminal.

H

Thermal conserving port. The thermal port is optional and is hidden by default. To enable this port, select a variant that includes a thermal port.

Parameters

- "Main Tab" on page 1-207
- "Integral Diode Tab" on page 1-207
- "Thermal Model Tab" on page 1-157

Main Tab

On-state resistance, R_DS(on)

Drain-source resistance when the device is on. The default value is `0.01 Ohm`.

Off-state conductance

Drain-source conductance when the device is off. The value must be less than 1/R, where R is the value of **On-state resistance**. The default value is `1e-6 1/Ohm`.

Threshold voltage, Vth

Gate-source voltage threshold. The device turns on when the gate-source voltage is above this value. The default value is `2 V`.

Integral Diode Tab

Integral protection diode

Block integral protection diode. The default value is `Protection diode with no dynamics`.

The diodes you can select are:

- `Protection diode with no dynamics`

- `Protection diode with charge dynamics`

Parameters for Protection diode with no dynamics

When you select `Protection diode with no dynamics`, additional parameters appear.

Additional Parameters for Protection diode with no dynamics

Forward voltage

Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is `0.8` V.

On resistance

Rate of change of voltage versus current above the **Forward voltage**. The default value is `0.001` Ohm.

Off conductance

Conductance of the reverse-biased diode. The default value is `1e-5 1/Ohm`.

For more information on these parameters, see `Diode`.

Parameters for Protection diode with charge dynamics

When you select `Protection diode with charge dynamics`, additional parameters appear.

Additional Parameters for Protection diode with charge dynamics

Forward voltage

Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is `0.8` V.

On resistance

Rate of change of voltage versus current above the **Forward voltage**. The default value is `0.001` Ohm.

Off conductance

Conductance of the reverse-biased diode. The default value is `1e-5 1/Ohm`.

Junction capacitance

Diode junction capacitance. The default value is `50 nF`.

Peak reverse current, iRM

Peak reverse current measured by an external test circuit. This value must be less than zero. The default value is `-235 A`.

Initial forward current when measuring iRM

Initial forward current when measuring peak reverse current. This value must be greater than zero. The default value is `300 A`.

Rate of change of current when measuring iRM

Rate of change of current when measuring peak reverse current. This value must be less than zero. The default value is `-50 A/`μ`s`.

Reverse recovery time parameterization

Determines how you specify reverse recovery time in the block. The default value is `Specify reverse recovery time directly`.

If you select `Specify stretch factor` or `Specify reverse recovery charge`, you specify a value that the block uses to derive the reverse recovery time. For more information on these options, see "Alternatives to Specifying t_{rr} Directly" on page 1-83.

Reverse recovery time, trr

Interval between the time when the current initially goes to zero (when the diode turns off) and the time when the current falls to less than 10% of the peak reverse current. The default value is `15 `μ`s`.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery time directly`.

The value of the **Reverse recovery time, trr** parameter must be greater than the value of the **Peak reverse current, iRM** parameter divided by the value of the **Rate of change of current when measuring iRM** parameter.

Reverse recovery time stretch factor

Value that the block uses to calculate **Reverse recovery time, trr**. This value must be greater than `1`. The default value is `3`.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify stretch factor`.

Specifying the stretch factor is an easier way to parameterize the reverse recovery time than specifying the reverse recovery charge. The larger the value of the stretch factor, the longer it takes for the reverse recovery current to dissipate.

Reverse recovery charge, Qrr

Value that the block uses to calculate **Reverse recovery time, trr**. Use this parameter if the data sheet for your diode device specifies a value for the reverse recovery charge instead of a value for the reverse recovery time.

The reverse recovery charge is the total charge that continues to dissipate when the diode turns off. The value must be less than $-\dfrac{i^2_{RM}}{2a}$,

where:

- i_{RM} is the value specified for **Peak reverse current, iRM**.
- a is the value specified for **Rate of change of current when measuring iRM**.

The default value is `1500 μAs`.

The parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery charge`.

For more information on these parameters, see `Commutation Diode`.

Thermal Model Tab

The **Thermal Model** tab is enabled only when you select a block variant that includes a thermal port.

Thermal loss dependent on

Select a parameterization method. The option that you select determines which other parameters are enabled. Options are:

- `Voltage and current` — Use scalar values to specify the output current, switch-on loss, switch-off loss, and on-state voltage data.
- `Voltage, current, and temperature` — Use vectors to specify the output current, switch-on loss, switch-off loss, on-state voltage, and temperature data. This is the default parameterization method.

Off-state voltage for losses data

The output voltage of the device during the off state. This is the blocking voltage at which the switch-on loss and switch-off loss data are defined. The default value is 300 V.

Energy dissipation time constant

Time constant used to average the switch-on losses, switch-off losses, and conduction losses. This value is equal to the period of the minimum switching frequency. The default value is 1e-4 s.

Additional Parameters for Parameterizing by Voltage, Current, and Temperature

Temperature vector, Tj

Temperature values at which the switch-on loss, switch-off loss, and on-state voltage are specified. Specify this parameter using a vector quantity. The default value is [298.15 398.15] K.

Output current vector, Iout

Output currents for which the switch-on loss, switch-off- loss and on-state voltage are defined. The first element must be zero. Specify this parameter using a vector quantity. The default value is [0 10 50 100 200 400 600] A.

Switch-on loss, Eon=fcn(Tj,Iout)

Energy dissipated during a single swtich on event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a vector quantity. The default value is [0 2.9e-4 0.00143 0.00286 0.00571 0.01314 0.02286; 0 5.7e-4 0.00263 0.00514 0.01029 0.02057 0.03029] J.

Switch-off loss, Eoff=fcn(Tj,Iout)

Energy dissipated during a single switch-off event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a vector quantity. The default value is [0 2.1e-4 0.00107 0.00214 0.00429 0.009859999999999999 0.01714; 0 4.3e-4 0.00197 0.00386 0.00771 0.01543 0.02271] J.

On-state voltage, Von=fcn(Tj,Iout)

Voltage drop across the device while it is in a triggered conductive state.. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a vector quantity. The default value is [0 1.1 1.3 1.45 1.75 2.25 2.7; 0 1 1.15 1.35 1.7 2.35 3] V.

Additional Parameters for Parameterizing by Voltage and Current

Output current, Iout

> Output currents for which the switch-on loss, switch-off loss, and on-state voltage are defined. The first element must be zero. Specify this parameter using a scalar quantity. The default value is 600 A.

Switch-on loss

> Energy dissipated during a single switch-on event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a scalar quantity. The default value is 0.02286 J.

Switch-off loss

> Energy dissipated during a single switch-off event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a scalar quantity. The default value is 0.01714 J.

On-state voltage

> Voltage drop across the block while it is in a triggered conductive state. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a scalar quantity. The default value is 2.7 V.

See Also

See Also
Commutation Diode | Diode | GTO | Ideal Semiconductor Switch | IGBT | Thyristor

Topics
"Simulate Thermal Losses in Semiconductors"
"Switch Between Physical Signal and Electrical Ports"

Introduced in R2013b

Neutral Port

Connect phases of three-phase system to electrical conserving port

Library

Connections

Description

The Neutral Port block connects the phases of a three-phase system to an electrical conserving port. You can connect the electrical port to electrical components from the Simscape and Simscape Electronics™ libraries.

Note: If you do not need to connect the neutral port to other blocks, use a Floating Neutral block instead. If you want to ground the neutral port, use a Grounded Neutral block.

Ports

The block has the following ports:

~

    Expandable three-phase port

n

    Electrical conserving port associated with the neutral point

See Also

See Also
Floating Neutral | Neutral Port

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Nonlinear Inductor

Model inductor with nonideal core

Library

Passive Devices / Fundamental Components

Description

The Nonlinear Inductor block represents an inductor with a nonideal core. A core may be nonideal due to its magnetic properties and dimensions. The block provides the following parameterization options:

- "Single Inductance (Linear)" on page 1-215
- "Single Saturation Point" on page 1-216
- "Magnetic Flux Versus Current Characteristic" on page 1-217
- "Magnetic Flux Density Versus Magnetic Field Strength Characteristic" on page 1-218
- "Magnetic Flux Density Versus Magnetic Field Strength Characteristic with Hysteresis" on page 1-219

Single Inductance (Linear)

The relationships between voltage, current, and flux are defined by the following equations:

$$i = i_L + vG_p$$

$$v = N_w \frac{d\Phi}{dt}$$

$$\Phi = \frac{L}{N_w} i_L$$

where:

- v is the terminal voltage.
- i is the terminal current.
- i_L is the current through inductor.
- G_p is the parasitic parallel conductance.
- N_w is the number of winding turns.
- Φ is the magnetic flux.
- L is the unsaturated inductance.

Single Saturation Point

The relationships between voltage, current, and flux are defined by the following equations:

$$i = i_L + v G_p$$

$$v = N_w \frac{d\Phi}{dt}$$

$$\Phi = \frac{L}{N_w} i_L \ \text{(for unsaturated)}$$

$$\Phi = \frac{L_{sat}}{N_w} i_L \pm \Phi_{offset} \ \text{(for saturated)}$$

where:

- v is the terminal voltage.
- i is the terminal current.

- i_L is the current through inductor.
- G_p is the parasitic parallel conductance.
- N_w is the number of winding turns.
- Φ is the magnetic flux.
- Φ_{offset} is the magnetic flux saturation offset.
- L is the unsaturated inductance.
- L_{sat} is the saturated inductance.

Magnetic Flux Versus Current Characteristic

The relationships between voltage, current, and flux are defined by the following equations:

$$i = i_L + v G_p$$

$$v = N_w \frac{d\Phi}{dt}$$

$$\Phi = f(i_L)$$

where:

- v is the terminal voltage.
- i is the terminal current.
- i_L is the current through inductor.
- G_p is the parasitic parallel conductance.
- N_w is the number of winding turns.
- Φ is the magnetic flux.

Magnetic flux is determined by one-dimensional table lookup, based on the vector of current values and the vector of corresponding magnetic flux values that you provide. You can construct these vectors using either negative and positive data, or positive data only. If using positive data only, the vector must start at 0, and the negative data is automatically calculated by rotation about (0,0).

Magnetic Flux Density Versus Magnetic Field Strength Characteristic

The relationships between voltage, current, and flux are defined by the following equations:

$$i = i_L + v G_p$$

$$v = N_w \frac{d\Phi}{dt}$$

$$\Phi = B \cdot A_e$$

$$B = f(H)$$

$$H = \frac{N_w}{l_e} i_L$$

where:

- v is the terminal voltage.
- i is the terminal current.
- i_L is the current through inductor.
- G_p is the parasitic parallel conductance.
- N_w is the number of winding turns.
- Φ is the magnetic flux.
- B is the magnetic flux density.
- H is the magnetic field strength.
- l_e is the effective core length.
- A_e is the effective core cross-sectional area.

Magnetic flux density is determined by one-dimensional table lookup, based on the vector of magnetic field strength values and the vector of corresponding magnetic flux density values that you provide. You can construct these vectors using either negative

and positive data, or positive data only. If using positive data only, the vector must start at 0, and the negative data is automatically calculated by rotation about (0,0).

Magnetic Flux Density Versus Magnetic Field Strength Characteristic with Hysteresis

The relationships between voltage, current, and flux are defined by the following equations:

$$i = i_L + v G_p$$

$$v = N_w \frac{d\Phi}{dt}$$

$$\Phi = B \cdot A_e$$

$$B = \mu_0 \left(H + M \right)$$

$$H = \frac{N_w}{l_e} i_L$$

where:

- v is the terminal voltage.
- i is the terminal current.
- i_L is the current through inductor.
- G_p is the parasitic parallel conductance.
- N_w is the number of winding turns.
- Φ is the magnetic flux.
- B is the magnetic flux density.
- μ_0 is the magnetic constant, permeability of free space.
- H is the magnetic field strength.
- M is the magnetization of the inductor core.

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- l_e is the effective core length.
- A_e is the effective core cross-sectional area.

The magnetization acts to increase the magnetic flux density, and its value depends on both the current value and the history of the field strength H. The Jiles-Atherton [1], [2] equations are used to determine M at any given time. The figure shows a typical plot of the resulting relationship between B and H.
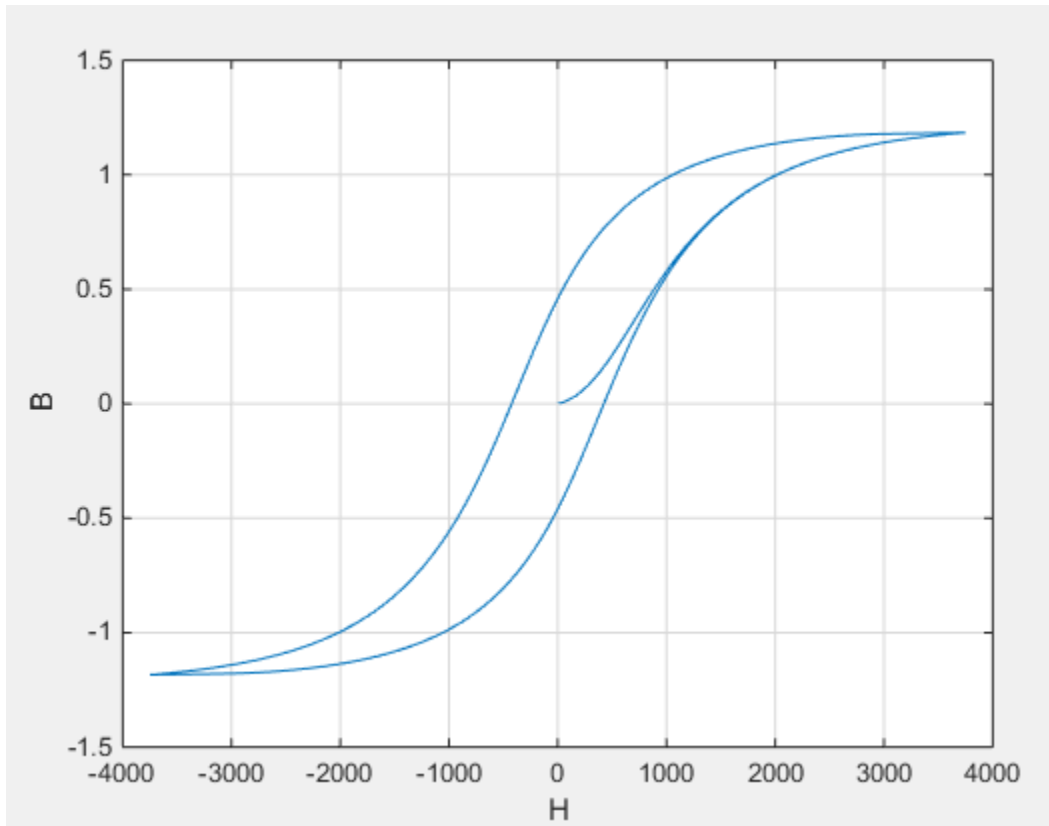
In this case, the magnetization starts as zero, and hence the plot starts at $B = H = 0$. As the field strength increases, the plot tends to the positive-going hysteresis curve; then on reversal the rate of change of H, it follows the negative-going hysteresis curve. The difference between positive-going and negative-going curves is due to the dependence of M on the trajectory history. Physically the behavior corresponds to magnetic dipoles in

the core aligning as the field strength increases, but not then fully recovering to their original position as field strength decreases.

The starting point for the Jiles-Atherton equation is to split the magnetization effect into two parts, one that is purely a function of effective field strength (H_{eff}) and one that is an irreversible part that depends on history:

$$M = cM_{an} + (1-c)M_{irr}$$

The M_{an} term is called the anhysteretic magnetization because it exhibits no hysteresis. It is described by the following function of the current value of the effective field strength, H_{eff}:

$$M_{an} = M_s \left(\coth\left(\frac{H_{eff}}{\alpha} \right) - \frac{\alpha}{H_{eff}} \right)$$

This function defines a saturation curve with limiting values $\pm M_s$ and point of saturation determined by the value of α, the anhysteretic shape factor. It can be thought of as describing the average of the two hysteretic curves. In the Nonlinear Inductor block, you provide values for dM_{an}/dH_{eff} when $H_{eff} = 0$ and a point $[H_1, B_1]$ on the anhysteretic B-H curve. These values are used to determine values for α and M_s.

The parameter c is the coefficient for reversible magnetization, and dictates how much of the behavior is defined by M_{an} and how much by the irreversible term M_{irr}. The Jiles-Atherton model defines the irreversible term by a partial derivative with respect to field strength:

$$\frac{dM_{irr}}{dH} = \frac{M_{an} - M_{irr}}{K\delta - \alpha(M_{an} - M_{irr})}$$

$$\delta = \begin{cases} 1 & \text{if } H \geq 0 \\ -1 & \text{if } H < 0 \end{cases}$$

Comparison of this equation with a standard first order differential equation reveals that as increments in field strength, H, are made, the irreversible term M_{irr} attempts to track the reversible term M_{an}, but with a variable tracking gain of $1/(K\delta - \alpha(M_{an} - M_{irr}))$.

The tracking error acts to create the hysteresis at the points where δ changes sign. The main parameter that shapes the irreversible characteristic is K, which is called the *bulk*

coupling coefficient. The parameter α is called the *inter-domain coupling factor*, and is also used to define the effective field strength used when defining the anhysteretic curve:

$$H_{eff} = H + \alpha M$$

The value of α affects the shape of the hysteresis curve, larger values acting to increase the B-axis intercepts. However, notice that for stability the term $K\delta - \alpha \left(M_{an} - M_{irr} \right)$ must be positive for $\delta > 0$ and negative for $\delta < 0$. Therefore not all values of α are permissible, a typical maximum value being of the order 1e-3.

Procedure for Finding Approximate Values for Jiles-Atherton Equation Coefficients

You can determine representative parameters for the equation coefficients by using the following procedure:

1   Provide a value for the **Anhysteretic B-H gradient when H is zero** parameter (dM_{an} / dH_{eff} when $H_{eff} = 0$) plus a data point $[H_1, B_1]$ on the anhysteretic B-H curve. From these values, the block initialization determines values for α and M_s.

2   Set the **Coefficient for reversible magnetization, c** parameter to achieve correct initial B-H gradient when starting a simulation from [H B] = [0 0]. The value of c is approximately the ratio of this initial gradient to the **Anhysteretic B-H gradient when H is zero**. The value of c must be greater than 0 and less than 1.

3   Set the **Bulk coupling coefficient, K** parameter to the approximate magnitude of H when $B = 0$ on the positive-going hysteresis curve.

4   Start with α very small, and gradually increase to tune the value of B when crossing $H = 0$ line. A typical value is in the range of 1e-4 to 1e-3. Values that are too large cause the gradient of the B-H curve to tend to infinity, which is nonphysical and generates a run-time assertion error.

Sometimes iteration on these four steps is required to get a good match against a predefined B-H curve.

Parameters

- "Main Tab" on page 1-223

- "Initial Conditions Tab" on page 1-226

Main Tab

Parameterized by

Select one of the following methods for block parameterization:

- `Single inductance (linear)` — Provide the values for number of turns, unsaturated inductance, and parasitic parallel conductance.

- `Single saturation point` — Provide the values for number of turns, unsaturated and saturated inductances, saturation magnetic flux, and parasitic parallel conductance. This is the default option.

- `Magnetic flux versus current characteristic` — In addition to the number of turns and the parasitic parallel conductance value, provide the current vector and the magnetic flux vector, to populate the magnetic flux versus current lookup table.

- `Magnetic flux density versus magnetic field strength characteristic` — In addition to the number of turns and the parasitic parallel conductance value, provide the values for effective core length and cross-sectional area, as well as the magnetic field strength vector and the magnetic flux density vector, to populate the magnetic flux density versus magnetic field strength lookup table.

- `Magnetic flux density versus magnetic field strength characteristic with hysteresis` — In addition to the number of turns and the effective core length and cross-sectional area, provide the values for the initial anhysteretic B-H curve gradient, the magnetic flux density and field strength at a certain point on the B-H curve, as well as the coefficient for the reversible magnetization, bulk coupling coefficient, and inter-domain coupling factor, to define magnetic flux density as a function of both the current value and the history of the field strength.

Number of turns

The total number of turns of wire wound around the inductor core. The default value is `10`.

Unsaturated inductance

The value of inductance used when the inductor is operating in its linear region. This parameter is visible only when you select `Single inductance (linear)` or

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`Single saturation point` for the **Parameterized by** parameter. The default value is `2e-4 H`.

Saturated inductance

The value of inductance used when the inductor is operating beyond its saturation point. This parameter is visible only when you select `Single saturation point` for the **Parameterized by** parameter. The default value is `1e-4 H`.

Saturation magnetic flux

The value of magnetic flux at which the inductor saturates. This parameter is visible only when you select `Single saturation point` for the **Parameterized by** parameter. The default value is `1.3e-5 Wb`.

Current, i

The current data used to populate the magnetic flux versus current lookup table. This parameter is visible only when you select `Magnetic flux versus current characteristic` for the **Parameterized by** parameter. The default value is `[ 0 0.64 1.28 1.92 2.56 3.20 ] A`.

Magnetic flux vector, phi

The magnetic flux data used to populate the magnetic flux versus current lookup table. This parameter is visible only when you select `Magnetic flux versus current characteristic` for the **Parameterized by** parameter. The default value is `[0 1.29 2.00 2.27 2.36 2.39 ].*1e-5 Wb`.

Magnetic field strength vector, H

The magnetic field strength data used to populate the magnetic flux density versus magnetic field strength lookup table. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic` for the **Parameterized by** parameter. The default value is `[ 0 200 400 600 800 1000 ] A/m`.

Magnetic flux density vector, B

The magnetic flux density data used to populate the magnetic flux density versus magnetic field strength lookup table. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic` for the **Parameterized by** parameter. The default value is `[ 0 0.81 1.25 1.42 1.48 1.49 ] T`.

Effective length

The effective core length, that is, the average distance of the magnetic path. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic` or `Magnetic flux density`

versus magnetic field strength characteristic with hysteresis for the **Parameterized by** parameter. The default value is `0.032 m`.

Effective cross-sectional area

The effective core cross-sectional area, that is, the average area of the magnetic path. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic` or `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Parameterized by** parameter. The default value is `1.6e-5 m^2`.

Anhysteretic B-H gradient when H is zero

The gradient of the anhyseretic (no hysteresis) B-H curve around zero field strength. Set it to the average gradient of the positive-going and negative-going hysteresis curves. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Parameterized by** parameter. The default value is `0.005 m*T/A`.

Flux density point on anhysteretic B-H curve

Specify a point on the anhysteretic curve by providing its flux density value. Picking a point at high field strength where the positive-going and negative-going hysteresis curves align is the most accurate option. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Parameterized by** parameter. The default value is `1.49 T`.

Corresponding field strength

The corresponding field strength for the point that you define by the **Flux density point on anhysteretic B-H curve** parameter. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Parameterized by** parameter. The default value is `1000 A/m`.

Coefficient for reversible magnetization, c

The proportion of the magnetization that is reversible. The value should be greater than zero and less than one. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Parameterized by** parameter. The default value is `0.1`.

Bulk coupling coefficient, K

The Jiles-Atherton parameter that primarily controls the field strength magnitude at which the B-H curve crosses the zero flux density line. This parameter is visible only

when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Parameterized by** parameter. The default value is `200 A/m`.

Inter-domain coupling factor, alpha

The Jiles-Atherton parameter that primarily affects the points at which the B-H curves intersect the zero field strength line. Typical values are in the range of 1e-4 to 1e-3. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Parameterized by** parameter. The default value is `1e-4`.

Parasitic parallel conductance

Use this parameter to represent small parasitic effects. A small parallel conductance may be required for the simulation of some circuit topologies. The default value is `1e-9 1/Ohm`.

Interpolation option

The lookup table interpolation option. This parameter is visible only when you select `Magnetic flux versus current characteristic` or `Magnetic flux density versus magnetic field strength characteristic` for the **Parameterized by** parameter. Select one of the following interpolation methods:

- `Linear` — Uses a linear interpolation function.
- `Cubic` — Uses the Piecewise Cubic Hermite Interpolation Polynomial (PCHIP).

For more information on interpolation algorithms, see the PS Lookup Table (1D) block reference page.

Initial Conditions Tab

Specify initial state by

Select the appropriate initial state specification option:

- `Current` — Specify the initial state of the inductor by the initial current through the inductor (i_L). This is the default option.
- `Magnetic flux` — Specify the initial state of the inductor by the magnetic flux.

This parameter is not visible when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Parameterized by** parameter on the **Main** tab.

Initial current

The initial current value used to calculate the value of magnetic flux at time zero. This is the current passing through the inductor. Component current consists of current passing through the inductor and current passing through the parasitic parallel conductance. This parameter is visible only when you select `Current` for the **Specify initial state by** parameter. The default value is `0 A`.

Initial magnetic flux

The value of magnetic flux at time zero. This parameter is visible only when you select `Magnetic flux` for the **Specify initial state by** parameter. The default is `0 Wb`.

Initial magnetic flux density

The value of magnetic flux density at time zero. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Parameterized by** parameter on the **Main** tab. The default is `0 T`.

Initial field strength

The value of magnetic field strength at time zero. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Parameterized by** parameter on the **Main** tab. The default is `0 A/m`.

Ports

The block has the following ports:

+

Electrical conserving port associated with the positive terminal of the inductor winding

-

Electrical conserving port associated with the negative terminal of the inductor winding

References

[1] Jiles, D. C., and D. L. Atherton. "Theory of ferromagnetic hysteresis." *Journal of Magnetism and Magnetic Materials*. Vol. 61, 1986, pp. 48–60.

[2] Jiles, D. C., and D. L. Atherton. "Ferromagnetic hysteresis." *IEEE Transactions on Magnetics*. Vol. 19, No. 5, 1983, pp. 2183–2184.
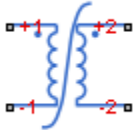
See Also

See Also
```
Nonlinear Transformer
```

Introduced in R2015b

Nonlinear Transformer

Model transformer with nonideal core

Library

Passive Devices / Fundamental Components

Description

The Nonlinear Transformer block represents a transformer with a nonideal core. A core may be nonideal due to its magnetic properties and dimensions. The equivalent circuit topology depends upon which of the two winding leakage parameterization options you select:

- Combined primary and secondary values

- Separate primary and secondary values

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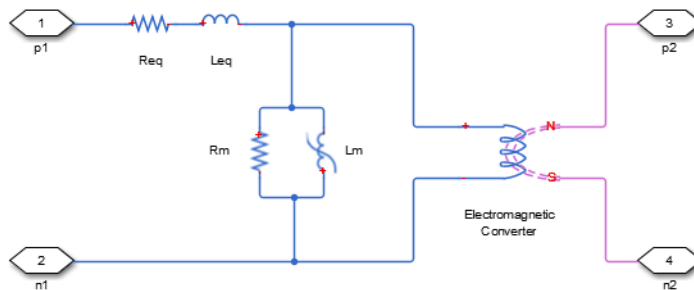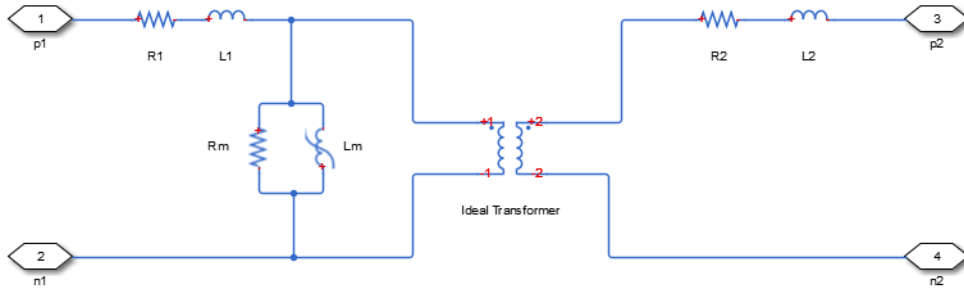
where:

- *Req* is the combined leakage resistance.
- *Leq* is the combined leakage inductance.
- *R1* is the primary leakage resistance.
- *L1* is the primary leakage inductance.
- *R2* is the secondary leakage resistance.
- *L2* is the secondary leakage inductance.
- *Rm* is the magnetization resistance.
- *Lm* is the magnetization inductance.

The block provides the following parameterization options for the nonlinear magnetization inductance:

- `Single inductance (linear)`
- `Single saturation point`
- `Magnetic flux versus current characteristic`
- `Magnetic flux density versus magnetic field strength characteristic`
- `Magnetic flux density versus magnetic field strength characteristic with hysteresis`

For more information, see the `Nonlinear Inductor` block reference page.

Parameters

- "Main Tab" on page 1-231
- "Magnetization Tab" on page 1-232
- "Initial Conditions Tab" on page 1-236
- "Parasitics Tab" on page 1-237

Main Tab

Primary number of turns

The number of turns of wire on the primary winding of the transformer. The default value is 100.

Secondary number of turns

The number of turns of wire on the secondary winding of the transformer. The default value is 200.

Winding parameterized by

Select one of the following methods for the winding leakage parameterization:

- Combined primary and secondary values — Use the lumped resistance and inductance values representing the combined leakage in the primary and secondary windings. This is the default option.
- Separate primary and secondary values — Use separate resistances and inductances to represent leakages in the primary and secondary windings.

Combined leakage resistance

The lumped equivalent resistance *Req*, which represents the combined power loss of the primary and secondary windings. This parameter is visible only when you select Combined primary and secondary values for the **Winding parameterized by** parameter. The default value is 0.01 Ohm.

Combined leakage inductance

The lumped equivalent inductance *Leq*, which represents the combined magnetic flux loss of the primary and secondary windings. This parameter is visible only when you select Combined primary and secondary values for the **Winding parameterized by** parameter. The default value is 1e-4 H.

Primary leakage resistance

The resistance *R1*, which represents the power loss of the primary winding. This parameter is visible only when you select `Separate primary and secondary values` for the **Winding parameterized by** parameter. The default value is `0.01 Ohm`.

Primary leakage inductance

The inductance *L1*, which represents the magnetic flux loss of the primary winding. This parameter is visible only when you select `Separate primary and secondary values` for the **Winding parameterized by** parameter. The default value is `1e-4 H`.

Secondary leakage resistance

The resistance *R2*, which represents the power loss of the secondary winding. This parameter is visible only when you select `Separate primary and secondary values` for the **Winding parameterized by** parameter. The default value is `0.01 Ohm`.

Secondary leakage inductance

The inductance *L2*, which represents the magnetic flux loss of the secondary winding. This parameter is visible only when you select `Separate primary and secondary values` for the **Winding parameterized by** parameter. The default value is `1e-4 H`.

Magnetization Tab

Magnetization resistance

The resistance *Rm*, which represents the magnetic losses in the transformer core. The default value is `100 Ohm`.

Magnetization inductance parameterized by

Select one of the following methods for the nonlinear magnetization inductance parameterization:

- `Single inductance (linear)` — Provide the unsaturated inductance value.
- `Single saturation point` — Provide the values for the unsaturated and saturated inductances, as well as saturation magnetic flux. This is the default option.
- `Magnetic flux versus current characteristic` — Provide the current vector and the magnetic flux vector, to populate the magnetic flux versus current lookup table.

- **Magnetic flux density versus magnetic field strength characteristic** — Provide the values for effective core length and cross-sectional area, as well as the magnetic field strength vector and the magnetic flux density vector, to populate the magnetic flux density versus magnetic field strength lookup table.

- **Magnetic flux density versus magnetic field strength characteristic with hysteresis** — In addition to the number of turns and the effective core length and cross-sectional area, provide the values for the initial anhysteretic B-H curve gradient, the magnetic flux density and field strength at a certain point on the B-H curve, as well as the coefficient for the reversible magnetization, bulk coupling coefficient, and inter-domain coupling factor, to define magnetic flux density as a function of both the current value and the history of the field strength.

Unsaturated inductance

The value of inductance used when the magnetization inductance *Lm* is operating in its linear region. This parameter is visible only when you select `Single inductance (linear)` or `Single saturation point` for the **Magnetization inductance parameterized by** parameter. The default value is `0.04 H`.

Saturated inductance

The value of inductance used when the magnetization inductance *Lm* is operating beyond its saturation point. This parameter is visible only when you select `Single saturation point` for the **Magnetization inductance parameterized by** parameter. The default value is `0.01 H`.

Saturation magnetic flux

The value of magnetic flux at which the magnetization inductance *Lm* saturates. This parameter is visible only when you select `Single saturation point` for the **Magnetization inductance parameterized by** parameter. The default value is `1.6e-4 Wb`.

Current, i

The current data used to populate the magnetic flux versus current lookup table. This parameter is visible only when you select `Magnetic flux versus current characteristic` for the **Magnetization inductance parameterized by** parameter. The default value is `[ 0 0.4 0.8 1.2 1.6 2.0 ] A`.

Magnetic flux vector, phi

The magnetic flux data used to populate the magnetic flux versus current lookup table. This parameter is visible only when you select `Magnetic flux`

versus current characteristic for the **Magnetization inductance parameterized by** parameter. The default value is [0 0 0.161 0.25 0.284 0.295 0.299].*1e-3 Wb.

Magnetic field strength vector, H

The magnetic field strength data used to populate the magnetic flux density versus magnetic field strength lookup table. This parameter is visible only when you select Magnetic flux density versus magnetic field strength characteristic for the **Magnetization inductance parameterized by** parameter. The default value is [0 200 400 600 800 1000] A/m.

Magnetic flux density vector, B

The magnetic flux density data used to populate the magnetic flux density versus magnetic field strength lookup table. This parameter is visible only when you select Magnetic flux density versus magnetic field strength characteristic for the **Magnetization inductance parameterized by** parameter. The default value is [0 0.81 1.25 1.42 1.48 1.49] T.

Effective length

The effective core length, that is, the average distance of the magnetic path around the transformer core. This parameter is visible only when you select Magnetic flux density versus magnetic field strength characteristic for the **Magnetization inductance parameterized by** parameter. The default value is 0.2 m.

Effective cross-sectional area

The effective core cross-sectional area, that is, the average area of the magnetic path around the transformer core. This parameter is visible only when you select Magnetic flux density versus magnetic field strength characteristic for the **Magnetization inductance parameterized by** parameter. The default value is 2e-4 m^2.

Anhysteretic B-H gradient when H is zero

The gradient of the anhysteretic (no hysteresis) B-H curve around zero field strength. Set it to the average gradient of the positive-going and negative-going hysteresis curves. This parameter is visible only when you select Magnetic flux density versus magnetic field strength characteristic with hysteresis for the **Magnetization inductance parameterized by** parameter. The default value is 0.005 m*T/A.

Flux density point on anhysteretic B-H curve

Specify a point on the anhysteretic curve by providing its flux density value. Picking a point at high field strength where the positive-going and negative-going hysteresis curves align is the most accurate option. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Magnetization inductance parameterized by** parameter. The default value is `1.49 T`.

Corresponding field strength

The corresponding field strength for the point that you define by the **Flux density point on anhysteretic B-H curve** parameter. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Magnetization inductance parameterized by** parameter. The default value is `1000 A/m`.

Coefficient for reversible magnetization, c

The proportion of the magnetization that is reversible. The value should be greater than zero and less than one. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Magnetization inductance parameterized by** parameter. The default value is `0.1`.

Bulk coupling coefficient, K

The Jiles-Atherton parameter that primarily controls the field strength magnitude at which the B-H curve crosses the zero flux density line. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Magnetization inductance parameterized by** parameter. The default value is `200 A/m`.

Inter-domain coupling factor, alpha

The Jiles-Atherton parameter that primarily affects the points at which the B-H curves intersect the zero field strength line. Typical values are in the range of 1e-4 to 1e-3. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Magnetization inductance parameterized by** parameter. The default value is `1e-4`.

Interpolation option

The lookup table interpolation option. This parameter is visible only when you select `Magnetic flux versus current characteristic` or `Magnetic flux density versus magnetic field strength characteristic` for the **Magnetization inductance parameterized by** parameter. Select one of the following interpolation methods:

- Linear — Uses a linear interpolation function.
- Cubic — Uses the Piecewise Cubic Hermite Interpolation Polynomial (PCHIP).

For more information on interpolation algorithms, see the PS Lookup Table (1D) block reference page.

Initial Conditions Tab

Combined leakage inductance initial current

The value of current through the combined leakage inductance *Leq* at time zero. This parameter is visible only when you select Combined primary and secondary values for the **Winding parameterized by** parameter on the **Main** tab. The default value is 0 A.

Primary leakage inductance initial current

The value of current through the primary leakage inductance *L1* at time zero. This parameter is visible only when you select Separate primary and secondary values for the **Winding parameterized by** parameter on the **Main** tab. The default value is 0 A.

Secondary leakage inductance initial current

The value of current through the secondary leakage inductance *L2* at time zero. This parameter is visible only when you select Separate primary and secondary values for the **Winding parameterized by** parameter on the **Main** tab. The default value is 0 A.

Specify magnetization inductance initial state by

Select the appropriate initial state specification option:

- Current — Specify the initial state of the magnetization inductance *Lm* by the initial current. This is the default option.
- Magnetic flux — Specify the initial state of the magnetization inductance *Lm* by the magnetic flux.

This parameter is not visible when you select Magnetic flux density versus magnetic field strength characteristic with hysteresis for the **Magnetization inductance parameterized by** parameter on the **Magnetization** tab.

Magnetization inductance initial current

The initial current value used to calculate the value of magnetic flux within the magnetization inductance *Lm* at time zero. This is the current passing through the magnetization inductance *Lm*. Total magnetization current consists of current passing through the magnetization resistance *Rm* and current passing through the magnetization inductance *Lm*. This parameter is visible only when you select `Current` for the **Specify magnetization inductance initial state by** parameter. The default value is `0 A`.

Magnetization inductance initial magnetic flux

The value of the magnetic flux in the magnetization inductance *Lm* at time zero. This parameter is visible only when you select `Magnetic flux` for the **Specify magnetization inductance initial state by** parameter. The default is `0 Wb`.

Magnetization inductance initial magnetic flux density

The value of magnetic flux density at time zero. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Magnetization inductance parameterized by** parameter on the **Magnetization** tab. The default is `0 T`.

Magnetization inductance initial field strength

The value of magnetic field strength at time zero. This parameter is visible only when you select `Magnetic flux density versus magnetic field strength characteristic with hysteresis` for the **Magnetization inductance parameterized by** parameter on the **Magnetization** tab. The default is `0 A/m`.

Parasitics Tab

Combined leakage inductance parasitic parallel conductance

Use this parameter to represent small parasitic effects in parallel to the combined leakage inductance *Leq*. A small parallel conductance may be required for the simulation of some circuit topologies. This parameter is visible only when you select `Combined primary and secondary values` for the **Winding parameterized by** parameter on the **Main** tab. The default value is `1e-9 1/Ohm`.

Primary leakage inductance parasitic parallel conductance

Use this parameter to represent small parasitic effects in parallel to the primary leakage inductance *L1*. A small parallel conductance may be required for the simulation of some circuit topologies. This parameter is visible only when you select `Separate primary and secondary values` for the **Winding parameterized by** parameter on the **Main** tab. The default value is `1e-9 1/Ohm`.

Secondary leakage inductance parasitic parallel conductance

Use this parameter to represent small parasitic effects in parallel to the secondary leakage inductance *L2*. A small parallel conductance may be required for the simulation of some circuit topologies. This parameter is visible only when you select `Separate primary and secondary values` for the **Winding parameterized by** parameter on the **Main** tab. The default value is `1e-9 1/Ohm`.

Ports

The block has the following ports:

`+1`

Electrical conserving port associated with the positive terminal of the primary winding

`+2`

Electrical conserving port associated with the positive terminal of the secondary winding

`-1`

Electrical conserving port associated with the negative terminal of the primary winding

`-2`

Electrical conserving port associated with the negative terminal of the secondary winding

See Also

See Also
```
Nonlinear Inductor
```

Introduced in R2015b

Open Circuit

Three-phase connection that draws no current

Library

Connections

Description

The Open Circuit block models a three-phase connection that draws no current on any of the three phases. In Simscape, physical network block diagrams do not allow unconnected conserving ports. Therefore, use the Open Circuit block to terminate three-phase electrical ports on other blocks that you want to leave open-circuit.

Ports

The block has the following ports:

~

    Expandable three-phase port

See Also

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Permanent Magnet Synchronous Motor

Permanent magnet synchronous motor with sinusoidal flux distribution
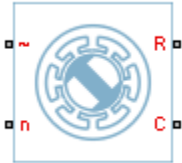
Library

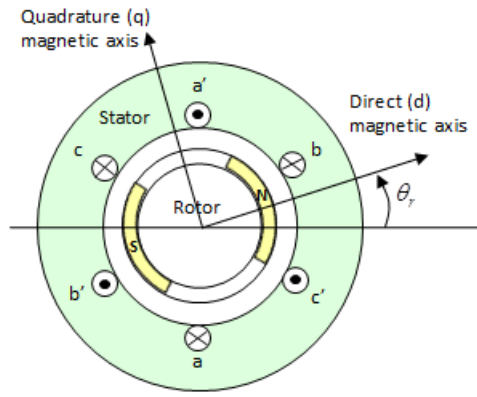Machines / Permanent Magnet Rotor

Description

The Permanent Magnet Synchronous Motor block models a permanent magnet synchronous motor with a three-phase wye-wound stator. The figure shows the equivalent electrical circuit for the stator windings.
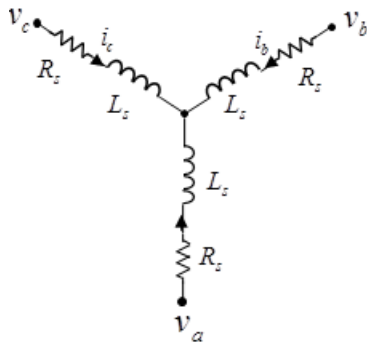
Motor Construction

This figure shows the motor construction with a single pole-pair on the rotor.

Permanent magnets generate a rotor magnetic field that creates a sinusoidal rate of change of flux with rotor angle.

For the axes convention in the preceding figure, the a-phase and permanent magnet fluxes are aligned when rotor mechanical angle, θ_r, is zero. The block supports a second rotor axis definition in which rotor mechanical angle is defined as the angle between the a-phase magnetic axis and the rotor q-axis.

Electrical Defining Equations

Voltages across the stator windings are defined by

$$
\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} \dfrac{d\psi_a}{dt} \\ \dfrac{d\psi_b}{dt} \\ \dfrac{d\psi_c}{dt} \end{bmatrix},
$$

where:

- v_a, v_b, and v_c are the individual phase voltages across the stator windings.
- R_s is the equivalent resistance of each stator winding.
- i_a, i_b, and i_c are the currents flowing in the stator windings.

1-241

$\cdot$ $\dfrac{d\psi_a}{dt}$, $\dfrac{d\psi_b}{dt}$, and $\dfrac{d\psi_c}{dt}$

are the rates of change of magnetic flux in each stator winding.

The permanent magnet and the three windings contribute to the total flux linking each winding. The total flux is defined by

$$
\begin{bmatrix} \psi_a \\ \psi_b \\ \psi_c \end{bmatrix} = \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} \psi_{am} \\ \psi_{bm} \\ \psi_{cm} \end{bmatrix},
$$

where:

- ψ_a, ψ_b, and ψ_c are the total fluxes linking each stator winding.
- L_{aa}, L_{bb}, and L_{cc} are the self-inductances of the stator windings.
- L_{ab}, L_{ac}, L_{ba}, etc. are the mutual inductances of the stator windings.
- ψ_{am}, ψ_{bm}, and ψ_{cm} are the permanent magnet fluxes linking the stator windings.

The inductances in the stator windings are functions of rotor electrical angle, defined by

$$\theta_e = N\theta_r,$$

$$L_{aa} = L_s + L_m \cos(2\theta_e),$$

$$L_{bb} = L_s + L_m \cos(2(\theta_e - 2\pi/3)),$$

$$L_{cc} = L_s + L_m \cos(2(\theta_e + 2\pi/3)),$$

$$L_{ab} = L_{ba} = -M_s - L_m \cos(2(\theta_e + \pi/6)),$$

$$L_{bc} = L_{cb} = -M_s - L_m \cos(2(\theta_e + \pi/6 - 2\pi/3)),$$

and

$$L_{ca} = L_{ac} = -M_s - L_m \cos\left(2\left(\theta_e + \pi/6 + 2\pi/3\right)\right),$$

where:

- θ_r is the rotor mechanical angle.
- θ_e is the rotor electrical angle.
- L_s is the stator self-inductance per phase. This value is the average self-inductance of each of the stator windings.
- L_m is the stator inductance fluctuation. This value is the amplitude of the fluctuation in self-inductance and mutual inductance with changing rotor angle.
- M_s is the stator mutual inductance. This value is the average mutual inductance between the stator windings.

The permanent magnet flux linking winding a is a maximum when $\theta_e = 0°$ and zero when $\theta_e = 90°$. Therefore, the linked motor flux is defined by

$$\begin{bmatrix} \psi_{am} \\ \psi_{bm} \\ \psi_{cm} \end{bmatrix} = \begin{bmatrix} \psi_m \cos\theta_e \\ \psi_m \cos\left(\theta_e - 2\pi/3\right) \\ \psi_m \cos\left(\theta_e + 2\pi/3\right) \end{bmatrix}.$$

Simplified Electrical Equations

Applying Park's transformation to the block electrical defining equations produces an expression for torque that is independent of rotor angle.

Park's transformation is defined by

$$P = 2/3 \begin{bmatrix} \cos\theta_e & \cos\left(\theta_e - 2\pi/3\right) & \cos\left(\theta_e + 2\pi/3\right) \\ -\sin\theta_e & -\sin\left(\theta_e - 2\pi/3\right) & -\sin\left(\theta_e + 2\pi/3\right) \\ 0.5 & 0.5 & 0.5 \end{bmatrix}.$$

where θ_e is the electrical angle defined as $N\theta_r$. N is the number of pole pairs.

The inverse of Park's transformation is defined by

$$P^{-1} = \begin{bmatrix} \cos\theta_e & -\sin\theta_e & 1 \\ \cos(\theta_e - 2\pi/3) & -\sin(\theta_e - 2\pi/3) & 1 \\ \cos(\theta_e + 2\pi/3) & -\sin(\theta_e + 2\pi/3) & 1 \end{bmatrix}.$$

Applying Park's transformation to the first two electrical defining equations produces the following equations that define the block behavior:

$$v_d = R_s i_d + L_d \frac{di_d}{dt} - N\omega i_q L_q,$$

$$v_q = R_s i_q + L_q \frac{di_q}{dt} + N\omega(i_d L_d + \psi_m),$$

$$v_0 = R_s i_0 + L_0 \frac{di_0}{dt},$$

and

$$T = \frac{3}{2} N \left(i_q \left(i_d L_d + \psi_m \right) - i_d i_q L_q \right),$$

where:

- v_d, v_q, and v_0 are the d-axis, q-axis, and zero-sequence voltages, defined by

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = P \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}.$$

- i_d, i_q, and i_0 are the d-axis, q-axis, and zero-sequence currents, defined by

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = P \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}.$$

- $L_d = L_s + M_s + 3/2\ L_m$. L_d is the stator d-axis inductance.

- $L_q = L_s + M_s - 3/2\ L_m$. L_q is the stator q-axis inductance.

- $L_0 = L_s - 2M_s$. L_0 is the stator zero-sequence inductance.

- ω is the rotor mechanical rotational speed.

- N is the number of rotor permanent magnet pole pairs.

- T is the rotor torque. Torque flows from the motor case (block physical port C) to the motor rotor (block physical port R).

Parameters

Main Tab

Number of pole pairs

Number of permanent magnet pole pairs on the rotor. The default value is `6`.

Permanent magnet flux linkage

Peak permanent magnet flux linkage with any of the stator windings. The default value is `0.03` Wb.

Stator parameterization

Choose `Specify Ld, Lq, and L0`, the default value, or `Specify Ls, Lm, and Ms`.

Stator d-axis inductance, Ld

D-axis inductance. This parameter is visible only if you set **Stator parameterization** to `Specify Ld, Lq, and L0`. The default value is `0.00019` H.

Stator q-axis inductance, Lq

Q-axis inductance. This parameter is visible only if you set **Stator parameterization** to `Specify Ld, Lq, and L0`. The default value is `0.00025` H.

Stator zero-sequence inductance, L0

Zero-sequence inductance. This parameter is visible only if you set **Stator parameterization** to `Specify Ld, Lq, and L0`. The default value is `0.00016` H.

Stator self-inductance per phase, Ls

Average self-inductance of each of the three stator windings. This parameter is visible only if you set **Stator parameterization** to `Specify Ls, Lm, and Ms`. The default value is `0.0002` H.

Stator inductance fluctuation, Lm

Amplitude of the fluctuation in self-inductance and mutual inductance of the stator windings with rotor angle. This parameter is visible only if you set **Stator parameterization** to `Specify Ls, Lm, and Ms`. The default value is `-0.00002 H`.

Stator mutual inductance, Ms

Average mutual inductance between the stator windings. This parameter is visible only if you set **Stator parameterization** to `Specify Ls, Lm, and Ms`. The default value is `0.00002 H`.

Stator resistance per phase, Rs

Resistance of each of the stator windings. The default value is `0.013 Ohm`.

Initial Conditions Tab

Initial currents, [i_d i_q i_0]

Initial d-axis, q-axis, and zero-sequence currents. The default value is `[0, 0, 0]` A.

Rotor angle definition

Reference point for the rotor angle measurement. The default value is `Angle between the a-phase magnetic axis and the d-axis`. This definition is shown in the "Motor Construction" on page 1-240 figure. When you select this value, the rotor and a-phase fluxes are aligned when the rotor angle is zero.

The other value you can choose for this parameter is `Angle between the a-phase magnetic axis and the q-axis`. When you select this value, the a-phase current generates maximum torque when the rotor angle is zero.

Initial rotor angle

Initial angle of the rotor. The default value is `0 deg`.

Ports

~

Expandable three-phase port

n

Electrical conserving port associated with the neutral phase

`R`

Mechanical rotational conserving port associated with the motor rotor

`C`

Mechanical rotational conserving port associated with the motor case

References

[1] Kundur, P. *Power System Stability and Control.* New York, NY: McGraw Hill, 1993.

[2] Anderson, P. M. *Analysis of Faulted Power Systems.* Hoboken, NJ: Wiley-IEEE Press, 1995.

See Also

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Phase Permute

Permute phases of three-phase system

Library

Connections

Description

The Phase Permute block cyclically permutes (changes the order of) the phases of a three-phase system.

The block has two three-phase connections associated with its terminals. If you consider the side of the block labeled **~123** (**a1,b1,c1** in expanded view) as side 1 and the side of the block labeled **~231** (**a2,b2,c2**) as side 2, then the block connects phases as shown in the table.

Side 1 Phase	Connects to Side 2 Phase
a1	c2
b1	a2
c1	b2

Ports

The block has the following ports:

~123

Expandable three-phase port

~231

Expandable three-phase port

See Also

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Phase Splitter

Expand composite three-phase port
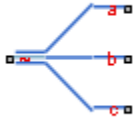
Library

Connections

Description

The Phase Splitter block expands a composite three-phase port into its constituent phases.

The expanded output ports are electrical conserving ports. Therefore, you can connect the output ports to electrical components from the Simscape and Simscape Electronics libraries.

Ports

The block has the following ports:

~

Composite three-phase port

`a,b,c`

Constituent phases of the expanded three-phase port

See Also

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Phase Voltage Sensor

Measure phase voltages in three-phase system
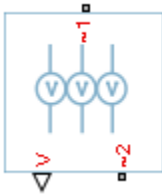
Library

Sensors

Description

The Phase Voltage Sensor block represents an ideal three-phase voltage sensor. It measures the voltages across the three-phase ports ~1 and ~2 and outputs a single three-element, physical signal vector. Each element of the physical signal output vector is equal to the voltage in the respective phase.

Ports

The block has the following ports:

~1

    Expandable three-phase port

~2

    Expandable three-phase port

V

    Three-element physical signal vector output port associated with the phase voltages

See Also

See Also
```
Line Voltage Sensor
```

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

# Primary Winding

Linear nonideal transformer winding

Library

Passive Devices / Transformers / Fundamental Components

Description

The Primary Winding block models linear nonideal winding of a transformer with linear winding leakage and linear core magnetization effects. Although magnetization effects occur in the magnetic core, it is common practice to place mathematically equivalent electrical components on the electrical winding and parameterize them using electrical parameters. The figure shows the equivalent circuit diagram for the primary winding.
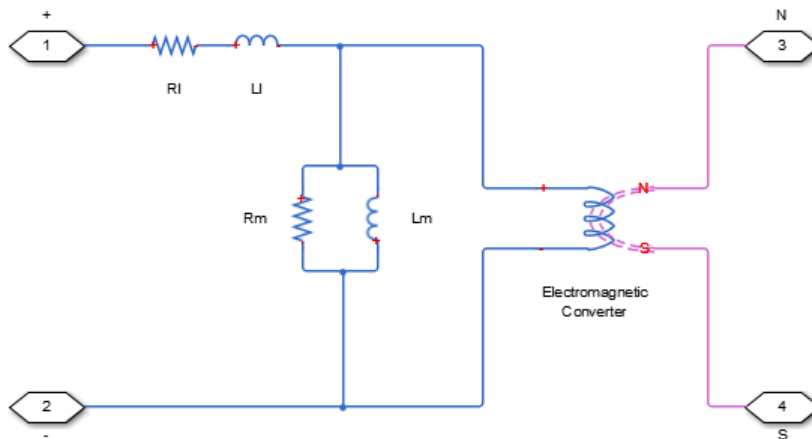
- R_1 is the leakage resistance.
- L_1 is the leakage inductance.
- R_m is the magnetization resistance.
- L_m is the magnetization inductance.

