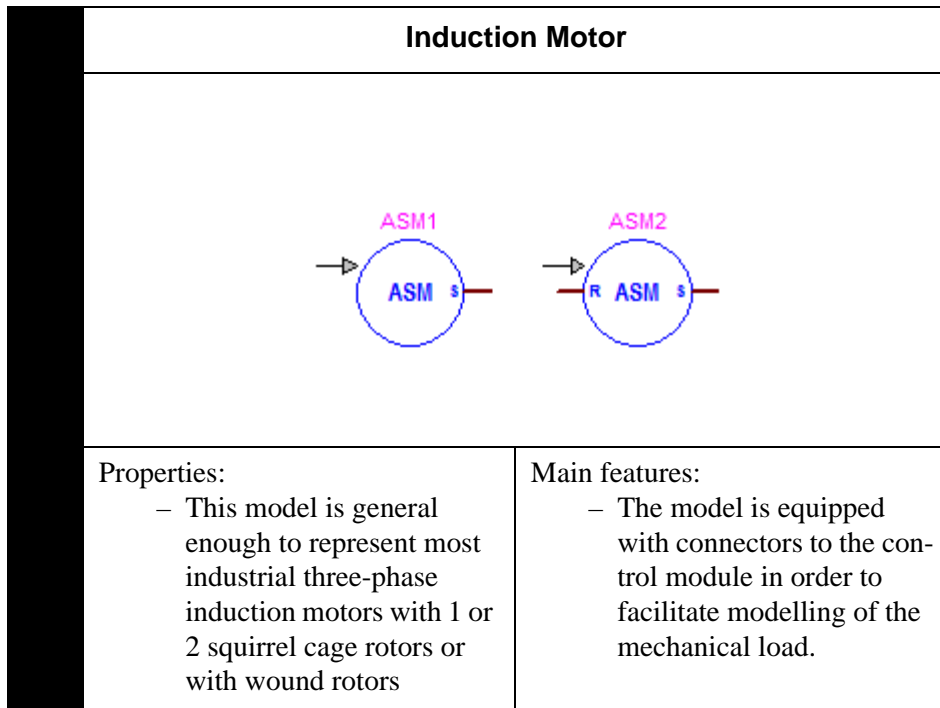


**9.5 INDUCTION MOTOR**



**Figure 9 - 20 Icon and diagram induction motor**

**A – Induction Motor Model**

The induction motor model can be represented by four pairs of equations.

The electrical equations convert the voltage signals into electrical fluxes in a DQ Park representation. A saturation relation introduces the non-linearity of mutual inductance in the motor. The current equations convert the fluxes for both rotor and stator into currents on the DQ axes. Finally, the mechanical equations represent the rotor speed, using mechanical and electrical torques and taking into account inertia and friction.

Electrical flux equations:

(EQ 9)

$$\Psi_{qs} = \frac{\omega_b}{s} \left[ v_{qs} - \frac{\omega}{\omega_b} \Psi_{ds} + \frac{r_s}{X_{ls}} (\Psi_{mq} - \Psi_{qs}) \right]$$

(EQ 10)

(EQ 11)

$$\Psi_{ds} = \frac{\omega_b}{s} \left[ v_{ds} + \frac{\omega}{\omega_b} \Psi_{qs} + \frac{r_s}{X_{ls}} (\Psi_{md} - \Psi_{ds}) \right]$$

$$\Psi_{qr1} = \frac{\omega_b}{s} \left[ v_{qr1} - \left( \frac{\omega - \omega_r}{\omega_b} \right) \Psi_{dr1} + \frac{r_{r1}}{X_{lr1}} (\Psi_{mq} - \Psi_{qr1}) \right]$$

(EQ 12)

$$\Psi_{dr1} = \frac{\omega_b}{s} \left[ v_{dr1} + \left( \frac{\omega - \omega_r}{\omega_b} \right) \Psi_{qr1} + \frac{r_{r1}}{X_{lr1}} (\Psi_{md} - \Psi_{dr1}) \right]$$

(EQ 13)

$$\Psi_{qr2} = \frac{\omega_b}{s} \left[ v_{qr2} - \left( \frac{\omega - \omega_r}{\omega_b} \right) \Psi_{dr2} + \frac{r_{r2}}{X_{lr2}} (\Psi_{mq} - \Psi_{qr2}) \right]$$

