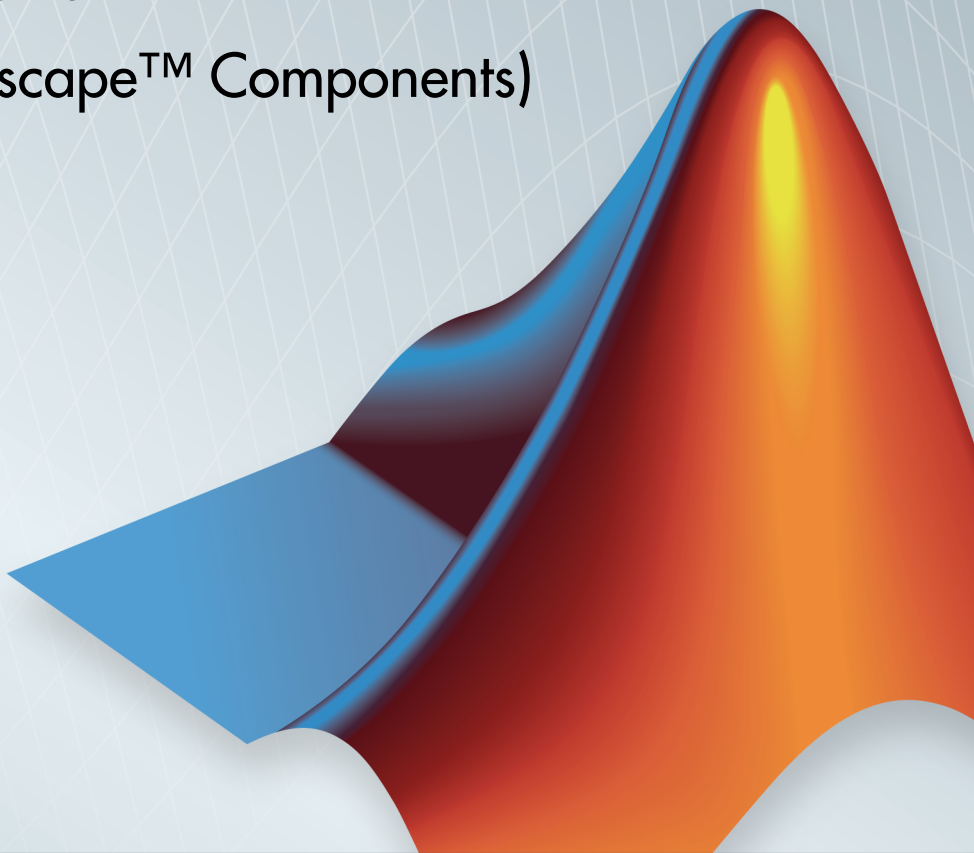


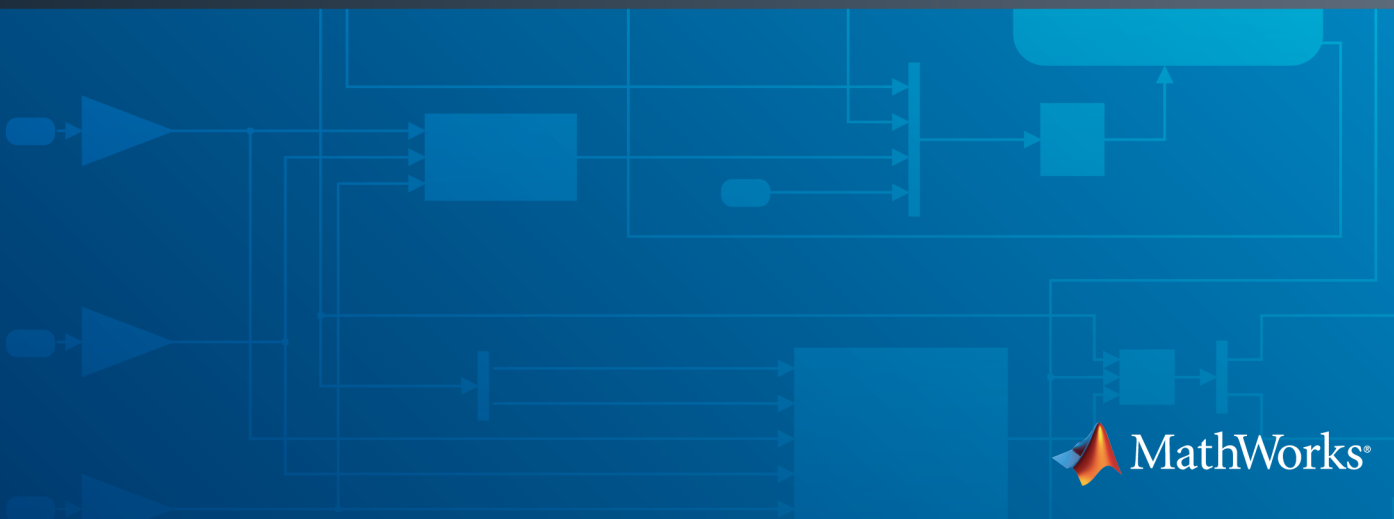
**SimPowerSystems™**

Reference (Simscape™ Components)

R2014b



**MATLAB® & SIMULINK®**



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### Revision History

September 2013	Online only	New for Version 6.0 (Release 2013b)
March 2014	Online only	Revised for Version 6.1 (Release 2014a) (Renamed from <i>SimPowerSystems™ Reference (Third Generation)</i> )
October 2014	Online only	Revised for Version 6.2 (Release 2014b)

**1** | Blocks — Alphabetical List

**2** | Functions — Alphabetical List

Abbreviations and Naming Conventions in Simscape  
Components Libraries



# Blocks — Alphabetical List

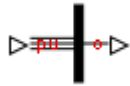
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# Asynchronous Machine Measurement

Per-unit measurement from asynchronous machine

## Library

Machines



## 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:

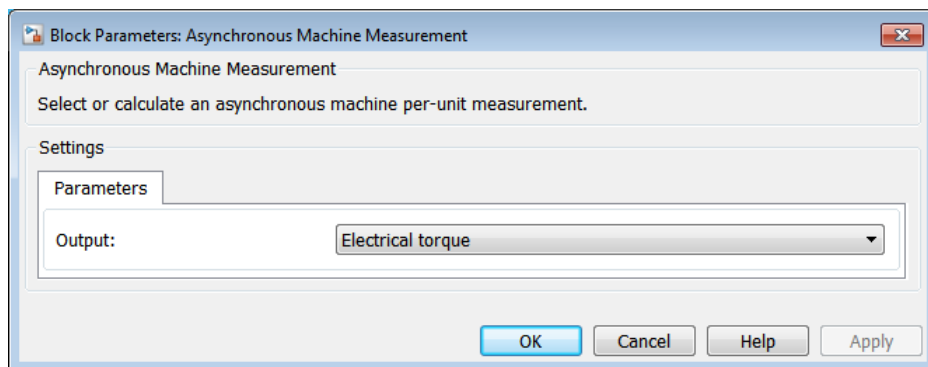
- Directly outputs the value of an element in the input signal vector
- Calculates the per-unit measurement by using values of elements in the input signal vector in mathematical expressions

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
Rotor velocity	pu_velocity

Output Parameter Setting	Output Value Expression
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	$cos(power\_factor\_angle)$

## Dialog Box and 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 \(fundamental\)](#)

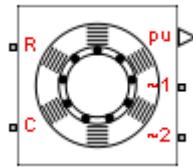


# Asynchronous Machine Squirrel Cage (fundamental)

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 with parameterization 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) 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  $\theta_e$  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

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

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

- $\omega_{base}$  is the per-unit base electrical speed.

- $\psi_{ds}$ ,  $\psi_{qs}$ , and  $\psi_{0s}$  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

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

where  $i_a$ ,  $i_b$ , 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.
- $\psi_{dr}$  and  $\psi_{qr}$  are the d-axis and q-axis rotor flux linkages.
- $\omega$  is the is the per-unit synchronous speed. For a synchronous reference frame, the value is 1.
- $\omega_r$  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

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

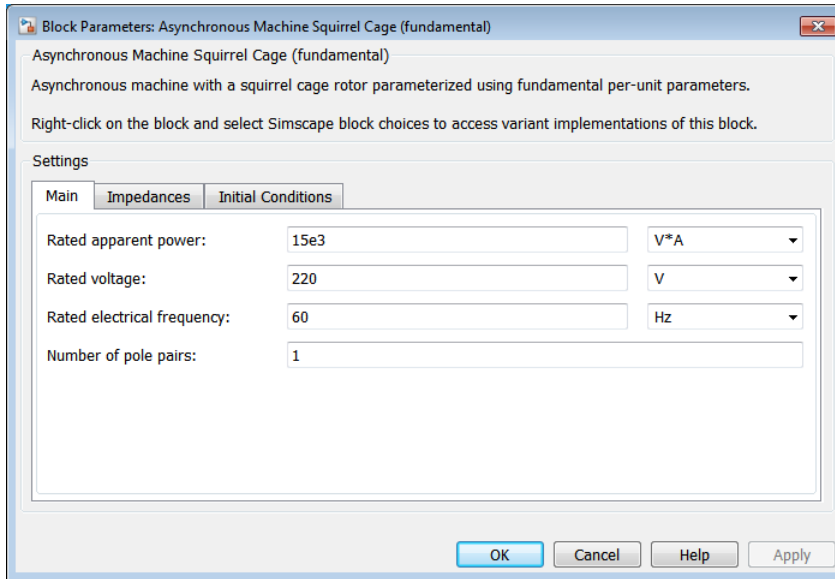
## Plotting and Displaying Options

For an asynchronous machine block, you can perform plotting and display actions using the **Power Systems** menu on the block context menu.

Right-click the block. From the context menu, select one of the following from the **Power Systems > Asynchronous Machine** menu:

- **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.

## Dialog Box and Parameters



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

- “Main Tab” on page 1-9
- “Impedances Tab” on page 1-10
- “Initial Conditions Tab” on page 1-10

### Main Tab

#### Rated apparent power

Rated apparent power of the asynchronous machine. The default value is 15e3 VA.

**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, i.e., 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

### Simscape Blocks

Asynchronous Machine Measurement | Asynchronous Machine Wound Rotor (fundamental)

## Related Examples

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

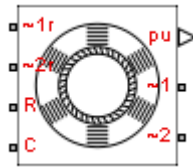


# Asynchronous Machine Wound Rotor (fundamental)

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 with parameterization 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, you must also 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  $\theta_e$  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  $\theta_r$  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

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

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

- $\omega_{base}$  is the per-unit base electrical speed.
- $\psi_{ds}$ ,  $\psi_{qs}$ , and  $\psi_{0s}$  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

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

where  $i_a$ ,  $i_b$ , 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

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

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

- $\psi_{dr}$ ,  $\psi_{qr}$ , and  $\psi_{0r}$  are the d-axis, q-axis, and zero-sequence rotor flux linkages.
- $\omega$  is the per-unit synchronous speed. For a synchronous reference frame, the value is 1.
- $\omega_r$  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

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

where  $i_{ar}$ ,  $i_{br}$ , 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 Displaying Options

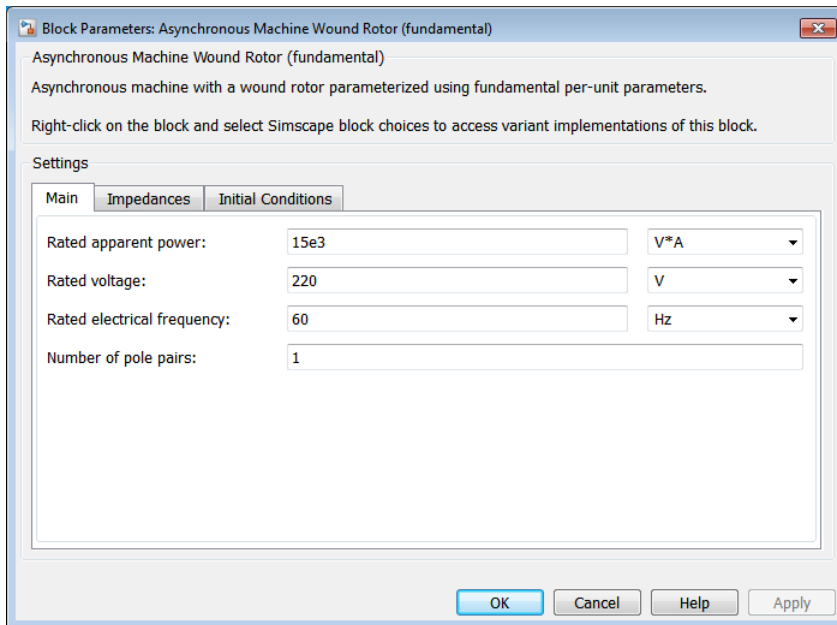
For an asynchronous machine block, you can perform plotting and display actions using the **Power Systems** menu on the block context menu.

Right-click the block. From the context menu, select one of the following from the **Power Systems > Asynchronous Machine** menu:

- **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.

## Dialog Box and Parameters



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

- “Main Tab” on page 1-18
- “Impedances Tab” on page 1-19
- “Initial Conditions Tab” on page 1-19

## Main Tab

### Rated apparent power

Rated apparent power of the asynchronous machine. The default value is 15e3 VA.

**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,  $R_s$  (pu)**

Stator resistance. The default value is 0.0258.

**Stator leakage inductance,  $L_{ls}$  (pu)**

Stator leakage inductance. The default value is 0.0930.

**Referred rotor resistance,  $R_r'$  (pu)**

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

**Referred rotor leakage inductance,  $L_{lr}'$  (pu)**

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

**Magnetizing inductance,  $L_m$  (pu)**

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

**Stator zero-sequence inductance,  $L_0$  (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

### Simscape Blocks

Asynchronous Machine Measurement | Asynchronous Machine Squirrel Cage (fundamental)

## Related Examples

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

# Battery

Simple battery as finite, charge-dependent voltage source with resistance

## Library

Sources



## Description

The Battery block models a finite, charge-dependent voltage source with a series resistance. The voltage has a reciprocal relationship with charge defined by the equation

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

where:

- $x$  is the ratio of the charge left to the rated or full charge for the battery.
- $V_0$  is the voltage when the battery is fully charged, which you specify using the **Nominal Voltage, Vnom** block parameter.
- $\alpha$  and  $\beta$  are curve-fitting constants. The block fits the voltage-charge equation above onto the points (0, 0) and (Q1, V1) on a charge-voltage graph and computes  $\alpha$  and  $\beta$  accordingly. Specify Q1 and V1 in the block dialog box.

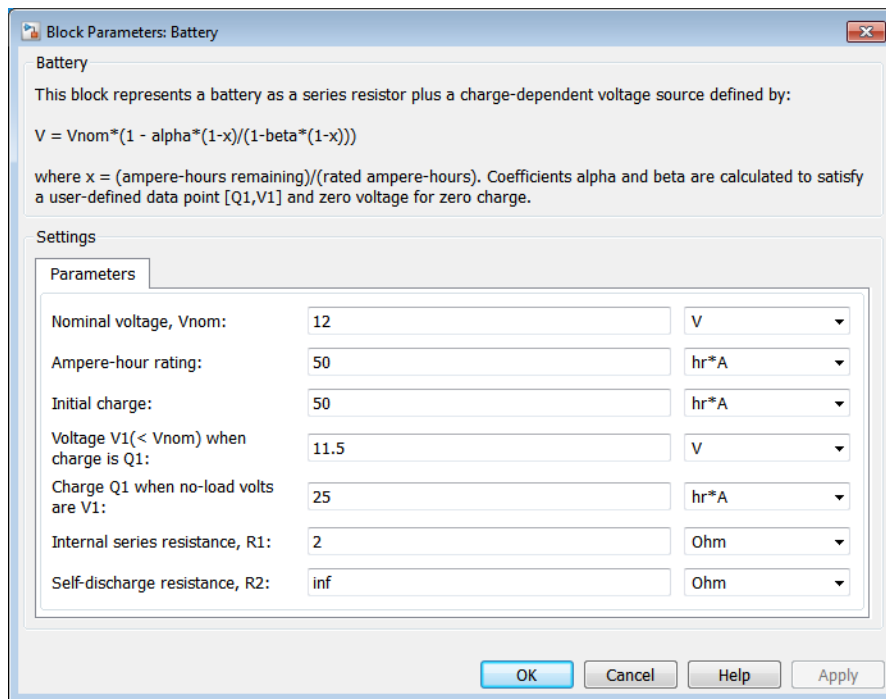
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**Note:** This equation is an approximation of actual discharge dynamics in a real battery but is easy to parameterize as you only have to provide voltage-charge data for a single discharge point.

---

The block includes a self-discharge resistance across the battery terminals. By default, self-discharging is disabled, as the parameter **Self-discharge resistance, R2** is set to `inf`.

## Dialog Box and Parameters



### Nominal voltage, Vnom

Voltage of the battery at full charge. The default value is 12 V.

### Ampere-Hour rating

Maximum battery charge. The default value is 50 hr\*A.

### Initial charge

Charge on the battery at the start of the simulation. The default value is 50 hr\*A.

### Voltage V1 < Vnom when charge is Q1

Voltage when the battery charge is at the rated value. The default value is 11.5 V.

**Charge Q1 when no-load volts are V1**

Charge when the battery potential is V1 Volts. The default value is 25 hr\*A.

**Internal series resistance, R1**

Internal connection resistance of the battery. The default value is 2  $\Omega$ .

**Self-discharge resistance, R2**

Self-discharge resistance of the battery, connected between the two terminals. The default value is `inf`  $\Omega$  (self-discharging disabled).

## Ports

The block has the following ports:

-

Negative battery terminal

+

Positive battery terminal

## See Also

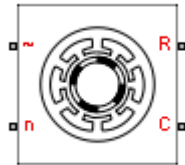
Current Source | Voltage Source

# Brushless DC Motor

Three-winding brushless DC motor with trapezoidal flux distribution

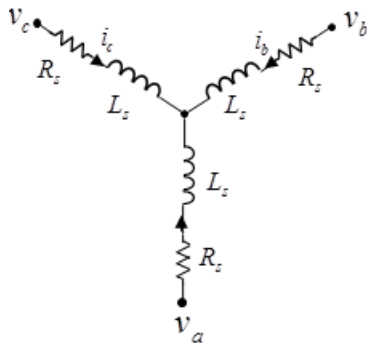
## Library

Machines / Permanent Magnet Rotor

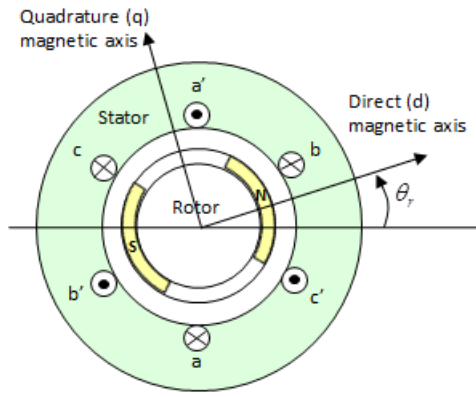


## Description

The Brushless DC Motor block models a permanent magnet synchronous machine with a three-phase wye-wound stator. The figure shows the equivalent electrical circuit for the stator windings.

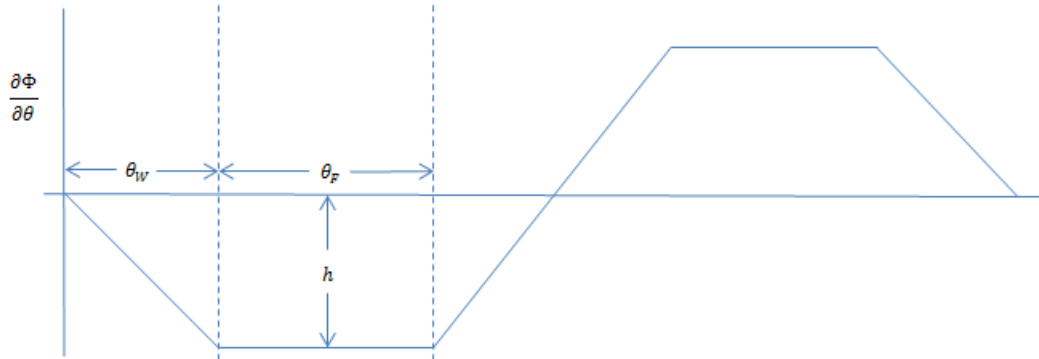


This figure shows the motor construction with a single pole-pair on the rotor.



For the axes convention in the preceding figure, the a-phase and permanent magnet fluxes are aligned when rotor angle  $\theta_r$  is zero. The block supports a second rotor axis definition in which rotor angle is defined as the angle between the a-phase magnetic axis and the rotor q axis.

The rotor magnetic field due to the permanent magnet(s) creates 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:

- $\Phi$  is the permanent magnet flux linkage.
- $\theta$  is the rotor angle.
- $\omega$  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  $\frac{\partial \Phi}{\partial \theta}$  over the range 0 to  $\pi/2$ ,

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

where:

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

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

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.
- $\frac{d\psi_a}{dt}$ ,  $\frac{d\psi_b}{dt}$ , and  $\frac{d\psi_c}{dt}$

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:

- $\psi_a$ ,  $\psi_b$ , and  $\psi_c$  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.
- $\psi_{am}$ ,  $\psi_{bm}$ , and  $\psi_{cm}$  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. This is the average self-inductance of each of the stator windings.
- $L_m$  is the stator inductance fluctuation. This is the amplitude of the fluctuation in self-inductance and mutual inductance with changing rotor angle.
- $M_s$  is the stator mutual inductance. This is 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

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

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

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

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

and

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

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

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

- $N$  is the number of rotor permanent magnet pole pairs.
- $\omega$  is the rotor mechanical rotational speed.
- $\frac{\partial \psi_a}{\partial \theta_r}$ ,  $\frac{\partial \psi_b}{\partial \theta_r}$ , and  $\frac{\partial \psi_c}{\partial \theta_r}$

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

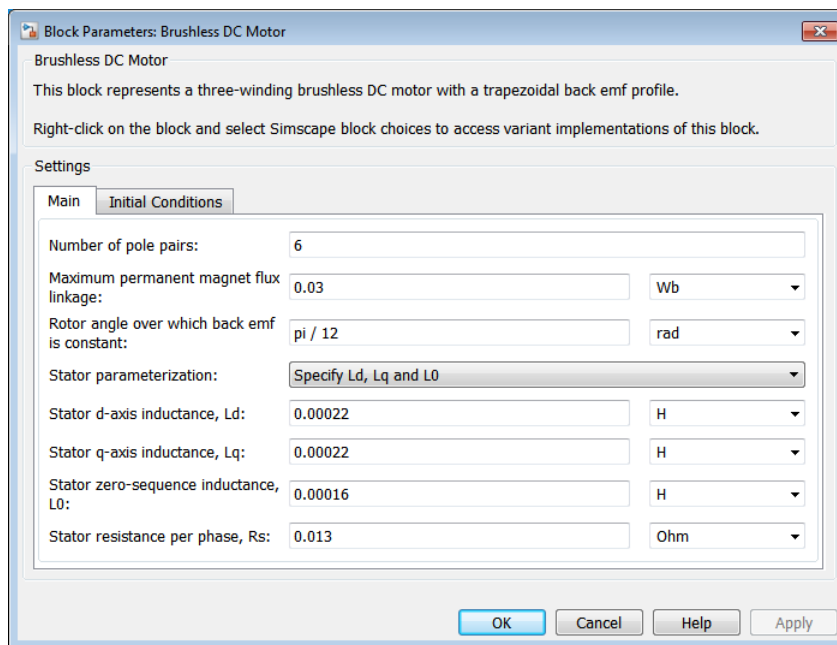
- $i_d$ ,  $i_q$ , and  $i_0$  are the d-axis, q-axis, and zero-sequence currents, defined by

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

- $L_d = L_s + M_s + 3/2 L_m$ .  $L_d$  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).

## Dialog Box and Parameters



### Main Tab

#### Number of pole pairs

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

#### Maximum permanent magnet flux linkage

Peak permanent magnet flux linkage with any of the stator windings. 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 is  $\theta_F$  in the trapezoidal rate of change of flux figure. The default value is  $\pi/12$  rad.

**Stator parameterization**

Set of stator parameters that the block dialog box shows. The default value is Specify Ld, Lq and L0.

**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  $\Omega$ .

**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 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.

## Related Examples

- “Expand and Collapse Three-Phase Ports on a Block”

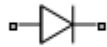
# Commutation Diode

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 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:

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

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

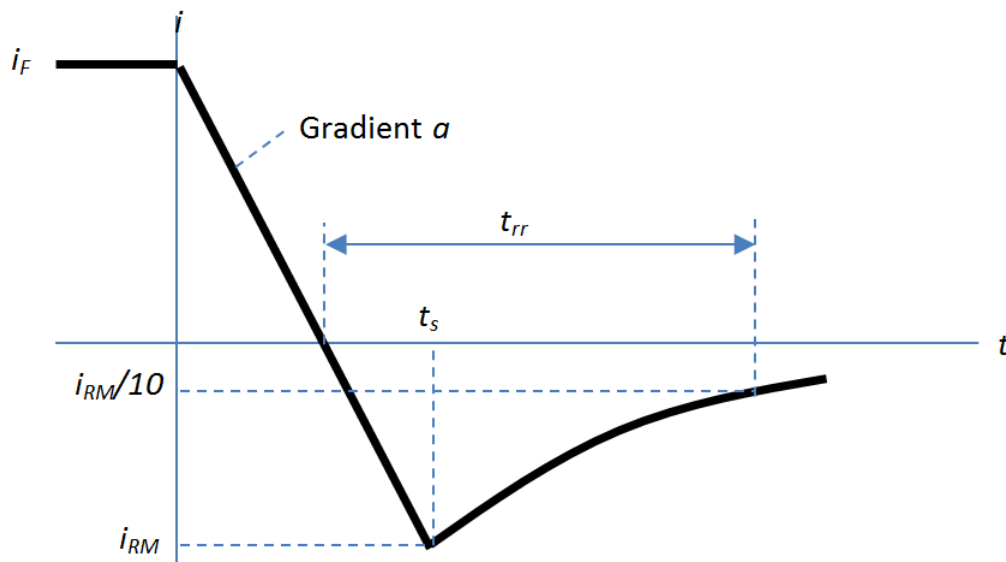
$$q_E = (\tau + T_M)(v_D - v_F(1 - RG)) / R \quad \text{if } v_D > v_F$$

$$q_E = (\tau + T_M)Gv_D \quad \text{if } v_D \leq v_F$$

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.
- $\tau$  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  $\tau$  based on the values you enter on the Charge Dynamics tab of the block dialog box. The block uses  $T_M$  and  $\tau$  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,

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

Substituting Equation 1-4 into Equation 1-2,

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

Solving Equation 1-5 for  $q_M$ ,

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

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,

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

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,

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

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, i.e., when  $t > t_s$ . The diode is reverse biased, and current and junction charge are effectively zero.

The current is defined by

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

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  $\tau$ . The calculation uses an iterative scheme because of the exponential term in Equation 1–9.

## Alternatives to Specifying $t_{rr}$ Directly

As well as 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  $\lambda$
- 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  $\lambda$  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  $\lambda$  is 3.  $\lambda$  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

$$Q_s = \frac{1}{2} \times -i_{RM} \times \frac{i_{RM}}{a}$$

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

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

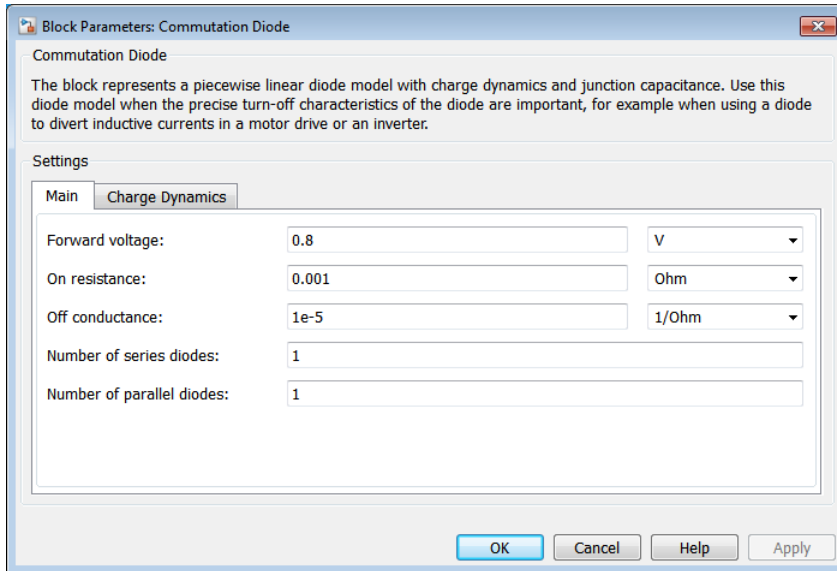
Therefore, total reverse recovery charge is given by the equation

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

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

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

## Dialog Box and Parameters



- “Main Tab” on page 1-40
- “Charge Dynamics Tab” on page 1-41

### 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  $\Omega$ .

#### Off conductance

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

#### 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 in the block dialog box. The default value is 1.

### **Number of parallel diodes**

The number of parallel diodes, or number of parallel paths of series-connected diodes, between the + and - block ports. Each diode has the forward voltage, on resistance, and off conductance that you specify in the block dialog box. The default value is 1.

## **Charge Dynamics Tab**

### **Junction capacitance**

Diode junction capacitance. The default value is 50 nF.

### **Peak reverse current, $i_{RM}$**

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 $i_{RM}$**

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 $i_{RM}$**

Rate of change of current when measuring peak reverse current. This value must be less than zero. The default value is -50 A/ $\mu$ 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 trr Directly”.

### **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  $\mu$ 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 for 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 reverse recovery charge instead of a value for reverse recovery time.

Reverse recovery charge is the total charge that remains to dissipate when the diode turns off. The value must be less than  $-\frac{i_{RM}^2}{2a}$ ,

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**  $\mu$ As.

