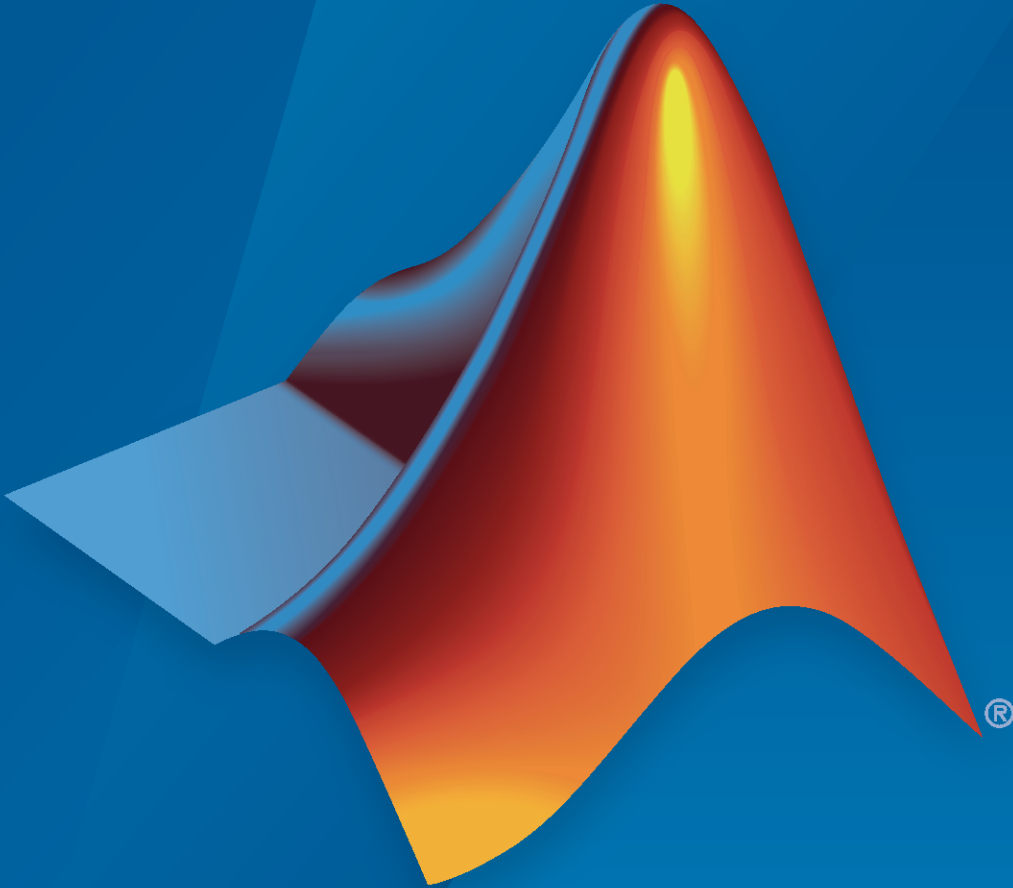


Motor Control Blockset™

Reference



MATLAB® & SIMULINK®

R2023a



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Motor Control Blockset™ Reference

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Revision History

March 2020	Online only	New for Version 1.0 (Release 2020a)
September 2020	Online only	Revised for Version 1.1 (Release R2020b)
March 2021	Online only	Revised for Version 1.2 (Release R2021a)
September 2021	Online only	Revised for Version 1.3 (Release R2021b)
March 2022	Online only	Revised for Version 1.4 (Release R2022a)
September 2022	Online only	Revised for Version 1.5 (Release R2022b)
March 2023	Online only	Revised for Version 2.0 (Release R2023a)

1	Blocks
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Blocks

DQ Limiter

Saturate voltages (or current) in the dq reference frame



Libraries:

Motor Control Blockset / Controls / Control Reference

Motor Control Blockset HDL Support / Controls / Control Reference

Description

The DQ Limiter block generates saturated values of the input voltages (or current) in the dq reference frame, depending on the specified saturation limit and the selected method of saturation.

The block accepts reference values of d and q axis voltages (or current) and outputs the corresponding saturated values. The block also provides the unsaturated peak value of the reference dq voltages (or current), which you can use to enable field weakening control.

Note The block supports a fixed-point data type size up to 128 bits.

Equations

These equations describe the computation of saturated dq voltage (or current) values by the block.

For DQ equivalence:

$$mag^{ref} = \sqrt{(d^{ref})^2 + (q^{ref})^2}$$

When $mag^{ref} > x_{max}$.

- $d^{sat} = \frac{d^{ref}}{mag^{ref}} \times x_{max}$
- $q^{sat} = \frac{q^{ref}}{mag^{ref}} \times x_{max}$

When $mag^{ref} \leq x_{max}$.

- $d^{sat} = d^{ref}$
- $q^{sat} = q^{ref}$

Where, x_{max} is the saturation limit.

When D-axis is prioritized:

$$mag^{ref} = \sqrt{(d^{ref})^2 + (q^{ref})^2}$$

$$d^{sat} = \min(\max(d^{ref}, -x_{max}), x_{max})$$

$$q^{sat} = \text{sign}(q^{ref}) \times \min(|q^{ref}|, \sqrt{x_{max}^2 - (d^{sat})^2})$$

Where, x_{max} is the saturation limit.

When Q-axis is prioritized:

$$\text{mag}^{ref} = \sqrt{(d^{ref})^2 + (q^{ref})^2}$$

$$q^{sat} = \min(\max(q^{ref}, -x_{max}), x_{max})$$

$$d^{sat} = \text{sign}(d^{ref}) \times \min(|d^{ref}|, \sqrt{x_{max}^2 - (q^{sat})^2})$$

Where, x_{max} is the saturation limit.

Ports

Input

d^{ref} — Reference d -axis voltage (or current)
scalar

Reference voltage (or current) value along the d -axis of the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

q^{ref} — Reference q -axis voltage (or current)
scalar

Reference voltage (or current) value along the q -axis of the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

satMethod — Saturation technique
scalar

Saturation method that the block uses to initiate saturation. The port accepts one of the following integer values:

- 1 - Prioritize D-axis
- 2 - Prioritize Q-axis
- Any other positive integer - D-Q equivalence method

Dependencies

To enable this port, select Input port for the **Saturation method** parameter.

Data Types: `uint16`

satLim — Saturation limit
scalar

Saturation limit value that the block uses to initiate saturation. The port accepts values greater than or equal to 0.

Dependencies

To enable this port, select **Input port** for the **Saturation limit** parameter.

Data Types: `single` | `double` | `fixed point`

Output

d^{sat} — Saturated d -axis voltage (or current)
scalar

Saturated voltage (or current) value along the d -axis of the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

q^{sat} — Saturated q -axis voltage (or current)
scalar

Saturated voltage (or current) value along the q -axis of the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

mag^{ref} — Unsaturated peak value of block inputs
scalar

Unsaturated peak value of the input voltages (or current).

Data Types: `single` | `double` | `fixed point`

Parameters

Saturation method — Saturation method selection technique
Specify via dialog (default) | Input port

Select whether the block should use dialog box or input port to specify the saturated method.

Programmatic Use

`satMethodInputType`

Saturation method selected — Saturation method used by block
D-Q equivalence (default) | Prioritize D axis | Prioritize Q axis

Select the saturation method that the block should use.

Dependencies

To enable this parameter, set **Saturation method** to Specify via dialog.

Programmatic Use

`satMethodSelected`

Saturation limit — Saturation limit selection technique
Specify via dialog (default) | Input port

Select whether the block should use dialog box or input port to specify the saturated limit.

Programmatic Use

satLimitInputType

Saturation limit value — Phase voltage (or current) peak limit

1 (default) | scalar

The maximum magnitude of voltage (or current) above which the block outputs are limited.

D – Q saturation limit (current) is usually the rated current of the motor. When you work with the Per-Unit system (PU), you should convert the rated current of the motor to Per-Unit value with respect to the base current.

D – Q saturation limit (voltage) is usually the maximum phase voltage supplied by the inverter.

Generally it is $\frac{V_{dc}}{\sqrt{3}}$ for Space Vector PWM and $\frac{V_{dc}}{2}$ for Sinusoidal PWM, where V_{dc} is the DC link voltage of the inverter.

Note You can enter either per unit or SI unit voltage (or current) value in this parameter (unit of the entered value should be same as that of the d^{ref} and q^{ref} inputs). For optimum performance, we recommend that you provide a per unit value.

Dependencies

To enable this parameter, set **Saturation limit** to Specify via dialog.

Programmatic Use

Vmax

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder™ provides additional configuration options™ that affect HDL implementation and synthesized logic.

Supported Block Parameters

For HDL code generation with the DQ Limiter block, set these parameters:

- Set **Saturation method** to Specify via dialog
- Set **Saturation method selected** to D-Q equivalence

- Set **Saturation limit** to Specify via dialog

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

PI Controller | ACIM Feed Forward Control | Inverse Park Transform | MTPA Control Reference | Vector Control Reference

Topics

“Open-Loop and Closed-Loop Control”
 “Field-Oriented Control (FOC)”

PMSM FeedForward Control

Decouple d -axis and q -axis current to eliminate disturbance



Libraries:

Motor Control Blockset / Controls / Control Reference

Description

The PMSM FeedForward Control block decouples d -axis and q -axis current controls and generates the corresponding feed-forward voltage gains to enable field-oriented control of a permanent magnet synchronous motor (PMSM).

The block accepts feedback values of d -axis and q -axis currents and the mechanical speed of the rotor.

The block generates feed-forward gains from motor parameters specified using one of these methods.

- Lumped parameters with d -axis and q -axis stator winding inductances and permanent magnet flux linkage.
- Nonlinear model with d -axis and q -axis flux linkage lookup tables.
- Nonlinear model with d -axis and q -axis stator winding inductances and permanent magnet flux linkage lookup tables.
- d -axis and q -axis stator winding inductances and permanent magnet flux linkage values provided using separate input ports.

In addition, the **Vsat input method** parameter configures the block to either accept a fixed saturation voltage through the **Output voltage saturation (V)** parameter or accept a variable saturation voltage through a separate input port V_{sat} .

Equations

If you select Per-Unit (PU) in the **Input units** parameter, the block scales down the internal parameters to match the per-unit scale by default. You can also configure the block to convert the inputs to SI units before performing any computation and convert them back to per unit values after calculating the output.

These equations describe the computation of feed-forward gain by the block.

$$\omega_e = p\omega_m$$

$$V_d^{FF} = -\omega_e \psi_q = -\omega_e L_q I_q$$

$$V_q^{FF} = \omega_e \psi_d = \omega_e L_d I_d + \omega_e \psi_m$$

where:

- p is the number of pole pairs available in the motor.
- ω_e is the electrical speed corresponding to frequency of stator voltages (rad/s).
- L_d and L_q are the d -axis and q -axis stator winding inductances (henry).
- I_d and I_q are the d -axis and q -axis currents (amperes).
- ψ_d and ψ_q are the magnetic fluxes along the d - and q -axes (weber).
- ψ_m is the permanent magnet flux linkage (weber).

For a detailed set of equations and assumptions that Motor Control Blockset uses for a PMSM, see “Mathematical Model of PMSM” on page 1-150.

Ports

Input

I_d — D-axis current
scalar

Current along the d -axis of the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

I_q — Q-axis current
scalar

Current along the q -axis of the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

ω_m — Mechanical speed of rotor
scalar

Mechanical speed of the rotor.

Data Types: `single` | `double` | `fixed point`

L_d — D-axis inductance
scalar

D-axis winding inductance (in henry).

Dependencies

To enable this input port, set **Motor parameter input method** to Input port based Ld, Lq and FluxPM.

Data Types: `single` | `double` | `fixed point`

L_q — Q-axis inductance
scalar

Q-axis winding inductance (in henry).

Dependencies

To enable this input port, set **Motor parameter input method** to Input port based Ld, Lq and FluxPM.

Data Types: single | double | fixed point

Flux_{PM} — Permanent magnet flux linkage
scalar

Peak permanent magnet flux linkage (in weber).

Dependencies

To enable this input port, set **Motor parameter input method** to Input port based Ld, Lq and FluxPM.

Data Types: single | double | fixed point

V_{sat} — Output voltage saturation limit
scalar

Variable saturation limit (in volts) for the output voltages V_d^{FF} and V_q^{FF} .

Dependencies

To enable this port, set **Vsat input method** to Input port.

Data Types: single | double | fixed point

Output

V_d^{FF} — D-axis feed-forward voltage gain
scalar

Feed-forward voltage gain along the d -axis of the rotating dq reference frame.

Data Types: single | double | fixed point

V_q^{FF} — Q-axis feed-forward voltage gain
scalar

Feed-forward voltage gain along the q -axis of the rotating dq reference frame.

Data Types: single | double | fixed point

Parameters**Motor parameters**

Number of pole pairs — Number of pole pairs available in motor
4 (default) | scalar

Number of pole pairs available in the motor.

Vsat input method — Input method for Vsat
Specify via dialog (default) | Input port

Method used to specify output voltage saturation limit (V_{sat}).

- **Specify via dialog** — Specify the fixed output voltage saturation limit V_{sat} using the parameter **Output voltage saturation (V)**.
- **Input port** — Specify the variable output voltage saturation limit V_{sat} using the input port V_{sat} .

Output voltage saturation (V) — Saturation limit for output values
24/sqrt(3) (default) | scalar

Saturation limit (in Volts) for the output voltages V_d^{FF} and V_q^{FF} .

Dependencies

To enable this parameter, set **Vsat input method** to **Specify via dialog**.

Motor parameter input method — Type of motor parameters
Linear model with lumped parameters (default) | Non-linear model with D,Q-flux linkage LUTs | Non-linear model with Ld,Lq and FluxPM LUTs | Input port based Ld,Lq and FluxPM

Motor parameters that the block uses to generate feedforward gains.

- **Linear model with lumped parameters** — Generate feed-forward voltages using lumped-circuit values for motor parameters L_d , L_q , and $FluxPM$.
- **Non-linear model with D,Q-flux linkage LUTs** — Generate feed-forward voltages using d -axis flux linkage $FluxD$ and q -axis flux linkage $FluxQ$ lookup tables (LUTs).
- **Non-linear model with Ld,Lq and FluxPM LUTs** — Generate feed-forward voltages using L_d , L_q , and $FluxPM$ LUTs, specified as block parameters.
- **Input port based Ld,Lq and FluxPM** — Generate feed-forward voltages using L_d , L_q , and $FluxPM$ LUTs, specified as block inputs.

Linear Model with Lumped Parameters

Stator d-axis inductance (H) — D-axis stator winding inductance
0.2e-3 (default) | scalar

Stator winding inductance (in Henry) along the direct-axis of the rotating dq reference frame.

Dependencies

To enable this parameter, set **Motor parameter input method** to **Linear model with lumped parameters**.

Stator q-axis inductance (H) — Q-axis stator winding inductance
0.2e-3 (default) | scalar

Stator winding inductance (in Henry) along the quadrature-axis of the rotating dq reference frame.

Dependencies

To enable this parameter, set **Motor parameter input method** to **Linear model with lumped parameters**.

Permanent magnet flux linkage (Wb) — PM flux linkage
6.4e-3 (default) | scalar

Peak permanent magnet flux linkage (in Weber).

Dependencies

To enable this parameter, set **Motor parameter input method** to Linear model with lumped parameters.

Nonlinear Model with FluxD and FluxQ Lookup Tables

D-axis current breakpoint vector (A) — D-axis current lookup vector
[-40, -20, 0, 20] (default) | vector

D-axis current vector (in Amperes) used in the following lookup tables, depending on the method used to specify the motor parameters.

- $FluxD(i_d, i_q)$ and $FluxQ(i_d, i_q)$ for the Non-linear model with D,Q-flux linkage LUTs method.
- $L_d(i_d, i_q)$, $L_q(i_d, i_q)$, and $FluxPM(i_d, i_q)$ for the Non-linear model with Ld,Lq and FluxPM LUTs method.

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with D,Q-flux linkage LUTs or Non-linear model with Ld,Lq and FluxPM LUTs.

Q-axis current breakpoint vector (A) — Q-axis current lookup vector
[-40, -20, 0, 20, 40] (default) | vector

Q-axis current vector (in Amperes) used in the following lookup tables, depending on the method used to specify the motor parameters.

- $FluxD(i_d, i_q)$ and $FluxQ(i_d, i_q)$ for the Non-linear model with D,Q-flux linkage LUTs method.
- $L_d(i_d, i_q)$, $L_q(i_d, i_q)$, and $FluxPM(i_d, i_q)$ for the Non-linear model with Ld,Lq and FluxPM LUTs method.