Parameters

- "Main Tab" on page 1-255
- "Variables Tab" on page 1-255

Main Tab

Number of winding turns

> Number of wire turns on the transformer winding. The default value is `10`.

Leakage resistance

> Power loss in the winding. The default value is `1e-3 Ohm`.

Leakage inductance

> Magnetic flux loss in the winding. The default value is `1e-3 H`.

Core-loss resistance

> Magnetic losses in the transformer core. The default value is `1e6 Ohm`.

Magnetization inductance

> Magnetic effects in the transformer core when operating in its linear region. The default value is `1e6 H`.

Variables Tab

Use the **Variables** tab to set the priority and initial target values for the block variables before simulation. For more information, see "Set Priority and Initial Target for Block Variables" (Simscape) .

Unlike block parameters, variables do not have conditional visibility. The **Variables** tab lists all the existing block variables. If a variable is not used in the set of equations corresponding to the selected block configuration, the values specified for this variable are ignored.

Ports

The block has the following ports:

+

   Positive electrical conserving port

-

   Negative electrical conserving port

N

   North magnetic conserving port

S

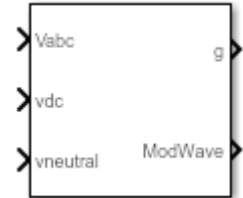   South magnetic conserving port

See Also

See Also

Electromagnetic Converter | `Secondary Winding`

Introduced in R2013b

PWM Generator (Three-phase, Three-level)

Generate three-phase, three-level pulse width modulated waveform
Library: Control

Description

The PWM Generator (Three-phase, Three-level) block controls switching behavior for a three-phase, three-level power converter. The block:

1   Calculates on- and off-gating times based on the block inputs:

   · Three sinusoidal reference voltages
   · A DC-link voltage
   · A DC-link neutral point balance control signal
2   Uses the gating times to generate 12 switch-controlling pulses.
3   Uses the gating times to generate modulation waveforms.

Sampling Mode

This block allows you to choose natural, symmetric, or asymmetric sampling of the modulation wave.

The PWM Generator (Three-phase, Two-level) block does not perform carrier-based pulse width modulation (PWM). Instead, the block uses input signals to calculate gating times and then uses the gating times to generate both the switch-controlling pulses and the modulation waveforms that it outputs.

Carrier-based PWM is, however, useful for showing how the sampling mode that you select relates to the switch-on and switch-off behavior of the pulses that the block generates. A generator that uses a three-level, carrier-based PWM method:

1 Samples a reference wave.

2 Compares the sample to two parallel triangle carrier waves, separated by one level.
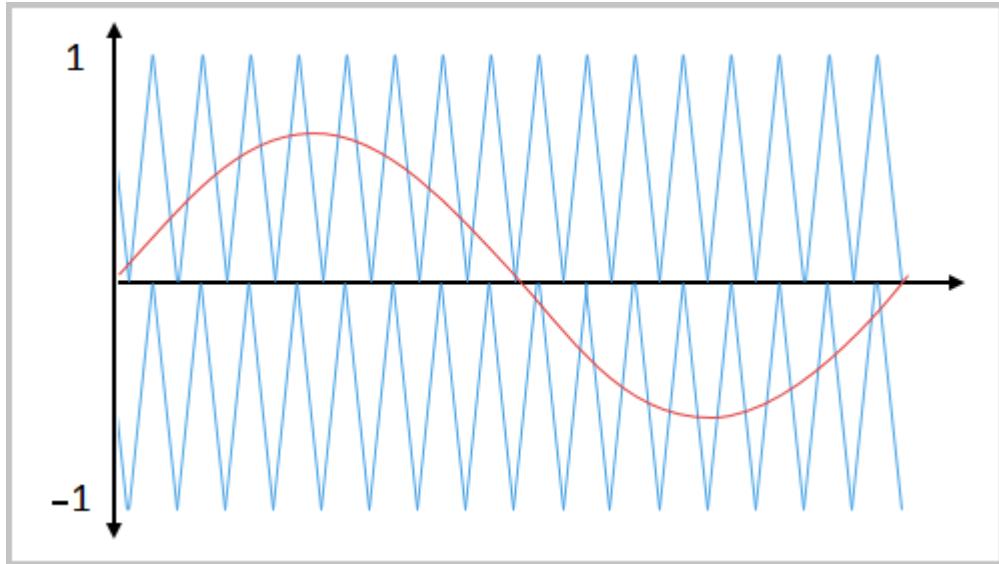
3 Generates a switch-on pulse if a sample is higher than the carrier signal or a switch-off pulse if a sample is lower than the carrier wave.

To determine switch-on and switch-off pulse behavior, a three-level carrier-based PWM generator uses these methods to sample each of the triangle waves:

· Natural — The sampling and comparison occur at the intersection points of the modulation wave and the carrier wave.
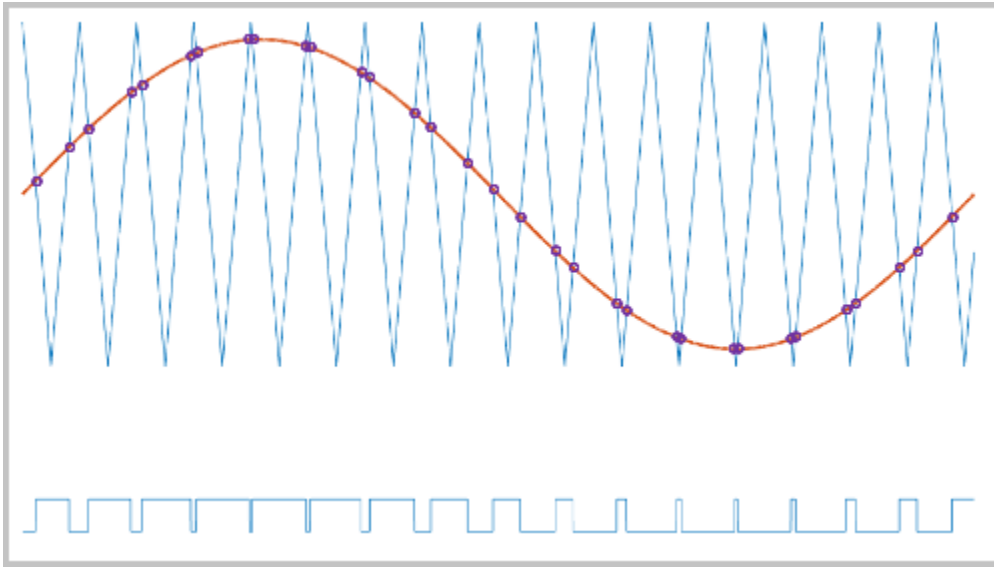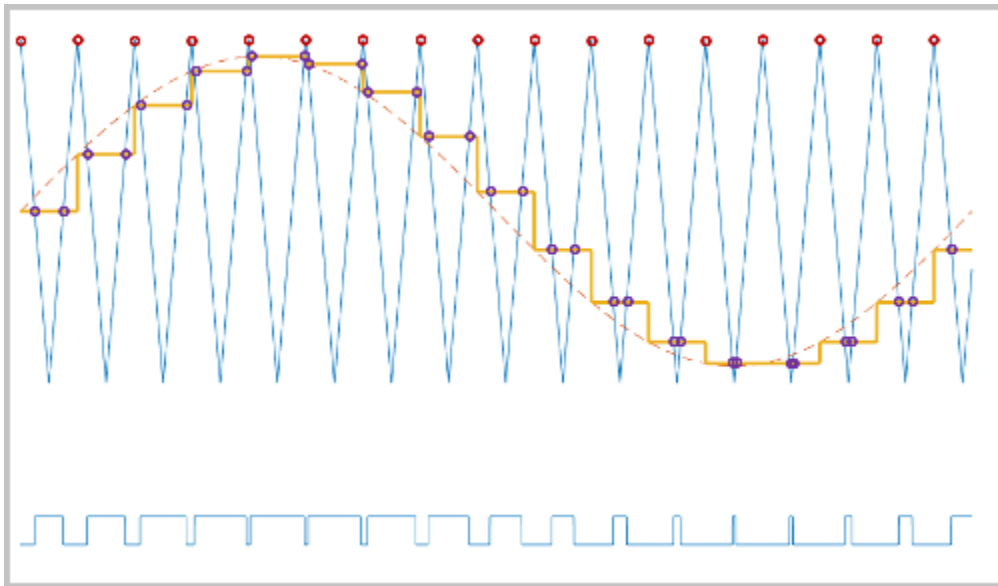
- Asymmetric — Sampling occurs at the upper and lower boundaries of the carrier wave. The comparison occurs at the intersection that follows the sampling.
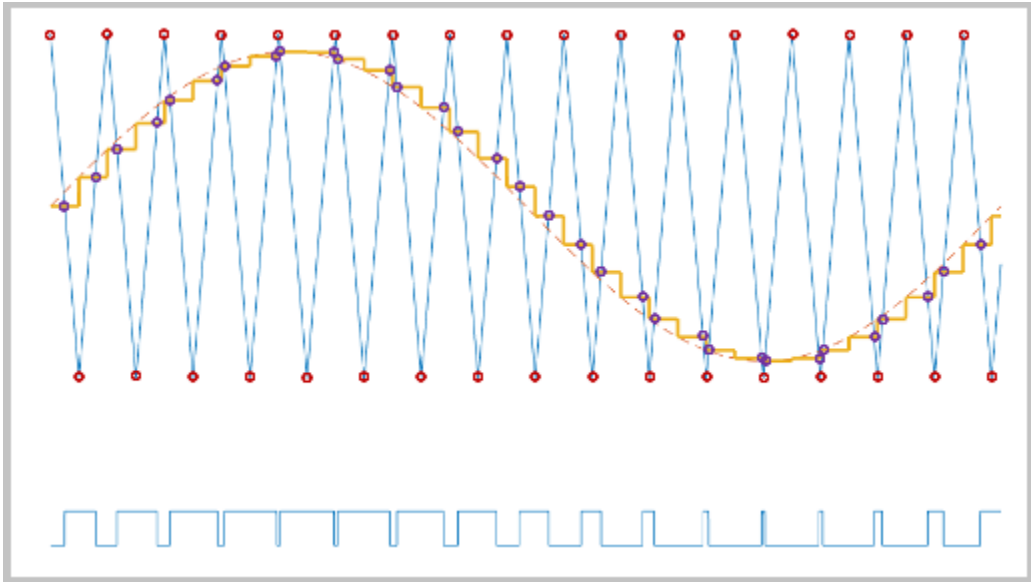
- Symmetric — Sampling occurs only at the upper or the lower boundaries of the carrier wave. The comparison occurs at the intersection that follows the sampling. The figure show upper boundary sampling.
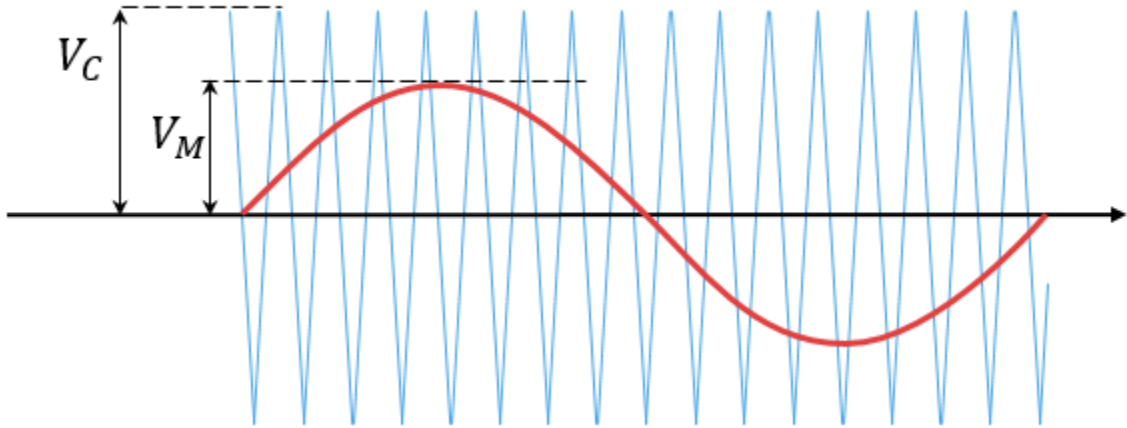
Overmodulation

The modulation index, which measures the ability of the power converter to output a given voltage, is defined as

$$m = \frac{V_M}{V_C},$$

where

- m is the modulation index.
- V_m is the peak value of the modulation wave.
- V_c is the peak value of the triangle carrier wave.

For three-phase SPWM,
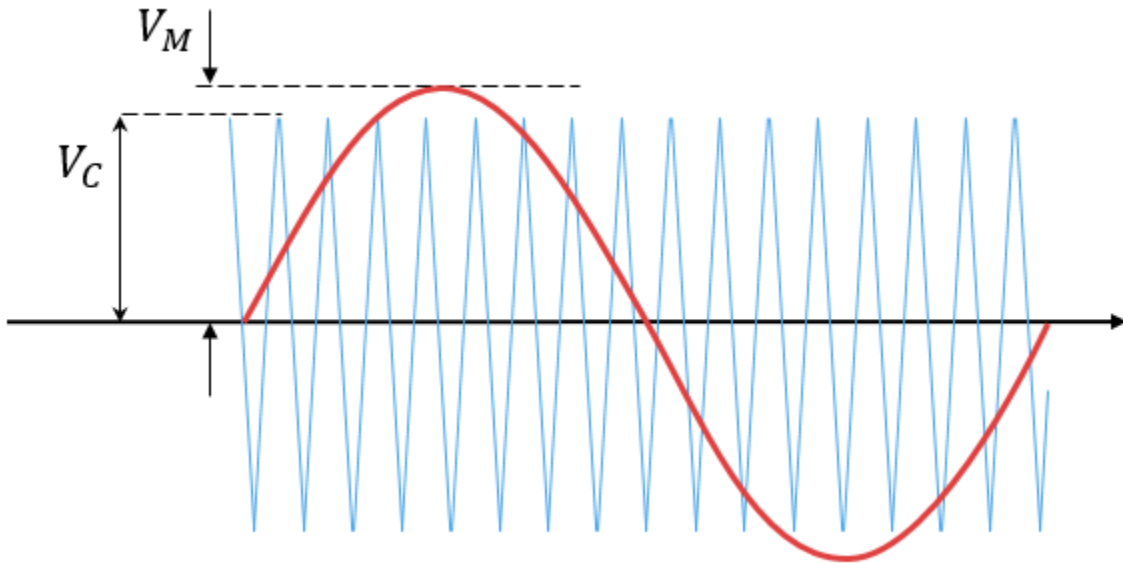
$$V_{peak} = m\frac{v_{dc}}{2},$$

where

- V_{peak} is the peak value of the fundamental component of the phase-to-neutral voltage.
- v_{dc} is the DC-link voltage.

For three-phase space-vector PWM (SVM),

$$V_{peak} = m\frac{v_{dc}}{\sqrt{3}}.$$

For normal steady-state operation, $0 < m \leq 1$. If a transient, such as a load increase, causes the amplitude of V_m to exceed the amplitude of V_c, overmodulation ($m > 1$) occurs

If overmodulation occurs, the output voltage of the power converter clamps to the positive or negative DC rail.

In the Three-Phase Three-Level PWM Generator example, the **Three-Level Controller** subsystem contains a 1800–V DC-link input, and a modulation index, m, of 0.8. For SVM, the maximal input voltage is $1800 / \sqrt{3}$ V, that is 1039.23 V. To demonstrate overmodulation, a transient is added at the beginning of the simulation. The transient forces the amplitudes of the reference voltages to exceed the amplitude of $1 / \sqrt{3}$ of the DC-link voltage. To highlight overmodulation, the scope includes simulation results for only one of the 12 output pulses and only the a-phase of the reference voltages, modulation waveforms, and output voltages.
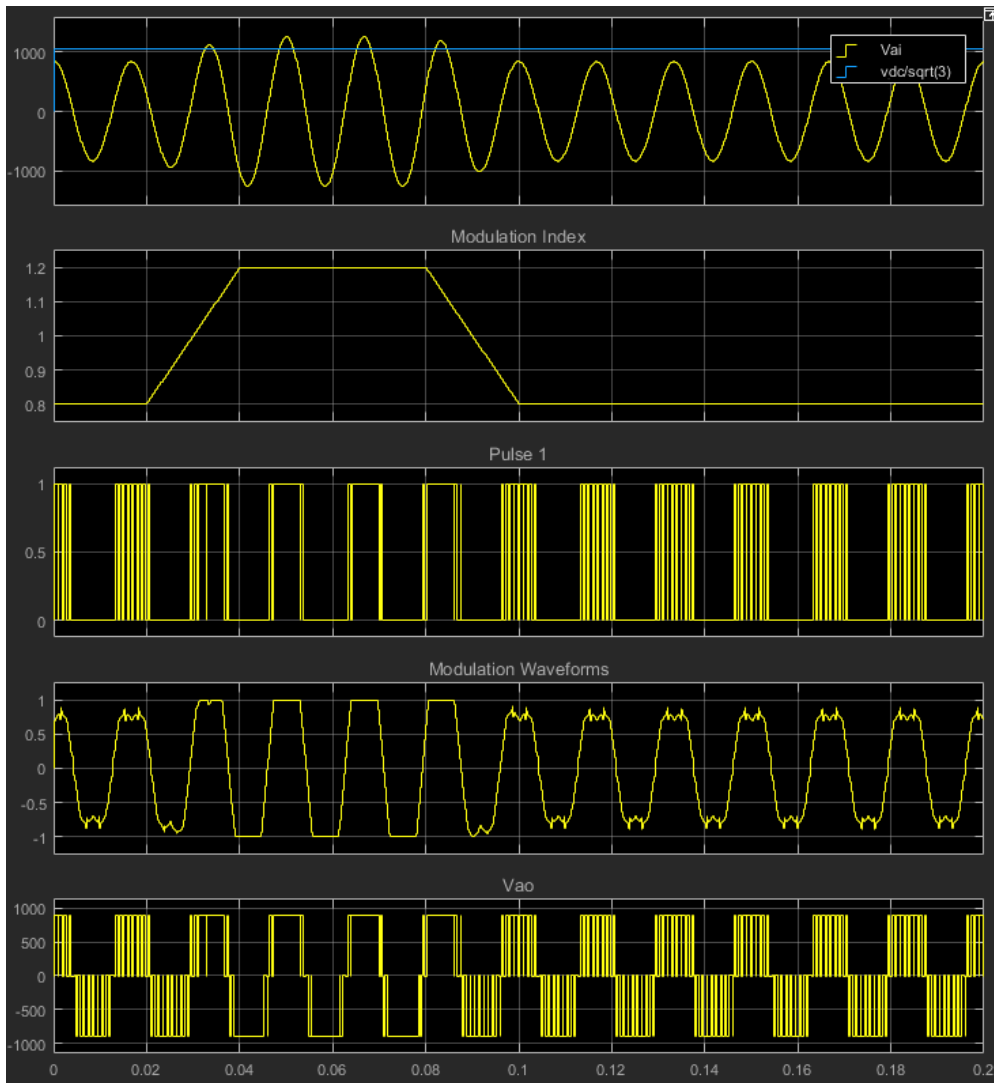
The modulation index is greater than one between 0.03–0.09 seconds. During overmodulation:

- The pulse remains in the on or off position.
- The output voltage clamps to the positive or negative DC rail.

Ports

Input

`Vabc` — Three-phase sinusoidal reference signal
vector

Specify the three sinusoidal voltages, one per phase, that you want the attached converter to output.

`vdc` — DC-link voltage signal
scalar

Specify a positive real number for the DC-link voltage of the converter.

`vneutral` — DC-link neutral point balance control
scalar

This signal is the output from a feedback-control loop that balances the DC supply. The value of the signal must be a real number between −1 and +1.

Output

`g` — Gate control
vector

12 pulse waveforms that determine switching behavior in the attached power converter.

`ModWave` — Modulation wave
vector

If you are generating code for a platform that has hardware with PWM capability, you can deploy the modulation wave to the hardware. Otherwise, this data is for reference only.

Parameters

`Continuous PWM` — Continuous pulse width modulation method
SPWM: sinusoidal PWM (default) | SVM: space vector modulation

Specify the waveform technique.

Sampling mode — Wave-sampling method
`Natural` (default) | `Asymmetric` | `Symmetric`

The sampling mode determines whether the block samples the modulation waveform when the waves intersect or when the carrier wave is at one or both of its boundary conditions.

Switching frequency (Hz) — Switching rate
`1e3` (default)

Specify the rate at which you want the switches in the power converter to switch.

Sample time (s) — Block sample time
`5e-5` (default)

Specify the time interval between successive block executions (output calculations).

Model Examples

References

[1] Chung, D. W., J. S. Kim, and S. K. Sul. "Unified Voltage Modulation Technique for Real Time Three-Phase Power Conversion." *IEEE Transactions on Industry Applications*, Vol. 34, No. 2, 1998, pp. 374–380.

[2] Seo, J. H., C. H. Choi, and D. S. Hyun. "A new simplified space-vector PWM method for three-level inverters." *IEEE Transactions on Power Electronics*, Vol. 16, No. 4, 2001, pp. 545-550.

See Also

See Also
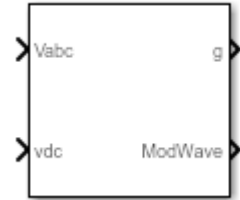`PWM Generator (Three-phase, Two-level) | Three-Level Converter`

Introduced in R2016b

PWM Generator (Three-phase, Two-level)

Generate three-phase, two-level pulse width modulated waveform
**Library:**   Control

Description

The PWM Generator (Three-phase, Two-level) block controls switching behavior for a three-phase, two-level power converter. The block:

1   Calculates on- and off-gating times based on the block inputs:

   · Three sinusoidal reference voltages, one per phase
   · A DC-link voltage

2   Uses the gating times to generate six switch-controlling pulses.

3   Uses the gating times to generate modulation waveforms.

Continuous and Discontinuous PWM

The block provides modes for both continuous and discontinuous pulse width modulation (PWM). The figure shows the general difference between continuous sinusoidal PWM (SPWM) and continuous space vector modulation (SVM) waveforms.
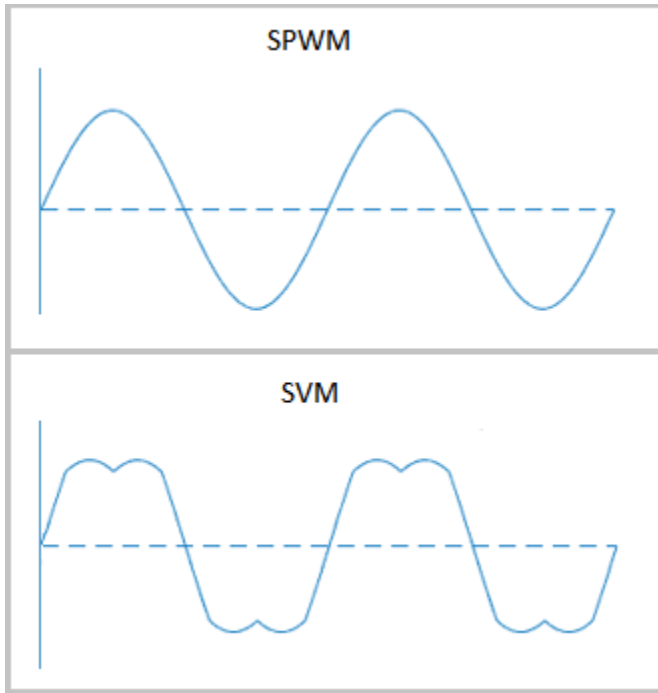
For discontinuous PWM (DPWM), the block clamps the modulation wave to the positive or negative DC rail for a total of 120 degrees during each fundamental period. During the clamping intervals, modulation discontinues.

A waveform with 30-degree DPWM has four 30-degree intervals per fundamental period.
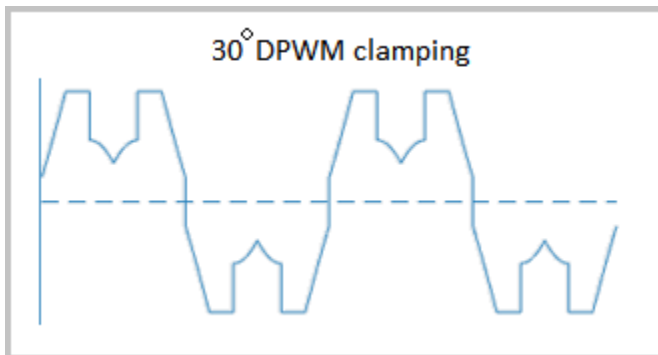
Selecting a positive or negative 30-degree phase shift affects the clamping intervals for 60-degree DPWM.
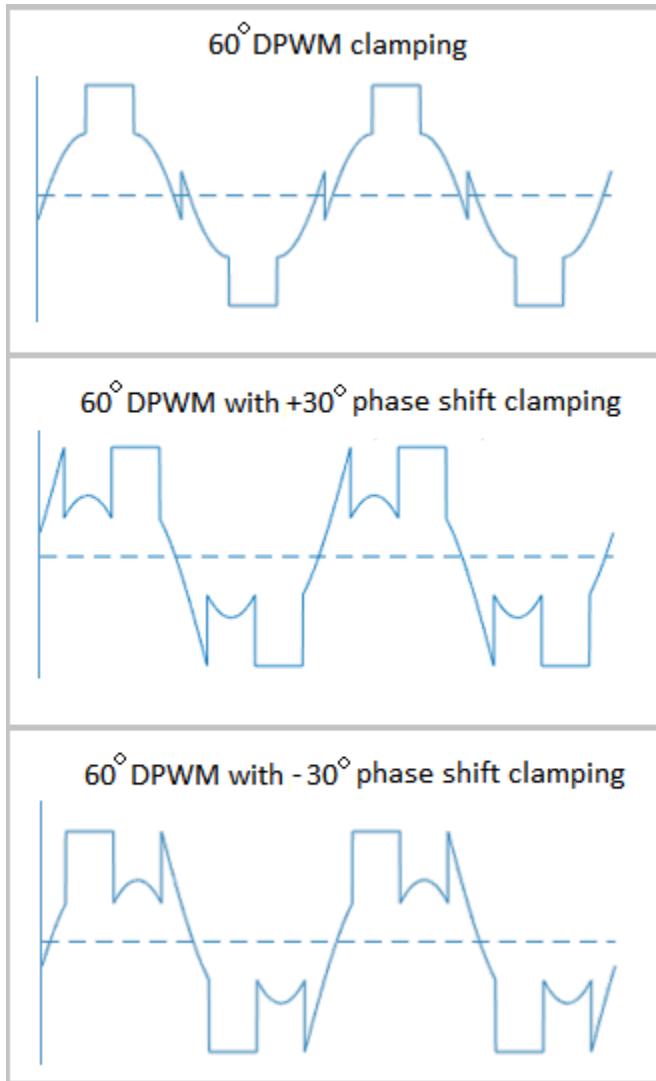
The figure shows the waveforms for positive and negative DC clamping for 120-degree DPWM.
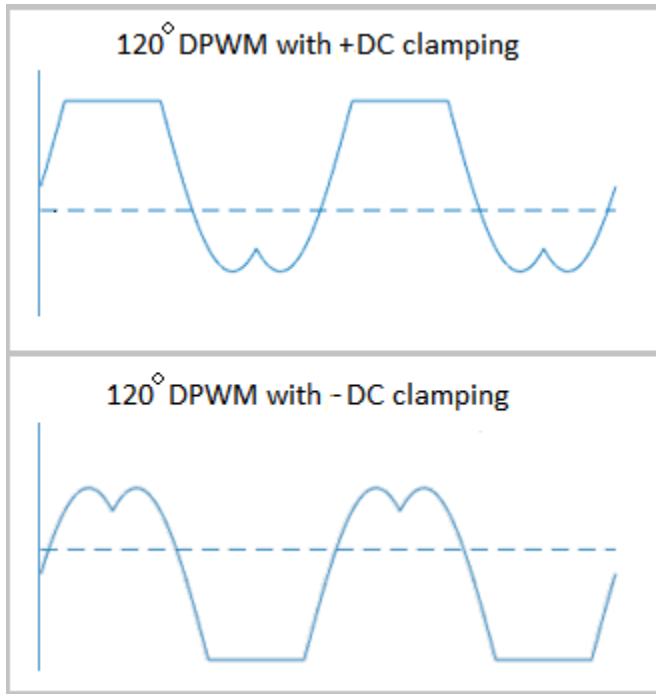
Sampling Mode

This block allows you to choose natural, symmetric, or asymmetric sampling of the modulation wave.

The PWM Generator (Three-phase, Two-level) block does not perform carrier-based PWM. Instead, the block uses input signals to calculate gating times and then uses the gating times to generate both the switch-controlling pulses and the modulation waveforms that it outputs.

Carrier-based PWM is, however, useful for showing how the sampling mode that you select relates to the switch-on and switch-off behavior of the pulses that the block generates. A generator that uses a two-level, carrier-based PWM method:

1 Samples a reference wave.

2 Compares the sample to a triangle carrier wave.

3 Generates a switch-on pulse if a sample is higher than the carrier signal or a switch-off pulse if a sample is lower than the carrier wave.

To determine switch-on and switch-off pulse behavior, a two-level carrier-based PWM generator uses these methods to sample the triangle wave:

- Natural — The sampling and comparison occur at the intersection points of the modulation wave and the carrier wave.
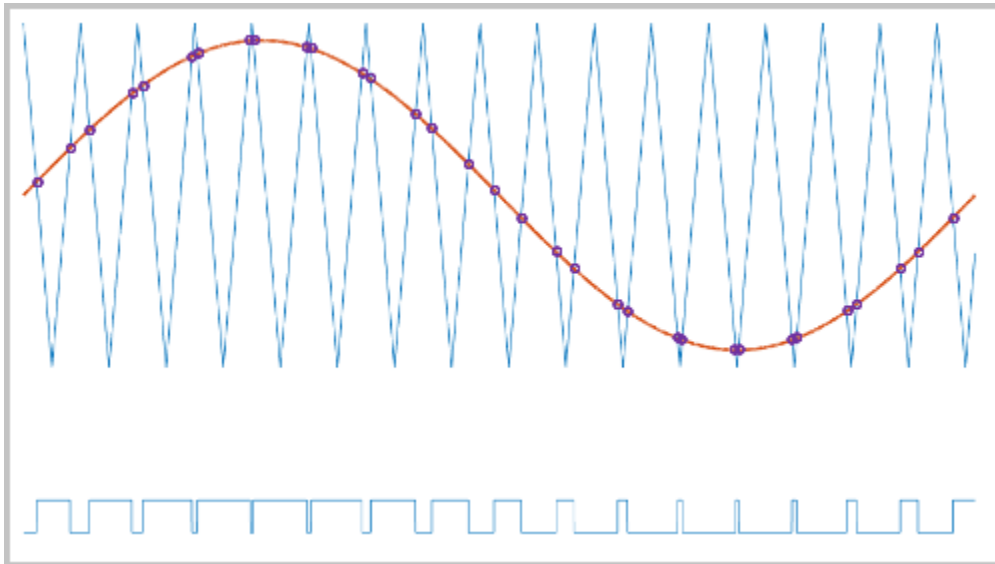
- Asymmetric — Sampling occurs at the upper and lower boundaries of the carrier wave. The comparison occurs at the intersection that follows the sampling.
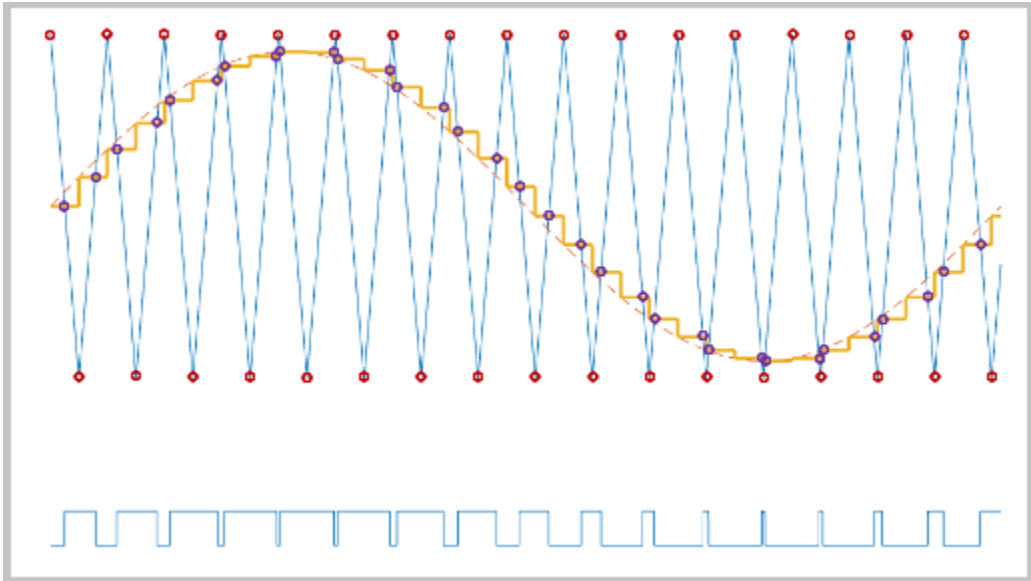
- Symmetric — Sampling occurs at only the upper or the lower boundaries of the carrier wave. The comparison occurs at the intersection that follows the sampling. The figure show upper boundary sampling.

Overmodulation

The modulation index, which measures the ability of the power converter to output a given voltage, is defined as

$$m = \frac{V_M}{V_C},$$

where

- m is the modulation index.
- V_m is the peak value of the modulation wave.
- V_c is the peak value of the triangle carrier wave.

For three-phase SPWM,

$$V_{peak} = m\frac{v_{dc}}{2},$$

where

- V_{peak} is the peak value of the fundamental component of the phase-to-neutral voltage.
- v_{dc} is the DC-link voltage.

For three-phase space-vector PWM (SVM) and DPWM,

$$V_{peak} = m\frac{v_{dc}}{\sqrt{3}}.$$

For normal steady-state operation, $0 < m \leq 1$. If a transient, such as a load increase, causes the amplitude of V_m to exceed the amplitude of V_c, overmodulation ($m > 1$) occurs.
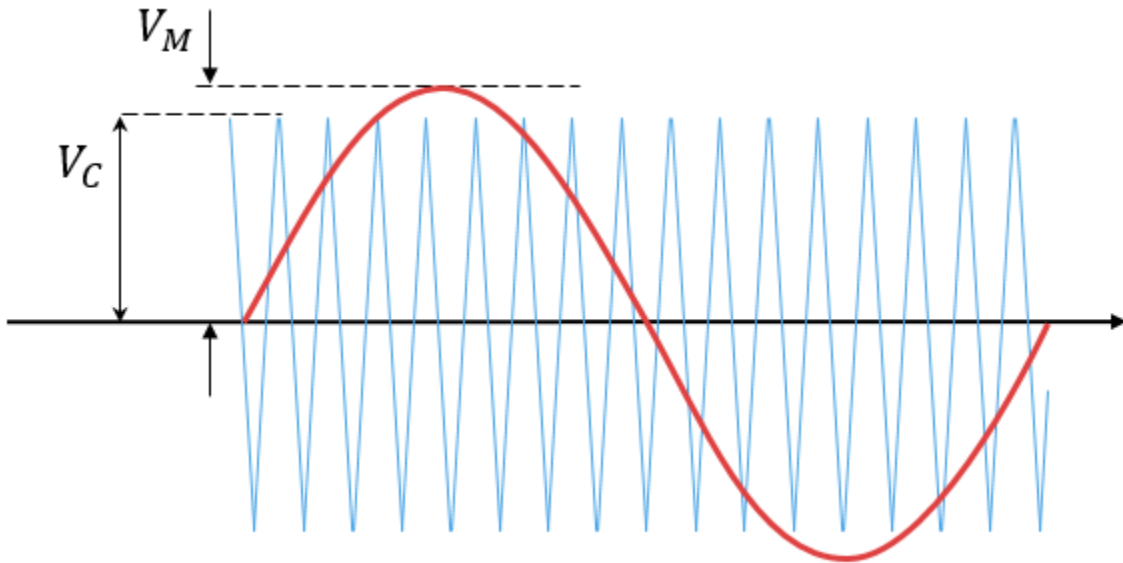
If overmodulation occurs, the output voltage of the power converter clamps to the positive or negative DC rail.

In the Three-Phase Two-Level PWM Generator example, the **Two-Level Controller** subsystem contains a 400–V DC-link input, and a modulation index, m, of 0.8. For SPWM, the maximal input voltage is 400 V/2, that is, 200 V. To demonstrate overmodulation, a transient is added at the beginning of the simulation. The transient forces the amplitudes of the reference voltages to exceed the amplitude of 1/2 of the DC-link voltage. To highlight overmodulation, the scope includes simulation results for only one of the six output pulses and only the a-phase of the reference voltages, modulation waveforms, and output voltages.
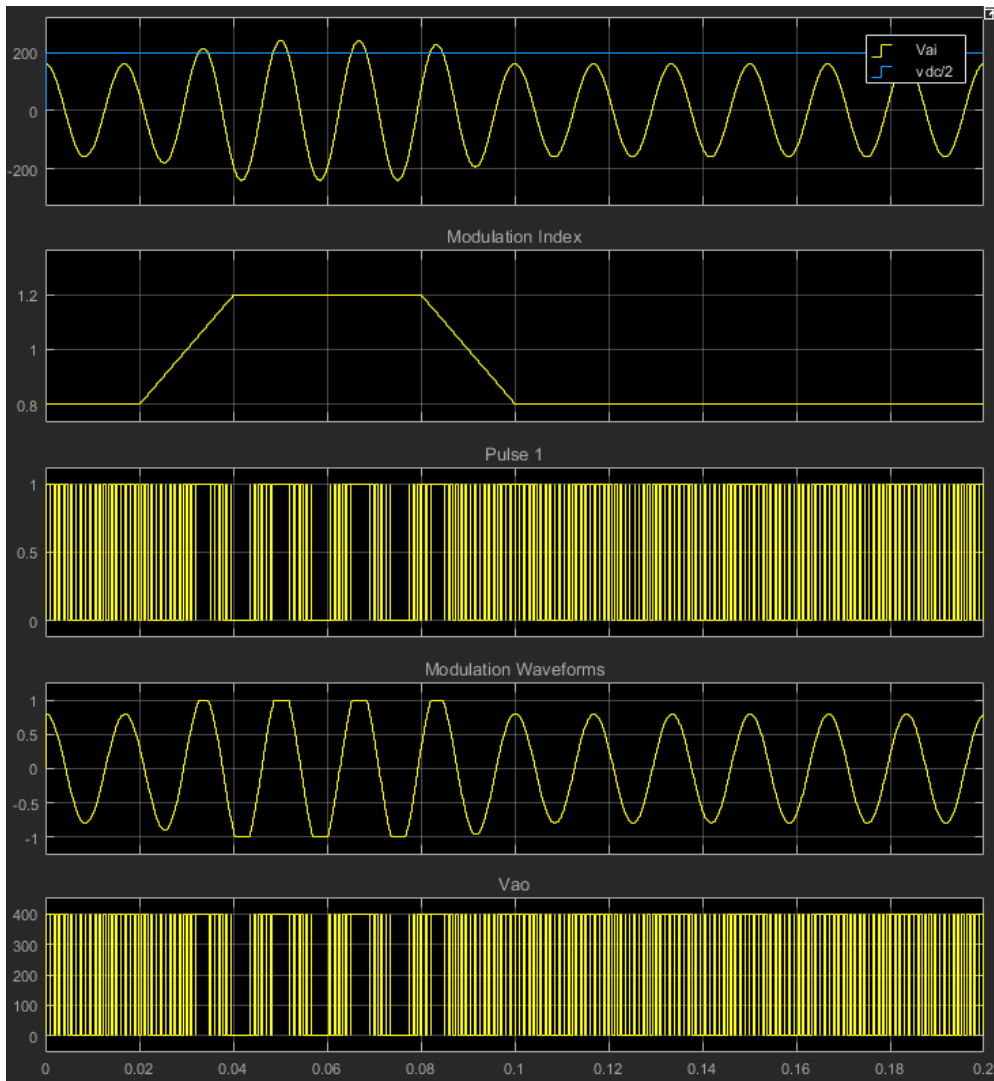
The modulation index is greater than one between 0.03–0.09 seconds. During overmodulation:

- The pulse remains in the on or off position.
- The output voltage, V_{ao}, clamps to the positive or negative DC rail.

Ports

Input

`Vabc` — Three-phase sinusoidal reference signal
vector

Specify the three sinusoidal voltages, one per phase, that you want the attached converter to output.

`vdc` — DC-link voltage signal
scalar

Specify a positive real number for the DC-link voltage of the converter.

Output

`g` — Gate control
vector

Six pulse waveforms that determine switching behavior in the attached power converter.

`ModWave` — Modulation wave
vector

If you are generating code for a platform that has hardware with PWM capability, you can deploy the modulation wave to the hardware. Otherwise, this data is only for your reference.

Parameters

`PWM mode` — Pulse width modulation method
Continuous PWM (CPWM) (default) | Discontinuous PWM (DPWM)

Discontinuous PWM clamps the waveform to the DC rail for a total of 120 degrees in each fundamental period. Continuous PWM does not.

`Continuous PWM` — Continuous pulse width modulation method
SPWM: sinusoidal PWM (default) | SVM: space vector modulation

Dependencies

The **Continuous PWM** parameter is only available when you set the **PWM mode** parameter to `Continuous PWM (CPWM)`.

`Sampling mode` — Wave-sampling method
`Natural` (default) | `Asymmetric` | `Symmetric`

The sampling mode determines whether the block samples the modulation waveform when the waves intersect or when the carrier wave is at one or both of its boundary conditions.

`Switching frequency (Hz)` — Switching rate
`1e3` (default)

Specify the rate at which you want the switches in the power converter to switch.

`Sample time (s)` — Block sample time
`5e-5` (default)

Specify the time interval between successive block executions (output calculations).

`Discontinuous PWM (DPWM)` — Clamping method
`60 DPWM: 60 degree discontinuous PWM` (default)

Specify the method for distributing the 120 degrees per period during which the block clamps the modulation wave to the DC rail. Other options are:

- `60 DPWM (+30 degree shift): +30 degree shift from 60 DPWM`
- `60 DPWM (-30 degree shift): -30 degree shift from 60 DPWM`
- `30 DPWM: 30 degree discontinuous PWM`
- `120 DPWM: positive dc component`
- `120 DPWM: negative dc component`

When the wave is clamped, modulation discontinues.

Dependencies

The **Discontinuous PWM** parameter is only available when you set the **PWM mode** parameter to `Discontinuous PWM (DPWM)`.

Model Examples

References

[1] Chung, D. W., J. S. Kim, and S. K. Sul. "Unified Voltage Modulation Technique for Real Time Three-Phase Power Conversion." *IEEE Transactions on Industry Applications*, Vol. 34, No. 2, 1998, pp. 374–380.

[2] Hava, A. M., R. J. Kerkman, and T. A. Lipo. "Simple Analytical and Graphical Methods for Carrier-Based PWM-VSI Drives." *IEEE Transactions on Power Electronics*, Vol. 14, No. 1, 1999, pp. 49–61.

See Also

See Also
Converter | PWM Generator (Three-phase, Three-level)

Introduced in R2016b

Rectifier

Convert three-phase AC voltage to DC voltage
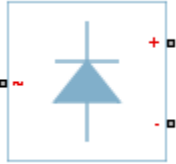
Library

Semiconductors

Description

The Rectifier block models a three-arm diode bridge circuit that converts a three-phase AC voltage to a DC voltage. The figure shows the equivalent circuit for the three-arm diode bridge.
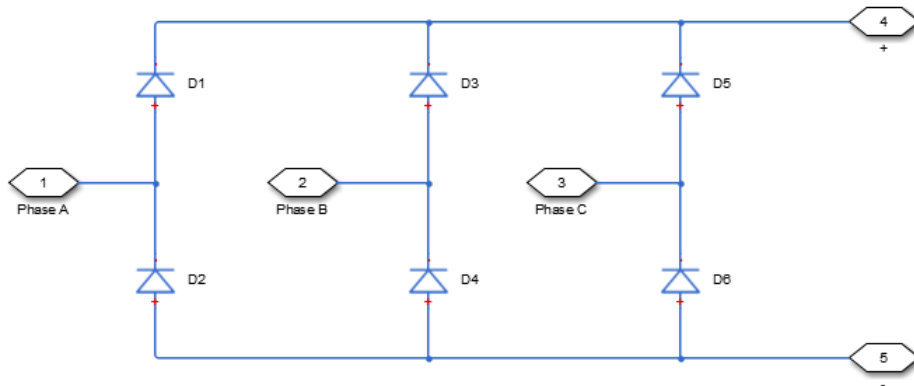
Using the Charge Dynamics tab of the block dialog box, you can choose the type of diode that the three-arm bridge circuit uses. The table shows you how to set the **Model dynamics** parameter based on your goals.

Goal	Value to Select	Block Behavior
Prioritize simulation speed.	`No dynamics`	Each arm of the bridge circuit uses a copy of the `Diode` block. The block dialog box does not display additional parameters.
Precisely specify reverse-mode charge dynamics.	`Model charge dynamics`	Each arm of the bridge circuit uses a copy of the `Commutation Diode` block. The block dialog box shows parameters relating to the Commutation Diode block.

Parameters

- "Main Tab" on page 1-281
- "Charge Dynamics Tab" on page 1-281

Main Tab

Forward voltage

Minimum voltage required across the + and - ports of each diode for the gradient of the diode i-v characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default forward voltage value is `0.8 V`.

On resistance

Rate of change of voltage versus current above the forward voltage for each diode. The default value is `0.001 Ohm`.

Off conductance

Conductance of each reverse-biased diode. The default value is `1e-5 1/Ohm`.

Charge Dynamics Tab

Model dynamics

Diode charge dynamics. The default value is `No dynamics`.

The charge dynamics options you can select are:

- `No dynamics`
- `Model charge dynamics`

Parameters for Model charge dynamics

When you select `Model charge dynamics`, additional parameters appear.

Additional Parameters for Model charge dynamics

Junction capacitance

Diode junction capacitance. The default value is `50 nF`.

Peak reverse current, iRM

Peak reverse current measured by an external test circuit. This value must be less than zero. The default value is `-235 A`.

Initial forward current when measuring iRM

Initial forward current when measuring peak reverse current. This value must be greater than zero. The default value is `300 A`.

Rate of change of current when measuring iRM

Rate of change of current when measuring peak reverse current. This value must be less than zero. The default value is `-50 A/`μ`s`.

Reverse recovery time parameterization

Determines how you specify reverse recovery time in the block. The default value is `Specify reverse recovery time directly`.

If you select `Specify stretch factor` or `Specify reverse recovery charge`, you specify a value that the block uses to derive the reverse recovery time. For more information on these options, see "Alternatives to Specifying t_{rr} Directly" on page 1-83.

Reverse recovery time, trr

Interval between the time when the current initially goes to zero (when the diode turns off) and the time when the current falls to less than 10% of the peak reverse current. The default value is `15 `μ`s`.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery time directly`.

The value of the **Reverse recovery time, trr** parameter must be greater than the value of the **Peak reverse current, iRM** parameter divided by the value of the **Rate of change of current when measuring iRM** parameter.

Reverse recovery time stretch factor

Value that the block uses to calculate **Reverse recovery time, trr**. This value must be greater than 1. The default value is 3.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify stretch factor`.

Specifying the stretch factor is an easier way to parameterize the reverse recovery time than specifying the reverse recovery charge. The larger the value of the stretch factor, the longer it takes for the reverse recovery current to dissipate.

Reverse recovery charge, Qrr

Value that the block uses to calculate **Reverse recovery time, trr**. Use this parameter if the data sheet for your diode device specifies a value for the reverse recovery charge instead of a value for the reverse recovery time.

The reverse recovery charge is the total charge that continues to dissipate when the diode turns off. The value must be less than $-\dfrac{i^2{}_{RM}}{2a}$,

where:

- i_{RM} is the value specified for **Peak reverse current, iRM**.
- a is the value specified for **Rate of change of current when measuring iRM**.

The default value is 1500 μAs.

The parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery charge`.

For more information on these parameters, see `Commutation Diode`.

Ports

The block has the following ports:

~

Expandable three-phase port

+

Electrical conserving port associated with the positive terminal

-

Electrical conserving port associated with the negative terminal

See Also

See Also
Average-Value Inverter | Average-Value Rectifier | Converter

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

RLC

Three-phase line impedance
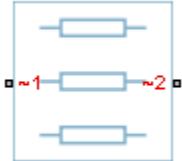
Library

Passive Devices

Description

The RLC block models a three-phase impedance with two three-phase connections. Each of the three identical impedance components can include any combination of a resistor (R), capacitor (C), and inductor (L), connected in series or in parallel.

Define the values for the R, L, and C components by specifying the appropriate block parameters. Do not set the parameter values to zero or infinity to remove terms; instead, select the correct option for the **Component structure** parameter.

For certain combinations of R, L, and C, for some circuit topologies, specify parasitic resistance or conductance values that help the simulation to converge numerically. These parasitic terms ensure that an inductor has a small parallel resistive path and that a capacitor has a small series resistance.

Parameters

- "Main Tab" on page 1-286
- "Parasitics Tab" on page 1-286
- "Initial Conditions Tab" on page 1-286

Main Tab

Component structure

Select the desired combination of a resistor (R), capacitor (C), and inductor (L), connected in series or in parallel. The default is R, resistor.

Resistance

Resistance of each of the line impedances. This parameter is visible only when you select a component structure that includes a resistor. The default value is 1 Ohm.

Inductance

Inductance of each of the line impedances. This parameter is visible only when you select a component structure that includes an inductor. The default value is 0.001 H.

Capacitance

Capacitance in each of the line impedances. This parameter is visible only when you select a component structure that includes a capacitor. The default value is 1e-6 F.

Parasitics Tab

Parasitic series resistance

Represents small parasitic effects. The parameter value corresponds to the series resistance value added to all instances of capacitors in the load. The default value is 1e-6 Ohm.

Parasitic parallel conductance

Represents small parasitic effects. The parameter value corresponds to the parallel conductance value added across all instances of inductors in the load. The default value is 1e-6 1/Ohm.

Initial Conditions Tab

Initial inductor current [Ia Ib Ic]

Initial current in the a, b, and c phase inductors, respectively. This parameter is visible only when you select a component structure that includes an inductor. The default value is [0 0 0] A.

Initial capacitor voltage [Va Vb Vc]

Initial voltage across the a, b, and c phase capacitors, respectively. This parameter is visible only when you select a component structure that includes a capacitor. The default value is [0 0 0] V.

Block Parameterization

The following table lists the block parameters for each of the configurations, based on the selected **Component structure** option.

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
R	Resistance	None	None
L	Inductance	Parasitic parallel conductance	Initial inductor current [Ia Ib Ic]
C	Capacitance	Parasitic series resistance	Initial capacitor voltage [Va Vb Vc]
Series RL	Resistance Inductance	Parasitic parallel conductance	Initial inductor current [Ia Ib Ic]
Series RC	Resistance Capacitance	None	Initial capacitor voltage [Va Vb Vc]
Series LC	Inductance Capacitance	Parasitic parallel conductance	Initial inductor current [Ia Ib Ic] Initial capacitor voltage [Va Vb Vc]
Series RLC	Resistance Inductance Capacitance	Parasitic parallel conductance	Initial inductor current [Ia Ib Ic] Initial capacitor voltage [Va Vb Vc]
Parallel RL	Resistance Inductance	None	Initial inductor current [Ia Ib Ic]
Parallel RC	Resistance Capacitance	Parasitic series resistance	Initial capacitor voltage [Va Vb Vc]
Parallel LC	Inductance Capacitance	Parasitic series resistance	Initial inductor current [Ia Ib Ic] Initial capacitor voltage [Va Vb Vc]

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
Parallel RLC	Resistance Inductance Capacitance	Parasitic series resistance	Initial inductor current [Ia Ib Ic] Initial capacitor voltage [Va Vb Vc]

Ports

The block has two expandable three-phase ports, ~1 and ~2, representing the two terminals of the three-phase line.