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

## **Ports**

The block has the following ports:

+

Electrical conserving port associated with the diode positive terminal

-

Electrical conserving port associated with the diode negative terminal

## References

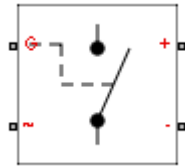
- [1] Lauritzen, P.O. & C.L. Ma, "A Simple Diode Model with Reverse Recovery." *IEEE<sup>®</sup> Transactions on Power Electronics*. Vol. 6, No. 2, 1991, pp. 188–191.

## Converter

Connect three-phase AC network to DC network

## Library

Semiconductors



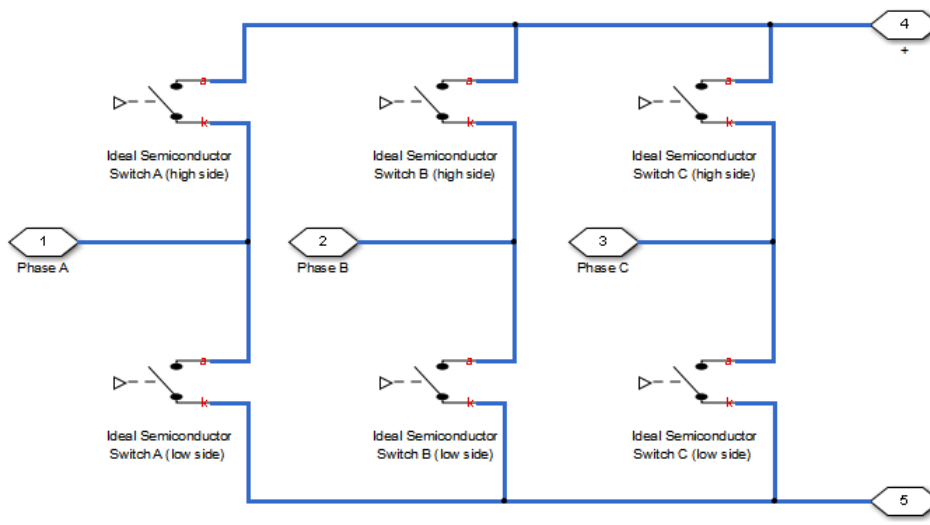
## Description

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 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 six switching devices via an input to the Converter block G port. To do this:

- 1 Use a Six-Pulse Gate Multiplexer block to multiplex all six gate signals into a single vector.
- 2 Connect the output of the Six-Pulse Gate Multiplexer block to the Converter block G port.

Using the Integral Diodes tab of the block dialog box, you can 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.

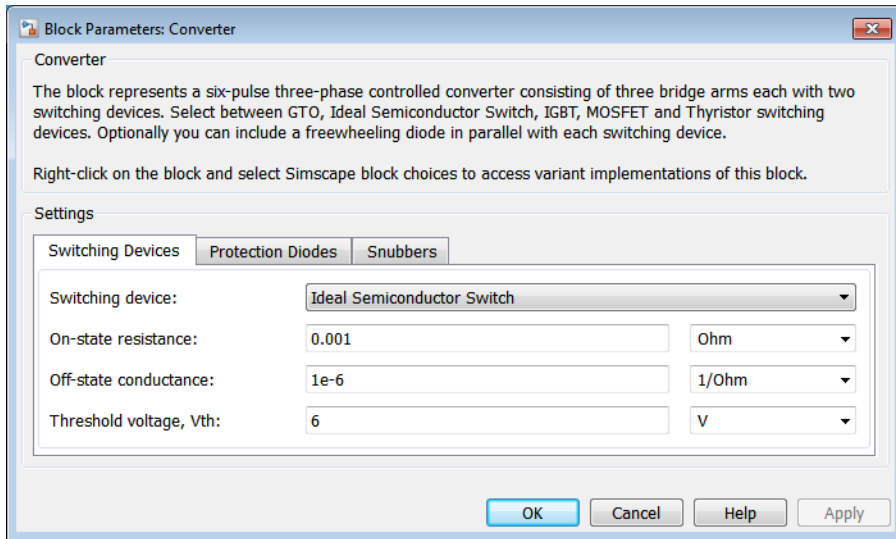
The table shows you how to set the **Integral protection diode** parameter based on your goals.

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

Goal	Value to Select	Block Behavior
		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.

Using the Snubbers tab of the block dialog box, you can include a snubber circuit for each switching device, consisting 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.

## Dialog Box and Parameters



- “Switching Devices Tab” on page 1-47
- “Protection Diodes Tab” on page 1-50

- “Snubbers Tab” on page 1-53

## 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, $V_f$

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  $\Omega$` .

### 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  $\Omega^{-1}$` .

### Gate trigger voltage, $V_{gt}$

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, $V_{gt\_off}$

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  $\Omega$ .

### **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  $1e-6 \Omega^{-1}$ .

### **Threshold voltage, $V_{th}$**

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, $V_f$**

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  $0.001 \Omega$ .

**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  $1e-6 \Omega^{-1}$ .

**Threshold voltage,  $V_{th}$** 

Collector-emitter voltage at which the device turns on. The default value is  $6 \text{ V}$ .

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  $0.001 \Omega$ .

**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  $1e-6 \Omega^{-1}$ .

**Threshold voltage,  $V_{th}$** 

Gate-source voltage threshold. The device turns on when the gate-source voltage is above this value. The default value is  $6 \text{ V}$ .

For more information, see MOSFET.

**Thyristor Parameters**

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

## Additional Thyristor Parameters

**Forward voltage,  $V_f$**

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  $\Omega$ .

**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  $1e-6 \Omega^{-1}$ .

**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  $1/R_{\text{on}}$ , where  $R_{\text{on}}$  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  $\Omega$ .

**Off conductance**

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

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  $1/R_{\text{on}}$ , where  $R_{\text{on}}$  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  $\Omega$ .

**Off conductance**

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

**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 trr Directly”.

**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 for 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 reverse recovery charge instead of a value for reverse recovery time.



Reverse recovery charge is the total charge that remains to dissipate when the diode turns off. The value must be less than  $-\frac{i_{RM}^2}{2\alpha}$ ,

where:

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

The default value is **1500**  $\mu$ 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.

## 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  $\Omega$ .

### 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**

Rectifier | Six-Pulse Gate Multiplexer

## **Related Examples**

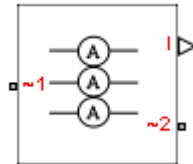
- “Expand and Collapse Three-Phase Ports on a Block”

# Current Sensor

Measure phase currents in three-phase system

## Library

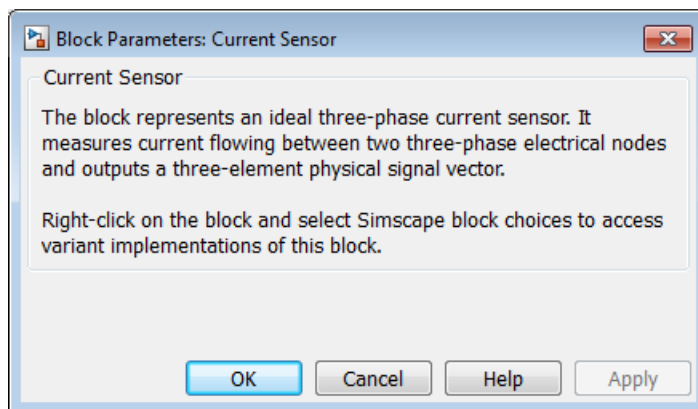
Sensors



## 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.

## Dialog Box and Parameters



The block has no parameters.

## 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.

## Related Examples

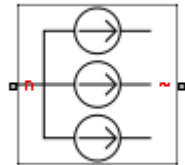
- “Expand and Collapse Three-Phase Ports on a Block”

# 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:

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

$$i_a = I_0 \cdot \sin(2\pi \cdot f \cdot t + \varphi)$$

$$i_b = I_0 \cdot \sin(2\pi \cdot f \cdot t + \varphi - 120^\circ)$$

$$i_c = I_0 \cdot \sin(2\pi \cdot f \cdot t + \varphi + 120^\circ),$$

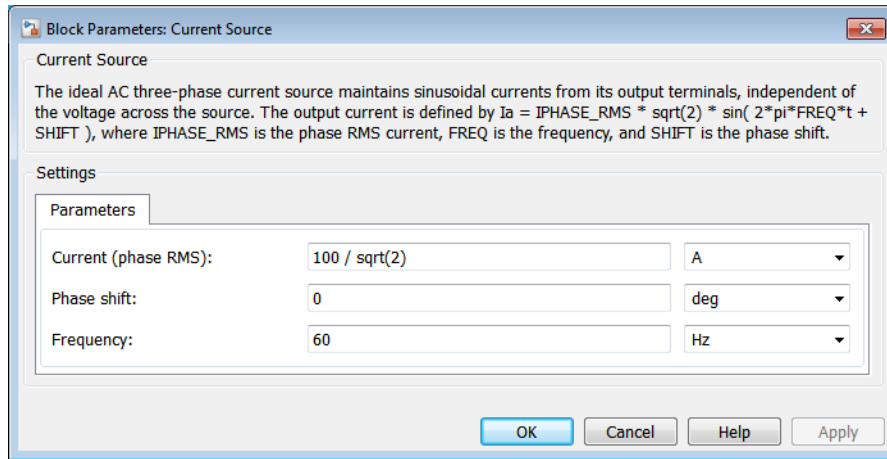
where:

- $I_0$  is the peak phase current.
- $i_{\text{phase\_rms}}$  is the RMS phase current.
- $i_a$ ,  $i_b$ ,  $i_c$  are the respective phase currents.
- $f$  is the frequency.

- $\varphi$  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.

## Dialog Box and 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**

Voltage Source

### **Related Examples**

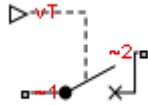
- “Expand and Collapse Three-Phase Ports on a Block”

# Circuit Breaker

Three-phase circuit breaker controlled by external signal

## Library

Switches & Breakers



## Description

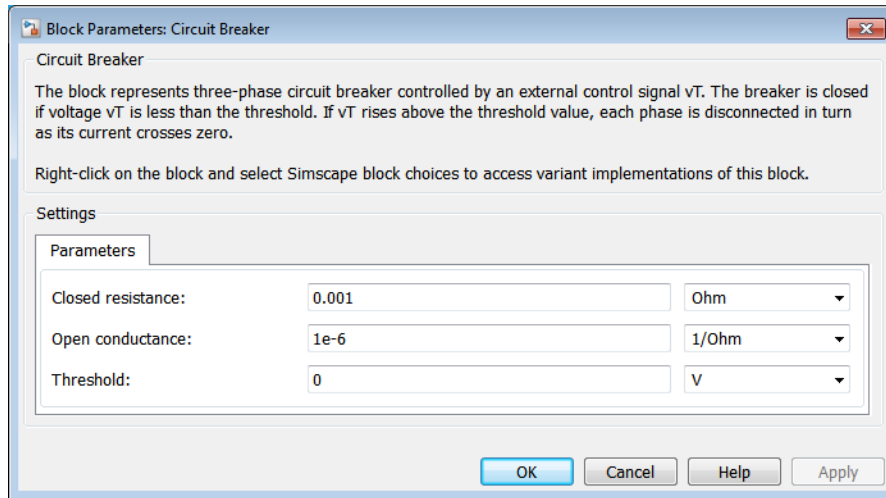
The Circuit Breaker block models a three-phase circuit breaker that uses an external signal and phase current information to break an electrical circuit.

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

Condition	Block Behavior	Resistance Parameter Used
$vT < \text{Threshold}$	The breaker is closed. Each phase in the composite three-phase port ~1 connects to the corresponding phase in the port ~2.	Closed Resistance
$vT \geq \text{Threshold}$	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



## Dialog Box and Parameters



### Closed resistance

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

### Open conductance

Conductance between ports ~1 and ~2 when the breaker is open. The default value is  $1e-6 \Omega^{-1}$ .

### Threshold

Threshold voltage for the control port  $v_T$ . The block uses the threshold voltage and the value of  $v_T$  at  $\text{time} = 0$  to determine whether the breaker is open or closed at the start of the simulation. 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  $0 \text{ V}$ .

## 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**

Single-Phase Circuit Breaker

### **Related Examples**

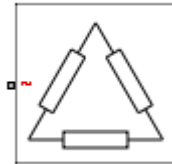
- “Switch Between Physical Signal and Electrical Ports”
- “Expand and Collapse Three-Phase Ports on a Block”

# Delta-Connected Load

Three-phase load wired in delta configuration

## Library

Passive Devices



## Description

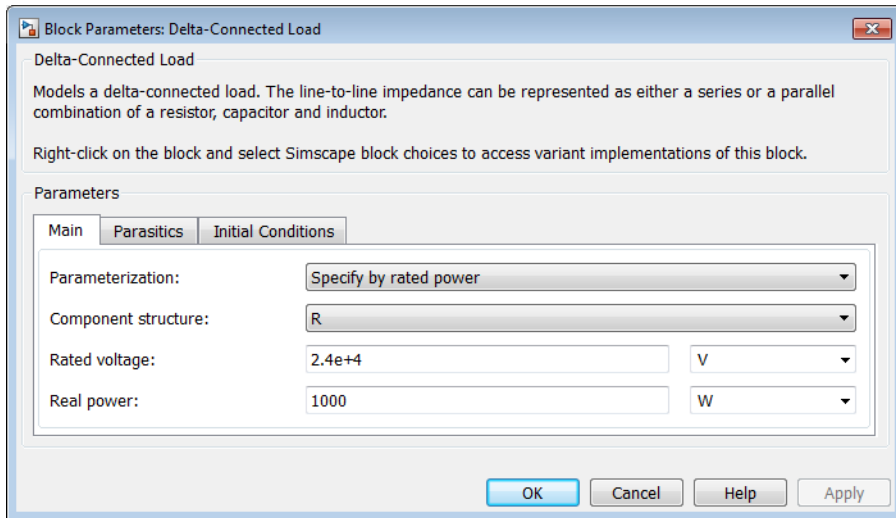
The Delta-Connected Load block models a three-phase load wired in a delta configuration. Each limb of the load can include any combination of a resistor (R), capacitor (C), and inductor (L), connected in series or in parallel.

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 of R, L, and C values, then for initialization you must 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 you must 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, you must specify parasitic resistance or conductance values, which can help numerical convergence when simulating some circuit topologies. 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.

## Dialog Box and Parameters



- “Main Tab” on page 1-64
- “Parasitics Tab” on page 1-66
- “Initial Conditions Tab” on page 1-66

### 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  $\Omega$ .

**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  $1e-6 \Omega$ .

### 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  $1e-6 \Omega^{-1}$ .

## 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 Inductive reactive power	Parasitic parallel conductance	Terminal voltage magnitude 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	None	Terminal voltage magnitude Terminal voltage angle Frequency

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
	Capacitive reactive power		
Series LC	Rated voltage Rated electrical frequency Inductive reactive power Capacitive reactive power	Parasitic parallel conductance	Terminal voltage magnitude Terminal voltage angle Frequency
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	Parasitic series resistance	Terminal voltage magnitude Terminal voltage angle



Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
	Capacitive reactive power		Frequency
Parallel LC	Rated voltage Rated electrical frequency Inductive reactive power Capacitive reactive power	Parasitic series resistance	Terminal voltage magnitude Terminal voltage angle Frequency
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	None	Initial capacitor voltage [ Va Vb Vc ]

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
	Capacitance		
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 ]
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

RLC | Wye-Connected Load

## **Related Examples**

- “Expand and Collapse Three-Phase Ports on a Block”

## Delta-Delta Transformer

Linear non-ideal delta-delta transformer with three-limb core

### Library

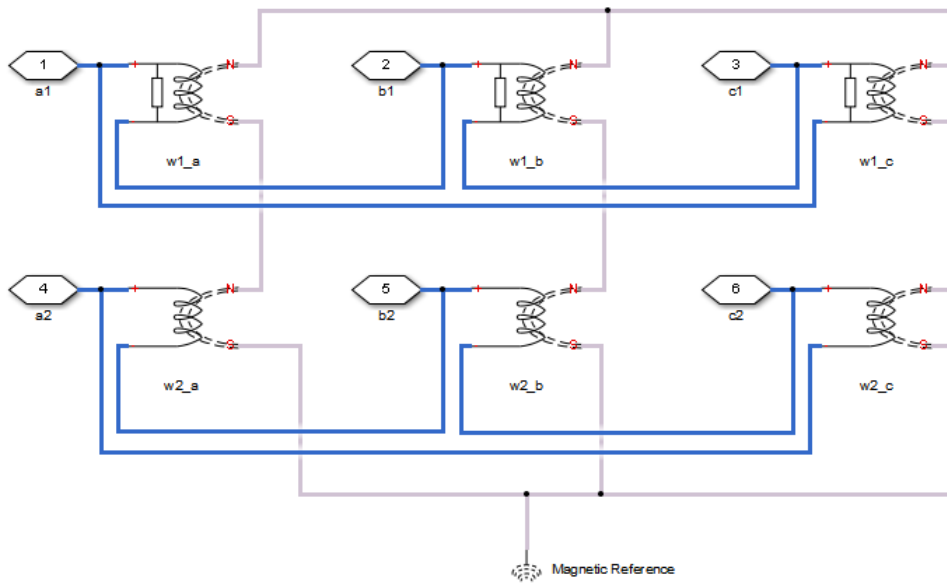
Passive Devices / Transformers



### Description

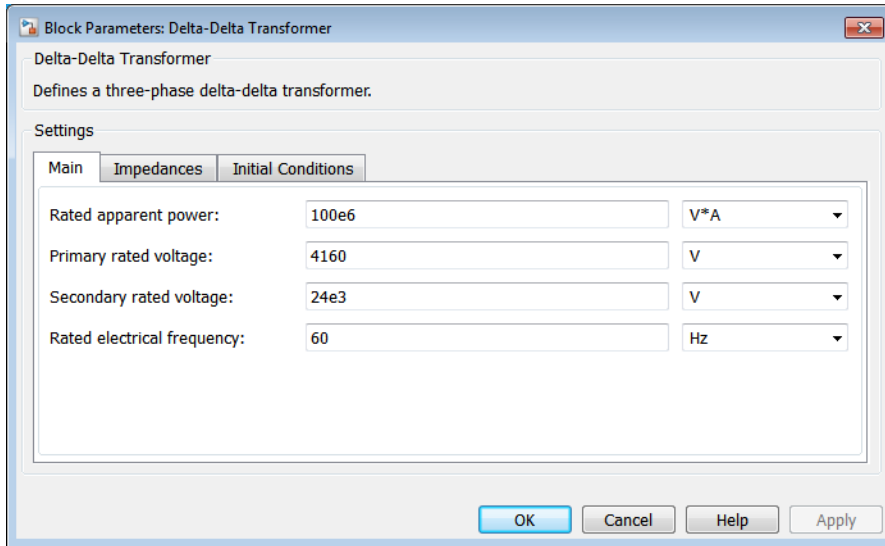
The Delta-Delta Transformer block models a linear non-ideal transformer with a three-limb core, in which both the primary and the secondary windings are configured in a delta connection. It includes linear winding leakage and linear core magnetization effects.

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.

## Dialog Box and Parameters



- “Main Tab” on page 1-74
- “Impedances Tab” on page 1-75
- “Initial Conditions Tab” on page 1-75

### Main Tab

#### Rated apparent power

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

#### 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

## Related Examples

- “Expand and Collapse Three-Phase Ports on a Block”



# Delta1-Delta1-Wye Transformer

Linear non-ideal delta1-delta1-wye transformer with three-limb core

## Library

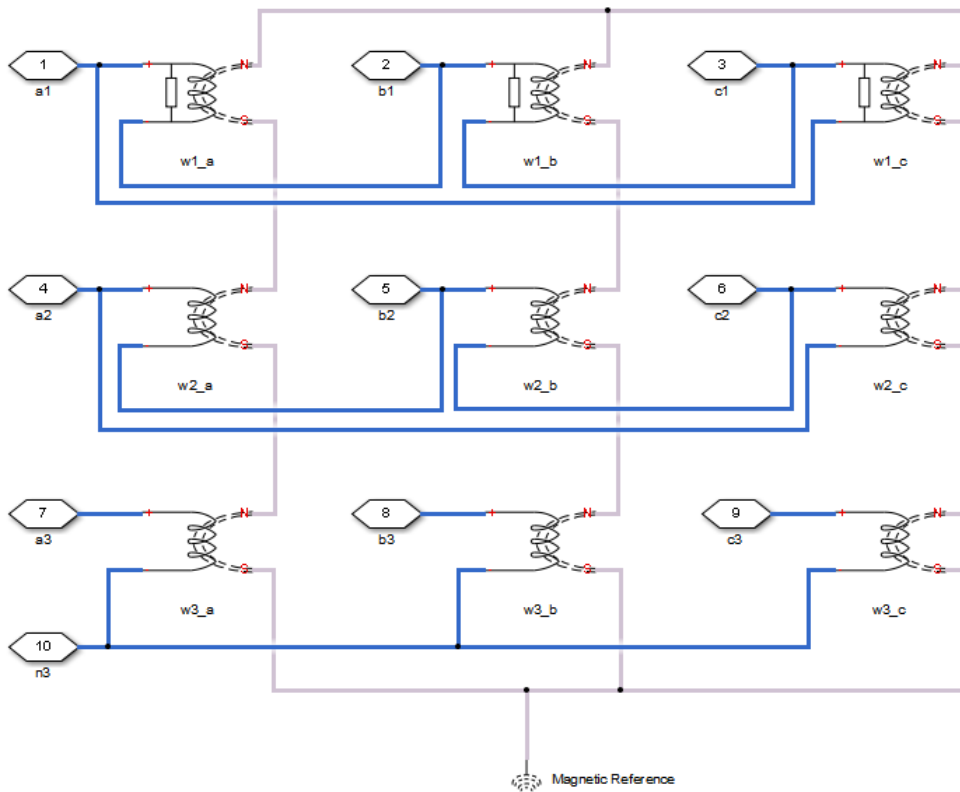
Passive Devices / Transformers



## Description

The Delta1-Delta1-Wye Transformer block models a linear non-ideal 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. It includes linear winding leakage and linear core magnetization effects.

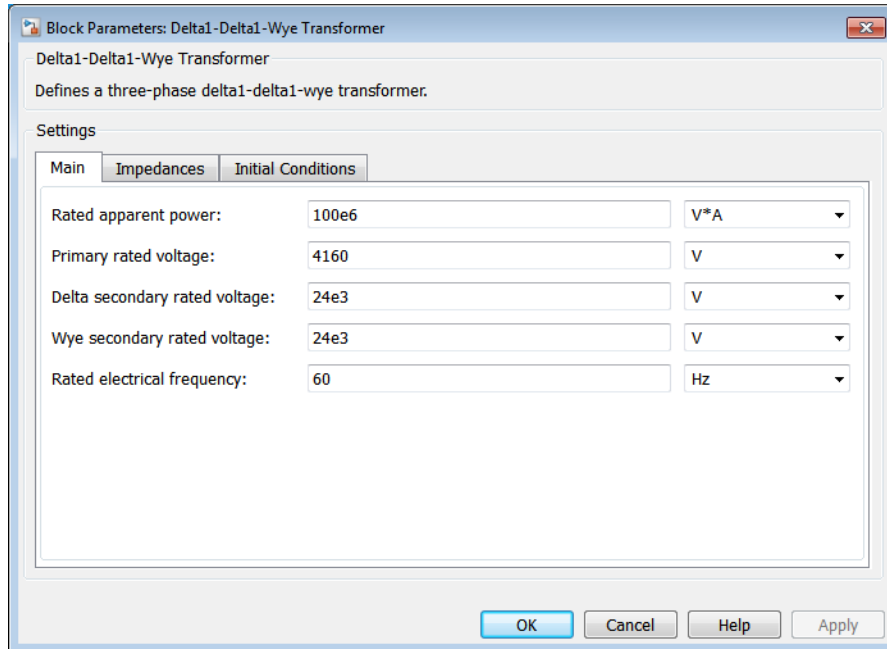
The figure shows the equivalent circuit diagram for the delta1-delta1-wye transformer.



- $w1_a$  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.

## Dialog Box and Parameters



- “Main Tab” on page 1-79
- “Impedances Tab” on page 1-80
- “Initial Conditions Tab” on page 1-81

### Main Tab

#### Rated apparent power

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

#### 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

## Related Examples

- “Expand and Collapse Three-Phase Ports on a Block”

# Delta 11-Delta 11-Wye Transformer

Linear non-ideal delta11-delta11-wye transformer with three-limb core

## Library

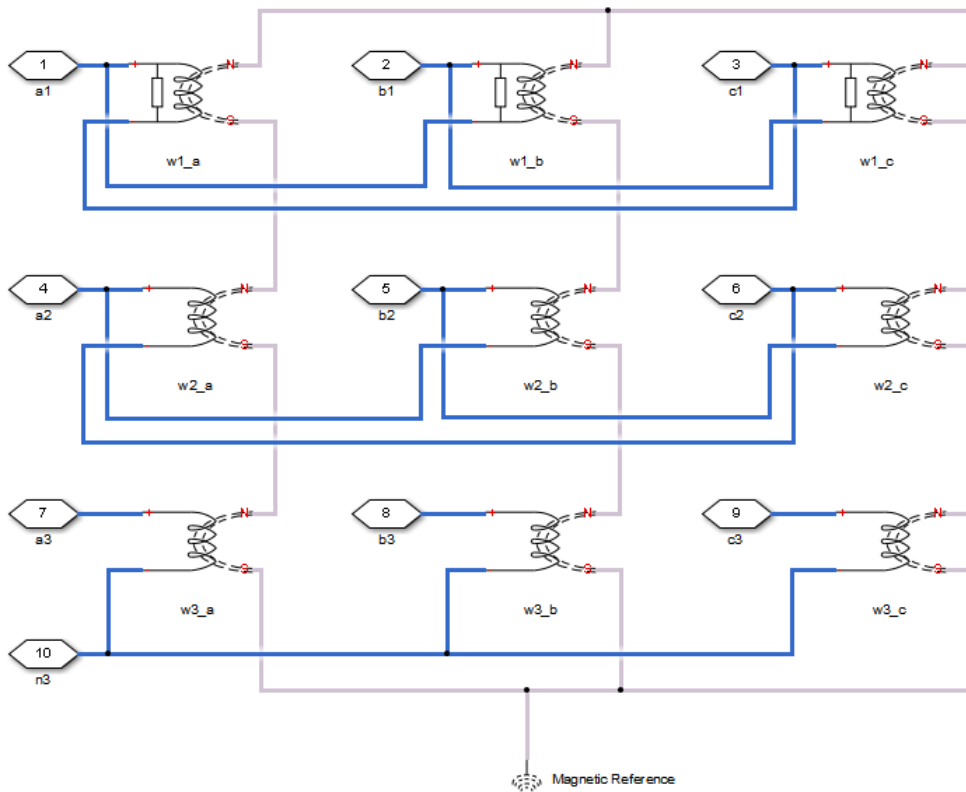
Passive Devices / Transformers



## Description

The Delta11-Delta11-Wye Transformer block models a linear non-ideal transformer with a three-limb core, in which the primary windings are configured in a delta connection, 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. It includes linear winding leakage and linear core magnetization effects.

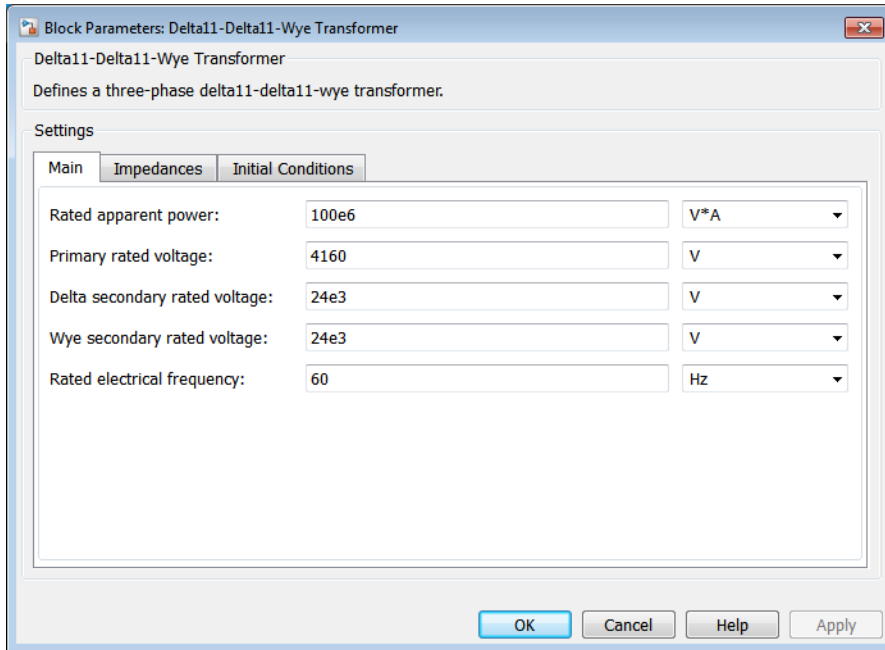
The figure shows the equivalent circuit diagram for the delta11-delta11-wye transformer.



- $w1_a$  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.

## Dialog Box and Parameters



- “Main Tab” on page 1-84
- “Impedances Tab” on page 1-85
- “Initial Conditions Tab” on page 1-86

### Main Tab

#### Rated apparent power

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

#### 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

## Related Examples

- “Expand and Collapse Three-Phase Ports on a Block”

# Delta Reference

Reference point for delta-connected network

## Library

Connections

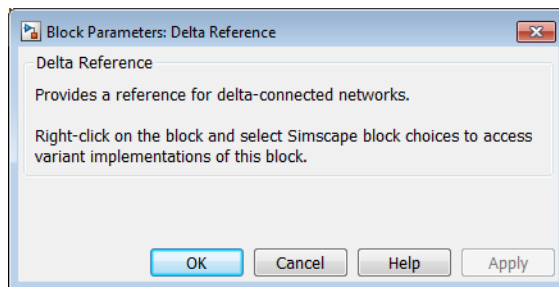
## Description



In a SimPowerSystems™ Simscape™ Components model, you must 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-to-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. You must connect a Delta Reference block to the part of the circuit between the two transformers.