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with D,Q-flux linkage LUTs or Non-linear model with Ld,Lq and FluxPM LUTs.

D-axis flux linkage LUT, FluxD(id,iq) (Wb) — D-axis flux linkage lookup data
[-1.6, -1.6, -1.6, -1.6, -1.6; 2.4, 2.4, 2.4, 2.4, 2.4; 6.4, 6.4, 6.4, 6.4, 6.4; 10.4, 10.4, 10.4, 10.4, 10.4]*1e-3 (default) | matrix

D-axis flux linkage $FluxD(i_d, i_q)$ lookup table data (in Weber).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with D,Q-flux linkage LUTs.

Q-axis flux linkage LUT, FluxQ(id,iq) (Wb) — Q-axis flux linkage lookup data
[-8, -4, 0, 4, 8; -8, -4, 0, 4, 8; -8, -4, 0, 4, 8; -8, -4, 0, 4, 8]*1e-3 (default) | matrix

Q-axis flux linkage $FluxQ(i_d, i_q)$ lookup table data (in Weber).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with D,Q-flux linkage LUTs.

Non-linear Model with Ld, Lq, and FluxPM Lookup Tables

Ld LUT, Ld(id,iq) (H) — D-axis inductance lookup data
0.2e-3 * ones(4, 5) (default) | matrix

D-axis inductance $L_d(i_d, i_q)$ lookup table data (in Henry).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with Ld, Lq and FluxPM LUTs.

Lq LUT, Lq(id,iq) (H) — Q-axis inductance lookup data
0.2e-3 * ones(4, 5) (default) | matrix

Q-axis inductance $L_q(i_d, i_q)$ lookup table data (in Henry).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with Ld, Lq and FluxPM LUTs.

PM flux linkage LUT, FluxPM(id,iq) (Wb) — PM flux linkage lookup data
6.4e-3 * ones(4, 5) (default) | matrix

Permanent magnet flux linkage $FluxPM(i_d, i_q)$ lookup table data (in Weber).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with Ld, Lq and FluxPM LUTs.

Input units

Input units — Unit of input values
Per-Unit (PU) (default) | SI Units

Unit of the input values.

Base voltage (V) — Nominal voltage limit
24/sqrt(3) (default) | scalar

Base voltage (in Volts) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Base current (A) — Nominal current limit
19.3 (default) | scalar

Base current (in Amperes) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Base speed (rpm) — Nominal speed limit
4107 (default) | scalar

Base speed (in rpm) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Allow scaled-down motor parameters with CodeGen (higher precision with Fixed-Point data type) — Scale down internal parameters to match per-unit scale
on (default) | off

Option to scale down internal parameters to match per-unit scale when generating code.

- When you enable this option, the block scales down the internal constants and coefficients to match the per-unit scale. This allows for higher precision when you use the fixed-point data type. If you use this option with the single or double data type, some precision loss can occur depending on the number of bits allotted to the integer portion.
- When you disable this option, the block converts all the constants and coefficients used for internal calculations to SI units and then converts them back to the PU scale. This allows you to update the lookup table values in the generated code, typically, for applications such as controller tuning or end-of-line operations. You can also update the values manually for debugging or reusing previously generated code.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

ACIM Feed Forward Control | Park Transform | Speed Measurement | PI Controller | DQ Limiter

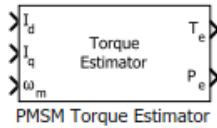
Topics

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

PMSM Torque Estimator

Estimate electromechanical torque and power



Libraries:

Motor Control Blockset / Controls / Control Reference

Description

The PMSM Torque Estimator block generates electromechanical torque and power estimates to enable field-oriented control of a permanent magnet synchronous motor (PMSM). The block outputs mathematically computed electromechanical torque for the given motor parameters. To measure the torque value accurately, consider using a physical sensor.

The block accepts feedback values of d - and q -axis currents and mechanical speed as inputs.

The block generates these estimates from motor parameters specified using one of these methods.

- Lumped parameters with d -axis and q -axis stator winding inductances and permanent magnet flux linkage.
- Nonlinear model with d -axis and q -axis flux linkage lookup tables.
- Nonlinear model with d -axis and q -axis stator winding inductances and permanent magnet flux linkage lookup tables.
- d -axis and q -axis stator winding inductances and permanent magnet flux linkage values provided using separate input ports.

Equations

If you select Per-Unit (PU) in the **Input units** parameter, the block scales down the internal parameters to match the per-unit scale by default. You can also configure the block to convert the inputs to SI units before performing any computation and convert them back to per unit values after calculating the output.

These equations describe the computation of electromechanical torque and power estimates by the block.

$$T_e = \frac{3}{2}p\{\psi_m I_q + (L_d - L_q)I_d I_q\}$$

or

$$T_e = \frac{3}{2}p(\psi_d i_q - \psi_q i_d)$$

$$P_e = T_e \cdot \omega_m$$

where:

- L_d and L_q are the d -axis and q -axis stator winding inductances (henry).

- I_d and I_q are the d -axis and q -axis current (amperes).
- ψ_m is the permanent magnet flux linkage (weber).
- ψ_d and ψ_q are the magnetic fluxes along the d - and q -axes (weber).
- p is the number of pole pairs available in the motor.
- ω_m is the mechanical speed of the rotor (rad/s).

For a detailed set of equations and assumptions that Motor Control Blockset uses for a PMSM, see “Mathematical Model of PMSM” on page 1-150.

Ports

Input

I_d — D-axis current
scalar

Current along the d -axis of the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

I_q — Q-axis current
scalar

Current along the q -axis of the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

ω_m — Mechanical speed of rotor
scalar

Mechanical speed of the rotor.

Data Types: `single` | `double` | `fixed point`

L_d — D-axis inductance
scalar

D-axis winding inductance (in henry).

Dependencies

To enable this input port, set **Motor parameter input method** to `Input port based Ld, Lq and FluxPM`.

Data Types: `single` | `double` | `fixed point`

L_q — Q-axis inductance
scalar

Q-axis winding inductance (in henry).

Dependencies

To enable this input port, set **Motor parameter input method** to `Input port based Ld, Lq and FluxPM`.

Data Types: single | double | fixed point

Flux_{PM} — Permanent magnet flux linkage
scalar

Peak permanent magnet flux linkage (in weber).

Dependencies

To enable this input port, set **Motor parameter input method** to Input port based Ld, Lq and FluxPM.

Data Types: single | double | fixed point

Output

T_e — Estimated torque
scalar

Mechanical torque output of the motor.

Data Types: single | double | fixed point

P_e — Estimated power
scalar

Power output of the motor.

Data Types: single | double | fixed point

Parameters

Motor parameters

Number of pole pairs — Number of pole pairs available in motor
4 (default) | scalar

Number of pole pairs available in the motor.

Motor parameter input method — Type of motor parameters

Linear model with lumped parameters (default) | Non-linear model with D,Q-flux linkage LUTs | Non-linear model with Ld,Lq and FluxPM LUTs | Input port based Ld, Lq and FluxPM

Motor parameters that the block uses to generate torque and power estimates.

- Linear model with lumped parameters — Generate estimates using lumped-circuit values for motor parameters L_d , L_q , and $FluxPM$.
- Non-linear model with D,Q-flux linkage LUTs — Generate estimates using d -axis flux linkage $FluxD$ and q -axis flux linkage $FluxQ$ lookup tables (LUTs).
- Non-linear model with Ld,Lq and FluxPM LUTs — Generate estimates using L_d , L_q , and $FluxPM$ LUTs, specified as block parameters.
- Input port based Ld,Lq and FluxPM — Generate estimates using L_d , L_q , and $FluxPM$ LUTs, specified as block inputs.

Linear Model with Lumped Parameters

Stator d-axis inductance, L_d (H) — D-axis stator winding inductance

0.2e-3 (default) | scalar

Stator winding inductance (henry) along the direct-axis of the rotating dq reference frame.

Dependencies

To enable this parameter, set **Motor parameter input method** to Linear model with lumped parameters.

Stator q-axis inductance, L_q (H) — Q-axis stator winding inductance

0.2e-3 (default) | scalar

Stator winding inductance (henry) along the quadrature-axis of the rotating dq reference frame.

Dependencies

To enable this parameter, set **Motor parameter input method** to Linear model with lumped parameters.

Permanent magnet flux linkage, $FluxPM$ (Wb) — Permanent magnet flux linkage

6.4e-3 (default) | scalar

Peak permanent magnet flux linkage (weber).

Dependencies

To enable this parameter, set **Motor parameter input method** to Linear model with lumped parameters.

Nonlinear Model with FluxD and FluxQ Lookup Tables

D-axis current breakpoint vector, id (A) — D-axis current lookup vector

[-40, -20, 0, 20] (default) | vector

D-axis current vector used in the following lookup tables, depending on the method used to specify the motor parameters.

- $FluxD(i_d, i_q)$ and $FluxQ(i_d, i_q)$ for the Non-linear model with D,Q-flux linkage LUTs method.
- $L_d(i_d, i_q)$, $L_q(i_d, i_q)$, and $FluxPM(i_d, i_q)$ for the Non-linear model with L_d, L_q and FluxPM LUTs method.

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with D,Q-flux linkage LUTs or Non-linear model with L_d, L_q and FluxPM LUTs.

Q-axis current breakpoint vector, iq (A) — Q-axis current lookup vector

[-40, -20, 0, 20, 40] (default) | vector

Q-axis current vector used in the following lookup tables, depending on the method used to specify the motor parameters.

- $FluxD(i_d, i_q)$ and $FluxQ(i_d, i_q)$ for the Non-linear model with D,Q-flux linkage LUTs method.

- $L_d(i_d, i_q)$, $L_q(i_d, i_q)$, and $FluxPM(i_d, i_q)$ for the Non-linear model with Ld, Lq and FluxPM LUTs method.

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with D,Q-flux linkage LUTs or Non-linear model with Ld, Lq and FluxPM LUTs.

D-axis flux linkage LUT, FluxD(id,iq) (Wb) — D-axis flux linkage lookup data

$[-1.6, -1.6, -1.6, -1.6, -1.6; 2.4, 2.4, 2.4, 2.4, 2.4; 6.4, 6.4, 6.4, 6.4, 6.4; 10.4, 10.4, 10.4, 10.4, 10.4] * 1e-3$ (default) | matrix

D-axis flux linkage $FluxD(i_d, i_q)$ lookup table data (in weber).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with D,Q-flux linkage LUTs.

Q-axis flux linkage LUT, FluxQ(id,iq) (Wb) — Q-axis flux linkage lookup data

$[-8, -4, 0, 4, 8; -8, -4, 0, 4, 8; -8, -4, 0, 4, 8; -8, -4, 0, 4, 8] * 1e-3$ (default) | matrix

Q-axis flux linkage $FluxQ(i_d, i_q)$ lookup table data (in weber).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with D,Q-flux linkage LUTs.

Nonlinear Model with Ld, Lq, and FluxPM Lookup Tables

Ld LUT, Ld(id,iq) (H) — D-axis inductance lookup data

$0.2e-3 * \text{ones}(4, 5)$ (default) | matrix

D-axis inductance $L_d(i_d, i_q)$ lookup table data (in henry).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with Ld, Lq and FluxPM LUTs.

Lq LUT, Lq(id,iq) (H) — Q-axis inductance lookup table data

$0.2e-3 * \text{ones}(4, 5)$ (default) | matrix

Q-axis inductance $L_q(i_d, i_q)$ lookup table data (in henry).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with Ld, Lq and FluxPM LUTs.

PM flux linkage LUT, FluxPM(id,iq) (Wb) — PM flux linkage lookup data

$6.4e-3 * \text{ones}(4, 5)$ (default) | matrix

Permanent magnet flux linkage $FluxPM(i_d, i_q)$ lookup table data (in weber).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with Ld, Lq and FluxPM LUTs.

Input units

Input units — Unit of input values

Per-Unit (PU) (default) | SI Units

Unit of the input values.

Base Voltage (V) — Nominal voltage limit

24/sqrt(3) (default) | scalar

Base voltage (in volts) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Base Current (A) — Nominal current limit

19.3 (default) | scalar

Base current (in amperes) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Base Speed (rpm) — Nominal speed limit

4107 (default) | scalar

Base speed (in rpm) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Base torque (Nm) — Nominal torque limit

0.74112 (default) | scalar

Base torque (in Nm) for per-unit system. See “Per-Unit System” page for more details.

You cannot configure this parameter when you set **Motor parameter input method** to Linear model with lumped parameters or Non-linear model with Ld, Lq and FluxPM LUTs. The block computes its value using the other parameters.

Dependencies

To display this parameter, set **Input units** to Per-Unit (PU).

Base power (W) — Nominal power limit

401.143 (default) | scalar

Base power (in W) for per-unit system. See “Per-Unit System” page for more details.

You cannot configure this parameter when you set **Motor parameter input method** to Linear model with lumped parameters or Non-linear model with Ld,Lq and FluxPM LUTs. The block computes its value using the other parameters.

Dependencies

To display this parameter, set **Input units** to Per-Unit (PU).

Allow scaled-down motor parameters with CodeGen (higher precision with Fixed-Point data type) — Scale down internal parameters to match per-unit scale
on (default) | off

Option to scale down internal parameters to match per-unit scale when generating code.

- When you enable this option, the block scales down the internal constants and coefficients to match the per-unit scale. This allows for higher precision when you use the fixed-point data type. If you use this option with the single or double data type, some precision loss can occur depending on the number of bits allotted to the integer portion.
- When you disable this option, the block converts all the constants and coefficients used for internal calculations to SI units and then converts them back to the PU scale. This allows you to update the lookup table values in the generated code, typically, for applications such as controller tuning or end-of-line operations. You can also update the values manually for debugging or reusing previously generated code.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

ACIM Torque Estimator | Park Transform | Speed Measurement | MTPA Control Reference | Vector Control Reference

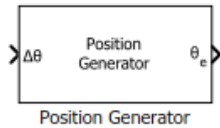
Topics

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

Position Generator

Generate position ramp of fixed frequency



Libraries:

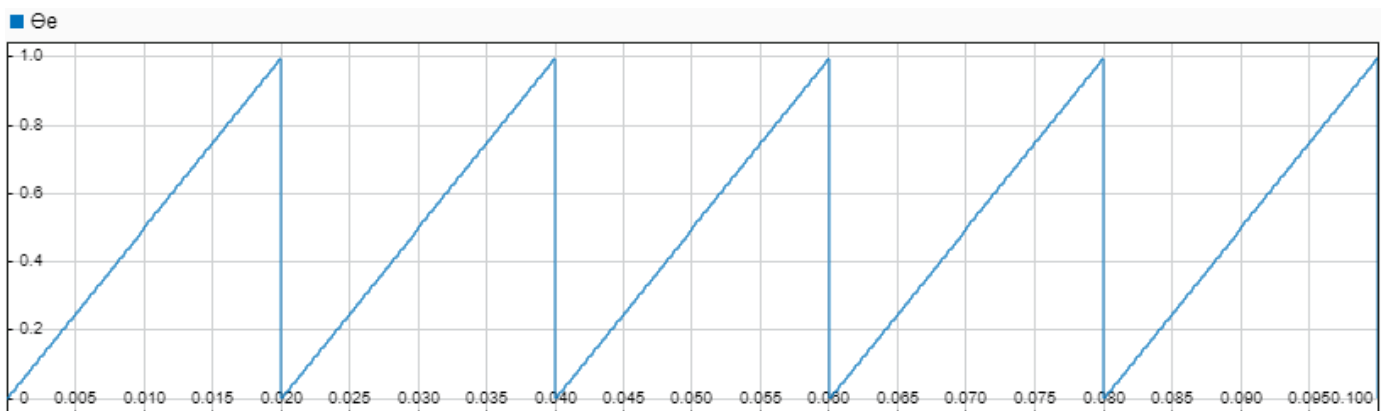
Motor Control Blockset / Controls / Control Reference

Motor Control Blockset HDL Support / Controls / Control Reference

Description

The Position Generator block generates a position ramp signal (with a frequency that is identical to that of the reference voltage signal) using the position increment value of the reference signal.

We recommend that you use fixed-step discrete solver for this block to enable code generation and ensure accurate simulation.



Ports

Input

Δθ — Position increment value
scalar

Position increment value of a fixed frequency reference voltage signal (in either per unit, radians, or degrees). These equations describe how the block computes the position increment:

- $\Delta\theta$ (per unit) = Frequency \times Sample Time
- $\Delta\theta$ (radians) = $2\pi \times$ Frequency \times Sample Time
- $\Delta\theta$ (degrees) = $360 \times$ Frequency \times Sample Time

Data Types: single | double | fixed point

Reset — External reset signal
scalar

External pulse that resets the position ramp output based on the value of the **External reset** parameter.