See Also

See Also
Delta-Connected Load | Wye-Connected Load

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Secondary Winding

Linear nonideal transformer winding
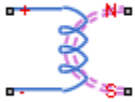
Library

Passive Devices / Transformers / Fundamental Components

Description

The Secondary Winding block models linear nonideal winding of a transformer with linear winding leakage effects. The figure shows the equivalent circuit diagram for the secondary winding.
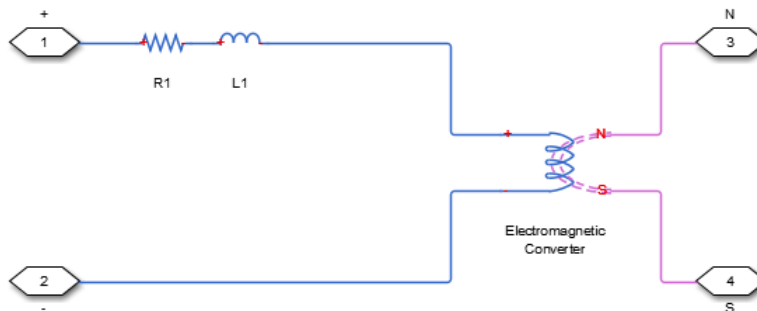
- R_1 is the leakage resistance.
- L_1 is the leakage inductance.

Parameters

- "Main Tab" on page 1-290
- "Variables Tab" on page 1-290

Main Tab

Number of winding turns

Number of wire turns on the transformer winding. The default value is 10.

Leakage resistance

Power loss in the winding. The default value is 1e-3 Ohm.

Leakage inductance

Magnetic flux loss in the winding. The default value is 1e-3 H.

Variables Tab

Use the **Variables** tab to set the priority and initial target values for the block variables before simulation. For more information, see "Set Priority and Initial Target for Block Variables" (Simscape) .

Unlike block parameters, variables do not have conditional visibility. The **Variables** tab lists all the existing block variables. If a variable is not used in the set of equations corresponding to the selected block configuration, the values specified for this variable are ignored.

Ports

The block has the following ports:

+

Positive electrical conserving port

-

Negative electrical conserving port

N

North magnetic conserving port

S

South magnetic conserving port

See Also

See Also

Electromagnetic Converter | `Primary Winding`

Introduced in R2013b

Single-Phase Circuit Breaker

Single-pole single-throw circuit breaker
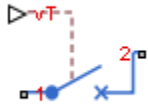
Library

Switches & Breakers / Fundamental Components

Description

The Single-Phase Circuit Breaker block models a single-phase circuit breaker that uses an external signal and phase current information to break an electrical circuit.

The table shows how the external signal vT controls the block behavior.

Condition	Block Behavior	Resistance Parameter Used
vT < **Threshold**	The breaker is closed. Port 1 connects to port 2.	**Closed Resistance**
vT ≥ **Threshold**	When the current in port 1 goes through zero, the phase disconnects from port 2. The breaker is open.	**Open Conductance**

Parameters

Closed resistance

Resistance between ports 1 and 2 when the breaker is closed. The default value is `0.001 Ohm`.

Open conductance

Conductance between ports 1 and 2 when the breaker is open. The default value is `1e-6 1/Ohm`.

Threshold

Threshold voltage for the control port `vT`. The block uses the threshold voltage and the value of `vT` at the start of the simulation to determine whether the breaker is initially open or closed. When the voltage rises above the threshold, the breaker opens. When the control port voltage falls below the threshold, the breaker closes. The default value is `0 V`.

Ports

The block has the following ports:

`1`

Electrical conserving port

`2`

Electrical conserving port

`vT`

Scalar control port, which is either a physical signal or an electrical port.

See Also

See Also
`Circuit Breaker` | `Single-Phase Circuit Breaker (with arc)`

Topics
"Switch Between Physical Signal and Electrical Ports"

Introduced in R2013b

Single-Phase Circuit Breaker (with arc)

Single-pole single-throw circuit breaker with Mayr arc representation
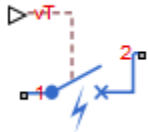
Library

Switches & Breakers / Fundamental Components

Description

The Single-Phase Circuit Breaker (with arc) block represents a single-phase circuit breaker with Mayr arc representation controlled by an external control signal vT. If vT is less than the threshold, then the breaker is closed. If vT is greater than or equal to the threshold, then the breaker opens with an arc during the current interruption. The external signal can open and close the breaker repeatedly.

The table shows how the external signal vT controls the block behavior.

Condition	Block Behavior
vT < **Threshold**	The circuit breaker is closed. Port 1 is connected to port 2.
vT ≥ **Threshold**	The circuit breaker is either opening or open. Port 1 is connected to port 2 via a nonlinear conductance.

The Single-Phase Circuit Breaker (with arc) block has a higher computational overhead than the Single-Phase Circuit Breaker block. If the fidelity of the representation of arc current or voltage is your overriding requirement, use the Single-Phase Circuit Breaker (with arc) block and use a global Simulink® variable-step solver. Otherwise, use the Single-Phase Circuit Breaker block.

Mayr Arc Model Equations

The defining equations for the breaker are

$$x = \ln(g)$$

and

$$i = gv,$$

where:

- g is the arc conductance.
- x is an internal state variable.
- v is the voltage across the breaker.
- i is the current through the breaker.

When the breaker is open,

$$\frac{dx}{dt} = 0.$$

When the breaker is closed,

$$\frac{dx}{dt} = \frac{1}{\tau}\left(\frac{gv^2}{P} - 1\right),$$

where:

- τ is the arc time constant.
- P is the cooling power.

Parameters

Arc time constant, tau

The default value is `0.3e-6 s`.

Cooling power, P

The default value is 30900 W.

Initial arc conductance, g0

Conductance between ports 1 and 2 when the breaker is closed. The default value is 1e4 S.

Threshold

Threshold voltage for the control port vT. The block uses the threshold voltage and the value of vT at the start of the simulation to determine whether the breaker is initially open or closed. When the voltage rises above the threshold, the breaker opens. When the control port voltage falls below the threshold, the breaker closes. The default value is 0 V.

Ports

The block has the following ports:

1

Electrical conserving port

2

Electrical conserving port

vT

Scalar control port, which is either a physical signal or an electrical port

References

[1] Schavemaker, P. H., and L. Van der Sluis. "The Arc Model Blockset." *Proceedings of the Second IASTED International Conference POWER AND ENERGY SYSTEMS (EuroPES).* Crete, Greece, June 25-28, 2002, pp. 644-648.

See Also

See Also
Circuit Breaker | Single-Phase Circuit Breaker

Topics

"Switch Between Physical Signal and Electrical Ports"

Introduced in R2015b

Single-Phase Switch

Single-pole single-throw switch
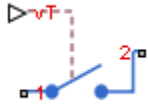
Library

Switches & Breakers / Fundamental Components

Description

The Single-Phase Switch block models a single-pole single-throw switch that uses an external signal to connect port 1 to port 2 via internal resistance.

The table shows how the external signal vT controls the block behavior.

Condition	Block Behavior	Resistance Parameter Used
vT ≤ **Threshold**	The switch is open. Port 1 is connected to port 2 via large internal resistance.	**Open conductance**
vT > **Threshold**	The switch is closed. Port 1 is connected to port 2 via small internal resistance.	**Closed resistance**

Parameters

Closed resistance

Resistance between ports 1 and 2 when the switch is closed. The default value is 0.001 Ohm.

Open conductance

Conductance between ports 1 and 2 when the switch is open. The default value is 1e-6 1/Ohm.

r **Threshold**

Threshold voltage for the control port vT. When the voltage is above the threshold, the switch is closed. The default value is 0 V.

Ports

The block has the following ports:

1

Electrical conserving port

2

Electrical conserving port

vT

Scalar control port, which is either a physical signal or an electrical port.

See Also

See Also

Single-Phase Two-Way Switch | Switch | Two-Way Switch

Topics

"Switch Between Physical Signal and Electrical Ports"

Introduced in R2013b

Single-Phase Two-Way Switch

Single-pole double-throw switch
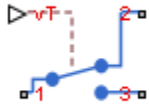
Library

Switches & Breakers / Fundamental Components

Description

The Single-Phase Two-Way Switch block models a single-pole double-throw switch that uses an external signal to connect the port 1 to either of two ports 2 or 3 via internal resistance.

The table shows how the external signal vT controls the block behavior.

Condition	Block Behavior	Resistance Parameter Used
vT ≤ **Threshold**	Port 1 is connected to port 2 via internal resistance. Port 3 is unconnected.	**Open conductance** (port 1 to port 3).**Closed resistance** (port 1 to port 2)
vT > **Threshold**	Port 1 is connected to port 3 via internal resistance. Port 2 is unconnected.	**Open conductance** (port 1 to port 2).**Closed resistance** (port 1 to port 3)

Parameters

Closed resistance

Resistance between ports 1 and 3 when the switch is closed. The default value is 0.001 Ohm.

Open conductance

Conductance between ports 1 and 2 when the switch is open. The default value is 1e-6 1/Ohm.

Threshold

Threshold voltage for the control port vT. When the voltage is above the threshold, the switch is closed. The default value is 0 V.

Ports

The block has the following ports:

1

Electrical conserving port

2

Electrical conserving port

3

Electrical conserving port

vT

Scalar control port, which is either a physical signal or an electrical port.

See Also

See Also
Single-Phase Switch | Switch | Two-Way Switch

Topics
"Switch Between Physical Signal and Electrical Ports"

Introduced in R2013b

Six-Pulse Gate Multiplexer

Multiplex gate input signals to Converter block
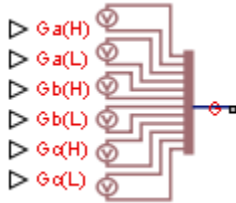
Library

Semiconductors

Description

The Six-Pulse Gate Multiplexer block routes gate voltage signals to the six switching devices in a Converter block. The block multiplexes the six separate gate signals into a single vector.

If you want to use Simscape Electronics to model the electronics that drive the Converter block, you can switch the input ports of the Six-Pulse Gate Multiplexer block from physical signal ports to electrical ports.

When you switch the block inputs to electrical ports, the block shows additional electrical reference input ports. The additional electrical reference ports are associated with the individual phase voltages that connect to the high-side switching devices in the Converter block and the negative DC voltage common to each low-side switching device in the Converter block.

Ports

The block has the following ports:

Ga(H),Gb(H),Gc(H)

Ports associated with the gate terminals of the Converter block high-side switching devices. You can set the ports to either physical signal or electrical ports.

`Ga(L),Gb(L),Gc(L)`

Ports associated with the gate terminals of the Converter block low-side switching devices. You can set the ports to either physical signal or electrical ports.

`G`

Vector output port associated with the multiplexed gate signals. Connect this port to the `G` port of the Converter block.

`a,b,c`

Electrical conserving ports associated with the individual phase voltages that connect to the high-side switching devices of the Converter block. These ports are visible only if you set the input ports of the Six-Pulse Gate Multiplexer block to electrical ports.

`L`

Electrical conserving port associated with the negative DC voltage common to each low-side switching device in the Converter block. These ports are visible only if you set the input ports of the Six-Pulse Gate Multiplexer block to electrical ports.

See Also

See Also
`Converter`

Topics
"Switch Between Physical Signal and Electrical Ports"

Introduced in R2013b

Supercapacitor

Represent an electrochemical double-layer capacitor
Library: Sources

Description

The Supercapacitor block represents an electrochemical double-layer capacitor (ELDC), which is commonly referred to as a supercapacitor or an ultracapacitor. The capacitance values for supercapacitors are orders of magnitude larger than the values for regular capacitors. Supercapacitors can provide bursts of energy because they can charge and discharge rapidly.

You can model any number of supercapacitor cells connected in series or in parallel using a single Supercapacitor block. To do so, set the relevant parameter, that is **Number of series cells** or **Number of parallel cells**, to a value larger than 1. Internally, the block simulates only the equations for a single supercapacitor cell, but it calculates:

- The output voltage according to the number of series-connected cells
- The current according to the number of parallel-connected cells

Calculating the output of a multiple-cell supercapacitor based on the output for a single cell is more efficient than simulating the equations for each cell individually.

The figure shows the equivalent circuit for a single cell in the Supercapacitor block. The circuit is a network of resistors and capacitors that is commonly used to model superconductor behavior.
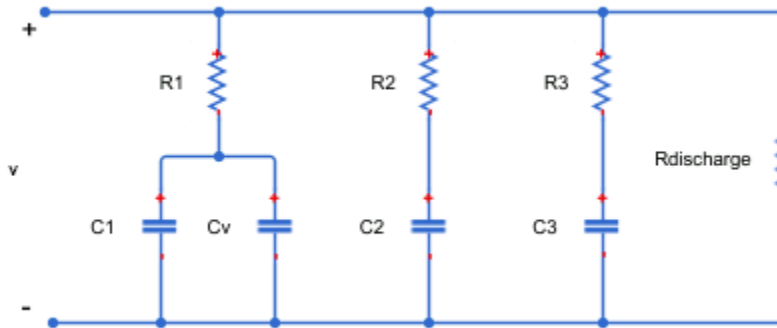
Capacitors C_1, C_2, and C_3 have fixed capacitances. The capacitance of capacitor C_v depends on the voltage across it. Resistors R_1, R_2, and R_3 have fixed resistances. The voltage across each individual fixed capacitor in the Supercapacitor block is calculated as

$$V_{cn} = \frac{v}{N_{series}} - i_n R_n,$$

where:

- v is the voltage across the block.
- N_{series} is the number of cells in series.
- n is the branch number. $n = [1, 2, 3]$.
- i_n is the current through the nth branch.
- R_n is the resistance in the nth branch.
- V_{cn} is voltage across the capacitor in the nth branch.

The equation for the current through the first branch of the supercapacitor depends on the voltage across the capacitors in the branch. If the capacitors experience a positive voltage, that is

$$V_{c1} > 0,$$

then

$$i_1 = (C_1 + K_v V_{c1}) \frac{dV_{c1}}{dt},$$

else

$$i_1 = C_1 \frac{dV_{c1}}{dt},$$

where:

- V_{c1} is voltage across the capacitors in the first branch.
- C_1 is the capacitance of the fixed capacitor in the first branch.
- K_v is the voltage-dependent capacitance gain.
- i_1 is the current through the first branch.

For the remaining branches, the current is defined as

$$i_n = C_n \frac{dV_{cn}}{dt},$$

where:

- n is the branch number. $n = [2, 3]$.
- C_n is the capacitance of the nth branch.

The total current through the Supercapacitor block is

$$i = N_{parallel} \left(i_1 + i_2 + i_3 + \frac{v}{R_{discharge}} \right),$$

where:

- $N_{parallel}$ is the number of cells in parallel.
- $R_{discharge}$ is the self-discharge resistance of the supercapacitor.

- i is the current through the supercapacitor.

Ports

Conserving

+ — Positive electrical terminal
electrical

Electrical conserving port associated with the positive terminal.

- — Negative electrical terminal
electrical

Electrical conserving port associated with the negative terminal.

Parameters

Cell Characteristics

Fixed resistances, [R1 R2 R3] — Fixed resistance values for each branch
[0.2, 90.0, 1000.0] Ohm (default)

Specify the resistances for the fixed resistors in the individual branches of the supercapacitor as an array.

Fixed capacitances, [C1 C2 C3] — Fixed capacitance values for each branch
[2.5, 1.5, 4.0] F (default)

Specify the individual capacitances for the fixed capacitors in the supercapacitor as an array.

Voltage-dependent capacitor gain — Variable capacitance coefficient for the first branch
0.95 F/V (default)

Specify the variable capacitance coefficient, K_v, for the voltage-dependent capacitor in the first branch of the supercapacitor. For information on determining the variable capacitance coefficient, see [1].

Self-discharge resistance — Resistance to self-discharge
inf (default)

Specify the self-discharge resistance of the supercapacitor that is connected between the two terminals.

Configuration

Number of series cells — Number of supercapacitor cells in series
1 (default)

Specify the number of cells in the supercapacitor that are in a series configuration.

Number of parallel cells — Number of supercapacitor cells in parallel
1 (default)

Specify the number of cells in the supercapacitor that are in a parallel configuration.

Variables

Beginning Value — Initial target value
0 (default)

Use the **Variables** tab to set the priority and initial target values for the block variables before simulation. For more information, see "Set Priority and Initial Target for Block Variables" (Simscape).

Model Examples

References

[1] Zubieta, L. and R. Bonert. "Characterization of Double-Layer Capacitors for Power Electronics Applications." *IEEE Transactions on Industry Applications*, Vol. 36, No. 1, 2000, pp. 199–205.

[2] Weddell, A. S., G. V. Merrett, T. J. Kazmierski, and B. M. Al-Hashimi. "Accurate Supercapacitor Modeling for Energy-Harvesting Wireless Sensor Nodes." *IEEE Transactions on Circuits And Systems–II: Express Briefs*, Vol. 58, No. 12, 2011, pp. 911–915.

See Also

See Also

Simscape Blocks
Battery | Current Source | Voltage Source

Introduced in R2016b

Switch

Three-phase single-throw switch
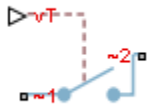
Library

Switches & Breakers

Description

The Switch block models a three-phase single-throw switch that uses an external signal to connect each phase of port ~1 with the corresponding phase of port ~2 via internal resistance.

The table shows how the external signal vT controls the block behavior.

Condition	Block Behavior	Resistance Parameter Used
vT ≤ **Threshold**	The switch is open. Each phase in the composite three-phase port ~1 connects to the corresponding phase in the port ~2 via large internal resistance.	**Open conductance**
vT > **Threshold**	The switch is closed. Each phase in the composite three-phase port ~1 connects to the corresponding phase in the port ~2 via small internal resistance.	**Closed resistance**

Parameters

Closed resistance

Resistance between ports ~1 and ~2 when the switch is closed. The default value is 0.001 Ohm.

Open conductance

Conductance between ports ~1 and ~2 when the switch is open. The default value is 1e-6 1/Ohm.

Threshold

Threshold voltage for the control port vT. When the voltage is above the threshold, the switch is closed. The default value is 0 V.

Ports

The block has the following ports:

~1

Expandable three-phase port

~2

Expandable three-phase port

vT

Scalar control port, which is either a physical signal or an electrical port.

See Also

See Also
Single-Phase Switch | Single-Phase Two-Way Switch | Two-Way Switch

Topics
"Expand and Collapse Three-Phase Ports on a Block"
"Switch Between Physical Signal and Electrical Ports"

Introduced in R2013b

Synchronous Machine Field Circuit (pu)

Synchronous machine field circuit per-unit voltage supply and current measurement
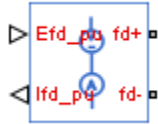
Library

Machines

Description

The Synchronous Machine Field Circuit (pu) block applies specified voltage to, and measures current through, the field circuit of the synchronous machine that it is connected to. It includes an electrical reference. The physical signal input Efd_pu defines the voltage and the physical signal output Ifd_pu provides the current, both in per-unit.

The per-unit bases are the nonreciprocal per-unit system, Efd and Ifd, rather than the reciprocal per-unit system, efd and ifd.

The figure shows the schematic for the Synchronous Machine Field Circuit (pu) block.
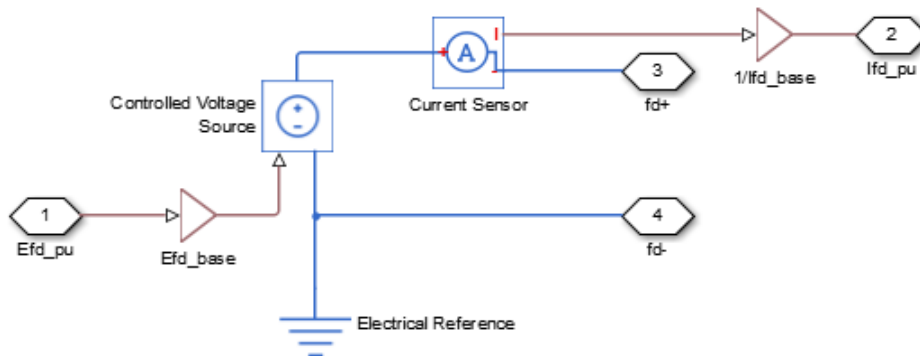
Parameters

- "Main Tab" on page 1-313
- "Machine Parameters Tab" on page 1-313

Main Tab

Rated apparent power

Rated apparent power of the connected machine. The default value is `555e6 V*A`.

Rated electrical frequency

Nominal electrical frequency at which rated apparent power of the connected machine is quoted. The default value is `60 Hz`.

Specify field circuit input required to produce rated terminal voltage at no load by

Choose between `Field circuit voltage` and `Field circuit current`. The default value is `Field circuit current`.

Field circuit current

This value is used to calculate the per-unit bases for the field circuit (nonreciprocal per-unit system). This parameter is visible only when **Specify field circuit input required to produce rated terminal voltage at no load by** is set to `Field circuit current`. The default value is `1300 A`.

Field circuit voltage

This value is used to calculate the per-unit bases for the field circuit (nonreciprocal per-unit system). This parameter is visible only when **Specify field circuit input required to produce rated terminal voltage at no load by** is set to `Field circuit voltage`. The default value is `92.95 V`.

Machine Parameters Tab

Specify parameterization by

Choose between `Fundamental Parameters` and `Standard Parameters`. The default value is `Fundamental Parameters`.

Stator d-axis mutual inductance (unsaturated), Ladu

Unsaturated stator d-axis mutual inductance. This parameter is visible only when **Specify parameterization by** is set to `Fundamental Parameters`. The default value is `1.66` pu.

1-313

Rotor field circuit resistance, Rfd

Rotor field-circuit resistance. This parameter is visible only when **Specify parameterization by** is set to `Fundamental Parameters`. The default value is `0.0006` pu.

Stator leakage reactance, Xl

Stator leakage reactance. This parameter is visible only when **Specify parameterization by** is set to `Standard Parameters`. The default value is `0.15` pu.

d-axis synchronous reactance, Xd

The d-axis synchronous reactance. This parameter is visible only when **Specify parameterization by** is set to `Standard Parameters`. The default value is `1.81` pu.

d-axis transient reactance, Xd'

The d-axis transient reactance. This parameter is visible only when **Specify parameterization by** is set to `Standard Parameters`. The default value is `0.3` pu.

Specify d-axis transient time constant by

This parameter is visible only when **Specify parameterization by** is set to `Standard Parameters`. Choose between `Open-circuit value` and `Short-circuit value`. The default value is `Open-circuit value`.

d-axis transient open-circuit, Td0'

The d-axis transient open-circuit time constant. This parameter is visible only when **Specify d-axis transient time constant by** is set to `Open-circuit value`. The default value is `8 s`.

d-axis transient short-circuit, Td'

The d-axis transient short-circuit time constant. This parameter is visible only when **Specify d-axis transient time constant by** is set to `Short-circuit value`. The default value is `1.326 s`.

Ports

The block has the following ports:

`Efd_pu`
Field voltage input, per-unit

`Ifd_pu`

> Field current output, per-unit

`fd+`

> Electrical conserving port corresponding to the field winding positive terminal

`fd-`

> Electrical conserving port corresponding to the field winding negative terminal

See Also

See Also
`Synchronous Machine Salient Pole (standard)` | `Synchronous Machine Salient Pole (fundamental)` | `Synchronous Machine Field Circuit (SI)` | `Synchronous Machine Round Rotor (standard)` | `Synchronous Machine Round Rotor (fundamental)`

Topics
Three-Phase Synchronous Machine Control

Introduced in R2014b

Synchronous Machine Field Circuit (SI)

Synchronous machine field circuit voltage supply and current measurement in SI units
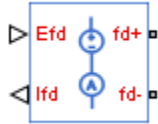
Library

Machines

Description

The Synchronous Machine Field Circuit (SI) block applies specified voltage to, and measures current through, the field circuit of the synchronous machine that it is connected to. It includes an electrical reference. The physical signal input Efd defines the voltage, in Volts, and the physical signal output Ifd provides the current, in Amperes.

The figure shows the schematic for the Synchronous Machine Field Circuit (SI) block.
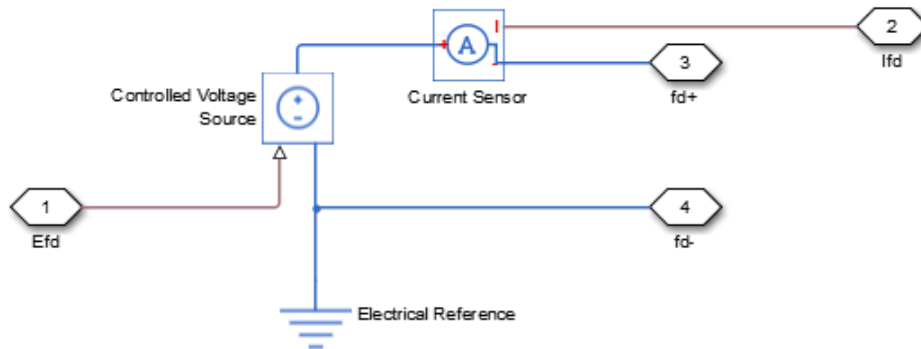
Ports

The block has the following ports:

Efd

    Field voltage input, V

Ifd

    Field current output, A

fd+

    Electrical conserving port corresponding to the field winding positive terminal

fd-

    Electrical conserving port corresponding to the field winding negative terminal

See Also

See Also

Synchronous Machine Salient Pole (standard) | Synchronous Machine Salient Pole (fundamental) | Synchronous Machine Field Circuit (pu) | Synchronous Machine Round Rotor (standard) | Synchronous Machine Round Rotor (fundamental)

Introduced in R2014b

Synchronous Machine Measurement

Per-unit measurement from synchronous machine

Library

Machines

Description

The Synchronous Machine Measurement block outputs a per-unit measurement associated with a connected Synchronous Machine Round Rotor or Synchronous Machine Salient Pole block. The input of the Synchronous Machine Measurement block connects to the pu output port of the synchronous machine block.

You set the **Output** parameter to a per-unit measurement associated with the synchronous machine. Based on the value you select, the Synchronous Machine Measurement block:

- Directly outputs the value of an element in the input signal vector
- Calculates the per-unit measurement by using values of elements in the input signal vector in mathematical expressions

The Synchronous Machine Measurement block outputs a per-unit measurement from the synchronous machine according to the output value expressions in the table. For example, when you set **Output** to Stator d-axis voltage, the block directly outputs the value of the pu_ed element in the input signal vector. However, when you set **Output** to Reactive power, the block calculates the value from the pu_ed, pu_eq, pu_id, and pu_iq elements.

Output Parameter Setting	Output Value Expression
Field voltage (field circuit base, Efd)	pu_fd_Efd

Output Parameter Setting	Output Value Expression
Field current (field circuit base, Ifd)	`pu_fd_Ifd`
Electrical torque	`pu_torque`
Rotor velocity	`pu_velocity`
Stator d-axis voltage	`pu_ed`
Stator q-axis voltage	`pu_eq`
Stator zero-sequence voltage	`pu_e0`
Stator d-axis current	`pu_id`
Stator q-axis current	`pu_iq`
Stator zero-sequence current	`pu_i0`
Apparent power	$\sqrt{pu\_Pt^2 + pu\_Qt^2}$
Real power	`pu_Pt = (pu_ed*pu_id) + (pu_eq*pu_iq) + 2(pu_e0*pu_i0)`
Reactive power	`pu_Qt = (pu_eq*pu_id) − (pu_ed*pu_iq)`
Terminal voltage	$\sqrt{(pu\_ed^2 + pu\_eq^2)}$
Terminal current	$\sqrt{(pu\_id^2 + pu\_iq^2)}$
Power factor angle (rad)	`power_factor_angle = atan2(pu_Qt, pu_Pt)`
Power factor	`cos(power_factor_angle)`
Load angle (rad)	`load_angle(rad) = atan2(pu_ed, pu_eq)`

Parameters

Output

Per-unit measurement from synchronous machine. The default value is `Field voltage (field circuit base, Efd)`.

Ports

The block has the following ports:

pu

>   Physical signal vector port associated with per-unit measurements from a connected synchronous machine. The vector elements are:
>
>   - `pu_fd_Efd`
>   - `pu_fd_Ifd`
>   - `pu_torque`
>   - `pu_velocity`
>   - `pu_ed`
>   - `pu_eq`
>   - `pu_e0`
>   - `pu_id`
>   - `pu_iq`
>   - `pu_i0`

o

>   Per-unit measurement output port.

See Also

See Also
```
Synchronous Machine Round Rotor (fundamental) | Synchronous
Machine Round Rotor (standard) | Synchronous Machine Salient Pole
(fundamental) | Synchronous Machine Salient Pole (standard)
```

Introduced in R2013b

Synchronous Machine Model 2.1 (fundamental)

Synchronous machine with simplified transformation, simplified representation, and fundamental parameterization
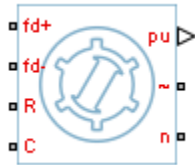
Library

Machines / Synchronous Machine (Simplified)

Description

The Synchronous Machine Model 2.1 (fundamental) block models a synchronous machine with one field winding and one damper on the *d*-axis and one damper on the *q*-axis. You use fundamental parameters to define the characteristics of the machine. This block contains a *dq* Park transformation, so use it only for balanced operation.

Electrical Defining Equations

The synchronous machine equations are expressed with respect to a rotating reference frame defined by the equation

$$\theta_e(t) = N\theta_r(t),$$

where:

- θ_e is the electrical angle.
- N is the number of pole pairs.
- θ_r is the rotor angle.

The Park transformation maps the synchronous machine equations to the rotating reference frame with respect to the electrical angle. The Park transformation is defined by

$$P_s = \frac{2}{3} \begin{bmatrix} \cos\theta_e & \cos(\theta_e - \frac{2\pi}{3}) & \cos(\theta_e + \frac{2\pi}{3}) \\ -\sin\theta_e & -\sin(\theta_e - \frac{2\pi}{3}) & -\sin(\theta_e + \frac{2\pi}{3}) \end{bmatrix}.$$

The Park transformation is used to define the per-unit synchronous machine equations. The stator voltage equations are defined by

$$e_d = e_d^{''} - R_a i_d + x_q^{''} i_q$$

and

$$e_q = e_q^{''} - x_d^{''} i_d - R_a i_q,$$

where:

- $e_d^{''}$ and $e_q^{''}$ are the d-axis and q-axis voltages behind subtransient reactances.
- R_a is the stator resistance.
- i_d and i_q are the d-axis and q-axis stator currents, defined by

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = P_s \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}.$$

  i_a, i_b, and i_c are the stator currents flowing from port ~ to port n.
- $x_d^{''}$ and $x_q^{''}$ are the d-axis and q-axis subtransient reactances.
- e_d and e_q are the d-axis and q-axis stator voltages, defined by

$$\begin{bmatrix} e_d \\ e_q \end{bmatrix} = P_s \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}.$$

v_a, v_b, and v_c are the stator voltages measured from port ~ to neutral port n.

The rotor voltage equation is defined by

$$e_{fd} = R_{fd} \cdot i_{fd},$$

where:

- R_{fd} is the resistance of rotor field circuit.
- i_{fd} is the per-unit field current using the synchronous machine model reciprocal per-unit system.
- e_{fd} is the per-unit field voltage using the synchronous machine model reciprocal per-unit system.

The voltage-behind-transient-reactance equations are defined by

$$\frac{de_d''}{dt} = \frac{\left(x_q - x_q''\right)i_q - e_d''}{T_{q0}''},$$

$$\frac{de_q'}{dt} = \frac{E_{fd} - \left(x_d - x_d'\right)i_d - e_q'}{T_{d0}'},$$

and

$$\frac{de_q''}{dt} = \frac{e_q' - \left(x_d' - x_d''\right)i_d - e_q''}{T_{d0}''},$$

where:

- x_d and x_q are the d-axis and q-axis synchronous reactances.
- T''_{d0} and T''_{q0} are the d-axis and q-axis subtransient open-circuit time constants.
- E_{fd} is the per-unit field voltage using the exciter model nonreciprocal per-unit system.
- x'_d is the d-axis transient reactance.

- e'_q is the q-axis voltage behind transient reactance.
- T''_{d0} is the d-axis transient open-circuit time constant.

The rotor torque is defined by

$$T_e = e''_d i_d + e''_q i_q - \left(x''_d - x''_q \right) i_d i_q.$$

These defining equations do not describe the parameters you can set in the dialog box. To see their relationship with the equation coefficients, see [1].

Display Options

You can perform display actions using the **Power Systems** menu on the block context menu.

Right-click the block and, from the **Power Systems** menu, select an option:

- **Display Base Values** displays the machine per-unit base values in the MATLAB Command Window.
- **Display Associated Base Values** displays associated per-unit base values in the MATLAB Command Window.
- **Display Associated Initial Conditions** displays associated initial conditions in the MATLAB Command Window.

Parameters

- "Main Tab" on page 1-324
- "Impedances Tab" on page 1-325
- "Initial Conditions Tab" on page 1-326

Main Tab

Rated apparent power

Rated apparent power. The default value is 555e6 V*A.

Rated voltage

RMS rated line-line voltage. The default value is `24e3` V.

Rated electrical frequency

Nominal electrical frequency at which rated apparent power is quoted. The default value is `60 Hz`.

Number of pole pairs

Number of machine pole pairs. The default value is `1`.

Specify field circuit input required to produce rated terminal voltage at no load by

Select between `Field circuit voltage` and `Field circuit current`. The default value is `Field circuit current`.

Field circuit current

This parameter is visible only when **Specify field circuit input required to produce rated terminal voltage at no load by** is set to `Field circuit current`. The default value is `1300` A.

Field circuit voltage

This parameter is visible only when **Specify field circuit input required to produce rated terminal voltage at no load by** is set to `Field circuit voltage`. The default value is `92.95` V.

Impedances Tab

Stator d-axis mutual inductance (unsaturated), Ladu

Unsaturated stator d-axis mutual inductance. The default value is `1.66` pu.

Stator q-axis mutual inductance (unsaturated), Laqu

Unsaturated stator q-axis mutual inductance. The default value is `1.61` pu.

Stator leakage inductance, Ll

Stator leakage inductance. The default value is `0.15` pu.

Stator resistance, Ra

Stator resistance. The default value is `0.003` pu.

Rotor field circuit inductance, Lfd

Rotor field circuit inductance. The default value is `0.165` pu.

Rotor field circuit resistance, Rfd

Rotor field circuit resistance. The default value is `0.0006` pu.

Rotor d-axis damper winding 1 inductance, L1d

Rotor d-axis damper winding 1 inductance. The default value is `0.1713` pu.

Rotor d-axis damper winding 1 resistance, R1d

Rotor d-axis damper winding 1 resistance. The default value is `0.0284` pu.

Rotor q-axis damper winding 1 inductance, L1q

Rotor q-axis damper winding 1 inductance. The default value is `0.1066` pu.

Rotor q-axis damper winding 1 resistance, R1q

Rotor q-axis damper winding 1 resistance. The default value is `0.0650` pu.

Initial Conditions Tab

Specify initialization by

Select between `Electrical power and voltage output` and `Mechanical and voltage states`. The default value is `Electrical power and voltage output`.

Terminal voltage magnitude

Initial RMS line-line voltage. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `24e3` V.

Terminal voltage angle

Initial voltage angle. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `0 deg`.

Terminal active power

Initial active power. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `500e6 V*A`.

Terminal reactive power

Initial reactive power. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `0 V*A`.

Initial rotor angle

Initial rotor angle. During steady-state operation, set this parameter to the sum of the load angle and required terminal voltage offset. This parameter is visible only

when you set **Specify initialization by** to `Mechanical and voltage states`. The default value is `0` deg.

Initial voltage behind d-axis subtransient reactance

Initial voltage behind *d*-axis subtransient reactance. This parameter is visible only when you set **Specify initialization by** to `Mechanical and voltage states`. The default value is `0` pu.

Initial voltage behind q-axis transient reactance

Initial voltage behind *q*-axis transient reactance. This parameter is visible only when you set **Specify initialization by** to `Mechanical and voltage states`. The default value is `0` pu.

Initial voltage behind q-axis subtransient reactance

Initial voltage behind *q*-axis subtransient reactance. This parameter is visible only when you set **Specify initialization by** to `Mechanical and voltage states`. The default value is `0` pu.

Ports

The block has the following ports:

`fd+`

Electrical conserving port corresponding to the field winding positive terminal.

`fd-`

Electrical conserving port corresponding to the field winding negative terminal.

`R`

Mechanical rotational conserving port associated with the machine rotor.

`C`

Mechanical rotational conserving port associated with the machine case.

`pu`

Physical signal vector port associated with the machine per-unit measurements. The vector elements are:

- `pu_fd_Efd`
- `pu_fd_Ifd`
- `pu_torque`

- `pu_velocity`
- `pu_ed`
- `pu_eq`
- `pu_e0` — This port is provided to maintain a compatible interface for existing machine models. Its value is always zero.
- `pu_id`
- `pu_iq`
- `pu_i0` — This port is provided to maintain a compatible interface for existing machine models. Its value is always zero.

~

Expandable three-phase port associated with the stator windings.

n

Electrical conserving port associated with the neutral point of the wye winding configuration. This port is provided to maintain a compatible interface for existing machine models. The voltage and current on this port are ignored.

References

[1] Kundur, P. *Power System Stability and Control.* New York, NY: McGraw Hill, 1993.

[2] Lyshevski, S. E. *Electromechanical Systems, Electric Machines and Applied Mechatronics.* Boca Raton, FL: CRC Press, 1999.

[3] Pal, M. K. *Lecture Notes on Power System Stability.* http://www.mkpalconsulting.com/files/stabilitybook.pdf, 2007.

See Also

See Also

```
Synchronous Machine Measurement | Synchronous Machine Model 2.1
(standard) | Synchronous Machine Round Rotor (fundamental) |
Synchronous Machine Round Rotor (standard) | Synchronous Machine
Salient Pole (fundamental) | Synchronous Machine Salient Pole
(standard)
```

Topics

"Expand and Collapse Three-Phase Ports on a Block"
Three-Phase Synchronous Machine Control

Introduced in R2015a

Synchronous Machine Model 2.1 (standard)

Synchronous machine with simplified transformation, simplified representation, and standard parameterization
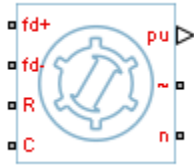
Library

Machines / Synchronous Machine (Simplified)

Description

The Synchronous Machine Model 2.1 (standard) block models a synchronous machine with one field winding and one damper on the *d*-axis and one damper on the *q*-axis. You use standard parameters to define the characteristics of the machine. The block converts the standard parameters to fundamental parameters. This block contains a *dq* Park transformation, so use it only for balanced operation.

Electrical Defining Equations

The synchronous machine equations are expressed with respect to a rotating reference frame defined by the equation

$$\theta_e(t) = N\theta_r(t),$$

where:

- θ_e is the electrical angle.
- N is the number of pole pairs.
- θ_r is the rotor angle.

The Park transformation maps the synchronous machine equations to the rotating reference frame with respect to the electrical angle. The Park transformation is defined by

$$
P_s = \frac{2}{3}
\begin{bmatrix}
\cos\theta_e & \cos(\theta_e - \dfrac{2\pi}{3}) & \cos(\theta_e + \dfrac{2\pi}{3}) \\
-\sin\theta_e & -\sin(\theta_e - \dfrac{2\pi}{3}) & -\sin(\theta_e + \dfrac{2\pi}{3})
\end{bmatrix}.
$$

The Park transformation is used to define the per-unit synchronous machine equations. The stator voltage equations are defined by

$$
e_d = e_d'' - R_a i_d + x_q'' i_q
$$

and

$$
e_q = e_q'' - x_d'' i_d - R_a i_q,
$$

where:

- e''_d and e''_q are the d-axis and q-axis voltages behind subtransient reactances.
- R_a is the stator resistance.
- i_d and i_q are the d-axis and q-axis stator currents, defined by

$$
\begin{bmatrix} i_d \\ i_q \end{bmatrix} = P_s \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}.
$$

  i_a, i_b, and i_c are the stator currents flowing from port ~ to port n.
- x''_d and x''_q are the d-axis and q-axis subtransient reactances.
- e_d and e_q are the d-axis and q-axis stator voltages, defined by

$$
\begin{bmatrix} e_d \\ e_q \end{bmatrix} = P_s \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}.
$$

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v_a, v_b, and v_c are the stator voltages measured from port ~ to neutral port n.

The rotor voltage equation is defined by

$$e_{fd} = R_{fd} \cdot i_{fd},$$

where:

- R_{fd} is the resistance of rotor field circuit.
- i_{fd} is the per-unit field current using the synchronous machine model reciprocal per-unit system.
- e_{fd} is the per-unit field voltage using the synchronous machine model reciprocal per-unit system.

The voltage-behind-transient-reactance equations are defined by

$$\frac{de_d^{''}}{dt} = \frac{\left(x_q - x_q^{''}\right)i_q - e_d^{''}}{T_{q0}^{''}},$$

$$\frac{de_q^{'}}{dt} = \frac{E_{fd} - \left(x_d - x_d^{'}\right)i_d - e_q^{'}}{T_{d0}^{'}},$$

and

$$\frac{de_q^{''}}{dt} = \frac{e_q^{'} - \left(x_d^{'} - x_d^{''}\right)i_d - e_q^{''}}{T_{d0}^{''}},$$

where:

- x_d and x_q are the d-axis and q-axis synchronous reactances.
- $T^{''}_{d0}$ and $T^{''}_{q0}$ are the d-axis and q-axis subtransient open-circuit time constants.
- E_{fd} is the per-unit field voltage using the exciter model nonreciprocal per-unit system.
- x'_d is the d-axis transient reactance.
- e'_q is the q-axis voltage behind transient reactance.

- T'_{d0} is the d-axis transient open-circuit time constant.

The rotor torque is defined by

$$T_e = e''_d i_d + e''_q i_q - \left(x''_d - x''_q \right) i_d i_q.$$

These defining equations do not describe the short-circuit time constants you can set in the dialog box. To see their relationship with the equation coefficients, see [1].

Display Options

You can perform display actions using the **Power Systems** menu on the block context menu.

Right-click the block and, from the **Power Systems** menu, select an option:

- **Display Base Values** displays the machine per-unit base values in the MATLAB Command Window.
- **Display Associated Base Values** displays associated per-unit base values in the MATLAB Command Window.
- **Display Associated Initial Conditions** displays associated initial conditions in the MATLAB Command Window.

Parameters

- "Main Tab" on page 1-333
- "Impedances Tab" on page 1-334
- "Time Constants Tab" on page 1-335
- "Initial Conditions Tab" on page 1-336

Main Tab

Rated apparent power

Rated apparent power. The default value is 555e6 VA.

Rated voltage

RMS rated line-line voltage. The default value is 24e3 V.

Rated electrical frequency

Nominal electrical frequency at which rated apparent power is quoted. The default value is `60 Hz`.

Number of pole pairs

Number of machine pole pairs. The default value is `1`.

Specify field circuit input required to produce rated terminal voltage at no load by

Select between `Field circuit voltage` and `Field circuit current`. The default value is `Field circuit current`.

Field circuit current

This parameter is visible only when **Specify field circuit input required to produce rated terminal voltage at no load by** is set to `Field circuit current`. The default value is `1300 A`.

Field circuit voltage

This parameter is visible only when **Specify field circuit input required to produce rated terminal voltage at no load by** is set to `Field circuit voltage`. The default value is `92.95` V.

Impedances Tab

Stator resistance, Ra

Stator resistance. The default value is `0.003` pu.

Stator leakage reactance, Xl

Stator leakage reactance. The default value is `0.15` pu.

d-axis synchronous reactance, Xd

The *d*-axis synchronous reactance. The default value is `1.81` pu.

q-axis synchronous reactance, Xq

The *q*-axis synchronous reactance. The default value is `1.76` pu.

d-axis transient reactance, Xd'

The *d*-axis transient reactance. The default value is `0.3` pu.

d-axis subtransient reactance, Xd"

The *d*-axis subtransient reactance. The default value is `0.23` pu.

q-axis subtransient reactance, Xq"

The *q*-axis subtransient reactance. The default value is `0.25` pu.

Time Constants Tab

Specify d-axis transient time constant

Select between `Open-circuit value` and `Short-circuit value`. The default value is `Open-circuit value`.

d-axis transient open-circuit, Td0'

The *d*-axis transient open-circuit time constant. This parameter is visible only when **Specify d-axis transient time constant** is set to `Open-circuit value`. The default value is `8 s`.

d-axis transient short-circuit, Td'

The *d*-axis transient short-circuit time constant. This parameter is visible only when **Specify d-axis transient time constant** is set to `Short-circuit value`. The default value is `1.326 s`.

Specify d-axis subtransient time constant

Select between `Open-circuit value` and `Short-circuit value`. The default value is `Open-circuit value`.

d-axis subtransient open-circuit, Td0"

The *d*-axis subtransient open-circuit time constant. This parameter is visible only when **Specify d-axis subtransient time constant** is set to `Open-circuit value`. The default value is `0.03 s`.

d-axis subtransient short-circuit, Td"

The *d*-axis subtransient short-circuit time constant. This parameter is visible only when **Specify d-axis subtransient time constant** is set to `Short-circuit value`. The default value is `0.023 s`.

Specify q-axis subtransient time constant

Select between `Open-circuit value` and `Short-circuit value`. The default value is `Open-circuit value`.

q-axis subtransient open-circuit, Tq0"

The *q*-axis subtransient open-circuit time constant. This parameter is visible only when **Specify q-axis subtransient time constant** is set to `Open-circuit value`. The default value is `0.07 s`.

q-axis subtransient short-circuit, Tq"

The *q*-axis subtransient short-circuit time constant. This parameter is visible only when **Specify q-axis subtransient time constant** is set to `Short-circuit value`. The default value is `0.0269 s`.

Initial Conditions Tab

Specify initialization by

Select between `Electrical power and voltage output` and `Mechanical and voltage states`. The default value is `Electrical power and voltage output`.

Terminal voltage magnitude

Initial RMS line-line voltage. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `24e3 V`.

Terminal voltage angle

Initial voltage angle. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `0 deg`.

Terminal active power

Initial active power. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `500e6 V*A`.

Terminal reactive power

Initial reactive power. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `0 V*A`.

Initial rotor angle

Initial rotor angle. During steady-state operation, set this parameter to the sum of the load angle and required terminal voltage offset. This parameter is visible only when you set **Specify initialization by** to `Mechanical and voltage states`. The default value is `0 deg`.

Initial voltage behind d-axis subtransient reactance

Initial voltage behind *d*-axis subtransient reactance. This parameter is visible only when you set **Specify initialization by** to `Mechanical and voltage states`. The default value is `0 pu`.

Initial voltage behind q-axis transient reactance

Initial voltage behind *q*-axis transient reactance. This parameter is visible only when you set **Specify initialization by** to `Mechanical and voltage states`. The default value is `0` pu.

Initial voltage behind q-axis subtransient reactance

Initial voltage behind *q*-axis subtransient reactance. This parameter is visible only when you set **Specify initialization by** to `Mechanical and voltage states`. The default value is `0` pu.

Ports

The block has the following ports:

`fd+`

Electrical conserving port corresponding to the field winding positive terminal.

`fd-`

Electrical conserving port corresponding to the field winding negative terminal.

`R`

Mechanical rotational conserving port associated with the machine rotor.

`C`

Mechanical rotational conserving port associated with the machine case.

`pu`

Physical signal vector port associated with the machine per-unit measurements. The vector elements are:

- `pu_fd_Efd`
- `pu_fd_Ifd`
- `pu_torque`
- `pu_velocity`
- `pu_ed`
- `pu_eq`
- `pu_e0` — This port is provided to maintain a compatible interface for existing machine models. Its value is always zero.

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- `pu_id`
- `pu_iq`
- `pu_i0` — This port is provided to maintain a compatible interface for existing machine models. Its value is always zero.

~

Expandable three-phase port associated with the stator windings.

n

Electrical conserving port associated with the neutral point of the wye winding configuration. This port is provided to maintain a compatible interface for existing machine models. The voltage and current on this port are ignored.

References

[1] Kundur, P. *Power System Stability and Control*. New York, NY: McGraw Hill, 1993.

[2] Lyshevski, S. E. *Electromechanical Systems, Electric Machines and Applied Mechatronics*. Boca Raton, FL: CRC Press, 1999.

[3] Pal, M. K. *Lecture Notes on Power System Stability*. http://www.mkpalconsulting.com/files/stabilitybook.pdf, 2007.

See Also

See Also
```
Synchronous Machine Measurement | Synchronous Machine Model 2.1
(fundamental) | Synchronous Machine Round Rotor (fundamental) |
Synchronous Machine Round Rotor (standard) | Synchronous Machine
Salient Pole (fundamental) | Synchronous Machine Salient Pole
(standard)
```

Topics
"Expand and Collapse Three-Phase Ports on a Block"
Three-Phase Synchronous Machine Control

Introduced in R2015a

Synchronous Machine Round Rotor (fundamental)

Round-rotor synchronous machine with fundamental parameterization

Library

Machines / Synchronous Machine (Round Rotor)

Description

The Synchronous Machine Round Rotor (fundamental) block models a round-rotor synchronous machine using fundamental parameters.

Electrical Defining Equations

The synchronous machine equations are expressed with respect to a rotating reference frame defined by the equation

$$\theta_e(t) = N\theta_r(t),$$

where:

- θ_e is the electrical angle.
- N is the number of pole pairs.
- θ_r is the rotor angle.

Park's transformation maps the synchronous machine equations to the rotating reference frame with respect to the electrical angle. Park's transformation is defined by

$$P_s = \frac{2}{3} \begin{bmatrix} \cos\theta_e & \cos(\theta_e - \frac{2\pi}{3}) & \cos(\theta_e + \frac{2\pi}{3}) \\ -\sin\theta_e & -\sin(\theta_e - \frac{2\pi}{3}) & -\sin(\theta_e + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}.$$

Park's transformation is used to define the per-unit synchronous machine equations. The stator voltage equations are defined by

$$e_d = \frac{1}{\omega_{base}} \frac{d\psi_d}{dt} - \Psi_q \omega_r - R_a i_d,$$

$$e_q = \frac{1}{\omega_{base}} \frac{d\psi_q}{dt} + \Psi_d \omega_r - R_a i_q,$$

and

$$e_0 = \frac{1}{\omega_{base}} \frac{d\Psi_0}{dt} - R_a i_0,$$

where:

- e_d, e_q, and e_0 are the d-axis, q-axis, and zero-sequence stator voltages, defined by

$$\begin{bmatrix} e_d \\ e_q \\ e_0 \end{bmatrix} = P_s \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}.$$

  v_a, v_b, and v_c are the stator voltages measured from port ~ to neutral port n.
- ω_{base} is the per-unit base electrical speed.
- ψ_d, ψ_q, and ψ_0 are the d-axis, q-axis, and zero-sequence stator flux linkages.
- ω_r is the per-unit rotor rotational speed.
- R_a is the stator resistance.

- i_d, i_q, and i_0 are the d-axis, q-axis, and zero-sequence stator currents, defined by

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = P_s \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}.$$

i_a, i_b, and i_c are the stator currents flowing from port ~ to port n.

The rotor voltage equations are defined by

$$e_{fd} = \frac{1}{\omega_{base}} \frac{d\Psi_{fd}}{dt} + R_{fd} i_{fd},$$

$$e_{1d} = \frac{1}{\omega_{base}} \frac{d\Psi_{1d}}{dt} + R_{1d} i_{1d} = 0,$$

$$e_{1q} = \frac{1}{\omega_{base}} \frac{d\Psi_{1q}}{dt} + R_{1q} i_{1q} = 0,$$

and

$$e_{2q} = \frac{1}{\omega_{base}} \frac{d\Psi_{2q}}{dt} + R_{2q} i_{2q} = 0,$$

where:

- e_{fd} is the field voltage.
- e_{1d}, e_{1q}, and e_{2q} are the voltages across the d-axis damper winding 1, q-axis damper winding 1, and q-axis damper winding 2. They are all equal to 0.
- ψ_{fd}, ψ_{1d}, ψ_{1q}, and ψ_{2q} are the magnetic fluxes linking the field circuit, d-axis damper winding 1, q-axis damper winding 1, and q-axis damper winding 2.
- R_{fd}, R_{1d}, R_{1q}, and R_{2q} are the resistances of rotor field circuit, d-axis damper winding 1, q-axis damper winding 1, and q-axis damper winding 2.
- i_{fd}, i_{1d}, i_{1q}, and i_{2q} are the currents flowing in the field circuit, d-axis damper winding 1, q-axis damper winding 1, and q-axis damper winding 2.