## Dialog Box and Parameters



The block has no parameters.

## Ports

The block has the following ports:

~

Expandable “three-phase port”

## Related Examples

- “Expand and Collapse Three-Phase Ports on a Block”

# 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 block **On resistance** parameter specifies the resistance of the linear resistor.

If the voltage across the diode is less than the forward voltage, then the diode behaves like a linear resistor with low conductance specified by the value of the block **Off conductance** parameter.

When forward biased, the series voltage source is described by the equation

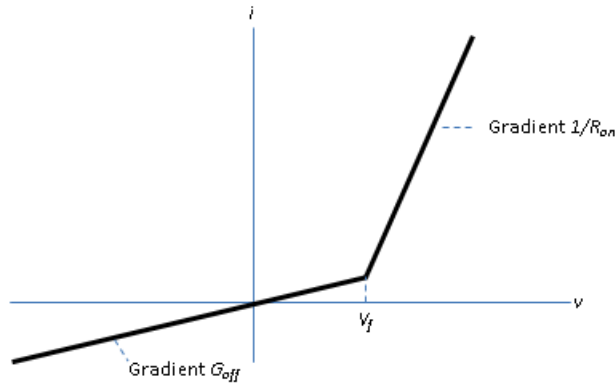
$$V = V_f(1 - R_{on}G_{off}),$$

where:

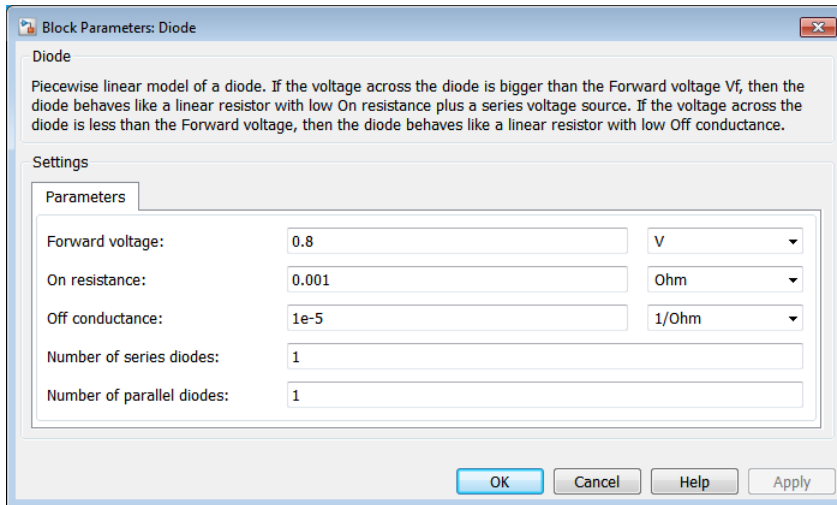
- $V$  is the voltage supplied by the series voltage source.
- $V_f$  is the forward voltage.
- $R_{on}$  is the on resistance.
- $G_{off}$  is the off conductance.

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.



## Dialog Box and 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  $0.001 \Omega$ .

**Off conductance**

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

**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 in the block dialog box. The default value is 1.

**Number of parallel diodes**

The number of parallel diodes, or number of parallel paths of series-connected diodes, between the + and - block ports. Each diode has the forward voltage, on resistance, and off conductance that you specify in the block dialog box. The default value is 1.

## Ports

The block has the following ports:

+

Electrical conserving port associated with the diode positive terminal

-

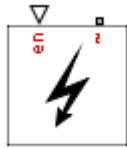
Electrical conserving port associated with the diode negative terminal

## Enabled Fault

Signal-enabled single-phase, two-phase, or three-phase grounded or ungrounded fault

### Library

Passive Devices / Faults



### Description

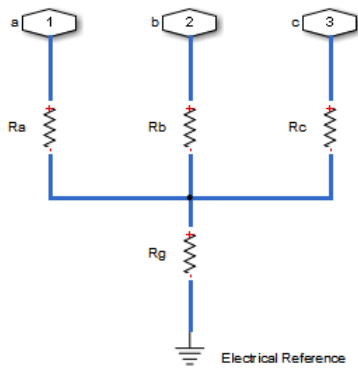
The Enabled Fault models any permutation of a single-phase, two-phase, or three-phase grounded or ungrounded fault. You specify the fault activation threshold using the block **Threshold** parameter. An external control signal *en* enables the fault. The fault is active when *en* is greater than the 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:

- 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 Enabled Fault block.





You can determine the resistance in the equivalent circuit using the equations in the table.

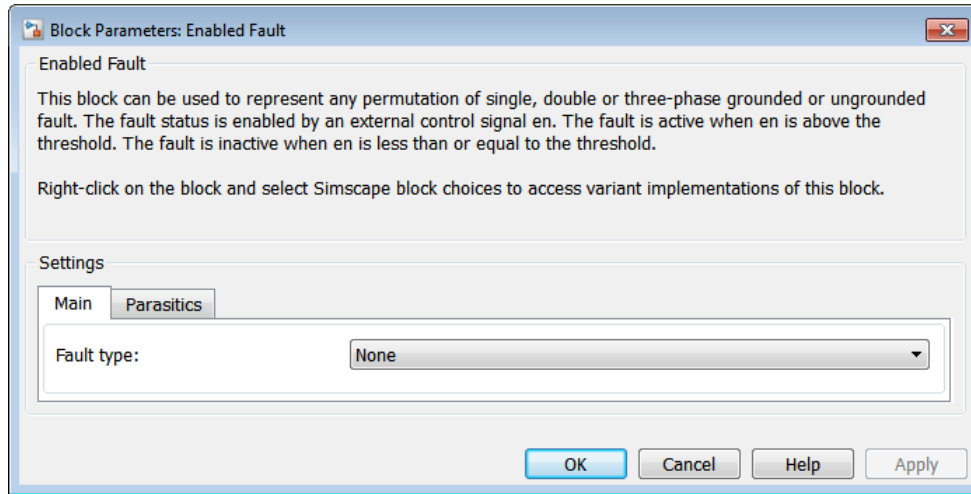
Fault type	Value of $R_a$	Value of $R_b$	Value of $R_c$	Value of $R_g$
None / inactive	$\frac{1}{G_{pn}}$	$\frac{1}{G_{pn}}$	$\frac{1}{G_{pn}}$	Infinity / open circuit
a-g	$R_{pn}$	$\frac{1}{G_{pn}}$	$\frac{1}{G_{pn}}$	$R_{ng}$
b-g	$\frac{1}{G_{pn}}$	$R_{pn}$	$\frac{1}{G_{pn}}$	$R_{ng}$
c-g	$\frac{1}{G_{pn}}$	$\frac{1}{G_{pn}}$	$R_{pn}$	$R_{ng}$
a-b	$R_{pn}$	$R_{pn}$	$\frac{1}{G_{pn}}$	Infinity / open circuit
b-c	$\frac{1}{G_{pn}}$	$R_{pn}$	$R_{pn}$	Infinity / open circuit

Fault type	Value of $R_a$	Value of $R_b$	Value of $R_c$	Value of $R_g$
c-a	$R_{pn}$	$\frac{1}{G_{pn}}$	$R_{pn}$	Infinity / open circuit
a-b-g	$R_{pn}$	$R_{pn}$	$\frac{1}{G_{pn}}$	$R_{ng}$
b-c-g	$\frac{1}{G_{pn}}$	$R_{pn}$	$R_{pn}$	$R_{ng}$
c-a-g	$R_{pn}$	$\frac{1}{G_{pn}}$	$R_{pn}$	$R_{ng}$
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.

## Dialog Box and Parameters



- “Main Tab” on page 1-95
- “Parasitics Tab” on page 1-96

### 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  $1\text{e-}3\ \Omega$ .

### **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  $1\text{e-}3\ \Omega$ .

### **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  $1\text{e-}6\ \Omega^{-1}$ .

## **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**

Time-Based Fault

# Floating Neutral

Floating neutral point for phases of three-phase system

## Library

Connections

## Description



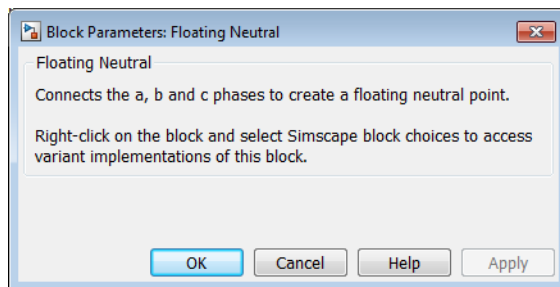
The Floating Neutral block connects the individual phases of a three-phase system to form a floating neutral point.

---

**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.

---

## Dialog Box and Parameters



The block has no parameters.

## Ports

The block has the following ports:

~

Expandable “three-phase port”

## See Also

Grounded Neutral | Neutral Port

## Related Examples

- “Expand and Collapse Three-Phase Ports on a Block”

# Grounded Neutral

Ground connection for phases of three-phase system

## Library

Connections

## Description



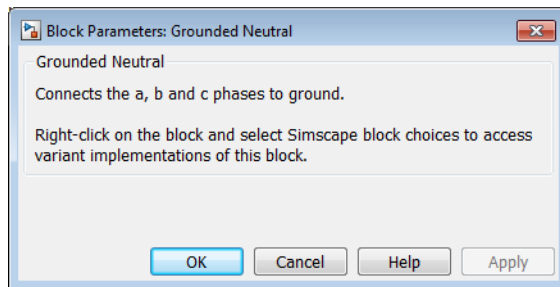
The Grounded Neutral block connects the phases of a three-phase system to ground.

---

**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.

---

## Dialog Box and Parameters



The block has no parameters.

## Ports

The block has the following ports:

~

Expandable “three-phase port”

### **See Also**

Floating Neutral | Neutral Port

### **Related Examples**

- “Expand and Collapse Three-Phase Ports on a Block”



# GTO

Gate Turn-Off Thyristor

## Library

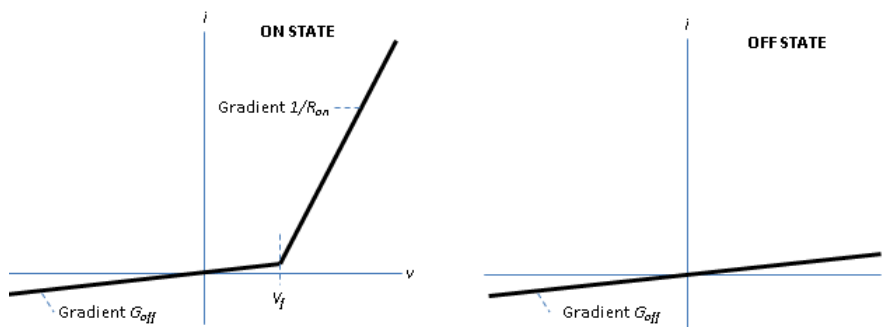
Semiconductors / Fundamental Components



## Description

The GTO block models a GTO (gate turn-off thyristor).

This figure shows a typical *i-v characteristic* for a GTO.



The GTO turns on if the gate-cathode voltage exceeds the specified gate trigger voltage. The device turns off 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.

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.
- $V_f$  is the forward voltage.
- $G$  is the gate voltage.
- $V_{gt}$  is the gate trigger voltage.
- $i$  is the anode-cathode current.
- $I_h$  is the holding current.
- $V_{gt\_off}$  is the gate turn-off voltage.
- $R_{on}$  is the on-state resistance.
- $G_{off}$  is the off-state conductance.

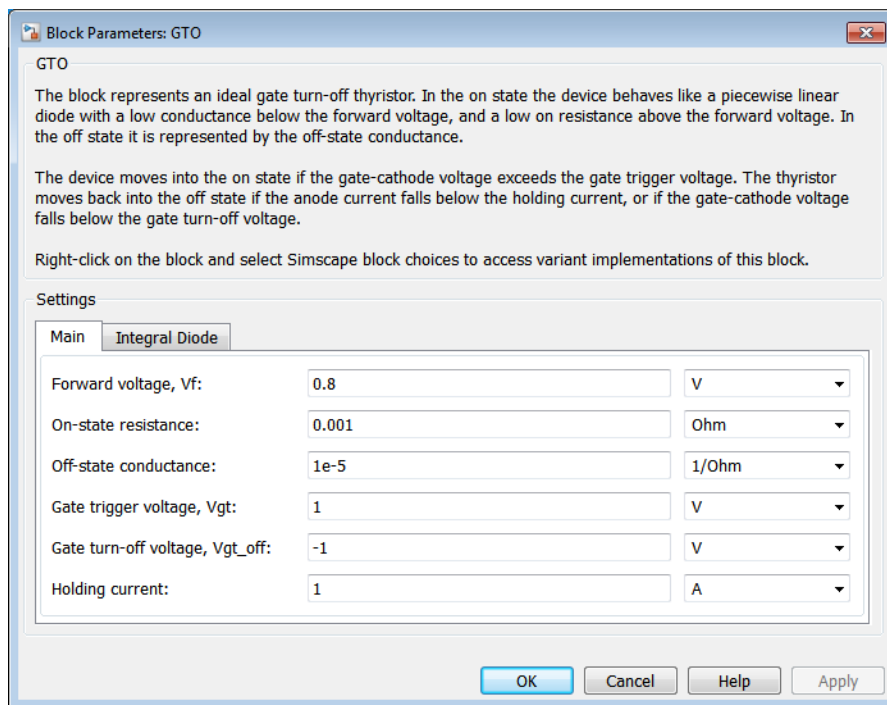
Using the Integral Diode tab of the block dialog box, you can include an integral cathode-anode diode. A GTO that includes an integral cathode-anode diode is known as an asymmetrical GTO (A-GTO) or reverse-conducting GTO (RCGTO). An integral diode protects the semiconductor device by providing a conduction 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

Goal	Value to Select	Block Behavior
		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.

## Dialog Box and Parameters



- “Main Tab” on page 1-104
- “Integral Diode Tab” on page 1-104

## 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  $\Omega$ .

### 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  $1e-5 \Omega^{-1}$ .

### 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  $\Omega$ .

### Off conductance

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

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  $\Omega$ .

### Off conductance

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

### Junction capacitance

Diode junction capacitance. The default value is 50 nF.

### **Peak reverse current, $i_{RM}$**

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 $i_{RM}$**

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 $i_{RM}$**

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 trr Directly”.

### **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,  $i_{RM}$**  parameter divided by the value of the **Rate of change of current when measuring  $i_{RM}$**  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 for the stretch factor, the longer it takes for the reverse recovery current to dissipate.

### Reverse recovery charge, $Q_{rr}$

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

Reverse recovery charge is the total charge that remains to dissipate when the diode turns off. The value must be less than  $-\frac{i_{RM}^2}{2a}$ ,

where:

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

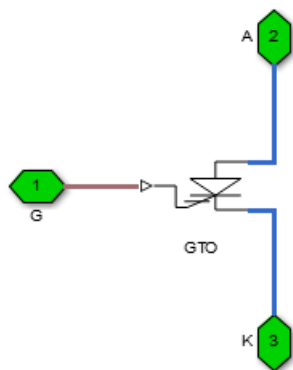
The default value is **1500**  $\mu\text{As}$ .

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.

### 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.

**Related Examples**

- “Switch Between Physical Signal and Electrical Ports”



# Ideal Semiconductor Switch

Ideal Semiconductor Switch

## Library

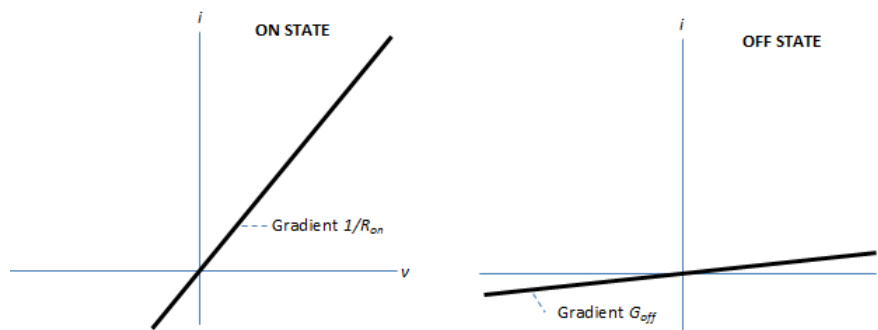
Semiconductors / Fundamental Components



## 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.



The ideal semiconductor switch is in the on state if the gate-cathode voltage exceeds the specified threshold voltage. Otherwise the device is in the off state.

In the on state, the anode-cathode path behaves like a linear resistor with on-resistance  $R_{on}$ .

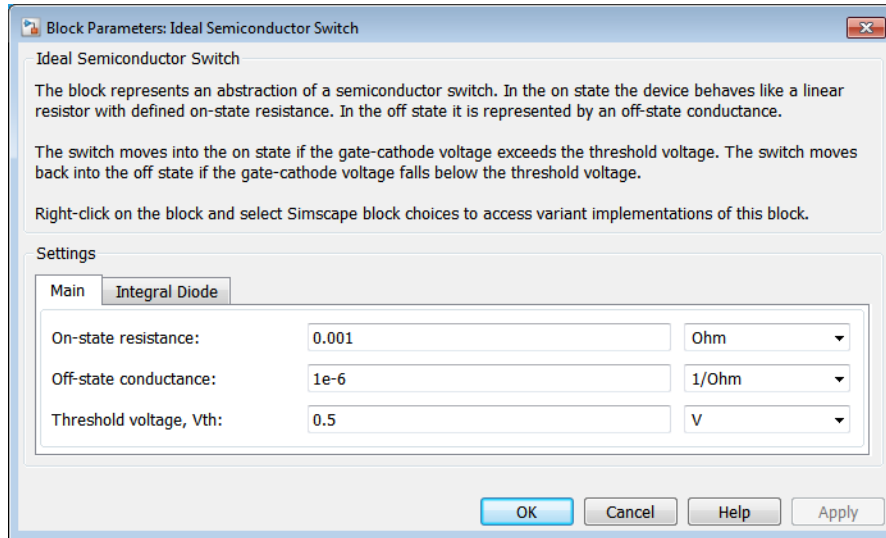
In the off state, the anode-cathode path behaves like a linear resistor with a low off-state conductance  $G_{off}$ .

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.

## Dialog Box and Parameters



- “Main Tab” on page 1-111
- “Integral Diode Tab” on page 1-111

## Main Tab

### On-state resistance

Anode-cathode resistance when the device is on. The default value is 0.001  $\Omega$ .

### 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  $1e-6 \Omega^{-1}$ .

### 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  $\Omega$ .

### **Off conductance**

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

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  $\Omega$ .

**Off conductance**

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

**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/ $\mu$ 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 trr Directly”.

**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  $\mu$ 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 for 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 reverse recovery charge instead of a value for reverse recovery time.

Reverse recovery charge is the total charge that remains to dissipate when the diode turns off. The value must be less than  $-\frac{i_{RM}^2}{2a}$ ,

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**.

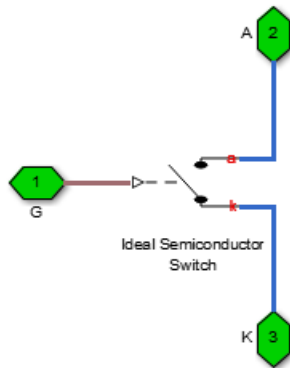
The default value is **1500**  $\mu$ As.

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.

## **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.

## Related Examples

- “Switch Between Physical Signal and Electrical Ports”

# IGBT

Insulated-Gate Bipolar Transistor

## Library

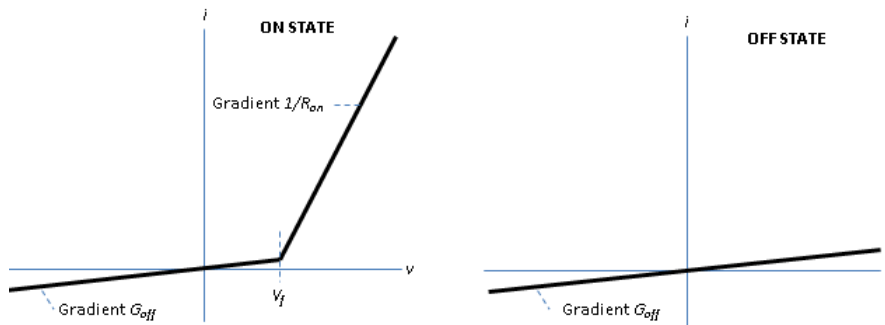
Semiconductors / Fundamental Components



## Description

The IGBT block models an IGBT (insulated-gate bipolar transistor).

This graphic shows a typical *i-v characteristic* for an IGBT.



The IGBT is in the on state if the gate-emitter voltage exceeds the specified threshold voltage  $V_{th}$ . 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.

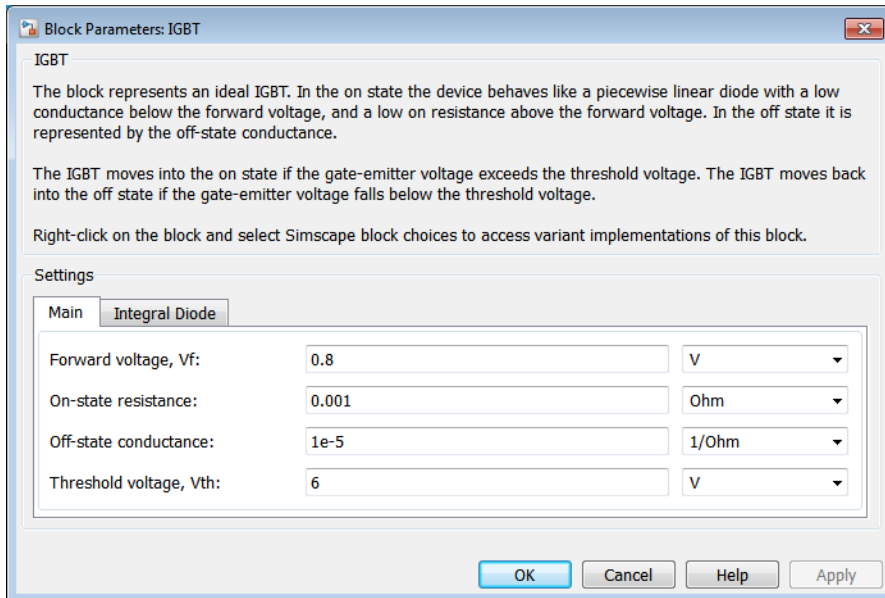
Using the Integral Diode tab of the block dialog box, you can include an integral emitter-collector diode. An integral diode protects the semiconductor device by providing a conduction path for reverse current. An inductive load can produce a high reverse-voltage spike when the semiconductor device suddenly switches off the voltage supply to the load.

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

Goal	Value to Select	Block Behavior
		parameters relating to the Commutation Diode block.

## Dialog Box and Parameters



- “Main Tab” on page 1-118
- “Integral Diode Tab” on page 1-119

### 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  $0.001 \Omega$ .

#### **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  $1e-5 \Omega^{-1}$ .

#### **Threshold voltage, $V_{th}$**

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  $0.001 \Omega$ .

### **Off conductance**

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

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  $\Omega$ .

### **Off conductance**

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

### **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/ $\mu$ 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 trr Directly”.

### 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**  $\mu\text{s}$ .

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 for 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 reverse recovery charge instead of a value for reverse recovery time.

Reverse recovery charge is the total charge that remains to dissipate when the diode turns off. The value must be less than  $-\frac{i_{RM}^2}{2a}$ ,

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**.

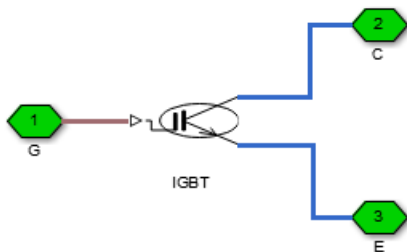
The default value is **1500**  $\mu\text{As}$ .

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.

## 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.

C

Electrical conserving port associated with the collector terminal.

E

Electrical conserving port associated with the emitter terminal.

## Related Examples

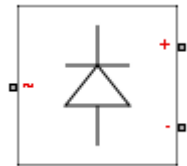
- “Switch Between Physical Signal and Electrical Ports”

# Ideal Rectifier

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

## Library

Semiconductors

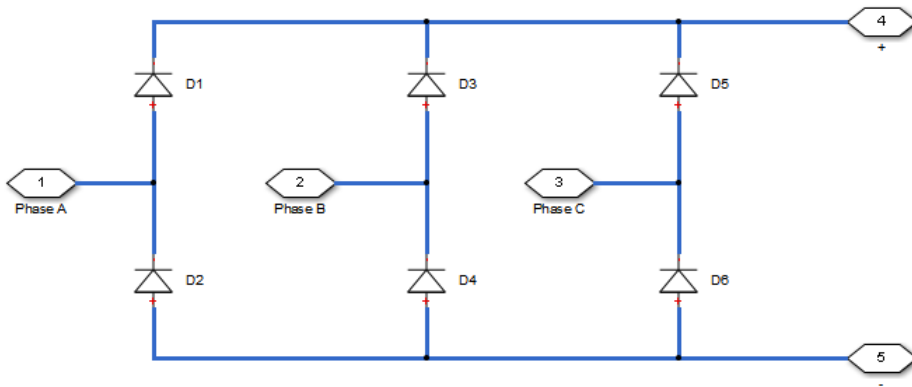


## Description

The Ideal Rectifier block models an average value, ideal, 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 Ideal Rectifier block only as a six-pulse rectifier. You cannot combine two Ideal 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 Ideal Rectifier block does not yield the harmonics that are typically associated with the detailed representation, however, because it converts power ideally.



## Electrical Defining Equations

The voltages are defined by these equations:

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

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

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

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

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

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. The  $v_{DC} / V_{RMS}$  ratio for a full-wave, six-pulse rectifier is  $3\sqrt{2} / \pi$ .
- $v_p, v_n$  are the voltages at the positive and negative terminals of the rectifier.

The resistance, power, and currents are defined by these equations:

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

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

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

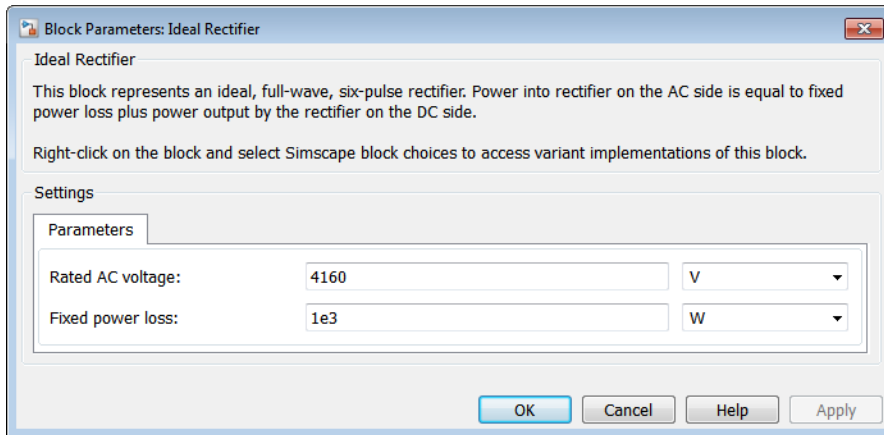
$$\begin{bmatrix} i_a & i_b & i_c \end{bmatrix} = \frac{\begin{bmatrix} v_a & v_b & v_c \end{bmatrix} - v_{ref}}{R_{AC}},$$

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.

## Dialog Box and 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 1 kW.

## 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**

Rectifier | Converter

### **Related Examples**

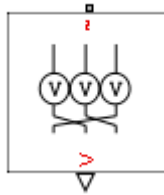
- “Expand and Collapse Three-Phase Ports on a Block”

# Line Voltage Sensor

Measure line voltages in three-phase system

## Library

Sensors



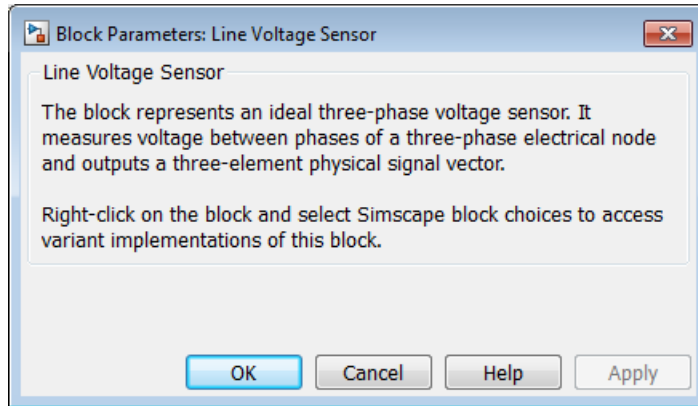
## Description

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.

## Dialog Box and Parameters



The block has no parameters.

## 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

Phase Voltage Sensor

## Related Examples

- “Expand and Collapse Three-Phase Ports on a Block”

# Machine Inertia

Machine inertia

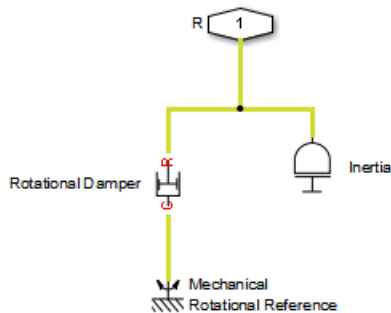
## Library

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  $\text{kg}\cdot\text{m}^2$ .
- $H$  is the inertia constant in  $\text{sW/VA}$ .
- $S_{rated}$  is the machine rated apparent power in  $\text{VA}$ .
- $F_{rated}$  is the machine rated electrical frequency in  $\text{Hz}$ .
- $N$  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:

- $\omega_{base}$  is the base mechanical speed in  $\text{rad/s}$ .
- $T_{base}$  is the base damping torque in  $\text{Nm}$ .
- $D_{base}$  is the base damping coefficient in  $\text{Nm}/(\text{rad/s})$ .
- $D_{pu}$  is the damping coefficient in per unit.
- $D$  is the damping coefficient in SI units of  $\text{Nm}/(\text{rad/s})$ .