Dependencies

To enable this port, set **External reset** to either active high resets to zero or active high resets to initial condition.

Data Types: `single` | `double` | `fixed point`

Output

θ_e — Reference voltage position
scalar

Position or phase value of the reference voltage signal (in either per unit, radians, or degrees).

Data Types: `single` | `double` | `fixed point`

Parameters

Theta Units — Unit of θ
`Per-unit (default)` | `Radians` | `Degrees`

Unit of the input position increment value and the output reference voltage position.

Initial theta output — Initial value of θ_e
 θ (default) | scalar

Output position ramp value (in either per unit, radians, or degrees) at initial time (0 seconds).

External reset — Output value on reset
`none (default)` | `active high resets to zero` | `active high resets to initial condition`

Output position ramp value (in either per unit, radians, or degrees) at the time when the block receives an active high external reset pulse. You can reset the output to either zero or to equal the value of the **Initial theta output** parameter.

Version History

Introduced in R2020a

Extended Capabilities

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

HDL Code Generation
Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Restriction

The block supports HDL code generation only when you set the **External reset** parameter to none.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

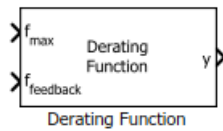
ACIM Slip Speed Estimator | Sine-Cosine Lookup | 3-Phase Sine Voltage Generator | Vector Control Reference

Topics

“Open-Loop and Closed-Loop Control”
 “Field-Oriented Control (FOC)”

Derating Function

Compute derating factor



Libraries:

Motor Control Blockset / Controls / Controllers

Motor Control Blockset HDL Support / Controls / Controllers

Description

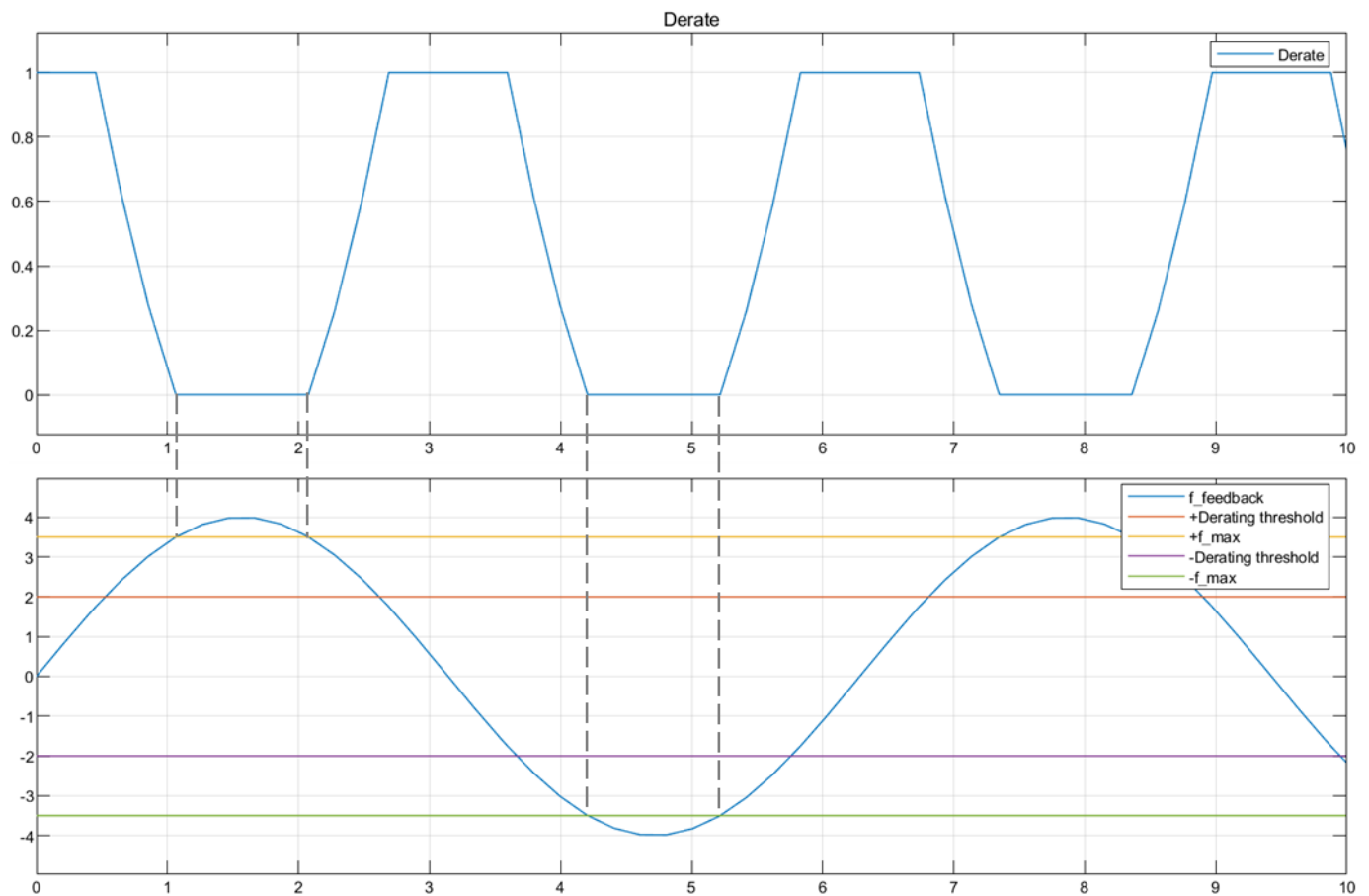
The Derating Function block generates the derating factor (y) according to the feedback (f_{feedback}) and maximum limit (f_{max}) values of the input reference signal.

The derating factor:

- Remains equal to one when f_{feedback} lies between positive and negative values of the **Derating threshold**. The derating factor varies linearly outside this range according to f_{feedback} .
- Remains equal to zero when the reference signal lies beyond (positive or negative) f_{max} .

Therefore, you can use the generated derating factor to derate a control signal after the reference signal crosses the specified **Derating threshold**.

This figure shows the block output when you use a sinusoidal wave as f_{feedback} .



Equations

The **Derating threshold** parameter, x indicates the percentage of peak amplitude for the reference signal. The **Derating threshold** is 0.5 in the block output shown, which results in a threshold value of 2 (for the peak amplitude value of 4 for the sinusoidal reference signal).

$$x = [0, 1)$$

This equation describes how the block computes the derating factor (y).

$$\text{Derating factor } (y) = 1 - \frac{f_{\text{feedback}} - x f_{\text{max}}}{(1 - x) f_{\text{max}}}$$

Ports

Input

f_{max} — Maximum reference signal limit
scalar

Maximum limit of the reference signal value beyond which the derating factor becomes zero.

Data Types: single | double | fixed point

f_{feedback} — Reference feedback signal
scalar

Reference signal that the block uses to generate the derating factor, which you can then use to derate a control signal.

Data Types: `single` | `double` | `fixed point`

Output

y — Derating factor
scalar

Derating factor that the block generates based on the feedback and maximum limit values of the reference signal when the signal exceeds the value of the **Derating threshold** parameter.

Data Types: `single` | `double` | `fixed point`

Parameters

Derating threshold — Threshold beyond which derating must occur
0.9 (default) | scalar in the range [0, 1)

The reference signal value beyond which the block generates the derating factor.

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
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InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

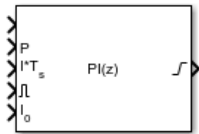
[Speed Measurement](#) | [MTPA Control Reference](#) | [Vector Control Reference](#) | [PMSM Torque Estimator](#)

Topics

“Open-Loop and Closed-Loop Control”
“Field-Oriented Control (FOC)”

PI Controller

Discrete-time PID Controller



Libraries:

Motor Control Blockset / Controls / Controllers

Motor Control Blockset HDL Support / Controls / Controllers

Description

The PI Controller block implements a discrete-time PID controller (PID, PI, PD, P only, or I only). The block is identical to the Discrete PID Controller Simulink® block.

The block output is a weighted sum of the input signal, the integral of the input signal, and the derivative of the input signal. The weights are the proportional, integral, and derivative gain parameters. A first-order pole filters the derivative action.

- Controller type (PID, PI, PD, P only, or I only) — See the **Controller** parameter.
- Controller form (Parallel or Ideal) — See the **Form** parameter.
- Time domain (continuous or discrete) — See the **Time domain** parameter.
- Initial conditions and reset trigger — See the **Source** and **External reset** parameters.
- Output saturation limits and built-in anti-windup mechanism — See the **Limit output** parameter.
- Signal tracking for bumpless control transfer and multiloop control — See the **Enable tracking mode** parameter.

As you change these options, the internal structure of the block changes by activating different variant subsystems. (For more information, see “Implement Variations in Separate Hierarchy Using Variant Subsystems”). To examine the internal structure of the block and its variant subsystems, right-click the block and select **Mask > Look Under Mask**.

PID Gain Tuning

The PID controller gains are tunable either manually or automatically. Automatic tuning requires Simulink Control Design™ software. For more information about automatic tuning, see the **Select tuning method** parameter.

Ports

Input

Port_1(u) — Error signal input

scalar | vector

Difference between a reference signal and the output of the system under control.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64 | fixed point

P — Proportional gain

scalar | vector

Proportional gain, provided from a source external to the block. External gain input is useful, for example, when you want to map a different PID parameterization to the PID gains of the block. You can also use external gain input to implement gain-scheduled PID control. In gain-scheduled control, you determine the PID coefficients by logic or other calculations in your model and feed them to the block.

Dependencies

To enable this port, set **Controller parameters Source** to external.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64 | fixed point

I*T_s — Integral gain multiplied by sample time

scalar | vector

Integral gain multiplied by the controller sample time, provided from a source external to the block. External gain input is useful, for example, when you want to map a different PID parameterization to the PID gains of the block. You can also use external gain input to implement gain-scheduled PID control. In gain-scheduled control, you determine the PID coefficients by logic or other calculations in your model and feed them to the block.

Note PID tuning tools, such as the **PID Tuner** app and Closed-Loop PID Autotuner block, tune the gain **I** but not **I*T_s**. Therefore, multiply the integral gain value you obtain from a tuning tool by the sample time before you supply it to this port.

When you use **I*T_s** instead of **I**, the block requires fewer calculations to perform integration. This improves the execution time of the generated code.

Dependencies

To enable this port, set **Controller parameters Source** to external, set **Controller** to a controller type that has integral action, and enable the **Use I*T_s** parameter.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64 | fixed point

I — Integral gain

scalar | vector

Integral gain, provided from a source external to the block. External gain input is useful, for example, when you want to map a different PID parameterization to the PID gains of the block. You can also use external gain input to implement gain-scheduled PID control. In gain-scheduled control, you determine the PID coefficients by logic or other calculations in your model and feed them to the block.

When you supply gains externally, time variations in the integral gain are also integrated. This result occurs because of the way the PID gains are implemented within the block. For details, see the **Controller parameters Source** parameter.

Dependencies

To enable this port, set **Controller parameters Source** to `external`, and set **Controller** to a controller type that has integral action.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `fixed point`

D — Derivative gain

`scalar` | `vector`

Derivative gain, provided from a source external to the block. External gain input is useful, for example, when you want to map a different PID parameterization to the PID gains of the block. You can also use external gain input to implement gain-scheduled PID control. In gain-scheduled control, you determine the PID coefficients by logic or other calculations in your model and feed them to the block.

When you supply gains externally, time variations in the derivative gain are also differentiated. This result occurs because of the way the PID gains are implemented within the block. For details, see the **Controller parameters Source** parameter.

Dependencies

To enable this port, set **Controller parameters Source** to `external`, and set **Controller** to a controller type that has derivative action.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `fixed point`

N — Filter coefficient

`scalar` | `vector`

Derivative filter coefficient, provided from a source external to the block. External coefficient input is useful, for example, when you want to map a different PID parameterization to the PID gains of the block. You can also use the external input to implement gain-scheduled PID control. In gain-scheduled control, you determine the PID coefficients by logic or other calculations in your model and feed them to the block.

Dependencies

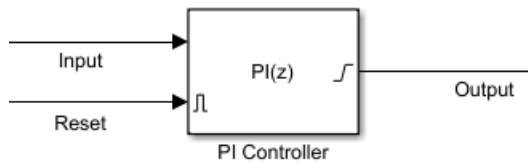
To enable this port, set **Controller parameters Source** to `external`, and set **Controller** to a controller type that has a filtered derivative.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `fixed point`

Reset — External reset trigger

`scalar`

Trigger to reset the integrator and filter to their initial conditions. The value of the **External reset** parameter determines whether reset occurs on a rising signal, a falling signal, or a level signal. The port icon indicates the selected trigger type. For example, the following illustration shows a PID block with **External reset** set to `level`.



When the trigger occurs, the block resets the integrator and filter to the initial conditions specified by the **Integrator Initial condition** and **Filter Initial condition** parameters or the **I₀** and **D₀** ports.

Note To be compliant with the Motor Industry Software Reliability Association (MISRA™) software standard, your model must use Boolean signals to drive the external reset ports of the PID controller block.

Dependencies

To enable this port, set **External reset** to any value other than none.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64 | fixed point | Boolean

I₀ — Integrator initial condition

scalar | vector

Integrator initial condition, provided from a source external to the block.

Dependencies

To enable this port, set **Initial conditions Source** to external, and set **Controller** to a controller type that has integral action.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64 | fixed point

D₀ — Filter initial condition

scalar | vector

Initial condition of the derivative filter, provided from a source external to the block.

Dependencies

To enable this port, set **Initial conditions Source** to external, and set **Controller** to a controller type that has derivative action.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64 | fixed point

up — Output saturation upper limit

scalar | vector

Upper limit of the block output, provided from a source external to the block. If the weighted sum of the proportional, integral, and derivative actions exceeds the value provided at this port, the block output is held at that value.

Dependencies

To enable this port, select **Limit output** and set the output saturation **Source** to external.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `fixed point`

lo — Output saturation lower limit

`scalar` | `vector`

Lower limit of the block output, provided from a source external to the block. If the weighted sum of the proportional, integral, and derivative actions goes below the value provided at this port, the block output is held at that value.

Dependencies

To enable this port, select **Limit output** and set the output saturation **Source** to `external`.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `fixed point`

TR — Tracking signal

`scalar` | `vector`

Signal for controller output to track. When signal tracking is active, the difference between the tracking signal and the block output is fed back to the integrator input. Signal tracking is useful for implementing bumpless control transfer in systems that switch between two controllers. It can also be useful to prevent block windup in multiloop control systems. For more information, see the **Enable tracking mode** parameter.

Dependencies

To enable this port, select the **Enable tracking mode** parameter.

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `fixed point`

T_{DTI} — Discrete-integrator time

`scalar`

Discrete-integrator time, provided as a scalar to the block. You can use your own value of discrete-time integrator sample time that defines the rate at which the block is going to be run either in Simulink or on external hardware. The value of the discrete-time integrator time should match the average sampling rate of the external interrupts, when the block is used inside a conditionally-executed subsystem.

In other words, you can specify T_s for any of the integrator methods below such that the value matches the average sampling rate of the external interrupts. In discrete time, the derivative term of the controller transfer function is:

$$D\left[\frac{N}{1 + N\alpha(z)}\right],$$

where $\alpha(z)$ depends on the integrator method you specify with this parameter.

Forward Euler

$$\alpha(z) = \frac{T_s}{z - 1} \cdot$$

Backward Euler

$$\alpha(z) = \frac{T_s z}{z - 1} \cdot$$

Trapezoidal

$$\alpha(z) = \frac{T_s}{2} \frac{z + 1}{z - 1} \cdot$$

For more information about discrete-time integration, see the Discrete-Time Integrator block reference page. For more information on conditionally executed subsystems, see “Conditionally Executed Subsystems Overview”.

Dependencies

To enable this port, set **Time Domain** to Discrete-time and select the **PID Controller is inside a conditionally executed subsystem** option.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

Output

Port_1(y) — Controller output

scalar | vector

Controller output, generally based on a sum of the input signal, the integral of the input signal, and the derivative of the input signal, weighted by the proportional, integral, and derivative gain parameters. A first-order pole filters the derivative action. Which terms are present in the controller signal depends on what you select for the **Controller** parameter. The base controller transfer function for the current settings is displayed in the **Compensator formula** section of the block parameters and under the mask. Other parameters modify the block output, such as saturation limits specified by the **Upper Limit** and **Lower Limit** saturation parameters.

The controller output is a vector signal when any of the inputs is a vector signal. In that case, the block acts as N independent PID controllers, where N is the number of signals in the input vector.

