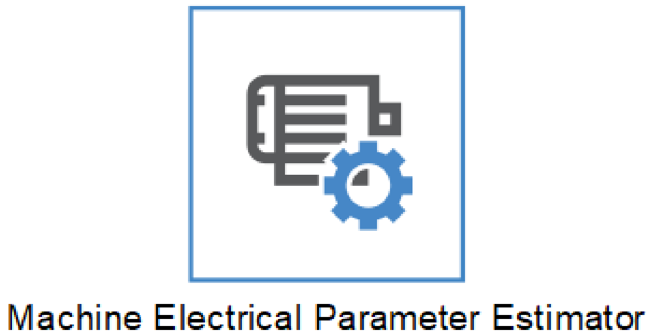
Machine Electrical Parameter Estimator

Machine Electrical Parameter Estimator estimates equivalent electrical circuit parameters using manufacturers data for Three Phase Squirrel Cage, Wound Rotor and Double Cage Induction and Wound Rotor Synchronous Machines.

Component Icon

Figure 1: Machine parameter estimator



Description

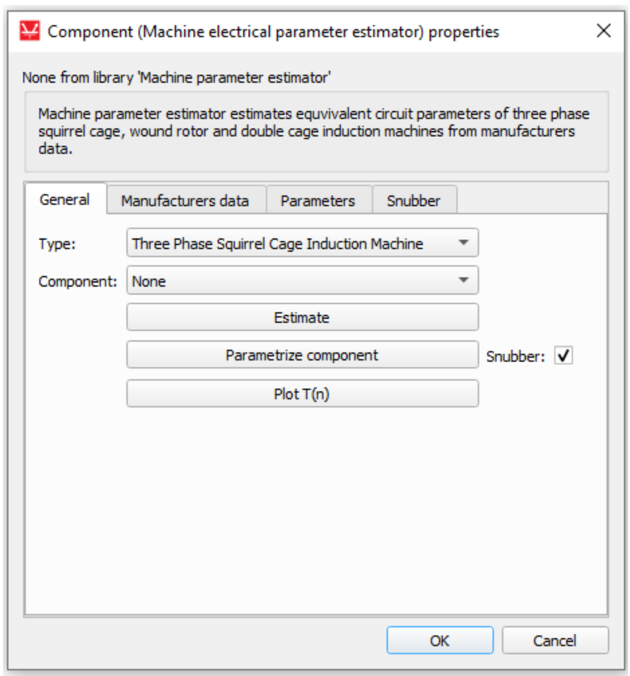
The MEPE estimates the equivalent circuit parameters of Squirrel Cage, Wound Rotor and Double Cage Induction Machines and Wound Rotor Synchronous Machines using only manufacturers data. Equivalent circuit parameters can be read, copied to clipboard or loaded to a machine component in the model. Also, torque-speed characteristics can be plotted.

Properties

General tab:

- *Type* – choose a type of machine for estimation
- *Component* – choose a machine component from the model
- *Estimate* – estimate machine parameters using given machine data
- *Parametrize component* – load estimated parameters to chosen machine component
- *Snubber* – if checked, snubber will also be loaded to chosen machine
- *Plot T(n)* - plot torque-speed characteristics for current data and parameters

Figure 2: General tab

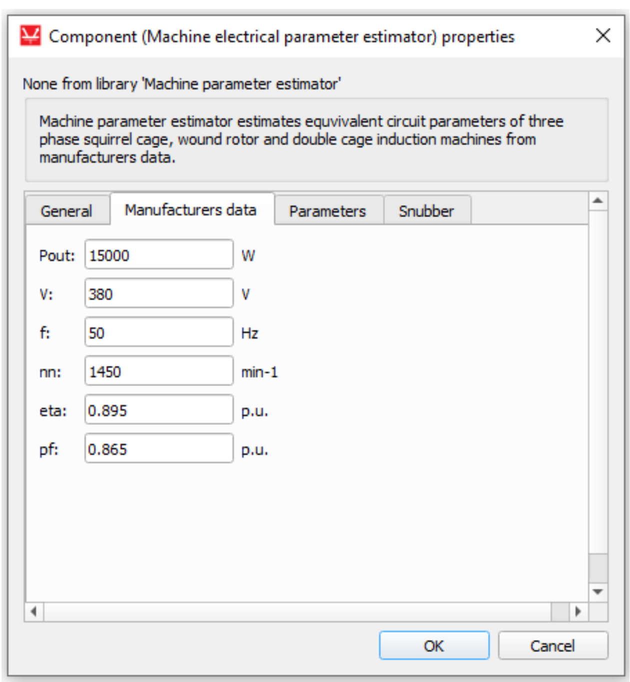


Manufacturers data tab:

Specify manufacturers data of the machine.