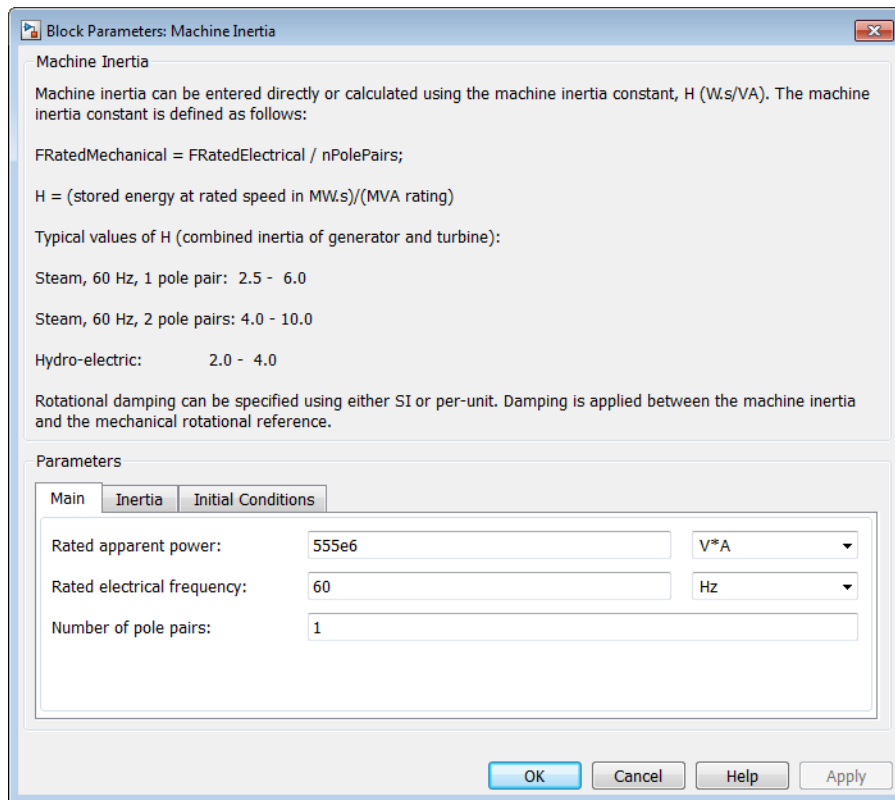
## Parameter Display Option

You can display the inertia parameter and per-unit base values using the **Power Systems** menu on the block context menu.

Right-click the block. From the context menu, select **Display Parameters** on the **Power Systems > Machine Inertia** menu.

The block displays parameter values in the MATLAB Command Window.

## Dialog Box and Parameters



- “Main Tab” on page 1-133



- “Inertia Tab” on page 1-133
- “Initial Conditions Tab” on page 1-134

## Main Tab

### Rated apparent power

Machine rated apparent power. The default value is 555e6 VA.

### 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<sup>2</sup>.

### 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

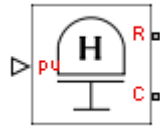
[1] Kundur, P. *Power System Stability and Control*. New York, NY: McGraw Hill, 1993.

# Machine Mechanical Power (pu)

Machine mechanical power defined in the per-unit system

## Library

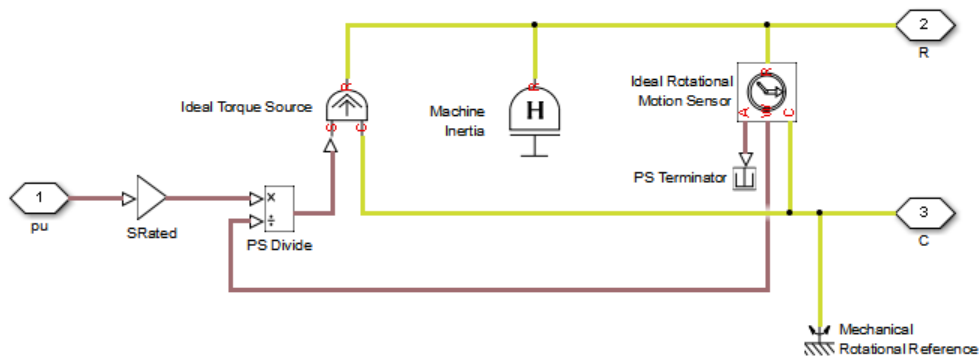
Machines



## 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. Specify the **Peak torque to rated torque ratio** parameter to set the peak torque limit. Use the **Specify inertia parameterization by** parameter to specify inertia,  $J$ , directly or indirectly, with the machine's inertia constant,  $H$ .

If you specify the machine's inertia constant, the block calculates inertia as

$$J = \frac{2HS_{rated}}{(2\pi F_{rated} / N)^2},$$

where:

- $J$  is inertia in kg#m<sup>2</sup>.
- $H$  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:

$$\omega_{base} = \frac{2\pi F_{rated}}{N},$$

$$T_{base} = \frac{S_{rated}}{\omega_{base}},$$

$$D_{base} = \frac{T_{base}}{\omega_{base}},$$

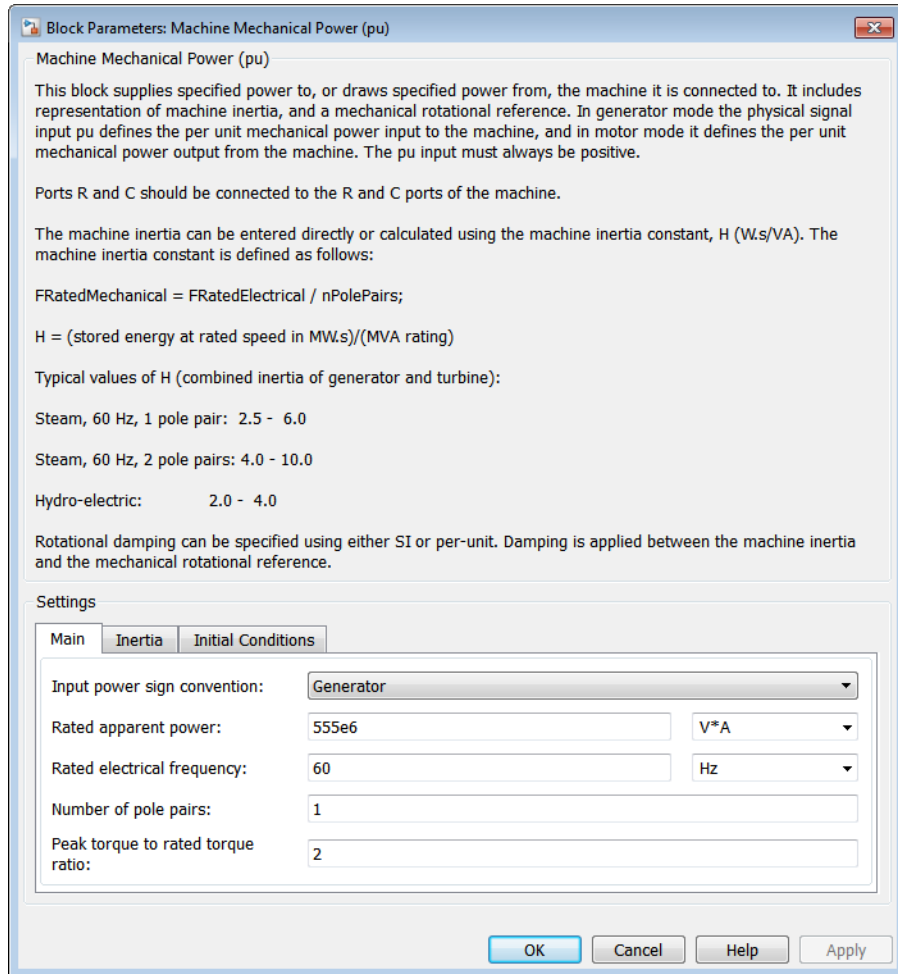
and

$$D = D_{pu} D_{base},$$

where:

- $\omega_{base}$  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).

## Dialog Box and Parameters



- “Main Tab” on page 1-139
- “Inertia Tab” on page 1-139
- “Initial Conditions Tab” on page 1-140

## 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 VA**.

### 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 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<sup>2</sup>**.

### 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

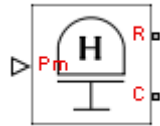
Machine Inertia | Machine Mechanical Power (SI)

# Machine Mechanical Power (SI)

Machine mechanical power defined in SI units

## Library

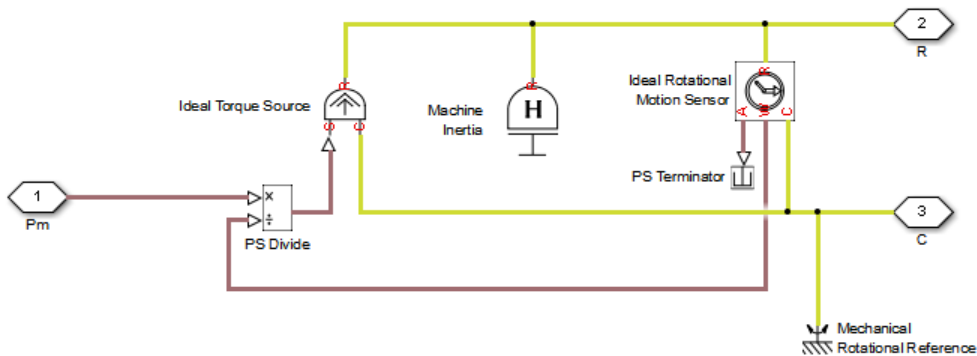
Machines



## 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  $P_m$  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  $P_m$  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. Specify the **Peak torque to rated torque ratio** parameter to set the peak torque limit. Use the **Specify inertia parameterization by** parameter to specify inertia,  $J$ , directly or indirectly, with the machine's inertia constant,  $H$ .

If you specify the machine's inertia constant, the block calculates inertia as

$$J = \frac{2HS_{rated}}{(2\pi F_{rated} / N)^2},$$

where:

- $J$  is inertia in kg#m<sup>2</sup>.
- $H$  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:

$$\omega_{base} = \frac{2\pi F_{rated}}{N},$$

$$T_{base} = \frac{S_{rated}}{\omega_{base}},$$

$$D_{base} = \frac{T_{base}}{\omega_{base}},$$

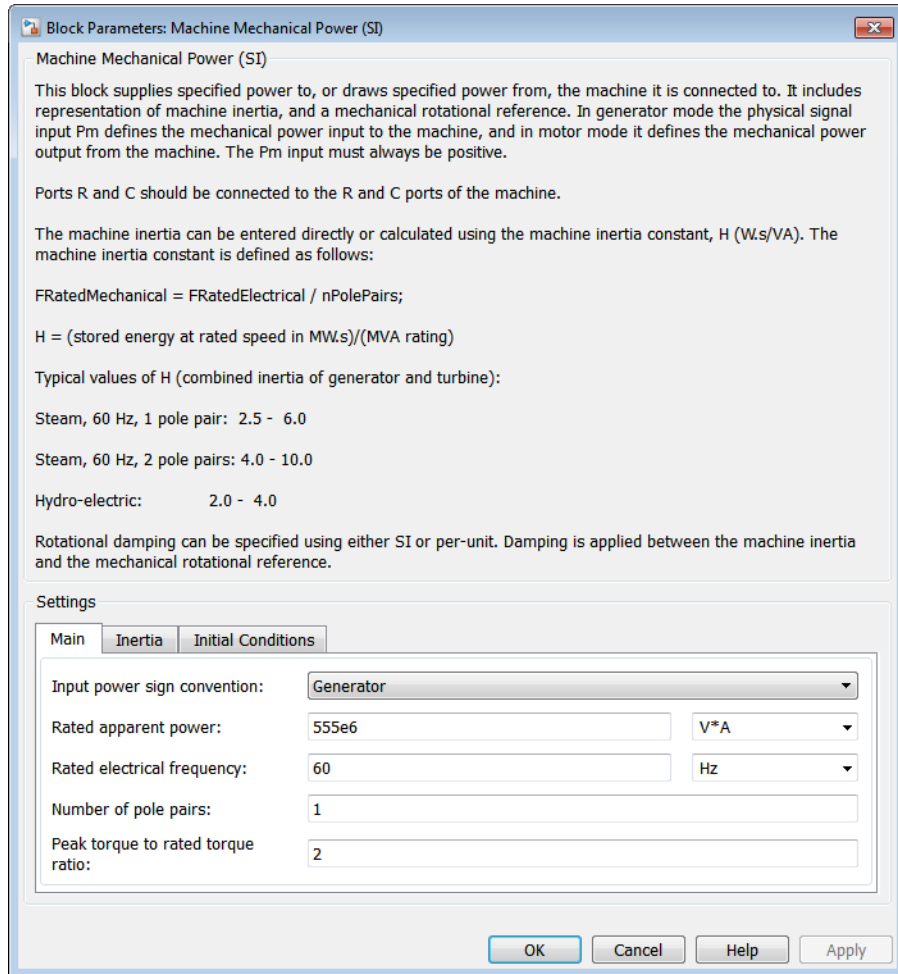
and

$$D = D_{pu}D_{base},$$

where:

- $\omega_{base}$  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).

## Dialog Box and Parameters



- “Main Tab” on page 1-146
- “Inertia Tab” on page 1-146
- “Initial Conditions Tab” on page 1-147

## 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 VA**.

### 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 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<sup>2</sup>**.

### 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**

Machine Inertia | Machine Mechanical Power (pu)

### **Related Examples**

- Three-Phase Asynchronous Machine Starting



# MOSFET

N-channel MOSFET

## Library

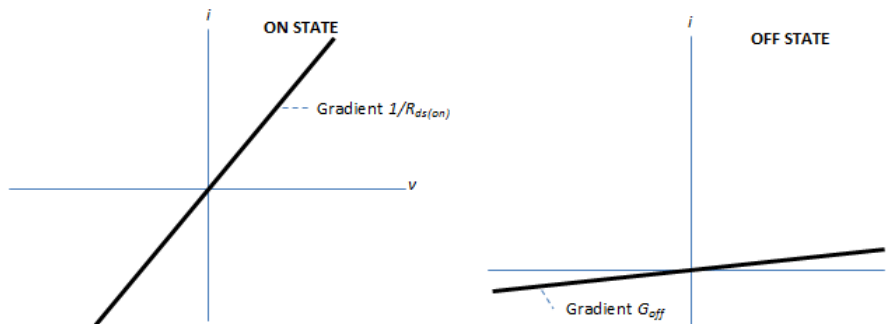
Semiconductors / Fundamental Components



## Description

The MOSFET block models an n-channel MOSFET (metal-oxide-semiconductor field-effect transistor).

The figure shows typical *i-v characteristic* for an n-channel MOSFET.



The MOSFET is in the on state if the gate-source voltage exceeds the specified threshold voltage. 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:

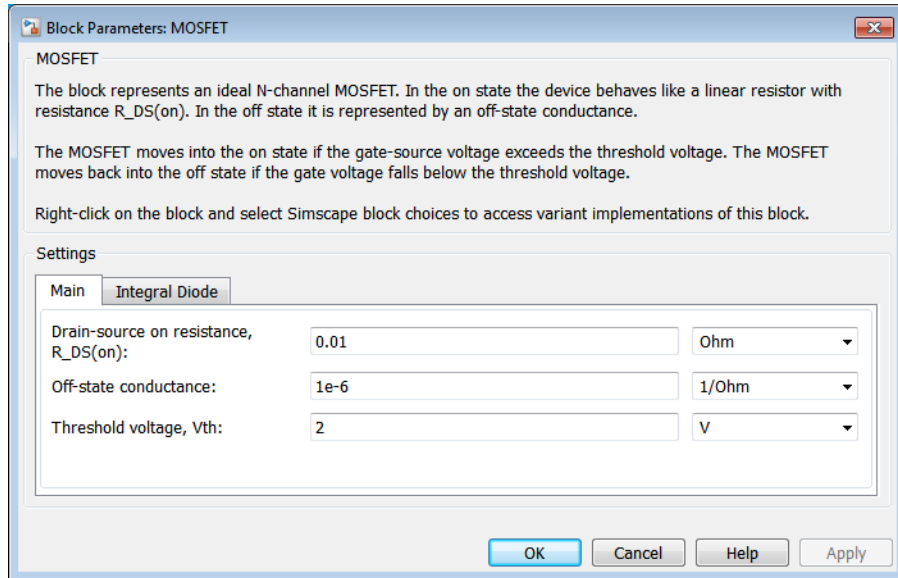
- $G$  is the gate-source voltage.
- $V_{th}$  is the threshold voltage.
- $v$  is the drain-source voltage.
- $i$  is the drain-source current.
- $R_{ds\_on}$  is the on-state resistance.
- $G_{off}$  is the off-state conductance.

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.

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.

## Dialog Box and Parameters



- “Main Tab” on page 1-151
- “Integral Diode Tab” on page 1-151

### Main Tab

#### On-state resistance, $R_{DS(on)}$

Drain-source resistance when the device is on. The default value is 0.01  $\Omega$ .

#### 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  $1e-6 \Omega^{-1}$ .

#### Threshold voltage, $V_{th}$

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  $\Omega$ .

### **Off conductance**

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

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  $\Omega$ .

**Off conductance**

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

**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/ $\mu$ 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 trr Directly”.

**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  $\mu$ 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 for 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 reverse recovery charge instead of a value for reverse recovery time.

Reverse recovery charge is the total charge that remains to dissipate when the diode turns off. The value must be less than  $-\frac{i_{RM}^2}{2a}$ ,

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**.

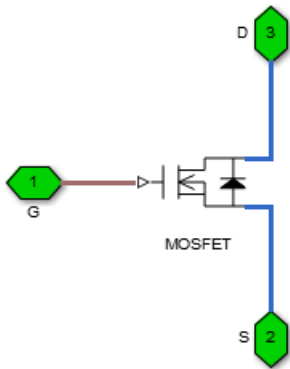
The default value is **1500**  $\mu$ As.

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.

## **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.

S

Electrical conserving port associated with the source terminal.

D

Electrical conserving port associated with the drain terminal.

## Related Examples

- “Switch Between Physical Signal and Electrical Ports”

# Neutral Port

Connect phases of three-phase system to electrical conserving port

## Library

Connections



## Description

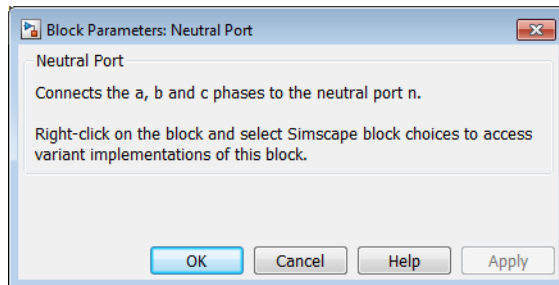
The Neutral Port block connects the phases of a three-phase system to an electrical conserving port. You can connect the electrical port to electrical components from the Simscape and SimElectronics® libraries.

---

**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.

---

## Dialog Box and Parameters



The block has no parameters.



## Ports

The block has the following ports:

~

Expandable “three-phase port”

n

Electrical conserving port associated with the neutral point

## See Also

Floating Neutral | Neutral Port

## Related Examples

- “Expand and Collapse Three-Phase Ports on a Block”

# Open Circuit

Three-phase connection that draws no current

## Library

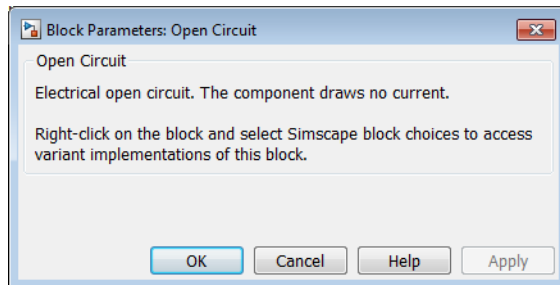
Connections



## 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.

## Dialog Box and Parameters



The block has no parameters.

## Ports

The block has the following ports:

~

Expandable “three-phase port”

### **Related Examples**

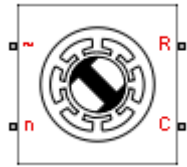
- “Expand and Collapse Three-Phase Ports on a Block”

# Permanent Magnet Synchronous Motor

Permanent magnet synchronous motor with sinusoidal flux distribution

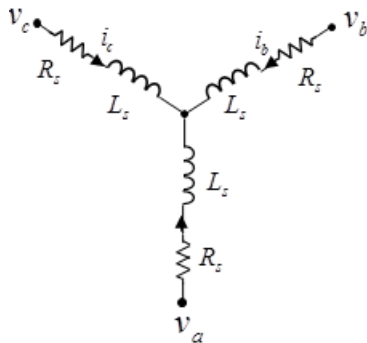
## Library

Machines / Permanent Magnet Rotor

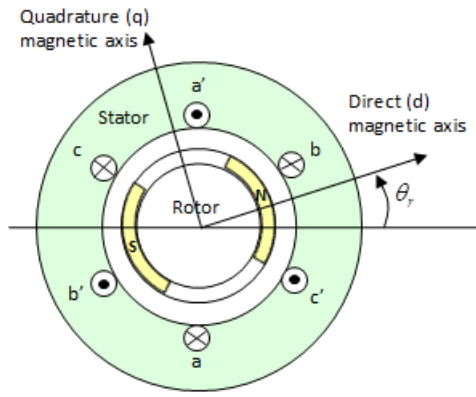


## Description

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.



This figure shows the motor construction with a single pole-pair on the rotor.



The rotor magnetic field due to the permanent magnet(s) 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 angle  $\theta_r$  is zero. The block supports a second rotor axis definition in which rotor 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

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

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.

$$\bullet \quad \frac{d\psi_a}{dt}, \frac{d\psi_b}{dt}, \text{ and } \frac{d\psi_c}{dt}$$

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:

- $\psi_a, \psi_b,$  and  $\psi_c$  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.
- $\psi_{am}, \psi_{bm},$  and  $\psi_{cm}$  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. This is the average self-inductance of each of the stator windings.
- $L_m$  is the stator inductance fluctuation. This is the amplitude of the fluctuation in self-inductance and mutual inductance with changing rotor angle.
- $M_s$  is the stator mutual inductance. This is the average mutual inductance between the stator windings.

The permanent magnet flux linking winding a is a maximum when  $\theta_r = 0^\circ$  and zero when  $\theta_r = 90^\circ$ . Therefore, the linked motor flux is defined by

$$\begin{bmatrix} \psi_{am} \\ \psi_{bm} \\ \psi_{cm} \end{bmatrix} = \begin{bmatrix} \psi_m \cos \theta_r \\ \psi_m \cos(\theta_r - 2\pi / 3) \\ \psi_m \cos(\theta_r + 2\pi / 3) \end{bmatrix}.$$

## 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

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

where  $\theta_e$  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

$$T = \frac{3}{2} N (i_q (i_d L_d + \psi_m) - i_d i_q L_q),$$

where:

- $v_d$ ,  $v_q$ , and  $v_0$  are the d-axis, q-axis, and zero-sequence voltages, defined by

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = P \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}.$$

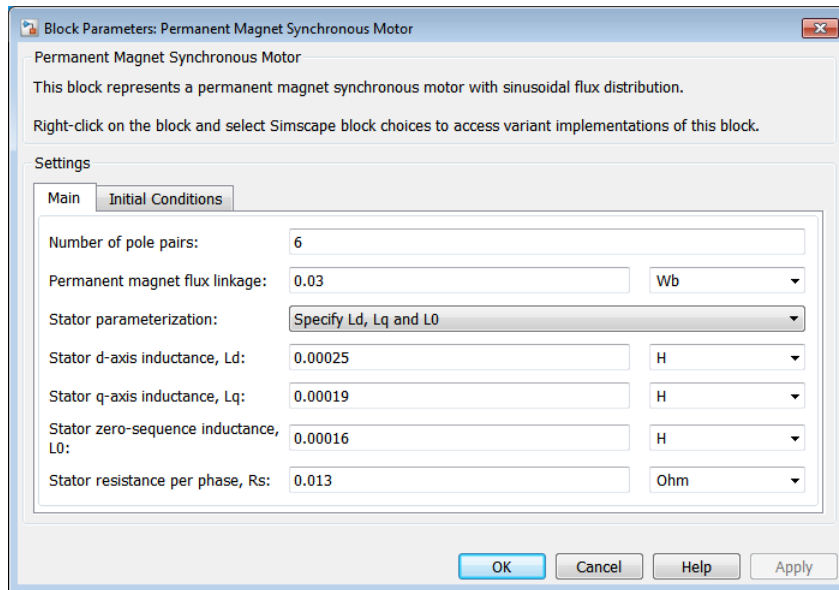
- $i_d$ ,  $i_q$ , and  $i_0$  are the d-axis, q-axis, and zero-sequence currents, defined by

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

- $L_d = L_s + M_s + 3/2 L_m$ .  $L_d$  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.
- $\omega$  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).



## Dialog Box and 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

Set of stator parameters that the block dialog box shows. The default value is Specify Ld, Lq and L0.

#### 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 0.00025 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 0.00019 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  $\Omega$ .

## 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 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.

## Related Examples

- “Expand and Collapse Three-Phase Ports on a Block”

# Phase Permute

Permute phases of three-phase system

## Library

Connections



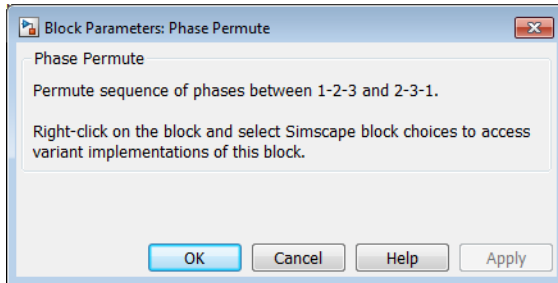
## Description

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

## Dialog Box and Parameters



The block has no parameters.

## Ports

The block has the following ports:

~123

Expandable “three-phase port”

~231

Expandable three-phase port

## Related Examples

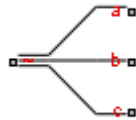
- “Expand and Collapse Three-Phase Ports on a Block”

# Phase Splitter

Expand composite three-phase port

## Library

Connections

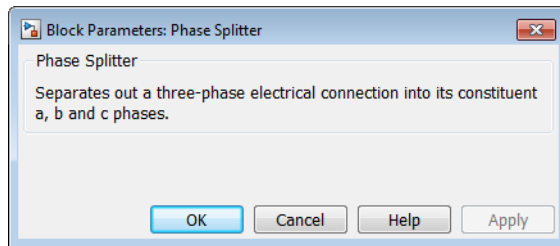


## Description

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 SimElectronics<sup>®</sup> libraries.

## Dialog Box and Parameters



The block has no parameters.

## Ports

The block has the following ports:

~

Composite “three-phase port”

a, b, c

Constituent phases of the expanded three-phase port

## Related Examples

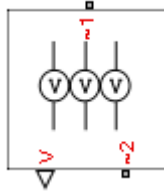
- “Expand and Collapse Three-Phase Ports on a Block”

# Phase Voltage Sensor

Measure phase voltages in three-phase system

## Library

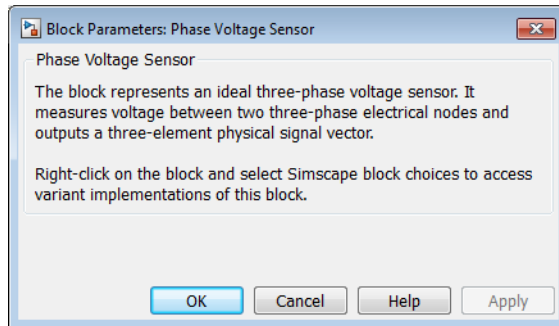
Sensors



## 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.

## Dialog Box and Parameters



The block has no parameters.



## 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

Line Voltage Sensor

## Related Examples

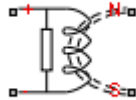
- “Expand and Collapse Three-Phase Ports on a Block”

# Primary Winding

Linear non-ideal transformer winding

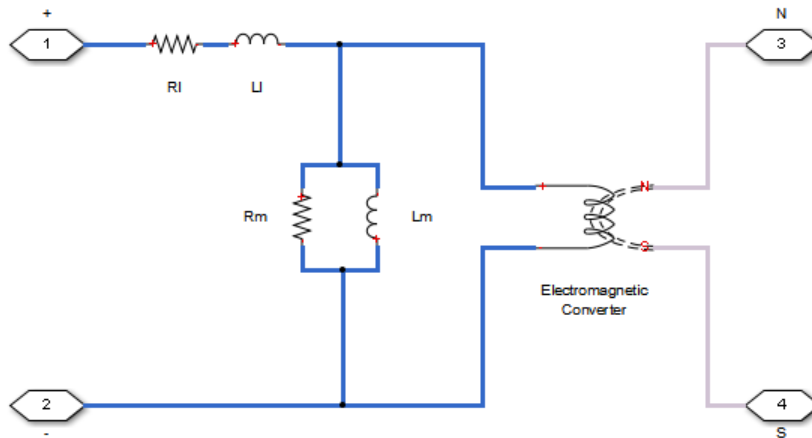
## Library

Passive Devices / Transformers / Fundamental Components



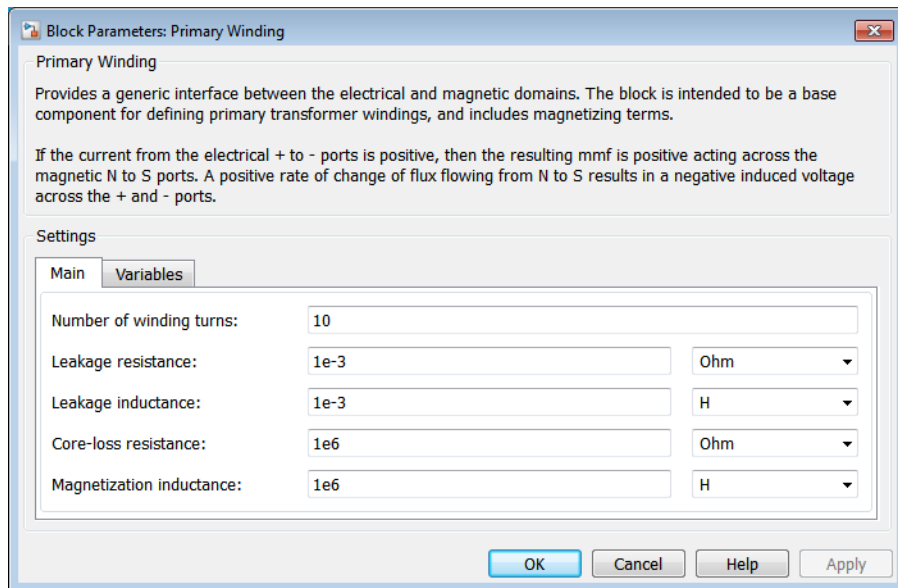
## Description

The Primary Winding block models linear non-ideal 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.

