Permanent Magnet Synchronous Machine in dq (EMPSMDQ301MSEREF) Documentation

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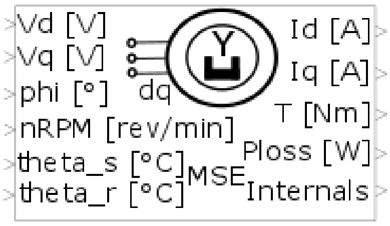

Description

This is the electromagnetic model of a permanent magnet synchronous machine (PMSM) in (d)irect and (q)uadrature coordinates.

Features

- Linear magnetic effects assumed
- Saliency effects considered (assuming sinusoidal[1] rotor flux and inductances over rotor position.)
- Linear temperature effects are considered for the stator windings respectively for the rotor magnets
- Ohmic losses considered
- Simple cogging torque effects considered

[1] german: Grundwellenmodell.

Application area

For more information about the application area, please consult the library documentation of the MSERef emachines library.

Model assumptions and limits

- No iron loss (neither eddy current nor magnetic hysteresis effects) considered

Solver settings

It is recommended to use a stiff solver if this model is connected to a drive (b6-bridge) where commutation effects are considered.

Model Equations

Note that the following equations hold for SI units. Since some inputs of this model are not in SI units a unit conversion is done before the calculation. The following conversions are performed:

$$\omega = n_{RPM} \cdot \frac{\pi}{30} \frac{min}{rev} \frac{rad}{s} \tag{1}$$

$$\varphi = \varphi_{In} \cdot \frac{\pi}{180} \frac{1^\circ}{rad} \tag{2}$$

The expression of the currents in the machine expressed in dq-coordinates is given by equations [3].

$$\boxed{V_d = R_m \cdot I_d + L_d \cdot \frac{dI_d}{dt} - L_q \cdot I_q \cdot N \cdot \omega} \tag{3a}$$

$$\boxed{V_q = R_m \cdot I_q + L_q \cdot \frac{dI_q}{dt} + L_d \cdot I_d \cdot N \cdot \omega + K_m \cdot N \cdot \omega} \tag{3b}$$

The expression of the ideal electromagnetic motor torque is given by equation [4].

$$\boxed{T = \frac{3}{2} \cdot N \cdot [K_m I_q + (L_d - L_q) I_d I_q] + T_{cog}} \tag{4}$$

Where

$$T_{cog} = A_{cog} \cdot \sin(N_{cog} \cdot \varphi). \tag{5a}$$

The expression of the winding losses is given by equation [6].

$$\boxed{P_{loss} = \frac{3}{2} \cdot R_m \cdot (I_d^2 + I_q^2)} \tag{6}$$

Temperature effects are taken into account via the stator winding temperature dependent stator winding resistance:

$$R_m = R_{20} \cdot [1 + \alpha \cdot (\vartheta_s - 20)] \tag{7}$$

In addition, the reduction of the magnetic remanence caused by rotor temperature is taken into account:

$$K_m \quad = \quad K_{m20} \cdot [1 + \alpha_{mag} \cdot (\vartheta_r - 20)] \tag{8}$$

The derivation of the equations [3] and [4] is documented in the background documentation of the MSERef emachines library.

Model validation

This model has been validated for machines with sinusoidal rotor flux, please consult the *Validation* section in the overview documentation of the MSERef emachines library.

Code Generation

To inquire if it is principally possible to generate code from this block, please consult the related *Code generation* section in the overview documentation.

Parameter Transformations

There exists a dq - abc inductance transformation that makes it possible to parameterize the model of a three-phase permanent magnet synchronous machine described in abc coordinates with inductance values computed in dq coordinates and vice-versa. For more information about this transformation, please consult the *Dq - abc inductance transformation* section in the background documentation of the MSERef emachines library.

Parameters

Type[2]	Name	Description	Symbol	Unit	Default	Values
Initial values						
F	xIdinit	Initial stator current in d direction	$I_{d,0}$	A	0	$[-10^9, 10^9]$
F	xIqinit	Initial stator current in q direction	$I_{q,0}$	A	0	$[-10^9, 10^9]$
Parameters						
I	N	Number of pole pairs	N		2	$[1, 1000]$
F	R20	Winding resistance at 20 °C	R_{20}	Ω	0.1	$[0, 10^9]$
F	Ld	d axis inductance	L_d	H	0.5^{-4}	$]0.0, 1.0]$
F	Lq	q axis inductance	L_q	H	10^{-4}	$]0.0, 1.0]$
F	Km20	Fundamental of flux at 20 °C	K_{m20}	V s	0.005	$[0, 10^9]$
F	Acog	Amplitude of cogging torque	A_{cog}	N m	0	$[0, 10^9]$
F	Ncog	Number of cogging positions	N_{cog}	-	0	$[0, 10^3]$
F	alpha	Thermal coefficient of resistance	α	1/K	0	$[-1, 1]$
F	alphamag	Thermal coefficient of remanence	α_{mag}	1/K	0	$[-1, 1]$

Ports

Inputs

Direction	Type	Name	Symbol	Description	Unit
input	Float	Vd	V_d	Stator voltage in d direction	V
input	Float	Vq	V_q	Stator voltage in q direction	V
input	Float	phi	φ_{In}	Rotor position	deg
input	Float	nRPM	n_RPM	Rotor speed	rev min^{-1}
input	Float	theta_s	ϑ_s	Stator winding temperature	°C
input	Float	theta_r	ϑ_r	Rotor magnet temperature	°C

Outputs

Direction	Type	Name	Symbol	Description	Unit
output	Float	Id	I_d	Stator current in d direction	A
output	Float	Iq	I_q	Stator current in q direction	A
output	Float	T	T	Motor torque	N m
output	Float	Ploss	P_loss	Power loss	W
output	Vector/Bus	Internals		Internals output vector (more information)	

[2] I: Integer parameter, F: Float parameter

States

Type[3]	Name	Symbol	Description	Unit	Initial Value
CS	`xId`	I_d	Stator current in d direction	A	xIdinit
CS	`xIq`	I_q	Stator current in q direction	A	xIqinit

Internal Variables

Type[4]	Name	Symbol	Description	Unit
IF	`Km`	K_m	Magnetic remanence	V s
IF	`Tcog`	T_{cog}	Cogging torque	N m
IF	`Rm`	R_m	Winding resistance	Ω

[3] CS: Continuous state
[4] IF: Internal float