(EQ 14)

$$\Psi_{dr2} = \frac{\omega_b}{s} \left[ v_{dr2} + \left( \frac{\omega - \omega_r}{\omega_b} \right) \Psi_{qr2} + \frac{r_{r2}}{X_{lr2}} (\Psi_{md} - \Psi_{dr2}) \right]$$



(EQ 15)

$$\Psi_{mq} = X_{aq} \left( \frac{\Psi_{qs}}{X_{ls}} + \frac{\Psi_{qr1}}{X_{lr1}} + \frac{\Psi_{qr2}}{X_{lr2}} \right)$$

(EQ 16)

$$\Psi_{md} = X_{ad} \left( \frac{\Psi_{ds}}{X_{ls}} + \frac{\Psi_{dr1}}{X_{lr1}} + \frac{\Psi_{dr2}}{X_{lr2}} \right)$$

In the preceding equation, the  $V_{dr}$  and  $V_{qr}$  rotor voltages are set at zero for the squirrel cage rotor.

Current equations:

(EQ 17)

$$i_{qs} = \frac{1}{X_{ls}} (\Psi_{qs} - \Psi_{mq})$$

(EQ 18)

$$i_{ds} = \frac{1}{X_{ls}} (\Psi_{ds} - \Psi_{md})$$

(EQ 19)

$$i_{qr1} = \frac{1}{X_{lr1}} (\Psi_{qr1} - \Psi_{mq})$$

(EQ 20)

(EQ 21)

Saturation equations:

(EQ 22)

(EQ 23)

$$i_{dr1} = \frac{1}{X_{lr1}}(\Psi_{dr1} - \Psi_{md})$$

$$X_{aq} = X_{ad} = \left( \frac{1}{X_M} + \frac{1}{X_{ls}} + \frac{1}{X_{lr1}} + \frac{1}{X_{lr2}} \right)^{-1}$$

$$\Psi_{mqsat} = \Psi_{mq} - \frac{X_{aq}}{X_M} \cdot \frac{f(\Psi_m)}{\Psi_m} \Psi_{mq}$$

Mechanical equations:

(EQ 24)

$$\Psi_{mdsat} = \Psi_{md} - \frac{X_{ad}}{X_M} \cdot \frac{f(\Psi_m)}{\Psi_m} \Psi_{md}$$

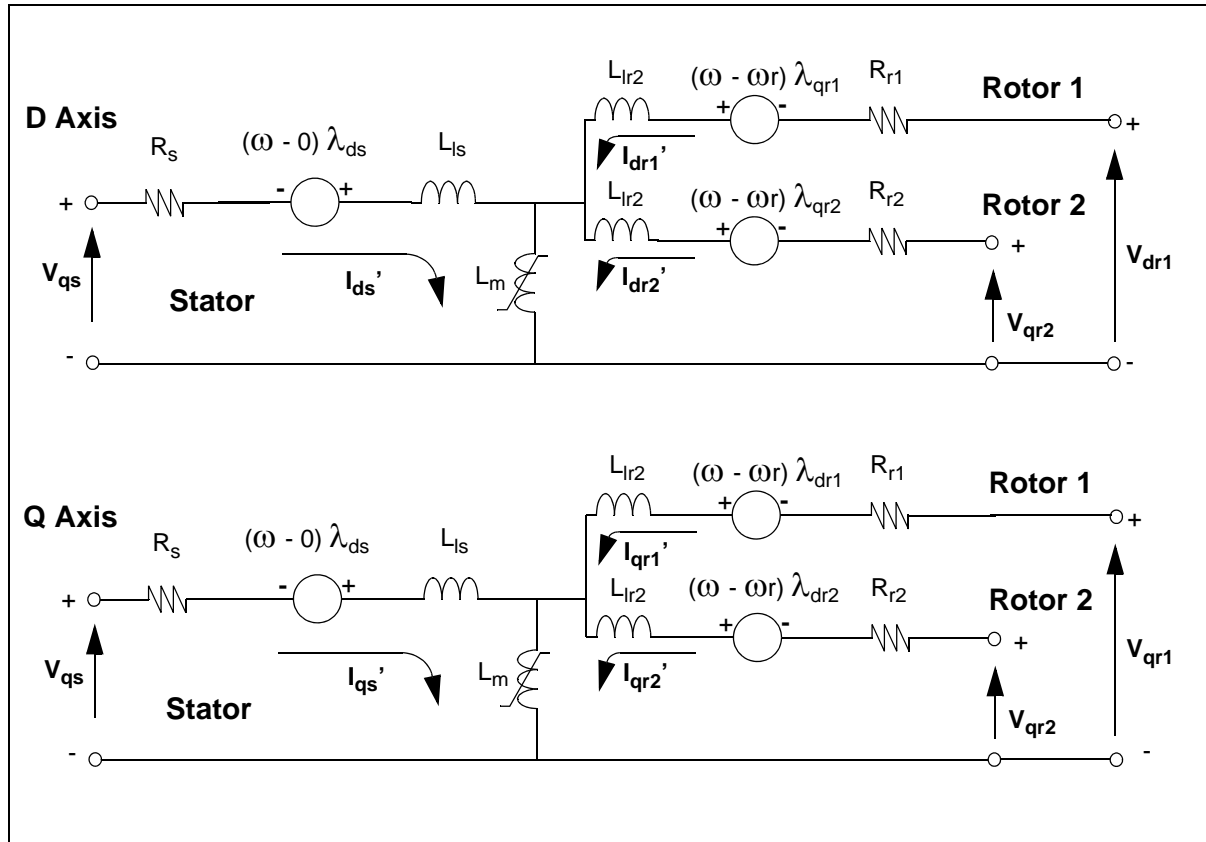
(EQ 25)