## Dialog Box and Parameters



- “Main Tab” on page 1-175
- “Variables Tab” on page 1-176

## 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  $1 \text{ e-}3 \text{ } \Omega$ .

### **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  $1e6$   $\Omega$ .

### **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 prior to simulation. For more information, see the Simscape topic, “Set Priority and Initial Target for Block Variables”.

## **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**

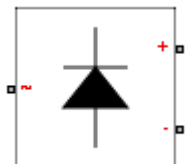
Electromagnetic Converter | Secondary Winding

# Rectifier

Convert three-phase AC voltage to fixed DC voltage

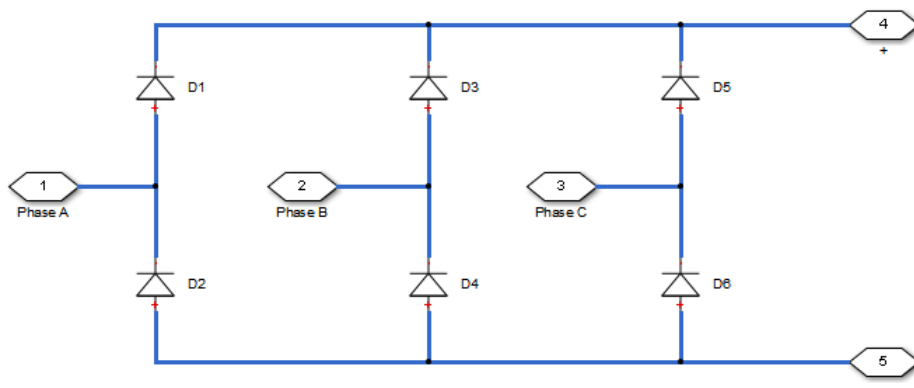
## Library

Semiconductors



## Description

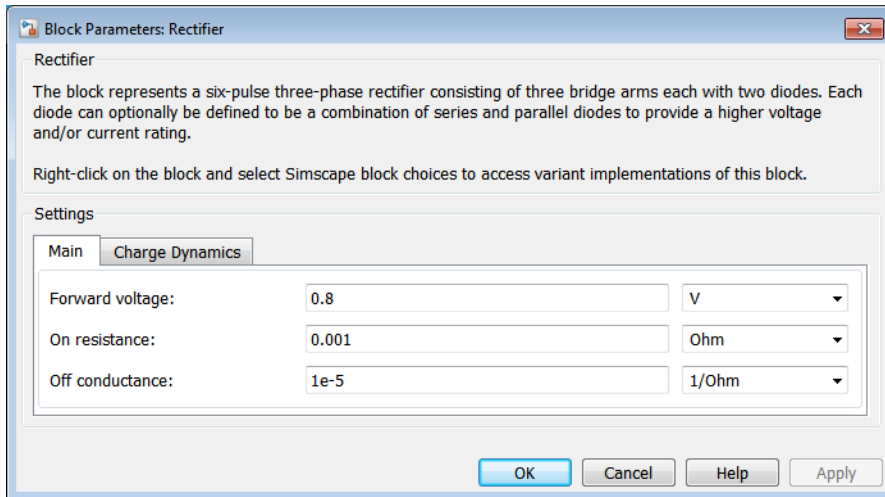
The Rectifier block models a three-arm diode bridge circuit that converts a three-phase AC voltage to a fixed DC voltage. The figure shows the equivalent circuit for the three-arm diode bridge.



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.

## Dialog Box and Parameters



- “Main Tab” on page 1-178
- “Charge Dynamics Tab” on page 1-179

### 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  $1/R_{\text{on}}$ , where  $R_{\text{on}}$  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  $\Omega$ .

### **Off conductance**

Conductance of each reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

## **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/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 trr Directly”.

### 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 for 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 reverse recovery charge instead of a value for reverse recovery time.

Reverse recovery charge is the total charge that remains to dissipate when the diode

turns off. The value must be less than  $-\frac{i_{RM}^2}{2a}$ ,



where:

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

The default value is **1500**  $\mu$ 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.

## 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

Converter

## Related Examples

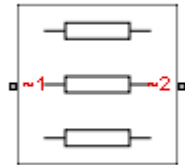
- “Expand and Collapse Three-Phase Ports on a Block”

## RLC

Three-phase line impedance

## Library

Passive Devices



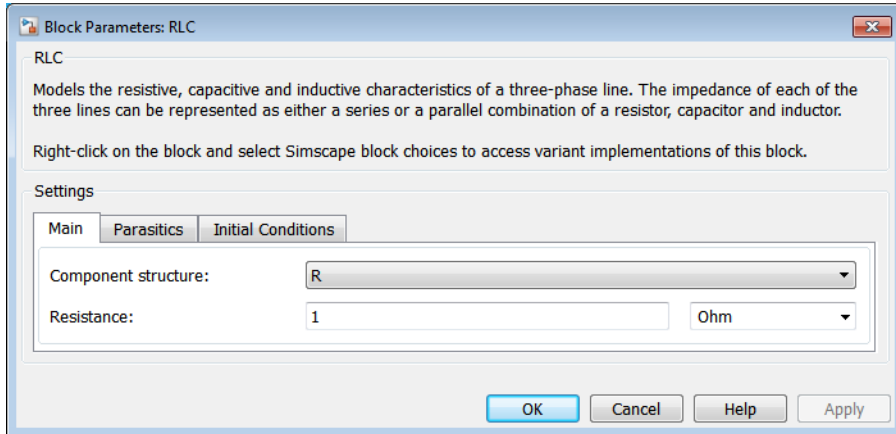
## Description

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, you must specify parasitic resistance or conductance values, which can help numerical convergence when simulating some circuit topologies. These parasitic terms ensure that an inductor has a small parallel resistive path and that a capacitor has a small series resistance.

## Dialog Box and Parameters



- “Main Tab” on page 1-183
- “Parasitics Tab” on page 1-184
- “Initial Conditions Tab” on page 1-184

## 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  $\Omega$ .

### 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  $1 \text{e-}6$  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  $1e-6 \Omega$ .

### 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  $1e-6 1/\Omega$ .

## 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	Parasitic parallel conductance	Initial inductor current [ Ia Ib Ic ]

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
	Inductance		
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 ]
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**

Delta-Connected Load | Wye-Connected Load

### **Related Examples**

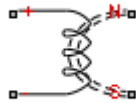
- “Expand and Collapse Three-Phase Ports on a Block”

# Secondary Winding

Linear non-ideal transformer winding

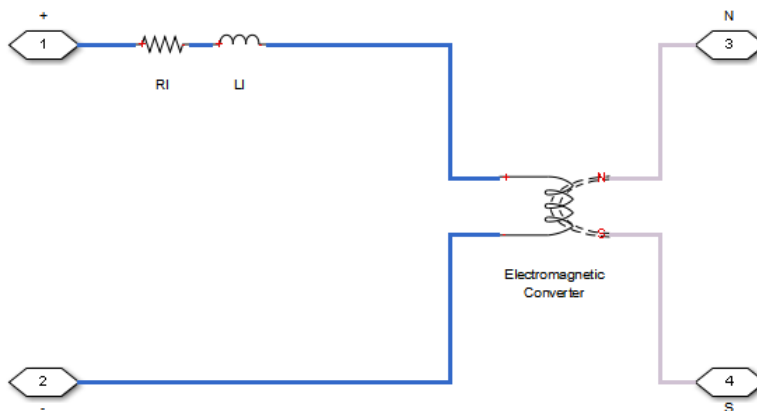
## Library

Passive Devices / Transformers / Fundamental Components



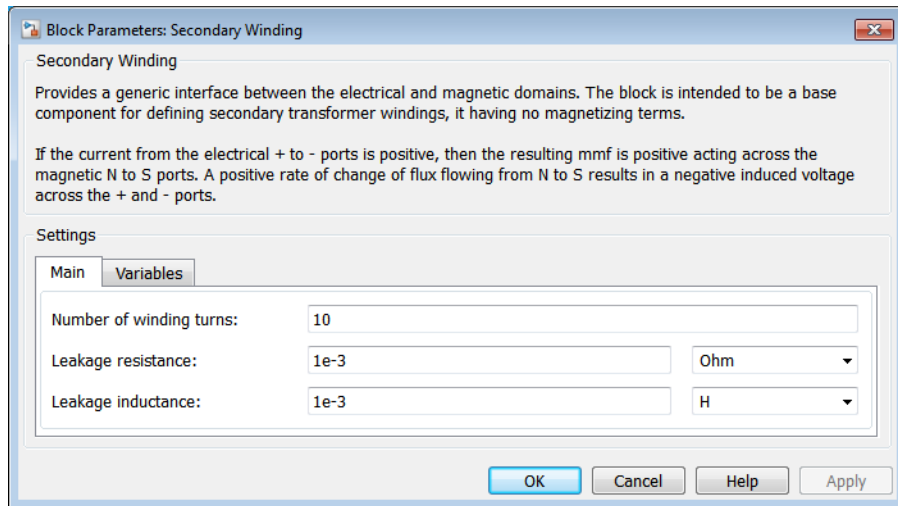
## Description

The Secondary Winding block models linear non-ideal 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.

## Dialog Box and Parameters



- “Main Tab” on page 1-188
- “Variables Tab” on page 1-188

### 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  $1\text{e-}3\ \Omega$ .

#### Leakage inductance

Magnetic flux loss in the winding. The default value is  $1\text{e-}3\ \text{H}$ .

### Variables Tab

Use the **Variables** tab to set the priority and initial target values for the block variables prior to simulation. For more information, see the Simscape topic, “Set Priority and Initial Target for Block Variables”.



## 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

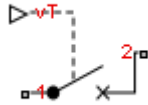
Electromagnetic Converter | Primary Winding

# Single-Phase Circuit Breaker

Single-pole single-throw circuit breaker

## Library

Switches & Breakers / Fundamental Components



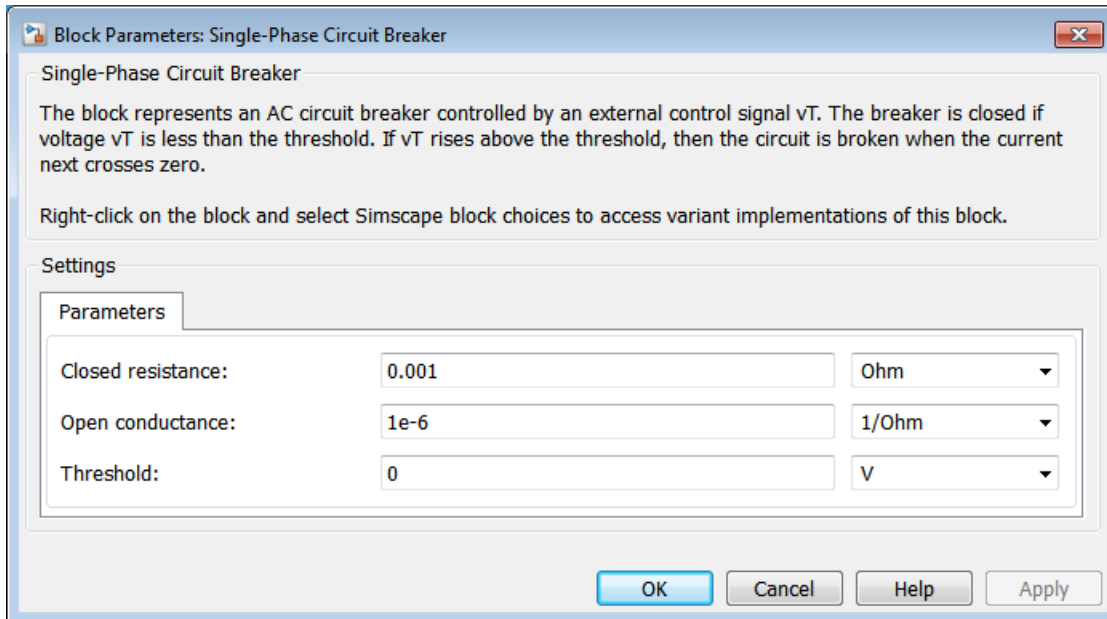
## Description

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
$vT < \text{Threshold}$	The breaker is closed. Port 1 connects to port 2.	<b>Closed Resistance</b>
$vT \geq \text{Threshold}$	When the current in port 1 goes through zero, the phase disconnects from port 2. The breaker is open.	<b>Open Conductance</b>

## Dialog Box and Parameters



### Closed resistance

Resistance between ports 1 and 2 when the breaker is closed. The default value is  $0.001 \Omega$ .

### Open conductance

Conductance between ports 1 and 2 when the breaker is open. The default value is  $1e-6 \Omega^{-1}$ .

### Threshold

Threshold voltage for the control port  $v_T$ . The block uses the threshold voltage and the value of  $v_T$  at `time = 0` to determine whether the breaker is open or closed at the start of the simulation. 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  $0 \text{ V}$ .

## Ports

The block has the following ports:

1

Single-phase port

2

Single-phase port

vT

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

## See Also

Circuit Breaker

## Related Examples

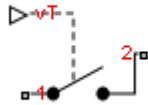
- “Switch Between Physical Signal and Electrical Ports”

# Single-Phase Switch

Single-pole single-throw switch

## Library

Switches & Breakers / Fundamental Components



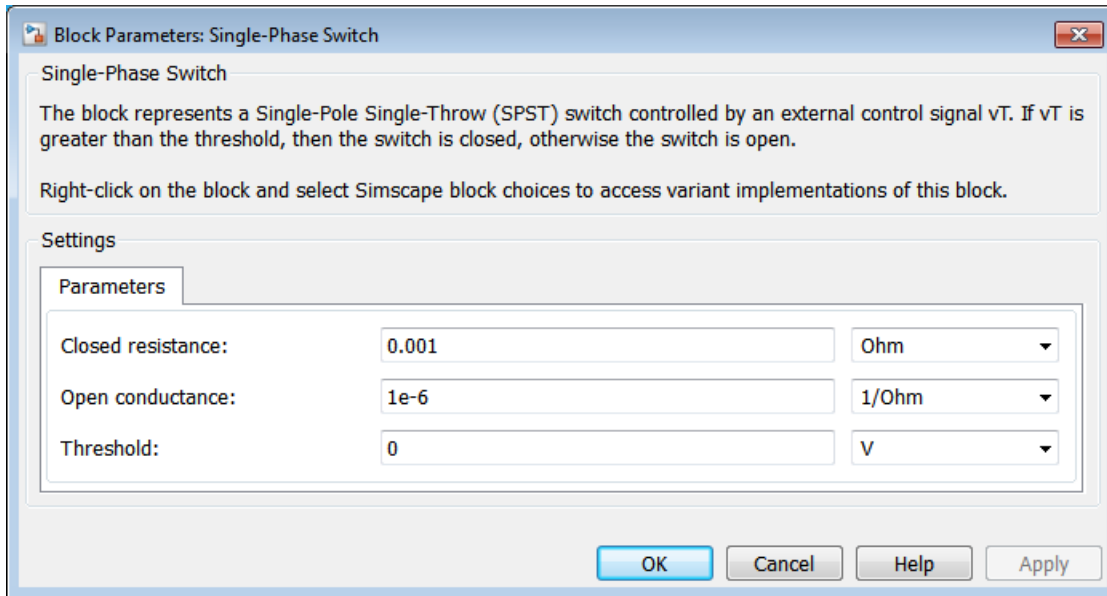
## Description

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
$vT \leq \text{Threshold}$	The switch is open. Port 1 is connected to port 2 via large internal resistance.	<b>Open conductance</b>
$vT > \text{Threshold}$	The switch is closed. Port 1 is connected to port 2 via small internal resistance.	<b>Closed resistance</b>

## Dialog Box and Parameters



### Closed resistance

Resistance between ports 1 and 2 when the switch is closed. The default value is  $0.001 \Omega$ .

### Open conductance

Conductance between ports 1 and 2 when the switch is open. The default value is  $1e-6 \Omega^{-1}$ .

### Threshold

Threshold voltage for the control port  $vT$ . When the voltage is above the threshold, the switch is closed. The default value is  $0 \text{ V}$ .

## Ports

The block has the following ports:

1

Single-phase port

2

Single-phase port

vT

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

### **See Also**

[Single-Phase Two-Way Switch](#) | [Switch](#) | [Two-Way Switch](#)

### **Related Examples**

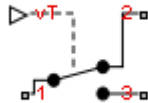
- [“Switch Between Physical Signal and Electrical Ports”](#)

# Single-Phase Two-Way Switch

Single-pole double-throw switch

## Library

Switches & Breakers / Fundamental Components



## Description

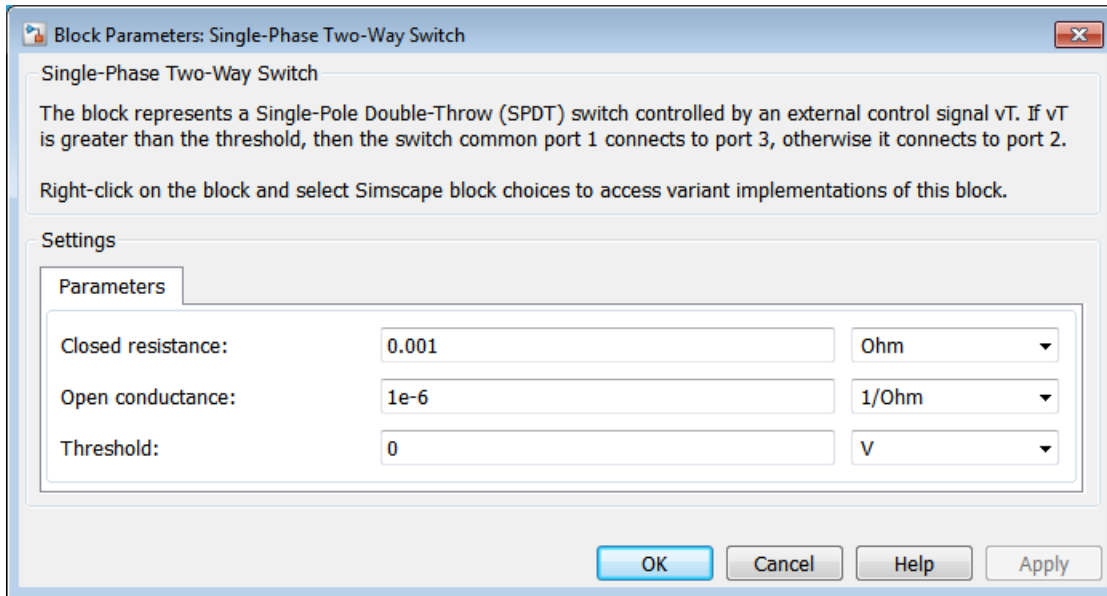
The Single-Phase Two-Way Switch block models a single-pole double-throw switch that uses an external signal to connect the port 1 to either of two ports 2 or 3 via internal resistance.

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

Condition	Block Behavior	Resistance Parameter Used
$vT \leq \text{Threshold}$	Port 1 is connected to port 2 via internal resistance. Port 3 is unconnected.	<b>Open conductance</b> (port 1 to port 3). <b>Closed resistance</b> (port 1 to port 2)
$vT > \text{Threshold}$	Port 1 is connected to port 3 via internal resistance. Port 2 is unconnected.	<b>Open conductance</b> (port 1 to port 2). <b>Closed resistance</b> (port 1 to port 3)



## Dialog Box and Parameters



### Closed resistance

Resistance between ports 1 and 3 when the switch is closed. The default value is  $0.001 \Omega$ .

### Open conductance

Conductance between ports 1 and 2 when the switch is open. The default value is  $1e-6 \Omega^{-1}$ .

### 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

Single-phase port

2

Single-phase port

3

Single-phase port

vT

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

### **See Also**

Single-Phase Switch | Switch | Two-Way Switch

### **Related Examples**

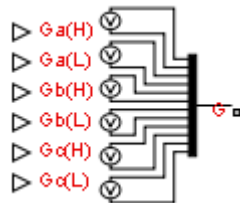
- “Switch Between Physical Signal and Electrical Ports”

# Six-Pulse Gate Multiplexer

Multiplex gate input signals to Converter block

## Library

Semiconductors



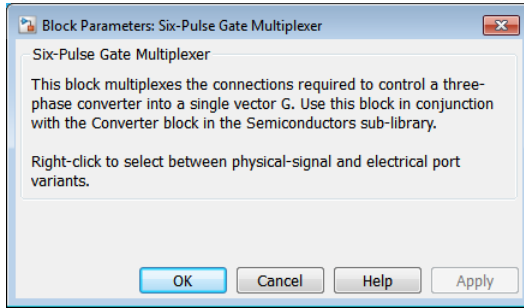
## Description

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 SimElectronics 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.

## Dialog Box and Parameters



The block has no parameters.

## 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**

Converter

## **Related Examples**

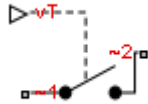
- “Switch Between Physical Signal and Electrical Ports”

# Switch

Three-phase single-throw switch

## Library

Switches & Breakers



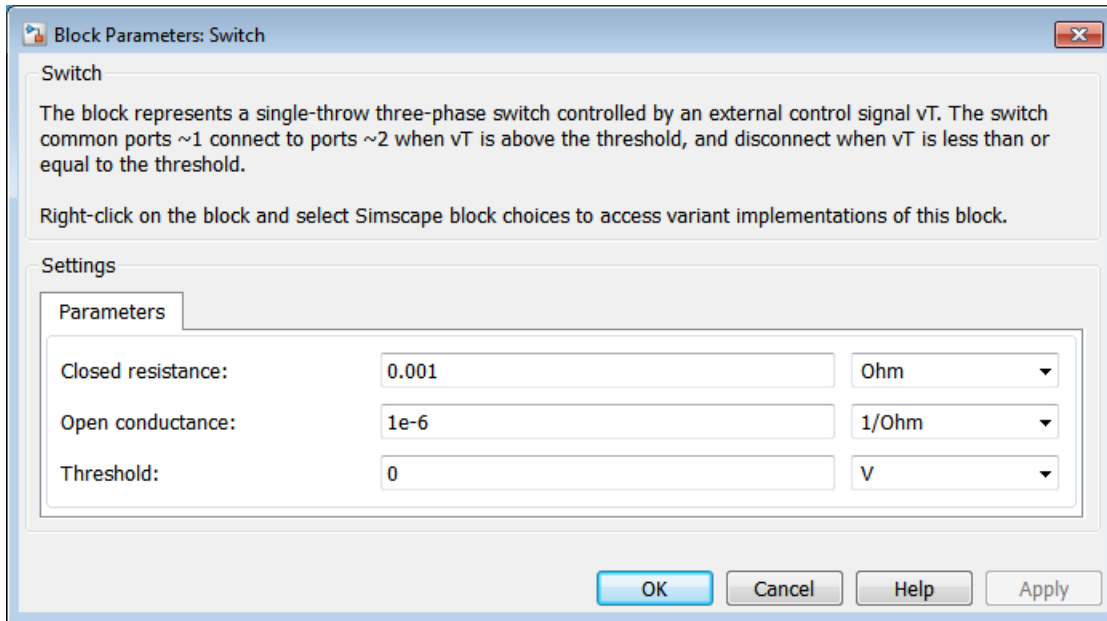
## Description

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
$vT \leq \text{Threshold}$	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.	<b>Open conductance</b>
$vT > \text{Threshold}$	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.	<b>Closed resistance</b>

## Dialog Box and Parameters



### Closed resistance

Resistance between ports ~1 and ~2 when the switch is closed. The default value is 0.001  $\Omega$ .

### Open conductance

Conductance between ports ~1 and ~2 when the switch is open. The default value is  $1e-6 \Omega^{-1}$ .

### 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**

Single-Phase Switch | Single-Phase Two-Way Switch | Two-Way Switch

### **Related Examples**

- “Expand and Collapse Three-Phase Ports on a Block”
- “Switch Between Physical Signal and Electrical Ports”

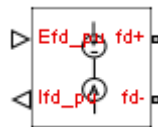


# Synchronous Machine Field Circuit (pu)

Synchronous machine field circuit per-unit voltage supply and current measurement

## Library

Machines

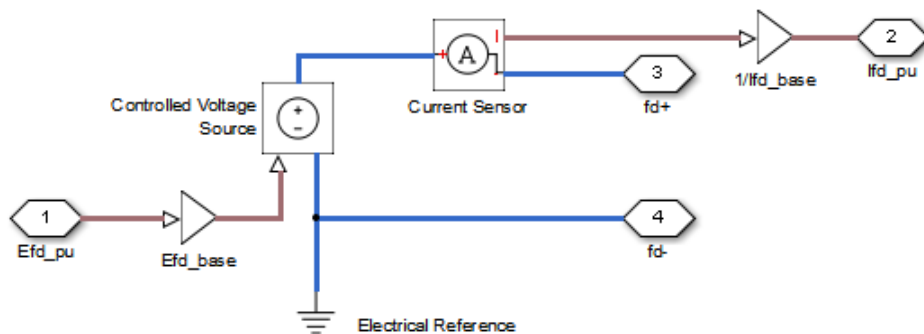


## Description

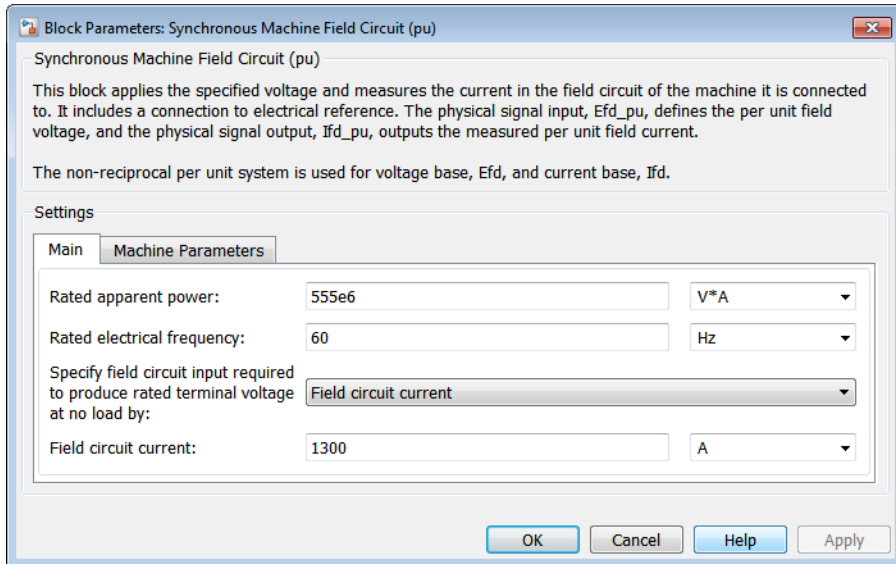
The Synchronous Machine Field Circuit (pu) block applies specified voltage to, and measures current through, the field circuit of the synchronous machine that it is connected to. It includes an electrical reference. The physical signal input  $E_{fd\_pu}$  defines the voltage and the physical signal output  $I_{fd\_pu}$  provides the current, both in per-unit.

The per-unit bases are the non-reciprocal per-unit system,  $E_{fd}$  and  $I_{fd}$ , rather than the reciprocal per-unit system,  $efd$  and  $ifd$ .

The figure shows the schematic for the Synchronous Machine Field Circuit (pu) block.



## Dialog Box and Parameters



- “Main Tab” on page 1-206
- “Machine Parameters Tab” on page 1-207

### Main Tab

#### Rated apparent power

Rated apparent power of the connected machine. The default value is 555e6 VA.

#### 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 (non-reciprocal 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 (non-reciprocal 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.

#### 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

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)

## Related Examples

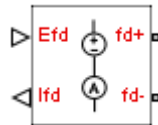
- Three-Phase Synchronous Machine Control

# Synchronous Machine Field Circuit (SI)

Synchronous machine field circuit voltage supply and current measurement in SI units

## Library

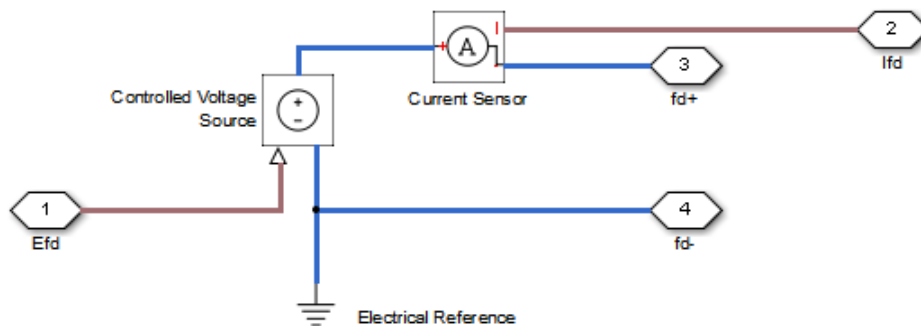
Machines



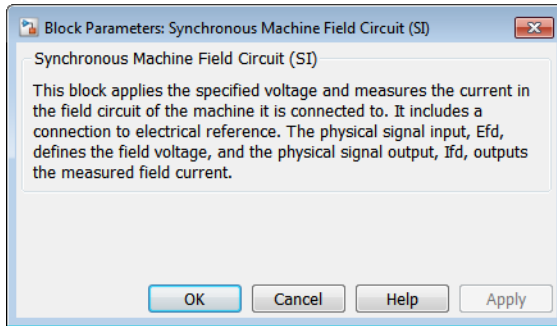
## Description

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  $E_{fd}$  defines the voltage, in Volts, and the physical signal output  $I_{fd}$  provides the current, in Amperes.

The figure shows the schematic for the Synchronous Machine Field Circuit (SI) block.