The saturation equations are defined by

$$\psi_{ad} = \psi_d + L_l i_d,$$

$$\psi_{aq} = \psi_q + L_l i_q,$$

$$\psi_{at} = \sqrt{\psi_{ad}^2 + \psi_{aq}^2},$$

$K_s = 1$ (If saturation is disabled),

$K_s = f\left(\psi_{at}\right)$ (If saturation is enabled),

$$L_{ad} = K_s * L_{adu},$$

and

$$L_{aq} = K_s * L_{aqu},$$

where:

- ψ_{ad} is the d-axis air-gap or mutual flux linkage.
- ψ_{aq} is the q-axis air-gap or mutual flux linkage.
- ψ_{at} is the air-gap flux linkage.
- K_s is the saturation factor.
- L_{adu} is the unsaturated mutual inductance of the stator d-axis.
- L_{ad} is the mutual inductance of the stator d-axis.
- L_{aqu} is the unsaturated mutual inductance of the stator q-axis.
- L_{aq} is the mutual inductance of the stator q-axis.

The saturation factor function, f, is calculated from the per-unit open-circuit lookup table as:

$$L_{ad} = \frac{d\psi_{at}}{di_{fd}},$$

$$V_{ag} = g(i_{fd}),$$

and

$$L_{ad} = \frac{dg(i_{fd})}{di_{fd}} = \frac{dV_{ag}}{di_{fd}},$$

where V_{ag} is the per-unit air-gap voltage.

In per-unit,

$$K_s = \frac{L_{ad}}{L_{adu}},$$

and

$$\psi_{at} = V_{ag}$$

can be rearranged to

$$K_s = f(\psi_{at}).$$

The stator flux linkage equations are defined by

$$\Psi_d = -(L_{ad} + L_l)i_d + L_{ad}i_{fd} + L_{ad}i_{1d},$$

$$\Psi_q = -(L_{aq} + L_l)i_q + L_{aq}i_{1q} + L_{aq}i_{2q},$$

and

$$\Psi_0 = -L_0 i_0,$$

where:

- L_l is the stator leakage inductance.
- L_{ad} and L_{aq} are the mutual inductances of the stator d-axis and q-axis.

The rotor flux linkage equations are defined by

$$\psi_{fd} = L_{ffd}i_{fd} + L_{f1d}i_{1d} - L_{ad}i_d,$$

$$\psi_{1d} = L_{f1d}i_{fd} + L_{11d}i_{1d} - L_{ad}i_d,$$

$$\psi_{1q} = L_{11q}i_{1q} + L_{aq}i_{2q} - L_{aq}i_q,$$

and

$$\psi_{2q} = L_{aq}i_{1q} + L_{22q}i_{2q} - L_{aq}i_q,$$

where:

- L_{ffd}, L_{11d}, L_{11q}, and L_{22q} are the self-inductances of the rotor field circuit, d-axis damper winding 1, q-axis damper winding 1 and q-axis damper winding 2. L_{f1d} is the rotor field circuit and d-axis damper winding 1 mutual inductance. They are defined by the following equations.

$$L_{ffd} = L_{ad} + L_{fd}$$

$$L_{f1d} = L_{ffd} - L_{fd}$$

$$L_{11d} = L_{f1d} + L_{1d}$$

$$L_{11q} = L_{aq} + L_{1q}$$

$$L_{22q} = L_{aq} + L_{2q}$$

These equations assume that per-unit mutual inductance $L_{12q} = L_{aq}$, that is, the stator and rotor currents in the q-axis all link a single mutual flux represented by L_{aq}.

The rotor torque is defined by

$$T_e = \Psi_d i_q - \Psi_q i_d.$$

Plotting and Display Options

You can perform plotting and display actions using the **Power Systems** menu on the block context menu.

Right-click the block and, from the **Power Systems** menu, select an option:

- **Display Base Values** displays the machine per-unit base values in the MATLAB Command Window.
- **Display Associated Base Values** displays associated per-unit base values in the MATLAB Command Window.
- **Display Associated Initial Conditions** displays associated initial conditions in the MATLAB Command Window.
- **Plot Open-Circuit Saturation (pu)** plots air-gap voltage, V_{ag}, versus field current, i_{fd}, both measured in per-unit, in a MATLAB figure window. The plot contains three traces:

  - Unsaturated: **Stator d-axis mutual inductance (unsaturated), Ladu** you specify
  - Saturated: **Per-unit open-circuit lookup table (Vag versus ifd)** you specify
  - Derived: Open-circuit lookup table (per-unit) derived from the **Per-unit open-circuit lookup table (Vag versus ifd)** you specify. This data is used to calculate the saturation factor,K_s, versus magnetic flux linkage, ψ_{at}, characteristic.

- **Plot Saturation Factor (pu)** plots saturation factor,K_s, versus magnetic flux linkage, ψ_{at}, both measured in per-unit, in a MATLAB figure window using the machine parameters. This parameter is derived from other parameters that you specify:

  - **Stator d-axis mutual inductance (unsaturated), Ladu**
  - **Per-unit field current saturation data, ifd**
  - **Per-unit air-gap voltage saturation data, Vag**

Parameters

Main Tab

Rated apparent power

Rated apparent power. The default value is `555e6 V*A`.

Rated voltage

RMS rated line-line voltage. The default value is `24e3 V`.

Rated electrical frequency

Nominal electrical frequency at which rated apparent power is quoted. The default value is `60 Hz`.

Number of pole pairs

Number of machine pole pairs. The default value is `1`.

Specify field circuit input required to produce rated terminal voltage at no load by

Select between

· `Field circuit voltage`
· `Field circuit current`

The default value is `Field circuit current`.

Field circuit current

This parameter is visible only when **Specify field circuit input required to produce rated terminal voltage at no load by** is set to `Field circuit current`. The default value is `1300 A`.

Field circuit voltage

This parameter is visible only when **Specify field circuit input required to produce rated terminal voltage at no load by** is set to `Field circuit voltage`. The default value is `92.95 V`.

Impedances Tab

Stator d-axis mutual inductance (unsaturated), Ladu

Unsaturated stator d-axis mutual inductance. If **Magnetic saturation representation** is set to `None`, this is equivalent to the stator d-axis mutual inductance. The default value is `1.66` pu.

Stator q-axis mutual inductance (unsaturated), Laqu

Unsaturated stator q-axis mutual inductance. If **Magnetic saturation representation** is set to None, this is equivalent to the stator q-axis mutual inductance. The default value is 1.61 pu.

Stator zero-sequence inductance, L0

Stator zero-sequence inductance. The default value is 0.15 pu.

Stator leakage inductance, Ll

Stator leakage inductance. The default value is 0.15 pu.

Stator resistance, Ra

Stator resistance. The default value is 0.003 pu.

Rotor field circuit inductance, Lfd

Rotor field circuit inductance. The default value is 0.165 pu.

Rotor field circuit resistance, Rfd

Rotor field circuit resistance. The default value is 0.0006 pu.

Rotor d-axis damper winding 1 inductance, L1d

Rotor d-axis damper winding 1 inductance. The default value is 0.1713 pu.

Rotor d-axis damper winding 1 resistance, R1d

Rotor d-axis damper winding 1 resistance. The default value is 0.0284 pu.

Rotor q-axis damper winding 1 inductance, L1q

Rotor q-axis damper winding 1 inductance. The default value is 0.7252 pu.

Rotor q-axis damper winding 1 resistance, R1q

Rotor q-axis damper winding 1 resistance. The default value is 0.00619 pu.

Rotor q-axis damper winding 2 inductance, L2q

Rotor q-axis damper winding 2 inductance. The default value is 0.125 pu.

Rotor q-axis damper winding 2 resistance, R2q

Rotor q-axis damper winding 2 resistance. The default value is 0.02368 pu.

Saturation Tab

Magnetic saturation representation

Block magnetic saturation representation. Options are:

- None
- Per-unit open-circuit lookup table (Vag versus ifd)

The default value is None.

Per-unit field current saturation data, ifd

The field current, i_{fd}, data populates the air-gap voltage, V_{ag}, versus field current, i_{fd}, lookup table. This parameter is only visible when you set **Magnetic saturation representation** to Per-unit open-circuit lookup table (Vag versus ifd). This parameter must contain a vector with at least five elements. The default value is [0.00, 0.48, 0.76, 1.38, 1.79] pu.

Per-unit air-gap voltage saturation data, Vag

The air-gap voltage, V_{ag}, data populates the air-gap voltage, V_{ag}, versus field current, i_{fd}, lookup table. This parameter is only visible when you set **Magnetic saturation representation** to Per-unit open-circuit lookup table (Vag versus ifd). This parameter must contain a vector with at least five elements. The default value is [0.00, 0.80, 1.08, 1.31, 1.40] pu.

Initial Conditions Tab

Specify initialization by

Select between Electrical power and voltage output and Mechanical and magnetic states. The default value is Electrical power and voltage output.

Terminal voltage magnitude

Initial RMS line-line voltage. This parameter is visible only when you set **Specify initialization by** to Electrical power and voltage output. The default value is 24e3 V.

Terminal voltage angle

Initial voltage angle. This parameter is visible only when you set **Specify initialization by** to Electrical power and voltage output. The default value is 0 deg.

Terminal active power

Initial active power. This parameter is visible only when you set **Specify initialization by** to Electrical power and voltage output. The default value is 500e6 V*A.

Terminal reactive power

Initial reactive power. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `0 V*A`.

Initial rotor angle

Initial rotor angle. During steady-state operation, set this parameter to the sum of the load angle and required terminal voltage offset. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 deg`.

Initial stator d-axis magnetic flux linkage

Stator *d*-axis initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial stator q-axis magnetic flux linkage

Stator *q*-axis initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial stator zero-sequence magnetic flux linkage

Zero-sequence initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial field circuit magnetic flux linkage

Field circuit initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial d-axis damper winding 1 magnetic flux linkage

The *d*-axis damper winding 1 initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial q-axis damper winding 1 magnetic flux linkage

The *q*-axis damper winding 1 initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial q-axis damper winding 2 magnetic flux linkage

The *q*-axis damper winding 2 initial flux linkage. This parameter is visible only when you set **Specify initialization by** to Mechanical and magnetic states. The default value is 0 pu.

Ports

The block has the following ports:

fd+

    Electrical conserving port corresponding to the field winding positive terminal

fd-

    Electrical conserving port corresponding to the field winding negative terminal

R

    Mechanical rotational conserving port associated with the machine rotor

C

    Mechanical rotational conserving port associated with the machine case

pu

    Physical signal vector port associated with the machine per-unit measurements. The vector elements are:

- pu_fd_Efd
- pu_fd_Ifd
- pu_torque
- pu_velocity
- pu_ed
- pu_eq
- pu_e0
- pu_id
- pu_iq
- pu_i0

~

    Expandable three-phase port associated with the stator windings

n

Electrical conserving port associated with the neutral point of the wye winding configuration

References

[1] Kundur, P. *Power System Stability and Control.* New York, NY: McGraw Hill, 1993.

[2] Lyshevski, S. E. *Electromechanical Systems, Electric Machines and Applied Mechatronics.* Boca Raton, FL: CRC Press, 1999.

See Also

See Also

Synchronous Machine Measurement | Synchronous Machine Model 2.1 (fundamental) | Synchronous Machine Model 2.1 (standard) | Synchronous Machine Round Rotor (standard) | Synchronous Machine Salient Pole (fundamental) | Synchronous Machine Salient Pole (standard)

Topics
"Expand and Collapse Three-Phase Ports on a Block"
Three-Phase Synchronous Machine Control

Introduced in R2013b

Synchronous Machine Round Rotor (standard)

Round-rotor synchronous machine with standard parameterization
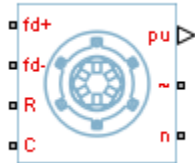
Library

Machines / Synchronous Machine (Round Rotor)

Description

The Synchronous Machine Round Rotor (standard) block models a round-rotor synchronous machine using standard parameters.

Electrical Defining Equations

The synchronous machine equations are expressed with respect to a rotating reference frame defined by the equation

$$\theta_e(t) = N\theta_r(t),$$

where:

- θ_e is the electrical angle.
- N is the number of pole pairs.
- θ_r is the rotor angle.

Park's transformation maps the synchronous machine equations to the rotating reference frame with respect to the electrical angle. Park's transformation is defined by

$$P_s = \frac{2}{3} \begin{bmatrix} \cos\theta_e & \cos(\theta_e - \frac{2\pi}{3}) & \cos(\theta_e + \frac{2\pi}{3}) \\ -\sin\theta_e & -\sin(\theta_e - \frac{2\pi}{3}) & -\sin(\theta_e + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}.$$

Park's transformation is used to define the per-unit synchronous machine equations. The stator voltage equations are defined by

$$e_d = \frac{1}{\omega_{base}} \frac{d\psi_d}{dt} - \Psi_q \omega_r - R_a i_d,$$

$$e_q = \frac{1}{\omega_{base}} \frac{d\psi_q}{dt} + \Psi_d \omega_r - R_a i_q,$$

and

$$e_0 = \frac{1}{\omega_{base}} \frac{d\Psi_0}{dt} - R_a i_0,$$

where:

- e_d, e_q, and e_0 are the d-axis, q-axis, and zero-sequence stator voltages, defined by

$$\begin{bmatrix} e_d \\ e_q \\ e_0 \end{bmatrix} = P_s \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}.$$

  where v_a, v_b, and v_c are the stator voltages measured from port ~ to neutral port n.

- ω_{base} is the per-unit base electrical speed.

- ψ_d, ψ_q, and ψ_0 are the d-axis, q-axis, and zero-sequence stator flux linkages.

- ω_r is the per-unit rotor rotational speed.

- R_a is the stator resistance.

- i_d, i_q, and i_0 are the d-axis, q-axis, and zero-sequence stator currents, defined by

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = P_s \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}.$$

where i_a, i_b, and i_c are the stator currents flowing from port ~ to port n.

The rotor voltage equations are defined by

$$e_{fd} = \frac{1}{\omega_{base}} \frac{d\Psi_{fd}}{dt} + R_{fd} i_{fd},$$

$$e_{1d} = \frac{1}{\omega_{base}} \frac{d\Psi_{1d}}{dt} + R_{1d} i_{1d} = 0,$$

$$e_{1q} = \frac{1}{\omega_{base}} \frac{d\Psi_{1q}}{dt} + R_{1q} i_{1q} = 0,$$

and

$$e_{2q} = \frac{1}{\omega_{base}} \frac{d\Psi_{2q}}{dt} + R_{2q} i_{2q} = 0,$$

where:

- e_{fd} is the field voltage.
- e_{1d}, e_{1q}, and e_{2q} are the voltages across the d-axis damper winding 1, q-axis damper winding 1, and q-axis damper winding 2. They are all equal to 0.
- ψ_{fd}, ψ_{1d}, ψ_{1q}, and ψ_{2q} are the magnetic fluxes linking the field circuit, d-axis damper winding 1, q-axis damper winding 1, and q-axis damper winding 2.
- R_{fd}, R_{1d}, R_{1q}, and R_{2q} are the resistances of rotor field circuit, d-axis damper winding 1, q-axis damper winding 1, and q-axis damper winding 2.
- i_{fd}, i_{1d}, i_{1q}, and i_{2q} are the currents flowing in the field circuit, d-axis damper winding 1, q-axis damper winding 1, and q-axis damper winding 2.

The saturation equations are defined by

$$\psi_{ad} = \psi_d + L_l i_d,$$

$$\psi_{aq} = \psi_q + L_l i_q,$$

$$\psi_{at} = \sqrt{\psi_{ad}^2 + \psi_{aq}^2},$$

$K_s = 1$ (If saturation is disabled),

$K_s = f(\psi_{at})$ (If saturation is enabled),

$$L_{ad} = K_s * L_{adu},$$

and

$$L_{aq} = K_s * L_{aqu},$$

where:

- ψ_{ad} is the d-axis air-gap or mutual flux linkage.
- ψ_{aq} is the q-axis air-gap or mutual flux linkage.
- ψ_{at} is the air-gap flux linkage.
- K_s is the saturation factor.
- L_{adu} is the unsaturated mutual inductance of the stator d-axis.
- L_{ad} is the mutual inductance of the stator d-axis.
- L_{aqu} is the unsaturated mutual inductance of the stator q-axis.
- L_{aq} is the mutual inductance of the stator q-axis.

The saturation factor function, f, is calculated from the per-unit open-circuit lookup table as:

$$L_{ad} = \frac{d\psi_{at}}{di_{fd}},$$

$$V_{ag} = g(i_{fd}),$$

and

$$L_{ad} = \frac{dg(i_{fd})}{di_{fd}} = \frac{dV_{ag}}{di_{fd}},$$

where V_{ag} is the per-unit air-gap voltage.

In per-unit,

$$K_s = \frac{L_{ad}}{L_{adu}},$$

and

$$\psi_{at} = V_{ag}$$

can be rearranged to

$$K_s = f(\psi_{at}).$$

The stator flux linkage equations are defined by

$$\Psi_d = -(L_{ad} + L_l)i_d + L_{ad}i_{fd} + L_{ad}i_{1d},$$

$$\Psi_q = -(L_{aq} + L_l)i_q + L_{aq}i_{1q} + L_{aq}i_{2q},$$

and

$$\Psi_0 = -L_0 i_0,$$

where:

- L_l is the stator leakage inductance.
- L_{ad} and L_{aq} are the mutual inductances of the stator d-axis and q-axis.

The rotor flux linkage equations are defined by

$$\psi_{fd} = L_{ffd}i_{fd} + L_{f1d}i_{1d} - L_{ad}i_d,$$

$$\psi_{1d} = L_{f1d}i_{fd} + L_{11d}i_{1d} - L_{ad}i_d,$$

$$\psi_{1q} = L_{11q}i_{1q} + L_{aq}i_{2q} - L_{aq}i_q,$$

and

$$\psi_{2q} = L_{aq}i_{1q} + L_{22q}i_{2q} - L_{aq}i_q,$$

where:

* L_{ffd}, L_{11d}, L_{11q}, and L_{22q} are the self-inductances of the rotor field circuit, d-axis damper winding 1, q-axis damper winding 1, and q-axis damper winding 2. L_{f1d} is the rotor field circuit and d-axis damper winding 1 mutual inductance. They are defined by the following equations.

$$L_{ffd} = L_{ad} + L_{fd}$$

$$L_{f1d} = L_{ffd} - L_{fd}$$

$$L_{11d} = L_{f1d} + L_{1d}$$

$$L_{11q} = L_{aq} + L_{1q}$$

$$L_{22q} = L_{aq} + L_{2q}$$

These equations assume that per-unit mutual inductance $L_{12q} = L_{aq}$, that is, the stator and rotor currents in the q-axis all link a single mutual flux represented by L_{aq}.

The rotor torque is defined by

$$T_e = \Psi_d i_q - \Psi_q i_d.$$

These defining equations do not describe the time constants you can set in the dialog box. To see their relationship with the equation coefficients, see [1].

Plotting and Display Options

You can perform plotting and display actions using the **Power Systems** menu on the block context menu.

Right-click the block and, from the **Power Systems** menu, select an option:

- **Display Base Values** displays the machine per-unit base values in the MATLAB Command Window.
- **Display Associated Base Values** displays associated per-unit base values in the MATLAB Command Window.
- **Display Associated Initial Conditions** displays associated initial conditions in the MATLAB Command Window.
- **Plot Open-Circuit Saturation (pu)** plots air-gap voltage, V_{ag}, versus field current, i_{fd}, both measured in per-unit, in a MATLAB figure window. The plot contains three traces:

  - Unsaturated: **Stator d-axis mutual inductance (unsaturated), Ladu** you specify
  - Saturated: **Per-unit open-circuit lookup table (Vag versus ifd)** you specify
  - Derived: Open-circuit lookup table (per-unit) derived from the **Per-unit open-circuit lookup table (Vag versus ifd)** you specify. This data is used to calculate the saturation factor, K_s, versus magnetic flux linkage, ψ_{at}, characteristic.

- **Plot Saturation Factor (pu)** plots saturation factor, K_s, versus magnetic flux linkage, ψ_{at}, both measured in per-unit, in a MATLAB figure window using the present machine parameters. This parameter is derived from other parameters that you specify:

  - **Stator d-axis mutual inductance (unsaturated), Ladu**
  - **Per-unit field current saturation data, ifd**
  - **Per-unit air-gap voltage saturation data, Vag**

Parameters

Main Tab

Rated apparent power

Rated apparent power. The default value is `555e6 V*A`.

Rated voltage

RMS rated line-line voltage. The default value is `24e3 V`.

Rated electrical frequency

Nominal electrical frequency at which rated apparent power is quoted. The default value is `60 Hz`.

Number of pole pairs

Number of machine pole pairs. The default value is `1`.

Specify field circuit input required to produce rated terminal voltage at no load by

Choose between `Field circuit voltage` and `Field circuit current`. The default value is `Field circuit current`.

Field circuit current

This parameter is visible only when **Specify field circuit input required to produce rated terminal voltage at no load by** is set to `Field circuit current`. The default value is `1300 A`.

Field circuit voltage

This parameter is visible only when **Specify field circuit input required to produce rated terminal voltage at no load by** is set to `Field circuit voltage`. The default value is `92.95 V`.

Impedances Tab

Stator resistance, Ra

Stator resistance. The default value is `0.003` pu.

Stator leakage reactance, Xl

Stator leakage reactance. The default value is `0.15` pu.

d-axis synchronous reactance, Xd

The *d*-axis synchronous reactance. The default value is `1.81` pu.

q-axis synchronous reactance, Xq

The *q*-axis synchronous reactance. The default value is `1.76` pu.

zero-sequence reactance, X0

The zero-sequence reactance. The default value is `0.15` pu.

d-axis transient reactance, Xd'

The *d*-axis transient reactance. The default value is `0.3` pu.

q-axis transient reactance, Xq'

The *q*-axis transient reactance. The default value is `0` pu.

d-axis subtransient reactance, Xd"

The *d*-axis subtransient reactance. The default value is `0.23` pu.

q-axis subtransient reactance, Xq"

The *q*-axis subtransient reactance. The default value is `0.25` pu.

Time Constants Tab

Specify d-axis transient time constant

Select between `Open-circuit value` and `Short-circuit value`. The default value is `Open-circuit value`.

d-axis transient open-circuit, Td0'

The *d*-axis transient open-circuit time constant. This parameter is visible only when **Specify d-axis transient time constant** is set to `Open-circuit value`. The default value is `8 s`.

d-axis transient short-circuit, Td'

The *d*-axis transient short-circuit time constant. This parameter is visible only when **Specify d-axis transient time constant** is set to `Short-circuit value`. The default value is `1.326 s`.

Specify d-axis subtransient time constant

Select between `Open-circuit value` and `Short-circuit value`. The default value is `Open-circuit value`.

d-axis subtransient open-circuit, Td0"

The *d*-axis subtransient open-circuit time constant. This parameter is visible only when **Specify d-axis subtransient time constant** is set to `Open-circuit value`. The default value is `0.03 s`.

d-axis subtransient short-circuit, Td"

The *d*-axis subtransient short-circuit time constant. This parameter is visible only when **Specify d-axis subtransient time constant** is set to `Short-circuit value`. The default value is `0.023 s`.

Specify q-axis transient time constant

Select between `Open-circuit value` and `Short-circuit value`. The default value is `Open-circuit value`.

q-axis transient open-circuit, Tq0'

The *q*-axis transient open-circuit time constant. This parameter is visible only when **Specify q-axis transient time constant** is set to `Open-circuit value`. The default value is `1 s`.

q-axis transient short-circuit, Tq'

The *q*-axis transient short-circuit time constant. This parameter is visible only when **Specify q-axis transient time constant** is set to `Short-circuit value`. The default value is `0.3693 s`.

Specify q-axis subtransient time constant

Select between `Open-circuit value` and `Short-circuit value`. The default value is `Open-circuit value`.

q-axis subtransient open-circuit, Tq0"

The *q*-axis subtransient open-circuit time constant. This parameter is visible only when **Specify q-axis subtransient time constant** is set to `Open-circuit value`. The default value is `0.07 s`.

q-axis subtransient short-circuit, Tq"

The *q*-axis subtransient short-circuit time constant. This parameter is visible only when **Specify q-axis subtransient time constant** is set to `Short-circuit value`. The default value is `0.0269 s`.

Saturation Tab

Magnetic saturation representation

Block magnetic saturation representation. Options are:

- `None`
- `Per-unit open-circuit lookup table (Vag versus ifd)`

The default value is `None`.

Per-unit field current saturation data, ifd

The field current, i_{fd}, data populates the air-gap voltage, V_{ag}, versus field current, i_{fd}, lookup table. This parameter is only visible when you set **Magnetic saturation representation** to `Per-unit open-circuit lookup table (Vag versus ifd)`. This parameter must contain a vector with at least five elements. The default value is `[0.00, 0.48, 0.76, 1.38, 1.79]` pu.

Per-unit air-gap voltage saturation data, Vag

The air-gap voltage, V_{ag}, data populates the air-gap voltage, V_{ag}, versus field current, i_{fd}, lookup table. This parameter is only visible when you set **Magnetic saturation representation** to `Per-unit open-circuit lookup table (Vag versus ifd)`. This parameter must contain a vector with at least five elements. The default value is `[0.00, 0.80, 1.08, 1.31, 1.40]` pu.

Initial Conditions Tab

Specify initialization by

Select between `Electrical power and voltage output` and `Mechanical and magnetic states`. The default value is `Electrical power and voltage output`.

Terminal voltage magnitude

Initial RMS line-line voltage. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `24e3` V.

Terminal voltage angle

Initial voltage angle. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `0 deg`.

Terminal active power

Initial active power. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `500e6 V*A`.

Terminal reactive power

Initial reactive power. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `0 V*A`.

Initial rotor angle

Initial rotor angle. During steady-state operation, set this parameter to the sum of the load angle and required terminal voltage offset. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 deg`.

Initial stator d-axis magnetic flux linkage

Stator d-axis initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial stator q-axis magnetic flux linkage

Stator q-axis initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial stator zero-sequence magnetic flux linkage

Zero-sequence initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial field circuit magnetic flux linkage

Field circuit initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial d-axis damper winding 1 magnetic flux linkage

The d-axis damper winding 1 initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial q-axis damper winding 1 magnetic flux linkage

The q-axis damper winding 1 initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial q-axis damper winding 2 magnetic flux linkage

The *q*-axis damper winding 2 initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0` pu.

Ports

The block has the following ports:

`fd+`

Electrical conserving port corresponding to the field winding positive terminal

`fd-`

Electrical conserving port corresponding to the field winding negative terminal

`R`

Mechanical rotational conserving port associated with the machine rotor

`C`

Mechanical rotational conserving port associated with the machine case

`pu`

Physical signal vector port associated with the machine per-unit measurements. The vector elements are:

- `pu_fd_Efd`
- `pu_fd_Ifd`
- `pu_torque`
- `pu_velocity`
- `pu_ed`
- `pu_eq`
- `pu_e0`
- `pu_id`
- `pu_iq`
- `pu_i0`

`~`

Expandable three-phase port associated with the stator windings

n

    Electrical conserving port associated with the neutral point of the wye winding configuration

References

[1] Kundur, P. *Power System Stability and Control.* New York, NY: McGraw Hill, 1993.

[2] Lyshevski, S. E. *Electromechanical Systems, Electric Machines and Applied Mechatronics.* Boca Raton, FL: CRC Press, 1999.

See Also

See Also

Synchronous Machine Measurement | Synchronous Machine Model 2.1 (fundamental) | Synchronous Machine Model 2.1 (standard) | Synchronous Machine Round Rotor (fundamental) | Synchronous Machine Salient Pole (fundamental) | Synchronous Machine Salient Pole (standard)

Topics

"Expand and Collapse Three-Phase Ports on a Block"
Three-Phase Synchronous Machine Control

Introduced in R2013b

Synchronous Machine Salient Pole (fundamental)

Salient-pole synchronous machine with fundamental parameterization

Library

Machines / Synchronous Machine (Salient Pole)

Description

The Synchronous Machine Salient Pole (fundamental) block models a salient-pole synchronous machine using fundamental parameters.

Electrical Defining Equations

The synchronous machine equations are expressed with respect to a rotating reference frame defined by the equation

$$\theta_e(t) = N\theta_r(t),$$

where:

- θ_e is the electrical angle.
- N is the number of pole pairs.
- θ_r is the rotor angle.

Park's transformation maps the synchronous machine equations to the rotating reference frame with respect to the electrical angle. Park's transformation is defined by

$$
P_s = \frac{2}{3}
\begin{bmatrix}
\cos\theta_e & \cos(\theta_e - \frac{2\pi}{3}) & \cos(\theta_e + \frac{2\pi}{3}) \\
-\sin\theta_e & -\sin(\theta_e - \frac{2\pi}{3}) & -\sin(\theta_e + \frac{2\pi}{3}) \\
\frac{1}{2} & \frac{1}{2} & \frac{1}{2}
\end{bmatrix}.
$$

Park's transformation is used to define the per-unit synchronous machine equations. The stator voltage equations are defined by

$$
e_d = \frac{1}{\omega_{base}} \frac{d\psi_d}{dt} - \Psi_q \omega_r - R_a i_d,
$$

$$
e_q = \frac{1}{\omega_{base}} \frac{d\psi_q}{dt} + \Psi_d \omega_r - R_a i_q,
$$

and

$$
e_0 = \frac{1}{\omega_{base}} \frac{d\Psi_0}{dt} - R_a i_0,
$$

where:

- e_d, e_q, and e_0 are the d-axis, q-axis, and zero-sequence stator voltages, defined by

$$
\begin{bmatrix}
e_d \\
e_q \\
e_0
\end{bmatrix}
= P_s
\begin{bmatrix}
v_a \\
v_b \\
v_c
\end{bmatrix}.
$$

  v_a, v_b, and v_c are the stator voltages measured from port ~ to neutral port n.
- ω_{base} is the per-unit base electrical speed.
- ψ_d, ψ_q, and ψ_0 are the d-axis, q-axis, and zero-sequence stator flux linkages.
- ω_r is the per-unit rotor rotational speed.
- R_a is the stator resistance.

- i_d, i_q, and i_0 are the d-axis, q-axis, and zero-sequence stator currents, defined by

$$
\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = P_s \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}.
$$

i_a, i_b, and i_c are the stator currents flowing from port ~ to port n.

The rotor voltage equations are defined by

$$
e_{fd} = \frac{1}{\omega_{base}} \frac{d\Psi_{fd}}{dt} + R_{fd} i_{fd},
$$

$$
e_{1d} = \frac{1}{\omega_{base}} \frac{d\Psi_{1d}}{dt} + R_{1d} i_{1d} = 0,
$$

and

$$
e_{1q} = \frac{1}{\omega_{base}} \frac{d\Psi_{1q}}{dt} + R_{1q} i_{1q} = 0,
$$

where:

- e_{fd} is the field voltage.
- e_{1d}, and e_{1q} are the voltages across the d-axis damper winding 1 and q-axis damper winding 1. They are equal to 0.
- ψ_{fd}, ψ_{1d}, and ψ_{1q} are the magnetic fluxes linking the field circuit, d-axis damper winding 1, and q-axis damper winding 1.
- R_{fd}, R_{1d}, and R_{1q} are the resistances of rotor field circuit, d-axis damper winding 1, and q-axis damper winding 1.
- i_{fd}, i_{1d}, and i_{1q} are the currents flowing in the field circuit, d-axis damper winding 1, and q-axis damper winding 1.

The saturation equations are defined by

$$
\psi_{ad} = \psi_d + L_l i_d,
$$

$$\psi_{aq} = \psi_q + L_l i_q,$$

$$\psi_{at} = \sqrt{\psi_{ad}^2 + \psi_{aq}^2},$$

$K_s = 1$ (If saturation is disabled),

$K_s = f(\psi_{at})$ (If saturation is enabled),

and

$$L_{ad} = K_s * L_{adu},$$

where:

- ψ_{ad} is the d-axis air-gap or mutual flux linkage.
- ψ_{aq} is the q-axis air-gap or mutual flux linkage.
- ψ_{at} is the air-gap flux linkage.
- K_s is the saturation factor.
- L_{adu} is the unsaturated mutual inductance of the stator d-axis.
- L_{ad} is the mutual inductance of the stator d-axis.

The saturation factor function, f, is calculated from the per-unit open-circuit lookup table as:

$$L_{ad} = \frac{d\psi_{at}}{di_{fd}},$$

$$V_{ag} = g(i_{fd}),$$

and

$$L_{ad} = \frac{dg(i_{fd})}{di_{fd}} = \frac{dV_{ag}}{di_{fd}},$$

where:

- V_{ag} is the per-unit air-gap voltage.

In per-unit,

$$K_s = \frac{L_{ad}}{L_{adu}},$$

and

$$\psi_{at} = V_{ag}$$

can be rearranged to

$$K_s = f(\psi_{at}).$$

The stator flux linkage equations are defined by

$$\Psi_d = -(L_{ad} + L_l)i_d + L_{ad}i_{fd} + L_{ad}i_{1d},$$

$$\Psi_q = -(L_{aq} + L_l)i_q + L_{aq}i_{1q},$$

and

$$\Psi_0 = -L_0 i_0,$$

where:

- L_l is the stator leakage inductance.
- L_{ad} and L_{aq} are the mutual inductances of the stator d-axis and q-axis.

The rotor flux linkage equations are defined by

$$\psi_{fd} = L_{ffd}i_{fd} + L_{f1d}i_{1d} - L_{ad}i_d,$$

$$\psi_{1d} = L_{f1d}\, i_{fd} + L_{11d}\, i_{1d} - L_{ad}\, i_d\,,$$

and

$$\psi_{1q} = L_{11q}\, i_{1q} - L_{aq}\, i_q\,,$$

where:

- L_{ffd}, L_{11d}, and L_{11q} are the self-inductances of the rotor field circuit, d-axis damper winding 1, and q-axis damper winding 1. L_{f1d} is the rotor field circuit and d-axis damper winding 1 mutual inductance. They are defined by the following equations.

$$L_{ffd} = L_{ad} + L_{fd}$$

$$L_{f1d} = L_{ffd} - L_{fd}$$

$$L_{11d} = L_{f1d} + L_{1d}$$

$$L_{11q} = L_{aq} + L_{1q}$$

These equations assume that per-unit mutual inductance $L_{12q} = L_{aq}$, that is, the stator and rotor currents in the q-axis all link a single mutual flux represented by L_{aq}.

The rotor torque is defined by

$$T_e = \Psi_d\, i_q - \Psi_q\, i_d\,.$$

Plotting and Display Options

You can perform plotting and display actions using the **Power Systems** menu on the block context menu.

Right-click the block and, from the **Power Systems** menu, select an option:

- **Display Base Values** displays the machine per-unit base values in the MATLAB Command Window.

- **Display Associated Base Values** displays associated per-unit base values in the MATLAB Command Window.
- **Display Associated Initial Conditions** displays associated initial conditions in the MATLAB Command Window.
- **Plot Open-Circuit Saturation (pu)** plots air-gap voltage, V_{ag}, versus field current, i_{fd}, both measured in per-unit, in a MATLAB figure window. The plot contains three traces:

    - Unsaturated: **Stator d-axis mutual inductance (unsaturated), Ladu** you specify
    - Saturated: **Per-unit open-circuit lookup table (Vag versus ifd)** you specify
    - Derived: Open-circuit lookup table (per-unit) derived from the **Per-unit open-circuit lookup table (Vag versus ifd)** you specify. This data is used to calculate the saturation factor, K_s, versus magnetic flux linkage, ψ_{at}, characteristic.

- **Plot Saturation Factor (pu)** plots saturation factor, K_s, versus magnetic flux linkage, ψ_{at}, both measured in per-unit, in a MATLAB figure window using the present machine parameters. This parameter is derived from other parameters that you specify:

    - **Stator d-axis mutual inductance (unsaturated), Ladu**
    - **Per-unit field current saturation data, ifd**
    - **Per-unit air-gap voltage saturation data, Vag**

Parameters

- "Main Tab" on page 1-372
- "Impedances Tab" on page 1-373
- "Saturation Tab" on page 1-374
- "Initial Conditions Tab" on page 1-375

Main Tab

Rated apparent power

Rated apparent power. The default value is 300e6 V*A.

Rated voltage

RMS rated line-line voltage. The default value is `24e3` V.

Rated electrical frequency

Nominal electrical frequency at which rated apparent power is quoted. The default value is `60 Hz`.

Number of pole pairs

Number of machine pole pairs. The default value is `10`.

Specify field circuit input required to produce rated terminal voltage at no load by

Choose between `Field circuit voltage` and `Field circuit current`. The default value is `Field circuit current`.

Field circuit current

This parameter is visible only when **Specify field circuit input required to produce rated terminal voltage at no load by** is set to `Field circuit current`. The default value is `1000 A`.

Field circuit voltage

This parameter is visible only when **Specify field circuit input required to produce rated terminal voltage at no load by** is set to `Field circuit voltage`. The default value is `216.54` V.

Impedances Tab

Stator d-axis mutual inductance (unsaturated), Ladu

Unsaturated stator d-axis mutual inductance, L_{adu}. If **Magnetic saturation representation** is set to `None`, this is equivalent to the stator d-axis mutual inductance, L_{ad}. The default value is `0.9` pu.

Stator q-axis mutual inductance, Laq

Stator q-axis mutual inductance, Laq. The default value is `0.55` pu.

Stator zero-sequence inductance, L0

Stator zero-sequence inductance, L0. The default value is `0.15` pu.

Stator leakage inductance, Ll

Stator leakage inductance. The default value is `0.15` pu.

Stator resistance, Ra

Stator resistance. The default value is `0.011` pu.

Rotor field circuit inductance, Lfd

Rotor field circuit inductance. The default value is `0.2571` pu.

Rotor field circuit resistance, Rfd

Rotor field circuit resistance. The default value is `0.0006` pu.

Rotor d-axis damper winding 1 inductance, L1d

Rotor d-axis damper winding 1 inductance. The default value is `0.2` pu.

Rotor d-axis damper winding 1 resistance, R1d

Rotor d-axis damper winding 1 resistance. The default value is `0.0354` pu.

Rotor q-axis damper winding 1 inductance, L1q

Rotor q-axis damper winding 1 inductance. The default value is `0.2567` pu.

Rotor q-axis damper winding 1 resistance, R1q

Rotor q-axis damper winding 1 resistance. The default value is `0.0428` pu.

Saturation Tab

Magnetic saturation representation

Block magnetic saturation representation. Options are:

- `None`
- `Per-unit open-circuit lookup table (Vag versus ifd)`

The default value is `None`.

Per-unit field current saturation data, ifd

The field current, i_{fd}, data populates the air-gap voltage, V_{ag}, versus field current, i_{fd}, lookup table. This parameter is only visible when you set **Magnetic saturation representation** to `Per-unit open-circuit lookup table (Vag versus ifd)`. This parameter must contain a vector with at least five elements. The default value is `[0.00, 0.48, 0.76, 1.38, 1.79]` pu.

Per-unit air-gap voltage saturation data, Vag

The air-gap voltage, V_{ag}, data populates the air-gap voltage, V_{ag}, versus field current, i_{fd}, lookup table. This parameter is only visible when you set **Magnetic saturation representation** to `Per-unit open-circuit lookup table (Vag versus ifd)`. This parameter must contain a vector with at least five elements. The default value is `[0.00 0.43 0.59 0.71 0.76]` pu.

Initial Conditions Tab

Specify initialization by

Select between `Electrical power and voltage output` and `Mechanical and magnetic states`. The default value is `Electrical power and voltage output`.

Terminal voltage magnitude

Initial RMS line-line voltage. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `24e3 V`.

Terminal voltage angle

Initial voltage angle. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `0 deg`.

Terminal active power

Initial active power. This parameter is visible only when **Specify initialization by** is set to `Electrical power and voltage output`. The default value is `270e6 V*A`.

Terminal reactive power

Initial reactive power. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `0 V*A`.

Initial rotor angle

Initial rotor angle. During steady-state operation, set this parameter to the sum of the load angle and required terminal voltage offset. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 deg`.

Initial stator d-axis magnetic flux linkage

Stator d-axis initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial stator q-axis magnetic flux linkage

Stator q-axis initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial stator zero-sequence magnetic flux linkage

Zero-sequence initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0` pu.

Initial field circuit magnetic flux linkage

Field circuit initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0` pu.

Initial d-axis damper winding 1 magnetic flux linkage

The *d*-axis damper winding 1 initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0` pu.

Initial q-axis damper winding 1 magnetic flux linkage

The *q*-axis damper winding 1 initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0` pu.

Initial q-axis damper winding 2 magnetic flux linkage

The *q*-axis damper winding 2 initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0` pu.

Ports

The block has the following ports:

`fd+`

Electrical conserving port corresponding to the field winding positive terminal

`fd-`

Electrical conserving port corresponding to the field winding negative terminal

`R`

Mechanical rotational conserving port associated with the machine rotor

`C`

Mechanical rotational conserving port associated with the machine case

pu

> Physical signal vector port associated with the machine per-unit measurements. The vector elements are:
>
> - pu_fd_Efd
> - pu_fd_Ifd
> - pu_torque
> - pu_velocity
> - pu_ed
> - pu_eq
> - pu_e0
> - pu_id
> - pu_iq
> - pu_i0

~

> Expandable three-phase port associated with the stator windings

n

> Electrical conserving port associated with the neutral point of the wye winding configuration

References

[1] Kundur, P. *Power System Stability and Control.* New York, NY: McGraw Hill, 1993.

[2] Lyshevski, S. E. *Electromechanical Systems, Electric Machines and Applied Mechatronics.* Boca Raton, FL: CRC Press, 1999.

See Also

See Also
Synchronous Machine Measurement | Synchronous Machine Model 2.1 (fundamental) | Synchronous Machine Model 2.1 (standard) | Synchronous

`Machine Round Rotor (fundamental)` | `Synchronous Machine Round Rotor (standard)` | `Synchronous Machine Salient Pole (standard)`

Topics

"Expand and Collapse Three-Phase Ports on a Block"
Three-Phase Synchronous Machine Control

Introduced in R2013b

Synchronous Machine Salient Pole (standard)

Salient-pole synchronous machine with standard parameterization
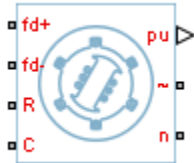
Library

Machines / Synchronous Machine (Salient Pole)

Description

The Synchronous Machine Salient Pole (standard) block models a salient-pole synchronous machine n using standard parameters.

Electrical Defining Equations

The synchronous machine equations are expressed with respect to a rotating reference frame defined by the equation

$$\theta_e(t) = N\theta_r(t),$$

where:

- θ_e is the electrical angle.
- N is the number of pole pairs.
- θ_r is the rotor angle.

Park's transformation maps the synchronous machine equations to the rotating reference frame with respect to the electrical angle. Park's transformation is defined by

$$P_s = \frac{2}{3} \begin{bmatrix} \cos\theta_e & \cos(\theta_e - \frac{2\pi}{3}) & \cos(\theta_e + \frac{2\pi}{3}) \\ -\sin\theta_e & -\sin(\theta_e - \frac{2\pi}{3}) & -\sin(\theta_e + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}.$$

Park's transformation is used to define the per-unit synchronous machine equations. The stator voltage equations are defined by

$$e_d = \frac{1}{\omega_{base}} \frac{d\psi_d}{dt} - \Psi_q \omega_r - R_a i_d,$$

$$e_q = \frac{1}{\omega_{base}} \frac{d\psi_q}{dt} + \Psi_d \omega_r - R_a i_q,$$

and

$$e_0 = \frac{1}{\omega_{base}} \frac{d\Psi_0}{dt} - R_a i_0,$$

where:

- e_d, e_q, and e_0 are the d-axis, q-axis, and zero-sequence stator voltages, defined by

$$\begin{bmatrix} e_d \\ e_q \\ e_0 \end{bmatrix} = P_s \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}.$$

  v_a, v_b, and v_c are the stator voltages measured from port ~ to neutral port n.
- ω_{base} is the per-unit base electrical speed.
- ψ_d, ψ_q, and ψ_0 are the d-axis, q-axis, and zero-sequence stator flux linkages.
- ω_r is the per-unit rotor rotational speed.
- R_a is the stator resistance.

- i_d, i_q, and i_0 are the d-axis, q-axis, and zero-sequence stator currents, defined by

$$
\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = P_s \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}.
$$

i_a, i_b, and i_c are the stator currents flowing from port ~ to port n.

The rotor voltage equations are defined by

$$
e_{fd} = \frac{1}{\omega_{base}} \frac{d\Psi_{fd}}{dt} + R_{fd} i_{fd},
$$

$$
e_{1d} = \frac{1}{\omega_{base}} \frac{d\Psi_{1d}}{dt} + R_{1d} i_{1d} = 0,
$$

and

$$
e_{1q} = \frac{1}{\omega_{base}} \frac{d\Psi_{1q}}{dt} + R_{1q} i_{1q} = 0,
$$

where:

- e_{fd} is the field voltage.
- e_{1d}, and e_{1q} are the voltages across the d-axis damper winding 1 and q-axis damper winding 1. They are equal to 0.
- ψ_{fd}, ψ_{1d}, and ψ_{1q}, are the magnetic fluxes linking the field circuit, d-axis damper winding 1, and q-axis damper winding 1.
- R_{fd}, R_{1d}, and R_{1q} are the resistances of rotor field circuit, d-axis damper winding 1, and q-axis damper winding 1.
- i_{fd}, i_{1d}, and i_{1q} are the currents flowing in the field circuit, d-axis damper winding 1, and q-axis damper winding 1.

The saturation equations are defined by

$$
\psi_{ad} = \psi_d + L_l i_d,
$$

$$\psi_{aq} = \psi_q + L_l i_q,$$

$$\psi_{at} = \sqrt{\psi_{ad}^2 + \psi_{aq}^2},$$

$K_s = 1$ (If saturation is disabled),

$K_s = f(\psi_{at})$ (If saturation is enabled),

and

$$L_{ad} = K_s * L_{adu},$$

where:

- ψ_{ad} is the d-axis air-gap or mutual flux linkage.
- ψ_{aq} is the q-axis air-gap or mutual flux linkage.
- ψ_{at} is the air-gap flux linkage.
- K_s is the saturation factor.
- L_{adu} is the unsaturated mutual inductance of the stator d-axis.
- L_{ad} is the mutual inductance of the stator d-axis.

The saturation factor function, f, is calculated from the per-unit open-circuit lookup table as:

$$L_{ad} = \frac{d\psi_{at}}{di_{fd}},$$

$$V_{ag} = g(i_{fd}),$$

and

$$L_{ad} = \frac{dg(i_{fd})}{di_{fd}} = \frac{dV_{ag}}{di_{fd}},$$

where:

- V_{ag} is the per-unit air-gap voltage.

In per-unit,

$$K_s = \frac{L_{ad}}{L_{adu}},$$

and

$$\psi_{at} = V_{ag}$$

can be rearranged to

$$K_s = f(\psi_{at}).$$

The stator flux linkage equations are defined by

$$\Psi_d = -(L_{ad} + L_l)i_d + L_{ad}i_{fd} + L_{ad}i_{1d},$$

$$\Psi_q = -(L_{aq} + L_l)i_q + L_{aq}i_{1q},$$

and

$$\Psi_0 = -L_0 i_0,$$

where:

- L_l is the stator leakage inductance.
- L_{ad} and L_{aq} are the mutual inductances of the stator d-axis and q-axis.

The rotor flux linkage equations are defined by

$$\psi_{fd} = L_{ffd}i_{fd} + L_{f1d}i_{1d} - L_{ad}i_d,$$

$$\psi_{1d} = L_{f1d}i_{fd} + L_{11d}i_{1d} - L_{ad}i_d,$$

and

$$\psi_{1q} = L_{11q}i_{1q} - L_{aq}i_q,$$

where:

- L_{ffd}, L_{11d}, and L_{11q} are the self-inductances of the rotor field circuit, d-axis damper winding 1, and q-axis damper winding 1. L_{f1d} is the rotor field circuit and d-axis damper winding 1 mutual inductance. They are defined by the following equations.

$$L_{ffd} = L_{ad} + L_{fd}$$

$$L_{f1d} = L_{ffd} - L_{fd}$$

$$L_{11d} = L_{f1d} + L_{1d}$$

$$L_{11q} = L_{aq} + L_{1q}$$

These equations assume that per-unit mutual inductance $L_{12q} = L_{aq}$, that is, the stator and rotor currents in the q-axis all link a single mutual flux represented by L_{aq}.

The rotor torque is defined by

$$T_e = \Psi_d i_q - \Psi_q i_d.$$

These defining equations do not describe the time constants you can set in the dialog box. To see their relationship with the equation coefficients, see [1].

Plotting and Display Options

You can perform plotting and display actions using the **Power Systems** menu on the block context menu.

Right-click the block and, from the **Power Systems** menu, select an option:

- **Display Base Values** displays the machine per-unit base values in the MATLAB Command Window.

- **Display Associated Base Values** displays associated per-unit base values in the MATLAB Command Window.
- **Display Associated Initial Conditions** displays associated initial conditions in the MATLAB Command Window.
- **Plot Open-Circuit Saturation (pu)** plots air-gap voltage, V_{ag}, versus field current, i_{fd}, both measured in per-unit, in a MATLAB figure window. The plot contains three traces:

    - Unsaturated: **Stator d-axis mutual inductance (unsaturated), Ladu** you specify
    - Saturated: **Per-unit open-circuit lookup table (Vag versus ifd)** you specify
    - Derived: Open-circuit lookup table (per-unit) derived from the **Per-unit open-circuit lookup table (Vag versus ifd)** you specify. This data is used to calculate the saturation factor,K_s, versus magnetic flux linkage, ψ_{at}, characteristic.

- **Plot Saturation Factor (pu)** plots saturation factor,K_s, versus magnetic flux linkage, ψ_{at}, both measured in per-unit, in a MATLAB figure window using the present machine parameters. This parameter is derived from other parameters that you specify:

    - **Stator d-axis mutual inductance (unsaturated), Ladu**
    - **Per-unit field current saturation data, ifd**
    - **Per-unit air-gap voltage saturation data, Vag**

Parameters

Main Tab

Rated apparent power

Rated apparent power. The default value is 300e6 V*A.

Rated voltage

    RMS rated line-line voltage. The default value is `24e3` V.

Rated electrical frequency

    Nominal electrical frequency at which rated apparent power is quoted. The default value is `60` Hz.

Number of pole pairs

    Number of machine pole pairs. The default value is `10`.

Specify field circuit input required to produce rated terminal voltage at no load by

    Choose between `Field circuit voltage` and `Field circuit current`. The default value is `Field circuit current`.

Field circuit current

    This parameter is visible only when **Specify field circuit input required to produce rated terminal voltage at no load by** is set to `Field circuit current`. The default value is `1000` A.

Field circuit voltage

    This parameter is visible only when **Specify field circuit input required to produce rated terminal voltage at no load by** is set to `Field circuit voltage`. The default value is `216.54` V.

Impedances Tab

Stator resistance, Ra

    Stator resistance. The default value is `0.011` pu.

Stator leakage reactance, Xl

    Stator leakage reactance. The default value is `0.15` pu.

d-axis synchronous reactance, Xd

    The d-axis synchronous reactance. The default value is `1.05` pu.

q-axis synchronous reactance, Xq

    The q-axis synchronous reactance. The default value is `0.7` pu.

zero-sequence reactance, X0

    The zero-sequence reactance. The default value is `0.15` pu.

d-axis transient reactance, Xd'

The *d*-axis transient reactance. The default value is `0.35` pu.

d-axis subtransient reactance, Xd"

The *d*-axis subtransient reactance. The default value is `0.25` pu.

q-axis subtransient reactance, Xq"

The *q*-axis subtransient reactance. The default value is `0.325` pu.

Time Constants Tab

Specify d-axis transient time constant

Select between `Open-circuit value` and `Short-circuit value`. The default value is `Open-circuit value`.

d-axis transient open-circuit, Td0'

The *d*-axis transient open-circuit time constant. This parameter is visible only when **Specify d-axis transient time constant** is set to `Open-circuit value`. The default value is `5.25` s.

d-axis transient short-circuit, Td'

The *d*-axis transient short-circuit time constant. This parameter is visible only when **Specify d-axis transient time constant** is set to `Short-circuit value`. The default value is `1.75` s.

Specify d-axis subtransient time constant

Select between `Open-circuit value` and `Short-circuit value`. The default value is `Open-circuit value`.

d-axis subtransient open-circuit, Td0"

The *d*-axis subtransient open-circuit time constant. This parameter is visible only when **Specify d-axis subtransient time constant** is set to `Open-circuit value`. The default value is `0.03` s.

d-axis subtransient short-circuit, Td"

The *d*-axis subtransient short-circuit time constant. This parameter is visible only when **Specify d-axis subtransient time constant** is set to `Short-circuit value`. The default value is `0.0214` s.

Specify q-axis subtransient time constant

Select between `Open-circuit value` and `Short-circuit value`. The default value is `Open-circuit value`.

q-axis subtransient open-circuit, Tq0"

The *q*-axis subtransient open-circuit time constant. This parameter is visible only when **Specify q-axis subtransient time constant** is set to `Open-circuit value`. The default value is `0.05 s`.

q-axis subtransient short-circuit, Tq"

The *q*-axis subtransient short-circuit time constant. This parameter is visible only when **Specify q-axis subtransient time constant** is set to `Short-circuit value`. The default value is `0.0232 s`.

