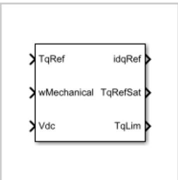
PMSM Current Reference Generator

Permanent magnet synchronous machine current reference generator

Library: Simscape / Electrical / Control / PMSM Control



Description

The PMSM Current Reference Generator block implements a current reference generator for permanent magnet synchronous machine (PMSM) current control in the rotor d-q reference frame.

You typically use this block in a series of blocks making up a control structure.

- You can generate a voltage reference in the d-q frame by placing this block before a PMSM Current Control or PMSM Current Control with Pre-Control block.
- You can implement velocity control by placing this block after a Velocity Controller block.

You can see an example of a full control structure, from machine measurements to machine inputs, in the PMSM Field-Oriented Control block.

Equations

The PMSM Current Reference Generator block can obtain the current reference using one of these methods:

- Zero *d*-axis control (ZDAC)
- User defined lookup tables
- Automatically generated lookup tables

For the ZDAC method, the block sets the *d*-axis current reference i_d^{ref} to zero and determines the *q*-axis current reference i_q^{ref} using the torque equation:

$$i_d^{ref} = 0,$$

and

$$i_q^{ref} = \frac{2T_{ref}}{3p\psi_m},$$

where:

- T_{ref} is the reference torque input.
- p is the number of pole pairs.
- ψ_m is the permanent magnet flux linkage.

For operation below the base speed of the synchronous machine, ZDAC is a suitable method. Above base speed, a field weakening controller is required to adjust the *d*-axis reference.

To pregenerate optimal current references for several operating points offline, define two lookup tables using the user-defined lookup table approach:

$$i_d^{ref} = \mathrm{f}(n_m, T_{ref}, v_{dc}),$$

and

$$i_q^{ref} = \mathrm{g}(n_m, T_{ref}, v_{dc}),$$

where:

- n_m is the rotor angular velocity.
- v_{dc} is the DC-link voltage of the converter.

To let the block create the lookup tables, choose the automatically generated lookup table approach. The block generates the lookup table using two strategies:

- Maximum torque per ampere
- Field weakening

The selection between the two strategies is based on the modulation index, which can be computed as follows:

$$M = \frac{V_s}{kV_{ph\_max}},$$

where V_s is the stator voltage amplitude, k is the modulation factor, and V_{ph_max} is the maximum allowable phase voltage. In the case that the modulation index is greater than 1, the block generates current references using the field weakening procedure. Otherwise, current references are computed using the maximum torque per ampere procedure.

Maximum Torque Per Ampere

You can generate current references in the constant torque region (occurring below rated speed) by using the maximum torque per ampere (MTPA) strategy.

The direct and quadrature components of the stator current are written in terms of angle and magnitude as:

$$i_d = -I_s \sin\beta,$$

and

$$i_q = I_s \cos\beta,$$

where:

- β is the angle of the stator current vector.
- I_s is the stator current amplitude.

Using the angle-magnitude variant of the d-q currents, the PMSM torque equation is written as:

$$T_e = \frac{3p}{2}\psi_m I_s \cos\beta + \frac{3p}{4}(L_q - L_d)I_s^2 \sin 2\beta,$$

where L_d and L_q are the direct and quadrature inductances, respectively.

To obtain fast transient response and maximize torque with the smallest possible stator current amplitude, MTPA imposes $(dT_e)/d\beta = 0$ to the torque equation, which yields

$$-\frac{3p}{2}\psi_m I_s \sin\beta + \frac{3p}{2}(L_q - L_d)I_s^2(\cos^2\beta - \sin^2\beta) = 0.$$

The MTPA *d*-axis current i_{d_mtpa} is written in terms of the *q*-axis component i_{q_mtpa} by substituting the d-q currents back from their angle and magnitude variants:

$$i_{d\_mtpa} = \frac{\psi_m}{2(L_q - L_d)} - \sqrt{\frac{\psi_m^2}{4(L_q - L_d)^2} + i_{q\_mtpa}^2}.$$

Finally, by plugging the previous equation into the d-q variant of the PMSM torque equation, the following polynomial is obtained:

$$9p^2(L_q - L_d)^2 i_{q\_mtpa}^4 + 6T_{ref}\, p\psi_m i_{q\_mtpa} - 4T_{ref}^2 = 0.$$

The *q*-axis component is obtained by solving this polynomial.

Field Weakening

You can generate current references in the above rated speed region by using the field weakening (FW) strategy.

Above the rated speed, the stator voltage is limited by the power converter and the available DC-link voltage. The maximum stator voltage is:

$$V_s = \sqrt{v_d^2 + v_q^2} \leq V_{ph\_max},$$

where V_{ph_max} is the maximum available stator phase voltage.

