SCIM Section

The Squirrel-Cage Induction Machine model implements a three-phase induction machine (asynchronous machine) with a squirrel-cage rotor model with resolvers and encoders. The machine can operate in both motoring mode, when the mechanical torque is positive, and generating mode when the mechanical torque is negative.

SCIM Configuration Page

In the **System Explorer** window configuration tree, expand the **Power Electronics Add-On** custom device and select **Circuit Model >> SCIM** to display this page. Use this page to configure the SCIM machine model.

This page includes the following components:

Name	Specifies the name of the machine model.
Description	Specifies a description for the machine model.

Motor Configuration

	Symbol	Units	Default	Description
Motor Type			Squirrel-Cage Induction Machine	Choose from one of the following types: • Squirrel Cage Induction Machine
Enable			True	Indicates whether this model is currently enabled. When a motor model is enabled, the machine outputs are made available at the specified **Solver Timestep**. Because this model can simulate up to four machines at once, the number of enabled machines impacts the minimum achievable time step of each machine.
Stator Resistance	R_s	Ohm	0.6	Stator winding phase resistance
Stator Leakage Inductance	L_{ls}	H	0.00035	Stator winding leakage inductance
Mutual Inductance	L_m	H	0.62	Magnetizing inductance
Rotor Resistance	R_r'	Ohm	0.62	Specifies the equivalent rotor winding resistance of phases A, B, and C, as seen from the stator.
Rotor Leakage Inductance	L_{lr}'	H	0.00547	Specifies the equivalent rotor winding leakage inductance of phases A, B, and C, as seen from the stator.
Pole Pairs	PP		2	Number of machine pole pairs
Initial Speed	$_0$	RPM	0	Describes the initial speed of the machine
Solver Timestep	T_s	s	4.81E-7	Describes the execution timestep of the machine model. The minimum timestep is a function of how many SCIM machines are enabled in the application. When all four machines are enabled, the minimum achievable timestep is 4.81E-7s, which is also the default value.
Zero Sequence			Don't Include	When **Include** is selected, the **Zero-Sequence Resistance** and **Zero-Sequence Inductance** parameters are enabled to include a Zero Sequence Model. See **Including a Zero Sequence Model** for more information.
Zero-Sequence Resistance	R_0	Ohm	0.0029069	Describes the zero-sequence stator winding resistance. This component is enabled when **Zero Sequence** is set to **Included**.
Zero-Sequence Inductance	L_0	H	0.00030892	Describes the zero-sequence stator winding inductance. This component is enabled when **Zero Sequence** is set to **Included**.

Use the Input Mapping Configuration to route signals to the **Voltage Phase A**, **Voltage Phase B**, and **Voltage Phase C** inputs of the machine model. Available routing options may vary depending on the selected **Hardware Configuration**.

Group	Specifies the group that will be routed to the input voltages of the machine. The available routing options are defined by the selected Hardware Configuration, however it is typical to see the following options by default: • **Measurements** - eHS circuit model measurements

Element	Specifies the index of the measurement in the group that has been selected as the input voltage of the machine.

SCIM Section Channels

This section includes the following custom device channels:

Channel Name	Symbol	Type	Units	Default Value	Description
Stator Current Phase A	I_a	Output	A	0 A	Phase A current measured at the stator terminal
Stator Current Phase B	I_b	Output	A	0 A	Phase B current measured at the stator terminal
Stator Current Phase C	I_c	Output	A	0 A	Phase C current measured at the stator terminal
Stator Direct Axis Current	I^r_{ds}	Output	A	0 A	Direct-axis current measured at the stator in the reference frame aligned with the rotor
Stator Quadrature Axis Current	I^r_{qs}	Output	A	0 A	Quadrature-axis current measured at the stator in the reference frame aligned with the rotor
Stator Direct Axis Voltage	V^r_{ds}	Output	V	0 V	Direct-axis voltage measured at the stator in the reference frame aligned with the rotor
Stator Quadrature Axis Voltage	V^r_{qs}	Output	V	0 V	Quadrature-axis voltage measured at the stator in the reference frame aligned with the rotor
Stator Direct Axis Flux	$^r_{ds}$	Output	Wb	0 Wb	Direct-axis flux measured at the stator in the reference frame aligned with the rotor
Stator Quadrature Axis Flux	$^r_{qs}$	Output	Wb	0 Wb	Quadrature-axis flux measured at the stator in the reference frame aligned with the rotor
Rotor Current Phase A	$I_{ar'}$	Output	A	0 A	Phase A current measured at the rotor as seen from the stator
Rotor Current Phase B	$I_{br'}$	Output	A	0 A	Phase B current measured at the rotor as seen from the stator
Rotor Current Phase C	$I_{cr'}$	Output	A	0 A	Phase C current measured at the rotor as seen from the stator
Rotor Direct Axis Current	$I_{dr}{}^{r'}$	Output	A	0 A	Direct-axis rotor current in the reference frame aligned with the rotor as seen from the stator
Rotor Quadrature Axis Current	$I_{qr}{}^{r'}$	Output	A	0 A	Quadrature-axis rotor current in the reference frame aligned with the rotor as seen from the stator
Rotor Direct Axis Voltage	$V_{dr}{}^{r'}$	Output	V	0 V	Direct-axis rotor voltage in the reference frame aligned with the rotor as seen from the stator
Rotor Quadrature Axis Voltage	$V_{qr}{}^{r'}$	Output	V	0 V	Quadrature-axis rotor voltage in the reference frame aligned with the rotor as seen from the stator
Rotor Direct Axis Flux	$_{dr}{}^{r'}$	Output	Wb	0 Wb	Direct-axis rotor flux in the reference frame aligned with the rotor as seen from the stator
Rotor Quadrature Axis Flux	$_{qr}{}^{r'}$	Output	Wb	0 Wb	Quadrature-axis rotor flux in the reference frame aligned with the rotor as seen from the stator

SCIM Model Description

Squirrel-Cage Induction Machines are common electrical machines in the the automotive and transportation industry. AC Induction Motors are usually chosen because they are relatively low cost in terms of production and maintenance, and are self-starting. However, compared to Permanent Magnet Synchronous Machines, they are typically less efficient and larger in size.

The following figure illustrates the equivalent circuits of the SCIM motor model in the D-Q frame.

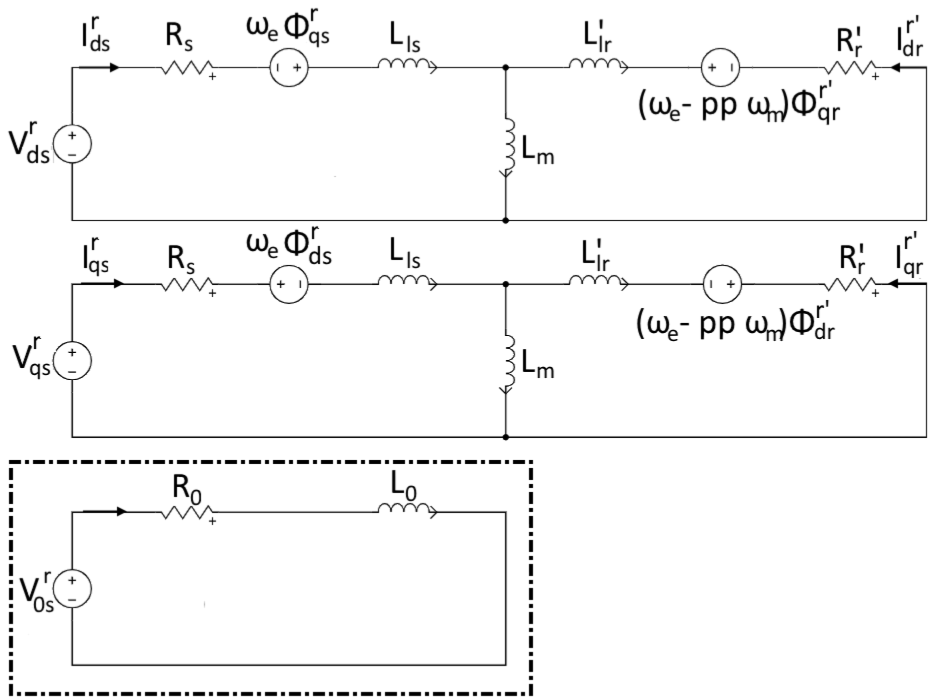


Figure 1. Electrical Model for SCIM in the D-Q frame

DQ Transform

The D-Q transform and the inverse used for the model are:

(1)
$$\begin{bmatrix} V_q \\ V_d \\ V_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin(\theta) & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

(2)
$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta + \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix}\begin{bmatrix} V_q \\ V_d \\ V_0 \end{bmatrix}$$

required for the D-Q transform depends on the chosen reference frame as follows:

- Rotor reference frame: $=_{r}$,
- Stationary reference frame: =0,
- Synchronous reference frame: $=_{e}$.

Because the Induction Machine is modeled in the rotor reference frame, the required for the dq0 transform is the rotor electrical angle ($_{r}$).

Induction Machine Electrical Model

Induction machine models in state space frameworks output winding currents and use magnetic fluxes as the state variables. They can be represented as follows:

(3)
$$\phi[n+1] = A_d[n]\phi(n) + B_d[n]u[n]$$
$$I[n+1] = C[n+1]\phi[n+1]$$

where the coefficient matrices are defined as:

(4)
$$A_d = T_s\left(\text{-}RL^{-1} - \Omega\right) + I$$

(5)
$$B_d = T_s \times I$$

(6)
$$\boldsymbol{C} = \boldsymbol{L}^{-1}$$

and

$$\boldsymbol{u} = \begin{bmatrix} V_{qs}^r & V_{ds}^r & V_{qr}^{r'} & V_{dr}^{r'} \end{bmatrix}^t$$
$$\boldsymbol{I} = \begin{bmatrix} I_{qs}^r & I_{ds}^r & I_{qr}^{r'} & I_{dr}^{r'} \end{bmatrix}^t$$
$$\boldsymbol{\psi} = \begin{bmatrix} \phi_{qs}^r & \psi_{ds}^r & \psi_{qr}^{r'} & \psi_{dr}^{r'} \end{bmatrix}^t$$
$$\boldsymbol{R} = \begin{bmatrix} R_s & R_s & R_r' & R_r' \end{bmatrix}^t$$
$$L = \begin{bmatrix} L_{ls} & 0 & L_m & 0 \\ 0 & L_{ls} & 0 & L_m \\ L_m & 0 & L_{lr}' & 0 \\ 0 & L_m & 0 & L_{lr}' \end{bmatrix}$$
$$\Omega = \begin{bmatrix} 0 & \omega & 0 & 0 \\ -\omega & 0 & 0 & 0 \\ 0 & 0 & 0 & \omega - \omega_r \\ 0 & 0 & -(\omega - \omega_r) & 0 \end{bmatrix}$$

The Induction Machine is modeled in the rotor reference frame, so =r.

In the model, all the rotor parameters and variables are seen from the stator, distinguished by a prime sign. Since the squirrel-cage rotor type is not supplied by an external source, then it is always the case that

