PMSM Field-Oriented Control

Permanent magnet synchronous machine field-oriented control

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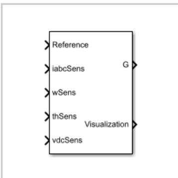


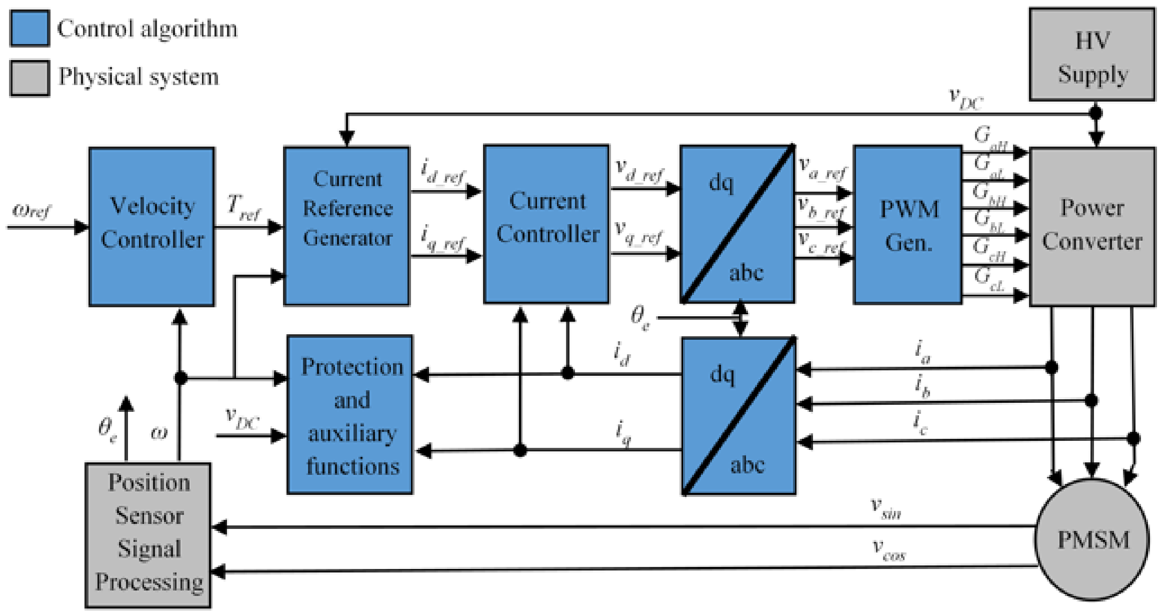
Description

The PMSM Field-Oriented Control block implements a field-oriented control structure for a permanent magnet synchronous machine (PMSM). Field Oriented Control (FOC) is a performant AC motor control strategy that decouples torque and flux by transforming the stationary phase currents to a rotating frame. Use FOC when rotor speed and position are known and your application requires:

- High torque and low current at startup.
- High efficiency.

Equations

The PMSM FOC structure decouples the torque and flux by using the rotor d-q reference frame. This diagram shows the overall architecture of the block.



In the diagram:

- ω and ω_{ref} are the measured and reference angular velocities, respectively.
- T_{ref} is the reference electromagnetic torque.
- i and v are stator currents and voltages and subscripts d and q represent the *d*-axis and *q*-axis, and subscripts a, b, and c, represent the three stator windings.
- θ_e is the rotor electrical angle.
- G is a gate pulse, subscripts H and L, represent high and low, and subscripts a, b, and c represent the three stator windings.

You can choose to implement either velocity or torque control with the `Control mode` parameter. The block implements velocity control exactly as shown in the diagram. The block implements torque control by removing the Velocity Controller block and accepting the reference torque directly.

Assumptions

The machine parameters are known.

Limitations

The control structure is implemented with a single sample rate.

Ports

Input

collapse all

`Reference` — **System reference**
scalar

System reference specified as torque reference in N*m or velocity reference in rad/s, depending on the control mode selected.