Saturation Tab

Magnetic saturation representation

Block magnetic saturation representation. Options are:

- `None`
- `Per-unit open-circuit lookup table (Vag versus ifd)`

The default value is `None`.

Per-unit field current saturation data, ifd

The field current, i_{fd}, data populates the air-gap voltage, V_{ag}, versus field current, i_{fd}, lookup table. This parameter is only visible when you set **Magnetic saturation representation** to `Per-unit open-circuit lookup table (Vag versus ifd)`. This parameter must contain a vector with at least five elements. The default value is `[0.00, 0.48, 0.76, 1.38, 1.79]` pu.

Per-unit air-gap voltage saturation data, Vag

The air-gap voltage, V_{ag}, data populates the air-gap voltage, V_{ag}, versus field current, i_{fd}, lookup table. This parameter is only visible when you set **Magnetic saturation representation** to `Per-unit open-circuit lookup table (Vag versus ifd)`. This parameter must contain a vector with at least five elements. The default value is `[0.00 0.43 0.59 0.71 0.76]` pu.

Initial Conditions Tab

Specify initialization by

Select between `Electrical power and voltage output` and `Mechanical and magnetic states`. The default value is `Electrical power and voltage output`.

Terminal voltage magnitude

Initial RMS line-line voltage. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `24e3` V.

Terminal voltage angle

Initial voltage angle. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `0 deg`.

Terminal active power

Initial active power. This parameter is visible only when **Specify initialization by** is set to `Electrical power and voltage output`. The default value is `270e6 V*A`.

Terminal reactive power

Initial reactive power. This parameter is visible only when you set **Specify initialization by** to `Electrical power and voltage output`. The default value is `0 V*A`.

Initial rotor angle

Initial rotor angle. During steady-state operation, set this parameter to the sum of the load angle and required terminal voltage offset. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 deg`.

Initial stator d-axis magnetic flux linkage

Stator d-axis initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial stator q-axis magnetic flux linkage

Stator q-axis initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial stator zero-sequence magnetic flux linkage

Zero-sequence initial flux linkage. This parameter is visible only when you set **Specify initialization by** to `Mechanical and magnetic states`. The default value is `0 pu`.

Initial field circuit magnetic flux linkage

Field circuit initial flux linkage. This parameter is visible only when you set **Specify initialization by** to Mechanical and magnetic states. The default value is 0 pu.

Initial d-axis damper winding 1 magnetic flux linkage

The *d*-axis damper winding 1 initial flux linkage. This parameter is visible only when you set **Specify initialization by** to Mechanical and magnetic states. The default value is 0 pu.

Initial q-axis damper winding 1 magnetic flux linkage

The *q*-axis damper winding 1 initial flux linkage. This parameter is visible only when you set **Specify initialization by** to Mechanical and magnetic states. The default value is 0 pu.

Initial q-axis damper winding 2 magnetic flux linkage

The *q*-axis damper winding 2 initial flux linkage. This parameter is visible only when you set **Specify initialization by** to Mechanical and magnetic states. The default value is 0 pu.

Ports

The block has the following ports:

fd+

Electrical conserving port corresponding to the field winding positive terminal

fd-

Electrical conserving port corresponding to the field winding negative terminal

R

Mechanical rotational conserving port associated with the machine rotor

C

Mechanical rotational conserving port associated with the machine case

pu

Physical signal vector port associated with the machine per-unit measurements. The vector elements are:

- pu_fd_Efd
- pu_fd_Ifd

- pu_torque
- pu_velocity
- pu_ed
- pu_eq
- pu_e0
- pu_id
- pu_iq
- pu_i0

~

Expandable three-phase port associated with the stator windings

n

Electrical conserving port associated with the neutral point of the wye winding configuration

References

[1] Kundur, P. *Power System Stability and Control.* New York, NY: McGraw Hill, 1993.

[2] Lyshevski, S. E. *Electromechanical Systems, Electric Machines and Applied Mechatronics.* Boca Raton, FL: CRC Press, 1999.

See Also

See Also
Synchronous Machine Measurement | Synchronous Machine Model 2.1 (fundamental) | Synchronous Machine Model 2.1 (standard) | Synchronous Machine Round Rotor (fundamental) | Synchronous Machine Salient Pole (fundamental) | Synchronous Machine Salient Pole (fundamental)

Topics
"Expand and Collapse Three-Phase Ports on a Block"
Three-Phase Synchronous Machine Control

Introduced in R2013b

Thermal Resistor

Heat transfer by conduction through a layer of material

Library

Semiconductors / Fundamental Components / Thermal

Description

The Thermal Resistor block represents heat transfer by conduction through a layer of material. The heat transfer is:

- Governed by Fourier's law
- Proportional to the temperature difference across the layer of material
- Inversely proportional to the thermal resistance of the material

The equation for conductive heat transfer is:

$$Q_{AB} = \frac{T_{AB}}{R_{thermal}},$$

where:

- Q_{AB} is the heat flow through the material.
- T_{AB} is the temperature difference across the layer of material.
- $R_{thermal}$ is the thermal resistance of the material.

Thermal resistance can be calculated as:

$$R_{thermal} = \frac{D}{kA},$$

where:

- *D* is the thickness of the layer of material.
- *k* is the thermal conductivity of the material.
- *A* is the area normal to the heat flow direction.

Use the Thermal Resistor block to parameterize an equivalent component in terms of thermal resistance of the material layer. To parameterize an equivalent component in terms of the thickness, thermal conductivity, and area of the material layer, use the Conductive Heat Transfer block from the Simscape Foundation library.

Parameters

- "Parameters Tab" on page 1-394
- "Variables Tab" on page 1-394

Parameters Tab

Thermal resistance

The default value for the thermal resistance, $R_{thermal}$, is 1e-3 K/W.

Variables Tab

Use the **Variables** tab to set the priority and initial target values for the block variables before simulation. For more information, see "Set Priority and Initial Target for Block Variables" (Simscape) .

Unlike block parameters, variables do not have conditional visibility. The **Variables** tab lists all the existing block variables. If a variable is not used in the set of equations corresponding to the selected block configuration, the values specified for this variable are ignored.

Ports

The block has the following ports:

A

Thermal conserving port associated with surface A of the material that the heat flows through.

B

Thermal conserving port associated with surface B of the material that the heat flows through.

See Also

See Also

Cauer Thermal Model Element | Foster Thermal Model

Introduced in R2016a

Three Element Demux

Convert three-element physical signal vector into scalar physical signals
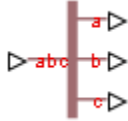
Library

Sensors

Description

The Three Element Demux block splits a three-element physical signal vector into three scalar physical signals.

Ports

The block has the following ports:

abc

    Three-element physical signal input port.

a

    Scalar physical signal output port.

b

    Scalar physical signal output port.

c

    Scalar physical signal output port.

Introduced in R2013b

Three-Level Converter

Connect three-phase AC network to three-level DC network

Library

Semiconductors

Description

The Three-Level Converter block models a three-arm converter circuit that connects a three-phase AC network to a three-level DC network.

Each component in the three-arm circuit is the same switching device, which you specify using an option in the Converter block dialog box. The switching devices are in the **Semiconductors** > **Fundamental Components** sublibrary.

The figure shows the equivalent circuit for the block using an Ideal Semiconductor block as the switching device.
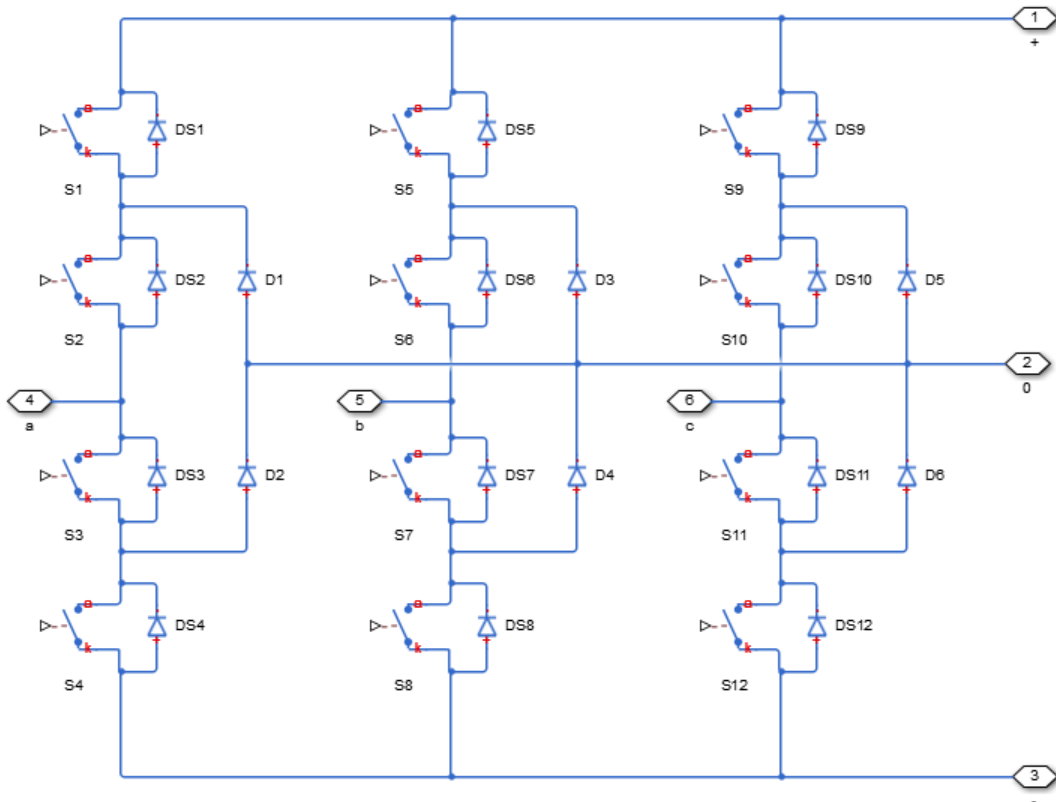
You control the gate ports of the 12 switching devices via an input to the Three-Level Converter block G port.

1 Use a `Twelve-Pulse Gate Multiplexer` block to multiplex all 12 gate signals into a single vector.

2 Connect the output of the Twelve-Pulse Gate Multiplexer block to the Three-Level Converter block G port.

You use the **Diodes** tab of the block dialog box to include an integral protection diode for each switching device. An integral diode protects the semiconductor device by providing a conduction path for reverse current. An inductive load can produce a high reverse-voltage spike when the semiconductor device suddenly switches off the voltage supply to the load.

The table shows how to set the **Integral protection diode** parameter based on your goals.

Goal	Value to Select	Block Behavior
Prioritize simulation speed.	`Protection diode with no dynamics`	The block includes an integral copy of the `Diode` block. The block dialog box shows parameters relating to the Diode block.
Precisely specify reverse-mode charge dynamics.	`Protection diode with charge dynamics`	The block includes an integral copy of the `Commutation Diode` block. The block dialog box shows parameters relating to the Commutation Diode block.

You use the **Snubbers** tab of the block dialog box to include a snubber circuit for each switching device. Each snubber consists of a resistor and capacitor connected in series. Typically, a snubber circuit protects a switching device against very high voltages produced by an inductive load when the device turns off the voltage supply to the load. Snubber circuits also prevent excessive rates of change of current when a switching device turns on.

Parameters

- "Switching Devices Tab" on page 1-399
- "Diodes Tab" on page 1-402
- "Snubbers Tab" on page 1-405

Switching Devices Tab

Switching device

Converter switching device. The default value is `Ideal Semiconductor Switch`.

The switching devices you can select are:

- GTO

- Ideal Semiconductor Switch
- IGBT
- MOSFET

GTO Parameters

When you select `GTO`, parameters for the GTO block appear.

Additional GTO Parameters

Forward voltage, Vf

Minimum voltage required across the anode and cathode block ports for the gradient of the device i-v characteristic to be $1/R_{on}$, where R_{on} is the value of **On-state resistance**. The default value is `0.8 V`.

On-state resistance

Rate of change of voltage versus current above the forward voltage. The default value is `0.001 Ohm`.

Off-state conductance

Anode-cathode conductance when the device is off. The value must be less than $1/R$, where R is the value of **On-state resistance**. The default value is `1e-6 1/Ohm`.

Gate trigger voltage, Vgt

Gate-cathode voltage threshold. The device turns on when the gate-cathode voltage is above this value. The default value is `1 V`.

Gate turn-off voltage, Vgt_off

Gate-cathode voltage threshold. The device turns off when the gate-cathode voltage is below this value. The default value is `-1 V`.

Holding current

Current threshold. The device stays on when the current is above this value, even when the gate-cathode voltage falls below the gate trigger voltage. The default value is `1 A`.

For more information, see `GTO`.

Ideal Semiconductor Switch Parameters

When you select `Ideal Semiconductor Switch`, parameters for the Ideal Semiconductor Switch block appear.

Additional Ideal Semiconductor Switch Parameters

On-state resistance

Anode-cathode resistance when the device is on. The default value is `0.001 Ohm`.

Off-state conductance

Anode-cathode conductance when the device is off. The value must be less than 1/R, where R is the value of **On-state resistance**. The default value is `1e-6 1/Ohm`.

Threshold voltage, Vth

Gate-cathode voltage threshold. The device turns on when the gate-cathode voltage is above this value. The default value is `6 V`.

For more information, see `Ideal Semiconductor Switch`.

IGBT Parameters

When you select `IGBT`, parameters for the IGBT block appear.

Additional IGBT Parameters

Forward voltage, Vf

Minimum voltage required across the collector and emitter block ports for the gradient of the diode i-v characteristic to be $1/R_{on}$, where R_{on} is the value of **On-state resistance**. The default value is `0.8 V`.

On-state resistance

Collector-emitter resistance when the device is on. The default value is `0.001 Ohm`.

Off-state conductance

Collector-emitter conductance when the device is off. The value must be less than 1/R, where R is the value of **On-state resistance**. The default value is `1e-6 1/Ohm`.

Threshold voltage, Vth

Collector-emitter voltage at which the device turns on. The default value is `6 V`.

For more information, see `IGBT`.

MOSFET Parameters

When you select `MOSFET`, parameters for the MOSFET block appear.

Additional MOSFET Parameters

On-state resistance, R_DS(on)

Drain-source resistance when the device is on. The default value is `0.001 Ohm`.

Off-state conductance

Drain-source conductance when the device is off. The value must be less than 1/R, where R is the value of **On-state resistance**. The default value is `1e-6 1/Ohm`.

Threshold voltage, Vth

Gate-source voltage threshold. The device turns on when the gate-source voltage is above this value. The default value is `6 V`.

For more information, see `MOSFET`.

Diodes Tab

Integral protection diode

Integral protection diode for each switching device. Choose between `Diode with no dynamics` and `Diode with charge dynamics`. The default value is `Diode with no dynamics`.

Parameters for Diode with no dynamics

When you select `Diode with no dynamics`, additional parameters appear.

Additional Parameters for Diode with no dynamics

Forward voltage

Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is `0.8 V`.

On resistance

Rate of change of voltage versus current above the **Forward voltage**. The default value is `0.001 Ohm`.

Off conductance

Conductance of the reverse-biased diode. The default value is `1e-5 1/Ohm`.

For more information on these parameters, see `Diode`.

Parameters for Diode with charge dynamics

When you select `Protection diode with charge dynamics`, additional parameters appear.

Additional Parameters for Diode with charge dynamics

Forward voltage

Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is `0.8 V`.

On resistance

Rate of change of voltage versus current above the **Forward voltage**. The default value is `0.001 Ohm`.

Off conductance

Conductance of the reverse-biased diode. The default value is `1e-5 1/Ohm`.

Junction capacitance

Diode junction capacitance. The default value is `50 nF`.

Peak reverse current, iRM

Peak reverse current measured by an external test circuit. This value must be less than zero. The default value is `-235 A`.

Initial forward current when measuring iRM

Initial forward current when measuring peak reverse current. This value must be greater than zero. The default value is `300 A`.

Rate of change of current when measuring iRM

Rate of change of current when measuring peak reverse current. This value must be less than zero. The default value is `-50 A/`μ`s`.

Reverse recovery time parameterization

Determines how you specify reverse recovery time in the block. The default value is `Specify reverse recovery time directly`.

If you select `Specify stretch factor` or `Specify reverse recovery charge`, you specify a value that the block uses to derive the reverse recovery time. For more information on these options, see "Alternatives to Specifying t_{rr} Directly" on page 1-83.

Reverse recovery time, trr

Interval between the time when the current initially goes to zero (when the diode turns off) and the time when the current falls to less than 10% of the peak reverse current. The default value is 15 μs.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery time directly`.

The value of the **Reverse recovery time, trr** parameter must be greater than the value of the **Peak reverse current, iRM** parameter divided by the value of the **Rate of change of current when measuring iRM** parameter.

Reverse recovery time stretch factor

Value that the block uses to calculate **Reverse recovery time, trr**. This value must be greater than 1. The default value is 3.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify stretch factor`.

Specifying the stretch factor is an easier way to parameterize the reverse recovery time than specifying the reverse recovery charge. The larger the value of the stretch factor, the longer it takes for the reverse recovery current to dissipate.

Reverse recovery charge, Qrr

Value that the block uses to calculate **Reverse recovery time, trr**. Use this parameter if the data sheet for your diode device specifies a value for the reverse recovery charge instead of a value for the reverse recovery time.

The reverse recovery charge is the total charge that continues to dissipate when the diode turns off. The value must be less than $-\dfrac{i^2_{RM}}{2a}$,

where:

- i_{RM} is the value specified for **Peak reverse current, iRM**.
- a is the value specified for **Rate of change of current when measuring iRM**.

The default value is 1500 μAs.

The parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery charge`.

For more information on these parameters, see `Commutation Diode`.

Snubbers Tab

Snubber

Snubber for each switching device. The default value is `None`.

Snubber resistance

This parameter is visible only if you set **Snubber** to `RC snubber`. The default value is `0.1 Ohm`.

Snubber capacitance

This parameter is visible only if you set **Snubber** to `RC snubber`. The default value is `1e-7 F`.

Ports

The block has the following ports:

`G`

Vector input port associated with the gate terminals of the switching devices. Connect this port to a Twelve-Pulse Gate Multiplexer block.

`~`

Expandable three-phase port.

`+`

Electrical conserving port associated with the DC positive terminal.

`O`

Electrical conserving port associated with the DC neutral terminal.

`-`

Electrical conserving port associated with the DC negative terminal.

See Also

See Also
`Average-Value Inverter` | `Average-Value Rectifier` | `Converter` | `Rectifier` | `Twelve-Pulse Gate Multiplexer`

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2014b

Thyristor

Thyristor

Library

Semiconductors / Fundamental Components

Description

The Thyristor block models a thyristor. The I-V characteristic for a thyristor is such that the thyristor turns on if the gate-cathode voltage exceeds the specified gate trigger voltage. The device turns off if the load current falls below the specified holding-current value.
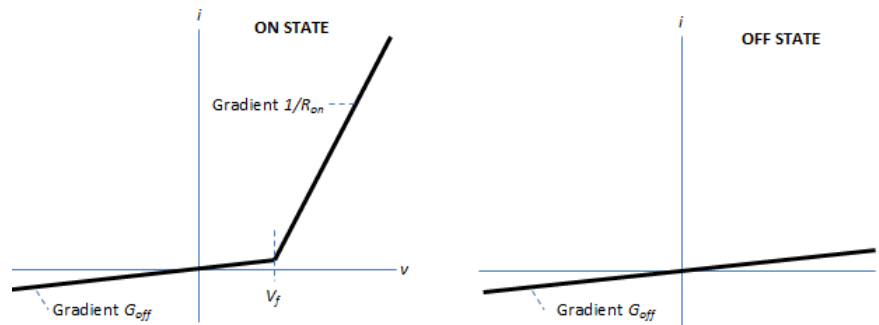
In the on state, the anode-cathode path behaves like a linear diode with forward-voltage drop, V_f, and on-resistance, R_{on}.

In the off state, the anode-cathode path behaves like a linear resistor with a low off-state conductance, G_{off}.

The defining Simscape equations for the block are:

```
if (v > Vf)&&((G>Vgt)||(i>Ih))
    i == (v - Vf*(1-Ron*Goff))/Ron;
else
    i == v*Goff;
end
```

where:

- v is the anode-cathode voltage.
- Vf is the forward voltage.
- G is the gate voltage.
- Vgt is the gate trigger voltage.
- i is the anode-cathode current.
- Ih is the holding current.
- Ron is the on-state resistance.
- $Goff$ is the off-state conductance.

Using the Integral Diode tab of the block dialog box, you can include an integral cathode-anode diode. An integral diode protects the semiconductor device by providing a conduction path for reverse current. An inductive load can produce a high reverse-voltage spike when the semiconductor device suddenly switches off the voltage supply to the load.

The table shows you how to set the **Integral protection diode** parameter based on your goals.

Goal	Value to Select	Block Behavior
Prioritize simulation speed.	`Protection diode with no dynamics`	The block includes an integral copy of the `Diode` block. The block dialog box shows parameters relating to the Diode block.
Precisely specify reverse-mode charge dynamics.	`Protection diode with charge dynamics`	The block includes an integral copy of the `Commutation Diode` block. The block dialog box shows parameters relating to the Commutation Diode block.

Modeling Variants

The block provides four modeling variants. To select the desired variant, right-click the block in your model. From the context menu, select **Simscape** > **Block choices**, and then one of these variants:
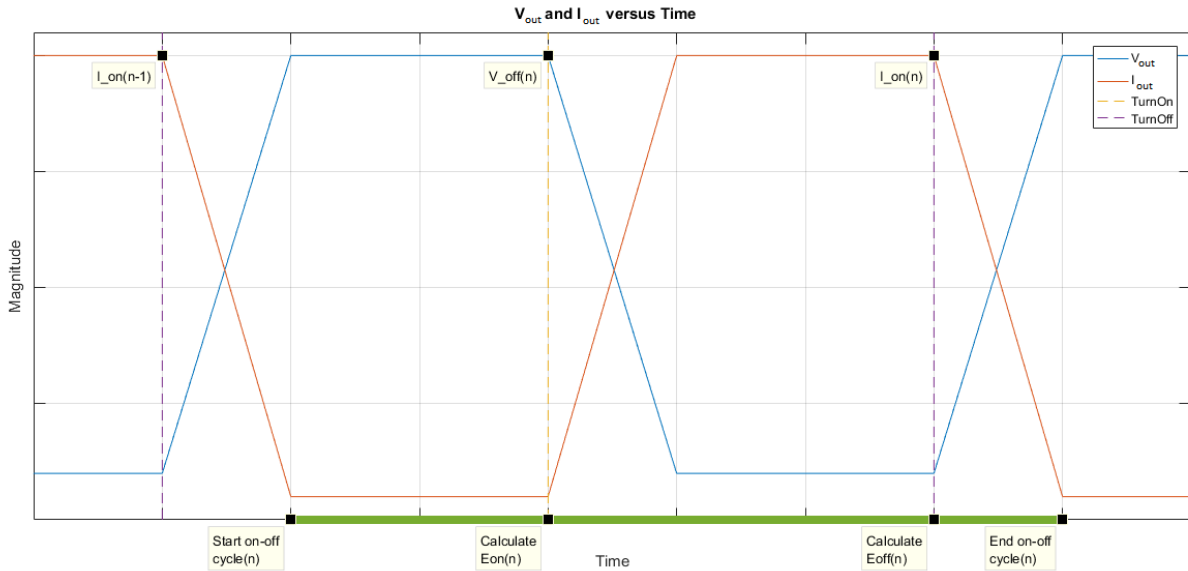
- **PS Control Port** — Contains a physical signal port that is associated with the gate terminal. This variant is the default.
- **Electrical Control Port** — Contains an electrical conserving port that is associated with the gate terminal.
- **PS Control Port | Thermal Port** — Contains a thermal port and a physical signal port that is associated with the gate terminal.
- **Electrical Control Port | Thermal Port** — Contains a thermal port and an electrical conserving port that is associated with the gate terminal.

The variants of this block without the thermal port do not simulate heat generation in the device.

The variants with the thermal port allow you to model the heat that switching events and conduction losses generate. For numerical efficiency, the thermal state does not affect the electrical behavior of the block. The thermal port is hidden by default. To enable the thermal port, select a thermal block variant.

Thermal Loss Equations

The figure shows an idealized representation of the output voltage, V_{out}, and the output current, I_{out}, of the semiconductor device. The interval shown includes the entire nth switching cycle, during which the block turns off and then on.

V_{out} and I_{out} versus Time

Heat Loss Due to a Switch-On Event

When the semiconductor turns on during the nth switching cycle, the amount of thermal energy that the device dissipates increments by a discrete amount. If you select `Voltage, current, and temperature` for the **Thermal loss dependent on** parameter, the equation for the incremental change is

$$E_{on(n)} = \frac{V_{off(n)}}{V_{off\_data}} fcn(T, I_{on(n-1)}),$$

where:

- $E_{on(n)}$ is the switch-on loss at the nth switch-on event.
- $V_{off(n)}$ is the off-state output voltage, V_{out}, just before the device switches on during the nth switching cycle.
- V_{off_data} is the **Off-state voltage for losses data** parameter value.
- T is the device temperature.
- $I_{on(n-1)}$ is the on-state output current, I_{out}, just before the device switches off during the cycle that precedes the nth switching cycle.

The function *fcn* is a 2-D lookup table with linear interpolation and linear extrapolation:

$$E = tablelookup(T_{j\_data}, I_{out\_data}, E_{on\_data}, T, I_{on(n-1)}),$$

where:

- T_{j_data} is the **Temperature vector, Tj** parameter value.
- I_{out_data} is the **Output current vector, Iout** parameter value.
- E_{on_data} is the **Switch-on loss, Eon=fcn(Tj,Iout)** parameter value.

If you select `Voltage and current` for the **Thermal loss dependent on** parameter, when the semiconductor turns on during the *n*th switching cycle, the equation that the block uses to calculate the incremental change in the discrete amount of thermal energy that the device dissipates is

$$E_{on(n)} = \left(\frac{V_{off(n)}}{V_{off\_data}} \right) \left(\frac{I_{on(n-1)}}{I_{out\_scalar}} \right) (E_{on\_scalar})$$

where:

- I_{out_scalar} is the **Output current, Iout** parameter value.
- E_{on_scalar} is the **Switch-on loss** parameter value.

Heat Loss Due to a Switch-Off Event

When the semiconductor turns off during the *n*th switching cycle, the amount of thermal energy that the device dissipates increments by a discrete amount. If you select `Voltage, current, and temperature` for the **Thermal loss dependent on** parameter, the equation for the incremental change is

$$E_{off(n)} = \frac{V_{off(n)}}{V_{off\_data}} fcn(T, I_{on(n)}),$$

where:

- $E_{off(n)}$ is the switch-off loss at the *n*th switch-off event.

- $V_{off(n)}$ is the off-state output voltage, V_{out}, just before the device switches on during the nth switching cycle.
- V_{off_data} is the **Off-state voltage for losses data** parameter value.
- T is the device temperature.
- $I_{on(n)}$ is the on-state output current, I_{out}, just before the device switches off during the nth switching cycle.

The function *fcn* is a 2-D lookup table with linear interpolation and linear extrapolation:

$$E = tablelookup(T_{j\_data}, I_{out\_data}, E_{off\_data}, T, I_{on(n)}),$$

where:

- T_{j_data} is the **Temperature vector, Tj** parameter value.
- I_{out_data} is the **Output current vector, Iout** parameter value.
- E_{off_data} is the **Switch-off loss, Eoff=fcn(Tj,Iout)** parameter value.

If you select `Voltage and current` for the **Thermal loss dependent on** parameter, when the semiconductor turns off during the nth switching cycle, the equation that the block uses to calculate the incremental change in the discrete amount of thermal energy that the device dissipates is

$$E_{off(n)} = \left(\frac{V_{off(n)}}{V_{off\_data}} \right) \left(\frac{I_{on(n-1)}}{I_{out\_scalar}} \right) (E_{off\_scalar})$$

where:

- I_{out_scalar} is the **Output current, Iout** parameter value.
- E_{off_scalar} is the **Switch-off loss** parameter value.

Heat Loss Due to Electrical Conduction

If you select `Voltage, current, and temperature` for the **Thermal loss dependent on** parameter, then, for both the on state and the off state, the heat loss due to electrical conduction is

$$E_{conduction} = \int fcn(T, I_{out}) \, dt,$$

where:

- $E_{conduction}$ is the heat loss due to electrical conduction.
- T is the device temperature.
- I_{out} is the device output current.

The function *fcn* is a 2-D lookup table:

$$Q_{conduction} = tablelookup(T_{j\_data}, I_{out\_data}, I_{out\_data\_repmat} .*V_{on\_data}, T, I_{out}),$$

where:

- T_{j_data} is the **Temperature vector, Tj** parameter value.
- I_{out_data} is the **Output current vector, Iout** parameter value.
- $I_{out\_data\_repmat}$ is a matrix that contains length, T_{j_data}, copies of I_{out_data}.
- V_{on_data} is the **On-state voltage, Von=fcn(Tj,Iout)** parameter value.

If you select `Voltage and current` for the **Thermal loss dependent on** parameter, then, for both the on state and the off state, the heat loss due to electrical conduction is

$$E_{conduction} = \int \left(I_{out} * V_{on\_scalar} \right) dt,$$

where V_{on_scalar} is the **On-state voltage** parameter value.

Heat Flow

The block uses the **Energy dissipation time constant** parameter to filter the amount of heat flow that the block outputs. The filtering allows the block to:

- Avoid discrete increments for the heat flow output

- Handle a variable switching frequency
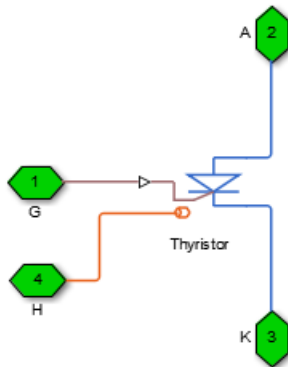
The filtered heat flow is

$$Q = \frac{1}{\tau} \left(\sum_{i=1}^{n} E_{on(i)} + \sum_{i=1}^{n} E_{off(i)} + E_{conduction} - \int Q \, dt \right),$$

where:

- *Q* is the heat flow from the component.
- *τ* is the **Energy dissipation time constant** parameter value.
- *n* is the number of switching cycles.
- $E_{on(i)}$ is the switch-on loss at the *i*th switch-on event.
- $E_{off(i)}$ is the switch-off loss at the *i*th switch-off event.
- $E_{conduction}$ is the heat loss due to electrical conduction.
- $\int Q dt$ is the total heat previously dissipated from the component.

Ports

The figure shows the block port names.

G

> Port associated with the gate terminal. You can set the port to either a physical signal or electrical port.

A

> Electrical conserving port associated with the anode terminal.

K

Electrical conserving port associated with the cathode terminal.

H

Thermal conserving port. The thermal port is optional and is hidden by default. To enable this port, select a variant that includes a thermal port.

Parameters

- "Main Tab" on page 1-415
- "Integral Diode Tab" on page 1-415
- "Thermal Model Tab" on page 1-157

Main Tab

Forward voltage, Vf

Forward voltage at which the device turns on. The default value is `0.8 V`.

On-state resistance

Anode-cathode resistance when the device is on. The default value is `0.001 Ohm`.

Off-state conductance

Anode-cathode conductance when the device is off. The value must be less than 1/R, where R is the value of **On-state resistance**. The default value is `1e-5 1/Ohm`.

Gate trigger voltage, Vgt

Gate-cathode voltage threshold. The device turns on when the gate-cathode voltage is above this value. The default value is `6 V`.

Holding current

Current threshold. The device stays on when the current is above this value, even when the gate-cathode voltage falls below the gate trigger voltage. The default value is `1 A`.

Integral Diode Tab

Integral protection diode

Block integral protection diode. The default value is `None`.

The diodes you can select are:

- Protection diode with no dynamics
- Protection diode with charge dynamics

Parameters for Protection diode with no dynamics

When you select `Protection diode with no dynamics`, additional parameters appear.

Additional Parameters for Protection diode with no dynamics

Forward voltage

Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is `0.8 V`.

On resistance

Rate of change of voltage versus current above the **Forward voltage**. The default value is `0.001 Ohm`.

Off conductance

Conductance of the reverse-biased diode. The default value is `1e-5 1/Ohm`.

For more information on these parameters, see `Diode`.

Parameters for Protection diode with charge dynamics

When you select `Protection diode with charge dynamics`, additional parameters appear.

Additional Parameters for Protection diode with charge dynamics

Forward voltage

Minimum voltage required across the + and - block ports for the gradient of the diode I-V characteristic to be $1/R_{on}$, where R_{on} is the value of **On resistance**. The default value is `0.8 V`.

On resistance

Rate of change of voltage versus current above the **Forward voltage**. The default value is `0.001 Ohm`.

Off conductance

Conductance of the reverse-biased diode. The default value is `1e-5 1/Ohm`.

Junction capacitance

Diode junction capacitance. The default value is `50 nF`.

Peak reverse current, iRM

Peak reverse current measured by an external test circuit. This value must be less than zero. The default value is `-235 A`.

Initial forward current when measuring iRM

Initial forward current when measuring peak reverse current. This value must be greater than zero. The default value is `300 A`.

Rate of change of current when measuring iRM

Rate of change of current when measuring peak reverse current. This value must be less than zero. The default value is `-50 A/`μ`s`.

Reverse recovery time parameterization

Determines how you specify reverse recovery time in the block. The default value is `Specify reverse recovery time directly`.

If you select `Specify stretch factor` or `Specify reverse recovery charge`, you specify a value that the block uses to derive the reverse recovery time. For more information on these options, see "Alternatives to Specifying t_{rr} Directly" on page 1-83.

Reverse recovery time, trr

Interval between the time when the current initially goes to zero (when the diode turns off) and the time when the current falls to less than 10% of the peak reverse current. The default value is `15 `μ`s`.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery time directly`.

The value of the **Reverse recovery time, trr** parameter must be greater than the value of the **Peak reverse current, iRM** parameter divided by the value of the **Rate of change of current when measuring iRM** parameter.

Reverse recovery time stretch factor

Value that the block uses to calculate **Reverse recovery time, trr**. This value must be greater than `1`. The default value is `3`.

This parameter is visible only if you set **Reverse recovery time parameterization** to `Specify stretch factor`.

Specifying the stretch factor is an easier way to parameterize the reverse recovery time than specifying the reverse recovery charge. The larger the value of the stretch factor, the longer it takes for the reverse recovery current to dissipate.

Reverse recovery charge, Qrr

Value that the block uses to calculate **Reverse recovery time, trr**. Use this parameter if the data sheet for your diode device specifies a value for the reverse recovery charge instead of a value for the reverse recovery time.

The reverse recovery charge is the total charge that continues to dissipate when the diode turns off. The value must be less than $-\dfrac{i^2_{RM}}{2a}$,

where:

- i_{RM} is the value specified for **Peak reverse current, iRM**.
- a is the value specified for **Rate of change of current when measuring iRM**.

The default value is `1500 µAs`.

The parameter is visible only if you set **Reverse recovery time parameterization** to `Specify reverse recovery charge`.

For more information on these parameters, see `Commutation Diode`.

Thermal Model Tab

The **Thermal Model** tab is enabled only when you select a block variant that includes a thermal port.

Thermal loss dependent on

Select a parameterization method. The option that you select determines which other parameters are enabled. Options are:

- `Voltage and current` — Use scalar values to specify the output current, switch-on loss, switch-off loss, and on-state voltage data.
- `Voltage, current, and temperature` — Use vectors to specify the output current, switch-on loss, switch-off loss, on-state voltage, and temperature data. This is the default parameterization method.

Off-state voltage for losses data

The output voltage of the device during the off state. This is the blocking voltage at which the switch-on loss and switch-off loss data are defined. The default value is 300 V.

Energy dissipation time constant

Time constant used to average the switch-on losses, switch-off losses, and conduction losses. This value is equal to the period of the minimum switching frequency. The default value is 1e-4 s.

Additional Parameters for Parameterizing by Voltage, Current, and Temperature

Temperature vector, Tj

Temperature values at which the switch-on loss, switch-off loss, and on-state voltage are specified. Specify this parameter using a vector quantity. The default value is [298.15 398.15] K.

Output current vector, Iout

Output currents for which the switch-on loss, switch-off- loss and on-state voltage are defined. The first element must be zero. Specify this parameter using a vector quantity. The default value is [0 10 50 100 200 400 600] A.

Switch-on loss, Eon=fcn(Tj,Iout)

Energy dissipated during a single swtich on event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a vector quantity. The default value is [0 2.9e-4 0.00143 0.00286 0.00571 0.01314 0.02286; 0 5.7e-4 0.00263 0.00514 0.01029 0.02057 0.03029] J.

Switch-off loss, Eoff=fcn(Tj,Iout)

Energy dissipated during a single switch-off event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a vector quantity. The default value is [0 2.1e-4 0.00107 0.00214 0.00429 0.009859999999999999 0.01714; 0 4.3e-4 0.00197 0.00386 0.00771 0.01543 0.02271] J.

On-state voltage, Von=fcn(Tj,Iout)

Voltage drop across the device while it is in a triggered conductive state.. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a vector quantity. The default value is [0 1.1 1.3 1.45 1.75 2.25 2.7; 0 1 1.15 1.35 1.7 2.35 3] V.

Additional Parameters for Parameterizing by Voltage and Current

Output current, Iout

> Output currents for which the switch-on loss, switch-off loss, and on-state voltage are defined. The first element must be zero. Specify this parameter using a scalar quantity. The default value is 600 A.

Switch-on loss

> Energy dissipated during a single switch-on event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a scalar quantity. The default value is 0.02286 J.

Switch-off loss

> Energy dissipated during a single switch-off event. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a scalar quantity. The default value is 0.01714 J.

On-state voltage

> Voltage drop across the block while it is in a triggered conductive state. This parameter is defined as a function of temperature and final on-state output current. Specify this parameter using a scalar quantity. The default value is 2.7 V.

See Also

See Also

Commutation Diode | Diode | GTO | Ideal Semiconductor Switch | IGBT | MOSFET

Topics

"Simulate Thermal Losses in Semiconductors"
"Switch Between Physical Signal and Electrical Ports"

Introduced in R2013b

Time-Based Fault

Time-based single-phase, two-phase, or three-phase grounded or ungrounded fault

Library
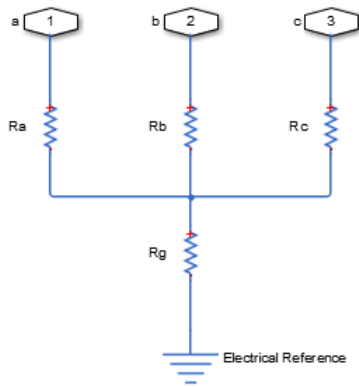
Passive Devices / Faults

Description

The Time-Based Fault block models any permutation of a single-phase, two-phase, or three-phase grounded or ungrounded fault. You specify the fault activation time using the block **Fault start time** parameter. The fault becomes inactive when the fault duration that you specify elapses.

You can set the Time-Based Fault block to represent any of these permutations:

- Single-phase-to-ground fault (a-g, b-g, or c-g)
- Two-phase fault (a-b, b-c, or c-a)
- Two-phase-to-ground fault (a-b-g, b-c-g, or c-a-g)
- Three-phase fault (a-b-c)
- Three-phase-to-ground fault (a-b-c-g)

The figure shows the equivalent circuit diagram for the Time-Based Fault block.

You can determine the resistance in the equivalent circuit using the equations in the table.

Fault type	Value of R_a	Value of R_b	Value of R_c	Value of R_g
None / inactive	$\dfrac{1}{G_{pn}}$	$\dfrac{1}{G_{pn}}$	$\dfrac{1}{G_{pn}}$	Infinity / open circuit
a-g	R_{pn}	$\dfrac{1}{G_{pn}}$	$\dfrac{1}{G_{pn}}$	R_{ng}
b-g	$\dfrac{1}{G_{pn}}$	R_{pn}	$\dfrac{1}{G_{pn}}$	R_{ng}
c-g	$\dfrac{1}{G_{pn}}$	$\dfrac{1}{G_{pn}}$	R_{pn}	R_{ng}
a-b	R_{pn}	R_{pn}	$\dfrac{1}{G_{pn}}$	Infinity / open circuit
b-c	$\dfrac{1}{G_{pn}}$	R_{pn}	R_{pn}	Infinity / open circuit

Fault type	Value of R_a	Value of R_b	Value of R_c	Value of R_g
c-a	R_{pn}	$\dfrac{1}{G_{pn}}$	R_{pn}	Infinity / open circuit
a-b-g	R_{pn}	R_{pn}	$\dfrac{1}{G_{pn}}$	R_{ng}
b-c-g	$\dfrac{1}{G_{pn}}$	R_{pn}	R_{pn}	R_{ng}
c-a-g	R_{pn}	$\dfrac{1}{G_{pn}}$	R_{pn}	R_{ng}
a-b-c	R_{pn}	R_{pn}	R_{pn}	Infinity / open circuit
a-b-c-g	R_{pn}	R_{pn}	R_{pn}	R_{ng}

where:

- R_a is the resistance between the a-phase and the neutral point of a wye connection.
- R_b is the resistance between the b-phase and the neutral point of a wye connection.
- R_c is the resistance between the c-phase and the neutral point of a wye connection.
- R_g is the resistance between the neutral point of a wye connection and electrical reference.
- R_{pn} is the value of the **Faulted phase-neutral resistance** parameter.
- R_{ng} is the value of the **Faulted neutral-ground resistance** parameter.
- G_{pn} is the value of the **Unfaulted phase-neutral conductance** parameter.

Parameters

- "Main Tab" on page 1-424
- "Parasitics Tab" on page 1-425

Main Tab

Fault type

Select one of the following:

- None — Specifies that the fault is not active. This is the default value.
- Single-phase to ground (a-g)
- Single-phase to ground (b-g)
- Single-phase to ground (c-g)
- Two-phase (a-b)
- Two-phase (b-c)
- Two-phase (c-a)
- Two-phase to ground (a-b-g)
- Two-phase to ground (b-c-g)
- Two-phase to ground (c-a-g)
- Three-phase (a-b-c)
- Three-phase to ground (a-b-c-g)

Faulted phase-neutral resistance

Resistance between the phase connection and the neutral point when the fault is active. This parameter is visible if the **Fault type** parameter is set to anything other than None. The default value is 1e-3 Ohm.

Faulted neutral-ground resistance

Resistance between the neutral point and the electrical reference when fault is active. This parameter is visible if the **Fault type** parameter is set to any fault which includes a ground connection. The default value is 1e-3 Ohm.

Fault start time

Simulation time when the fault becomes active. This parameter is visible if the **Fault type** parameter is set to anything other than None. The default value is 1 s.

Fault duration

Period of time that the fault is active. This parameter is visible if the **Fault type** parameter is set to anything other than None. The default value is 0.1 s.

Parasitics Tab

Unfaulted phase-neutral conductance

Conductance between the phase connections and the neutral point when a phase is not involved in the fault. The default value is `1e-6 1/Ohm`.

Ports

The block has one expandable three-phase port for connecting the fault to the system.
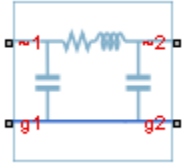
See Also

See Also
`Enabled Fault`

Introduced in R2014a

Transmission Line

Three-phase transmission line using lumped-parameter pi-line model

Library

Passive Devices

Description

The Transmission Line block models a three-phase transmission line using the lumped-parameter pi-line model. This model takes into account phase resistance, phase self-inductance, line-line mutual inductance and resistance, line-line capacitance, and line-ground capacitance.

To simplify the block-defining equations, Clarke's transformation is used. The resulting equations are:

$$V_1^{'} - V_2^{'} = \begin{bmatrix} R+2R_m & & \\ & R-R_m & \\ & & R-R_m \end{bmatrix} I_1^{'} + \begin{bmatrix} L+2M & & \\ & L-M & \\ & & L-M \end{bmatrix} \frac{dI_1^{'}}{dt}$$

$$I_1^{'} + I_2^{'} = \begin{bmatrix} C_g & & \\ & C_g+3C_l & \\ & & C_g+3C_l \end{bmatrix} \frac{dV_2^{'}}{dt}$$

$$I_1^{'} = T'I_1$$

$$I_2' = T'I_2$$

$$V_1' = T'V_1$$

$$V_2' = T'V_2$$

$$T = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & \sqrt{2} & 0 \\ 1 & -1/\sqrt{2} & \sqrt{3/2} \\ 1 & -1/\sqrt{2} & -\sqrt{3/2} \end{bmatrix}$$

where:

- R is the line resistance for the segment.
- R_m is the mutual resistance for the segment.
- L is the line inductance for the segment.
- C_g is the line-ground capacitance for the segment.
- C_l is the line-line capacitance for the segment.
- T is the Clarke's transformation matrix.
- $I1$ is the three-phase current flowing into the ~1 port.
- $I2$ is the three-phase current flowing into the ~2 port.
- $V1$ is the three-phase voltage at the ~1 port.
- $V2$ is the three-phase voltage at the ~2 port.

The positive and zero-sequence parameters are defined by the diagonal terms in the transformed equations:

$$R_0 = R + 2R_m$$

$$R_1 = R - R_m$$

$$L_0 = L + 2M$$

$$L_1 = L - M$$

$$C_0 = C_g$$

$$C_1 = C_g + 3C_l$$

Rearranging these equations gives the physical line quantities in terms of positive and zero-sequence parameters:

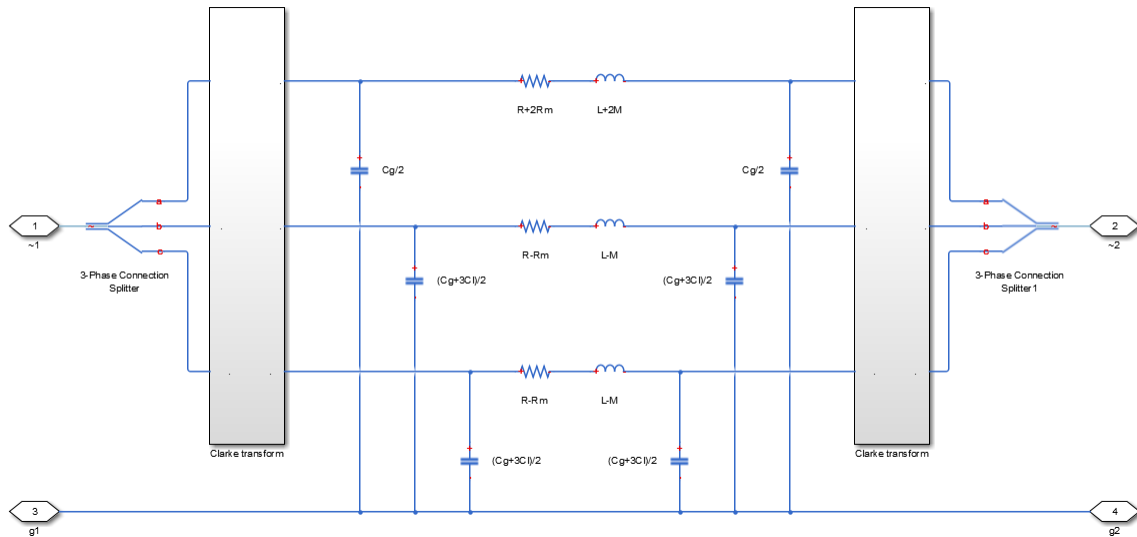$$R = \frac{2R_1 + R_0}{3}$$

$$R_m = \frac{R_0 - R_1}{3}$$

$$L = \frac{2L_1 + L_0}{3}$$

$$M = \frac{L_0 - L_1}{3}$$

$$C_l = \frac{C_1 - C_0}{3}$$

$$C_g = C_0$$

The figure shows the equivalent electrical circuit for a single-segment pi-line model using Clarke's transformation.

To increase fidelity, you can use the **Number of segments** parameter to repeat the pi-section N times, resulting in an N-segment transmission line model. More segments significantly slows down your simulation.

To improve numerical performance, you can add parasitic resistance and conductance components. Choosing large values for these components improves simulation speed but decreases simulation accuracy.

Parameters

- "Main tab" on page 1-429
- "Parasitics tab" on page 1-430

Main tab

Line length

Length of the transmission line. The default value is 1 km.

Resistance

5

Resistance of the transmission line per phase per-unit length. The default value is `0.02 Ohm/km`.

Inductance

Self-inductance of the transmission line per phase per-unit length. The default value is `0.5 mH/km`.

Mutual inductance

Line-line mutual inductance per-unit length. Set this to `0` to remove mutual inductance. The default value is `0.1 mH/km`.

Line-line capacitance

Line-line capacitance per-unit length. The default value is `0.3 μF/km`.

Line-ground capacitance

Line-ground capacitance per-unit length. The default value is `0 μF/km` (no line-ground capacitance).

Mutual Resistance

Line-line mutual resistance per unit length. The default value is `0 Ohm/km` (no line-line mutual resistance).

Number of segments

Number of segments in the pi-line model. The default value is `1`.

Parasitics tab

Parasitic series resistance

Resistance value, divided by the number of segments, that is added in series with every capacitor in the model. The default value is `1e-6 Ohm`.

Parasitic parallel conductance

Conductance value, divided by the number of segments, that is added in parallel with every series resistor and inductor in the model. The default value is `1e-6 1/Ohm`.

Ports

The block has the following ports:

~1

Expandable three-phase port

~2

Expandable three-phase port

g1

Electrical conserving port corresponding to ground connection at ~1 end of the transmission line

g2

Electrical conserving port corresponding to ground connection at ~2 end of the transmission line
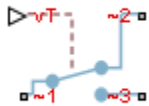
See Also

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Two-Way Switch

Three-phase double-throw switch

Library

Switches & Breakers

Description

The Two-Way Switch block models a three-phase double-throw switch that uses an external signal to connect each phase of the port ~1 with the corresponding phase of either port ~2 or ~3.

The table shows how the external signal vT controls the block behavior.

Condition	Block Behavior	Resistance Parameter Used
vT ≤ **Threshold**	Each phase of port ~1 is connected to the corresponding phase of port ~2 via internal resistance. Port ~3 is unconnected.	**Open conductance** (port ~1 to port ~3). **Closed resistance** (port ~1 to port ~2)
vT > **Threshold**	Each phase of port ~1 is connected to the corresponding phase of port ~3 via internal resistance. Port ~2 is unconnected.	**Open conductance** (port ~1 to port ~2). **Closed resistance** (port ~1 to port ~3)

Parameters

Closed resistance

Resistance between ports ~1 and ~3 when the switch is closed. The default value is 0.001 Ohm.

Open conductance

Conductance between ports ~1 and ~2 when the switch is open. The default value is 1e-6 1/Ohm.

Threshold

Threshold voltage for the control port vT. When the voltage is above the threshold, the switch is closed. The default value is 0 V.

Ports

The block has the following ports:

~1

Expandable three-phase port

~2

Expandable three-phase port

~3

Expandable three-phase port

vT

Scalar control port, which is either a physical signal or an electrical port.

See Also

See Also

Single-Phase Switch | Single-Phase Two-Way Switch | Switch

Topics
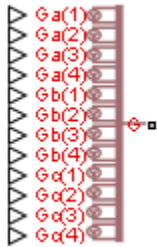"Expand and Collapse Three-Phase Ports on a Block"
"Switch Between Physical Signal and Electrical Ports"

Introduced in R2013b

Twelve-Pulse Gate Multiplexer

Multiplex gate input signals to Three-Level Converter block

Library

Semiconductors

Description

The Twelve-Pulse Gate Multiplexer block routes gate voltage signals to the 12 switching devices in a `Three-Level Converter` block. The block multiplexes the 12 gate signals into a single vector. Gate signals are ordered as A-phase, Behaves, and then Chafes, with four gate signals per phase.

If you want to use Simscape Electronics to model the electronics that drive the Three-Level Converter block, you can switch the input ports of the Twelve-Pulse Gate Multiplexer block from physical signal ports to electrical ports.

When you switch the block inputs to electrical ports, the block shows 12 pairs of electrical connections, each pair corresponding to the gate and cathode of a switching device.

Ports

The block has the following ports:

`Ga(1),Ga(2),Ga(3),Ga(4)`

Ports associated with the gate terminals of the Three-Level Converter A-phase switching devices. You can set the ports to either physical signal or electrical ports.

`Gb(1),Gb(2),Gb(3),Gb(4)`

Ports associated with the gate terminals of the Three-Level Converter Behaves switching devices. You can set the ports to either physical signal or electrical ports.

`Gc(1),Gc(2),Gc(3),Gc(4)`

Ports associated with the gate terminals of the Three-Level Converter Chafes switching devices. You can set the ports to either physical signal or electrical ports.