$$T_e = \Psi_{ds} I_{qs} - \Psi_{qs} I_{ds}$$

(EQ 26)

$$\omega_r = \frac{\omega_b}{2Hs} (T_e - T_L)$$

Generally, the steady-state representation of the model is presented as a transformer with a rotating secondary. Figure 9 - 21 shows the model for the D and Q Park axes. Both rotor circuits are depicted.



**Figure 9 - 21 Steady-state representation of induction motor model**

Hence, depending on the selected motor configuration, the rotor circuit will be simple or double. The values for  $V_{dr}$  and  $V_{qr}$  are zero since a squirrel cage rotor is being modeled. In the case of a coiled rotor, a startup resistance value can be set on the rotor and is added to  $R_{r1}$ .

### **B –General Parameters**

- Number of cages: number of squirrel cages per rotor, one or two;
- Number of poles: number of poles in the machine;
- Base power: rated power (kVA);
- Base voltage: rated voltage (kV);
- $\omega_0$ : rated angular speed (electrical radians/second);
- R start: startup resistance for a motor with coiled rotor. This value allows users to increase the resistance value of the squirrel no 1. (ohm);
- T start: application delay of mechanical load, since starting the simulation (s);

**C – DQ Speed Reference**

- Reference selection for the conversion in the DQ axis system: (Rotor, Stator, Stator rotating field)

**D – Motor Parameters**

- R Stator: stator resistance (ohm);
- Xl Stator: stator reactance (ohm);
- R Rotor 1: no 1 rotor resistance (ohm);
- Xl Rotor 1: no 1 rotor reactance (ohm);
- R Rotor 2: no 2 rotor resistance (ohm);
- Xl Rotor 2: no 2 rotor reactance (ohm);
- Xm: mutual reactance (ohm).

**E – Connectors to Control Module Interface**

Mechanical torque (Internal/External): internal or external mechanical torque (Interne = internal, from parameters  $W_{mec}$   $T_{mec}$ , Externe = external, from connector to the control module).

**F – Mechanical Load Parameters**

- H: inertia constant (second);
- Friction: viscous friction (pu).

The internal mechanical load can be characterized by a five point search table. The user provides the mechanical torque value  $T_{mec}$  for each rotor speed ( $W_{mec}$ ). The  $W_{mec}$  five point vector is in electrical radians/second. The  $T_{mec}$  vector allows users to modelize any type of non-linear mechanical load according to the speed signal.

- $W_{mec}$ : Speed vector (electrical radians/s);
- $T_{mec}$ : Mechanical torque vector (N.m).

**G – Saturation Parameters**

It is possible to add a no-load saturation characteristic. The saturation characteristic is given by two 10 point vectors representing the voltage and the r.m.s. current of the no-load machine.

- Saturation (Enable/Disable): saturation ON (Enable) or OFF (Disable);
- Irms: r.m.s. power line of current (A);
- Vrms: phase-ground r.m.s. voltage given to the machine (V).