## Dialog Box



The block has no parameters.

## 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

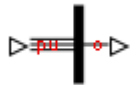
Synchronous Machine Salient Pole (standard) | Synchronous Machine Salient Pole (fundamental) | Synchronous Machine Field Circuit (pu) | Synchronous Machine Round Rotor (standard) | Synchronous Machine Round Rotor (fundamental)

# 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

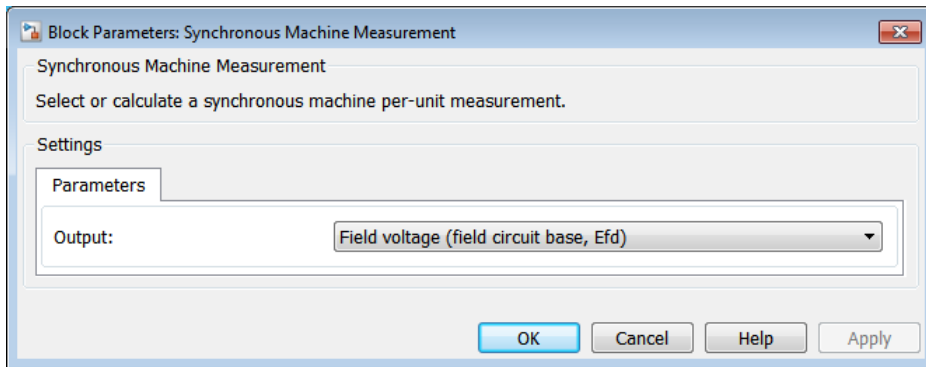
The Synchronous Machine Measurement block outputs a per-unit measurement from the synchronous machine according to the output value expressions in the table. For example, when you set **Output** to **Stator d-axis voltage**, the block directly outputs the value of the **pu\_ed** element in the input 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
Field current (field circuit base, Ifd)	pu_fd_Ifd
Electrical torque	pu_torque

Output Parameter Setting	Output Value Expression
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)



## Dialog Box and 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**

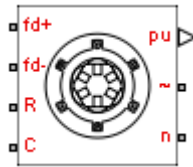
Synchronous Machine Round Rotor (fundamental) | Synchronous Machine Round Rotor (standard) | Synchronous Machine Salient Pole (fundamental) | Synchronous Machine Salient Pole (standard)

# 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 with parameterization 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:

- $\theta_e$  is the electrical angle.
- $N$  is the number of pole pairs.
- $\theta_r$  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  $\sim$  to neutral port n.

- $\omega_{base}$  is the per-unit base electrical speed.
- $\psi_d$ ,  $\psi_q$ , and  $\psi_0$  are the d-axis, q-axis, and zero-sequence stator flux linkages.
- $\omega_r$  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  $\sim$  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.
- $\Psi_{fd}$ ,  $\Psi_{1d}$ ,  $\Psi_{1q}$ , and  $\Psi_{2q}$  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

$$\psi_{at} = \sqrt{\psi_d^2 + \psi_q^2},$$

$K_s = 1$  (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:

- $\psi_{at}$  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

$$\Psi_0 = -L_0i_0,$$

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  $L_{12q} = L_{aq}$ , i.e., 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

$$T_e = \Psi_d i_q - \Psi_q i_d.$$

## Display Options

For synchronous machine blocks, you can perform display actions using the **Power Systems** menu on the block context menu.

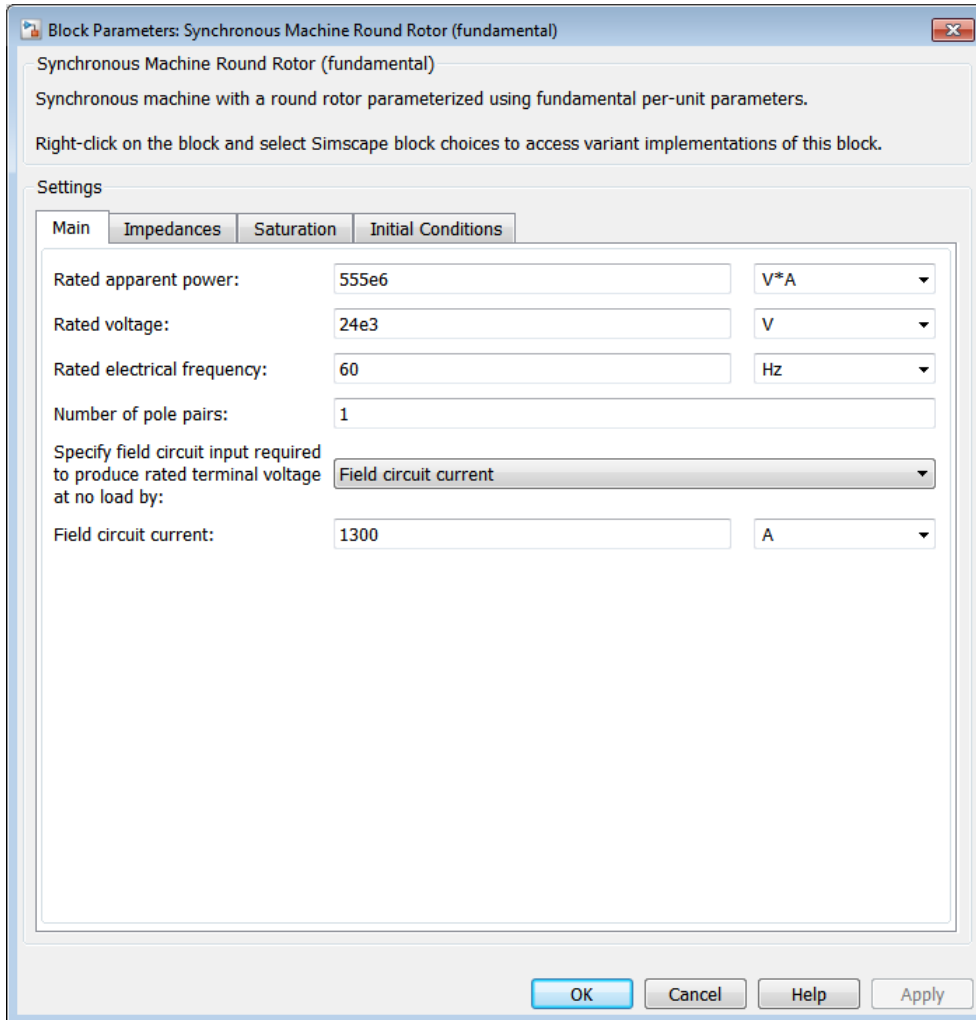
Right-click the block. From the context menu, select one of the following from the **Power Systems > Synchronous Machine** menu:

- **Display Base Values** displays the machine per-unit base values at the MATLAB command prompt.



- **Display Associated Base Values** displays associated per-unit base values at the MATLAB command prompt.
- **Associated Initial Conditions** displays associated initial conditions at the MATLAB command prompt.
- **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),  $L_{ad}$**  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,  $\psi_{at}$ , characteristic.
- **Plot Saturation Factor (pu)** plots saturation factor,  $K_s$ , versus magnetic flux linkage,  $\psi_{at}$ , (both measured in per-unit) in a MATLAB figure window using the present machine parameters. This is derived from parameters you specify:
  - **Stator d-axis mutual inductance (unsaturated),  $L_{ad}$**
  - **Per-unit field current saturation data, ifd**
  - **Per-unit air-gap voltage saturation data, Vag**

## Dialog Box and Parameters



- “Main Tab” on page 1-223
- “Impedances Tab” on page 1-223
- “Saturation Tab” on page 1-224
- “Initial Conditions Tab” on page 1-225

## 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
- 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 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

Options include:

- Electrical power and voltage output
- 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 VA.

### **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 VA.

### **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**

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\_ed
- pu\_e0
- pu\_id
- pu\_iq
- pu\_i0

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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

Synchronous Machine Measurement | Synchronous Machine Round Rotor (Standard) | Synchronous Machine Salient Pole (Fundamental) | Synchronous Machine Salient Pole (Standard)

## Related Examples

- “Expand and Collapse Three-Phase Ports on a Block”
- Three-Phase Synchronous Machine Control

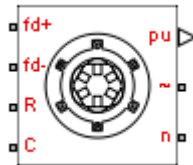


# Synchronous Machine Round Rotor (standard)

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 with parameterization 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:

- $\theta_e$  is the electrical angle.
- $N$  is the number of pole pairs.
- $\theta_r$  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  $\sim$  to neutral port n.

- $\omega_{base}$  is the per-unit base electrical speed.
- $\psi_d$ ,  $\psi_q$ , and  $\psi_0$  are the d-axis, q-axis, and zero-sequence stator flux linkages.
- $\omega_r$  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  $\sim$  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.
- $\Psi_{fd}$ ,  $\Psi_{1d}$ ,  $\Psi_{1q}$ , and  $\Psi_{2q}$  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

$$\psi_{at} = \sqrt{\psi_d^2 + \psi_q^2},$$

$$K_s = 1 \text{ (If saturation is disabled),}$$

$$K_s = f(\psi_{at}) \text{ (If saturation is enabled),}$$

$$L_{ad} = K_s * L_{adu},$$

and

$$L_{aq} = K_s * L_{aqu},$$

where:

- $\psi_{at}$  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

$$\Psi_0 = -L_0i_0,$$

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.  $L_{fd}$  is the rotor field circuit and d-axis damper winding 1 mutual inductance. They are defined by the following equations.

$$L_{ffd} = L_{ad} + L_{fd}$$

$$L_{fd} = L_{ffd} - L_{ad}$$

$$L_{11d} = L_{fd} + L_{1d}$$

$$L_{11q} = L_{aq} + L_{1q}$$

$$L_{22q} = L_{aq} + L_{2q}$$

These equations assume that per-unit mutual inductance  $L_{12q} = L_{aq}$ , i.e., 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].

## Display Options

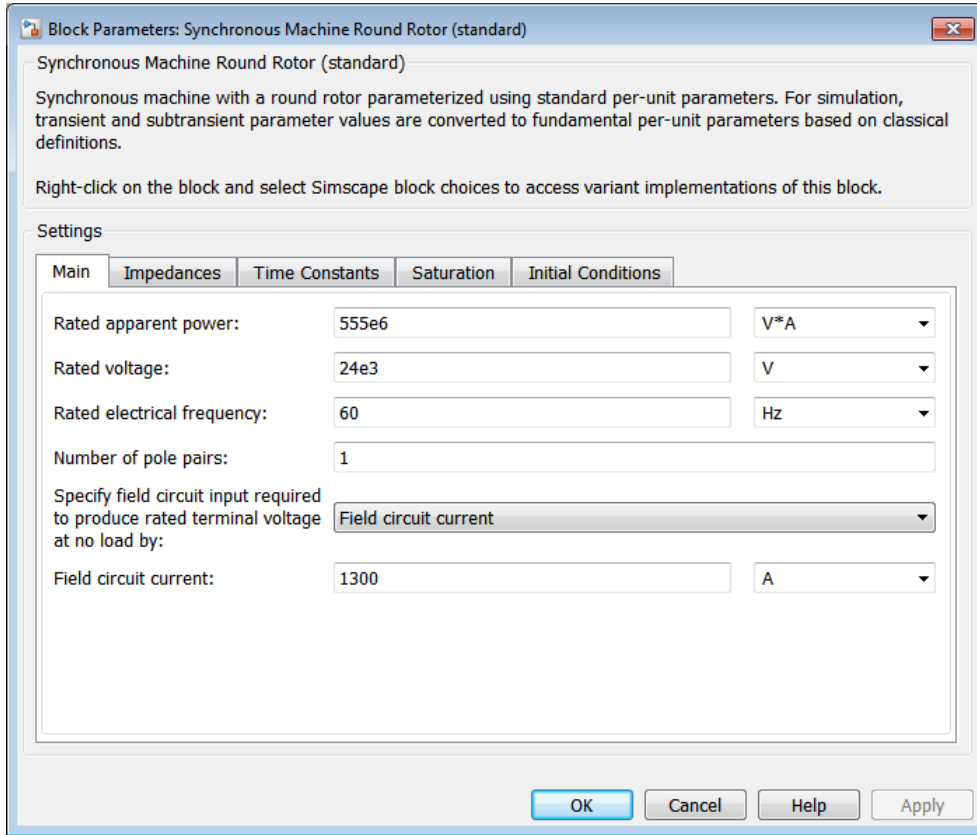
For synchronous machine blocks, you can perform display actions using the **Power Systems** menu on the block context menu.

Right-click the block. From the context menu, select one of the following from the **Power Systems > Synchronous Machine** menu:

- **Display Base Values** displays the machine per-unit base values at the MATLAB command prompt.

- **Display Associated Base Values** displays associated per-unit base values at the MATLAB command prompt.
- **Associated Initial Conditions** displays associated initial conditions at the MATLAB command prompt.
- **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),  $L_{adu}$**  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,  $\psi_{at}$ , characteristic.
- **Plot Saturation Factor (pu)** plots saturation factor,  $K_s$ , versus magnetic flux linkage,  $\psi_{at}$ , (both measured in per-unit) in a MATLAB figure window using the present machine parameters. This is derived from parameters you specify:
  - **Stator d-axis mutual inductance (unsaturated),  $L_{adu}$**
  - **Per-unit field current saturation data, ifd**
  - **Per-unit air-gap voltage saturation data, Vag**

## Dialog Box and Parameters



- “Main Tab” on page 1-236
- “Impedances Tab” on page 1-237
- “Time Constants Tab” on page 1-238
- “Saturation Tab” on page 1-239
- “Initial Conditions Tab” on page 1-240

### 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**

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 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

Options include:

- Electrical power and voltage output
- 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 VA.

### 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 VA.

### 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**

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\_ed
- 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**

Synchronous Machine Measurement | Synchronous Machine Round Rotor (Fundamental) | Synchronous Machine Salient Pole (Fundamental) | Synchronous Machine Salient Pole (Standard)

## **Related Examples**

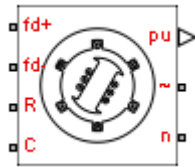
- “Expand and Collapse Three-Phase Ports on a Block”
- Three-Phase Synchronous Machine Control

# 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 with parameterization 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:

- $\theta_e$  is the electrical angle.
- $N$  is the number of pole pairs.
- $\theta_r$  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.

- $\omega_{base}$  is the per-unit base electrical speed.
- $\psi_d$ ,  $\psi_q$ , and  $\psi_0$  are the d-axis, q-axis, and zero-sequence stator flux linkages.
- $\omega_r$  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  $\sim$  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.
- $\Psi_{fd}$ ,  $\Psi_{1d}$ , and  $\Psi_{1q}$  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

$$\Psi_{at} = \sqrt{\Psi_d^2 + \Psi_q^2},$$

$K_s = 1$  (If saturation is disabled),

$K_s = f(\psi_{at})$  (If saturation is enabled),

and

$$L_{ad} = K_s * L_{adu},$$

where:

- $\psi_{at}$  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

$$\Psi_0 = -L_0i_0,$$

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  $L_{12q} = L_{aq}$ , i.e., 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

$$T_e = \Psi_d i_q - \Psi_q i_d.$$

## Display Options

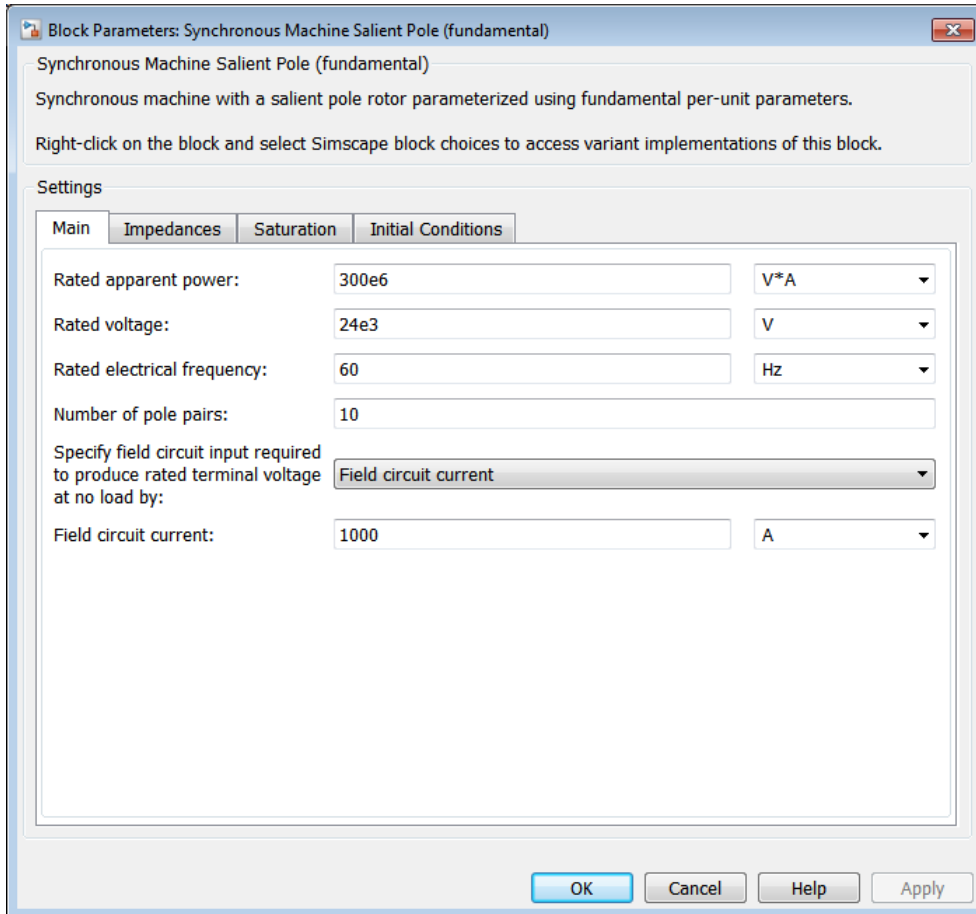
For synchronous machine blocks, you can perform display actions using the **Power Systems** menu on the block context menu.

Right-click the block. From the context menu, select one of the following from the **Power Systems > Synchronous Machine** menu:

- **Display Base Values** displays the machine per-unit base values at the MATLAB command prompt.
- **Display Associated Base Values** displays associated per-unit base values at the MATLAB command prompt.
- **Associated Initial Conditions** displays associated initial conditions at the MATLAB command prompt.
- **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)**,  $L_{ad}$  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,  $\Psi_{at}$ , characteristic.

- **Plot Saturation Factor (pu)** plots saturation factor,  $K_s$ , versus magnetic flux linkage,  $\psi_{at}$ , (both measured in per-unit) in a MATLAB figure window using the present machine parameters. This is derived from parameters you specify:
  - **Stator d-axis mutual inductance (unsaturated),  $L_{ad}$**
  - **Per-unit field current saturation data,  $ifd$**
  - **Per-unit air-gap voltage saturation data,  $V_{ag}$**

## Dialog Box and Parameters



- “Main Tab” on page 1-251
- “Impedances Tab” on page 1-251
- “Saturation Tab” on page 1-252
- “Initial Conditions Tab” on page 1-253

## Main Tab

### Rated apparent power

Rated apparent power. The default value is 300e6 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 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), $L_{adu}$

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 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 ( $V_{ag}$  versus  $i_{fd}$ )

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 ( $V_{ag}$  versus  $i_{fd}$ ). 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, $V_{ag}$

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 ( $V_{ag}$  versus  $i_{fd}$ ). 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

Options include:

- Electrical power and voltage output
- 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 VA.

### 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 VA.

### **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**

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\_ed
- 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

Synchronous Machine Measurement | Synchronous Machine Round Rotor (fundamental) | Synchronous Machine Round Rotor (standard) | Synchronous Machine Salient Pole (standard)

## Related Examples

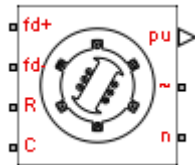
- “Expand and Collapse Three-Phase Ports on a Block”
- Three-Phase Synchronous Machine Control

# 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 with parameterization 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:

- $\theta_e$  is the electrical angle.
- $N$  is the number of pole pairs.
- $\theta_r$  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  $\sim$  to neutral port n.

- $\omega_{base}$  is the per-unit base electrical speed.
- $\psi_d$ ,  $\psi_q$ , and  $\psi_0$  are the d-axis, q-axis, and zero-sequence stator flux linkages.
- $\omega_r$  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  $\sim$  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.
- $\Psi_{fd}$ ,  $\Psi_{1d}$ , and  $\Psi_{1q}$ , 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

$$\Psi_{at} = \sqrt{\Psi_d^2 + \Psi_q^2},$$

$K_s = 1$  (If saturation is disabled),

$K_s = f(\psi_{at})$  (If saturation is enabled),

and

$$L_{ad} = K_s * L_{adu},$$

where:

- $\psi_{at}$  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

$$\Psi_0 = -L_0i_0,$$

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  $L_{12q} = L_{aq}$ , i.e., 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].

## Display Options

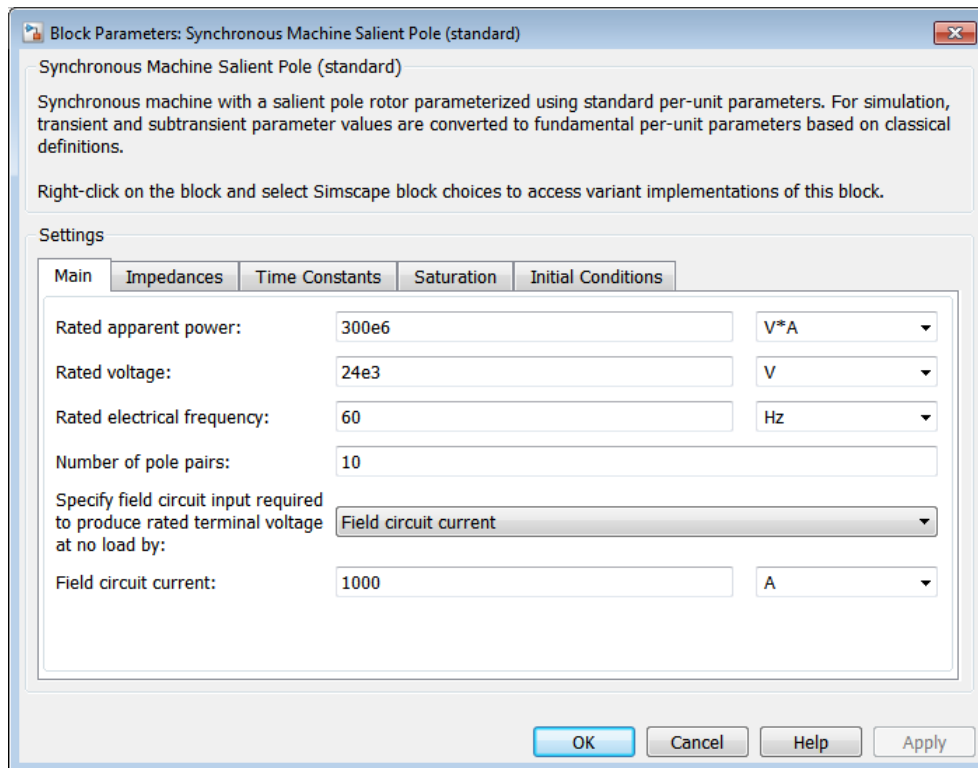
For synchronous machine blocks, you can perform display actions using the **Power Systems** menu on the block context menu.

Right-click the block. From the context menu, select one of the following from the **Power Systems > Synchronous Machine** menu:

- **Display Base Values** displays the machine per-unit base values at the MATLAB command prompt.
- **Display Associated Base Values** displays associated per-unit base values at the MATLAB command prompt.
- **Associated Initial Conditions** displays associated initial conditions at the MATLAB command prompt.
- **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 (V<sub>ag</sub> versus if<sub>d</sub>)** you specify. This data is used to calculate the saturation factor,  $K_s$ , versus magnetic flux linkage,  $\psi_{at}$ , characteristic.
- **Plot Saturation Factor (pu)** plots saturation factor,  $K_s$ , versus magnetic flux linkage,  $\psi_{at}$ , (both measured in per-unit) in a MATLAB figure window using the present machine parameters. This is derived from parameters you specify:
  - **Stator d-axis mutual inductance (unsaturated), L<sub>adu</sub>**
  - **Per-unit field current saturation data, if<sub>d</sub>**
  - **Per-unit air-gap voltage saturation data, V<sub>ag</sub>**

## Dialog Box and Parameters



- “Main Tab” on page 1-264
- “Impedances Tab” on page 1-264
- “Time Constants Tab” on page 1-265
- “Saturation Tab” on page 1-266
- “Initial Conditions Tab” on page 1-267

## Main Tab

### Rated apparent power

Rated apparent power. The default value is 300e6 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 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,  $X_l$** 

Stator leakage reactance. The default value is 0.15 pu.

**d-axis synchronous reactance,  $X_d$** 

The d-axis synchronous reactance. The default value is 1.05 pu.

**q-axis synchronous reactance,  $X_q$** 

The q-axis synchronous reactance. The default value is 0.7 pu.

**zero-sequence reactance,  $X_0$** 

The zero-sequence reactance. The default value is 0 pu.

**d-axis transient reactance,  $X_d'$** 

The d-axis transient reactance. The default value is 0.35 pu.

**d-axis subtransient reactance,  $X_d''$** 

The d-axis subtransient reactance. The default value is 0.25 pu.

**q-axis subtransient reactance,  $X_q''$** 

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,  $T_{d0}'$** 

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,  $T_{d}'$** 

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,  $T_{d0}''$**

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 ( $V_{ag}$  versus  $i_{fd}$ )

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 ( $V_{ag}$  versus  $i_{fd}$ )`. 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 ( $V_{ag}$  versus  $i_{fd}$ ). 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

Options include:

- Electrical power and voltage output
- 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 VA.

### 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 VA.

### 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**

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+



fd-	Electrical conserving port corresponding to the field winding positive terminal
R	Electrical conserving port corresponding to the field winding negative terminal
C	Mechanical rotational conserving port associated with the machine rotor
pu	Mechanical rotational conserving port associated with the machine case
	Physical signal vector port associated with the machine per-unit measurements. The vector elements are:
	<ul style="list-style-type: none"> <li>• pu_fd_Efd</li> <li>• pu_fd_Ifd</li> <li>• pu_torque</li> <li>• pu_velocity</li> <li>• pu_ed</li> <li>• pu_ed</li> <li>• pu_e0</li> <li>• pu_id</li> <li>• pu_iq</li> <li>• pu_i0</li> </ul>
~	
n	Expandable “three-phase port” associated with the stator windings
	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**

Synchronous Machine Measurement | Synchronous Machine Round Rotor (Fundamental) | Synchronous Machine Round Rotor (Standard) | Synchronous Machine Salient Pole (Fundamental)

## **Related Examples**

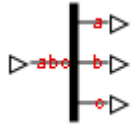
- “Expand and Collapse Three-Phase Ports on a Block”
- Three-Phase Synchronous Machine Control

# Three Element Demux

Convert three-element physical signal vector into scalar physical signals

## Library

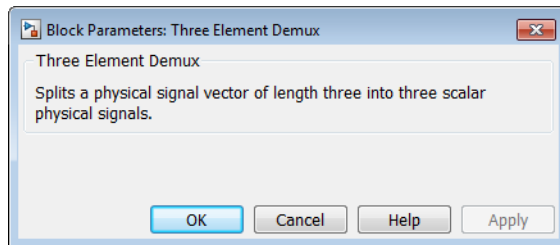
Sensors



## Description

The Three Element Demux block splits a three-element physical signal vector into three scalar physical signals.

## Dialog Box and Parameters



The block has no parameters.

## 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**

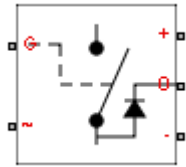
Scalar physical signal output port.

# Three-Level Converter

Connect three-phase AC network to three-level DC network

## Library

Semiconductors

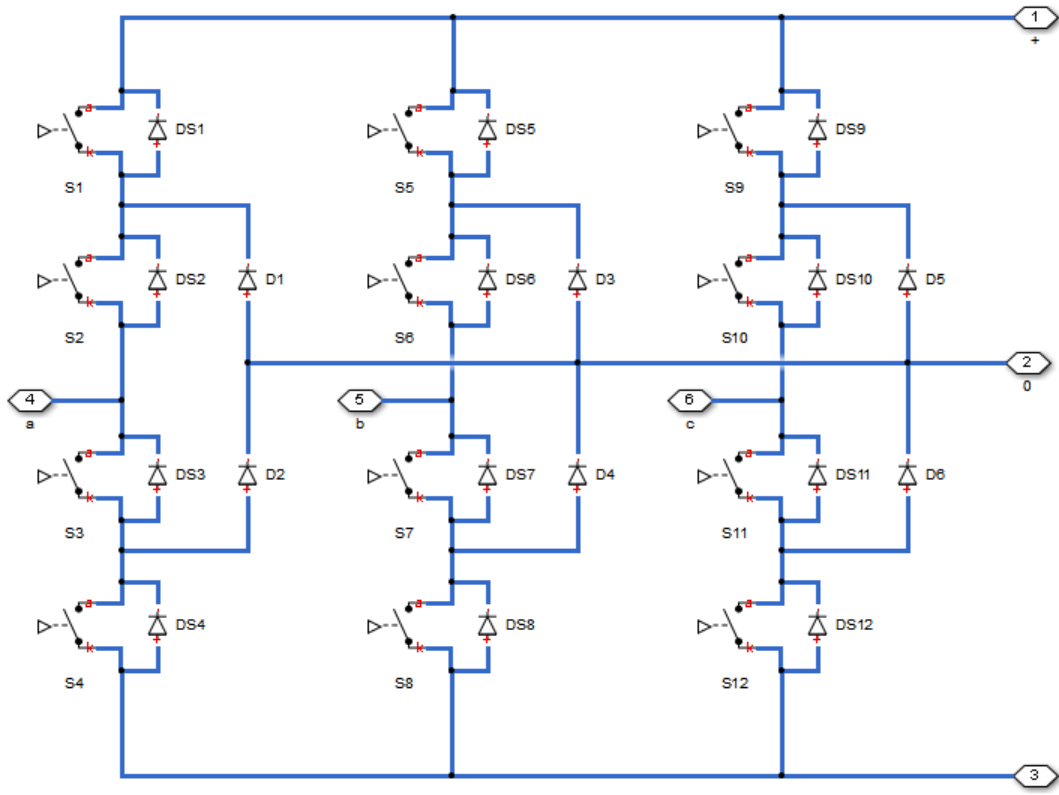


## Description

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.