The steady-state voltage equations for PMSMs are

$$v_d = R_s i_d - \omega_e L_q i_q\ ,$$

and

$$v_q = R_s i_q + \omega_e(L_d i_d + \psi_m).$$

For rotor speeds above rated, the stator resistance is negligible, and the field weakening *d*-axis current component i_{d_fw} is obtained in terms of the *q*-axis component i_{q_fw} from the v_q steady-state equation:

$$i_{d\_fw} = -\frac{\psi_m}{L_d} + \frac{1}{L_d}\sqrt{\frac{V_{ph\_max}^2}{{\omega_e}^2} - (L_q i_{q\_fw})^2},$$

Finally, by plugging the i_{d_fw} equation into the PMSM torque equation, the following polynomial is obtained:

$$9p^2(L_d - L_q)^2 L_q^2 {\omega_e}^2 i_{q\_fw}^4 + \left(9p^2\psi_m^2 L_q^2 {\omega_e}^2 - 9p^2(L_d - L_q)^2 V_{ph\_max}^2\right) i_{q\_fw}^2 - 12T_{ref}\, p\psi_m L_d L_q {\omega_e}^2 i_{q_{fw}} + 4T_{ref}^2 L_d^2 {\omega_e}^2 = 0$$

The *q*-axis component is obtained by solving this polynomial.

Assumptions

The machine parameters are constants.

Limitations

The automatically generated current references introduce latency in the presimulation phase. For medium-power PMSM drives the latency is around 300 ms.

Ports

Input

collapse all

`TqRef` — **Reference torque**
scalar

Desired mechanical torque produced by the PMSM, in N*m.

Data Types: `single` | `double`

`wMechanical` — **Rotor mechanical speed**
scalar

Mechanical angular velocity of the rotor, obtained via direct measurement of the PMSM, in rad/s.

Data Types: `single` | `double`

`Vdc` — **DC-link voltage**
scalar

DC-link voltage of the converter, in V. For the ZDAC method, this value is used to limit the output reference torque and torque limit. For the lookup table method, this value is used as an input to the lookup tables.

Data Types: `single` | `double`

Output

expand all

`idqRef` — **Reference currents**
vector

`TqRefSat` — **Reference torque**
scalar

`TqLim` — **Torque limit**
scalar

Parameters

expand all

General Parameters

`Nominal dc-link voltage (V)` — Rated DC voltage
`300V` (default) | positive number

`Maximum power (W)` — Rated power
`30000W` (default) | positive number

`Maximum torque (N*m)` — Rated torque
`250N*m` (default) | positive number

`Sample time (-1 for inherited)` — Block sample time
`-1` (default) | -1 or positive number

Reference Generation Strategy

`Current references` — Current reference strategy
`Zero d-axis control` (default) | `Lookup-table based` | `Automatically generated lookup-table`

`Mechanical speed vector, wMechanical (rpm)` — Rotor speed lookup vector
`[0, 3000]rpm` (default) | positive monotonically increasing vector

`Torque reference vector, TqRef (N*m)` — Torque reference lookup vector
`[-100, 0, 100]N*m` (default) | positive monotonically increasing vector

`DC-link voltage vector, Vdc (V)` — DC-link voltage lookup vector
`[300, 350]V` (default) | positive monotonically increasing vector

`D-axis current reference matrix, id(wMechanical,TqRef,Vdc) (A)` — Reference d-axis current values
`zeros(2,3,2)A` (default) | real matrix

`Q-axis current reference matrix, iq(wMechanical,TqRef,Vdc) (A)` — Reference q-axis current values
`zeros(2,3,2)A` (default) | real matrix

`PWM method` — Pulse width modulation method
`SVM: space vector modulation` (default) | `SPWM: sinusoidal PWM`

`Modulation factor` — Modulation factor
`1` (default) | positive scalar

`Number of pole pairs` — Pole pairs
`8` (default) | positive integer

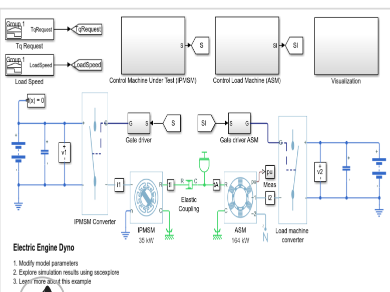
`Permanent magnet flux linkage (Wb)` — PM Flux Linkage
`0.04Wb` (default) | positive scalar

`D-axis inductance (H)` — Inductance of d-axis
`0.00024` (default) | positive scalar

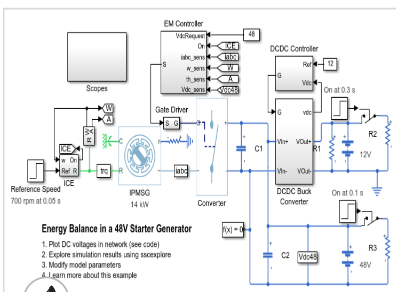
`Q-axis inductance (H)` — Inductance of q-axis
`0.00029` (default) | positive scalar