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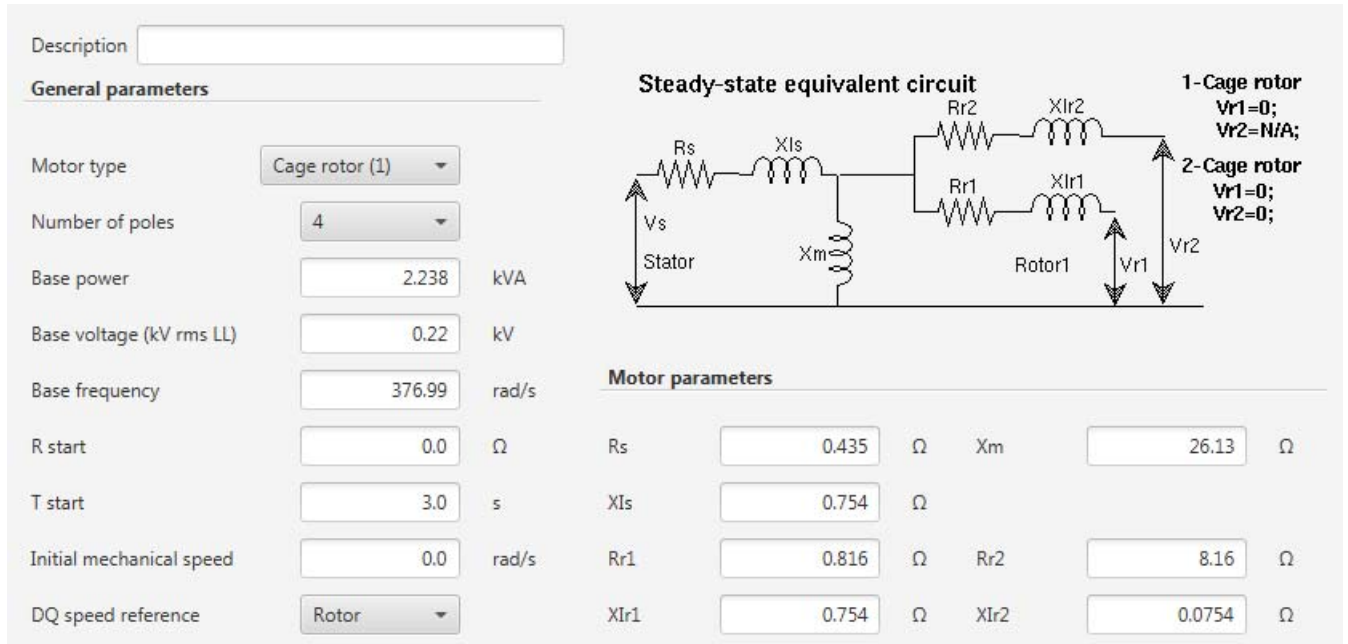
## ***H – List of Available Signals***

At acquisition, the following signals are made available by the sensors:

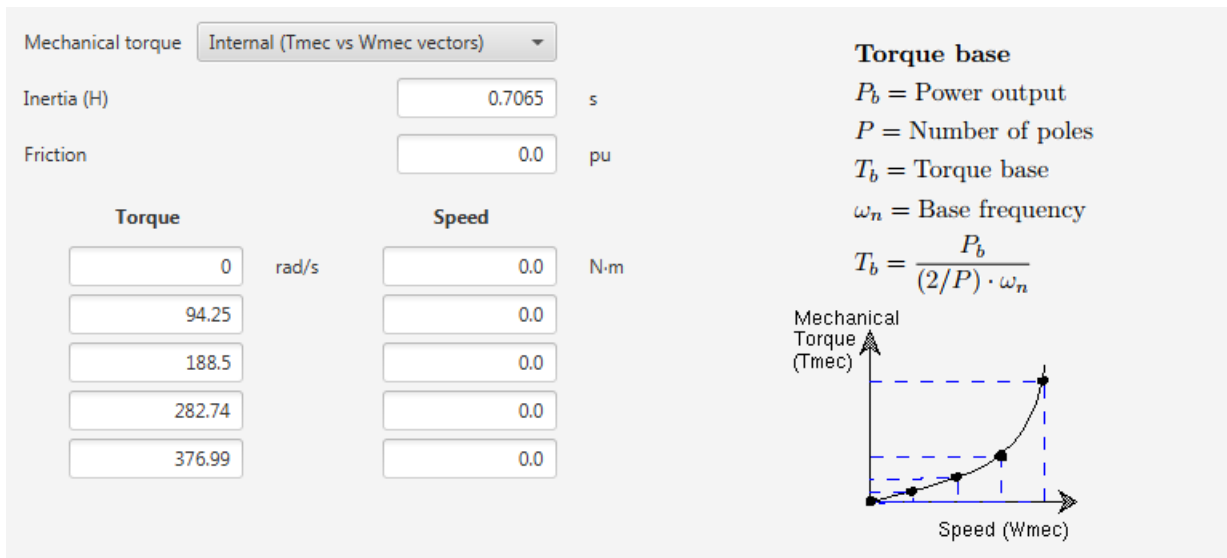
- *Vds\_label*: Direct axis stator voltage (V);
- *Vqs\_label*: Quadrature axis stator voltage (V);
- *Ids\_label*: Direct axis stator current (A);
- *Iqs\_label*: Quadrature axis stator current (A);
- *V(a,b,c)r\_label*: Stator Voltages (V)
- *Vdr\_label*: Direct axis voltage of rotor no 1 (V)
- *Vqr\_label*: Quadrature axis voltage of rotor no 1 (V)
- *I(a,b,c)s\_label*: Stator currents (A);
- *Idr\_label*: Direct axis current of rotor no 1 (A);
- *Iqr\_label*: Quadrature axis current of rotor no 1 (A);
- *I(a,b,c)r\_label*: Rotor no 1 currents (A);
- *Tmec\_label*: Mechanical torque (N.m);
- *Te\_label*: Electrical torque (N.m);
- *wr\_label*: Rotor speed (electrical rad/s);
- *w\_label*: Reference speed for DQ conversion (electrical rad/s);
- *PHIds\_label*: Direct axis stator flux (V);
- *PHIqs\_label*: Quadrature axis stator flux (V);
- *PHIdr\_label*: Direct axis rotor flux (V);
- *PHIqr\_label*: Quadrature axis rotor flux (V);
- *Tmec\_i\_label*: Mechanical torque signal from control module (N.m)

**I – Induction Motor Control Panels**

Figure 9 - 22 shows the induction motor control panels.