- *Pout* – nominal power
- *V* – nominal voltage
- *p* – number of pole pairs
- *f* – nominal frequency
- *nn*– nominal speed
- *eta[]* - efficiency for 50%/75%/100% of nominal load
- *eta* – nominal efficiency
- *pf[]* - power factor for 50%/75%/100% of nominal load
- *pf* – nominal power factor
- *a* – NEMA rod design coefficient
- *In* – nominal current
- *I0* – starting current, relative to nominal
- *Tn* – nominal torque
- *T0* – starting torque, relative to nominal
- *Tmax* – breakdown torque, relative to nominal
- *s_max* – breakdown slip
- *manual* – check the box to manually change the value of breakdown slip

Figure 3: manufacturers data tab

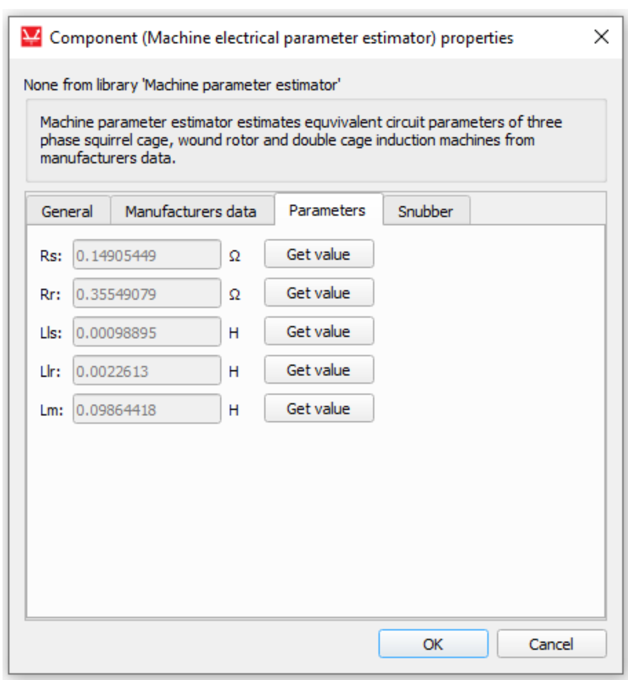


Parameters tab:

Shows estimated electrical parameters for the specified machine.

- *Rs* – stator resistance
- *Rr* – rotor resistance (inner cage), referred to the stator
- *Rr1* – outer cage rotor resistance, referred to the stator
- *Lls* – stator leakage inductance
- *Llr* – rotor leakage inductance (inner cage), referred to the stator
- *Llr1* – outer cage rotor leakage inductance, referred to the stator
- *Lm* – mutual inductance
- *Lmd* -direct axis mutual inductance
- *Lmq* – quadrature axis mutual inductance
- *Rf* - field winding resistance, referred to the stator
- *Llf* - field winding leakage inductance, referred to the stator
- *Rkd* - direct axis damper winding resistance, referred to the stator
- *Rkq* – quadrature axis damper winding resistance, referred to the stator
- *Llkd* - direct axis damper winding leakage inductance, referred to the stator
- *Llkq* – quadrature axis damper winding leakage inductance, referred to the stator

Figure 4: Parameters tab

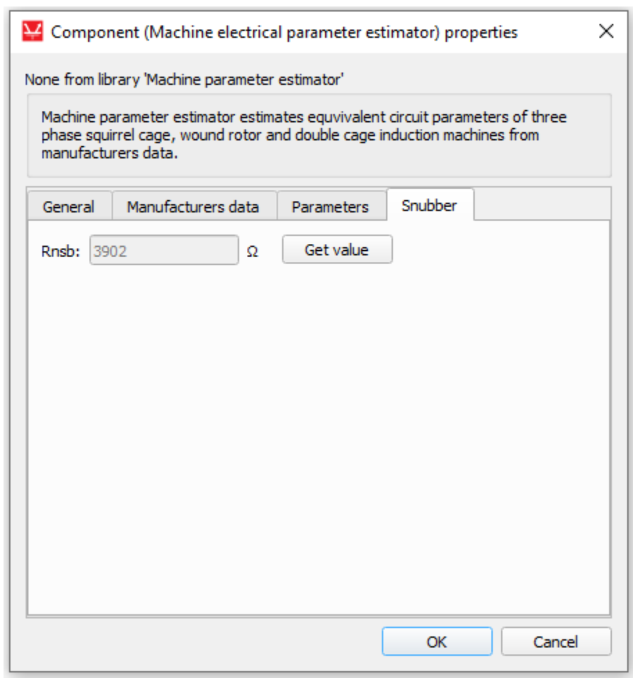


Snubber tab:

The snubber resistor value, calculated in a simple model, is a guideline as the maximum value for that machine. Change in simulation step is considered in this calculation, but model complicity is not. It is possible that for more complex models the snubber resistor value should be lowered.

- *Rsnb – sta*tor snubber resistance
- *Rsnbr* – rotor snubber resistance
- *Get value* – copy chosen parameter value to clipboard

Figure 5: Snubber tab



Estimation equations

Squirrel Cage Induction Machine:

Estimation of stator resistance and constant losses:

$$I_1 = \frac{P_{out_i}}{3Vpf_i\eta_i} \qquad P_{in_i} = \frac{P_{out_i}}{\eta_i}$$

$$\begin{bmatrix} P_{out_{50}} - (1-s_{50})P_{in_{50}} \\ P_{out_{75}} - (1-s_{75})P_{in_{75}} \\ P_{out_{100}} - (1-s_{100})P_{in_{100}} \end{bmatrix} = \begin{bmatrix} -(1-s_{50})3I_{1_{50}}^2 \\ -(1-s_{75})3I_{1_{75}}^2 \\ -(1-s_{100})3I_{1_{100}}^2 \end{bmatrix} \begin{bmatrix} r_1 \\ P_{rot} \end{bmatrix} \qquad \begin{matrix} Y_{3x1} = \psi_{3x2}\theta_{2x1} \\ \theta = (\psi'\psi)^{-1}\psi' Y \end{matrix}$$

$$r_1 = \theta(1,1) \qquad P_{out} = \theta(2,1)$$

Estimation of rotor resistance:

$$\begin{bmatrix} \frac{s_{50}}{(1-s_{50})}(P_{out_{50}}+P_{rot})) \\ \frac{s_{75}}{(1-s_{75})}(P_{out_{75}}+P_{rot})) \\ \frac{s_{100}}{(1-s_{100})}(P_{out_{100}}+P_{rot})) \end{bmatrix} = \begin{bmatrix} 3I_{1_{50}}^2 & 1 \\ 3I_{1_{75}}^2 & 1 \\ 3I_{1_{100}}^2 & 1 \end{bmatrix} \begin{bmatrix} r_2 \\ k \end{bmatrix}$$

Estimation of stator, rotor and mutual inductance

$$I_0 = \sqrt{\frac{3r_2I_1^2 - \frac{(P_{out}+P_{rot})s}{(1-s)}}{3r_2}} \qquad Q = \frac{P_{out}}{\eta\, pf}\sin(\cos^{-1}(pf))$$

$$Ax_m^2 + Bx_m + C = 0 \;\; x_m = \frac{-B+\sqrt{B^2-4AC}}{2A}$$

$$A = \frac{I_0^2 I_1^2 - I_0^4}{\left((a+1)I_1^2 - I_0^2\right)^2} \qquad B = -\frac{2Q}{3}\frac{I_1^2 - I_0^2}{\left((a+1)I_1^2 - I_0^2\right)^2}$$

$$C = \left(\frac{I_1^2}{I_0^2} - 1\right)\left(\frac{r_2^2}{s^2} + \frac{Q^2}{9\left((a+1)I_1^2 - I_0^2\right)^2}\right)$$

$$x_1 = \frac{a}{3}\frac{Q - 3x_m I_0^2}{(a+1)I_1^2 - I_0^2} \qquad x_2 = \frac{x_1}{a}$$

$$\lambda_s = \frac{x_1}{\omega_s} \qquad \lambda_r = \frac{x_2}{\omega_s} \qquad L_m = \frac{x_m}{\omega_s}$$