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64 | fixed point

Parameters

Controller — Controller type

PI (default) | PID | PD | P | I

Specify which of the proportional, integral, and derivative terms are in the controller.

PID

Proportional, integral, and derivative action.

PI

Proportional and integral action only.

PD

Proportional and derivative action only.

P

Proportional action only.

I

Integral action only.

Tip The controller transfer function for the current setting is displayed in the **Compensator formula** section of the block parameters and under the mask.

Programmatic Use

Block Parameter: Controller

Type: string, character vector
Values: "PID", "PI", "PD", "P", "I"
Default: "PI"

Form — Controller structure
 Parallel (default) | Ideal

Specify whether the controller structure is parallel or ideal.

Parallel

The controller output is the sum of the proportional, integral, and derivative actions, weighted independently by **P**, **I**, and **D**, respectively. For example, for a continuous-time parallel-form PID controller, the transfer function is:

$$C_{par}(s) = P + I\left(\frac{1}{s}\right) + D\left(\frac{Ns}{s+N}\right).$$

For a discrete-time parallel-form controller, the transfer function is:

$$C_{par}(z) = P + I\alpha(z) + D\left[\frac{N}{1+N\beta(z)}\right],$$

where the **Integrator method** and **Filter method** parameters determine $\alpha(z)$ and $\beta(z)$, respectively.

Ideal

The proportional gain **P** acts on the sum of all actions. For example, for a continuous-time ideal-form PID controller, the transfer function is:

$$C_{id}(s) = P\left[1 + I\left(\frac{1}{s}\right) + D\left(\frac{Ns}{s+N}\right)\right].$$

For a discrete-time ideal-form controller, the transfer function is:

$$C_{id}(z) = P\left[1 + I\alpha(z) + D\frac{N}{1+N\beta(z)}\right],$$

where the **Integrator method** and **Filter method** parameters determine $a(z)$ and $b(z)$, respectively.

Tip The controller transfer function for the current settings is displayed in the **Compensator formula** section of the block parameters and under the mask.

Programmatic Use

Block Parameter: Controller

Type: string, character vector
Values: "Parallel", "Ideal"
Default: "Parallel"

Time domain — Specify discrete-time or continuous-time controller
 Discrete-time (default) | Continuous-time

When you select **Discrete-time**, it is recommended that you specify an explicit sample time for the block. See the **Sample time (-1 for inherited)** parameter. Selecting **Discrete-time** also enables the **Integrator method**, and **Filter method** parameters.

When the PID Controller block is in a model with synchronous state control (see the State Control block), you cannot select **Continuous-time**.

Programmatic Use**Block Parameter:** TimeDomain**Type:** string, character vector**Values:** "Continuous-time", "Discrete-time"**Default:** "Discrete-time"**PID Controller is inside a conditionally executed subsystem** — Enable the discrete-integrator time port

off (default) | on

For discrete-time PID controllers, enable the discrete-time integrator port to use your own value of discrete-time integrator sample time. To ensure proper integration, use the T_{DTI} port to provide a scalar value of Δt for accurate discrete-time integration.

Dependencies

To enable this parameter, set **Time Domain** to **Discrete-time**.

Programmatic Use**Block Parameter:** UseExternalTs**Type:** string, character vector**Values:** "on", "off"**Default:** "off"**Sample time (-1 for inherited)** — Discrete interval between samples

-1 (default) | positive scalar

Specify a sample time by entering a positive scalar value, such as 0.1. The default discrete sample time of -1 means that the block inherits its sample time from upstream blocks. However, it is recommended that you set the controller sample time explicitly, especially if you expect the sample time of upstream blocks to change. The effect of the controller coefficients P, I, D, and N depend on the sample time. Thus, for a given set of coefficient values, changing the sample time changes the performance of the controller.

See “Specify Sample Time” for more information.

To implement a continuous-time controller, set **Time domain** to **Continuous-time**.

Tip If you want to run the block with an externally specified or variable sample time, set this parameter to -1 and put the block in a Triggered Subsystem. Then, trigger the subsystem at the desired sample time.

Dependencies

To enable this parameter, set **Time domain** to **Discrete-time**.

Programmatic Use**Block Parameter:** SampleTime**Type:** scalar**Values:** -1, positive scalar**Default:** -1**Integrator method** — Method for computing integral in discrete-time controller

Forward Euler (default) | Backward Euler | Trapezoidal

In discrete time, the integral term of the controller transfer function is $I\alpha(z)$, where $\alpha(z)$ depends on the integrator method you specify with this parameter.

Forward Euler

Forward rectangular (left-hand) approximation,

$$\alpha(z) = \frac{T_s}{z-1}.$$

This method is best for small sampling times, where the Nyquist limit is large compared to the bandwidth of the controller. For larger sampling times, the Forward Euler method can result in instability, even when discretizing a system that is stable in continuous time.

Backward Euler

Backward rectangular (right-hand) approximation,

$$\alpha(z) = \frac{T_s z}{z-1}.$$

An advantage of the Backward Euler method is that discretizing a stable continuous-time system using this method always yields a stable discrete-time result.

Trapezoidal

Bilinear approximation,

$$\alpha(z) = \frac{T_s z + 1}{2 z - 1}.$$

An advantage of the Trapezoidal method is that discretizing a stable continuous-time system using this method always yields a stable discrete-time result. Of all available integration methods, the Trapezoidal method yields the closest match between frequency-domain properties of the discretized system and the corresponding continuous-time system.

Tip The controller formula for the current setting is displayed in the **Compensator formula** section of the block parameters and under the mask.

Note For the BackwardEuler or Trapezoidal methods, you cannot generate HDL code for the block if either:

- **Limit output** is selected and **Anti-Windup Method** is anything other than none.
 - **Enable tracking mode** is selected.
-

For more information about discrete-time integration, see the Discrete-Time Integrator block reference page.

Dependencies

To enable this parameter, set **Time Domain** to Discrete-time and set **Controller** to a controller type with integral action.

Programmatic Use

Block Parameter: IntegratorMethod

Type: string, character vector

Values: "Forward Euler", "Backward Euler", "Trapezoidal"

Default: "Forward Euler"

Filter method — Method for computing derivative in discrete-time controller
Forward Euler (default) | Backward Euler | Trapezoidal

In discrete time, the derivative term of the controller transfer function is:

$$D\left[\frac{N}{1 + N\alpha(z)}\right],$$

where $\alpha(z)$ depends on the filter method you specify with this parameter.

Forward Euler

Forward rectangular (left-hand) approximation,

$$\alpha(z) = \frac{T_s}{z - 1}.$$

This method is best for small sampling times, where the Nyquist limit is large compared to the bandwidth of the controller. For larger sampling times, the Forward Euler method can result in instability, even when discretizing a system that is stable in continuous time.

Backward Euler

Backward rectangular (right-hand) approximation,

$$\alpha(z) = \frac{T_s z}{z - 1} \cdot$$

An advantage of the Backward Euler method is that discretizing a stable continuous-time system using this method always yields a stable discrete-time result.

Trapezoidal

Bilinear approximation,

$$\alpha(z) = \frac{T_s z + 1}{2 z - 1} \cdot$$

An advantage of the Trapezoidal method is that discretizing a stable continuous-time system using this method always yields a stable discrete-time result. Of all available integration methods, the Trapezoidal method yields the closest match between frequency-domain properties of the discretized system and the corresponding continuous-time system.

Tip The controller formula for the current setting is displayed in the **Compensator formula** section of the block parameters and under the mask.

For more information about discrete-time integration, see the Discrete-Time Integrator block reference page.

Dependencies

To enable this parameter, set **Time Domain** to Discrete-time and enable **Use filtered derivative**.

Programmatic Use

Block Parameter: FilterMethod

Type: string, character vector

Values: "Forward Euler", "Backward Euler", "Trapezoidal"

Default: "Forward Euler"

Main

Source — Source for controller gains and filter coefficient

external (default) | internal

Enabling external inputs for the parameters allows you to compute PID gains and filter coefficients externally to the block and provide them to the block as signal inputs.

internal

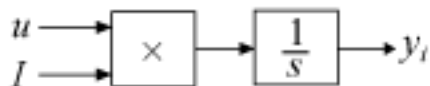
Specify the controller gains and filter coefficient using the block parameters **P**, **I** (or **I*Ts**), **D**, and **N**.

external

Specify the PID gains and filter coefficient externally using block inputs. An additional input port appears on the block for each parameter that is required for the current controller type.

External gain input is useful, for example, when you want to map a different PID parameterization to the PID gains of the block. You can also use external gain input to implement gain-scheduled PID control. In gain-scheduled control, you determine the PID gains by logic or other calculations in your model and feed them to the block.

When you supply gains externally, time variations in the integral and derivative gain values are integrated and differentiated, respectively. This result occurs because in both continuous time and discrete time, the gains are applied to the signal before integration or differentiation. For example, for a continuous-time PID controller with external inputs, the integrator term is implemented as shown in the following illustration.



Within the block, the input signal u is multiplied by the externally supplied integrator gain, I , before integration. This implementation yields:

$$y_i = \int uI dt.$$

Thus, the integrator gain is included in the integral. Similarly, in the derivative term of the block, multiplication by the derivative gain precedes the differentiation, which causes the derivative gain D to be differentiated.

Programmatic Use

Block Parameter: ControllerParametersSource

Type: string, character vector

Values: "internal", "external"

Default: "external"

Proportional (P) — Proportional gain

1 (default) | scalar | vector

Specify a finite, real gain value for the proportional gain. When **Controller form** is:

- **Parallel** — Proportional action is independent of the integral and derivative actions. For instance, for a continuous-time parallel PID controller, the transfer function is:

$$C_{par}(s) = P + I\left(\frac{1}{s}\right) + D\left(\frac{Ns}{s+N}\right).$$

For a discrete-time parallel-form controller, the transfer function is:

$$C_{par}(z) = P + I\alpha(z) + D\left[\frac{N}{1+N\beta(z)}\right],$$

where the **Integrator method** and **Filter method** parameters determine $\alpha(z)$ and $\beta(z)$, respectively.

- **Ideal** — The proportional gain multiplies the integral and derivative terms. For instance, for a continuous-time ideal PID controller, the transfer function is:

$$C_{id}(s) = P\left[1 + I\left(\frac{1}{s}\right) + D\left(\frac{Ns}{s+N}\right)\right].$$

For a discrete-time ideal-form controller, the transfer function is:

$$C_{id}(z) = P\left[1 + I\alpha(z) + D\frac{N}{1+N\beta(z)}\right],$$

where the **Integrator method** and **Filter method** parameters determine $\alpha(z)$ and $\beta(z)$, respectively.

Tunable: Yes

Dependencies

To enable this parameter, in the **Main** tab, set the controller-parameters **Source** to `internal` and set **Controller** to `PID`, `PD`, `PI`, or `P`.

Programmatic Use

Block Parameter: `P`

Type: scalar, vector

Default: 1

Integral (I) — Integral gain

1 (default) | scalar | vector

Specify a finite, real gain value for the integral gain.

Tunable: Yes

Dependencies

To enable this parameter, in the **Main** tab, set the controller-parameters **Source** to `internal`, and set **Controller** to a type that has integral action.

Programmatic Use

Block Parameter: `I`

Type: scalar, vector

Default: 1

Integral (I*Ts) — Integral gain multiplied by sample time
1 (default) | scalar | vector

Specify a finite, real gain value for the integral gain multiplied by the sample time.

Note PID tuning tools, such as the **PID Tuner** app and Closed-Loop PID Autotuner block, tune the gain **I** but not **I*Ts**. Therefore, multiply the integral gain value you obtain from a tuning tool by the sample time before you write it to this parameter.

When you use **I*Ts** instead of **I**, the block requires fewer calculations to perform integration. This improves the execution time of the generated code.

Tunable: No

Dependencies

To enable this parameter, in the **Main** tab, set the controller-parameters **Source** to `internal`, set **Controller** to a type that has integral action, and enable the **Use I*Ts** parameter.

Programmatic Use

Block Parameter: I

Type: scalar, vector

Default: 1

Use I*Ts — Use integral gain multiplied by sample time
`on` (default) | `off`

For discrete-time controllers with integral action, the block takes the integral gain as an input and multiplies it by the sample time internally as a part of performing the integration. You can enable this parameter to specify integral gain multiplied by sample time as input (**I*Ts**) in place of the integral gain (**I**). Doing so reduces the number of internal calculations and is useful when you want to improve the execution time of your generated code.

Dependencies

To enable this parameter, set **Controller** to a controller type that has integral action.

Programmatic Use

Block Parameter: UseKiTs

Type: string, character vector

Values: "on", "off"

Default: "on"

Derivative (D) — Derivative gain
0 (default) | scalar | vector

Specify a finite, real gain value for the derivative gain.

Tunable: Yes

Dependencies

To enable this parameter, in the **Main** tab, set the controller-parameters **Source** to `internal`, and set **Controller** to `PID` or `PD`.

Programmatic Use**Block Parameter:** D**Type:** scalar, vector**Default:** 0**Use filtered derivative** — Apply filter to derivative term

on (default) | off

For discrete-time PID controllers only, clear this option to replace the filtered derivative with an unfiltered discrete-time differentiator. When you do so, the derivative term of the controller transfer function becomes:

$$D \frac{z-1}{zT_s}$$

For continuous-time PID controllers, the derivative term is always filtered.

Dependencies

To enable this parameter, set **Time domain** to Discrete-time, and set **Controller** to a type that has derivative action.

Programmatic Use**Block Parameter:** UseFilter**Type:** string, character vector**Values:** "on", "off"**Default:** "on"**Filter coefficient (N)** — Derivative filter coefficient

100 (default) | scalar | vector

Specify a finite, real gain value for the filter coefficient. The filter coefficient determines the pole location of the filter in the derivative action of the block. The location of the filter pole depends on the **Time domain** parameter.

- When **Time domain** is Continuous-time, the pole location is $s = -N$.
- When **Time domain** is Discrete-time, the pole location depends on the **Filter method** parameter.

Filter Method	Location of Filter Pole
Forward Euler	$z_{pole} = 1 - NT_s$
Backward Euler	$z_{pole} = \frac{1}{1 + NT_s}$
Trapezoidal	$z_{pole} = \frac{1 - NT_s/2}{1 + NT_s/2}$

The block does not support $N = \text{Inf}$ (ideal unfiltered derivative). When the **Time domain** is Discrete-time, you can clear **Use filtered derivative** to remove the derivative filter.

Tunable: Yes

Dependencies

To enable this parameter, in the **Main** tab, set the controller-parameters **Source** to **internal** and set **Controller** to **PID** or **PD**.

Programmatic Use

Block Parameter: N

Type: scalar, vector

Default: 100

Select tuning method — Tool for automatic tuning of controller coefficients

Transfer Function Based (PID Tuner App) (default) | Frequency Response Based

If you have Simulink Control Design software, you can automatically tune the PID coefficients. To do so, use this parameter to select a tuning tool, and click **Tune**.

Transfer Function Based (PID Tuner App)

Use **PID Tuner**, which lets you interactively tune PID coefficients while examining relevant system responses to validate performance. By default, **PID Tuner** works with a linearization of your plant model. For models that cannot be linearized, you can tune PID coefficients against a plant model estimated from simulated or measured response data. For more information, see “Introduction to Model-Based PID Tuning in Simulink” (Simulink Control Design).

Frequency Response Based

Use **Frequency Response Based PID Tuner**, which tunes PID controller coefficients based on frequency-response estimation data obtained by simulation. This tuning approach is especially useful for plants that are not linearizable or that linearize to zero. For more information, see “Design PID Controller from Plant Frequency-Response Data” (Simulink Control Design).

Both of these tuning methods assume a single-loop control configuration. Simulink Control Design software includes other tuning approaches that suit more complex configurations. For information about other ways to tune a PID Controller block, see “Choose a Control Design Approach” (Simulink Control Design).

Enable zero-crossing detection — Detect zero crossings on reset and on entering or leaving a saturation state

on (default) | off

Zero-crossing detection can accurately locate signal discontinuities without resorting to excessively small time steps that can lead to lengthy simulation times. If you select **Limit output** or activate **External reset** in your PID Controller block, activating zero-crossing detection can reduce computation time in your simulation. Selecting this parameter activates zero-crossing detection:

- At initial-state reset
- When entering an upper or lower saturation state
- When leaving an upper or lower saturation state

For more information about zero-crossing detection, see “Zero-Crossing Detection”.