Data Types: `single` | `double`

`iabcSens` — Measured phase currents
vector

Measured stator phase currents, in A.

Data Types: `single` | `double`

`wSens` — Rotor speed
scalar

Measured mechanical angular velocity of rotor, in rad/s.

Data Types: `single` | `double`

`thSens` — Rotor angle
scalar

Measured mechanical angle of rotor, in rad.

Data Types: `single` | `double`

`vdcSens` — DC-link voltage
scalar

Measured DC-link voltage, in V.

Data Types: `single` | `double`

Output

collapse all

`G` — Gate pulses
vector

Six pulse waveforms that determine switching behavior in the attached power converter.

Data Types: `single` | `double`

`Visualization` — Visualization signals
bus

Bus containing signals for visualization, including:

- `Reference`
- `wElectrical`
- `iabc`
- `theta`
- `Vdc`
- `PwmEnable`
- `TqRef`
- `TqLim`
- `idqRef`
- `idq`
- `vdqRef`
- `modWave`

Data Types: `single` | `double`

Parameters

collapse all

General

`Control Mode` — Control mode strategy
`Torque control` (default) | `Velocity control`

Specify either a torque control or velocity control strategy.

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

Nominal DC-link voltage of the electrical source.

`Maximum power (W)` — Maximum power
`35000` `W` (default) | positive number

Maximum machine power.

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

Maximum machine torque.

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

Number of permanent magnet pole pairs on the rotor.

`Inverter dc-link voltage threshold (V)` — DC-link voltage threshold
`100` `V` (default) | positive number

Voltage threshold to activate the power inverter.

`Fundamental sample time (s)` — Block sample time
`5e-6` (default) | positive number

Fundamental sample time for the block.

`Control sample time (s)` — Control sample time
`1e-4` (default) | positive number

Sample time for the control system.

Outer Loop

`Control Type` — Control type strategy
`PI control` (default) | `P control` | `P-PI control`

Specify the type of the control strategy.

`Controller proportional gain` — Proportional gain of PI controller
1 (default) | positive number

Proportional gain of the PI controller.

`Controller integral gain` — Integral gain of PI controller
1 (default) | positive number

Integral gain of the PI controller.

`P controller proportional gain` — Proportional gain of P controller
1 (default) | positive number

Proportional gain of P controller.

`Integral anti-windup gain` — Anti-windup gain
1 (default) | positive number

Anti-windup gain of the PI controller.

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

Select the current reference strategy.

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

Speed vector used in the lookup tables for determining current references.

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

Torque vector used in the lookup tables for determining current references.

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

: DC-link voltage vector used in the lookup tables for determining current references.

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

Direct-axis current reference lookup data.

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

Quadrature-axis current reference lookup data.

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

Safety factor used to compute the maximum allowed phase voltage for current references generation.

Dependencies

This parameter is only visible when **Current references** is set to `Automatically generated lookup-table`.

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

Peak permanent magnet flux linkage.

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

Direct-axis inductance.

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

Quadrature-axis inductance.

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

Stator resistance per phase.

Inner Loop

`D-axis current proportional gain` — D-axis proportional gain
`1` (default) | positive number

Proportional gain of the PI controller used for direct-axis current control.

`D-axis current integral gain` — D-axis integral gain
`100` (default) | positive number

Integrator gain of the PI controller used for direct-axis current control.

`D-axis current anti-windup gain` **— D-axis anti-windup gain**
`1` (default) | positive number

Anti-windup gain of the PI controller used for direct-axis current control.

`Q-axis current proportional gain` **— Q-axis proportional gain**
`1` (default) | positive number

Proportional gain of the PI controller used for quadrature-axis current control.

`Q-axis current integral gain` **— Q-axis integral gain**
`100` (default) | positive number

Integrator gain of the PI controller used for quadrature-axis current control.

`Q-axis current anti-windup gain` **— Q-axis anti-windup gain**
`1` (default) | positive number

Anti-windup gain of the PI controller used for quadrature-axis current control.