(7)
$$V_{qr}^{r'} = V_{dr}^{r'} = 0$$

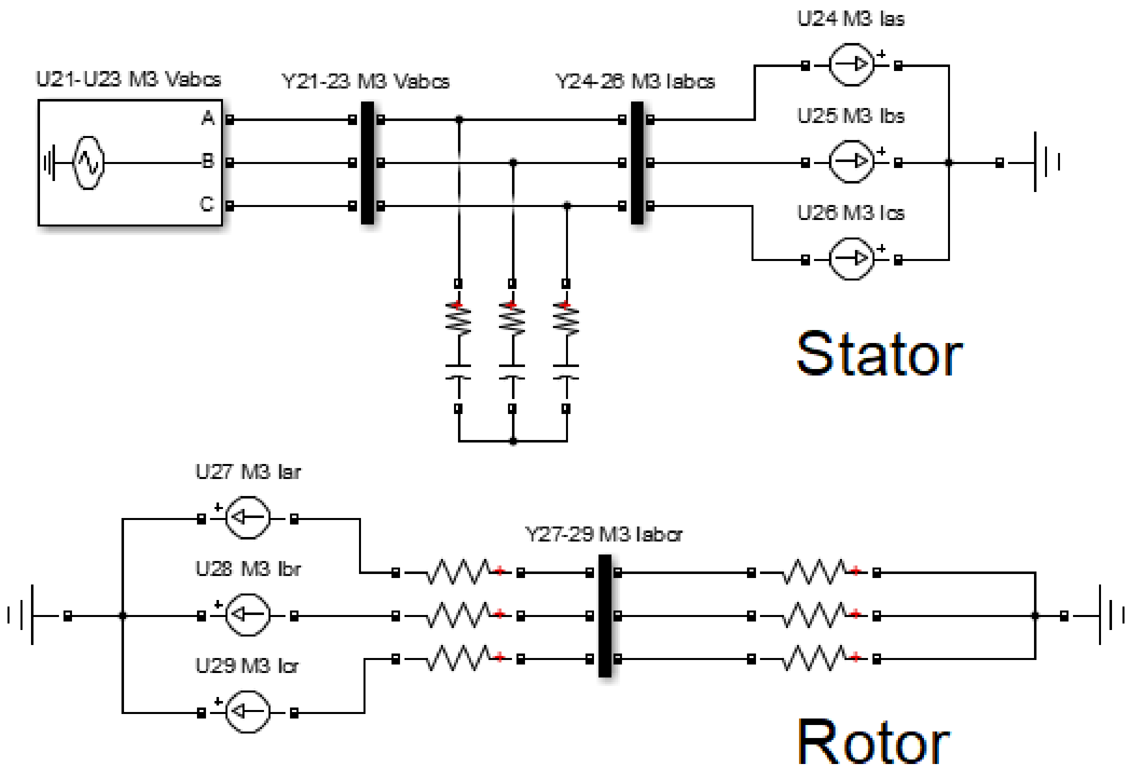
The electrical torque can be calculated as follows:

(8)
$$T_e = \frac{3}{2}pp\left(\psi_d i_q - \psi_q i_d\right)$$

Including a Zero Sequence Model

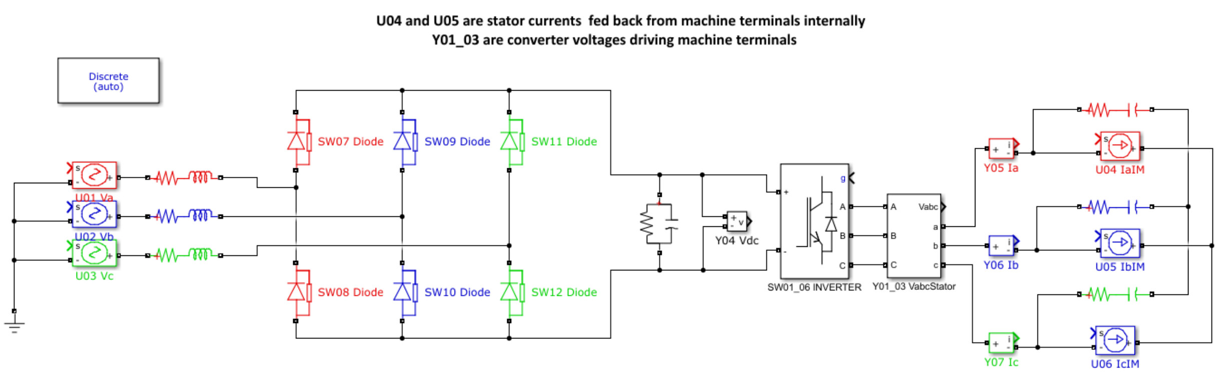
The **Zero Sequence** option allows the user to add a zero-sequence resistance and zero-sequence inductance modeling the system as unbalanced, which allows for better fidelity. By enabling this option, the zero-sequence inductance and the zero-sequence resistance can be specified allowing a wye with neutral or delta connection to the stator side of the machine.

When enabling this option, the three stator currents should be mapped to eHS.



In order to do this, the machine can be connected in wye or in Delta as shown in the following circuits:

Connecting the SCIM in wye



Connecting the SCIM in Delta

U04 and U05 are stator currents fed back from machine terminals internally
Y01_03 are converter voltages driving machine terminals