`G`

Vector output port associated with the multiplexed gate signals. Connect this port to the G port of the Three-Level Converter block.

`Ka(1),Ka(2),Ka(3),Ka(4)`

Electrical conserving ports associated with the individual cathode terminals corresponding to the Three-Level Converter block A-phase switching devices. These ports are visible only if you set the input ports of the Twelve-Pulse Gate Multiplexer block to electrical ports.

`Kb(1),Kb(2),Kb(3),Kb(4)`

Electrical conserving ports associated with the individual cathode terminals corresponding to the Three-Level Converter block Behaves switching devices. These ports are visible only if you set the input ports of the Twelve-Pulse Gate Multiplexer block to electrical ports.

`Kc(1),Kc(2),Kc(3),Kc(4)`

Electrical conserving ports associated with the individual cathode terminals corresponding to the Three-Level Converter block Chafes switching devices. These ports are visible only if you set the input ports of the Twelve-Pulse Gate Multiplexer block to electrical ports.

See Also

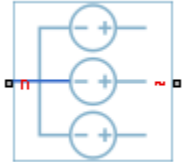## See Also
`Six-Pulse Gate Multiplexer | Three-Level Converter`

Topics
"Switch Between Physical Signal and Electrical Ports"

Introduced in R2014b

Voltage Source

Three-phase voltage source

Library

Sources

Description

The Voltage Source block models an ideal three-phase voltage source or a three-phase voltage source with harmonics. You specify the configuration using the Source representation parameter.

When you specify the ideal three-phase voltage source representation, the Voltage Source block models an ideal three-phase voltage source that maintains sinusoidal voltage of the specified magnitude across its terminals, independent of the current flowing through the source.

The output voltage is defined by the following equations:

$$V_0 = \frac{\sqrt{2}}{\sqrt{3}} v_{line\_rms}$$

$$v_a = V_0 \sin(2\pi f t + \varphi)$$

$$v_b = V_0 \sin(2\pi f t + \varphi - 120°)$$

$$v_c = V_0 \sin(2\pi f t + \varphi + 120°),$$

where:

- V_0 is the peak phase voltage.
- $v_{\text{line\_rms}}$ is the RMS phase-to-phase voltage.
- v_a, v_b, v_c are the respective phase voltages.
- f is the frequency.
- φ is the phase shift.
- t is the time.

When you specify the three-phase voltage source with harmonics representation, the Voltage Source block models a three-phase voltage source that maintains the fundamental frequency and harmonics of the specified magnitude across its terminals, independent of the current flowing through the source.

The output voltage is defined by the following equations:

$$V_0 = \frac{\sqrt{2}}{\sqrt{3}} v_{line\_rms} H_{ratios}$$

$$v_a = V_0 \sin((2\pi ft + \varphi) H'_{orders})$$

$$v_b = V_0 \sin((2\pi ft + \varphi - \theta) H'_{orders})$$

$$v_c = V_0 \sin((2\pi ft + \varphi + \theta) H'_{orders}),$$

where:

- V_0 is a row-vector containing the peak voltage of the fundamental and harmonic sinusoids.
- $v_{\text{line\_rms}}$ is the RMS phase-to-phase voltage.
- H_{ratios} is a row-vector of harmonic ratios. The first element is 1 to represent the fundamental.
- H_{orders} is a row-vector of harmonic orders. The first element is 1 to represent the fundamental.
- v_a, v_b, v_c are the respective phase voltages.

- *f* is a column-vector of harmonic frequencies. The first element is the fundamental frequency.
- *φ* is a column-vector of harmonic phase shifts. The first element is the fundamental phase shift.
- *θ* is a column-vector of harmonic phase offsets. The first element is 120°.
- *t* is the time.

The source has a wye configuration, and port n provides a connection to the center of the wye. Port ~ is an expandable three-phase port representing the three phases, a, b, and c. The current is positive if it flows from positive to the center of the wye, and the voltage across each phase is equal to the difference between the voltage at the positive terminal and the center of the wye, $V(+) - V\text{n}$.

Parameters

- "Main Tab" on page 1-439
- "Harmonics Tab" on page 1-439

Main Tab

Voltage (phase-to-phase RMS)

RMS phase-to-phase, or line, voltage. The default value is `sqrt(3)*100/sqrt(2)`, or 122.4745, `V`.

Phase shift

Phase shift in angular units. The default value is `0 deg`.

Frequency

Voltage frequency, specified in Hz or units directly convertible to Hz (where Hz is defined as 1/s). For example, `kHz` and `MHz` are valid units, but `rad/s` is not. The default value is `60 Hz`.

Harmonics Tab

Source Representation

Choose between `Ideal` and `Include harmonics`. The default value is `Ideal`.

Harmonic orders

A row-vector of additional integer harmonic orders at which harmonics are to be generated. This parameter is only visible when you set the **Source representation** parameter to `Include harmonics`. The default value is `[ 5 7 11 13]`.

Harmonic magnitude to peak magnitude ratios

A row-vector of ratios of harmonic magnitudes relative to the fundamental magnitude. This parameter is only visible when you set the **Source representation** parameter to `Include harmonics`. The default value is `[0.1 0.1 0.1 0.1]`.

Ports

The block has the following ports:

~

Expandable three-phase port

n

Electrical conserving port associated with the center of the wye
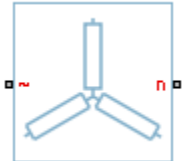
See Also

See Also
`Current Source`

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Wye-Connected Load

Three-phase load wired in wye configuration

Library

Passive Devices

Description

The Wye-Connected Load block models a three-phase load wired in a wye configuration. Each limb of the load can include any combination of a resistor (R), capacitor (C), and inductor (L), connected in series or in parallel.

You can specify values for the R, L, and C components directly in terms of resistance, inductance, and capacitance, or by rated powers at a rated voltage and frequency.

- If you parameterize the block directly in terms or R, L, and C values, then for initialization, provide a three-element row vector of initial voltages for a capacitor, and a three-element row vector of initial currents for an inductor.

- If you parameterize the block in terms of rated powers, then specify initial conditions in terms of an initial voltage, initial voltage phase, and initial frequency. For example, if the load is connected directly to a three-phase voltage source, then the initial conditions are identical to the source values for RMS line voltage, frequency, and phase shift. To specify zero initial-voltage magnitude, set the initial voltage to 0.

For certain combinations of R, L, and C, for some circuit topologies, specify parasitic resistance or conductance values that help the simulation to converge numerically. These parasitic terms ensure that an inductor has a small parallel resistive path and that a capacitor has a small series resistance. When you parameterize the block in terms of

1-441

rated powers, the rated power values do not account for these small parasitic terms. The rated powers represent only the R, L, and C values of the load itself.

Parameters

- "Main Tab" on page 1-442
- "Parasitics Tab" on page 1-443
- "Initial Conditions Tab" on page 1-444

Main Tab

Parameterization

Select one of these values:

- `Specify by rated power` — Specify values for the R, L, and C components by rated powers at a rated voltage and frequency. This is the default.
- `Specify component values directly` — Specify values for the R, L, and C components directly in terms of resistance, inductance, and capacitance.

Switching the **Parameterization** value resets the **Component structure** value. Select the component parameterization option first, and then the component structure. If you later switch the **Parameterization** value, check the **Component structure** value and reselect it, if necessary.

Component structure

Select the desired combination of a resistor (R), capacitor (C), and inductor (L), connected in series or in parallel. The default is `R`, resistor.

Rated voltage

Voltage for which load powers are specified. This parameter is visible only when you specify values by rated power. The default value is `2.4e4` V.

Real power

Total real power dissipated by three-phase load when supplied at the rated voltage. This parameter is visible only when you specify values by rated power and select a component structure that includes a resistor. The value must be greater than 0. The default value is `1000` W.

Rated electrical frequency

Frequency for which reactive load powers are specified. This parameter is visible only when you specify values by rated power. The default value is 60 Hz.

Inductive reactive power

Total inductive reactive power taken by the three-phase load when supplied at the rated voltage. This parameter is visible only when you specify values by rated power and select a component structure that includes an inductor. The value must be greater than 0. The default value is 100 V*A.

Capacitive reactive power

Total capacitive reactive power taken by the three-phase load when supplied at the rated voltage. This parameter is visible only when you specify values by rated power and select a component structure that includes a capacitor. The value must be less than 0. The default value is -100 V*A.

Resistance

Resistance of each of the load limbs. This parameter is visible only when you specify component values directly and select a component structure that includes a resistor. The default value is 1 Ohm.

Inductance

Inductance of each of the load limbs. This parameter is visible only when you specify component values directly and select a component structure that includes an inductor. The default value is 0.001 H.

Capacitance

Capacitance in each of the load limbs. This parameter is visible only when you specify component values directly and select a component structure that includes a capacitor. The default value is 1e-6 F.

Parasitics Tab

Parasitic series resistance

Represents small parasitic effects. The parameter value corresponds to the series resistance value added to all instances of capacitors in the load. The default value is 1e-6 Ohm.

Parasitic parallel conductance

Represents small parasitic effects. The parameter value corresponds to the parallel conductance value added across all instances of inductors in the load. The default value is 1e-6 1/Ohm.

Initial Conditions Tab

Terminal voltage magnitude

Expected initial RMS line voltage at the load. This parameter is visible only when you specify values by rated power. The default value is `2.4e4` V.

Terminal voltage angle

Expected initial phase of the voltage at the load. This parameter is visible only when you specify values by rated power. The default value is `0 deg`.

Frequency

Expected initial frequency at the load. This parameter is visible only when you specify values by rated power. The default value is `60 Hz`.

Initial inductor current [Ia Ib Ic]

Initial current in the a, b, and c phase inductors, respectively. This parameter is visible only when you specify component values directly and select a component structure that includes an inductor. The default value is `[0 0 0]` A.

Initial capacitor voltage [Va Vb Vc]

Initial voltage across the a, b, and c phase capacitors, respectively. This parameter is visible only when you specify component values directly and select a component structure that includes a capacitor. The default value is `[0 0 0]` V.

Block Parameterization

The following two tables list the block parameters for each **Component structure**, based on the selected **Parameterization** option:

- Specify by rated power
- Specify component values directly

Specify by Rated Power

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
R	Rated voltage Real power	None	None
L	Rated voltage Rated electrical frequency	Parasitic parallel conductance	Terminal voltage magnitude

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
	Inductive reactive power		Terminal voltage angle Frequency
C	Rated voltage Rated electrical frequency Capacitive reactive power	Parasitic series resistance	Terminal voltage magnitude Terminal voltage angle Frequency
Series RL	Rated voltage Rated electrical frequency Real power Inductive reactive power	Parasitic parallel conductance	Terminal voltage magnitude Terminal voltage angle Frequency
Series RC	Rated voltage Rated electrical frequency Real power Capacitive reactive power	None	Terminal voltage magnitude Terminal voltage angle Frequency
Series LC	Rated voltage Rated electrical frequency Inductive reactive power Capacitive reactive power	Parasitic parallel conductance	Terminal voltage magnitude Terminal voltage angle Frequency

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
Series RLC	Rated voltage Rated electrical frequency Real power Inductive reactive power Capacitive reactive power	Parasitic parallel conductance	Terminal voltage magnitude Terminal voltage angle Frequency
Parallel RL	Rated voltage Rated electrical frequency Real power Inductive reactive power	None	Terminal voltage magnitude Terminal voltage angle Frequency
Parallel RC	Rated voltage Rated electrical frequency Real power Capacitive reactive power	Parasitic series resistance	Terminal voltage magnitude Terminal voltage angle Frequency
Parallel LC	Rated voltage Rated electrical frequency Inductive reactive power	Parasitic series resistance	Terminal voltage magnitude Terminal voltage angle Frequency

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
	Capacitive reactive power		
Parallel RLC	Rated voltage Rated electrical frequency Real power Inductive reactive power Capacitive reactive power	Parasitic series resistance	Terminal voltage magnitude Terminal voltage angle Frequency

Specify Component Values Directly

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
R	Resistance	None	None
L	Inductance	Parasitic parallel conductance	Initial inductor current [Ia Ib Ic]
C	Capacitance	Parasitic series resistance	Initial capacitor voltage [Va Vb Vc]
Series RL	Resistance Inductance	Parasitic parallel conductance	Initial inductor current [Ia Ib Ic]
Series RC	Resistance Capacitance	None	Initial capacitor voltage [Va Vb Vc]
Series LC	Inductance Capacitance	Parasitic parallel conductance	Initial inductor current [Ia Ib Ic] Initial capacitor voltage [Va Vb Vc]
Series RLC	Resistance Inductance	Parasitic parallel conductance	Initial inductor current [Ia Ib Ic]

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
	Capacitance		Initial capacitor voltage [Va Vb Vc]
Parallel RL	Resistance Inductance	None	Initial inductor current [Ia Ib Ic]
Parallel RC	Resistance Capacitance	Parasitic series resistance	Initial capacitor voltage [Va Vb Vc]
Parallel LC	Inductance Capacitance	Parasitic series resistance	Initial inductor current [Ia Ib Ic] Initial capacitor voltage [Va Vb Vc]
Parallel RLC	Resistance Inductance Capacitance	Parasitic series resistance	Initial inductor current [Ia Ib Ic] Initial capacitor voltage [Va Vb Vc]

Ports

The block has the following ports:

~

    Expandable three-phase port

n

    Electrical conserving port associated with the neutral phase

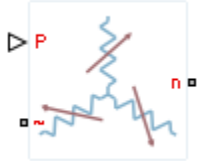## See Also

See Also
Delta-Connected Load | RLC

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Wye-Connected Variable Load

Three-phase variable load wired in wye configuration

Library

Passive Devices / Time Varying

Description

The Wye-Connected Variable Load block models a three-phase variable load wired in a wye configuration. Each limb of the load contains a resistor. The block calculates the resistance required to draw the real power of the physical signal input P at the rated voltage that you specify. Therefore, the block can represent a real load.

To ensure that the resistance is always greater than zero, you specify the minimum real power that the load consumes. The minimum real power must be greater than zero.

Electrical Defining Equations

The resistance is defined by

$$R = \frac{V_{Rated}^2}{P},$$

where:

- R is the per-phase series resistance.

- V_{Rated} is the RMS, rated line-line voltage.
- P is the three-phase real power required.

Parameters

Main Tab

Rated voltage

RMS, rated line-line voltage for the resistance equation. The default value is `24e3` V.

Minimum real power

Minimum real power that the three-phase load dissipates when supplied at the rated voltage. The value must be greater than 0. The default value is `1e3` W.

Ports

The block has the following ports:

P

Physical signal input port for real power

~

Expandable three-phase port

n

Electrical conserving port associated with the neutral phase

See Also

See Also
Wye-Connected Load | Wye-Connected Variable Load (lagging)

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2014b

Wye-Connected Variable Load (lagging)

Three-phase variable, lagging load wired in wye configuration
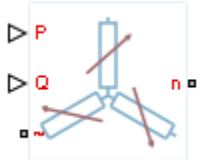
Library

Passive Devices / Time Varying

Description

The Wye-Connected Variable Load (lagging) block models a three-phase variable, lagging load wired in a wye configuration. Each limb of the load contains a resistor (R) and an inductor (L) connected in series. The block calculates the resistance and inductance required to draw the real and reactive powers of the physical signal inputs P and Q at the rated voltage and rated frequency that you specify. Therefore, the block can represent a real and lagging reactive load.

To ensure that the resistance and inductance are always greater than zero, you specify the minimum real power and the reactive power that the load consumes. The minimum real power and the reactive power must be greater than zero.

Electrical Defining Equations

The per-phase series resistance and inductance are defined by

$$R = \frac{PV_{Rated}^2}{P^2 + Q^2}$$

and

$$L = \frac{QV_{Rated}^2}{2\pi F_{Rated}\left(P^2 + Q^2\right)},$$

where:

- R is the per-phase series resistance.
- L is the per-phase series inductance.
- V_{Rated} is the RMS, rated line-line voltage.
- F_{Rated} is the nominal AC electrical frequency.
- P is the three-phase real power required.
- Q is the three-phase lagging reactive power required.

The inductance is defined as the ratio of the magnetic flux, φ, to the steady-state current:

$$L(i) = \frac{\phi(i)}{i}.$$

Therefore the current-voltage relationship for the inductor is:

$$v = \frac{dL}{dt}i + L\frac{di}{dt}.$$

Parameters

- "Main Tab" on page 1-454
- "Parasitics" on page 1-455
- "Variables Tab" on page 1-455

Main Tab

Rated voltage

RMS, rated line-line voltage for the resistance equation. The default value is 24e3 V.

Rated electrical frequency

Nominal AC electrical frequency for the inductance equation. The default value is `60 Hz`.

Minimum real power

Minimum real power that the three-phase load dissipates when supplied at the rated voltage. The value must be greater than 0. The default value is `1e3 W`.

Minimum reactive power

Minimum reactive power that the three-phase load dissipates when supplied at the rated voltage. The value must be greater than 0. The default value is `1e3 V*A`.

Parasitics

Parasitic parallel conductance

Conductance that the block adds, in parallel, to the series RL. The default value is `1e-6 1/Ohm`.

Variables Tab

Use the **Variables** tab to set the priority and initial target values for the block variables before simulation. For more information, see "Set Priority and Initial Target for Block Variables" (Simscape) .

Unlike block parameters, variables do not have conditional visibility. The **Variables** tab lists all the existing block variables. If a variable is not used in the set of equations corresponding to the selected block configuration, the values specified for this variable are ignored.

Ports

The block has the following ports:

`P`

Physical signal input port for real power

`Q`

Physical signal input port for reactive power

`~`

Expandable three-phase port

n

Electrical conserving port associated with the neutral phase.

See Also

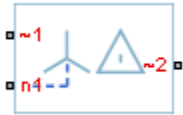### See Also
Wye-Connected Load | Wye-Connected Variable Load

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2014b

Wye-Delta1 Transformer

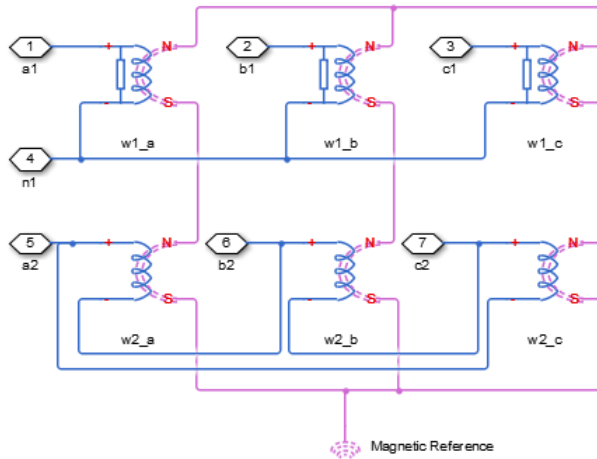Linear nonideal wye-delta1 transformer with three-limb core

Library

Passive Devices / Transformers

Description

The Wye-Delta1 Transformer block models a linear, nonideal transformer with a three-limb core, in which the primary windings are configured in a wye connection and the secondary windings are configured in a delta connection. The delta voltages lag the wye voltages by 30 degrees, hence the name 1 o'clock delta. The block includes linear winding leakage and linear core magnetization effects.

The figure shows the equivalent circuit diagram for the wye-delta1 transformer.

Magnetic Reference

- $w1_a$ is the primary winding connected between the a-phase and the primary neutral point.
- $w1_b$ is the primary winding connected between the b-phase and the primary neutral point.
- $w1_c$ is the primary winding connected between the c-phase and the primary neutral point.
- $w2_a$ is the secondary winding connected between the a-phase and the b-phase.
- $w2_b$ is the secondary winding connected between the b-phase and the c-phase.
- $w2_c$ is the secondary winding connected between the c-phase and the a-phase.

Display Options

You can display the transformer per-unit base values in the MATLAB command window using the block context menu. To display the values, right-click the block and select **Power Systems** > **Display Base Values**.

Parameters

- "Main Tab" on page 1-459

Main Tab

Rated apparent power

Apparent power flowing through the transformer when operating at rated capacity. The default value is 100e6 V*A.

Primary rated voltage

RMS line voltage applied to the primary winding under normal operating conditions. The default value is 4160 V.

Secondary rated voltage

RMS line voltage applied to the secondary winding under normal operating conditions. The default value is 24e3 V.

Rated electrical frequency

Rated or nominal frequency of the AC network to which the transformer is connected. The default value is 60 Hz.

Impedances Tab

Parameters in this tab are expressed in per unit (pu). For more information, see "Per-Unit System of Units".

Primary leakage resistance (pu)

Power loss in the primary winding. The default value is 0.01.

Primary leakage reactance (pu)

Magnetic flux loss in the primary winding. The default value is 0.001.

Secondary leakage resistance (pu)

Power loss in the secondary winding. The default value is 0.01.

Secondary leakage reactance (pu)

Magnetic flux loss in the secondary winding. The default value is 0.001.

Shunt magnetizing resistance (pu)

Magnetic losses in transformer core. The default value is 500.

Shunt magnetizing reactance (pu)

Magnetic effects of the transformer core when operating in its linear region. The default value is 500.

Initial Conditions Tab

Initial primary currents

Current through the primary leakage inductors at time zero. The default value is [0 0 0] A.

Initial secondary currents

Current through the secondary leakage inductors at time zero. The default value is [0 0 0] A.

Initial magnetizing currents

Current through the shunt magnetization inductors at time zero. The default value is [0 0 0] A.

Initial fluxes

Magnetic fluxes in the limbs of the core at time zero. The default value is [0 0 0] Wb.

Ports

The block has the following ports:

~1

Expandable three-phase port for primary winding

~2

Expandable three-phase port for secondary winding

n1

Electrical conserving port associated with the primary winding neutral point

See Also

See Also
Delta-Delta Transformer | Delta1-Delta1-Wye Transformer | Delta11-Delta11-Wye Transformer | Wye-Delta1-Wye Transformer | Wye-Delta11

Transformer | Wye-Delta11-Wye Transformer | Wye-Wye Transformer |
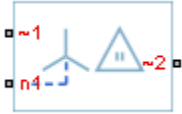Zigzag-Delta1-Wye Transformer | Zigzag-Delta11-Wye Transformer

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Wye-Delta11 Transformer

Linear nonideal wye-delta11 transformer with three-limb core

Library

Passive Devices / Transformers

Description

The Wye-Delta11 Transformer block models a linear, nonideal transformer with a three-limb core, in which the primary windings are configured in a wye connection and the secondary windings are configured in a delta connection. The delta voltages lead the wye voltages by 30 degrees, hence the name 11 o'clock delta. The block includes linear winding leakage and linear core magnetization effects.

The figure shows the equivalent circuit diagram for the wye-delta11 transformer.
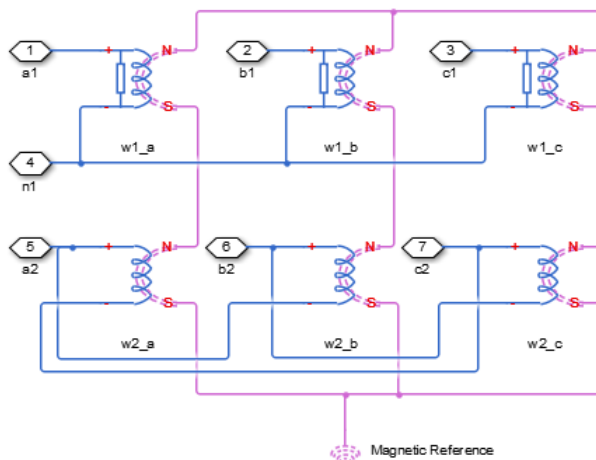
- $w1_a$ is the primary winding connected between the a-phase and the primary neutral point.
- $w1_b$ is the primary winding connected between the b-phase and the primary neutral point.
- $w1_c$ is the primary winding connected between the c-phase and the primary neutral point.
- $w2_a$ is the secondary winding connected between the a-phase and the c-phase.
- $w2_b$ is the secondary winding connected between the b-phase and the a-phase.
- $w2_c$ is the secondary winding connected between the c-phase and the b-phase.

Display Options

You can display the transformer per-unit base values in the MATLAB command window using the block context menu. To display the values, right-click the block and select **Power Systems** > **Display Base Values**.

Parameters

- "Main Tab" on page 1-463
- "Impedances Tab" on page 1-464
- "Initial Conditions Tab" on page 1-464

Main Tab

Rated apparent power

Apparent power flowing through the transformer when operating at rated capacity. The default value is 100e6 V*A.

Primary rated voltage

RMS line voltage applied to the primary winding under normal operating conditions. The default value is 4160 V.

Secondary rated voltage

RMS line voltage applied to the secondary winding under normal operating conditions. The default value is 24e3 V.

Rated electrical frequency

Rated or nominal frequency of the AC network to which the transformer is connected. The default value is 60 Hz.

Impedances Tab

Parameters in this tab are expressed in per-unit (pu). For more information, see "Per-Unit System of Units".

Primary leakage resistance (pu)

Power loss in the primary winding. The default value is 0.01.

Primary leakage reactance (pu)

Magnetic flux loss in the primary winding. The default value is 0.001.

Secondary leakage resistance (pu)

Power loss in the secondary winding. The default value is 0.01.

Secondary leakage reactance (pu)

Magnetic flux loss in the secondary winding. The default value is 0.001.

Shunt magnetizing resistance (pu)

Magnetic losses in transformer core. The default value is 500.

Shunt magnetizing reactance (pu)

Magnetic effects of the transformer core when operating in its linear region. The default value is 500.

Initial Conditions Tab

Initial primary currents

Current through the primary leakage inductors at time zero. The default value is [0 0 0] A.

Initial secondary currents

Current through the secondary leakage inductors at time zero. The default value is [0 0 0] A.

Initial magnetizing currents

Current through the shunt magnetization inductors at time zero. The default value is [0 0 0] A.

Initial fluxes

Magnetic fluxes in the limbs of the core at time zero. The default value is `[0 0 0]` Wb.

Ports

The block has the following ports:

~1

Expandable three-phase port for primary winding

~2

Expandable three-phase port for secondary winding

n1

Electrical conserving port associated with the primary winding neutral point

See Also

See Also

Delta-Delta Transformer | Delta1-Delta1-Wye Transformer | Delta11-Delta11-Wye Transformer | Wye-Delta1 Transformer | Wye-Delta1-Wye Transformer | Wye-Delta11-Wye Transformer | Wye-Wye Transformer | Zigzag-Delta1-Wye Transformer | Zigzag-Delta11-Wye Transformer
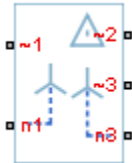
Topics

"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Wye-Delta1-Wye Transformer

Linear nonideal wye-delta1-wye transformer with three-limb core
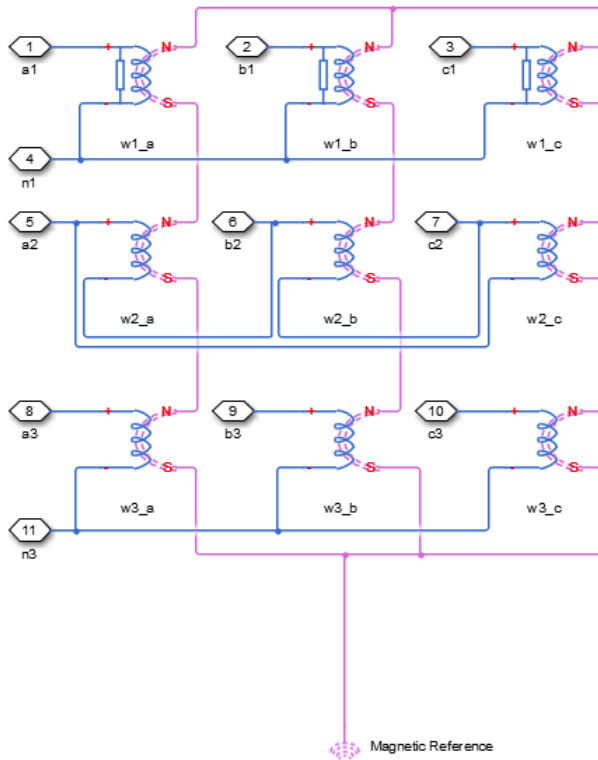

Library

Passive Devices / Transformers

Description

The Wye-Delta1-Wye Transformer block models a linear, nonideal transformer with a three-limb core, in which the primary windings are configured in a wye connection and there are delta secondary windings and wye secondary windings. The delta voltages lag the wye voltages by 30 degrees, hence the name 1 o'clock delta. The block includes linear winding leakage and linear core magnetization effects.

The figure shows the equivalent circuit diagram for the wye-delta1-wye transformer.

- $w1_a$ is the primary winding connected between the a-phase and the primary neutral point.
- $w1_b$ is the primary winding connected between the b-phase and the primary neutral point.
- $w1_c$ is the primary winding connected between the c-phase and the primary neutral point.
- $w2_a$ is the secondary winding connected between the a-phase and the b-phase.
- $w2_b$ is the secondary winding connected between the b-phase and the c-phase.
- $w2_c$ is the secondary winding connected between the c-phase and the a-phase.
- $w3_a$ is the secondary winding connected between the a-phase and the secondary neutral point.

- $w3_b$ is the secondary winding connected between the b-phase and the secondary neutral point.
- $w3_c$ is the secondary winding connected between the c-phase and the secondary neutral point.

Display Options

You can display the transformer per-unit base values in the MATLAB command window using the block context menu. To display the values, right-click the block and select **Power Systems** > **Display Base Values**.

Parameters

- "Main Tab" on page 1-468
- "Impedances Tab" on page 1-469
- "Initial Conditions Tab" on page 1-469

Main Tab

Rated apparent power

Apparent power flowing through the transformer when operating at rated capacity. The default value is 100e6 V*A.

Primary rated voltage

RMS line voltage applied to the primary winding under normal operating conditions. The default value is 4160 V.

Delta secondary rated voltage

RMS line voltage applied to the delta secondary winding under normal operating conditions. The default value is 24e3 V.

Wye secondary rated voltage

RMS line voltage applied to the wye secondary winding under normal operating conditions. The default value is 24e3 V.

Rated electrical frequency

Rated or nominal frequency of the AC network to which the transformer is connected. The default value is 60 Hz.

Impedances Tab

Parameters in this tab are expressed in per-unit (pu). For more information, see "Per-Unit System of Units".

Primary leakage resistance (pu)

Power loss in the primary winding. The default value is `0.01`.

Primary leakage reactance (pu)

Magnetic flux loss in the primary winding. The default value is `0.001`.

Delta secondary leakage resistance (pu)

Power loss in the delta secondary winding. The default value is `0.01`.

Delta secondary leakage reactance (pu)

Magnetic flux loss in the delta secondary winding. The default value is `0.001`.

Wye secondary leakage resistance (pu)

Power loss in the wye secondary winding. The default value is `0.01`.

Wye secondary leakage reactance (pu)

Magnetic flux loss in the wye secondary winding. The default value is `0.001`.

Shunt magnetizing resistance (pu)

Magnetic losses in transformer core. The default value is `500`.

Shunt magnetizing reactance (pu)

Magnetic effects of the transformer core when operating in its linear region. The default value is `500`.

Initial Conditions Tab

Initial primary currents

Current through the primary leakage inductors at time zero. The default value is `[0 0 0]` A.

Initial delta secondary currents

Current through the delta secondary leakage inductors at time zero. The default value is `[0 0 0]` A.

Initial wye secondary currents

Current through the wye secondary leakage inductors at time zero. The default value is `[0 0 0]` A.

Initial magnetizing currents

Current through the shunt magnetization inductors at time zero. The default value is [0 0 0] A.

Initial fluxes

Magnetic fluxes in the limbs of the core at time zero. The default value is [0 0 0] Wb.

Ports

The block has the following ports:

~1

Expandable three-phase port for primary winding

~2

Expandable three-phase port for delta secondary winding

~3

Expandable three-phase port for wye secondary winding

n1

Electrical conserving port associated with the primary winding neutral point

n3

Electrical conserving port associated with the wye secondary winding neutral point

See Also

See Also

Delta-Delta Transformer | Delta1-Delta1-Wye Transformer | Delta11-Delta11-Wye Transformer | Wye-Delta1 Transformer | Wye-Delta11 Transformer | Wye-Delta11-Wye Transformer | Wye-Wye Transformer | Zigzag-Delta1-Wye Transformer | Zigzag-Delta11-Wye Transformer

Topics
"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Wye-Delta11-Wye Transformer

Linear nonideal wye-delta11-wye transformer with three-limb core

Library

Passive Devices / Transformers

Description

The Wye-Delta11-Wye Transformer block models a linear, nonideal transformer with a three-limb core, in which the primary windings are configured in a wye connection and there are delta secondary windings and wye secondary windings. The delta voltages lead the wye voltages by 30 degrees, hence the name 11 o'clock delta. The block includes linear winding leakage and linear core magnetization effects.

The figure shows the equivalent circuit diagram for the wye-delta11-wye transformer.
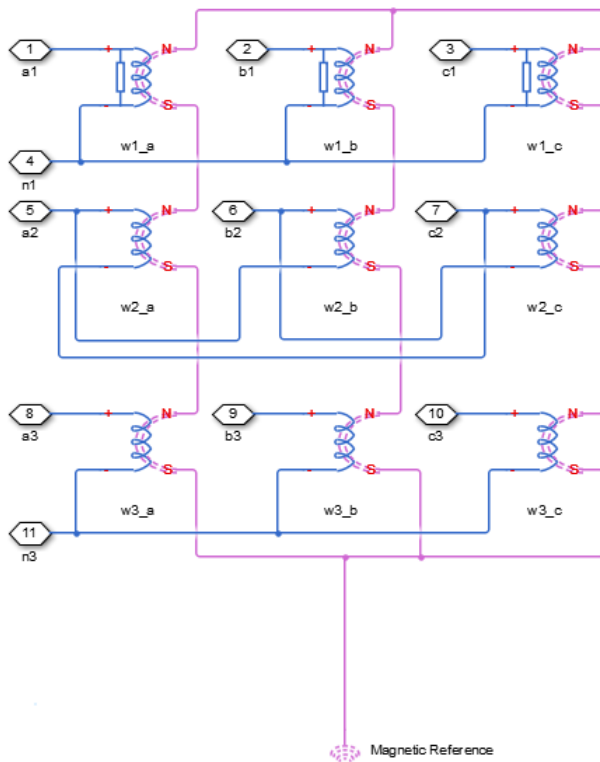
Magnetic Reference

- $w1_a$ is the primary winding connected between the a-phase and the primary neutral point.
- $w1_b$ is the primary winding connected between the b-phase and the primary neutral point.
- $w1_c$ is the primary winding connected between the c-phase and the primary neutral point.
- $w2_a$ is the delta secondary winding connected between the a-phase and the c-phase.
- $w2_b$ is the delta secondary winding connected between the b-phase and the a-phase.
- $w2_c$ is the delta secondary winding connected between the c-phase and the b-phase.
- $w3_a$ is the wye secondary winding connected between the a-phase and the secondary neutral point.

- $w3_b$ is the wye secondary winding connected between the b-phase and the secondary neutral point.
- $w3_c$ is the wye secondary winding connected between the c-phase and the secondary neutral point.

Display Options

You can display the transformer per-unit base values in the MATLAB command window using the block context menu. To display the values, right-click the block and select **Power Systems** > **Display Base Values**.

Parameters

- "Main Tab" on page 1-474
- "Impedances Tab" on page 1-475
- "Initial Conditions Tab" on page 1-475

Main Tab

Rated apparent power

Apparent power flowing through the transformer when operating at rated capacity. The default value is 100e6 V*A.

Primary rated voltage

RMS line voltage applied to the primary winding under normal operating conditions. The default value is 4160 V.

Delta secondary rated voltage

RMS line voltage applied to the delta secondary winding under normal operating conditions. The default value is 24e3 V.

Wye secondary rated voltage

RMS line voltage applied to the wye secondary winding under normal operating conditions. The default value is 24e3 V.

Rated electrical frequency

Rated or nominal frequency of the AC network to which the transformer is connected. The default value is 60 Hz.

Impedances Tab

Parameters in this tab are expressed in per-unit (pu). For more information, see "Per-Unit System of Units".

Primary leakage resistance (pu)

Power loss in the primary winding. The default value is `0.01`.

Primary leakage reactance (pu)

Magnetic flux loss in the primary winding. The default value is `0.001`.

Delta secondary leakage resistance (pu)

Power loss in the delta secondary winding. The default value is `0.01`.

Delta secondary leakage reactance (pu)

Magnetic flux loss in the delta secondary winding. The default value is `0.001`.

Wye secondary leakage resistance (pu)

Power loss in the wye secondary winding. The default value is `0.01`.

Wye secondary leakage reactance (pu)

Magnetic flux loss in the wye secondary winding. The default value is `0.001`.

Shunt magnetizing resistance (pu)

Magnetic losses in transformer core. The default value is `500`.

Shunt magnetizing reactance (pu)

Magnetic effects of the transformer core when operating in its linear region. The default value is `500`.

Initial Conditions Tab

Initial primary currents

Current through the primary leakage inductors at time zero. The default value is `[0 0 0]` A.

Initial delta secondary currents

Current through the delta secondary leakage inductors at time zero. The default value is `[0 0 0]` A.

Initial wye secondary currents

Current through the wye secondary leakage inductors at time zero. The default value is `[0 0 0]` A.

Initial magnetizing currents

Current through the shunt magnetization inductors at time zero. The default value is [0 0 0] A.

Initial fluxes

Magnetic fluxes in the limbs of the core at time zero. The default value is [0 0 0] Wb.

Ports

The block has the following ports:

~1

Expandable three-phase port for primary winding

~2

Expandable three-phase port for delta secondary winding

~3

Expandable three-phase port for wye secondary winding

n1

Electrical conserving port associated with the primary winding neutral point

n3

Electrical conserving port associated with the wye secondary winding neutral point

See Also

See Also

Delta-Delta Transformer | Delta1-Delta1-Wye Transformer | Delta11-Delta11-Wye Transformer | Wye-Delta1 Transformer | Wye-Delta1-Wye Transformer | Wye-Delta11 Transformer | Wye-Wye Transformer | Zigzag-Delta1-Wye Transformer | Zigzag-Delta11-Wye Transformer
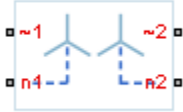
Topics

"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Wye-Wye Transformer

Linear nonideal wye-wye transformer with three-limb core

Library

Passive Devices / Transformers

Description

The Wye-Wye Transformer block models a linear, nonideal transformer with a three-limb core, in which both the primary and the secondary windings are configured in a wye connection. The block includes linear winding leakage and linear core magnetization effects.

The figure shows the equivalent circuit diagram for the wye-wye transformer.
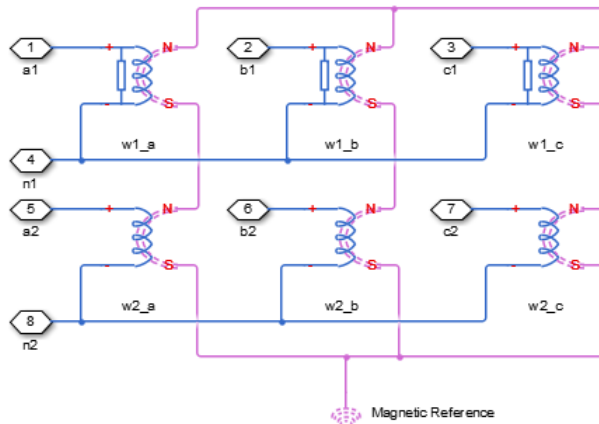
- $w1_a$ is the primary winding connected between the a-phase and the primary neutral point.
- $w1_b$ is the primary winding connected between the b-phase and the primary neutral point.
- $w1_c$ is the primary winding connected between the c-phase and the primary neutral point.
- $w2_a$ is the secondary winding connected between the a-phase and the secondary neutral point.
- $w2_b$ is the secondary winding connected between the b-phase and the secondary neutral point.
- $w2_c$ is the secondary winding connected between the c-phase and the secondary neutral point.

Display Options

You can display the transformer per-unit base values in the MATLAB command window using the block context menu. To display the values, right-click the block and select **Power Systems** > **Display Base Values**.

Parameters

- "Main Tab" on page 1-479
- "Impedances Tab" on page 1-480
- "Initial Conditions Tab" on page 1-480

Main Tab

Rated apparent power

Apparent power flowing through the transformer when operating at rated capacity. The default value is 100e6 V*A.

Primary rated voltage

RMS line voltage applied to the primary winding under normal operating conditions. The default value is 4160 V.

Secondary rated voltage

RMS line voltage applied to the secondary winding under normal operating conditions. The default value is `24e3 V`.

Rated electrical frequency

Rated or nominal frequency of the AC network to which the transformer is connected. The default value is `60 Hz`.

Impedances Tab

Parameters in this tab are expressed in per-unit (pu). For more information, see "Per-Unit System of Units"

Primary leakage resistance (pu)

Power loss in the primary winding. The default value is `0.01`.

Primary leakage reactance (pu)

Magnetic flux loss in the primary winding. The default value is `0.001`.

Secondary leakage resistance (pu)

Power loss in the secondary winding. The default value is `0.01`.

Secondary leakage reactance (pu)

Magnetic flux loss in the secondary winding. The default value is `0.001`.

Shunt magnetizing resistance (pu)

Magnetic losses in transformer core. The default value is `500`.

Shunt magnetizing reactance (pu)

Magnetic effects of the transformer core when operating in its linear region. The default value is `500`.

Initial Conditions Tab

Initial primary currents

Current through the primary leakage inductors at time zero. The default value is `[0 0 0] A`.

Initial secondary currents

Current through the secondary leakage inductors at time zero. The default value is `[0 0 0] A`.

Initial magnetizing currents

Current through the shunt magnetization inductors at time zero. The default value is `[0 0 0]` A.

Initial fluxes

Magnetic fluxes in the limbs of the core at time zero. The default value is `[0 0 0]` Wb.

Ports

The block has the following ports:

`~1`

Expandable three-phase port for primary winding

`~2`

Expandable three-phase port for secondary winding

`n1`

Electrical conserving port associated with the primary winding neutral point

`n2`

Electrical conserving port associated with the secondary winding neutral point

See Also

See Also

`Delta-Delta Transformer` | `Delta1-Delta1-Wye Transformer` | `Delta11-Delta11-Wye Transformer` | `Wye-Delta1 Transformer` | `Wye-Delta1-Wye Transformer` | `Wye-Delta11 Transformer` | `Wye-Delta11-Wye Transformer` | `Zigzag-Delta1-Wye Transformer` | `Zigzag-Delta11-Wye Transformer`

Topics

"Expand and Collapse Three-Phase Ports on a Block"

Introduced in R2013b

Zigzag-Delta1-Wye Transformer

Linear nonideal zigzag-delta1-wye transformer with three-limb core
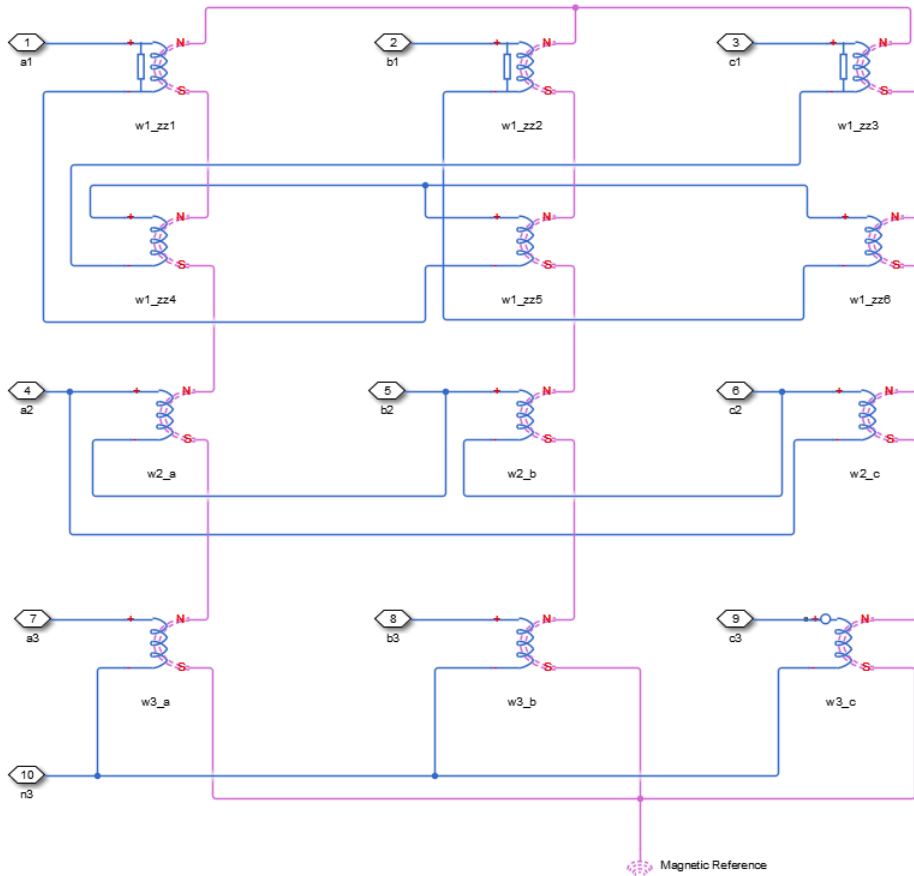

Library

Passive Devices / Transformers

Description

The Zigzag-Delta1-Wye Transformer block models a linear, nonideal transformer with a three-limb core, in which the primary windings are configured in a zigzag connection and there are delta secondary windings and wye secondary windings. You can specify the phase offset between the zigzag and wye windings via a block parameter. The delta voltages lag the wye voltages by 30 degrees, hence the name one o'clock delta. The block includes linear winding leakage and linear core magnetization effects.

The figure shows the equivalent circuit diagram for the zigzag-delta1-wye transformer.

Magnetic Reference

- $w1_{zz1}$ is the primary winding located on the first limb of the core, connected between the a-phase and the negative terminal of winding $w1_{zz5}$.

- $w1_{zz2}$ is the primary winding located on the second limb of the core, connected between the b-phase and the negative terminal of winding $w1_{zz6}$.

- $w1_{zz3}$ is the primary winding located on the third limb of the core, connected between the c-phase and the negative terminal of winding $w1_{zz4}$.

- $w1_{zz4}$ is the primary winding located on the first limb of the core, connected between the zigzag neutral point and the negative terminal of winding $w1_{zz3}$.

- $w1_{zz5}$ is the primary winding located on the second limb of the core, connected between the zigzag neutral point and the negative terminal of winding $w1_{zz1}$.
- $w1_{zz6}$ is the primary winding located on the third limb of the core, connected between the zigzag neutral point and the negative terminal of winding $w1_{zz2}$.
- $w2_a$ is the secondary winding connected between the a-phase and the b-phase.
- $w2_b$ is the secondary winding connected between the b-phase and the c-phase.
- $w2_c$ is the secondary winding connected between the c-phase and the a-phase.
- $w3_a$ is the secondary winding connected between the a-phase and the secondary neutral point.
- $w3_b$ is the secondary winding connected between the b-phase and the secondary neutral point.
- $w3_c$ is the secondary winding connected between the c-phase and the secondary neutral point.

Display Options

You can display the transformer per-unit base values in the MATLAB command window using the block context menu. To display the values, right-click the block and select **Power Systems** > **Display Base Values**.

Parameters

- "Main Tab" on page 1-484
- "Impedances Tab" on page 1-485
- "Initial Conditions Tab" on page 1-486

Main Tab

Rated apparent power

Apparent power flowing through the transformer when operating at rated capacity. The default value is `100e6 V*A`.

Primary rated voltage

RMS line voltage applied to the primary winding under normal operating conditions. The default value is `24e3 V`.

Delta secondary rated voltage

RMS line voltage applied to the delta secondary winding under normal operating conditions. The default value is 4160 V.

Wye secondary rated voltage

RMS line voltage applied to the wye secondary winding under normal operating conditions. The default value is 4160 V.

Rated electrical frequency

Rated or nominal frequency of the AC network to which the transformer is connected. The default value is 60 Hz.

Wye secondary phase shift

The phase offset between the zigzag and wye secondary windings. The default value is -7.5 deg.

Impedances Tab

Parameters in this tab are expressed in per unit (pu). For more information, see "Per-Unit System of Units".

Primary leakage resistance (pu)

Power loss in the primary winding. The default value is 0.01.

Primary leakage reactance (pu)

Magnetic flux loss in the primary winding. The default value is 0.001.

Delta secondary leakage resistance (pu)

Power loss in the delta secondary winding. The default value is 0.01.

Delta secondary leakage reactance (pu)

Magnetic flux loss in the delta secondary winding. The default value is 0.001.

Wye secondary leakage resistance (pu)

Power loss in the wye secondary winding. The default value is 0.01.

Wye secondary leakage reactance (pu)

Magnetic flux loss in the wye secondary winding. The default value is 0.001.

Shunt magnetizing resistance (pu)

Magnetic losses in transformer core. The default value is 500.

Shunt magnetizing reactance (pu)

Magnetic effects of the transformer core when operating in its linear region. The default value is 500.

Initial Conditions Tab

Initial primary currents

Current through the primary leakage inductors at time zero. The default value is [0 0 0] A.

Initial delta secondary currents

Current through the delta secondary leakage inductors at time zero. The default value is [0 0 0] A.

Initial wye secondary currents

Current through the wye secondary leakage inductors at time zero. The default value is [0 0 0] A.

Initial magnetizing currents

Current through the shunt magnetization inductors at time zero. The default value is [0 0 0] A.

Initial fluxes

Magnetic fluxes in the limbs of the core at time zero. The default value is [0 0 0] Wb.

Ports

The block has the following ports:

~1

Expandable three-phase port for primary winding

~2

Expandable three-phase port for delta secondary winding

~3

Expandable three-phase port for wye secondary winding

n3

Electrical conserving port associated with the wye secondary winding neutral point

See Also

See Also

Delta-Delta Transformer | Delta1-Delta1-Wye Transformer | Delta11-Delta11-Wye Transformer | Wye-Delta1 Transformer | Wye-Delta1-Wye Transformer | Wye-Delta11 Transformer | Wye-Delta11-Wye Transformer | Wye-Wye Transformer | Zigzag-Delta11-Wye Transformer

Topics

"Expand and Collapse Three-Phase Ports on a Block"
Custom Zigzag Transformer

Introduced in R2015a

Zigzag-Delta11-Wye Transformer

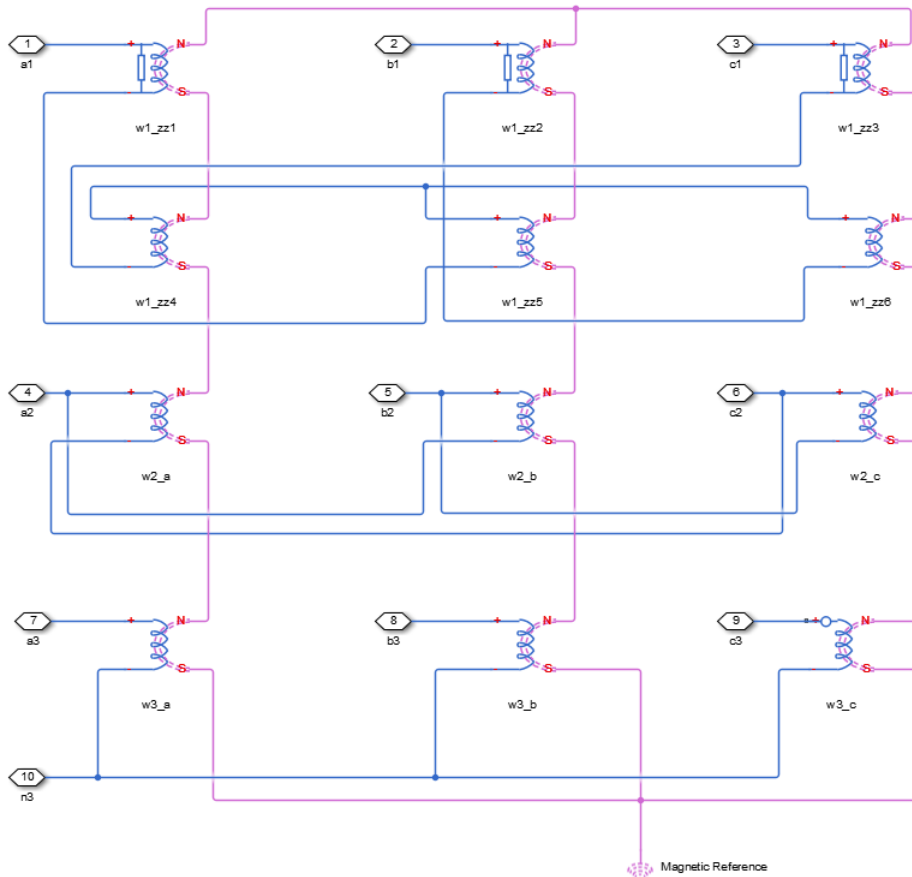Linear nonideal zigzag-delta11-wye transformer with three-limb core

Library

Passive Devices / Transformers

Description

The Zigzag-Delta11-Wye Transformer block models a linear, nonideal transformer with a three-limb core, in which the primary windings are configured in a zigzag connection and there are delta secondary windings and wye secondary windings. You can specify the phase offset between the zigzag and wye windings via a block parameter. The delta voltages lead the wye voltages by 30 degrees, hence the name 11 o'clock delta. The block includes linear winding leakage and linear core magnetization effects.