Double Cage Induction Machine:

$$Q = \frac{P_{out}}{\eta\, pf}\sin(\cos^{-1}(pf)) \qquad s_{br} = s_n\left(T_{br}^* + \sqrt{T_{br}^{*2} - 1}\right) \quad T_{br}^* = \frac{T_{br}}{T_n}$$

$$x = [r_1, r_2, x_1, x_s, x_m]\ x_{init} = \left[\frac{U^2}{P_{outn}}s_n, 5\frac{U^2}{P_{outn}}s_n, \frac{U^2}{Q_n}, 0.05\frac{U^2}{Q_n}, 1.2\cdot 0.05\frac{U^2}{Q_n}\right]$$

$$r_s = 1.5r_1 \qquad x_2 = 0.5x_s$$

$$L_t = \frac{x_t}{\omega_s}$$

$$f_1(x) = \frac{P_{outn} - P_{out}(s_n)}{P_{outn}} = 0$$

$$f_2(x) = \frac{Q_n - Q(s_n)}{Q_n} = 0$$

$$f_3(x) = \frac{T_{br} - T(s_{br})}{T_{br}} = 0$$

$$f_4(x) = \frac{I_0 - I(1)}{I_0} = 0$$

$$f_5(x) = \frac{T_0 - T(1)}{T_0} = 0$$

$$P_{out}(s) = T(s)\frac{\omega_s}{p}(1 - s) \qquad Q(s) = 3Im\{\underline{V}\ \underline{I}(s)^*\}$$

$$T(s) = \frac{3p}{\omega_s}\left(\frac{r_1}{s}I_1(s)^2 + \frac{r_2}{s}I_2(s)^2\right) \qquad I_1(s) = -\frac{\underline{Z}(s)\underline{I}(s)}{\frac{r_1}{s} + jx_1} \qquad I_2(s) = -\frac{\underline{Z}(s)\underline{I}(s)}{\frac{r_2}{s} + jx_2}$$

$$I(s) = \frac{\underline{V}}{r_s + jx_s + \underline{Z}(s)} \qquad \underline{Z}(s) = \frac{1}{\frac{1}{jx_m} + \frac{1}{\frac{r_1}{s} + jx_1} + \frac{1}{\frac{r_2}{s} + jx_2}} \qquad \underline{V}(s) = \frac{U}{\sqrt{3}}$$

Wound Rotor Synchronous Machine:

This simple estimation algorithm is based on the *dq* equivalent circuit, assumptions regarding typical machine losses and voltage drops at nominal operating conditions.

$$S = \frac{P}{\eta\, pf} \qquad V_{ph}^{a} = \frac{\sqrt{2}}{\sqrt{3}}V_n \qquad I_{ph}^{a} = 2\frac{S}{\sqrt{3}V_{ph}^{a}} \quad \psi^{a} = \frac{V_{ph}^{a}}{\omega_s}$$

$$L_{md} = L_{mq} = \frac{\psi_a}{2I_{ph}^{a}} \qquad \lambda_s = \frac{L_{md}}{12} \qquad R_s = \frac{V_{ph}^{a}}{50I_{ph}^{a}}$$

$$\lambda_{kd} = \lambda_{kq} = \lambda_f = \lambda_s \; R_{kd} = R_{kq} = R_s \qquad R_f = \frac{V_{ph}^{a}}{20I_{ph}^{a}}$$

Snubber estimation:

Squirrel cage:

$$R_{snb} = \frac{135 \cdot 10^{-6}}{t_{sim}} \frac{\sqrt{3}{V_n}^2 \eta_n p f_n}{P}$$

Double cage:

$$R_{snb} = \frac{35 \cdot 10^{-6}}{t_{sim}} \frac{\sqrt{3}{V_n}^2 \eta_n p f_n}{P}$$

Wound rotor SM:

$$R_{snbs} = \frac{35 \cdot 10^{-6}}{t_{sim}} \frac{\sqrt{3}{V_n}^2 \eta_n p f_n}{P} \frac{50}{f_n}$$

$$R_{snbr} = \mathrm{inf}$$

References

[1] Gleison FVA, João MRB, Francisco CRC and Lane MR, "A *High Precision Method for Induction Machine Parameters Estimation from Manufacturer Data*", DOI 10.1109/TEC.2020.3032320, IEEE Transactions on Energy Conversion

[2] J. Pedra, F. Córcoles, "*Estimation of Induction Motor Double-Cage Model Parameters From Manufacturer Data*", IEEE Transactions on Energy Conversion, vol. 19, No. 2, June 2004