Programmatic Use

Block Parameter: ZeroCross

Type: string, character vector

Values: "on", "off"

Default: "on"

Initialization

Source — Source for integrator and derivative initial conditions
`external` (default) | `internal`

Simulink uses initial conditions to initialize the integrator and derivative-filter (or the unfiltered derivative) output at the start of a simulation or at a specified trigger event. (See the **External reset** parameter.) These initial conditions determine the initial block output. Use this parameter to select how to supply the initial condition values to the block.

`internal`

Specify the initial conditions using the **Integrator Initial condition** and **Filter Initial condition** parameters. If **Use filtered derivative** is not selected, use the **Differentiator** parameter to specify the initial condition for the unfiltered differentiator instead of a filter initial condition.

`external`

Specify the initial conditions externally using block inputs. Additional input ports **I₀** and **D₀** appear on the block. If **Use filtered derivative** is not selected, supply the initial condition for the unfiltered differentiator at **D₀** instead of a filter initial condition.

Programmatic Use

Block Parameter: `InitialConditionSource`

Type: string, character vector

Values: "internal", "external"

Default: "external"

Integrator — Integrator initial condition
`0` (default) | scalar | vector

Simulink uses the integrator initial condition to initialize the integrator at the start of a simulation or at a specified trigger event (see **External reset**). The integrator initial condition and the filter initial condition determine the initial output of the PID controller block.

The integrator initial condition cannot be NaN or Inf.

Dependencies

To use this parameter, in the **Initialization** tab, set **Source** to `internal`, and set **Controller** to a type that has integral action.

Programmatic Use

Block Parameter: `InitialConditionForIntegrator`

Type: scalar, vector

Default: `0`

Filter — Filter initial condition
`0` (default) | scalar | vector

Simulink uses the filter initial condition to initialize the derivative filter at the start of a simulation or at a specified trigger event (see **External reset**). The integrator initial condition and the filter initial condition determine the initial output of the PID controller block.

The filter initial condition cannot be NaN or Inf.

Dependencies

To use this parameter, in the **Initialization** tab, set **Source** to `internal`, and use a controller that has a derivative filter.

Programmatic Use

Block Parameter: `InitialConditionForFilter`

Type: scalar, vector

Default: 0

Differentiator — Initial condition for unfiltered derivative

0 (default) | scalar | vector

When you use an unfiltered derivative, Simulink uses this parameter to initialize the differentiator at the start of a simulation or at a specified trigger event (see **External reset**). The integrator initial condition and the derivative initial condition determine the initial output of the PID controller block.

The derivative initial condition cannot be NaN or Inf.

Dependencies

To use this parameter, set **Time domain** to `Discrete-time`, clear the **Use filtered derivative** check box, and in the **Initialization** tab, set **Source** to `internal`.

Programmatic Use

Block Parameter: `DifferentiatorICPrevScaledInput`

Type: scalar, vector

Default: 0

Initial condition setting — Location at which initial condition is applied

Auto (default) | Output

Use this parameter to specify whether to apply the **Integrator Initial condition** and **Filter Initial condition** parameter to the corresponding block state or output. You can change this parameter at the command line only, using `set_param` to set the `InitialConditionSetting` parameter of the block.

Auto

Use this option in all situations except when the block is in a triggered subsystem or a function-call subsystem and simplified initialization mode is enabled.

Output

Use this option when the block is in a triggered subsystem or a function-call subsystem and simplified initialization mode is enabled.

For more information about the **Initial condition setting** parameter, see the Discrete-Time Integrator block.

This parameter is only accessible through programmatic use.

Programmatic Use

Block Parameter: `InitialConditionSetting`

Type: string, character vector

Values: "Auto", "Output"

Default: "Auto"

External reset — Trigger for resetting integrator and filter values

level (default) | none | rising | falling | either

Specify the trigger condition that causes the block to reset the integrator and filter to initial conditions. (If **Use filtered derivative** is not selected, the trigger resets the integrator and differentiator to initial conditions.) Selecting any option other than **none** enables the **Reset** port on the block for the external reset signal.

none

The integrator and filter (or differentiator) outputs are set to initial conditions at the beginning of simulation, and are not reset during simulation.

rising

Reset the outputs when the reset signal has a rising edge.

falling

Reset the outputs when the reset signal has a falling edge.

either

Reset the outputs when the reset signal either rises or falls.

level

Reset the outputs when the reset signal either:

- Is nonzero at the current time step
- Changes from nonzero at the previous time step to zero at the current time step

This option holds the outputs to the initial conditions while the reset signal is nonzero.

Dependencies

To enable this parameter, set **Controller** to a type that has derivative or integral action.

Programmatic Use

Block Parameter: ExternalReset

Type: string, character vector

Values: "none", "rising", "falling", "either", "level"

Default: "level"

Ignore reset when linearizing — Force linearization to ignore reset

off (default) | on

Select to force Simulink and Simulink Control Design linearization commands to ignore any reset mechanism specified in the **External reset** parameter. Ignoring reset states allows you to linearize a model around an operating point even if that operating point causes the block to reset.

Programmatic Use

Block Parameter: IgnoreLimit

Type: string, character vector

Values: "off", "on"

Default: "off"

Enable tracking mode — Activate signal tracking

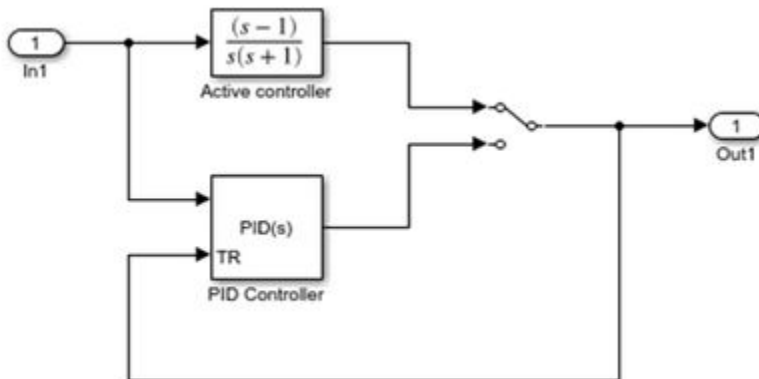
off (default) | on

Signal tracking lets the block output follow a tracking signal that you provide at the **TR** port. When signal tracking is active, the difference between the tracking signal and the block output is fed back

to the integrator input with a gain K_t , specified by the **Tracking gain (Kt)** parameter. Signal tracking has several applications, including bumpless control transfer and avoiding windup in multiloop control structures.

Bumpless control transfer

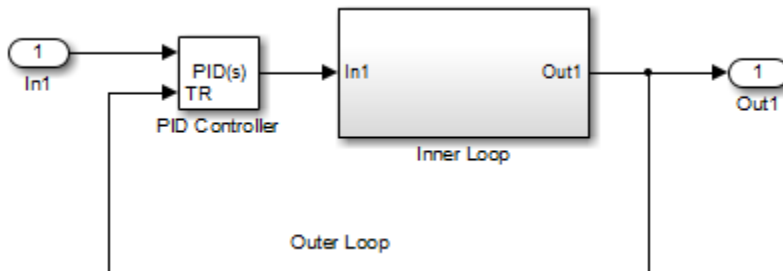
Use signal tracking to achieve bumpless control transfer in systems that switch between two controllers. Suppose you want to transfer control between a PID controller and another controller. To do so, connecting the controller output to the **TR** input as shown in the following illustration.



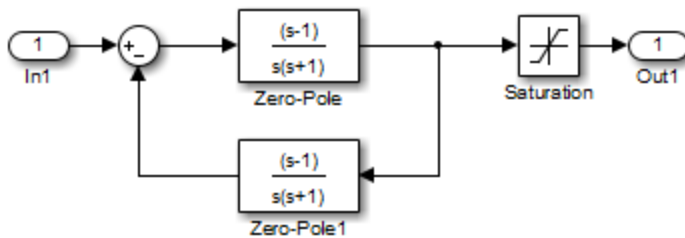
For more information, see “Bumpless Control Transfer”.

Multiloop control

Use signal tracking to prevent block windup in multiloop control approaches, as in the following model.



The Inner Loop subsystem contains the blocks shown in the following diagram.



Because the PID controller tracks the output of the inner loop, its output never exceeds the saturated inner-loop output. For more details, see “Prevent Block Windup in Multiloop Control”.

Dependencies

To enable this parameter, set **Controller** to a type that has integral action.

Programmatic Use

Block Parameter: TrackingMode

Type: string, character vector

Values: "off", "on"

Default: "off"

Tracking coefficient (Kt) — Gain of signal-tracking feedback loop

1 (default) | scalar

When you select **Enable tracking mode**, the difference between the signal **TR** and the block output is fed back to the integrator input with a gain K_t . Use this parameter to specify the gain in that feedback loop.

Dependencies

To enable this parameter, select **Enable tracking mode**.

Programmatic Use

Block Parameter: Kt

Type: scalar

Default: 1

Saturation**Output saturation**

Limit Output — Limit block output to specified saturation values

on (default) | off

Activating this option limits the block output, so that you do not need a separate Saturation block after the controller. It also allows you to activate the anti-windup mechanism built into the block (see the **Anti-windup method** parameter). Specify the output saturation limits using the **Lower limit** and **Upper limit** parameters. You can also specify the saturation limits externally as block input ports.

Programmatic Use

Block Parameter: LimitOutput

Type: string, character vector

Values: "off", "on"

Default: "on"

Source — Source for output saturation limits

internal (default) | external

Use this parameter to specify how to supply the upper and lower saturation limits of the block output.

internal

Specify the output saturation limits using the **Upper limit** and **Lower limit** parameters.

external

Specify the output saturation limits externally using block input ports. The additional input ports **up** and **lo** appear on the block. You can use the input ports to implement the upper and lower output saturation limits determined by logic or other calculations in the Simulink model and passed to the block.

Programmatic Use**Block Parameter:** SatLimitsSource**Type:** string, character vector**Values:** "internal", "external"**Default:** "internal"**Upper limit** — Upper saturation limit for block output

1 (default) | scalar

Specify the upper limit for the block output. The block output is held at the **Upper saturation limit** whenever the weighted sum of the proportional, integral, and derivative actions exceeds that value.

Dependencies

To enable this parameter, select **Limit output**.

Programmatic Use**Block Parameter:** UpperSaturationLimit**Type:** scalar**Default:** 1**Lower limit** — Lower saturation limit for block output

-1 (default) | scalar

Specify the lower limit for the block output. The block output is held at the **Lower saturation limit** whenever the weighted sum of the proportional, integral, and derivative actions goes below that value.

Dependencies

To enable this parameter, select **Limit output**.

Programmatic Use**Block Parameter:** LowerSaturationLimit**Type:** scalar**Default:** -1**Ignore saturation when linearizing** — Force linearization to ignore output limits

on (default) | off

Force Simulink and Simulink Control Design linearization commands to ignore block output limits specified in the **Upper limit** and **Lower limit** parameters. Ignoring output limits allows you to linearize a model around an operating point even if that operating point causes the block to exceed the output limits.

Dependencies

To enable this parameter, select the **Limit output** parameter.

Programmatic Use**Block Parameter:** LinearizeAsGain**Type:** string, character vector**Values:** "off", "on"**Default:** "on"**Anti-windup method** — Integrator anti-windup method

clamping (default) | none | back-calculation

When you select **Limit output** and the weighted sum of the controller components exceeds the specified output limits, the block output holds at the specified limit. However, the integrator output can continue to grow (integrator windup), increasing the difference between the block output and the sum of the block components. In other words, the internal signals in the block can be unbounded even if the output appears bounded by saturation limits. Without a mechanism to prevent integrator windup, two results are possible:

- If the sign of the input signal never changes, the integrator continues to integrate until it overflows. The overflow value is the maximum or minimum value for the data type of the integrator output.
- If the sign of the input signal changes once the weighted sum has grown beyond the output limits, it can take a long time to unwind the integrator and return the weighted sum within the block saturation limit.

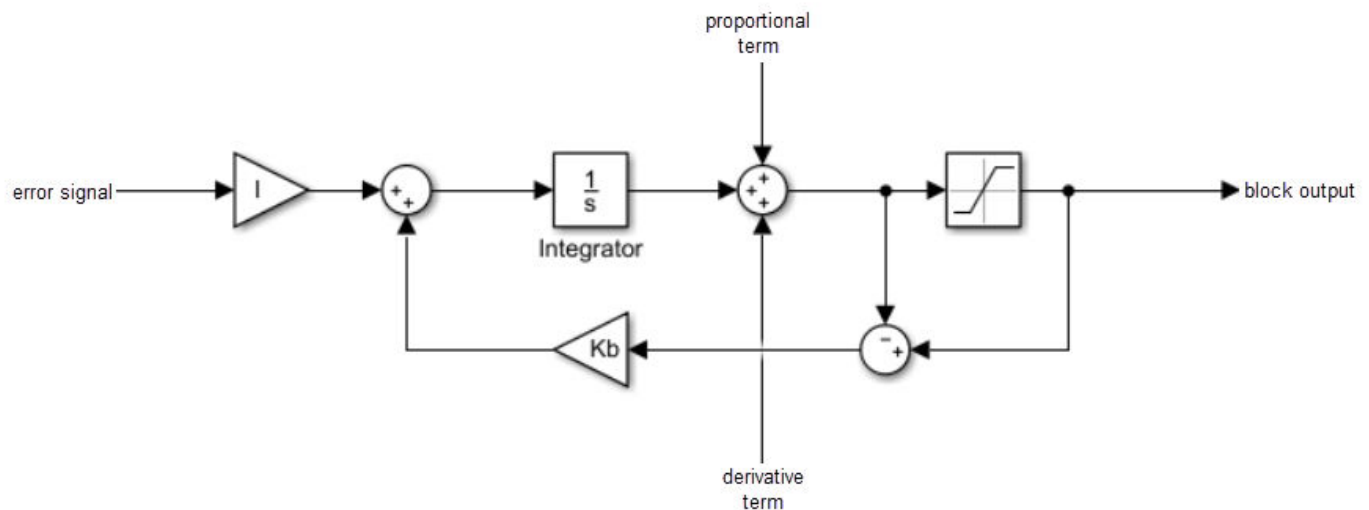
In either case, controller performance can suffer. To combat the effects of windup without an anti-windup mechanism, it may be necessary to detune the controller (for example, by reducing the controller gains), resulting in a sluggish controller. To avoid this problem, activate an anti-windup mechanism using this parameter:

none

Do not use an anti-windup mechanism.

back-calculation

Unwind the integrator when the block output saturates by feeding back to the integrator the difference between the saturated and unsaturated control signal. The following diagram represents the back-calculation feedback circuit for a continuous-time controller. To see the actual feedback circuit for your controller configuration, right-click on the block and select **Mask > Look Under Mask**.



Use the **Back-calculation coefficient (Kb)** parameter to specify the gain of the anti-windup feedback circuit. It is usually satisfactory to set $K_b = I$, or for controllers with derivative action, $K_b = \sqrt{I \cdot D}$. Back-calculation can be effective for plants with relatively large dead time [1].

clamping

Integration stops when the sum of the block components exceeds the output limits and the integrator output and block input have the same sign. Integration resumes when the sum of the

block components exceeds the output limits and the integrator output and block input have opposite sign. Clamping is sometimes referred to as conditional integration.

Clamping can be useful for plants with relatively small dead times, but can yield a poor transient response for large dead times [1].

Dependencies

To enable this parameter, select the **Limit output** parameter.

Programmatic Use

Block Parameter: AntiWindupMode

Type: string, character vector

Values: "none", "back-calculation", "clamping"

Default: "clamping"

Back-calculation coefficient (Kb) — Gain coefficient of anti-windup feedback loop

1 (default) | scalar

The back-calculation anti-windup method unwinds the integrator when the block output saturates. It does so by feeding back to the integrator the difference between the saturated and unsaturated control signal. Use the **Back-calculation coefficient (Kb)** parameter to specify the gain of the anti-windup feedback circuit. For more information, see the **Anti-windup method** parameter.

Dependencies

To enable this parameter, select the **Limit output** parameter, and set the **Anti-windup method** parameter to back-calculation.

Programmatic Use

Block Parameter: Kb

Type: scalar

Default: 1

Integrator saturation

Limit Output — Limit integrator output to specified saturation limits

off (default) | on

Enable this parameter to limit the integrator output to be within a specified range. When the integrator output reaches the limits, the integral action turns off to prevent integral windup. Specify the saturation limits using the **Lower limit** and **Upper limit** parameters.

Dependencies

To enable this parameter, set **Controller** to a controller type that has integral action.

Programmatic Use

Block Parameter: LimitIntegratorOutput

Type: string, character vector

Values: "off", "on"

Default: "off"

Upper limit — Upper saturation limit for integrator

Inf (default) | scalar

Specify the upper limit for the integrator output. The integrator output is held at this value whenever it would otherwise exceed this value.