`Axis prioritization` **— Axis prioritization for voltage limiter**
`q-axis` (default) | `d-axis` | `d-q equivalence`

Prioritize or maintain ratio between *d*- and *q*-axis when the block limits voltage.

`Enable zero cancellation` **— Feedforward zero cancellation**
`off` (default) | `on`

Enable or disable zero cancellation on the feedforward path.

`Enable pre-control voltage` — Precontrol voltage
on (default) | `off`

Enable or disable precontrol voltage.

`Machine parameters` — Machine parameterization
`Constant parameters` (default) | `Lookup table based parameters`

Specify how to parameterize the machine.

- `Constant parameters` — Specify machine parameters that are constant throughout the simulation.
- `Lookup table based parameters` — Specify machine parameters as lookup tables that depend on current.

`D-axis inductance for feed-forward pre-control (H)` — Feedforward d-axis inductance
`0.00024` (default) | positive scalar

Direct-axis inductance for feedforward precontrol.

`Q-axis inductance for feedforward precontrol (H)` — Feedforward q-axis inductance
`0.00029` (default) | positive scalar

Quadrature-axis inductance for feed-forward pre-control.

`Permanent magnet flux linkage for feedforward pre-control (H)` — Feedforward flux linkage
`0.04` (default) | scalar

Permanent magnet flux linkage for feedforward pre-control.

`D-axis current vector, id (A)` — D-axis current breakpoint vector
`[-200,0,200]` `A` (default) | monotonically increasing vector

Direct-axis current vector used in the lookup tables for parameters determination. For constant machine parameters, do not change the default.

`Q-axis current vector, iq (A)` — Q-axis current breakpoint vector
`[-200,0,200]` `A` (default) | monotonically increasing vector

Quadrature-axis current vector used in the lookup tables for parameters determination. For constant machine parameters, do not change the default.

`Ld matrix, Ld(id,iq) (H)` — D-axis inductance lookup data
`0.0002 * ones(3, 3)` `H` (default) | positive matrix

L_d matrix used as lookup table data. For constant machine parameters change only the constant factor, for example, L_d * `ones(3, 3)`.

`Lq matrix, Lq(id,iq) (H)` — Q-axis inductance lookup data
`0.0002 * ones(3, 3)` `H` (default) | positive matrix

L_q matrix used as lookup table data. For constant machine parameters change only the constant factor, for example, L_q * `ones(3, 3)`.

`Permanent magnet flux linkage matrix, PM(id,iq) (Wb)` — Flux linkage lookup data
`0.04 * ones(3, 3)` `Wb` (default) | real matrix

Permanent magnet flux linkage matrix used in the lookup table. For constant machine parameters change only the constant factor, for example, *psim* * `ones(3, 3)`.

PWM

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

Specify the waveform technique.

`Sampling mode` — Wave-sampling method
`Natural` (default) | `Asymmetric` | `Symmetric`

Specify whether the block samples the modulation waveform when the waves intersect or when the carrier wave is at one or both of its boundary conditions.

`Switching frequency (Hz)` — **Switching rate**
`1000` (default) | positive integer

Specify the rate at which you want the switches in the power converter to switch.

References

[1] Bernardes, T., V. F. Montagner, H. A. Gründling, and H. Pinheiro. "Discrete-time sliding mode observer for sensorless vector control of permanent magnet synchronous machine." *IEEE Transactions on Industrial Electronics.* Vol. 61, Number 4, 2014, pp. 1679–1691.

[2] Carpiuc, S., and C. Lazar. "Fast real-time constrained predictive current control in permanent magnet synchronous machine-based automotive traction drives." *IEEE Transactions on Transportation Electrification.* Vol.1, Number 4, 2015, pp. 326–335.

[3] 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.

[4] Yang, N., G. Luo, W. Liu, and K. Wang. "Interior permanent magnet synchronous motor control for electric vehicle using look-up table." *In 7th International Power Electronics and Motion Control Conference.* Vol. 2, 2012, pp. 1015–1019.

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 | PMSM Current Reference Generator

Topics

Three-Phase PMSM Drive

Introduced in R2017b