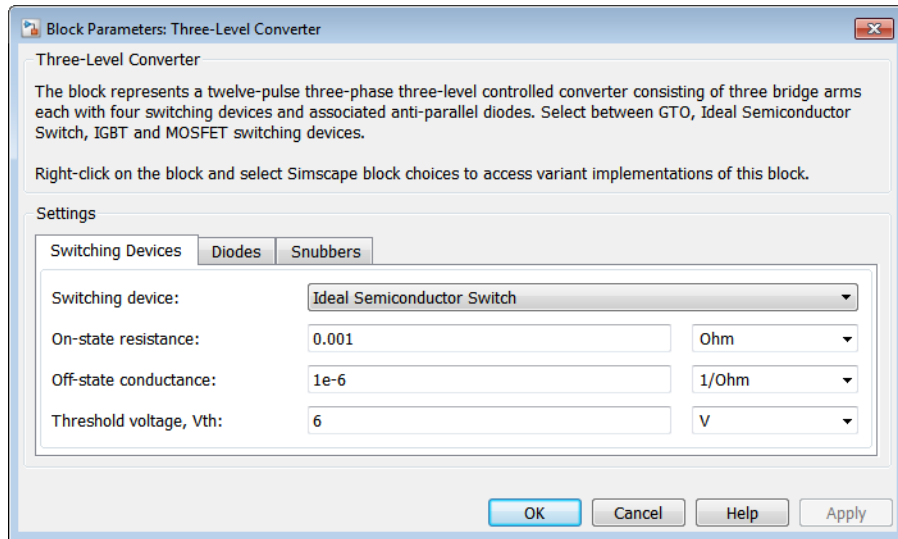
You use the **Diodes** tab of the block dialog box to include an integral protection diode for each switching device. An integral diode protects the semiconductor device by providing a conduction path for reverse current. An inductive load can produce a high reverse-voltage spike when the semiconductor 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.

## Dialog Box and Parameters



- “Switching Devices Tab” on page 1-276
- “Diodes Tab” on page 1-279
- “Snubbers Tab” on page 1-282

## 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  $\Omega$ .

### 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  $1e-6 \Omega^{-1}$ .

### 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  $\Omega$ .

### 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  $1e-6 \Omega^{-1}$ .

**Threshold voltage,  $V_{th}$**

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,  $V_f$**

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  $\Omega$ .

**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  $1e-6 \Omega^{-1}$ .

**Threshold voltage,  $V_{th}$**

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  $0.001 \Omega$ .

#### **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  $1e-6 \Omega^{-1}$ .

#### **Threshold voltage, $V_{th}$**

Gate-source voltage threshold. The device turns on when the gate-source voltage is above this value. The default value is  $6 \text{ V}$ .

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  $0.8 \text{ V}$ .

### **On resistance**

Rate of change of voltage versus current above the forward voltage. The default value is  $0.001 \Omega$ .

### **Off conductance**

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

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  $\Omega$ .

### Off conductance

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

### 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/ $\mu$ 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 trr Directly”.

**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**  $\mu\text{s}$ .

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 for 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 reverse recovery charge instead of a value for reverse recovery time.

Reverse recovery charge is the total charge that remains to dissipate when the diode turns off. The value must be less than  $-\frac{i_{RM}^2}{2a}$ ,

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**  $\mu\text{As}$ .

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.

## 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  $0.1 \Omega$ .

### 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.

0

Electrical conserving port associated with the DC neutral terminal.

-

Electrical conserving port associated with the DC negative terminal.

## See Also

Converter | Ideal Rectifier | Rectifier | Twelve-Pulse Gate Multiplexer

## Related Examples

- “Expand and Collapse Three-Phase Ports on a Block”

# Thyristor

Thyristor

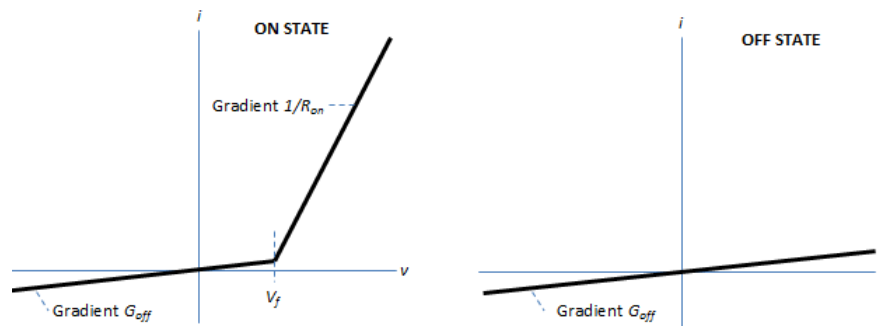
## Library

Semiconductors / Fundamental Components



## Description

The Thyristor block models a thyristor. The figure shows a typical *i-v characteristic* for a thyristor.



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.
- $V_f$  is the forward voltage.
- $G$  is the gate voltage.
- $V_{gt}$  is the gate trigger voltage.
- $i$  is the anode-cathode current.
- $I_h$  is the holding current.
- $R_{on}$  is the on-state resistance.
- $G_{off}$  is the off-state conductance.

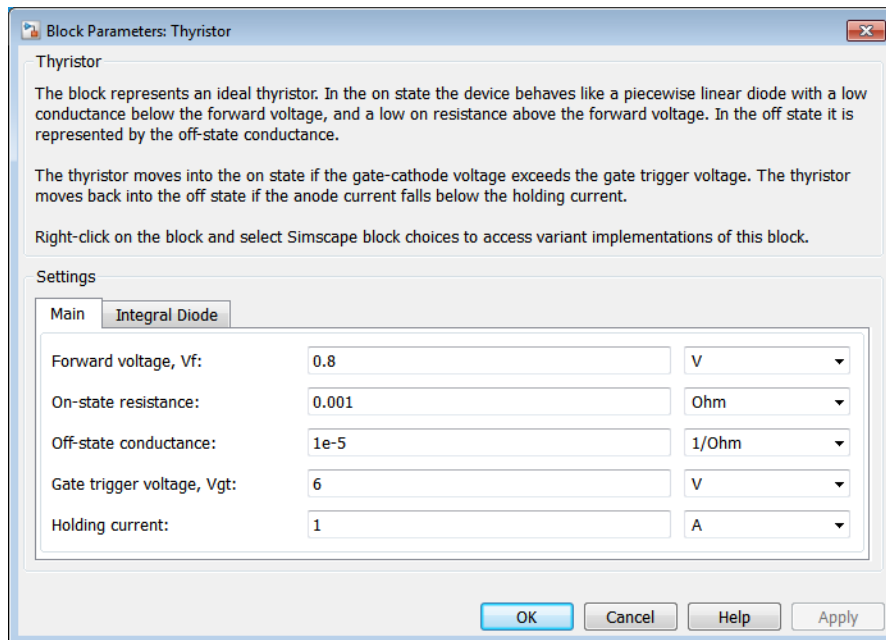
Using the Integral Diode tab of the block dialog box, you can include an integral cathode-anode diode. An integral diode protects the semiconductor device by providing a conduction path for reverse current. An inductive load can produce a high reverse-voltage spike when the semiconductor device suddenly 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.



## Dialog Box and Parameters



- “Main Tab” on page 1-285
- “Integral Diode Tab” on page 1-286

## 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  $\Omega$ .

### 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  $1e-5 \Omega^{-1}$ .

### 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  $\Omega$ .

### **Off conductance**

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

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  $\Omega$ .

### **Off conductance**

Conductance of the reverse-biased diode. The default value is  $1e-5 \Omega^{-1}$ .

### **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/ $\mu$ 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 trr Directly”.

#### **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**  $\mu\text{s}$ .

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 for 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 reverse recovery charge instead of a value for reverse recovery time.

Reverse recovery charge is the total charge that remains to dissipate when the diode turns off. The value must be less than  $-\frac{i_{RM}^2}{2a}$ ,

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**.

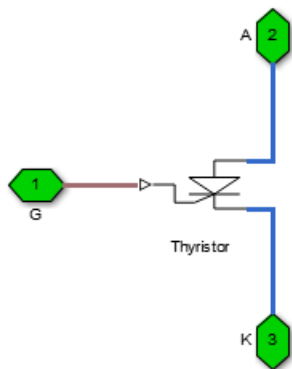
The default value is **1500**  $\mu\text{As}$ .

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.

## 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.

## Related Examples

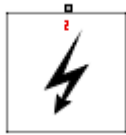
- “Switch Between Physical Signal and Electrical Ports”

## Time-Based Fault

Time-based single-phase, two-phase or three-phase grounded or ungrounded fault

### Library

Passive Devices / Faults



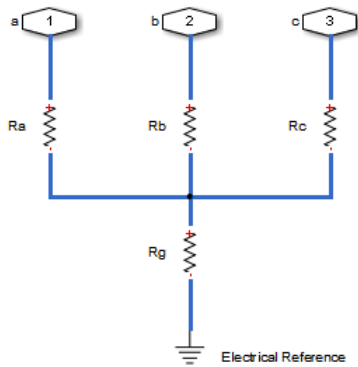
### Description

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:

- 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	$\frac{1}{G_{pn}}$	$\frac{1}{G_{pn}}$	$\frac{1}{G_{pn}}$	Infinity / open circuit
a-g	$R_{pn}$	$\frac{1}{G_{pn}}$	$\frac{1}{G_{pn}}$	$R_{ng}$
b-g	$\frac{1}{G_{pn}}$	$R_{pn}$	$\frac{1}{G_{pn}}$	$R_{ng}$
c-g	$\frac{1}{G_{pn}}$	$\frac{1}{G_{pn}}$	$R_{pn}$	$R_{ng}$
a-b	$R_{pn}$	$R_{pn}$	$\frac{1}{G_{pn}}$	Infinity / open circuit
b-c	$\frac{1}{G_{pn}}$	$R_{pn}$	$R_{pn}$	Infinity / open circuit

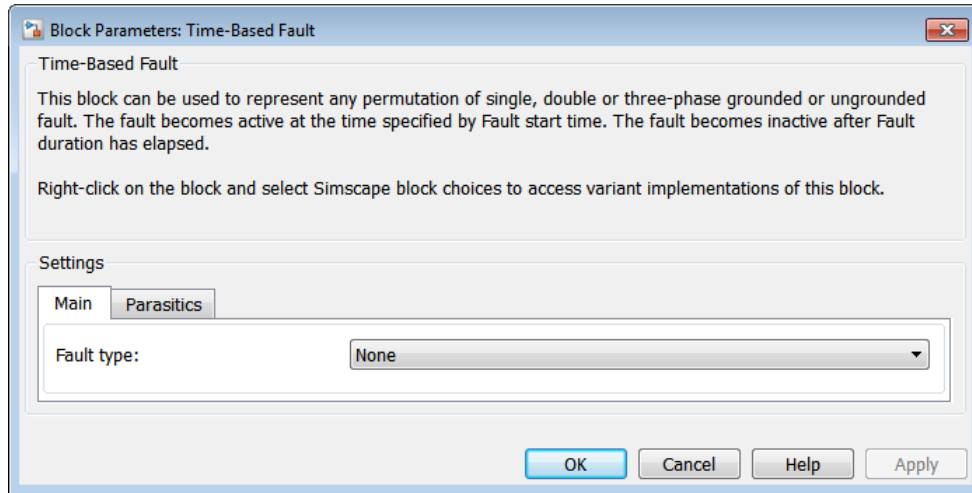
Fault type	Value of $R_a$	Value of $R_b$	Value of $R_c$	Value of $R_g$
c-a	$R_{pn}$	$\frac{1}{G_{pn}}$	$R_{pn}$	Infinity / open circuit
a-b-g	$R_{pn}$	$R_{pn}$	$\frac{1}{G_{pn}}$	$R_{ng}$
b-c-g	$\frac{1}{G_{pn}}$	$R_{pn}$	$R_{pn}$	$R_{ng}$
c-a-g	$R_{pn}$	$\frac{1}{G_{pn}}$	$R_{pn}$	$R_{ng}$
a-b-c	$R_{pn}$	$R_{pn}$	$R_{pn}$	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.



## Dialog Box and Parameters



- “Main Tab” on page 1-293
- “Parasitics Tab” on page 1-294

### 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  $1\text{e-}3\ \Omega$ .

#### **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  $1\text{e-}3\ \Omega$ .

#### **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  $1\text{e-}6\ \Omega^{-1}$ .

### **Ports**

The block has one expandable “three-phase port” for connecting the fault to the system.

### **See Also**

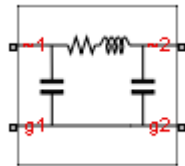
Enabled Fault

# 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, line-line capacitance, and line-ground capacitance.

To simplify the block-defining equations, Clarke's transformation is used. The resulting equations are:

$$V'_1 - V'_2 = \begin{bmatrix} R & & \\ & R & \\ & & R \end{bmatrix} I'_1 + \begin{bmatrix} L + 2M & & \\ & L - M & \\ & & L - M \end{bmatrix} \frac{dI'_1}{dt}$$

$$I'_1 + I'_2 = \begin{bmatrix} C_g & & \\ & C_g + 3C_l & \\ & & C_g + 3C_l \end{bmatrix} \frac{dV'_2}{dt}$$

$$I'_1 = T'I_1$$

$$I'_2 = T I_2$$

$$V'_1 = T V_1$$

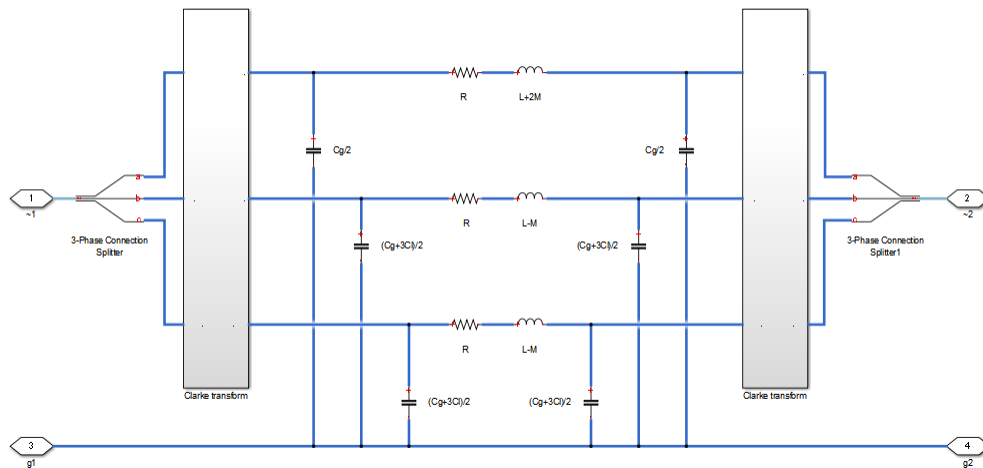
$$V'_2 = T V_2$$

$$T = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & \sqrt{2} & 0 \\ 1 & -1/\sqrt{2} & \sqrt{3/2} \\ 1 & -1/\sqrt{2} & -\sqrt{3/2} \end{bmatrix}$$

where:

- $R$  is the line resistance for the segment.
- $L$  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.

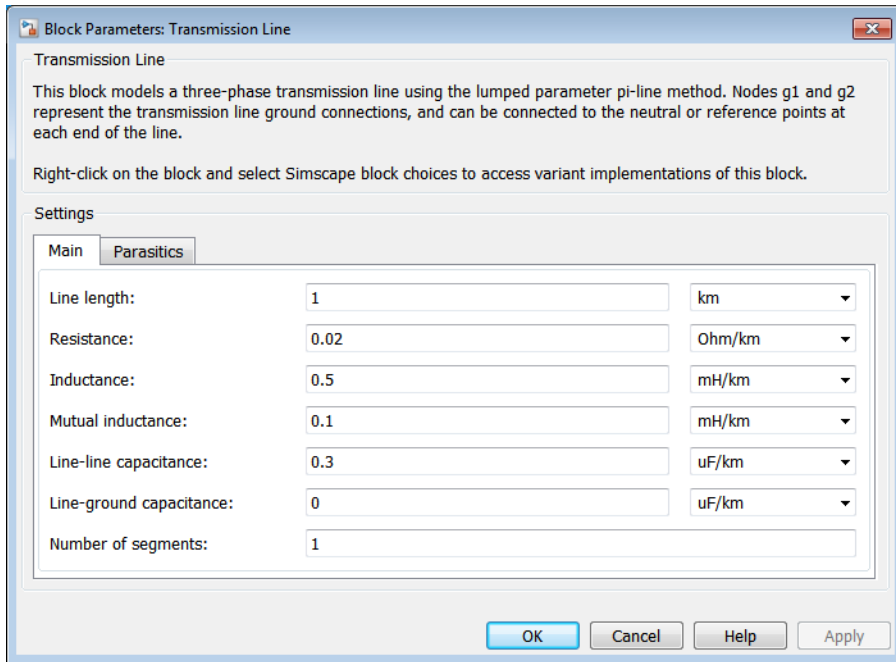
The figure shows the equivalent electrical circuit for a single-segment pi-line model using Clarke's transformation.



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.

## Dialog Box and Parameters



- “Main tab” on page 1-298
- “Parasitics tab” on page 1-299

### Main tab

#### Line length

Length of the transmission line. The default value is 1 km.

#### Resistance

Resistance of the transmission line per phase per unit length. The default value is 0.02  $\Omega$ /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  $\mu\text{F}/\text{km}$ .

#### **Line-ground capacitance**

Line-ground capacitance per unit length. The default value is 0  $\mu\text{F}/\text{km}$  (no line-ground capacitance).

#### **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  $1\text{e-}6\ \Omega$ .

#### **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  $1\text{e-}6\ \Omega^{-1}$ .

## **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

## **Related Examples**

- “Expand and Collapse Three-Phase Ports on a Block”

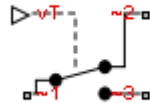


# Two-Way Switch

Three-phase double-throw switch

## Library

Switches & Breakers



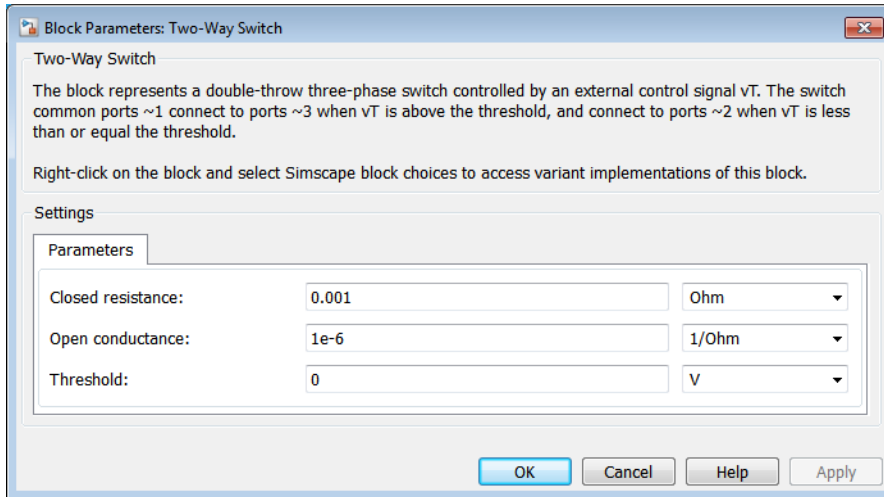
## Description

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
$vT \leq \text{Threshold}$	Each phase of port ~1 is connected to the corresponding phase of port ~2 via internal resistance. Port ~3 is unconnected.	<b>Open conductance</b> (port ~1 to port ~3). <b>Closed resistance</b> (port ~1 to port ~2)
$vT > \text{Threshold}$	Each phase of port ~1 is connected to the corresponding phase of port ~3 via internal resistance. Port ~2 is unconnected.	<b>Open conductance</b> (port ~1 to port ~2). <b>Closed resistance</b> (port ~1 to port ~3)

## Dialog Box and Parameters



### Closed resistance

Resistance between ports ~1 and ~3 when the switch is closed. The default value is  $0.001 \Omega$ .

### Open conductance

Conductance between ports ~1 and ~2 when the switch is open. The default value is  $1e-6 \Omega^{-1}$ .

### 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**

[Single-Phase Switch](#) | [Single-Phase Two-Way Switch](#) | [Switch](#)

### **Related Examples**

- [“Expand and Collapse Three-Phase Ports on a Block”](#)
- [“Switch Between Physical Signal and Electrical Ports”](#)

# Twelve-Pulse Gate Multiplexer

Multiplex gate input signals to Three-Level Converter block

## Library

Semiconductors



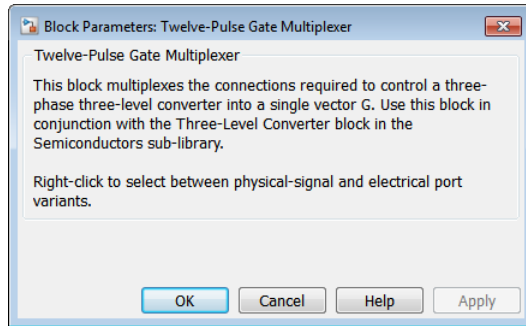
## Description

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, B-phase, and then C-phase, with four gate signals per phase.

If you want to use SimElectronics 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 twelve pairs of electrical connections, each pair corresponding to the gate and cathode of a switching device.

## Dialog Box and Parameters



The block has no parameters.

## 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**

Six-Pulse Gate Multiplexer | Three-Level Converter

**Related Examples**

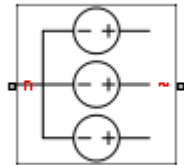
- “Switch Between Physical Signal and Electrical Ports”

# 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:

$$V_0 = \frac{\sqrt{2}}{\sqrt{3}} \cdot v_{line\_rms}$$

$$v_a = V_0 \cdot \sin(2\pi \cdot f \cdot t + \varphi)$$

$$v_b = V_0 \cdot \sin(2\pi \cdot f \cdot t + \varphi - 120^\circ)$$

$$v_c = V_0 \cdot \sin(2\pi \cdot f \cdot t + \varphi + 120^\circ),$$

where:

- $V_0$  is the peak phase voltage.
- $v_{line\_rms}$  is the RMS phase-to-phase voltage.
- $v_a, v_b, v_c$  are the respective phase voltages.
- $f$  is the frequency.
- $\varphi$  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:

$$V_0 = \frac{\sqrt{2}}{\sqrt{3}} \cdot v_{line\_rms} \cdot H_{ratios}$$

$$v_a = V_0 \cdot \sin((2\pi \cdot f \cdot t + \varphi)H'_{orders})$$

$$v_b = V_0 \cdot \sin((2\pi \cdot f \cdot t + \varphi - \theta)H'_{orders})$$

$$v_c = V_0 \cdot \sin((2\pi \cdot f \cdot t + \varphi + \theta)H'_{orders}),$$

where:

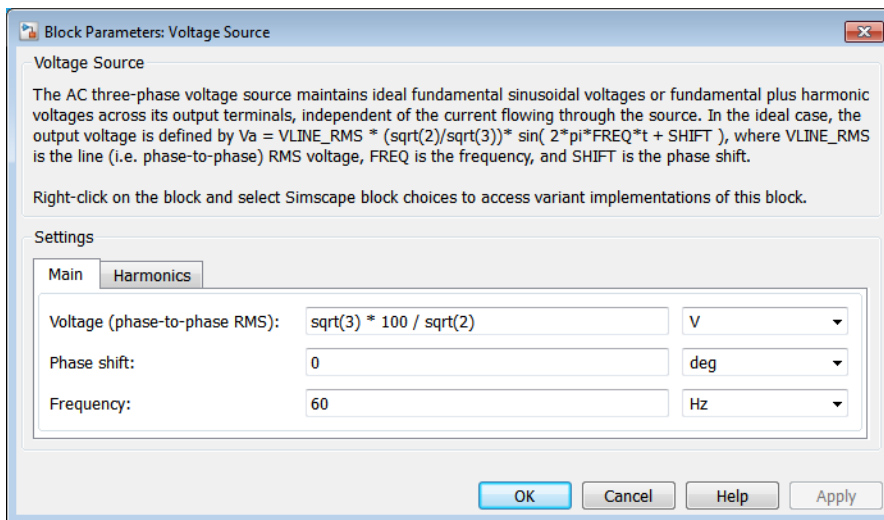
- $V_0$  is a row-vector containing the peak voltage of the fundamental and harmonic sinusoids.
- $v_{line\_rms}$  is the RMS phase-to-phase voltage.
- $H_{ratios}$  is a row-vector of harmonic ratios. The first element is 1 to represent the fundamental.
- $H_{orders}$  is a row-vector of harmonic orders. 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.



- $\phi$  is a column-vector of harmonic phase shifts. The first element is the fundamental phase shift.
- $\theta$  is a column-vector of harmonic phase offsets. The first element is  $120^\circ$ .
- $t$  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,  $V(+)-V_n$ .

## Dialog Box and Parameters



- “Main Tab” on page 1-309
- “Harmonics Tab” on page 1-310

## 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

Current Source

## Related Examples

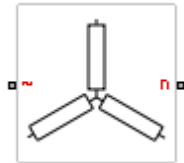
- “Expand and Collapse Three-Phase Ports on a Block”

# Wye-Connected Load

Three-phase load wired in wye configuration

## Library

Passive Devices



## Description

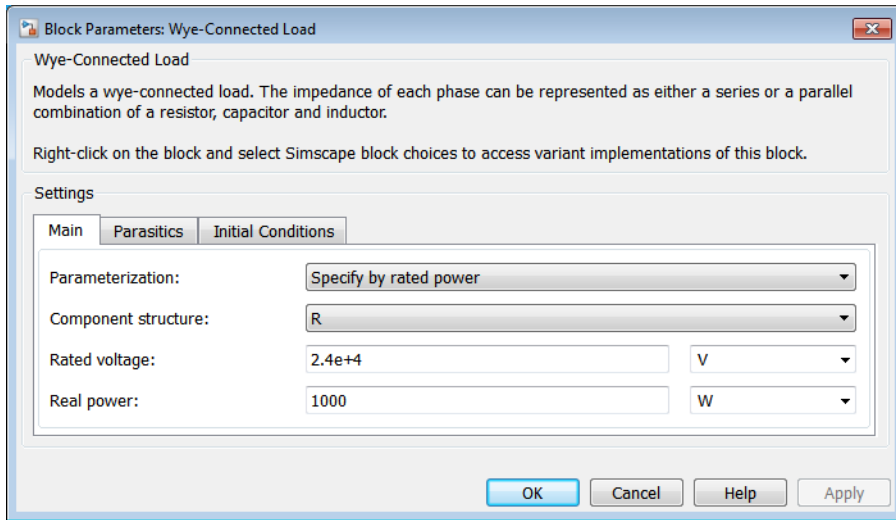
The Wye-Connected Load block models a three-phase load wired in a wye configuration. Each limb of the load can include any combination of a resistor (R), capacitor (C), and inductor (L), connected in series or in parallel.

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 of R, L, and C values, then for initialization you must 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 you must 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, you must specify parasitic resistance or conductance values, which can help numerical convergence when simulating some circuit topologies. 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.

## Dialog Box and Parameters



- “Main Tab” on page 1-312
- “Parasitics Tab” on page 1-314
- “Initial Conditions Tab” on page 1-314

### 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  $\Omega$ .

**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  $1e-6 \Omega$ .

### 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  $1e-6 \Omega^{-1}$ .

## 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 Inductive reactive power	Parasitic parallel conductance	Terminal voltage magnitude 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	None	Terminal voltage magnitude Terminal voltage angle Frequency

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
	Capacitive reactive power		
Series LC	Rated voltage Rated electrical frequency Inductive reactive power Capacitive reactive power	Parasitic parallel conductance	Terminal voltage magnitude Terminal voltage angle Frequency
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	Parasitic series resistance	Terminal voltage magnitude Terminal voltage angle



Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
	Capacitive reactive power		Frequency
Parallel LC	Rated voltage Rated electrical frequency Inductive reactive power Capacitive reactive power	Parasitic series resistance	Terminal voltage magnitude Terminal voltage angle Frequency
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	None	Initial capacitor voltage [ Va Vb Vc ]

Component Structure	Main Tab	Parasitics Tab	Initial Conditions Tab
	Capacitance		
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 ]
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**

Delta-Connected Load | RLC

### **Related Examples**

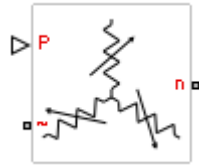
- “Expand and Collapse Three-Phase Ports on a Block”

# 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 is capable of representing a real load.

To ensure that the resistance is always greater than zero, you specify the minimum real power that the load will consume. The minimum real power must be greater than zero.

## Electrical Defining Equations

The resistance is defined by

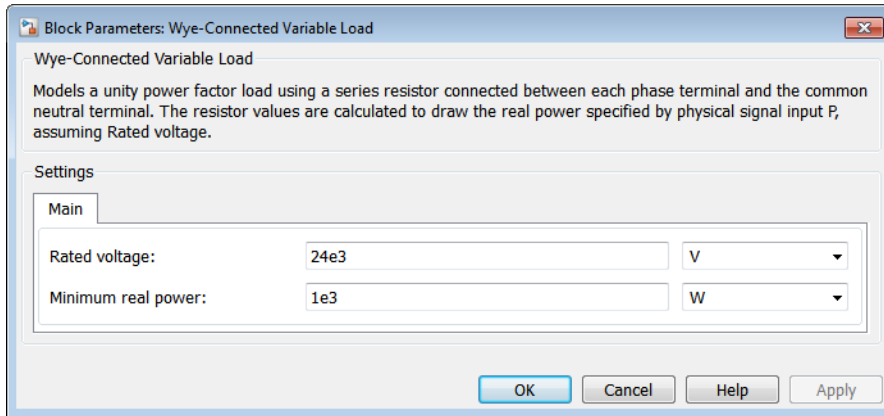
$$R = \frac{V_{Rated}^2}{P},$$

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.