Dependencies

To enable this parameter, under **Integrator saturation**, select **Limit output**.

Programmatic Use

Block Parameter: UpperIntegratorSaturationLimit

Type: scalar

Default: Inf

Lower limit — Lower saturation limit for integrator

- Inf (default) | scalar

Specify the lower limit for the integrator output. The integrator output is held at this value whenever it would otherwise go below this value.

Dependencies

To enable this parameter, under **Integrator saturation**, select **Limit output**.

Programmatic Use

Block Parameter: LowerIntegratorSaturationLimit

Type: scalar

Default: - Inf


Data Types

The parameters in this tab are primarily of use in fixed-point code generation using Fixed-Point Designer™. They define how numeric quantities associated with the block are stored and processed when you generate code.

If you need to configure data types for fixed-point code generation, click **Open Fixed-Point Tool** and use that tool to configure the rest of the parameters in the tab. For information about using Fixed-Point Tool, see “Autoscaling Data Objects Using the Fixed-Point Tool” (Fixed-Point Designer).

After you use Fixed-Point Tool, you can use the parameters in this tab to make adjustments to fixed-point data-type settings if necessary. For each quantity associated with the block, you can specify:

- Floating-point or fixed-point data type, including whether the data type is inherited from upstream values in the block.
- The minimum and maximum values for the quantity, which determine how the quantity is scaled for fixed-point representation.

For assistance in selecting appropriate values, click  to open the Data Type Assistant for the corresponding quantity. For more information, see “Specify Data Types Using Data Type Assistant”.

Main	Initialization	Output Saturation	Data Types	State Attributes
Fixed-point operational parameters				
Integer rounding mode: Simplest				
<input type="checkbox"/> Saturate on integer overflow				
<input type="checkbox"/> Lock data type settings against changes by the fixed-point tools Open Fixed-Point Tool...				
Data Type		Minimum	Maximum	
P product output:	Inherit: Same as first input	>>	[]	[]
I product output:	Inherit: Same as first input	>>	[]	[]
Sum output:	Inherit: Same as first input	>>	[]	[]
Saturation output:	Inherit: Inherit via back propagation	>>	[]	[]
▶ Additional data types				

The specific quantities listed in the Data Types tab vary depending on how you configure the PID controller block. In general, you can configure data types for the following types of quantities:

- Product output — Stores the result of a multiplication carried out under the block mask. For example, **P product output** stores the output of the gain block that multiplies the block input with the proportional gain **P**.
- Parameter — Stores the value of a numeric block parameter, such as **P**, **I**, or **D**.
- Block output — Stores the output of a block that resides under the PID controller block mask. For example, use **Integrator output** to specify the data type of the output of the block called Integrator. This block resides under the mask in the Integrator subsystem, and computes integrator term of the controller action.
- Accumulator — Stores values associated with a sum block. For example, **SumI2 Accumulator** sets the data type of the accumulator associated with the sum block SumI2. This block resides under the mask in the Back Calculation subsystem of the Anti-Windup subsystem.

In general, you can find the block associated with any listed parameter by looking under the PID Controller block mask and examining its subsystems. You can also use the Model Explorer to search under the mask for the listed parameter name, such as SumI2. (See **Model Explorer**.)

Matching Input and Internal Data Types

By default, the data types for product output and block output are set to **Inherit: Same as first input**. With this setting, the block uses the data type of its first input signal for these signals.

When data type is set to **Inherit: Inherit via internal** rule, Simulink chooses data types to balance numerical accuracy, performance, and generated code size, while accounting for the properties of the embedded target hardware.

Under some conditions, incompatibility can occur between data types within the block. For instance, in continuous time, the Integrator block under the mask can accept only signals of type **double**. If the block input signal is a type that cannot be converted to **double**, such as **uint16**, the internal rules for type inheritance generate an error when you generate code.

To avoid such errors, you can use the Data Types settings to force a data type conversion. For instance, you can explicitly set **P product output**, **I product output**, and **D product output** to `double`, ensuring that the signals reaching the continuous-time integrators are of type `double`.

In general, it is not recommended to use the block in continuous time for code generation applications. However, similar data type errors can occur in discrete time, if you explicitly set some values to data types that are incompatible with downstream signal constraints within the block. In such cases, use the Data Types settings to ensure that all data types are internally compatible.

Fixed-Point Operational Parameters

Integer rounding mode — Rounding mode for fixed-point operations

`Simplest` (default) | `Floor` | `Ceiling` | `Convergent` | `Nearest` | `Round` | `Zero`

Specify the rounding mode for fixed-point operations. For more information, see “Rounding” (Fixed-Point Designer).

Block parameters always round to the nearest representable value. To control the rounding of a block parameter, enter an expression using a MATLAB® rounding function into the mask field.

Programmatic Use

Block Parameter: `RndMeth`

Type: character vector

Values: `'Ceiling'` | `'Convergent'` | `'Floor'` | `'Nearest'` | `'Round'` | `'Simplest'` | `'Zero'`

Default: `'Simplest'`

Saturate on integer overflow — Method of overflow action

`off` (default) | `on`

Specify whether overflows saturate or wrap.

- `off` — Overflows wrap to the appropriate value that the data type can represent.

For example, the number 130 does not fit in a signed 8-bit integer and wraps to -126.

- `on` — Overflows saturate to either the minimum or maximum value that the data type can represent.

For example, an overflow associated with a signed 8-bit integer can saturate to -128 or 127.

Tip

- Consider selecting this check box when your model has a possible overflow and you want explicit saturation protection in the generated code.
- Consider clearing this check box when you want to optimize efficiency of your generated code.

Clearing this check box also helps you to avoid overspecifying how a block handles out-of-range signals. For more information, see “Troubleshoot Signal Range Errors”.

- When you select this check box, saturation applies to every internal operation on the block, not just the output or result.
 - In general, the code generation process can detect when overflow is not possible. In this case, the code generator does not produce saturation code.
-

Programmatic Use**Block Parameter:** SaturateOnIntegerOverflow**Type:** character vector**Values:** 'off' | 'on'**Default:** 'off'

Lock data type settings against changes by the fixed-point tools — Prevent fixed-point tools from overriding data types

off (default) | on

Select this parameter to prevent the fixed-point tools from overriding the data types you specify on this block. For more information, see “Lock the Output Data Type Setting” (Fixed-Point Designer).

Programmatic Use**Block Parameter:** LockScale**Type:** character vector**Values:** 'off' | 'on'**Default:** 'off'**State Attributes**

The parameters in this tab are primarily of use in code generation.

State name (e.g., 'position') — Name for continuous-time filter and integrator states

' ' (default) | character vector

Assign a unique name to the state associated with the integrator or the filter, for continuous-time PID controllers. (For information about state names in a discrete-time PID controller, see the **State name** parameter.) The state name is used, for example:

- For the corresponding variable in generated code
- As part of the storage name when logging states during simulation
- For the corresponding state in a linear model obtain by linearizing the block

A valid state name begins with an alphabetic or underscore character, followed by alphanumeric or underscore characters.

Dependencies

To enable this parameter, set **Time domain** to Continuous-time.

Programmatic Use**Parameter:** IntegratorContinuousStateAttributes, FilterContinuousStateAttributes**Type:** character vector**Default:** ''

State name — Names for discrete-time filter and integrator states

empty string (default) | string | character vector

Assign a unique name to the state associated with the integrator or the filter, for discrete-time PID controllers. (For information about state names in a continuous-time PID controller, see the **State name (e.g., 'position')** parameter.)

A valid state name begins with an alphabetic or underscore character, followed by alphanumeric or underscore characters. The state name is used, for example:

- For the corresponding variable in generated code
- As part of the storage name when logging states during simulation
- For the corresponding state in a linear model obtain by linearizing the block

For more information about the use of state names in code generation, see “C Code Generation Configuration for Model Interface Elements” (Simulink Coder).

Dependencies

To enable this parameter, set **Time domain** to Discrete-time.

Programmatic Use

Parameter: IntegratorStateIdentifier, FilterStateIdentifier

Type: string, character vector

Default: ""

State name must resolve to Simulink signal object — Require that state name resolve to a signal object

off (default) | on

Select this parameter to require that the discrete-time integrator or filter state name resolves to a Simulink signal object.

Dependencies

To enable this parameter for the discrete-time integrator or filter state:

- 1 Set **Time domain** to Discrete-time.
- 2 Specify a value for the integrator or filter **State name**.
- 3 Set the model configuration parameter **Signal resolution** to a value other than None.

Programmatic Use

Block Parameter: IntegratorStateMustResolveToSignalObject, FilterStateMustResolveToSignalObject

Type: string, character vector

Values: "off", "on"

Default: "off"

Version History

Introduced in R2022a

References

- [1] Visioli, A., "Modified Anti-Windup Scheme for PID Controllers," *IEE Proceedings - Control Theory and Applications*, Vol. 150, Number 1, January 2003

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

For discrete-time PID controllers (**Time domain** set to Discrete-time):

- Depends on absolute time when placed inside a triggered subsystem hierarchy.
- Generated code relies on memcopy or memset functions (`string.h`) under certain conditions.

For continuous-time PID controllers (**Time domain** set to `Continuous-time`):

- Consider using “Model Discretizer” to map continuous-time blocks to discrete equivalents that support code generation. To access Model Discretizer, from your model, in the **Apps** tab, under **Control Systems**, click **Model Discretizer**.
- Not recommended for production code.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has a single, default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Restrictions

- HDL code generation is supported for discrete-time PID controllers only (**Time domain** set to `Discrete-time`).
- If the **Integrator method** is set to `BackwardEuler` or `Trapezoidal`, you cannot generate HDL code for the block under either of the following conditions:
 - **Limit output** is selected and the **Anti-Windup Method** is anything other than none.
 - **Enable tracking mode** is selected.
- To generate HDL code:
 - Use a discrete-time PID controller. On the **Time domain** section, specify **Discrete-time**.
 - Leave the **Use filtered derivative** check box selected.
 - Specify the initial conditions of the filter and integrator internally. On the **Initialization** tab, specify **Source** as `internal`.

You can specify the filter coefficients internally and externally for HDL code generation. On the **Main** tab, for **Source**, you can use `internal` or `external`.

- Set **External reset** to none.
- When you use double inputs, do not set **Anti-windup Method** to clamping.

PLC Code Generation

Generate Structured Text code using Simulink® PLC Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

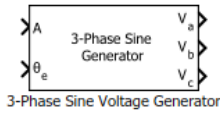
Fixed-point code generation is supported for discrete-time PID controllers only (**Time domain** set to **Discrete-time**).

See Also

Field Oriented Control Autotuner

3-Phase Sine Voltage Generator

Generate balanced three-phase sinusoidal signals



Libraries:

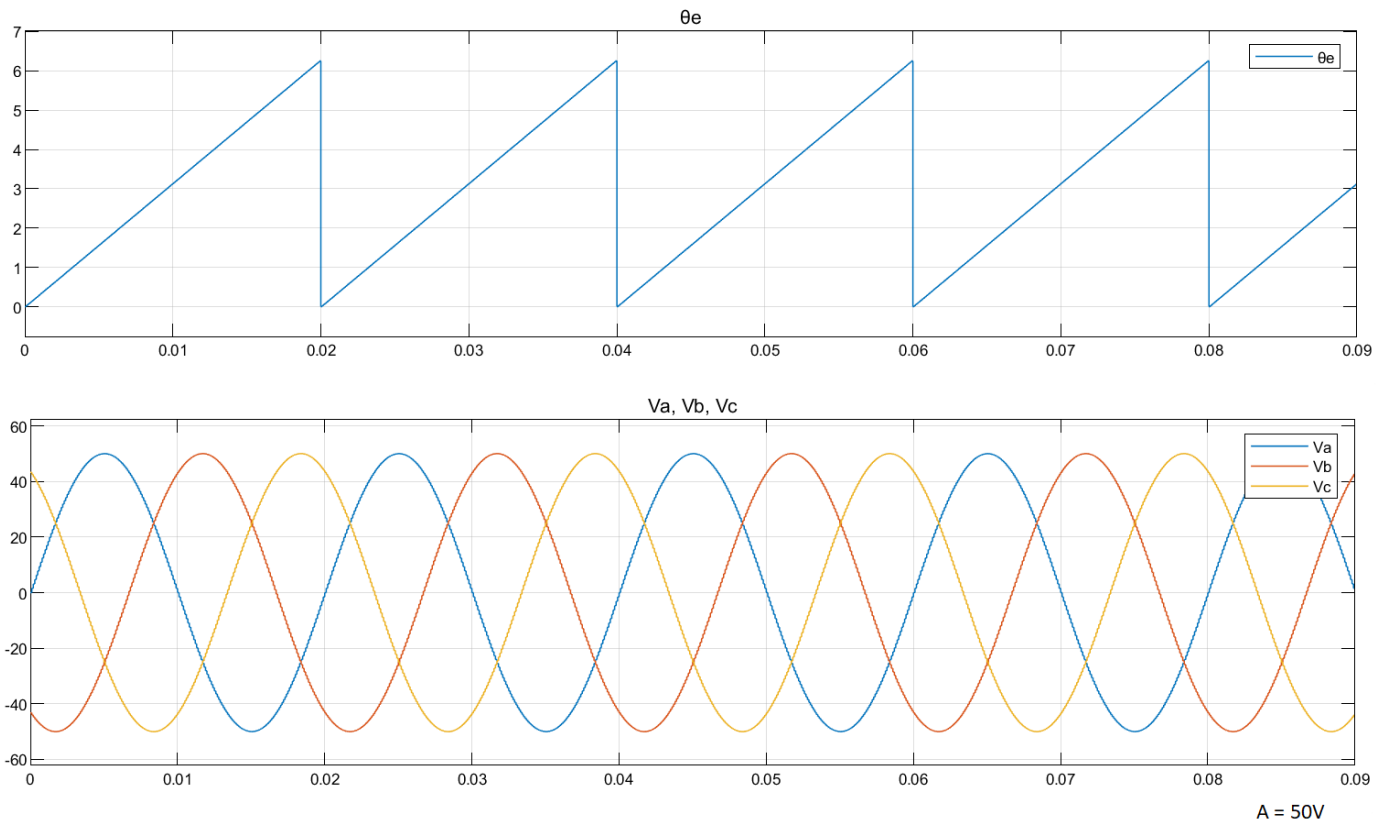
Motor Control Blockset / Controls / Math Transforms

Description

The 3-Phase Sine Voltage Generator block generates balanced, three-phase sinusoidal signals using signal amplitude and position inputs.

The block uses the lookup table approach. This approach results in optimized code-execution when used with the model settings and configuration adopted by the examples shipped in Motor Control Blockset. You can specify the number of lookup table points in the **Number of data points for lookup table** parameter.

The following image shows a plot of position input and three-phase sinusoidal output signals against time.



Equations

The following equations describe how the block computes balanced, three-phase sinusoidal signals.

- $V_a = A \times \sin\omega t$
- $V_b = A \times \sin\left(\omega t - \frac{2\pi}{3}\right)$
- $V_c = A \times \sin\left(\omega t - \frac{4\pi}{3}\right)$

where:

- A is the reference voltage amplitude (volts).
- ω is the frequency of the reference voltage position input signal (θ_e) (radians/ sec).
- t is the time (seconds).

Ports

Input

A — Reference voltage amplitude
scalar

Maximum amplitude of the reference voltage signal.

Data Types: `single` | `double` | `fixed point`

θ_e — Reference voltage position
scalar

Position or phase value of the reference voltage signal.

Data Types: `single` | `double` | `fixed point`

Output

V_a — a -axis component of balanced, three-phase voltage
scalar

Balanced, three-phase voltage signal component along the a -axis of the abc reference frame.

Data Types: `single` | `double` | `fixed point`

V_b — b -axis component of balanced, three-phase voltage
scalar

Balanced, three-phase voltage signal component along the b -axis of the abc reference frame.

Data Types: `single` | `double` | `fixed point`

V_c — c -axis component of balanced, three-phase voltage
scalar

Balanced, three-phase voltage signal component along the c -axis of the abc reference frame.

Data Types: `single` | `double` | `fixed point`

Parameters

Theta units — Unit of θ_e
Per-unit (default) | Radians | Degrees

Unit of the reference voltage position that you provide as input.

Number of data points for lookup table — Size of lookup table
1024 (default) | scalar

Size of the lookup table.