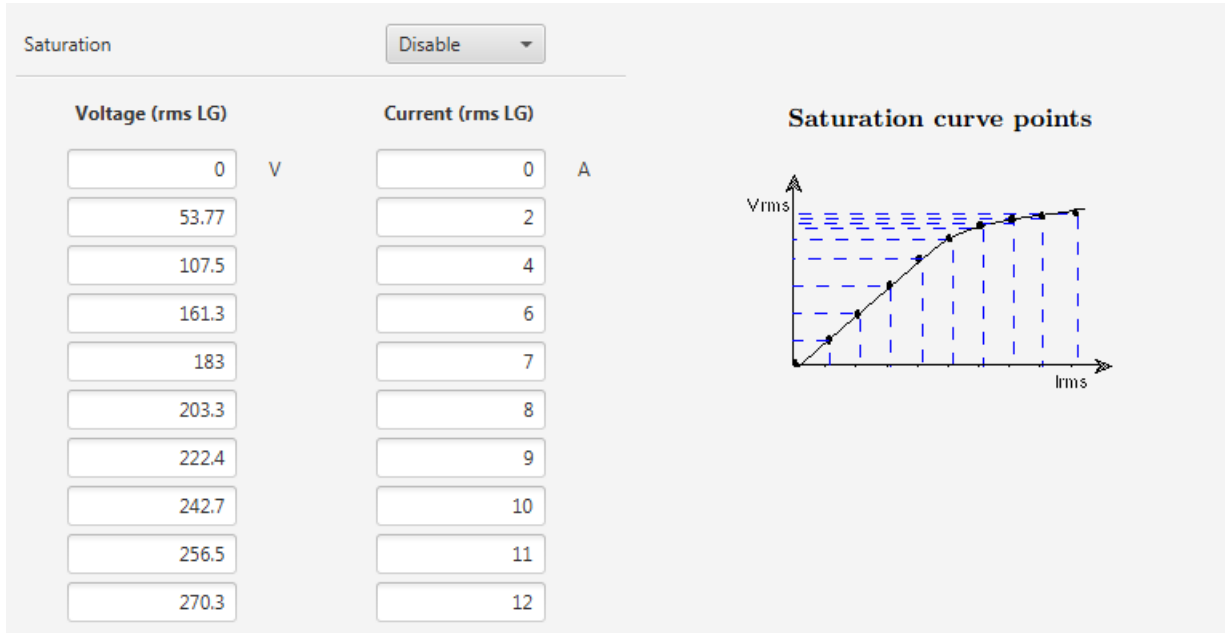


**Figure 9 - 22 Induction motor control panel (general)**



**Figure 9 - 23 Induction motor control panel (torque/load)**





**Figure 9 - 24 Induction motor control panel (saturation)**



Example using an induction motor

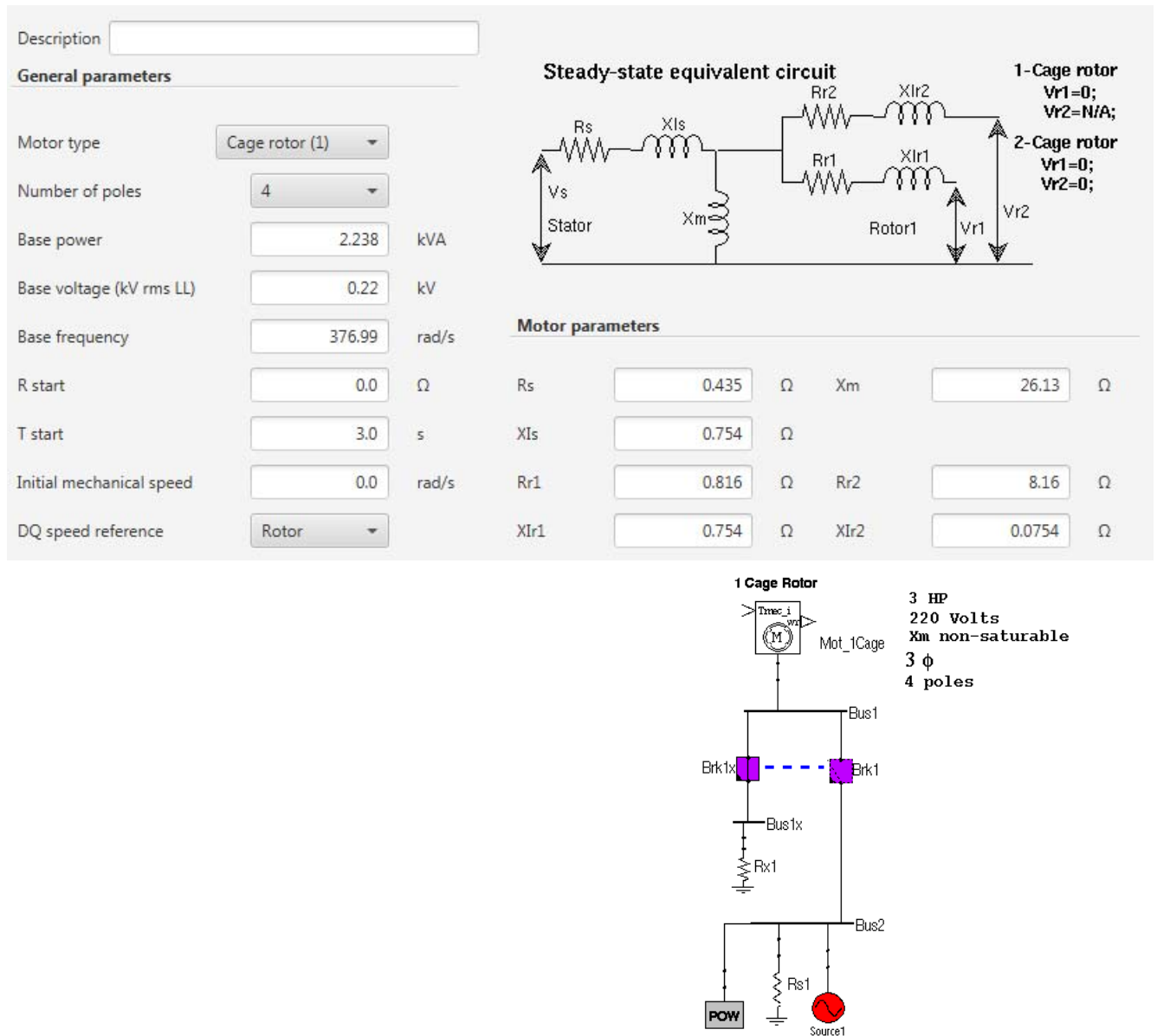


Figure 9 - 25 Example using an induction motor

**9.6 USING THE HYPERMIM® DYNAMIC LOAD MODEL**

The present document explains the HYPERMIM® dynamic load model, its applications and how to determine its parameters.