`Stator resistance (Ohm)` — Resistance of stator
`0.01` (default) | positive scalar

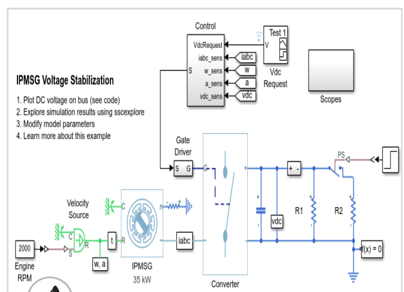
Model Examples



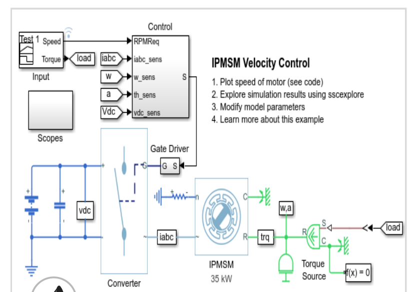
Electric Engine Dyno



Energy Balance in a 48V Starter Generator



IPMSG Voltage Stabilization



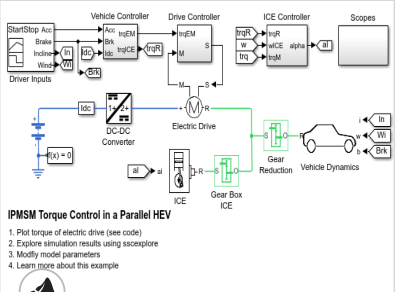
IPMSM Velocity Control

Model an electric vehicle dynamometer test. The test

An interior permanent magnet synchronous machine (IPMSM)

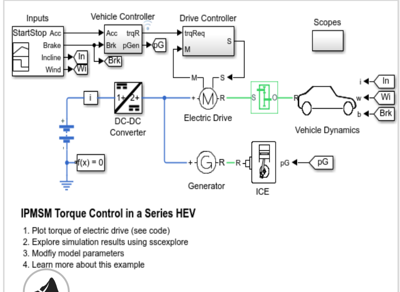
Control an Interior Permanent Magnet Synchronous Generator

Control the rotor angular velocity in an interior permanent magnet



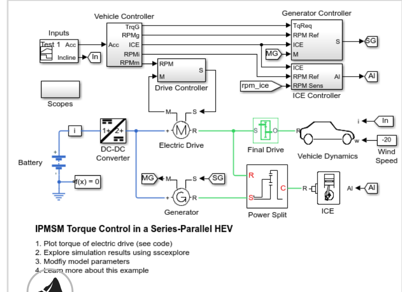
IPMSM Torque Control in a Parallel HEV

A simplified parallel hybrid electric vehicle (HEV). An interior permanent magnet synchronous machine (IPMSM) and an internal combustion



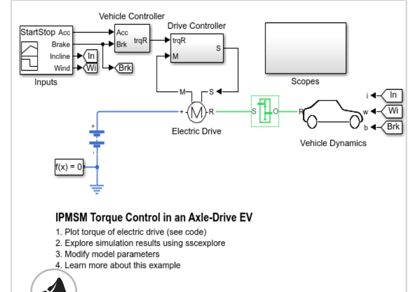
IPMSM Torque Control in a Series HEV

An interior permanent magnet synchronous machine (IPMSM) propelling a simplified series hybrid electric vehicle (HEV). An ideal



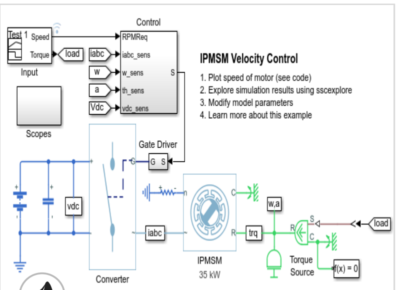
IPMSM Torque Control in a Series-Parallel HEV

A simplified series-parallel hybrid electric vehicle (HEV). An interior permanent magnet synchronous machine (IPMSM) and an internal



IPMSM Torque Control in an Axle-Drive HEV

An interior permanent magnet synchronous machine (IPMSM) propelling a simplified axle-drive electric vehicle. A high-voltage



IPMSM Velocity Control

Control the rotor angular velocity in an interior permanent magnet synchronous machine (IPMSM) based automotive electrical-traction

References

[1] Haque, M. E., L. Zhong, and M. F. Rahman. "Improved trajectory control for an interior permanent magnet synchronous motor drive with extended operating limit." *Journal of Electrical & Electronics Engineering.* Vol. 22, Number 1, 2003, p. 49.

[2] Carpiuc, S., C. Lazar, and D. I. Patrascu. "Optimal Torque Control of the Externally Excited Synchronous Machine." *Control Engineering and Applied Informatics.* Vol. 14, Number 2, 2012, pp. 80–88.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Blocks

PMSM Current Controller | PMSM Current Controller with Pre-Control

Introduced in R2017b