Version History

Introduced in R2020a

Extended Capabilities

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

Fixed-Point Conversion
Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

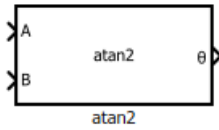
Position Generator

Topics

“Open-Loop and Closed-Loop Control”
“Field-Oriented Control (FOC)”

atan2

Compute four-quadrant arctangent



Libraries:

Motor Control Blockset / Controls / Math Transforms

Motor Control Blockset HDL Support / Controls / Math Transforms

Description

The atan2 block performs the four-quadrant arctangent on two real numbers.

Equations

This equation describes how the block computes the four-quadrant arctangent (θ).

$$\text{Theta} = \text{atan2}(A, B) = \begin{cases} \arctan\left(\frac{A}{B}\right) & \text{if } B > 0, \\ \arctan\left(\frac{A}{B}\right) + \pi & \text{if } B < 0 \text{ and } A \geq 0, \\ \arctan\left(\frac{A}{B}\right) - \pi & \text{if } B < 0 \text{ and } A < 0, \\ +\frac{\pi}{2} & \text{if } B = 0 \text{ and } A > 0, \\ -\frac{\pi}{2} & \text{if } B = 0 \text{ and } A < 0, \\ \text{undefined} & \text{if } B = 0 \text{ and } A = 0. \end{cases}$$

where:

$$-\pi < \text{Theta} \leq \pi \quad (\text{Radians})$$

Ports

Input

A — y-coordinate value (real number)
scalar

Real number on the y-axis that you provide as input to the block.

Data Types: `single` | `double` | `fixed point`

B — x-coordinate value (real number)
scalar

Real number on the x-axis that you provide as input to the block.

Data Types: `single` | `double` | `fixed point`

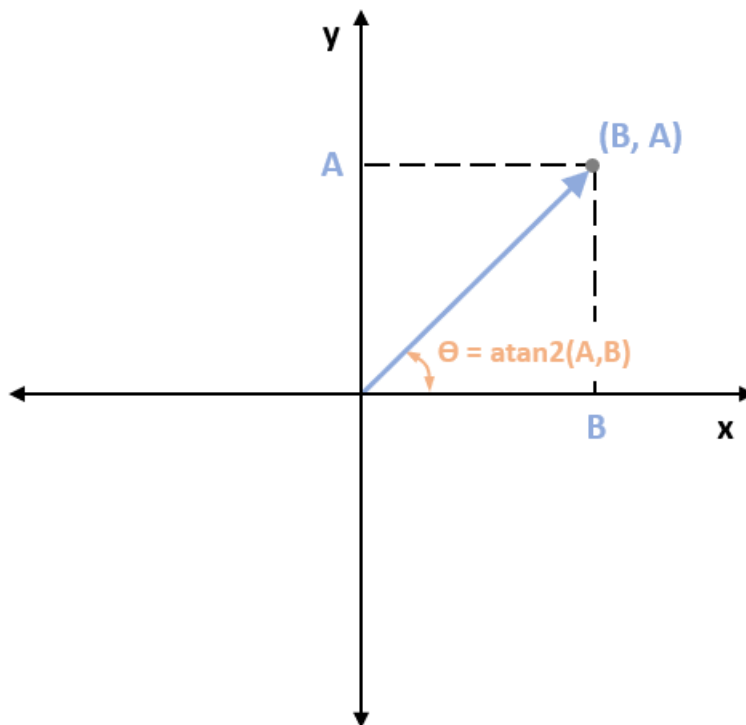
Output

θ — Angle represented by arctangent
scalar

Angle represented by arctangent. This is the angle made by a vector from the origin to a specified point (x,y) with the positive x-axis.

Data Types: `single` | `double` | `fixed point`

The following figure shows the representation of input values A, B, and arctangent on the x-y coordinate plane.



Parameters

Output unit — Unit of output values
`Radians (default)` | `PerUnit`

Unit of the output values.

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Restriction

If you run third-party (3p) simulation, the block may show a minor mismatch (of the order $1e-7$) in the simulation results because of an internal trigonometric function that uses the floating point datatype.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

Clarke Transform

Implement ab to $\alpha\beta$ transformation



Libraries:

Motor Control Blockset / Controls / Math Transforms

Motor Control Blockset HDL Support / Controls / Math Transforms

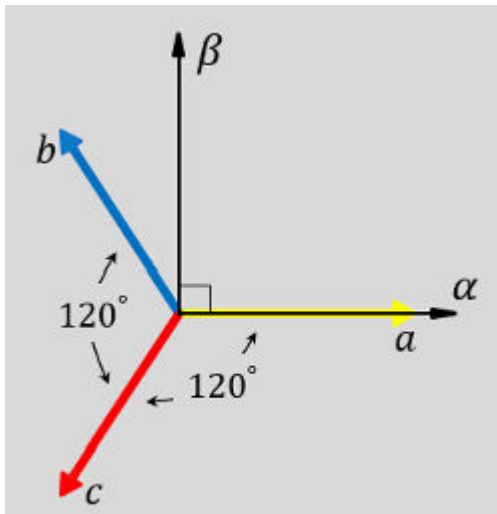
Description

The Clarke Transform block computes the Clarke transformation of balanced three-phase components in the abc reference frame and outputs the balanced two-phase orthogonal components in the stationary $\alpha\beta$ reference frame.

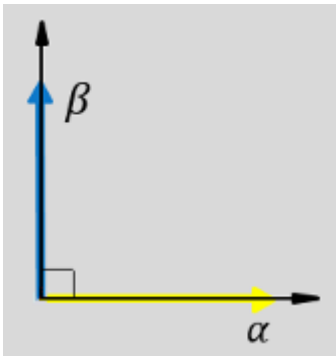
The block accepts two signals out of the three phases (abc), automatically calculates the third signal, and outputs the corresponding components in the $\alpha\beta$ reference frame.

For example, the block accepts a and b input values where the phase- a axis aligns with the α -axis.

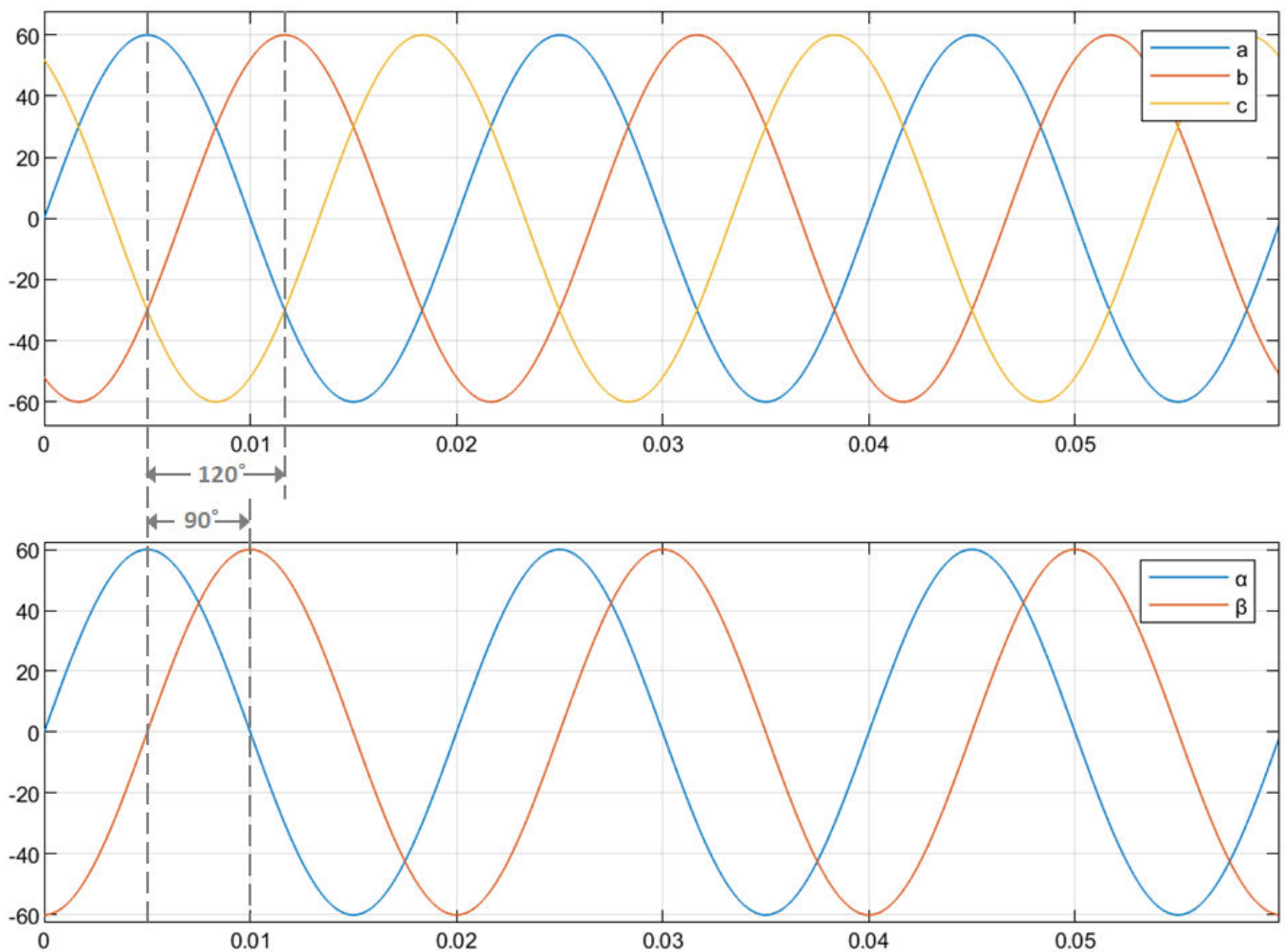
- This figure shows the direction of the magnetic axes of the stator windings in the abc reference frame and the stationary $\alpha\beta$ reference frame.



- This figure shows the equivalent α and β components in the stationary $\alpha\beta$ reference frame.



- The time-response of the individual components of equivalent balanced abc and $\alpha\beta$ systems.



Equations

The following equation describes the Clarke transform computation:

$$\begin{bmatrix} f_\alpha \\ f_\beta \\ f_0 \end{bmatrix} = \left(\frac{2}{3}\right) \times \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix}$$

For balanced systems like motors, the zero sequence component calculation is always zero. For example, the currents of the motor can be represented as,

$$i_a + i_b + i_c = 0$$

Therefore, you can use only two current sensors in three-phase motor drives, where you can calculate the third phase as,

$$i_c = -(i_a + i_b)$$

By using these equations, the block implements the Clarke transform as,

$$\begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \frac{1}{\sqrt{3}} & \frac{2}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} f_a \\ f_b \end{bmatrix}$$

where:

- f_a , f_b , and f_c are the balanced three-phase components in the abc reference frame.
- f_α and f_β are the balanced two-phase orthogonal components in the stationary $\alpha\beta$ reference frame.
- f_0 is the zero component in the stationary $\alpha\beta$ reference frame.

Ports

Input

a — Phase component
scalar

Component of the three-phase system in the abc reference frame.

Data Types: `single` | `double` | `fixed point`

b — Phase component
scalar

Component of the three-phase system in the abc reference frame.

Data Types: `single` | `double` | `fixed point`

Output

α — Axis component
scalar

Alpha-axis component, α , in the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

β — Axis component
scalar

Beta-axis component, β , in the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Inverse Clarke Transform | Park Transform

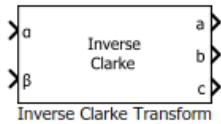
Topics

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

Inverse Clarke Transform

Implement $\alpha\beta$ to abc transformation



Libraries:

Motor Control Blockset / Controls / Math Transforms

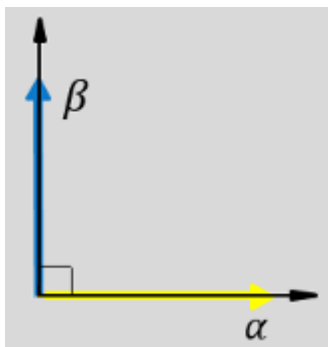
Motor Control Blockset HDL Support / Controls / Math Transforms

Description

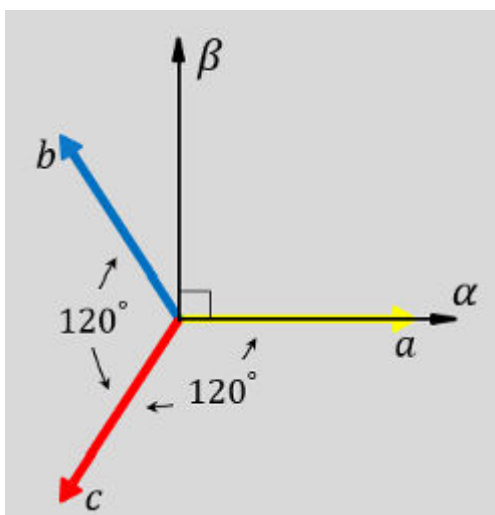
The Inverse Clarke Transform block computes the Inverse Clarke transformation of balanced, two-phase orthogonal components in the stationary $\alpha\beta$ reference frame. It outputs the balanced, three-phase components in the stationary abc reference frame.

The block accepts the α - β axis components as inputs and outputs the corresponding three-phase signals, where the phase- a axis aligns with the α -axis.

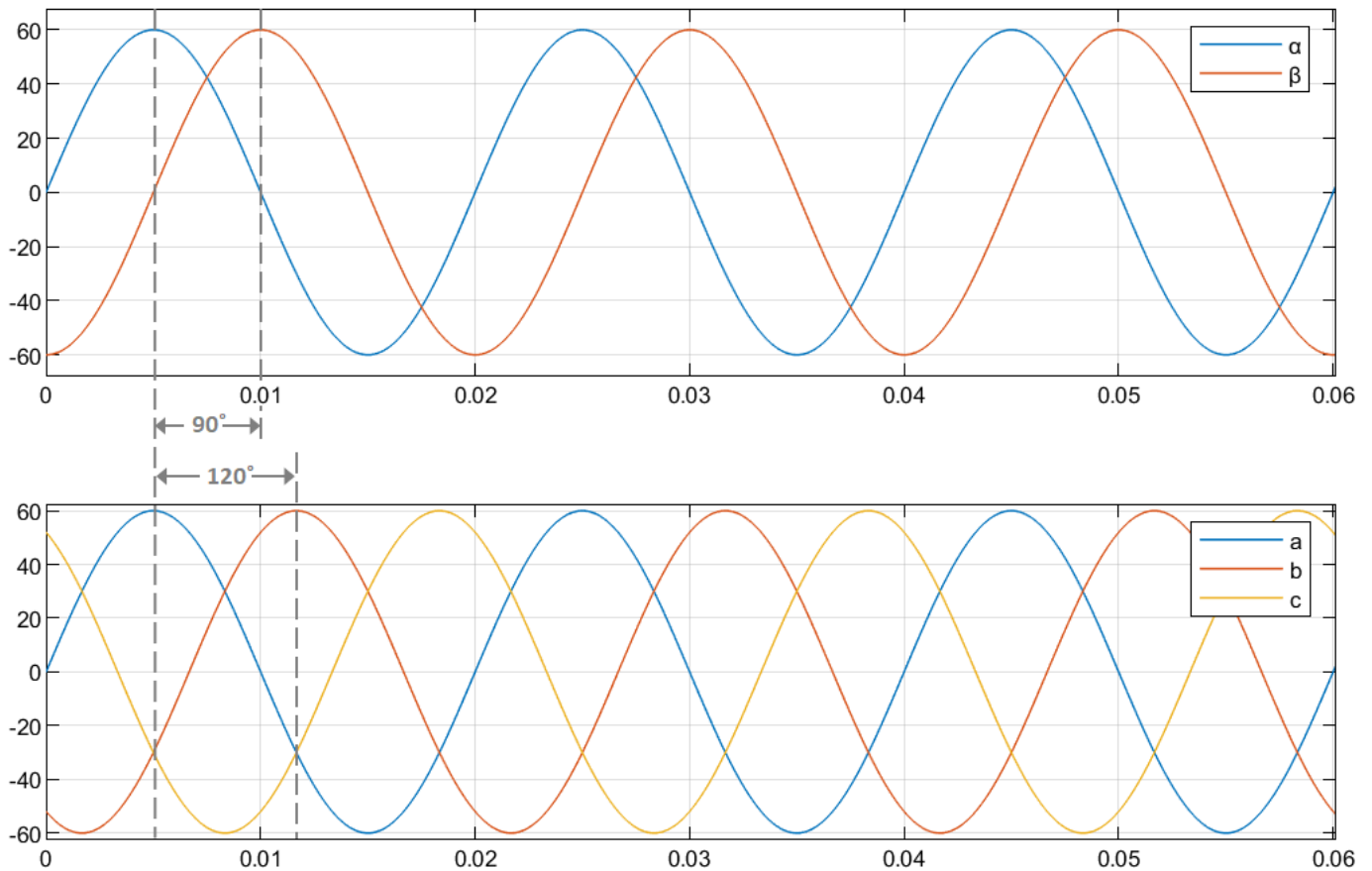
- The α and β input components in the $\alpha\beta$ reference frame.