## Dialog Box and Parameters



### Main Tab

#### Rated voltage

RMS, rated line-line voltage for the resistance equation. The default value is 24 kV.

#### 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 1 kW.

### 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**

Wye-Connected Load | Wye-Connected Variable Load (lagging)

### **Related Examples**

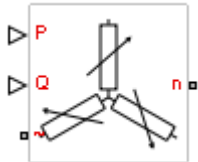
- “Expand and Collapse Three-Phase Ports on a Block”

# 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 is capable of representing 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

$$R = \frac{P \cdot V_{Rated}^2}{P^2 + Q^2}$$

and

$$L = \frac{QV_{Rated}^2}{2\pi F_{Rated} (P^2 + Q^2)},$$

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,  $\phi$ , to the steady-state current:

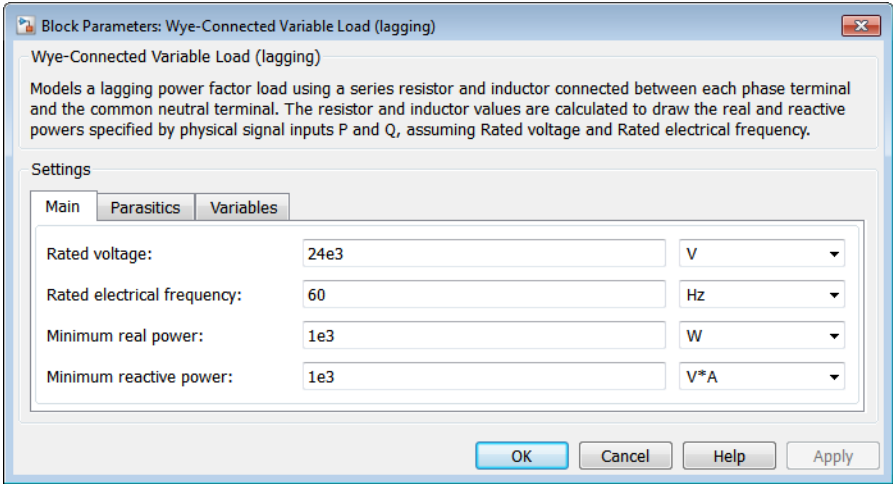
$$L(i) = \frac{\phi(i)}{i}.$$

Therefore the current-voltage relationship for the inductor is:

$$v = \frac{dL}{dt}i + L\frac{di}{dt}.$$



# Dialog Box and Parameters



- “Main Tab” on page 1-325
- “Parasitics” on page 1-326
- “Variables Tab” on page 1-326

## Main Tab

### Rated voltage

RMS, rated line-line voltage for the resistance equation. The default value is 24 kV.

### 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 1 kW.

### 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 1 kW.

## Parasitics

### Parasitic parallel conductance

Conductance that the block adds, in parallel, to the series RL. The default value is  $1 \mu\Omega^{-1}$ .

## Variables Tab

Use the **Variables** tab to set the priority and initial target values for the block variables prior to simulation. For more information, see the Simscape topic, “Set Priority and Initial Target for Block Variables”.

## 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

Wye-Connected Load | Wye-Connected Variable Load

## Related Examples

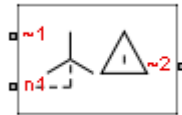
- “Expand and Collapse Three-Phase Ports on a Block”

# Wye-Delta1 Transformer

Linear non-ideal wye-delta1 transformer with three-limb core

## Library

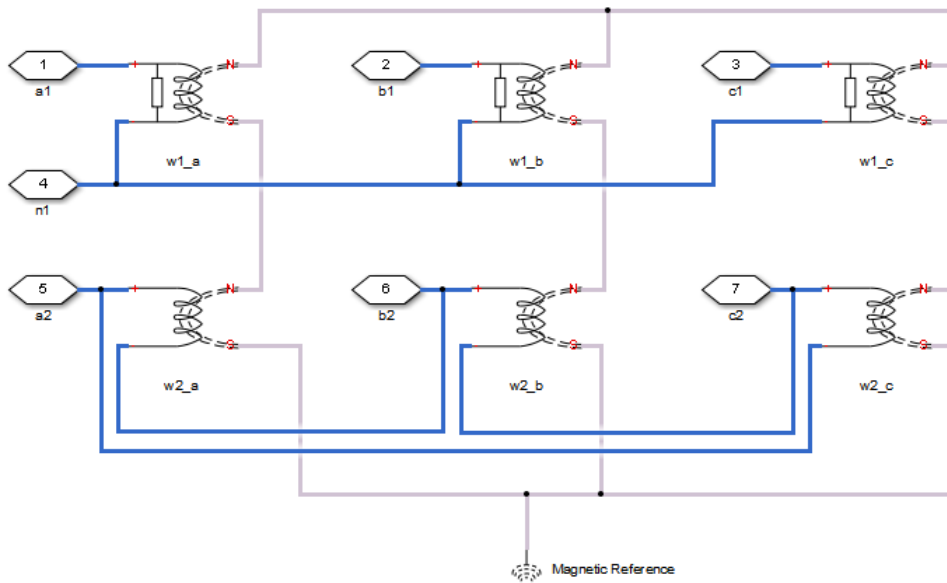
Passive Devices / Transformers



## Description

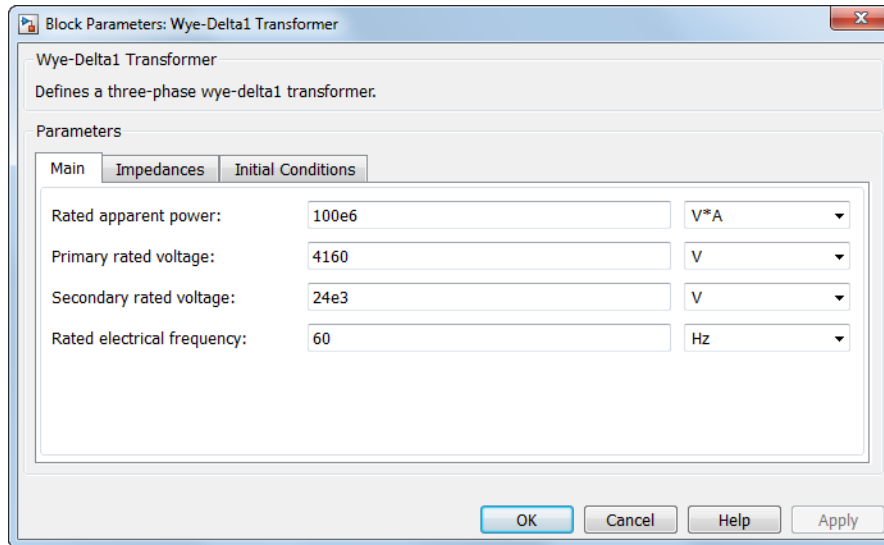
The Wye-Delta1 Transformer block models a linear non-ideal transformer with a three-limb core, in which the primary windings are configured in a wye connection and the secondary windings are configured in a delta connection. The delta voltages lag the wye voltages by 30 degrees, hence the name 1 o'clock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

The figure shows the equivalent circuit diagram for the wye-delta1 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.

## Dialog Box and Parameters



- “Main Tab” on page 1-329
- “Impedances Tab” on page 1-330
- “Initial Conditions Tab” on page 1-330

### Main Tab

#### Rated apparent power

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

#### 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

## Related Examples

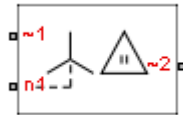
- “Expand and Collapse Three-Phase Ports on a Block”

# Wye-Delta 11 Transformer

Linear non-ideal wye-delta11 transformer with three-limb core

## Library

Passive Devices / Transformers

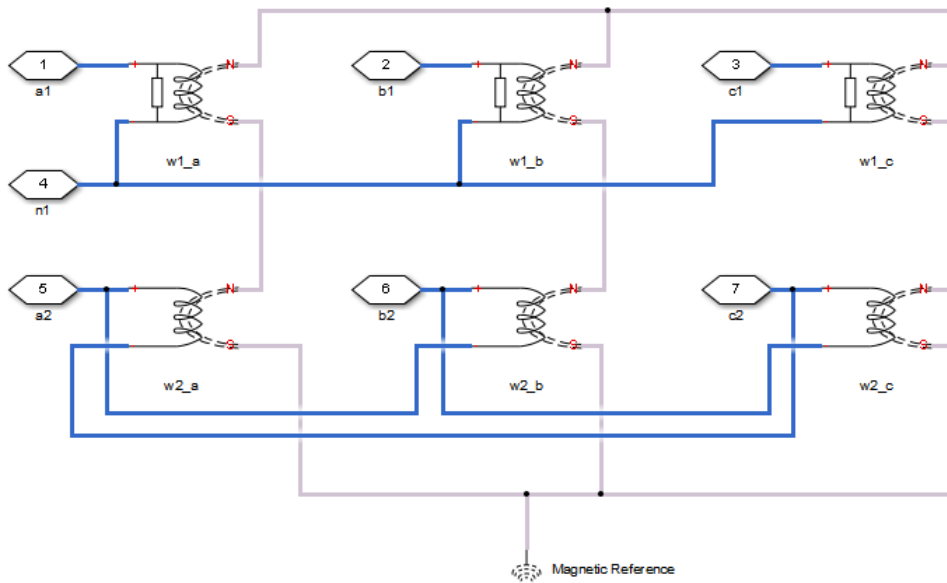


## Description

The Wye-Delta11 Transformer block models a linear non-ideal 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. It includes linear winding leakage and linear core magnetization effects.

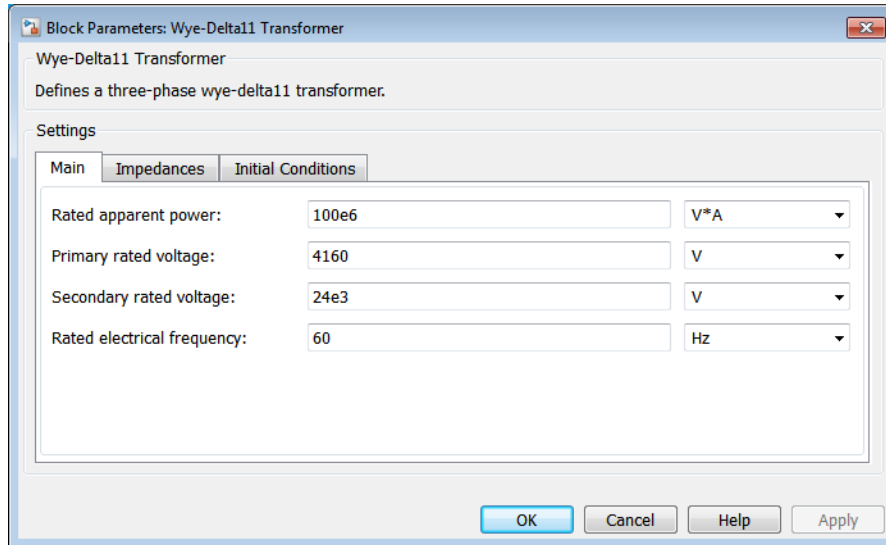
The figure shows the equivalent circuit diagram for the wye-delta11 transformer.





- $w1_a$  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.

## Dialog Box and Parameters



- “Main Tab” on page 1-334
- “Impedances Tab” on page 1-335
- “Initial Conditions Tab” on page 1-335

### Main Tab

#### Rated apparent power

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

#### 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

## Related Examples

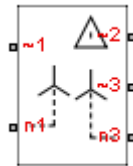
- “Expand and Collapse Three-Phase Ports on a Block”

# Wye-Delta1-Wye Transformer

Linear non-ideal wye-delta1-wye transformer with three-limb core

## Library

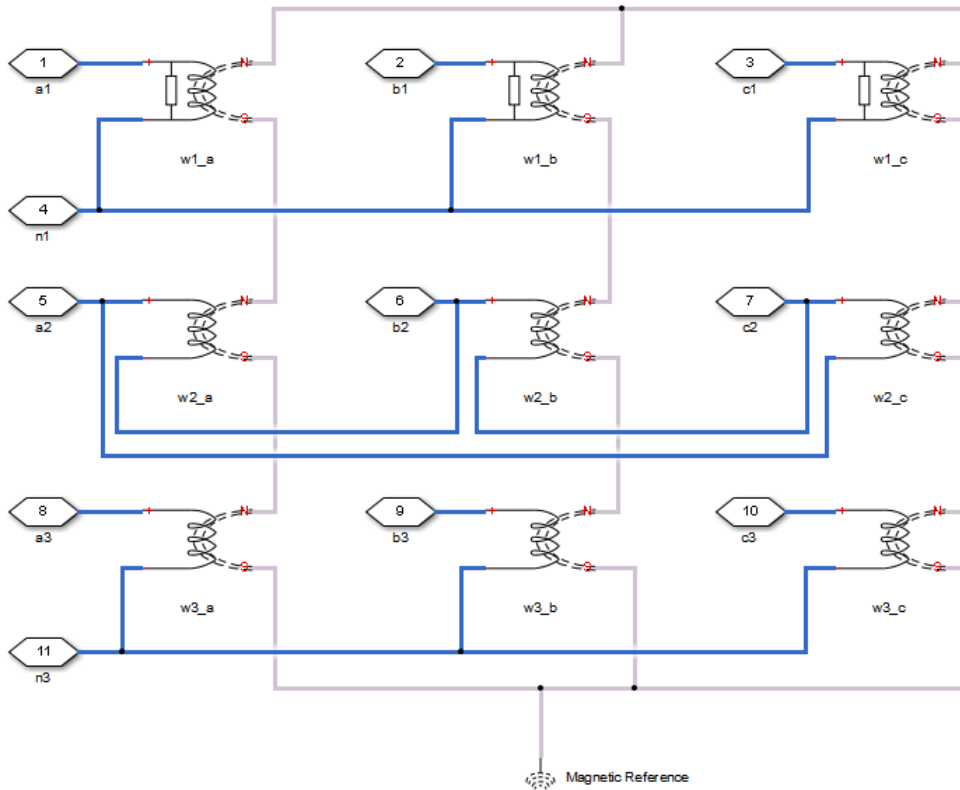
Passive Devices / Transformers



## Description

The Wye-Delta1-Wye Transformer block models a linear non-ideal 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. It includes linear winding leakage and linear core magnetization effects.

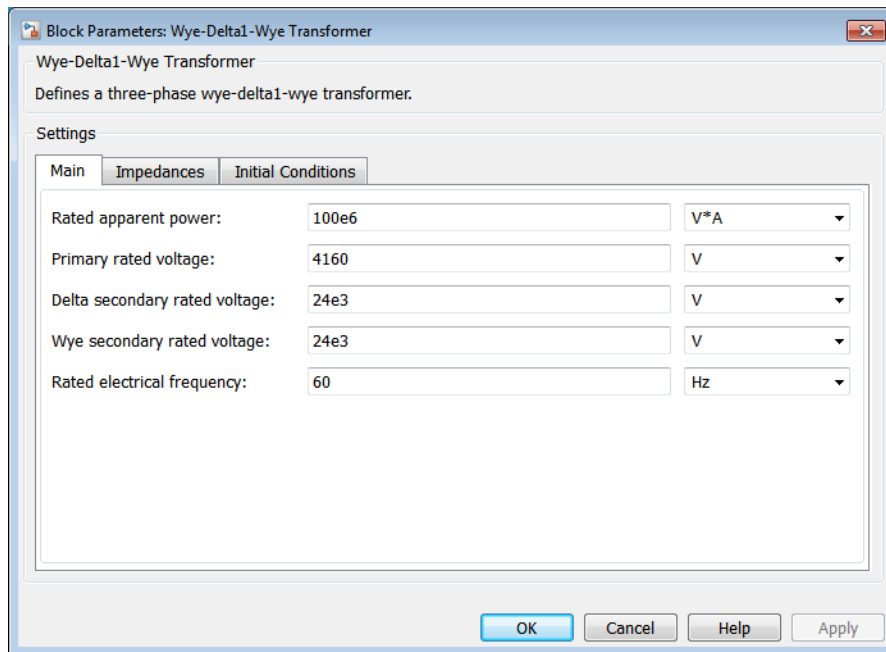
The figure shows the equivalent circuit diagram for the wye-delta1-wye transformer.



- $w1_a$  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.

## Dialog Box and Parameters



- “Main Tab” on page 1-339
- “Impedances Tab” on page 1-340
- “Initial Conditions Tab” on page 1-341

## Main Tab

### Rated apparent power

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

**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

### **Related Examples**

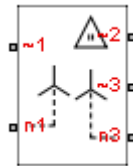
- “Expand and Collapse Three-Phase Ports on a Block”

# Wye-Delta11-Wye Transformer

Linear non-ideal wye-delta11-wye transformer with three-limb core

## Library

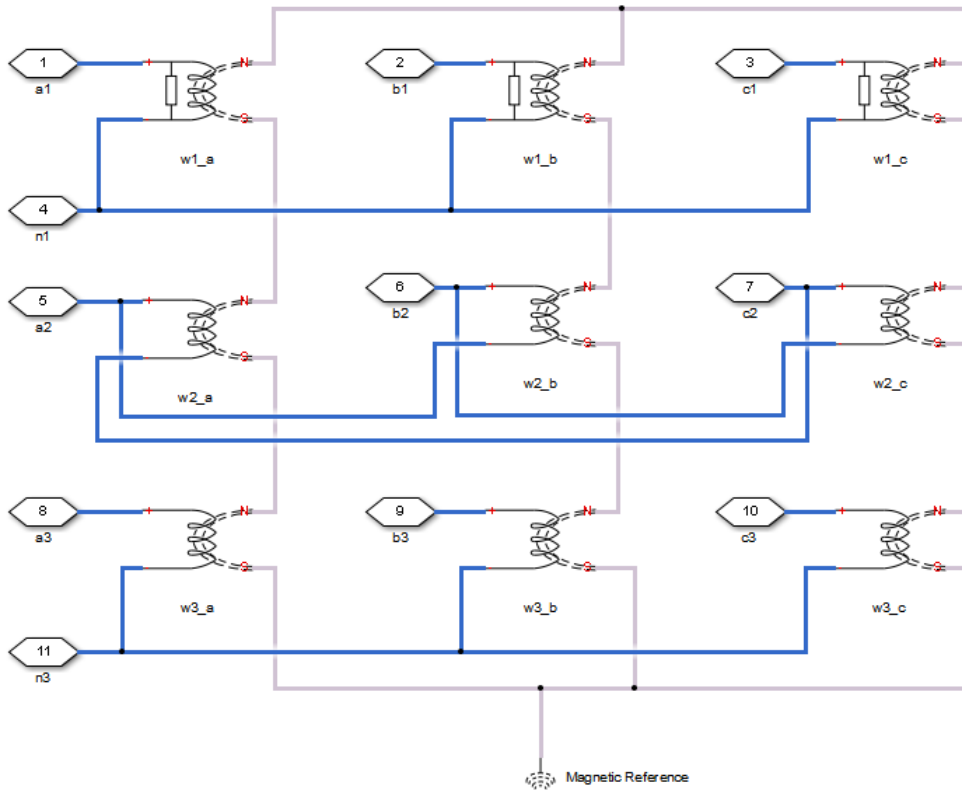
Passive Devices / Transformers



## Description

The Wye-Delta11-Wye Transformer block models a linear non-ideal 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. It includes linear winding leakage and linear core magnetization effects.

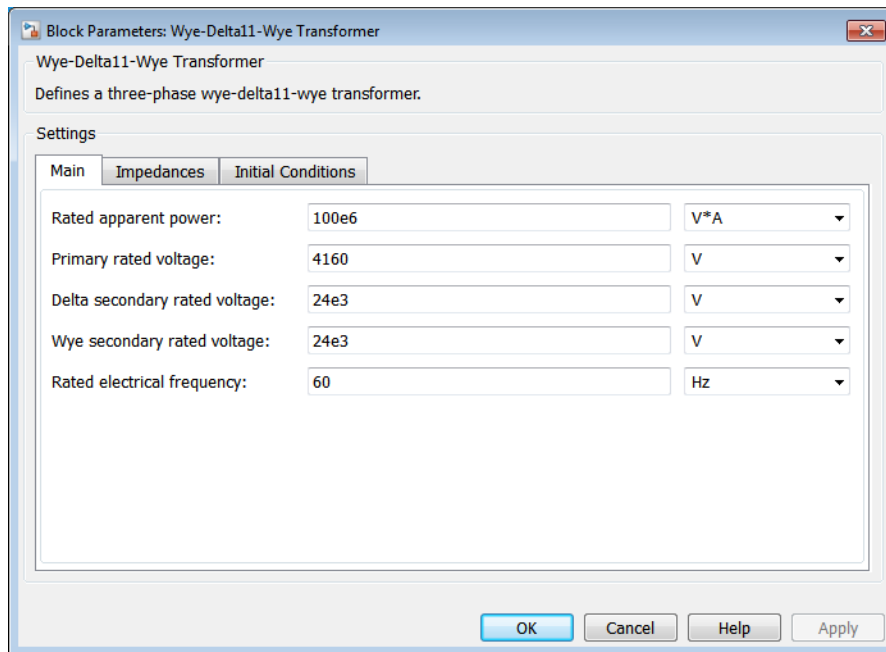
The figure shows the equivalent circuit diagram for the wye-delta11-wye transformer.



- $w1_a$  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 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.

## Dialog Box and Parameters



- “Main Tab” on page 1-345
- “Impedances Tab” on page 1-346
- “Initial Conditions Tab” on page 1-347

## Main Tab

### Rated apparent power

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

**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

### **Related Examples**

- “Expand and Collapse Three-Phase Ports on a Block”

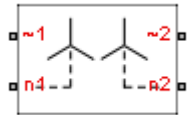


# Wye-Wye Transformer

Linear non-ideal wye-wye transformer with three-limb core

## Library

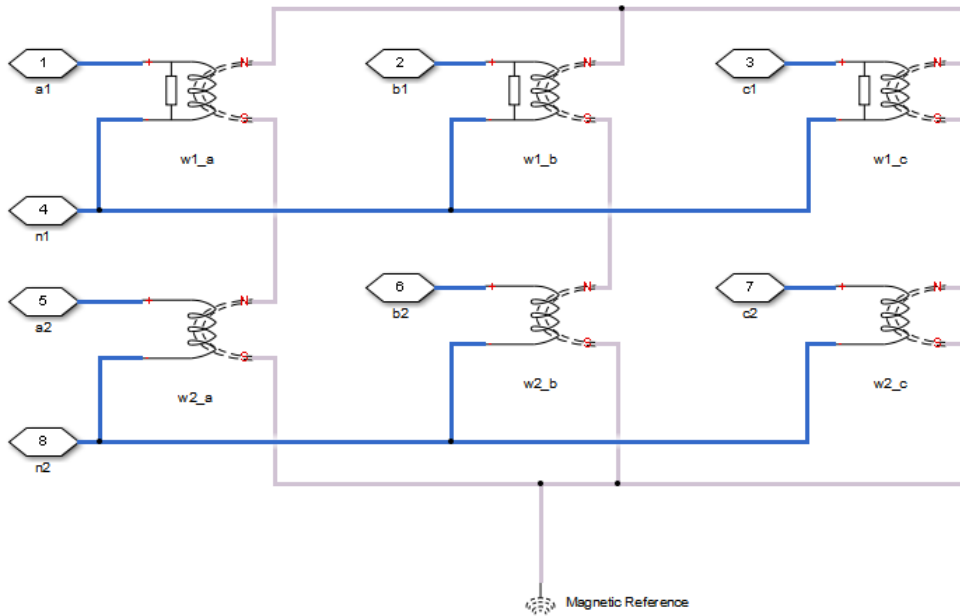
Passive Devices / Transformers



## Description

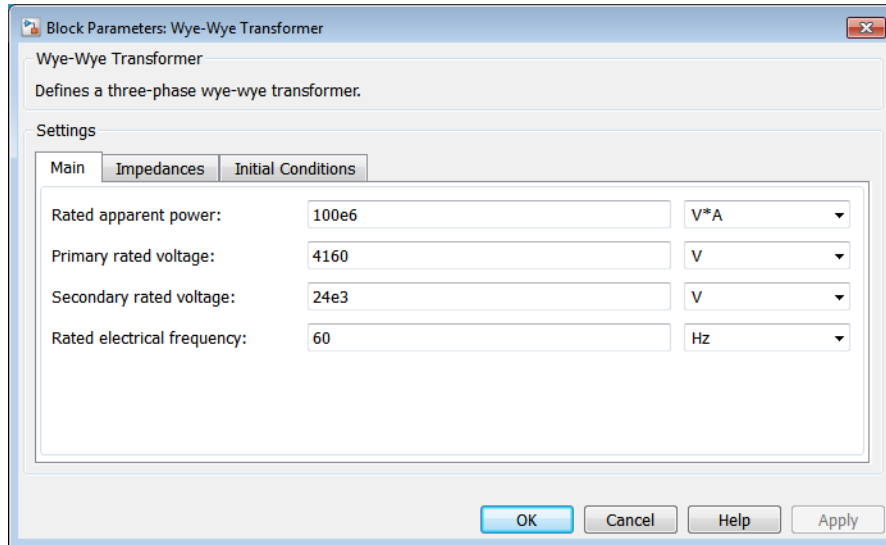
The Wye-Wye Transformer block models a linear non-ideal transformer with a three-limb core, in which both the primary and the secondary windings are configured in a wye connection. It includes linear winding leakage and linear core magnetization effects.

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.

## Dialog Box and Parameters



- “Main Tab” on page 1-351
- “Impedances Tab” on page 1-352
- “Initial Conditions Tab” on page 1-352

### Main Tab

#### Rated apparent power

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

#### 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

## Related Examples

- “Expand and Collapse Three-Phase Ports on a Block”



# 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:

$$M = \frac{\text{harmonic magnitude}}{\sqrt{2}},$$

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  $i^{\text{th}}$  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
```

- Harmonic Analysis of a Three-Phase Rectifier

## 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 0<sup>th</sup> 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

pe\_getHarmonics | pe\_plotHarmonics

## 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  $i^{\text{th}}$  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`).

**Note:** 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.

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. You enter [ ] to use the default value for an optional input argument if you are going to specify a value for a subsequent 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 will analyze the default signal, which is the first, or a-phase, signal at the final simulation time. The function will use 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 will analyze the second, or b-phase, signal at a simulation time of 2.3s. The function will use 10 periods of the signal, which has a bias of 1V. The function will analyze 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 will analyze the first, or a-phase, signal at a simulation time of 2.3s. The function will use 12 periods of the signal, which has a bias of 1V. The function will analyze 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. See “Enable Data Logging for the Whole Model” to learn how to enable data logging.

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  $i^{\text{th}}$  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`

## 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 0<sup>th</sup> 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.

### **See Also**

`pe_calculateThdPercent` | `pe_plotHarmonics` | `simscape.logging.Node`

### **Related Examples**

- Harmonic Analysis of a Three-Phase Rectifier
- “Log and Plot Simulation Data”

## 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. You enter `[]` to use the default value for an optional input argument if you are going to specify a value for a subsequent optional input argument.

The `pe_plotHarmonics` function uses the `pe_getHarmonics` function to:

- Find the points in the  $i^{\text{th}}$  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 will analyze the default signal, which is the first, or a-phase, signal at the final simulation time. The function will use 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 will analyze the second, or b-phase, signal at a simulation time of 2.3s. The function will use 10 periods of the signal, which has a bias of 1V. The function will analyze 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 will analyze the first, or a-phase, signal at a simulation time of 2.3s. The function will use the default number (12) of periods of the signal, which has a bias of 1V. The function will analyze 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. See “Enable Data Logging for the Whole Model” to learn how to enable data logging.

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  $i^{\text{th}}$  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**

`pe_calculateThdPercent` | `pe_getHarmonics` | `simscape.logging.Node`

### **Related Examples**

- Harmonic Analysis of a Three-Phase Rectifier
- “Log and Plot Simulation Data”

<b>B</b>	Susceptance.
<b>C</b>	Capacitance.
<b>composite three-phase port</b>	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.
<b>delta connection</b>	Three-phase winding configuration. Each of the three windings is connected between phases. Physically, the connection resembles the Greek capital letter $\Delta$ . 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.
<b>expanded three-phase port</b>	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.
<b><math>F_{\text{Rated}}</math></b>	Rated electrical frequency of three-phase machine.
<b>G</b>	Conductance.
<b>i</b>	Instantaneous current.
<b>I</b>	RMS current.
<b>L</b>	Inductance.
<b>line voltage</b>	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 $V_{ab}$ , $V_{ac}$ , $V_{bc}$ , etc. Line

	voltage is also known as rated voltage, rated RMS, name plate voltage, line-line voltage, and phase-phase voltage.
<b>nPolePairs</b>	Number of pole pairs for three-phase machine.
<b>phase voltage</b>	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 $V_a$ , $V_b$ , and $V_c$ .
<b><math>P_{PerPhase}</math></b>	Real power per phase.
<b>psi</b>	Instantaneous peak magnetic flux linkage.
<b>Psi</b>	RMS magnetic flux linkage.
<b><math>Q_{PerPhase}</math></b>	Reactive power per phase.
<b>R</b>	Resistance.
<b><math>S_{Rated}</math></b>	Rated apparent power.
<b><math>S_{PerPhase}</math></b>	Apparent power per phase.
<b>torque</b>	Torque of three-phase machine.
<b>v</b>	Instantaneous voltage.
<b>V</b>	RMS voltage.
<b><math>V_a, V_b, V_c</math></b>	Phase voltages.
<b><math>V_{ab}, V_{ac}, V_{bc}, \dots</math></b>	Line voltages.
<b><math>V_{Rated}</math></b>	Rated voltage of three-phase machine.
<b>#Electrical</b>	Electrical angular speed of three-phase machine.
<b>#Mechanical</b>	Mechanical angular speed of three-phase machine.

<b>winding voltage</b>	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.
<b>wye connection</b>	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.
<b>X</b>	Reactance.
<b>Y</b>	Admittance.
<b>z</b>	Impedance.