The figure shows the equivalent circuit diagram for the zigzag-delta11-wye transformer.

- $w1_{zz1}$ is the primary winding located on the first limb of the core, connected between the a-phase and the negative terminal of winding $w1_{zz5}$.

- $w1_{zz2}$ is the primary winding located on the second limb of the core, connected between the b-phase and the negative terminal of winding $w1_{zz6}$.

- $w1_{zz3}$ is the primary winding located on the third limb of the core, connected between the c-phase and the negative terminal of winding $w1_{zz4}$.

- $w1_{zz4}$ is the primary winding located on the first limb of the core, connected between the zigzag neutral point and the negative terminal of winding $w1_{zz3}$.

- $w1_{zz5}$ is the primary winding located on the second limb of the core, connected between the zigzag neutral point and the negative terminal of winding $w1_{zz1}$.
- $w1_{zz6}$ is the primary winding located on the third limb of the core, connected between the zigzag neutral point and the negative terminal of winding $w1_{zz2}$.
- $w2_a$ is the secondary winding connected between the a-phase and the c-phase.
- $w2_b$ is the secondary winding connected between the b-phase and the a-phase.
- $w2_c$ is the secondary winding connected between the c-phase and the b-phase.
- $w3_a$ is the secondary winding connected between the a-phase and the secondary neutral point.
- $w3_b$ is the secondary winding connected between the b-phase and the secondary neutral point.
- $w3_c$ is the secondary winding connected between the c-phase and the secondary neutral point.

Display Options

You can display the transformer per-unit base values in the MATLAB command window using the block context menu. To display the values, right-click the block and select **Power Systems** > **Display Base Values**.

Parameters

- "Main Tab" on page 1-490
- "Impedances Tab" on page 1-491
- "Initial Conditions Tab" on page 1-492

Main Tab

Rated apparent power

Apparent power flowing through the transformer when operating at rated capacity. The default value is 100e6 V*A.

Primary rated voltage

RMS line voltage applied to the primary winding under normal operating conditions. The default value is 24e3 V.

Delta secondary rated voltage

RMS line voltage applied to the delta secondary winding under normal operating conditions. The default value is 4160 V.

Wye secondary rated voltage

RMS line voltage applied to the wye secondary winding under normal operating conditions. The default value is 4160 V.

Rated electrical frequency

Rated or nominal frequency of the AC network to which the transformer is connected. The default value is 60 Hz.

Wye secondary phase shift

The phase offset between the zigzag and wye secondary windings. The default value is -7.5 deg.

Impedances Tab

Parameters in this tab are expressed in per-unit (pu). For more information, see "Per-Unit System of Units".

Primary leakage resistance (pu)

Power loss in the primary winding. The default value is 0.01.

Primary leakage reactance (pu)

Magnetic flux loss in the primary winding. The default value is 0.001.

Delta secondary leakage resistance (pu)

Power loss in the delta secondary winding. The default value is 0.01.

Delta secondary leakage reactance (pu)

Magnetic flux loss in the delta secondary winding. The default value is 0.001.

Wye secondary leakage resistance (pu)

Power loss in the wye secondary winding. The default value is 0.01.

Wye secondary leakage reactance (pu)

Magnetic flux loss in the wye secondary winding. The default value is 0.001.

Shunt magnetizing resistance (pu)

Magnetic losses in transformer core. The default value is 500.

Shunt magnetizing reactance (pu)

Magnetic effects of the transformer core when operating in its linear region. The default value is 500.

Initial Conditions Tab

Initial primary currents

Current through the primary leakage inductors at time zero. The default value is [0 0 0] A.

Initial delta secondary currents

Current through the delta secondary leakage inductors at time zero. The default value is [0 0 0] A.

Initial wye secondary currents

Current through the wye secondary leakage inductors at time zero. The default value is [0 0 0] A.

Initial magnetizing currents

Current through the shunt magnetization inductors at time zero. The default value is [0 0 0] A.

Initial fluxes

Magnetic fluxes in the limbs of the core at time zero. The default value is [0 0 0] Wb.

Ports

The block has the following ports:

~1

Expandable three-phase port for primary winding

~2

Expandable three-phase port for delta secondary winding

~3

Expandable three-phase port for wye secondary winding

n3

Electrical conserving port associated with the wye secondary winding neutral point

See Also

See Also

`Delta-Delta Transformer` | `Delta1-Delta1-Wye Transformer` | `Delta11-Delta11-Wye Transformer` | `Wye-Delta1 Transformer` | `Wye-Delta1-Wye Transformer` | `Wye-Delta11 Transformer` | `Wye-Delta11-Wye Transformer` | `Wye-Wye Transformer` | `Zigzag-Delta1-Wye Transformer`

Topics

"Expand and Collapse Three-Phase Ports on a Block"
Custom Zigzag Transformer

Introduced in R2015a

Functions — Alphabetical List

pe_calculateThdPercent

Compute the total harmonic distortion (THD) percentage

Syntax

```
[thdPercent] = pe_calculateThdPercent(harmonicOrder,
harmonicMagnitude)
```

Description

`[thdPercent] = pe_calculateThdPercent(harmonicOrder,` `harmonicMagnitude)` calculates the total harmonic distortion (THD) percentage using these equations:

$$M = \frac{harmonic\ magnitude}{\sqrt{2}},$$

and

$$\%THD = 100\frac{\sqrt{\sum_{i=2}^{n}M_i{}^2}}{M_1},$$

where:

- M_i is the root mean square (RMS) value of the harmonic magnitude corresponding to the ith harmonic order.

- M is V_{RMS} or I_{RMS} as required.

You can use the `pe_getHarmonics` function to obtain the vectors of harmonic order and harmonic magnitude for a simscape.logging.Node.

Examples

Calculate THD percent

Calculate the THD from harmonic orders [1;5;7;11;13] and harmonic magnitudes [1.1756e+03;0.0437e+03;0.0221e+03;0.0173e+03;0.0127e+03].

```
harmonicOrder = [1;5;7;11;13];
harmonicMagnitude = [1.1756e+03;0.0437e+03;0.0221e+03;0.0173e+03;...
    0.0127e+03];
thdPercent = pe_calculateThdPercent( harmonicOrder, harmonicMagnitude )
```

```
thdPercent =

    4.5480
```

- "Perform an Online Harmonic Analysis Using the Simscape Spectrum Analyzer Block"
- "Choose a Simscape Power Systems Function for an Offline Harmonic Analysis"
- "Data Logging" (Simscape)
-

Input Arguments

`harmonicOrder` — Harmonic orders
vector

Harmonic orders from 0 up to and including number of harmonics, specified as a vector.

Example: `[1;5;7;11;13]`

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`harmonicMagnitude` — Harmonic magnitudes
vector

Harmonic magnitudes from the 0th harmonic up to and including the number of harmonics included in the analysis, specified as a vector.

Example: [1.1756e+03;0.0437e+03;0.0221e+03;0.0173e+03;0.0127e+03]

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

See Also

See Also

Blocks
Spectrum Analyzer

Functions
`pe_getHarmonics` | `pe_plotHarmonics`

Using Objects
simscape.logging.Node

Topics
"Perform an Online Harmonic Analysis Using the Simscape Spectrum Analyzer Block"
"Choose a Simscape Power Systems Function for an Offline Harmonic Analysis"
"Data Logging" (Simscape)

Introduced in R2014a

pe_getEfficiency

Calculate efficiency as a function of dissipated power losses

Syntax

```
efficiency = pe_getEfficiency('loadIdentifier',node)
efficiency = pe_getEfficiency('loadIdentifier',node,startTime,
endTime)
[efficiency,lossesTable] = pe_getEfficiency('loadIdentifier',node)
```

Description

`efficiency = pe_getEfficiency('loadIdentifier',node)` returns the efficiency of a circuit based on the data extracted from a Simscape logging node.

Before you call this function, generate or load the simulation log variable to your workspace. To generate the variable, simulate the model with simulation data logging enabled. For more information, see "About Simulation Data Logging" (Simscape). To load a previously saved variable from a file, right-click on the file and select **Load**.

Checking efficiency allows you to determine if circuit components are operating within their requirements. Blocks in the Semiconductor > Fundamental Components library and the Delta-Connected Load, Wye-Connected Load, and RLC blocks have an internal block variable called *power_dissipated*. This variable represents the instantaneous dissipated power, which includes only the real power (not the reactive or apparent power) that the block dissipates. When you log simulation data, the time-value series for this variable represents the power dissipated by the block over time. You can view and plot this data using the Simscape Results Explorer. The `pe_getPowerLossTimeSeries` function also allows you to access this data.

The `pe_getEfficiency` function calculates the efficiency of the circuit based on the losses for blocks that have a *power_dissipated* variable and that you identify as a load block. The equation for efficiency is

$$Eff = 100 * \frac{P_{load}}{P_{loss} + P_{load}},$$

where:

- *Eff* is the efficiency of the circuit.
- P_{load} is the output power, that is, the power dissipated by load blocks.
- P_{loss} is the power dissipated by nonload blocks.

This equation assumes that all loss mechanisms are captured by blocks containing at least one *power_dissipated* variable. If the model contains any lossy blocks that do not have this variable, the efficiency calculation gives incorrect results.

Some blocks have more than one *power_dissipated* variable, depending on their configuration. For example, for the MOSFET block, both the `diode` node and the `ideal_switch` node have a `power_dissipated` logging node. The function sums the power losses for both nodes to provide the total power loss for the block, averaged over simulation time. The function uses the loss data to calculate the efficiency of the circuit.

The nonideal semiconductor blocks also have thermal variants. Thermal variants have thermal ports that allow you to model the heat that is generated due to switching events and conduction losses. If you use a thermal variant, the function calculates power losses and efficiencies based on the thermal parameters that you specify. Essentially, the power dissipated is equal to the heat generated.

If you use a variant without a thermal port, the function calculates power losses and efficiencies based on the electrical parameters that you specify, such as on-state resistance and off-state conductance.

`efficiency = pe_getEfficiency('loadIdentifier',node,startTime, endTime)` returns the efficiency of a circuit based on the *power_dissipated* data extracted from a Simscape logging node within a time interval. `startTime` and `endTime` represent the start and end of the time interval for calculating the efficiency. If you omit these two input arguments, the function calculates the efficiency over the whole simulation time.

`[efficiency,lossesTable] = pe_getEfficiency('loadIdentifier',node)` returns the efficiency of a circuit and the power loss contributions of the nonload blocks in a circuit based on the data extracted from a Simscape logging node.
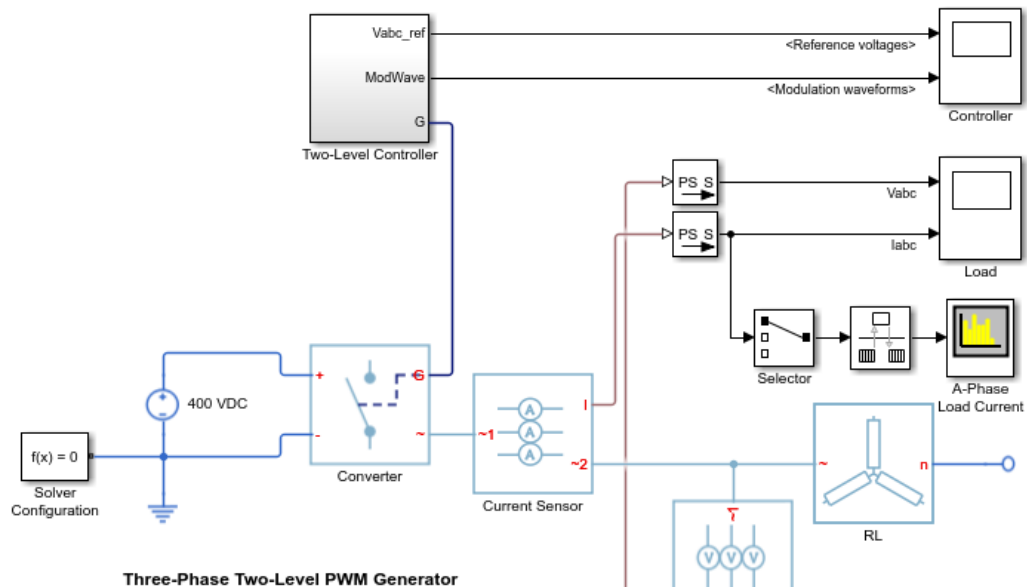
Examples

Calculate Efficiency for a Circuit

This example shows how to calculate efficiency based on the power dissipated by blocks in a circuit using the `pe_getEfficiency` function. Data logging is enabled locally, and the option to limit data points is off.

Open the model. At the MATLAB® command prompt, enter:

```
model = 'pe_pwm_two_level';
open_system(model)
```


Three-Phase Two-Level PWM Generator

This example shows how to use the PWM Generator (Three-phase, Two-level) to control a Converter. The inputs to the PWM Generator are reference AC waveforms and a DC-link voltage of 400 V. There are two time scopes: one for the controller waveforms and one for the load voltages and currents. When the model is executed, a Spectrum Analyzer opens and displays frequency data for the A-Phase Load Current.

Ensure that all blocks that have *power_dissipated* variables are considered in the efficiency calculation. Enable data logging for the whole model.

```
set_param(model,'SimscapeLogType','all')
```

Designate the load. Rename the Wye-Connected Load block from RL to RL_Load.

```
set_param([model,'/RL'],'Name','RL_Load')
```

Run the simulation and create the simulation log variable.

```
sim(model)
```

The simulation log variable *simlog_pe_pwm_two_level* is saved in the workspace.

Calculate the efficiency percentage.

```
efficiency = pe_getEfficiency('Load',simlog_pe_pwm_two_level)

efficiency =

    99.1940
```
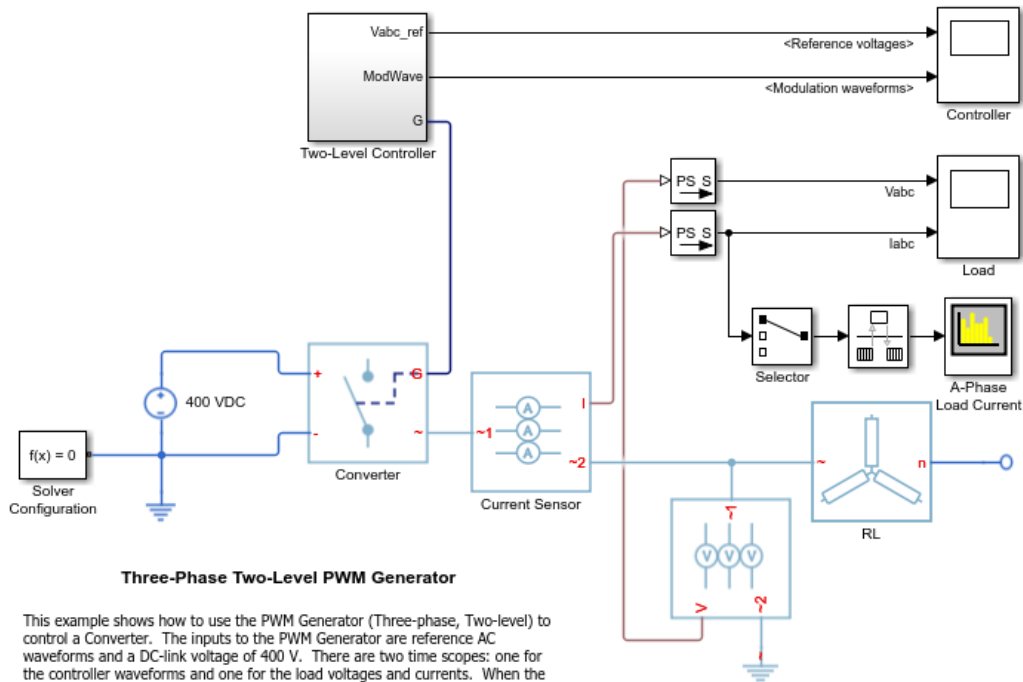
Calculate Efficiency of a Circuit for a Specific Time Period

This example shows how to calculate efficiency based on the power dissipated for a specific time period using the pe_getEfficiency function. Data logging is enabled locally, and the option to limit data points is off.

Open the model. At the MATLAB® command prompt, enter:

```
model = 'pe_pwm_two_level';
open_system(model)
```

Three-Phase Two-Level PWM Generator

This example shows how to use the PWM Generator (Three-phase, Two-level) to control a Converter. The inputs to the PWM Generator are reference AC waveforms and a DC-link voltage of 400 V. There are two time scopes: one for the controller waveforms and one for the load voltages and currents. When the model is executed, a Spectrum Analyzer opens and displays frequency data for the A-Phase Load Current.

Ensure that all blocks that have *power_dissipated* variables are considered in the efficiency calculation. Enable data logging for the whole model.

```
set_param(model,'SimscapeLogType','all')
```

Designate the load. Rename the Wye-Connected Load block from RL to RL_Load.

```
set_param([model,'/RL'],'Name','RL_Load')
```

Run the simulation and create the simulation log variable.

```
sim(model)
```

The simulation log variable *simlog_pe_pwm_two_level* is saved in the workspace.

The model simulation stop time is 0.2 seconds. Calculate efficiency for the interval when the simulation time, *t*, is between 0.00 and 0.005 seconds.
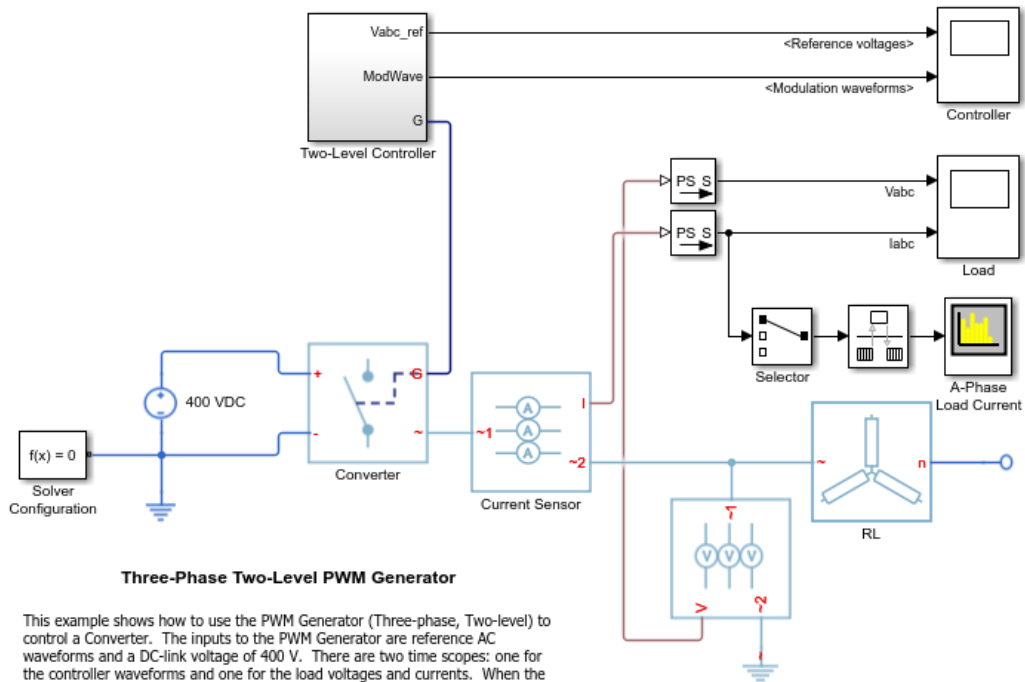
```
efficiency = pe_getEfficiency('Load',simlog_pe_pwm_two_level,0.000,0.005)

efficiency =

    99.1093
```

Calculate Efficiency and Power-Loss Contributions

This example shows how using the `pe_getEfficiency` function allows you to calculate both the efficiency of the circuit and the power-loss contributions of the nonload blocks based on the power that they dissipate. Data logging is enabled locally, and the option to limit data points is off.

Open the model. At the MATLAB® command prompt, enter:

```
model = 'pe_pwm_two_level';
open_system(model)
```

Three-Phase Two-Level PWM Generator

This example shows how to use the PWM Generator (Three-phase, Two-level) to control a Converter. The inputs to the PWM Generator are reference AC waveforms and a DC-link voltage of 400 V. There are two time scopes: one for the controller waveforms and one for the load voltages and currents. When the model is executed, a Spectrum Analyzer opens and displays frequency data for the A-Phase Load Current.

Ensure that all blocks that have *power_dissipated* variables are considered in the efficiency calculation. Enable data logging for the whole model.

```
set_param(model,'SimscapeLogType','all')
```

Designate the load. Rename the Wye-Connected Load block from RL to RL_Load.

```
set_param([model,'/RL'],'Name','RL_Load')
```

Run the simulation and create the simulation log variable.

```
sim(model)
```

The simulation log variable *simlog_pe_pwm_two_level* is saved in the workspace.

Calculate the efficiency and power-loss contributions due to dissipated power.

```
[efficiency,lossesTable] = pe_getEfficiency('Load',simlog_pe_pwm_two_level)

efficiency =

   99.1940


lossesTable =

  1×2 table

            LoggingNode              Power
    _____   _____

    'pe_pwm_two_level.Converter'     268.73
```

- "Perform a Power-Loss Analysis"
- "Data Logging" (Simscape)
- "About the Simscape Results Explorer" (Simscape)

Input Arguments

`'loadIdentifier'` — Identify load blocks in the circuit
case-sensitive string

String that is a complete or partial match for the names of load blocks in the circuit. For example, consider a circuit that contains the blocks shown in the table.

Block Name in the Model		DC Impedance	AC Impedance	Y-Ld
Block Type		RLC	RLC	Wye-Connected Load
Block Role in the Model		Source Impedance	Load Impedance	Load
`'loadIdentifier'`	`'d'`	Yes	Yes	Yes
	`'Load'`	No	No	No
	`'D'`	Yes	No	No

The pe_getEfficiency function does not return the correct data for any of these 'loadIdentifier' values.

A load-block naming schema that gives you better control over the output of the pe_getEfficiency function is shown in this table.

Block Name in the Model		DC Impedance	AC Impedance_Load_	Y-Load_2
Block Type		RLC	RLC	Wye-Connected Load
Block Role in the Model		Source Impedance	Load Impedance	Load
'loadIdentifier'	'1'	No	Yes	No
	'2'	No	No	Yes
	'Load'	No	Yes	Yes

Example: 'Load'

Data Types: string

node — Simulation log variable, or a specific node within the simulation log variable
Node object

Simulation log workspace variable, or a node within this variable, that contains the logged model simulation data, specified as a Node object. You specify the name of the simulation log variable by using the **Workspace variable name** parameter on the **Simscape** pane of the Configuration Parameters dialog box. To specify a node within the simulation log variable, provide the complete path to that node through the simulation data tree, starting with the top-level variable name.

If node is the name of the simulation log variable, then the table contains the data for all blocks in the model that contain *power_dissipated* variables. If node is the name of a node in the simulation data tree, then the table contains the data only for:

- Blocks or variables within that node
- Blocks or variables within subnodes at all levels of the hierarchy beneath that node

Example: simlog_pe_pwm_two_level

`startTime` — Start of the time interval for calculating the efficiency

0 (default) | real number

Start of the time interval for calculating the efficiency, specified as a real number, in seconds. `startTime` must be greater than or equal to the simulation **Start time** and less than `endTime`.

Data Types: `double`

`endTime` — End of the time interval for calculating the efficiency

simulation stop time (default) | real number

End of the time interval for calculating the efficiency, specified as a real number, in seconds. `endTime` must be greater than `startTime` and less than or equal to the simulation **Stop time**.

Data Types: `double`

Output Arguments

`efficiency` — Efficiency of the circuit

percentage

Efficiency of the circuit based on data extracted from a Simscape logging node.

`lossesTable` — Dissipated power for each nonload blocks

table

Dissipated power losses for each nonload block, returned as a table. The first column lists logging nodes for all blocks that have at least one *power_dissipated* variable. The second column lists the corresponding losses in watts.

Assumptions

- The output power equals the total power dissipated by blocks that you identify as load blocks.
- The input power equals the output power plus the total power dissipated by blocks that you do not identify as load blocks.
- The *power_dissipated* variables capture all loss contributions.

See Also

See Also
pe_getPowerLossSummary | pe_getPowerLossTimeSeries | sscexplore

Topics
"Perform a Power-Loss Analysis"
"Data Logging" (Simscape)
"About the Simscape Results Explorer" (Simscape)

Introduced in R2017a

pe_getHarmonics

Return harmonic orders, magnitudes, and fundamental frequency

Syntax

```
[harmonicOrder,harmonicMagnitude,fundamentalFrequency] =...
pe_getHarmonics(loggingNode)
[harmonicOrder,harmonicMagnitude,fundamentalFrequency] =...
pe_getHarmonics(loggingNode,valueIdx)
[harmonicOrder,harmonicMagnitude,fundamentalFrequency] =...
pe_getHarmonics(loggingNode,valueIdx,tOfInterest)
[harmonicOrder,harmonicMagnitude,fundamentalFrequency] =...
pe_getHarmonics(loggingNode,valueIdx,tOfInterest,nPeriodOfInterest)
[harmonicOrder,harmonicMagnitude,fundamentalFrequency] =...
pe_getHarmonics(loggingNode,valueIdx,tOfInterest,
nPeriodOfInterest,...
offsetOfInterest)
[harmonicOrder,harmonicMagnitude,fundamentalFrequency] =...
pe_getHarmonics(loggingNode,valueIdx,tOfInterest,
nPeriodOfInterest,...
offsetOfInterest,nHarmonic)
```

Description

`[harmonicOrder,harmonicMagnitude,fundamentalFrequency] =...`
`pe_getHarmonics(loggingNode)` calculates the harmonic orders, magnitudes, and
fundamental frequency of a `simscape.logging.Node` of an AC or periodic variable.

The function finds the points in the ith signal (valueIdx) where the Simscape log crosses
a threshold (offsetOfInterest). It uses the crossing points to find the required number of
periods (nPeriodOfInterest) preceding the specified time (tOfInterest). Then it inputs the
down-selected data to the Goertzel algorithm, which calculates the harmonic magnitudes
up to and including the required number of harmonics (nHarmonic).

You enter the input arguments in a specific order. The Simscape logging node input
argument is required. All other input arguments are optional and have default values. If

you are specifying a value for a subsequent optional input argument, enter [ ] to use the default value for an optional input argument.

You can use the `pe_plotHarmonics` function to obtain a bar chart from the same input arguments. You can use the outputs of this function as inputs to the `pe_calculateThdPercent` function to calculate the total harmonic distortion (THD) percentage.

```
[harmonicOrder,harmonicMagnitude,fundamentalFrequency] =...
pe_getHarmonics(loggingNode,valueIdx)
```
uses the index into value data.

```
[harmonicOrder,harmonicMagnitude,fundamentalFrequency] =...
pe_getHarmonics(loggingNode,valueIdx,tOfInterest)
```
uses the simulation time.

```
[harmonicOrder,harmonicMagnitude,fundamentalFrequency] =...
pe_getHarmonics(loggingNode,valueIdx,tOfInterest,nPeriodOfInterest)
```
uses the number of periods of fundamental frequency.

```
[harmonicOrder,harmonicMagnitude,fundamentalFrequency] =...
pe_getHarmonics(loggingNode,valueIdx,tOfInterest,
nPeriodOfInterest,...
offsetOfInterest)
```
uses the DC offset.

```
[harmonicOrder,harmonicMagnitude,fundamentalFrequency] =...
pe_getHarmonics(loggingNode,valueIdx,tOfInterest,
nPeriodOfInterest,...
offsetOfInterest,nHarmonic)
```
uses the number of harmonics.

Examples

Analyze Using Default Values

This set of function arguments uses the Simscape logging node `simlog.Load.V`, which contains data from a three-phase voltage. The function analyzes the default signal, which is the first, or a-phase, signal at the final simulation time. The function uses the default values of 12 for the number of periods of the signal, 0V for the signal bias, and 30 for the number of harmonics.

```
pe_getHarmonics(simlog.Load.V)
```

Analyze Using Specified Values

This set of function arguments uses the Simscape logging node `simlog.Load.V`, which contains data from a three-phase voltage. The function analyzes the second, or b-phase, signal at a simulation time of `2.3` s. The function uses `10` periods of the signal, which has a bias of `1` V. The function analyzes `15` harmonics.

```
pe_getHarmonics(simlog.Load.V,2,2.3,10,1,15)
```

Analyze Using Default and Specified Values

This set of function arguments uses the Simscape logging node `simlog.Load.V`, which contains data from a three-phase voltage. The function analyzes the first, or a-phase, signal at a simulation time of `2.3` s. The function uses `12` periods of the signal, which has a bias of `1` V. The function analyzes the default number, `30`, of harmonics.

```
pe_getHarmonics(simlog.Load.V,[],2.3,[],1)
```

Input Arguments

`loggingNode` — Simscape logging node
1-by-1 simscape.logging.Node

Simscape logging node, specified as a 1-by-1 `simscape.logging.Node`. You create a `simscape.logging.Node` by running a simulation with Simscape logging enabled. For information, see "Enable Data Logging for the Whole Model" (Simscape).

Example: `simlog.Load.V`

The Simscape logging node simlog.Load.V contains data from a three-phase voltage.

`valueIdx` — Index into value data
1 (default) | scalar

Index into value data, specified as a scalar. Specifies the ith variable of interest in the Simscape log.

Example: 2

Specify the b-phase, which is the second signal from a three-phase voltage.

Example: [ ]

Use [] to specify the default value of 1. The a-phase, which is the first signal from a three-phase voltage, is the default signal of interest.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`tOfInterest` — Simulation time
final time in Simscape log (default) | scalar

Simulation time of interest for harmonic analysis, specified as a scalar.

Example: `2.3`

Specify a 2.3 s simulation time.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`nPeriodOfInterest` — Number of periods
12 (default) | scalar

Number of periods of fundamental frequency to be included in harmonic analysis, specified as a scalar.

Example: `10`

Specify 10 periods of the signal.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`offsetOfInterest` — DC offset
0 (default) | scalar

DC offset in the input signal, specified as a scalar. The function uses this value to find the periods of interest.

Example: `1`

Specify a bias of 1 V for the signal.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`nHarmonic` — Number of harmonics
30 (default) | scalar

Number of harmonics to include in analysis, specified as a scalar.

Example: 15

Specify that the number of harmonics to be analyzed is 15.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

Output Arguments

`harmonicOrder` — Harmonic order
vector

Harmonic orders from 0 up to and including the number of harmonics used in the analysis, returned as a vector.

`harmonicMagnitude` — Harmonic magnitude
vector

Harmonic magnitudes from the 0th harmonic up to and including the number of harmonics used in the analysis, returned as a vector.

`fundamentalFrequency` — Fundamental frequency
scalar

Fundamental frequency over the range of the down-selected input data, returned as a scalar.

Limitations

- This function requires that you use a fixed-step solver for the Simscape Power Systems network that you are analyzing. To specify a fixed-step solver for the physical network, use one of the configuration combinations in the table.

Configuration Combination	Global Solver Configuration	Local Solver Configuration
Global variable-step with	Set **Type** to `Variable-step`	Enable the options to **Use local solver** and **Use fixed-cost runtime consistency iterations**

Configuration Combination	Global Solver Configuration	Local Solver Configuration
local fixed-step		
Global and local fixed-step	Set **Type** to `Fixed-step`	Enable the options to **Use local solver** and **Use fixed-cost runtime consistency iterations**
Global fixed-step	Set **Type** to `Fixed-step`	Clear the option to **Use local solver**

- This function uses threshold crossing points to determine the fundamental frequency of the data. If your input data is noisy or crosses the threshold more frequently than half of the fundamental period, filter it before you use this function to analyze it.

- This function requires a minimal number of periods. If the minimal number is not met, the function generates a warning message. To increase the number of periods, use one or both of these methods:

  - Increase the simulation time.
  - Increase the switching frequency.

See Also

See Also

Blocks
Spectrum Analyzer

Functions
pe_calculateThdPercent | pe_plotHarmonics

Using Objects
simscape.logging.Node

Topics
"Perform an Online Harmonic Analysis Using the Simscape Spectrum Analyzer Block"
"Choose a Simscape Power Systems Function for an Offline Harmonic Analysis"
"Data Logging" (Simscape)

Introduced in R2014a

pe_getPowerLossSummary

Calculate dissipated power losses

Syntax

```
lossesTable = pe_getPowerLossSummary(node)
lossesTable = pe_getPowerLossSummary(node,startTime,endTime)
```

Description

`lossesTable = pe_getPowerLossSummary(node)` calculates dissipated power losses for semiconductor blocks in a model, based on logged simulation data, and returns the data for each block in a table.

Before you call this function, generate or load the simulation log variable into your workspace. To generate the variable, simulate the model with simulation data logging enabled. For more information, see "About Simulation Data Logging" (Simscape). To load a previously saved variable from a file, right-click on the file and select **Load**.

Checking dissipated power allows you to determine if circuit components are operating within their efficiency requirements. Blocks in the **Semiconductor** > **Fundamental Components** library have an internal variable called *power_dissipated*. This variable represents the instantaneous dissipated power, which includes only the real power (not the reactive or apparent power) that the block dissipates. When you log simulation data, the time-value series for this variable represents the power dissipated by the block over time. You can view and plot this data using the Simscape Results Explorer. The `pe_getPowerLossTimeSeries` function also allows you to access this data from a cell array.

The `pe_getPowerLossSummary` function calculates average losses for each block that has a *power_dissipated* variable. Some blocks have more than one *power_dissipated* variable, depending on their configuration. For example, for the MOSFET block, both the `diode` node and the `ideal_switch` node have a `power_dissipated` logging node. The function sums the power losses for both nodes to provide the total power loss for the block, averaged over simulation time.

The nonideal semiconductor blocks also have thermal variants. Thermal variants have thermal ports that allow you to model the heat that is generated due to switching events and conduction losses. If you use a thermal variant, the function calculates power losses based on the thermal parameters that you specify. Essentially, the power dissipated is equal to the heat generated.

If you use a variant without a thermal port, the function calculates power losses based on the electrical parameters that you specify, such as on-state resistance and off-state conductance.

lossesTable = pe_getPowerLossSummary(node,startTime,endTime) calculates dissipated power losses within a time interval. startTime and endTime represent the start and end of the time interval for averaging the power losses. If you omit these two input arguments, the function averages the power losses over the total simulation time.

Examples

Calculate Average Power Losses by Block for the Whole Model

This example uses the Push-Pull Buck Converter in Continuous Conduction Mode model. Data logging is enabled for the whole model and the option to limit data points is off.

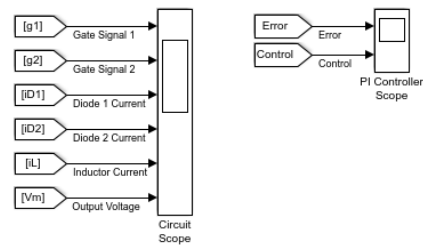1. Open the example model. At the MATLAB® command prompt, enter

```
model = 'pe_push_pull_converter_ccm';
open_system(model)
```

Push-Pull Buck Converter in Continuous Conduction Mode

This example shows how to control the output voltage of a push-pull buck converter. The current flowing through the inductor is never zero, therefore the DC-DC converter operates in Continuous Conduction Mode (CCM). To convert and maintain the nominal output voltage, the PI Controller subsystem uses a simple integral control. During startup, the reference voltage is ramped up to the desired output voltage.

1. Edit the parameterization script.
2. Explore simulation results using sscexplore.
3. Learn more about this example.

2. Run the simulation and create the simulation log variable.

```
sim(model);
```

The simulation log variable `simlog_pe_push_pull_converter_ccm` is saved in your workspace.

3. Calculate average power losses for each semiconductor in the model and display the results in a table.

```
tabulatedLosses = pe_getPowerLossSummary(simlog_pe_push_pull_converter_ccm)
```

```
tabulatedLosses =

  4×2 table

                    LoggingNode                              Power
```
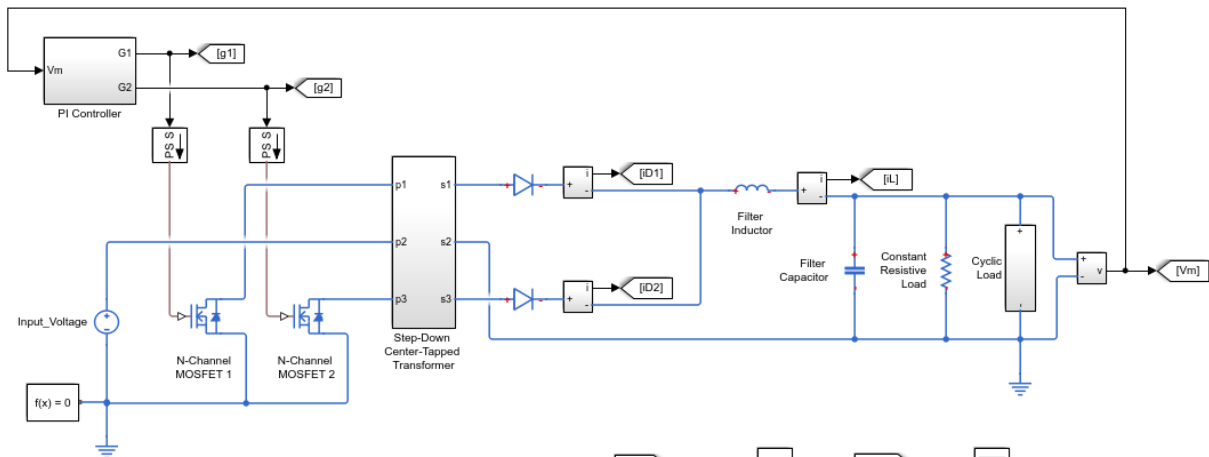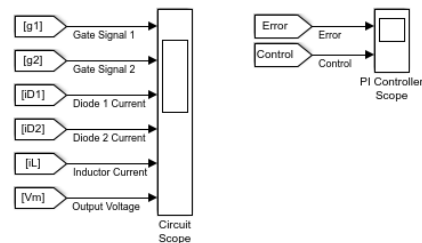
'pe_push_pull_converter_ccm.Diode1'	0.30937
'pe_push_pull_converter_ccm.Diode'	0.3092
'pe_push_pull_converter_ccm.N_Channel_MOSFET_1.mosfet_equation'	0.24497
'pe_push_pull_converter_ccm.N_Channel_MOSFET_2.mosfet_equation'	0.2449

The table shows dissipated power losses for each of the N-Channel MOSFET and Diode blocks, averaged over the entire simulation time.

Calculate Average Power Losses for a Single Block

1. Open the Push-Pull Buck Converter in Continuous Conduction Mode example model. At the MATLAB® command prompt, enter

```
model='pe_push_pull_converter_ccm';
open_system(model)
```


Push-Pull Buck Converter in Continuous Conduction Mode

This example shows how to control the output voltage of a push-pull buck converter. The current flowing through the inductor is never zero, therefore the DC-DC converter operates in Continuous Conduction Mode (CCM). To convert and maintain the nominal output voltage, the PI Controller subsystem uses a simple integral control. During startup, the reference voltage is ramped up to the desired output voltage.

1. Edit the parameterization script.
2. Explore simulation results using sscexplore.
3. Learn more about this example.

The model has data logging enabled.

2. Run the simulation and create the simulation log variable.

```
sim(model)
```

The simulation log variable `simlog_pe_push_pull_converter_ccm` is saved in your workspace.

3. Calculate power losses for the N-Channel MOSFET 1 block and display the results in a table.

```
tabulatedLosses = pe_getPowerLossSummary(simlog_pe_push_pull_converter_ccm.N_Channel_M
```

```
tabulatedLosses =

  1×2 table

               LoggingNode                 Power
    _____   _____

    'N_Channel_MOSFET_1.mosfet_equation'   0.24497
```

The table shows dissipated power losses for just the N-Channel MOSFET 1 block, averaged over the total simulation time.

4. Use the `sscexplore` function to explore the power loss data for the N-Channel MOSFET 1 block further.

a. Open the Results Explorer.

```
sscexplore(simlog_pe_push_pull_converter_ccm)
```
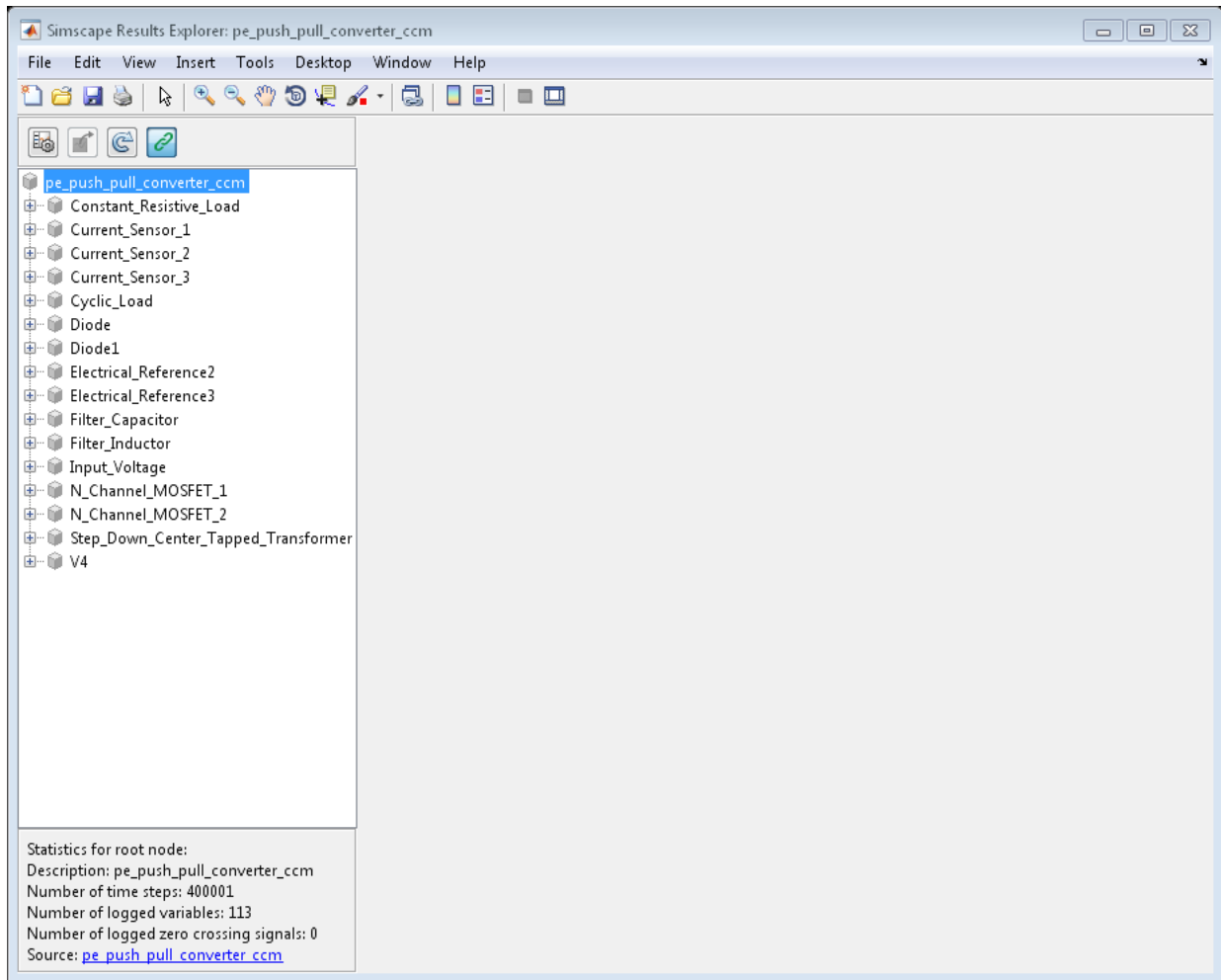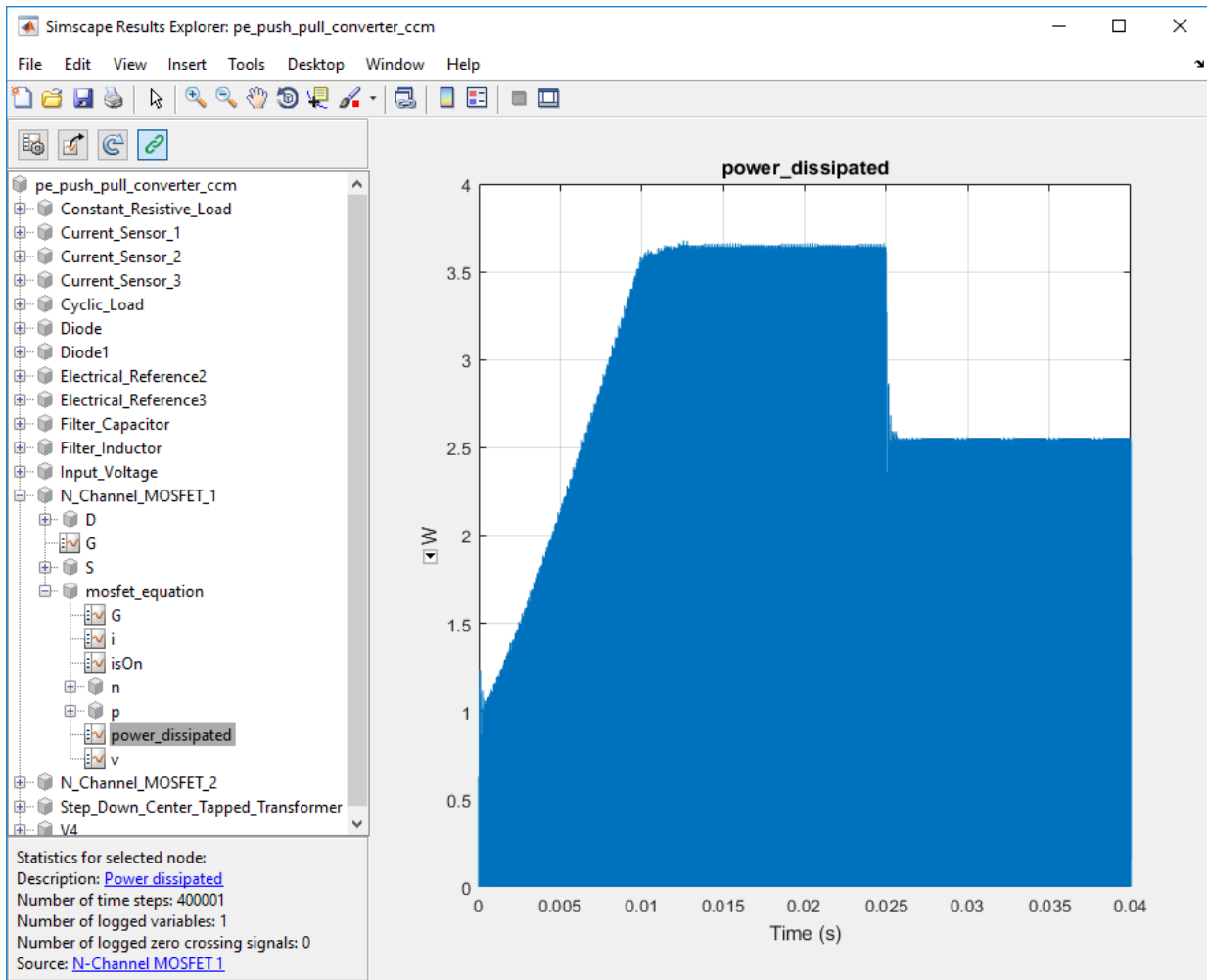
      b. Expand these nodes:

- N_Channel_MOSFET_1

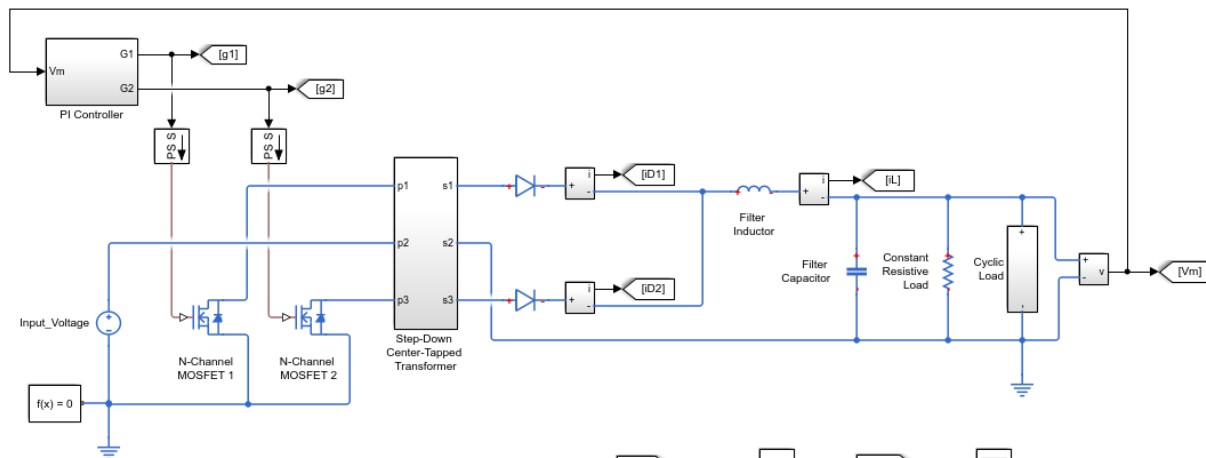- mosfet_equation

      c. Click the power_dissipated node.

The N-Channel MOSFET 1 block has one `power_dissipated` variable for the `mosfet_equation` node. The power_dissipated figure shows the instantaneous power loss for the N-Channel MOSFET 1 block during the simulation.

Calculate Average Power Losses for Components of a Block

You can calculate average power losses for the individual components of a block in your model.

1. Open the Push-Pull Buck Converter in Continuous Conduction Mode example model. At the MATLAB® command prompt, enter
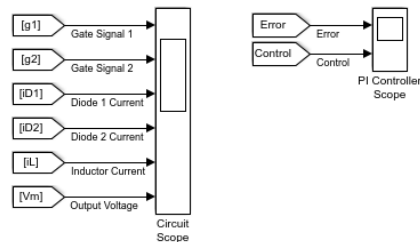
```
model = 'pe_push_pull_converter_ccm';
open_system(model)
```


Push-Pull Buck Converter in Continuous Conduction Mode

This example shows how to control the output voltage of a push-pull buck converter. The current flowing through the inductor is never zero, therefore the DC-DC converter operates in Continuous Conduction Mode (CCM). To convert and maintain the nominal output voltage, the PI Controller subsystem uses a simple integral control. During startup, the reference voltage is ramped up to the desired output voltage.

1. Edit the parameterization script.
2. Explore simulation results using sscexplore.
3. Learn more about this example.

The model has data logging enabled.

2. Add a diode subcomponent in the N-Channel MOSFET 1 block using the MATLAB® command prompt:

```
set_param('pe_push_pull_converter_ccm/ N-Channel  MOSFET 1','diode_param','2')
```

Alternatively, you can can add the component in the Simulink® Editor:

a. Open the Property Inspector pane. In the model window, in the menu bar, click **View** > **Property Inspector**

b. Click the N-Channel MOSFET1 block to access the block parameters.

c. In the Property Inspector pane, expand the Integral Diode setting and change the value for the **Integral protection** from `None` to `Protection diode with no dynamics`.

3. Run the simulation, create a simulation log variable, and open the simlog in the Simscape Results Explorer using the `sscexplore` function.

```
sim(model)
sscexplore(simlog_pe_push_pull_converter_ccm)
```
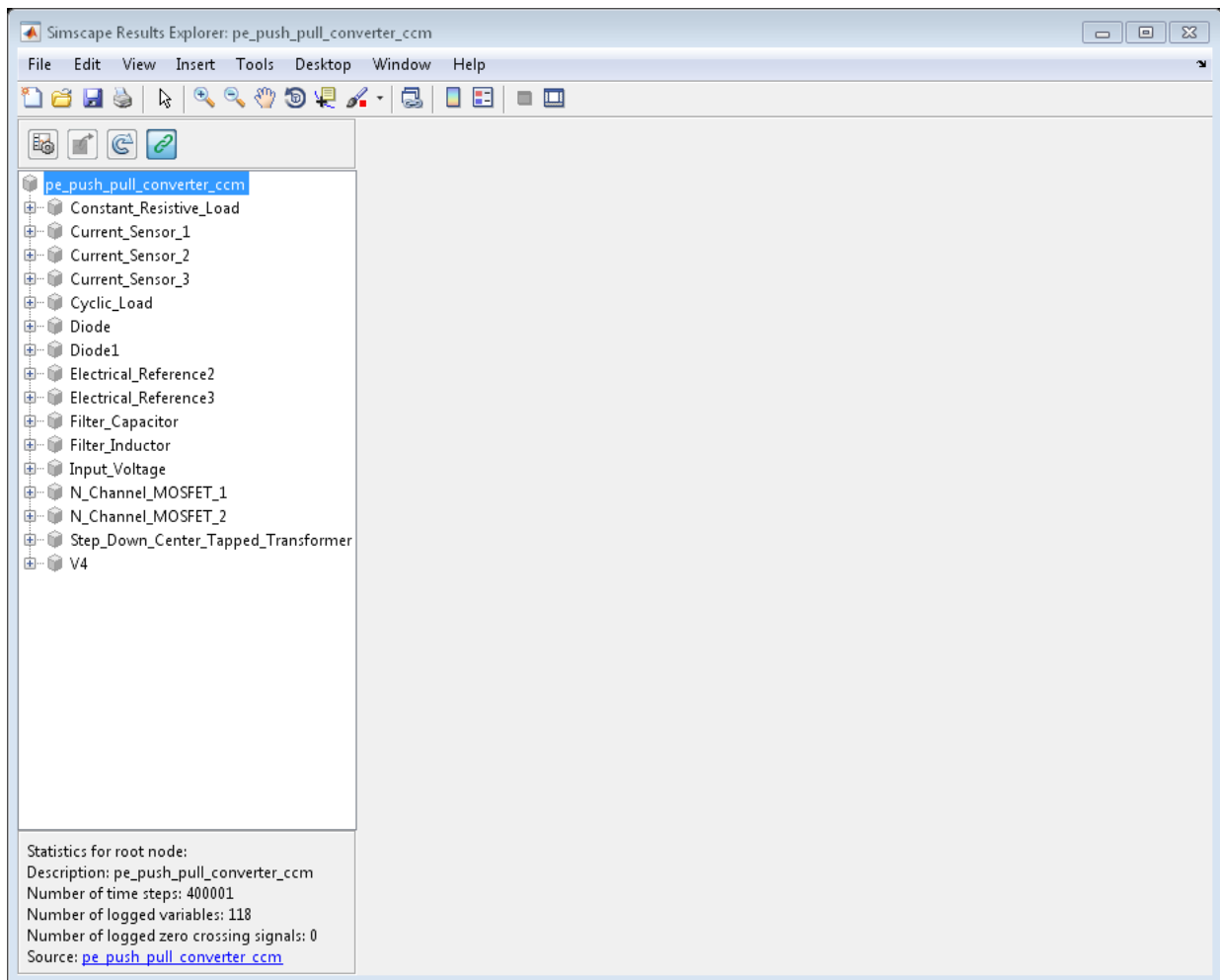
4. View the power loss data for the two N-Channel MOSFET blocks, expand these nodes and CTRL + click the `power_dissipated` nodes:

- `N_Channel_MOSFET_1 > diode > power_dissipated`
- `N_Channel_MOSFET_1 > mosfet_equation > power_dissipated`
- `N_Channel_MOSFET_2 > mosfet_equation > power_dissipated`
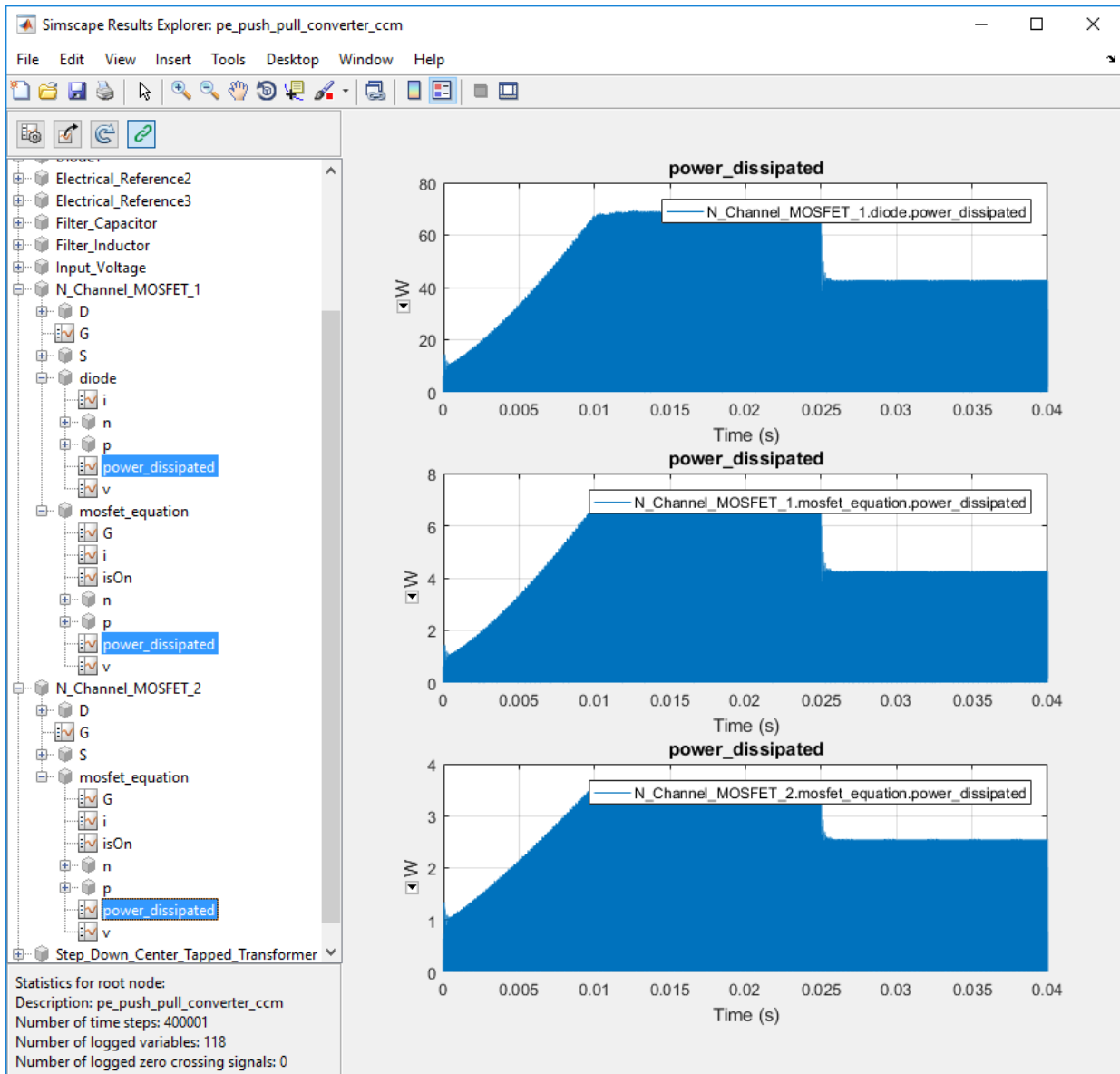
The N-Channel MOSFET 2 block has only one `power_dissipated` variable. The N-Channel MOSFET 1 block has one power_dissipated variable for each of the two subcomponents (MOSFET and diode) that the block contains.

5. Calculate power losses for both components of the N-Channel MOSFET 1 block and display the results in a table

```
tabulatedLosses = pe_getPowerLossSummary(simlog_pe_push_pull_converter_ccm.N_Channel_MO
```

```
tabulatedLosses =

  1×2 table

      LoggingNode          Power
    _____    _____

    'N_Channel_MOSFET_1'    2.6075
```

The table shows the combined dissipated power losses for both the diode and the MOSFET components of the N-Channel MOSFET 1 block, averaged over the total simulation time.

6. Calculate power losses for only the diode component of the NChannel MOSFET 1 block and display the results in a table.

```
tabulatedLosses = pe_getPowerLossSummary(simlog_pe_push_pull_converter_ccm.N_Channel_MO
```
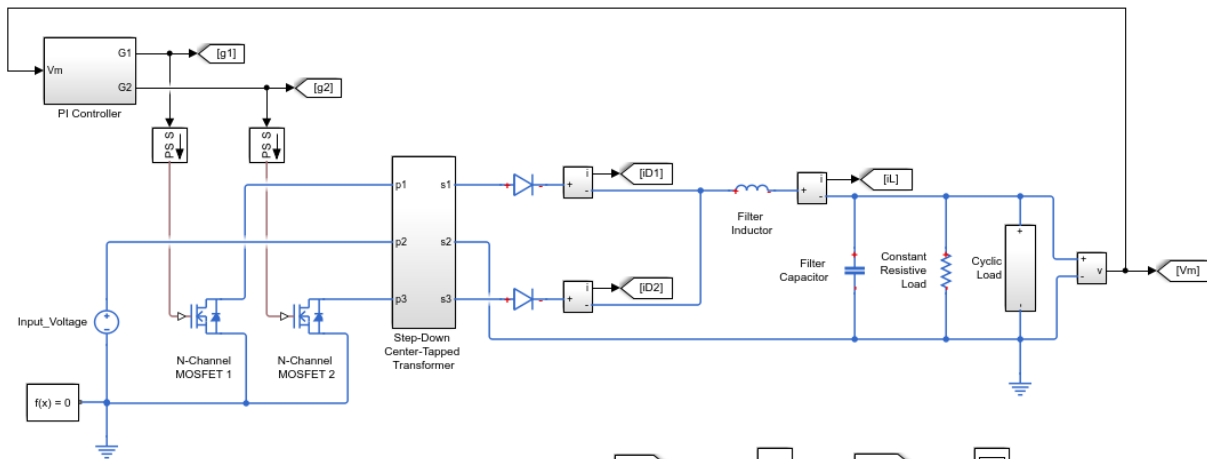
```
tabulatedLosses =

  1×2 table

    LoggingNode    Power
    _____    _____

    'diode'        2.3669
```

The table shows dissipated power losses only for the diode component of the block, averaged over the total simulation time.

Calculate Average Power Losses for a Specific Time Period

1. Open the Push-Pull Buck Converter in Continuous Conduction Mode example model. At the MATLAB® command prompt, enter
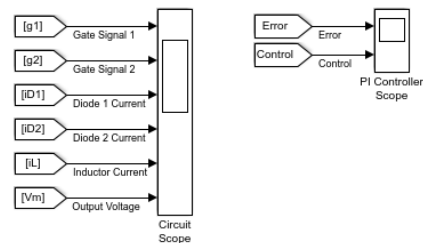
```
pe_push_pull_converter_ccm
```


Push-Pull Buck Converter in Continuous Conduction Mode

This example shows how to control the output voltage of a push-pull buck converter. The current flowing through the inductor is never zero, therefore the DC-DC converter operates in Continuous Conduction Mode (CCM). To convert and maintain the nominal output voltage, the PI Controller subsystem uses a simple integral control. During startup, the reference voltage is ramped up to the desired output voltage.

1. Edit the parameterization script.
2. Explore simulation results using sscexplore.
3. Learn more about this example.

The model has data logging enabled.

2. Run the simulation and create the simulation log variable.

```
sim('pe_push_pull_converter_ccm');
```

The simulation log variable `simlog_pe_push_pull_converter_ccm` is saved in your workspace.

3. The model simulation time (*t*) is 0.04 seconds. Calculate average power losses for the interval when *t* is 0.010–0.025 seconds

```
tabulatedLosses = pe_getPowerLossSummary(simlog_pe_push_pull_converter_ccm,0.010,0.025)
```

```
tabulatedLosses =

  4×2 table
```

LoggingNode	Power
'pe_push_pull_converter_ccm.Diode'	0.3703
'pe_push_pull_converter_ccm.Diode1'	0.37022
'pe_push_pull_converter_ccm.N_Channel_MOSFET_2.mosfet_equation'	0.26598
'pe_push_pull_converter_ccm.N_Channel_MOSFET_1.mosfet_equation'	0.26595

The table shows dissipated power losses for each of the Diode and MOSFET blocks, averaged over the specified portion of simulation time.

- "Perform a Power-Loss Analysis"
- "Data Logging" (Simscape)
- "About the Simscape Results Explorer" (Simscape)

Input Arguments

node — Simulation log variable, or a specific node within the simulation log variable
Node object

Simulation log workspace variable, or a node within this variable, that contains the logged model simulation data, specified as a Node object. You specify the name of the simulation log variable by using the **Workspace variable name** parameter on the **Simscape** pane of the Configuration Parameters dialog box. To specify a node within the simulation log variable, provide the complete path to that node through the simulation data tree, starting with the top-level variable name.

If node is the name of the simulation log variable, then the table contains the data for all blocks in the model that contain *power_dissipated* variables. If node is the name of a node in the simulation data tree, then the table contains the data only for:

- Blocks or variables within that node
- Blocks or variables within subnodes at all levels of the hierarchy beneath that node

Example: `simlog.Cell1.MOS1`

`startTime` — Start of the time interval for averaging dissipated power losses
real number

Start of the time interval for averaging dissipated power losses, specified as a real number, in seconds. `startTime` must be greater than or equal to the simulation **Start time** and less than `endTime`.

Data Types: `double`

`endTime` — End of the time interval for averaging dissipated power losses
real number

End of the time interval for averaging dissipated power losses, specified as a real number, in seconds. `endTime` must be greater than `startTime` and less than or equal to the simulation **Stop time**.

Data Types: `double`

Output Arguments

`lossesTable` — Dissipated power losses for each block
table

Dissipated power losses for each block, returned as a table. The first column lists logging nodes for all blocks that have at least one `power_dissipated` variable. The second column lists the corresponding losses in watts.

See Also

See Also
`pe_getEfficiency` | `pe_getPowerLossTimeSeries` | `sscexplore`

Topics
"Perform a Power-Loss Analysis"

"Data Logging" (Simscape)
"About the Simscape Results Explorer" (Simscape)

Introduced in R2017a

pe_getPowerLossTimeSeries

Calculate dissipated power losses and return the time series data

Syntax

```
lossesCell = pe_getPowerLossTimeSeries(node)
lossesCell = pe_getPowerLossTimeSeries(node,startTime,endTime)
lossesCell = pe_getPowerLossTimeSeries(node,startTime,endTime,
intervalWidth)
```

Description

`lossesCell = pe_getPowerLossTimeSeries(node)` calculates dissipated power losses for blocks, based on logged Simscape simulation data, and returns the time series data for each block.

Before you call this function, generate or load the simulation log variable into your workspace. To generate the variable, simulate the model with simulation data logging enabled. For more information, see "About Simulation Data Logging" (Simscape). To load a previously saved variable from a file, right-click on the file and select **Load**.

Checking dissipated power allows you to determine if circuit components are operating within their efficiency requirements. Blocks in the **Semiconductor** > **Fundamental Components** library have an internal variable called *power_dissipated*. This variable represents the instantaneous dissipated power, which includes only the real power (not the reactive or apparent power) that the block dissipates. When you log simulation data, the time-value series for this variable represents the power dissipated by the block over time. You can view and plot this data using the Simscape Results Explorer. The `pe_getPowerLossTimeSeries` function also allows you to access this data from a cell array.

The `pe_getPowerLossTimeSeries` function calculates losses for each block that has a *power_dissipated* variable. Some blocks have more than one *power_dissipated* variable, depending on their configuration. For example, for the MOSFET block, both the `diode` node and the `ideal_switch` node have a `power_dissipated` logging node.

The function sums the power losses for both nodes to provide the total power loss for the block.

The nonideal semiconductor blocks also have thermal variants. Thermal variants have thermal ports that allow you to model the heat that is generated due to switching events and conduction losses. If you use a thermal variant, the function calculates power losses based on the thermal parameters that you specify. Essentially, the power dissipated is equal to the heat generated.

If you use a variant without a thermal port, the function calculates power losses based on the electrical parameters that you specify, such as on-state resistance and off-state conductance.

`lossesCell = pe_getPowerLossTimeSeries(node,startTime,endTime)` calculates dissipated power losses for blocks in a model, based on logged Simscape simulation data, and returns the time series data for each block for time steps from `startTime` to `endTime`. If `startTime` is equal to `endTime`, the interval is effectively zero and the function returns the instantaneous power for the time step that occurs at that moment.

`lossesCell = pe_getPowerLossTimeSeries(node,startTime,endTime, intervalWidth)` calculates dissipated power losses for blocks in a model, based on logged Simscape simulation data, and returns the time series data for each block for time steps from `startTime` to `endTime`, with averaging applied over intervals equal to `intervalWidth`. If `intervalWidth` is 0, the function returns the instantaneous power dissipation.
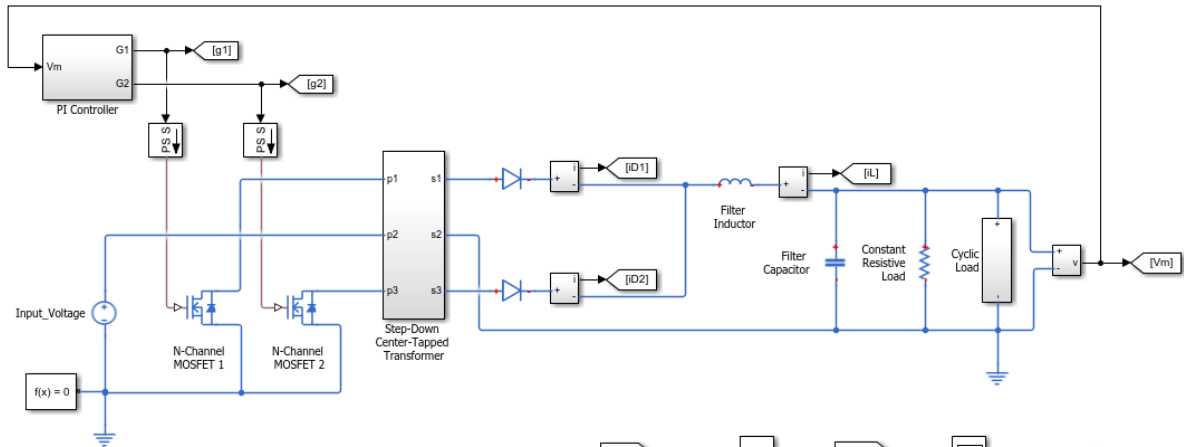
Examples

Calculate Dissipated Power Losses for the Entire Simulation Time

This example shows how to calculate instantaneous losses based on the power dissipated and return the time series data for all time steps in the entire simulation time using the `pe_getPowerLossTimeSeries` function. Data logging is enabled for the whole example model, and the option to limit data points is off.

Open the model. At the MATLAB® command prompt, enter:

```
model = 'pe_push_pull_converter_ccm';
```
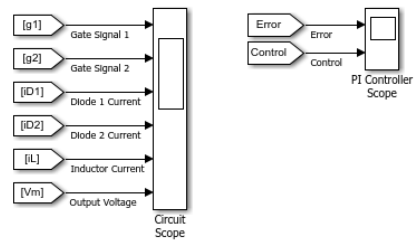
```
open_system(model)
```


Push-Pull Buck Converter in Continuous Conduction Mode

This example shows how to control the output voltage of a push-pull buck converter. The current flowing through the inductor is never zero, therefore the DC-DC converter operates in Continuous Conduction Mode (CCM). To convert and maintain the nominal output voltage, the PI Controller subsystem uses a simple integral control. During startup, the reference voltage is ramped up to the desired output voltage.

1. Edit the parameterization script.
2. Explore simulation results using sscexplore.
3. Learn more about this example.

Run the simulation and create the simulation log variable.

```
sim(model)
```

The simulation log variable *simlog_pe_push_pull_converter_ccm* is saved in your workspace.

Calculate dissipated power losses and return the time series data in a cell array.

```
lossesCell = pe_getPowerLossTimeSeries(simlog_pe_push_pull_converter_ccm)

lossesCell =

  4×2 cell array
```

```
'pe_push_pull_converter_ccm.N_Chann…'     [400001×3 double]
'pe_push_pull_converter_ccm.N_Chann…'     [400001×3 double]
'pe_push_pull_converter_ccm.Diode'        [400001×3 double]
'pe_push_pull_converter_ccm.Diode1'       [400001×3 double]
```

View the time series data. From the workspace, open the `lossesCell`
cell array, then open the `400001x3 double` numeric array for the
`pe_push_pull_converter_ccm.N_Channel_MOSFET_1.mosfet_equation`.

The first two columns contain the interval start and end time. The third column contains
the power loss data.

Plot the data.

```
plot(lossesCell{1, 2}(:,end))
title('Dissipated Power')
xlabel('Time Interval')
ylabel('Power (W)')
```
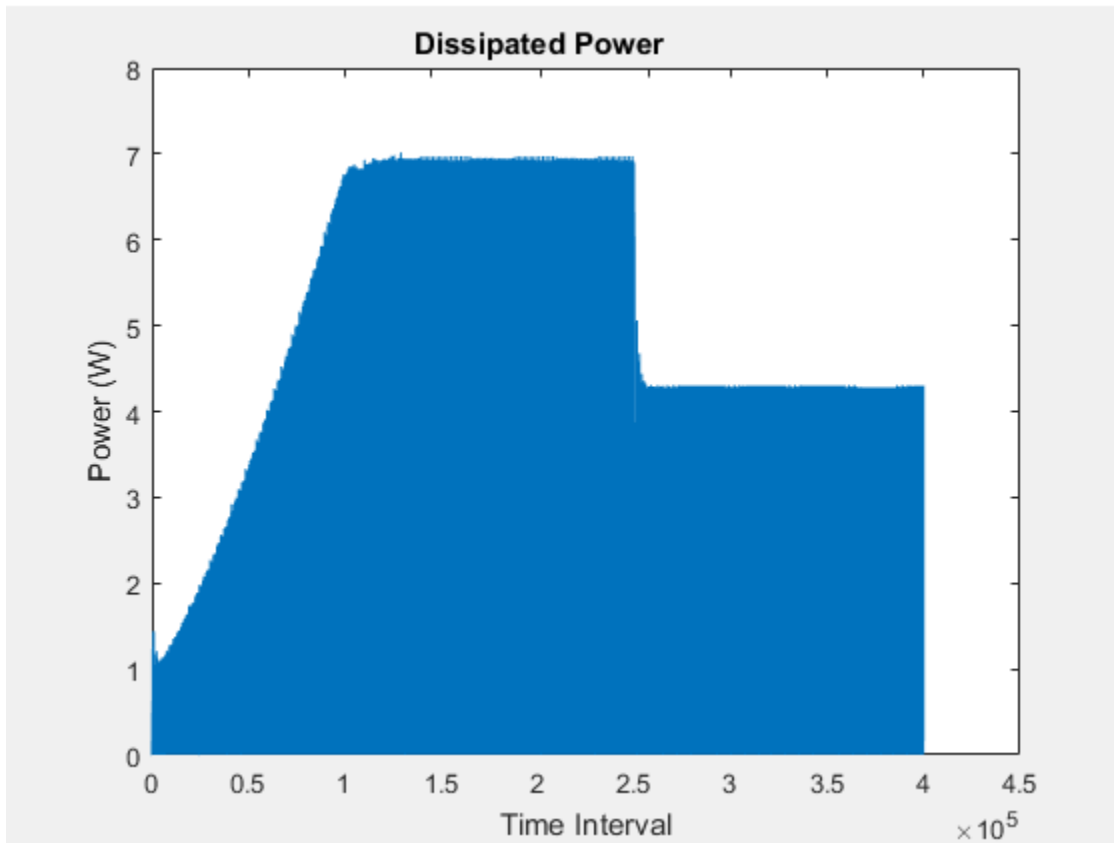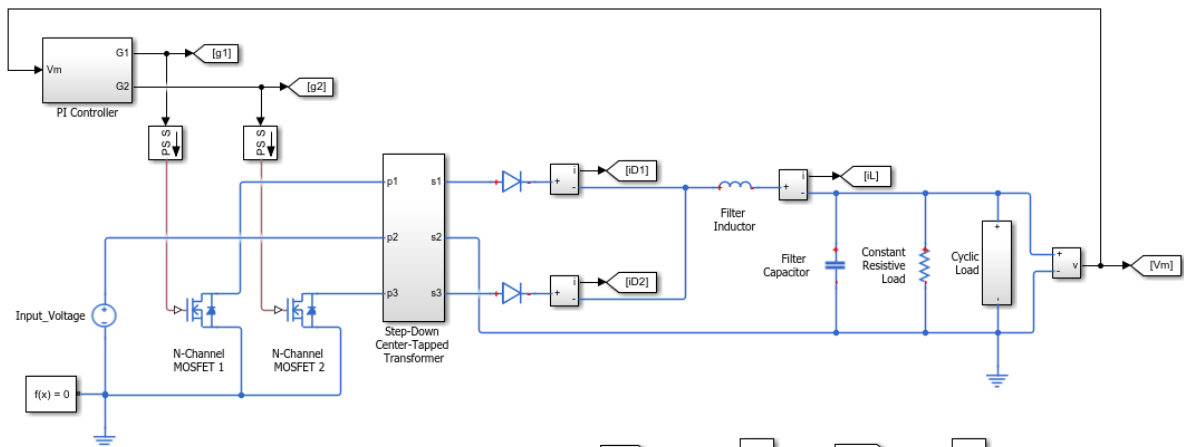
Calculate Dissipated Power Losses for a Specific Time Period

This example shows how to calculate instantaneous losses based on the power dissipated and return the time series data for all time steps in a specific time period using the `pe_getPowerLossTimeSeries` function. Data logging is enabled for the whole example model, and the option to limit data points is off.

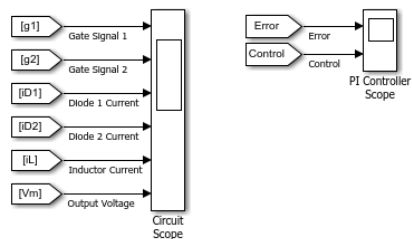Open the model. At the MATLAB® command prompt, enter:

```
model = 'pe_push_pull_converter_ccm';
open_system(model)
```

2-43

Push-Pull Buck Converter in Continuous Conduction Mode

This example shows how to control the output voltage of a push-pull buck converter. The current flowing through the inductor is never zero, therefore the DC-DC converter operates in Continuous Conduction Mode (CCM). To convert and maintain the nominal output voltage, the PI Controller subsystem uses a simple integral control. During startup, the reference voltage is ramped up to the desired output voltage.

1. Edit the parameterization script.
2. Explore simulation results using sscexplore.
3. Learn more about this example.

Run the simulation and create the simulation log variable.

```
sim(model)
```

The simulation log variable *simlog_pe_push_pull_converter_ccm* is saved in your workspace.

The model simulation time (*t*) is 0.04 seconds. Calculate dissipated power losses and return the time series data in a cell array for the interval when *t* is 0.010–0.025 seconds.

```
lossesCell = pe_getPowerLossTimeSeries(simlog_pe_push_pull_converter_ccm,0.010,0.025)
```

```
lossesCell =

  4×2 cell array

    'pe_push_pull_converter_ccm.N_Chann…'    [150002×3 double]
    'pe_push_pull_converter_ccm.N_Chann…'    [150002×3 double]
```

```
'pe_push_pull_converter_ccm.Diode'        [150002×3 double]
'pe_push_pull_converter_ccm.Diode1'       [150002×3 double]
```

View the time series data. From the workspace, open the `lossesCell`
cell array, then open the `150002x3 double` numeric array for the
`pe_push_pull_converter_ccm.N_Channel_MOSFET_1.mosfet_equation`.

The first two columns contain the interval start and end time. The third column contains
the power loss data.

Plot the data.

```matlab
plot(lossesCell{1, 2}(:,end))
title('Dissipated Power')
xlabel('Time Interval')
ylabel('Power (W)')
```
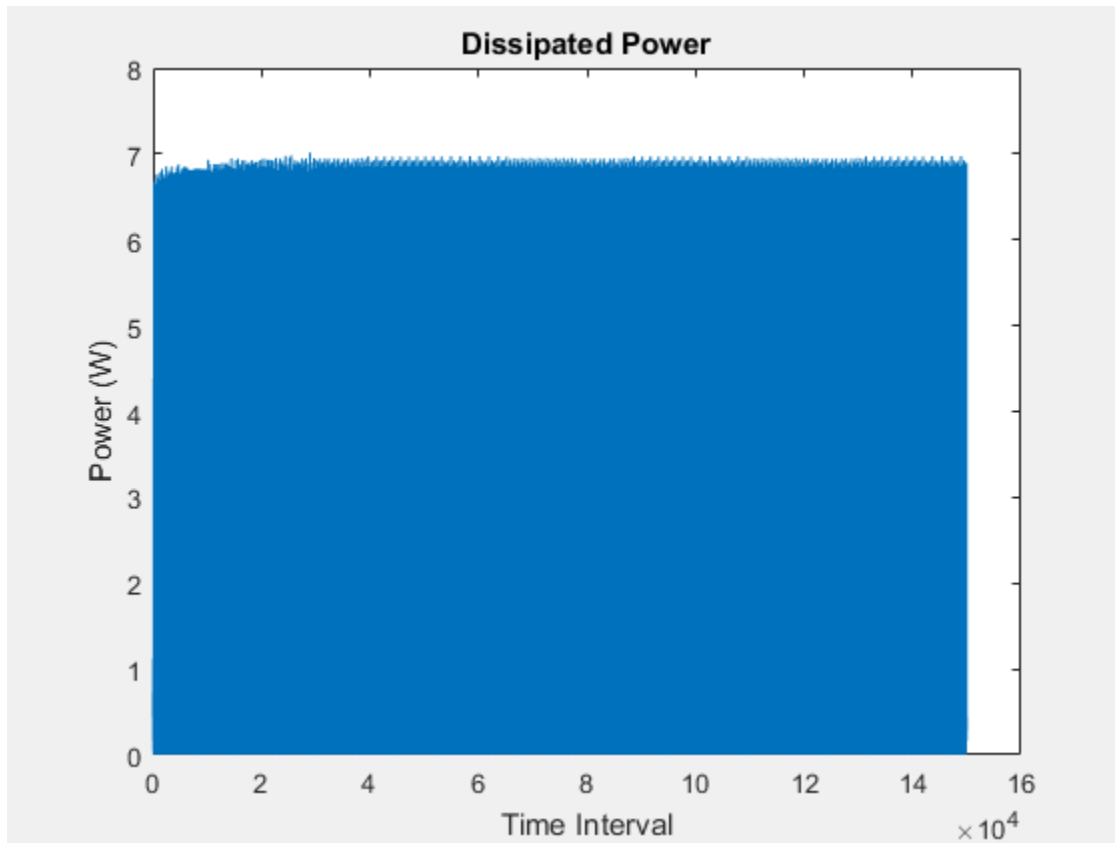
Calculate Dissipated Power Losses Using Specific Interval Widths

This example shows how to calculate losses based on the power dissipated and return the time series data for a specific time period with averaging applied over intervals of a specified width. Data logging is enabled for the whole example model, and the option to limit data points is off.

Open the model. At the MATLAB® command prompt, enter:

```
model = 'pe_push_pull_converter_ccm';
open_system(model)
```

Push-Pull Buck Converter in Continuous Conduction Mode

This example shows how to control the output voltage of a push-pull buck converter. The current flowing through the inductor is never zero, therefore the DC-DC converter operates in Continuous Conduction Mode (CCM). To convert and maintain the nominal output voltage, the PI Controller subsystem uses a simple integral control. During startup, the reference voltage is ramped up to the desired output voltage.

1. Edit the parameterization script.
2. Explore simulation results using sscexplore.
3. Learn more about this example.

Run the simulation and create the simulation log variable.

```
sim(model)
```
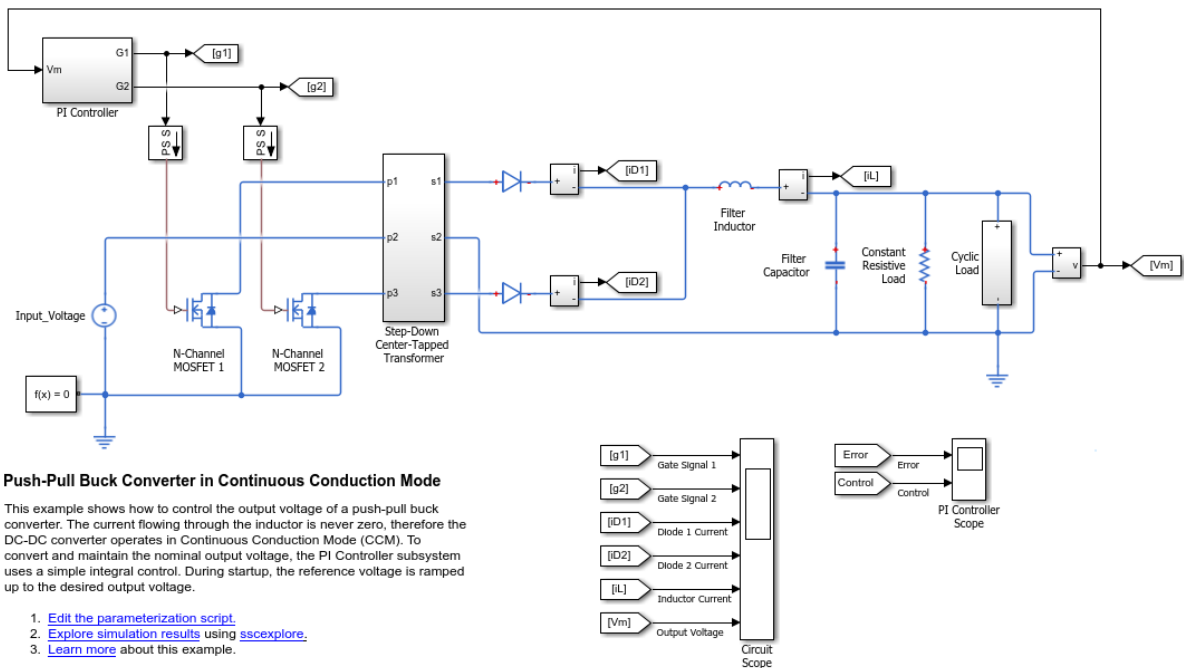
The simulation log variable *simlog_pe_push_pull_converter_ccm* is saved in your workspace.

The model simulation time, *t*, is 0.04 seconds. Calculate the average dissipated power losses for 1.1e-4 s intervals and return the time series data in a cell array for the period when simulation time, *t*, is 0.010–0.025 seconds.

```
lossesCell = pe_getPowerLossTimeSeries(simlog_pe_push_pull_converter_ccm,0.010,0.025,1.
```

```
lossesCell =

  4×2 cell array

    'pe_push_pull_converter_ccm.N_…'    [136×3 double]
```
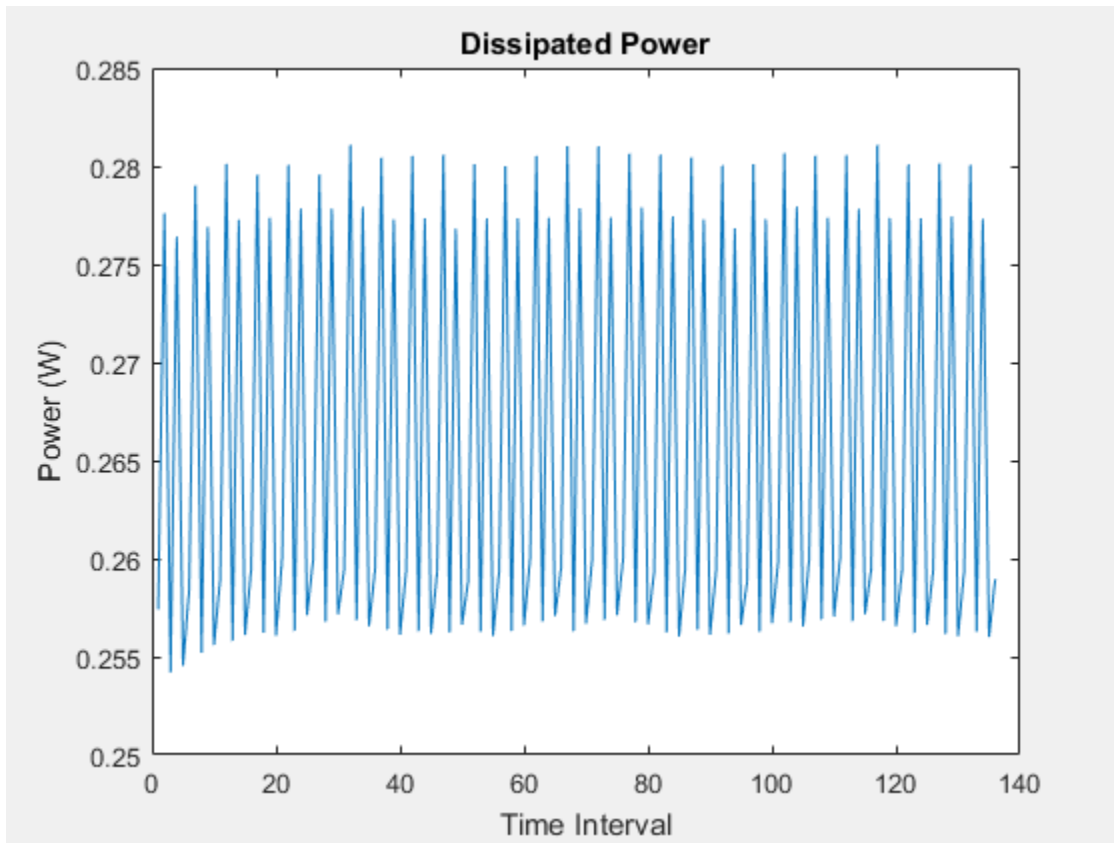
```
'pe_push_pull_converter_ccm.N_…'    [136×3 double]
'pe_push_pull_converter_ccm.Di…'    [136×3 double]
'pe_push_pull_converter_ccm.Di…'    [136×3 double]
```

View the time series data. From the workspace, open the `lossesCell` cell array, then open the `136x3 double` numeric array for the `pe_push_pull_converter_ccm.N_Channel_MOSFET_1.mosfet_equation`.

The first two columns contain the interval start and end time. The third column contains the power loss data. In this case, to use averaging intervals that are equal in width to 1.1e-4 seconds, the function adjusts the start time for the first interval from the specified value of 0.010 seconds to a value of 0.01004 seconds. There are 136 intervals of 1.1e-4 seconds.

Plot the data.

```
plot(lossesCell{1, 2}(:,end))
title('Dissipated Power')
xlabel('Time Interval')
ylabel('Power (W)')
```

- "Perform a Power-Loss Analysis"
- "Data Logging" (Simscape)
- "About the Simscape Results Explorer" (Simscape)

Input Arguments

node — Simulation log variable, or a specific node within the simulation log variable
Node object

Simulation log workspace variable, or a node within this variable, that contains the
logged model simulation data, specified as a Node object. You specify the name of the

simulation log variable by using the **Workspace variable name** parameter on the **Simscape** pane of the Configuration Parameters dialog box. To specify a node within the simulation log variable, provide the complete path to that node through the simulation data tree, starting with the top-level variable name.

If `node` is the name of the simulation log variable, then the table contains the data for all blocks in the model that contain *power_dissipated* variables. If `node` is the name of a node in the simulation data tree, then the table contains the data only for:

- Blocks or variables within that node
- Blocks or variables within subnodes at all levels of the hierarchy beneath that node

Example: `simlog_pe_push_pull_converter_ccm`

`startTime` — Start of the time interval for calculating the data
O (default) | real number

Start of the time interval for calculating the power loss time series, specified as a real number, in seconds. `startTime` must be greater than or equal to the simulation **Start time** and less than `endTime`.

Data Types: `double`

`endTime` — End of the time interval for calculating the data
simulation stop time (default) | real number

End of the time interval for calculating the power loss time series, specified as a real number, in seconds. `endTime` must be greater than `startTime` and less than or equal to the simulation **Stop time**.

Data Types: `double`

`intervalWidth` — size of the interval in time for calculating the average power dissipation
O (default)

If the time between the specified `startTime` and `endTime` is not an integer multiple of `intervalWidth`, the function adjusts the start time. The figure shows how the function adjusts the start time to ensure that width of each time interval that the dissipated power is averaged over is equal to the specified `intervalWidth`.
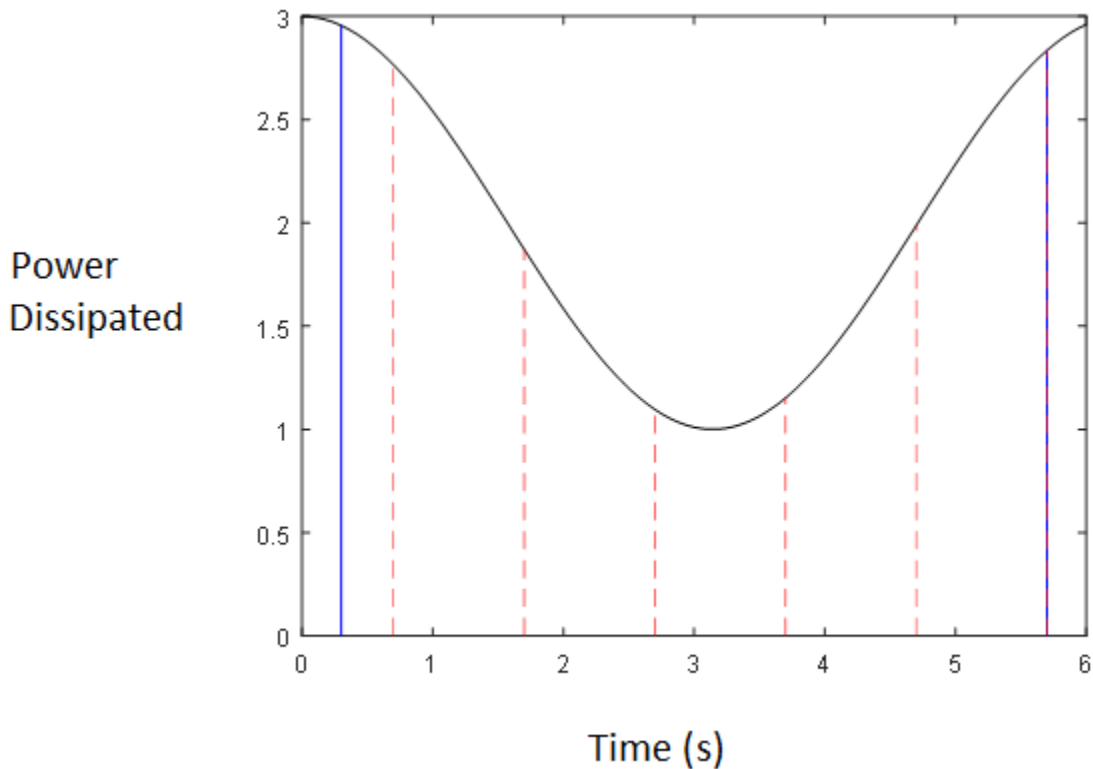
The black line is an example of the instantaneous *power_dissipated* variables summed over all elements in an individual block. The simulation runs for 6 seconds. The `startTime` and `endTime` are indicated by the solid blue lines. The `intervalWidth` is set to 1 second. There are five intervals as indicated by the red dashed lines. The right-most edge of the last interval coincides with `endTime`. The left-most edge of the first interval is always greater than or equal to `startTime`. The edge is equal to `startTime` only if (`endTime` -`startTime`)/`intervalWidth` is an integer. The output in this case consists of five values for the averaged power dissipation, one point for each time period. The function outputs the actual start and stop times in the tabulated output data.

Example: `1.1e-3`

Data Types: `double`

Output Arguments

`lossesCell` — Time series of the dissipated power losses for each block
cell array

Cell array that contains the names of the blocks in the nodes that contain *power_dissipated* variables and, for each block, a three-column array:

- Column one contains the interval start time.
- Column two contains the interval end time.
- Column three contains the dissipated power for the time interval.

If the interval width is 0 seconds, that is, the start time is equal to the end time, then the dissipated power is the instantaneous power loss. If the interval is greater than 0 seconds, the dissipated power is the average power loss for the time of the interval.

See Also

See Also
pe_getEfficiency | pe_getPowerLossSummary | sscexplore

Topics
"Perform a Power-Loss Analysis"
"Data Logging" (Simscape)
"About the Simscape Results Explorer" (Simscape)

Introduced in R2017a

pe_plotHarmonics

Plot percentage of fundamental magnitude versus harmonic order

Syntax

```
pe_plotHarmonics(loggingNode)
pe_plotHarmonics(loggingNode,valueIdx)
pe_plotHarmonics(loggingNode,valueIdx,tOfInterest)
pe_plotHarmonics(loggingNode,valueIdx,tOfInterest,nPeriodOfInterest)
pe_plotHarmonics(loggingNode,valueIdx,tOfInterest,
nPeriodOfInterest,...
offsetOfInterest)
pe_plotHarmonics(loggingNode,valueIdx,tOfInterest,
nPeriodOfInterest,...
offsetOfInterest,nHarmonic)
```

Description

`pe_plotHarmonics(loggingNode)` plots a bar chart of percentage of fundamental magnitude versus harmonic order of the `simscape.logging.Node` of an AC or periodic variable. The title of the bar chart includes the fundamental frequency, fundamental peak value, and total harmonic distortion (THD) percentage.

You enter the input arguments in a specific order. The Simscape logging node input argument is required. All other input arguments are optional and have default values. If you are specifying a value for a subsequent optional input argument, enter `[]` to use the default value for an optional input argument.

The `pe_plotHarmonics` function uses the `pe_getHarmonics` function to:

- Find the points in the ith signal (valueIdx) where the Simscape log crosses a threshold (offsetOfInterest).
- Use the crossing points to find the required number of periods (nPeriodOfInterest) preceding the specified time (tOfInterest).
- Calculate the harmonic magnitudes, up to and including the required number of harmonics (nHarmonic).

- Input the down-selected data to the Goertzel algorithm, which calculates the harmonic magnitudes up to and including the required number of harmonics (nHarmonic).

Note: The `pe_getHarmonics` function uses threshold crossing points to determine the fundamental frequency of the data. If your input data is noisy or crosses the threshold more frequently than half of the fundamental period, filter it before you use the `pe_plotHarmonics` function to plot it.

The `pe_plotHarmonics` function then inputs the harmonic orders and harmonic magnitudes to the `pe_calculateThdPercent` function to calculate the THD.

`pe_plotHarmonics(loggingNode,valueIdx)` uses the index into value data.

`pe_plotHarmonics(loggingNode,valueIdx,tOfInterest)` uses the simulation time.

`pe_plotHarmonics(loggingNode,valueIdx,tOfInterest,nPeriodOfInterest)` uses the number of periods of fundamental frequency.

`pe_plotHarmonics(loggingNode,valueIdx,tOfInterest,`
`nPeriodOfInterest,...`
`offsetOfInterest)` uses the DC offset.

`pe_plotHarmonics(loggingNode,valueIdx,tOfInterest,`
`nPeriodOfInterest,...`
`offsetOfInterest,nHarmonic)` uses the number of harmonics.

Examples

Plot Using Default Values

This set of function arguments uses the Simscape logging node `simlog.Load.V`, which contains data from a three-phase voltage. The function analyzes the default signal, which is the first, or a-phase, signal at the final simulation time. The function uses the default values of 12 for the number of periods of the signal, 0V for the signal bias, and 30 for the number of harmonics.

```
pe_plotHarmonics(simlog.Load.V)
```

Plot Using Specified Values

This set of function arguments uses the Simscape logging node `simlog.Load.V`, which contains data from a three-phase voltage. The function analyzes the second, or b-phase, signal at a simulation time of `2.3` s. The function uses `10` periods of the signal, which has a bias of `1` V. The function analyzes `15` harmonics.

```
pe_plotHarmonics(simlog.Load.V,2,2.3,10,1,15)
```

Plot Using Default and Specified Values

This set of function arguments uses the Simscape logging node `simlog.Load.V`, which contains data from a three-phase voltage. The function analyzes the first, or a-phase, signal at a simulation time of `2.3` s. The function uses the default number (`12`) of periods of the signal, which has a bias of `1` V. The function analyzes the default number (`30`) of harmonics.

```
pe_plotHarmonics(simlog.Load.V,[],2.3,[],1)
```

Input Arguments

`loggingNode` — Simscape logging node
1-by-1 simscape.logging.Node

Simscape logging node, specified as a 1-by-1 `simscape.logging.Node`. You create a `simscape.logging.Node` by running a simulation with Simscape logging enabled. To learn how to enable data logging, see "Enable Data Logging for the Whole Model" (Simscape).

Example: `simlog.Load.V`

The Simscape logging node simlog.Load.V contains data from a three-phase voltage.

`valueIdx` — Index into value data
1 (default) | scalar

Index into value data, specified as a scalar. Specifies the ith variable of interest in the Simscape log.

Example: 2

Specify the b-phase, which is the second signal from a three-phase voltage.

Example: [ ]

Use [] to specify the default value of 1. The a-phase, which is the first signal from a three-phase voltage, is the default signal of interest.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`tOfInterest` — Simulation time
final time in Simscape log (default) | scalar

Simulation time of interest for harmonic analysis, specified as a scalar.

Example: 2.3

Specify a 2.3s simulation time.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`nPeriodOfInterest` — Number of periods
12 (default) | scalar

Number of periods of fundamental frequency to be included in harmonic analysis, specified as a scalar.

Example: 10

Specify 10 periods of the signal.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`offsetOfInterest` — DC offset
0 (default) | scalar

DC offset in the input signal, specified as a scalar. The function uses this value to find the periods of interest.

Example: 1

Specify a bias of 1V for the signal.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

`nHarmonic` — Number of harmonics
30 (default) | scalar

Number of harmonics to include in analysis, specified as a scalar.

Example: `15`

Specify that the number of harmonics to be analyzed is `15`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

See Also

See Also

Blocks
Spectrum Analyzer

Functions
`pe_calculateThdPercent` | `pe_getHarmonics`

Using Objects
simscape.logging.Node

Topics
"Perform an Online Harmonic Analysis Using the Simscape Spectrum Analyzer Block"
"Choose a Simscape Power Systems Function for an Offline Harmonic Analysis"
"Data Logging" (Simscape)

Introduced in R2014a

Abstract

Explore the symbols and terminology that are used in Simscape Power Systems
Simscape Components.

B	Susceptance.
C	Capacitance.
composite three-phase port	Three-phase electrical conserving port, i.e., a port that represents three electrical conserving ports with a single connection. You can use composite three-phase ports to build models corresponding to single-line diagrams of three-phase electrical systems. Instead of explicitly connecting each phase of the three-phase system between blocks, you connect all three phases using a single port.
delta connection	Three-phase winding configuration. Each of the three windings is connected between phases. Physically, the connection resembles the Greek capital letter Δ. For a delta connection, phase shifts can be specified in terms of the hours of a clock. An 11 o'clock delta connection represents a 30 degree phase advance. A 1 o'clock delta connection represents a 30 degree phase delay.
expanded three-phase port	Three separate electrical conserving ports that represent the individual phases of a three-phase system. You individually connect each phase of the three-phase system between blocks.
F_{Rated}	Rated electrical frequency of three-phase machine.
G	Conductance.
i	Instantaneous current.
I	RMS current.
L	Inductance.
line voltage	RMS value of the voltage measured between phases. In a balanced three-phase system with no harmonics, peak

line voltage equals peak phase voltage multiplied by $\sqrt{3}$. The RMS value equals peak line voltage divided by $\sqrt{2}$. Standard abbreviations are Vab, Vac, Vbc, etc. Line voltage is also known as rated voltage, rated RMS, name plate voltage, line-line voltage, and phase-phase voltage.

nPolePairs   Number of pole pairs for three-phase machine.

phase voltage   RMS value of the voltage measured between a phase and reference point. The reference point is usually a neutral or ground point. In a balanced three-phase system with no harmonics, peak phase voltage is equal to peak line voltage divided by $\sqrt{3}$. The RMS value equals peak phase voltage divided by $\sqrt{2}$. Standard abbreviations are Va, Vb, and Vc.

P$_{PerPhase}$ Real power per phase.

psi   Instantaneous peak magnetic flux linkage.

Psi   RMS magnetic flux linkage.

Q$_{PerPhase}$ Reactive power per phase.

R   Resistance.

S$_{Rated}$ Rated apparent power.

S$_{PerPhase}$ Apparent power per phase.

torque   Torque of three-phase machine.

v   Instantaneous voltage.

V   RMS voltage.

Va, Vb, Vc   Phase voltages.

Vab, Vac, Vbc,...   Line voltages.

V$_{Rated}$ Rated voltage of three-phase machine.

ω_{Electrical}	Electrical angular speed of three-phase machine.
ω_{Mechanical}	Mechanical angular speed of three-phase machine.
winding voltage	Voltage measured between both ends of a winding. For a wye connection, winding voltage equals phase voltage. For a delta connection, winding voltage equals line voltage.
wye connection	Three-phase winding configuration. Each of the three windings is connected between a phase and neutral point. Physically, the connection resembles the letter Y. A wye connection is also referred to as a star connection, or Y connection.
X	Reactance.
Y	Admittance.
z	Impedance.