- The direction of the equivalent a , b , and c output components in the abc reference frame and the $\alpha\beta$ reference frame.



- The time-response of the individual components of equivalent balanced $\alpha\beta$ and abc systems.



Equations

The following equation describes the Inverse Clarke transform computation:

$$\begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \end{bmatrix} \begin{bmatrix} f_\alpha \\ f_\beta \\ f_0 \end{bmatrix}$$

For balanced systems like motors, the zero sequence component calculation is always zero:

$$i_a + i_b + i_c = 0$$

Therefore, you can use only two current sensors in three-phase motor drives, where you can calculate the third phase as,

$$i_c = -(i_a + i_b)$$

By using these equations, the block implements the Inverse Clarke transform as,

$$\begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix}$$

where:

- f_α and f_β are the balanced two-phase orthogonal components in the stationary $\alpha\beta$ reference frame.
- f_0 is the zero component in the stationary $\alpha\beta$ reference frame.
- f_a , f_b , and f_c are the balanced three-phase components in the abc reference frame.

Ports

Input

α — Axis component
scalar

Alpha-axis component, α , in the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

β — Axis component
scalar

Beta-axis component, β , in the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

Output

a — Phase component
scalar

Component of the three-phase system in the abc reference frame.

Data Types: `single` | `double` | `fixed point`

b — Phase component
scalar

Component of the three-phase system in the abc reference frame.

Data Types: `single` | `double` | `fixed point`

c — Phase component
scalar

Component of the three-phase system in the abc reference frame.

Data Types: `single` | `double` | `fixed point`

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Fixed-Point Conversion

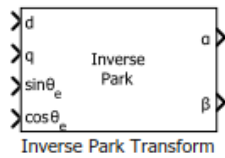
Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Clarke Transform

Inverse Park Transform

Implement dq to $\alpha\beta$ transformation



Libraries:

Motor Control Blockset / Controls / Math Transforms

Motor Control Blockset HDL Support / Controls / Math Transforms

Description

The Inverse Park Transform block computes the inverse Park transformation of the orthogonal direct and quadrature axes components in the rotating dq reference frame. You can configure the block to align either the d - or q -axis with the α -axis at time $t = 0$.

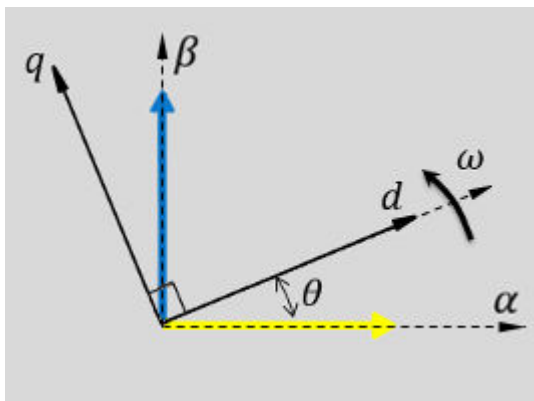
The block accepts the following inputs:

- d - q axes components in the rotating reference frame.
- Sine and cosine values of the corresponding angles of transformation.

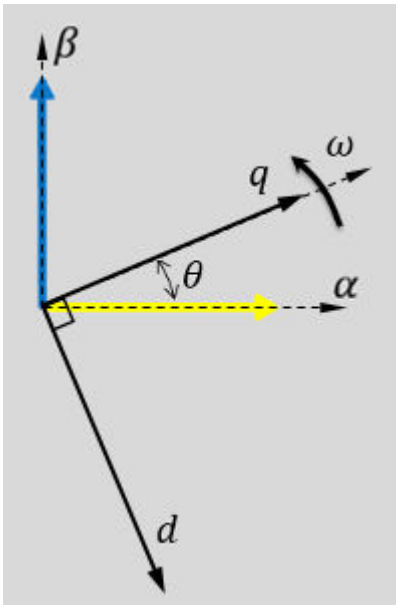
It outputs the two-phase orthogonal components in the stationary $\alpha\beta$ reference frame.

The figures show a rotating dq reference frame and the $\alpha\beta$ axes components in an $\alpha\beta$ reference frame for when:

- The d -axis aligns with the α -axis.



- The q -axis aligns with the α -axis.

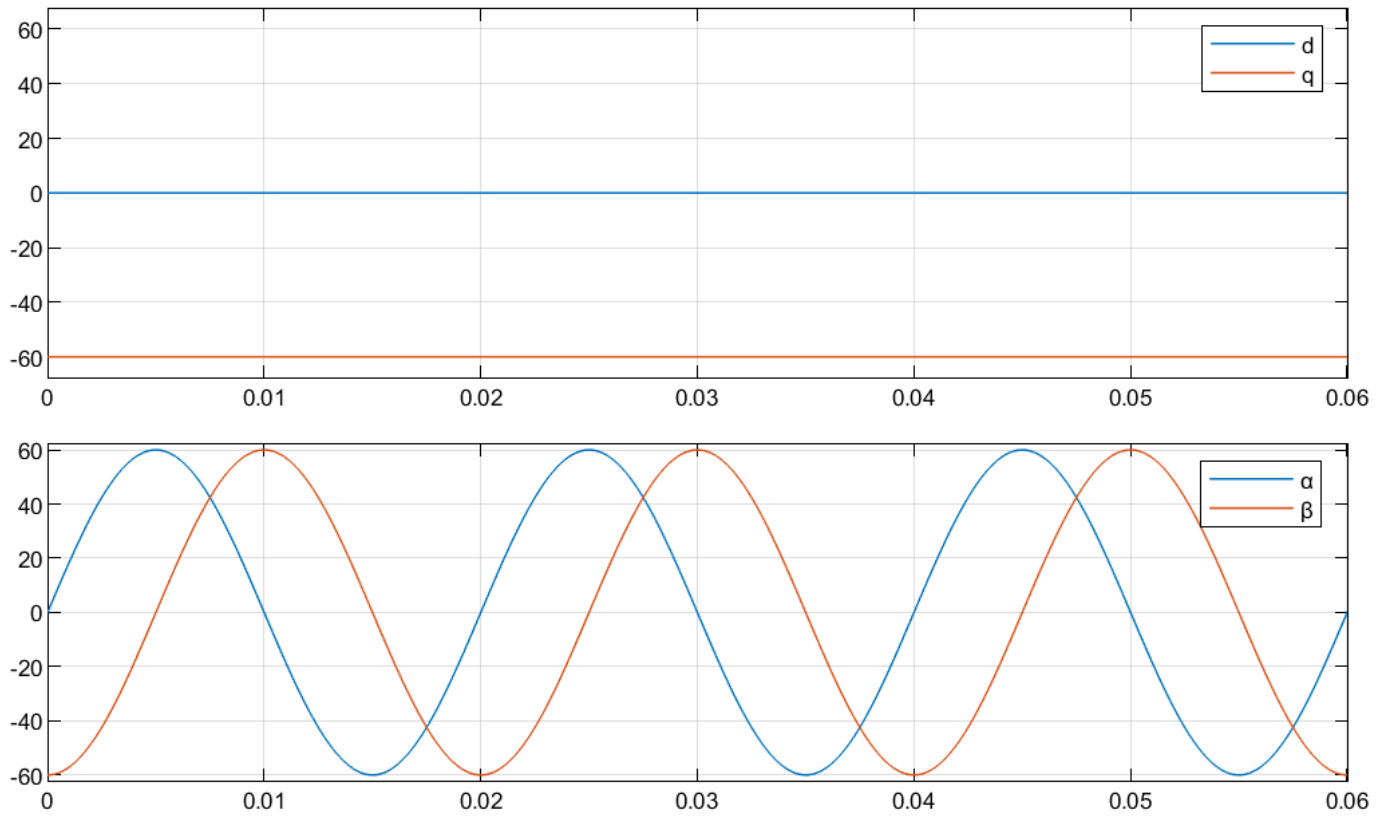


In both cases, the angle $\theta = \omega t$, where:

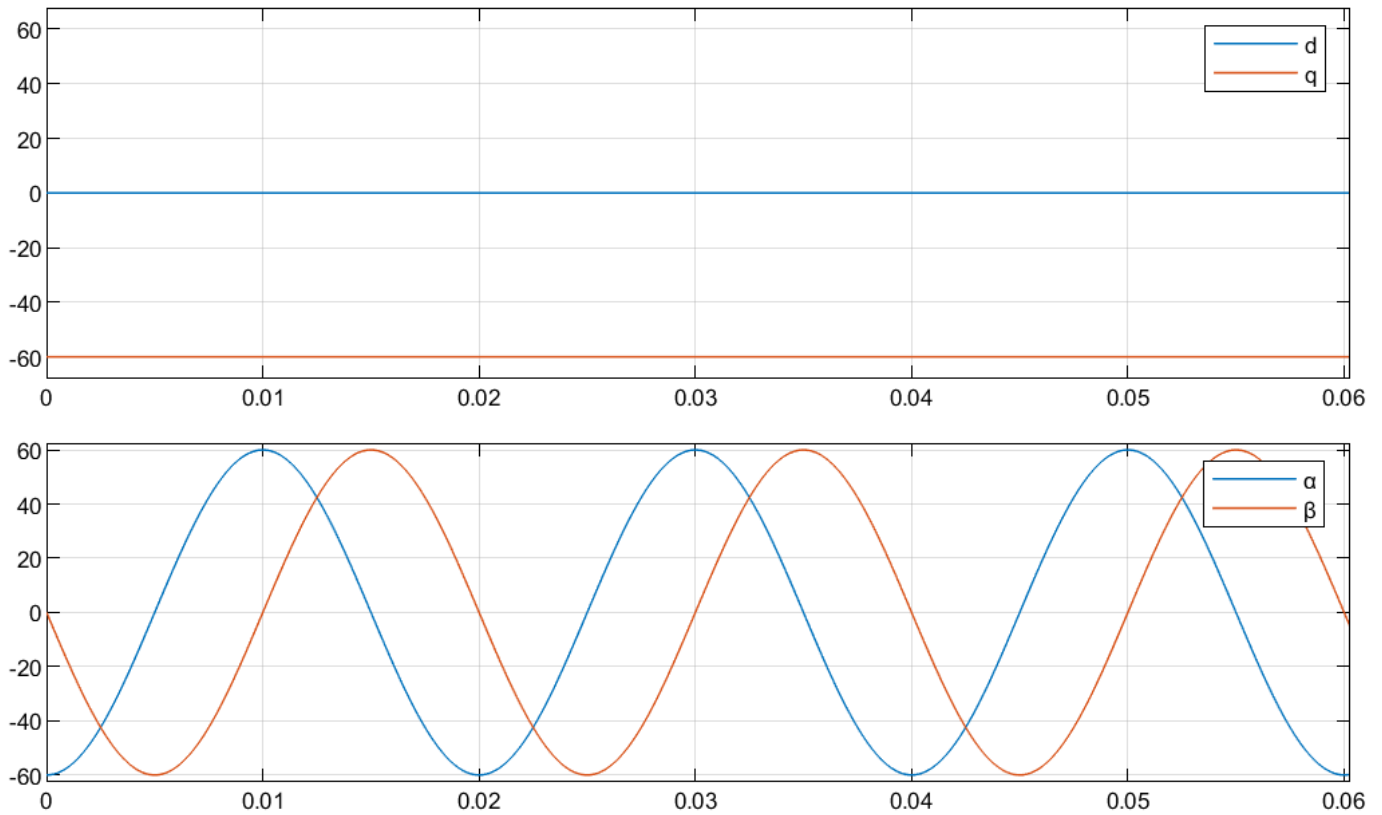
- θ is the angle between the α - and d -axes for the d -axis alignment or the angle between the α - and q -axes for the q -axis alignment. It indicates the angular position of the rotating dq reference frame with respect to the α -axis.
- ω is the rotational speed of the d - q reference frame.
- t is the time, in seconds, from the initial alignment.

The figures show the time-response of the individual components of the $\alpha\beta$ and dq reference frames when:

- The d -axis aligns with the α -axis.



- The q -axis aligns with the α -axis.



Equations

The following equations describe how the block implements inverse Park transformation.

- When the d -axis aligns with the α -axis.

$$\begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} f_d \\ f_q \end{bmatrix}$$

- When the q -axis aligns with the α -axis.

$$\begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} = \begin{bmatrix} \sin\theta & \cos\theta \\ -\cos\theta & \sin\theta \end{bmatrix} \begin{bmatrix} f_d \\ f_q \end{bmatrix}$$

where:

- f_d and f_q are the direct and quadrature axis orthogonal components in the rotating dq reference frame.
- f_α and f_β are the two-phase orthogonal components in the stationary $\alpha\beta$ reference frame.

Ports

Input

d — Axis component
scalar

Direct axis component, d , in the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

q — Axis component
scalar

Quadrature axis component, q , in the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

sin θ_e — Sine value of rotational angle
scalar

Sine value of the angle of transformation, θ_e . θ_e is the angle between the rotating reference frame and the α -axis.

Data Types: `single` | `double` | `fixed point`

cos θ_e — Cosine value of rotational angle
scalar

Cosine value of the angle of transformation, θ_e . θ_e is the angle between the rotating reference frame and the α -axis.

Data Types: `single` | `double` | `fixed point`

Output

α — Axis component
scalar

Alpha-axis component, α , in the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

β — Axis component
scalar

Beta-axis component, β , in the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

Parameters

Alpha (phase-a) axis alignment — dq reference frame alignment
D-axis (default) | Q-axis

Align either the d - or q -axis of the rotating reference frame to the α -axis of the stationary reference frame.

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

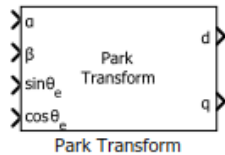
Park Transform | PI Controller | DQ Limiter | ACIM Feed Forward Control | Space Vector Generator | Sine-Cosine Lookup | PMSM Feed Forward Control

Topics

“Open-Loop and Closed-Loop Control”
 “Field-Oriented Control (FOC)”

Park Transform

Implement $\alpha\beta$ to dq transformation



Libraries:

Motor Control Blockset / Controls / Math Transforms

Motor Control Blockset HDL Support / Controls / Math Transforms

Description

The Park Transform block computes the Park transformation of two-phase orthogonal components in a stationary $\alpha\beta$ reference frame.

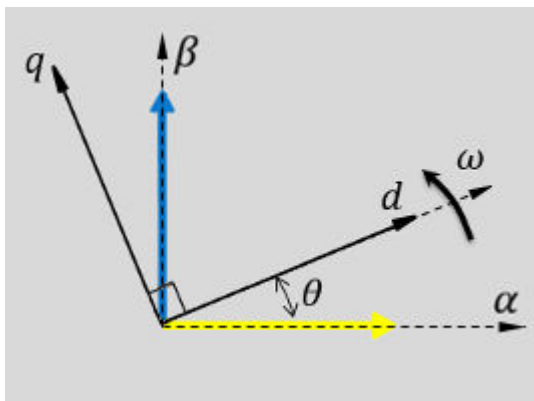
The block accepts the following inputs:

- α - β axes components in the stationary reference frame.
- Sine and cosine values of the corresponding angles of transformation.

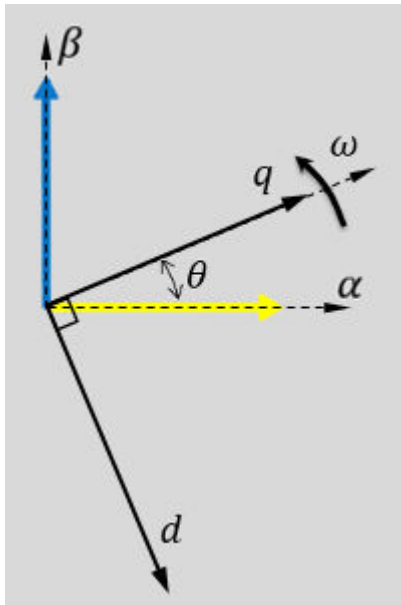
It outputs orthogonal direct and quadrature axis components in the rotating dq reference frame. You can configure the block to align either the d - or the q -axis with the α -axis at time $t = 0$.

The figures show the α - β axes components in an $\alpha\beta$ reference frame and a rotating dq reference frame for when:

- The d -axis aligns with the α -axis.



- The q -axis aligns with the α -axis.

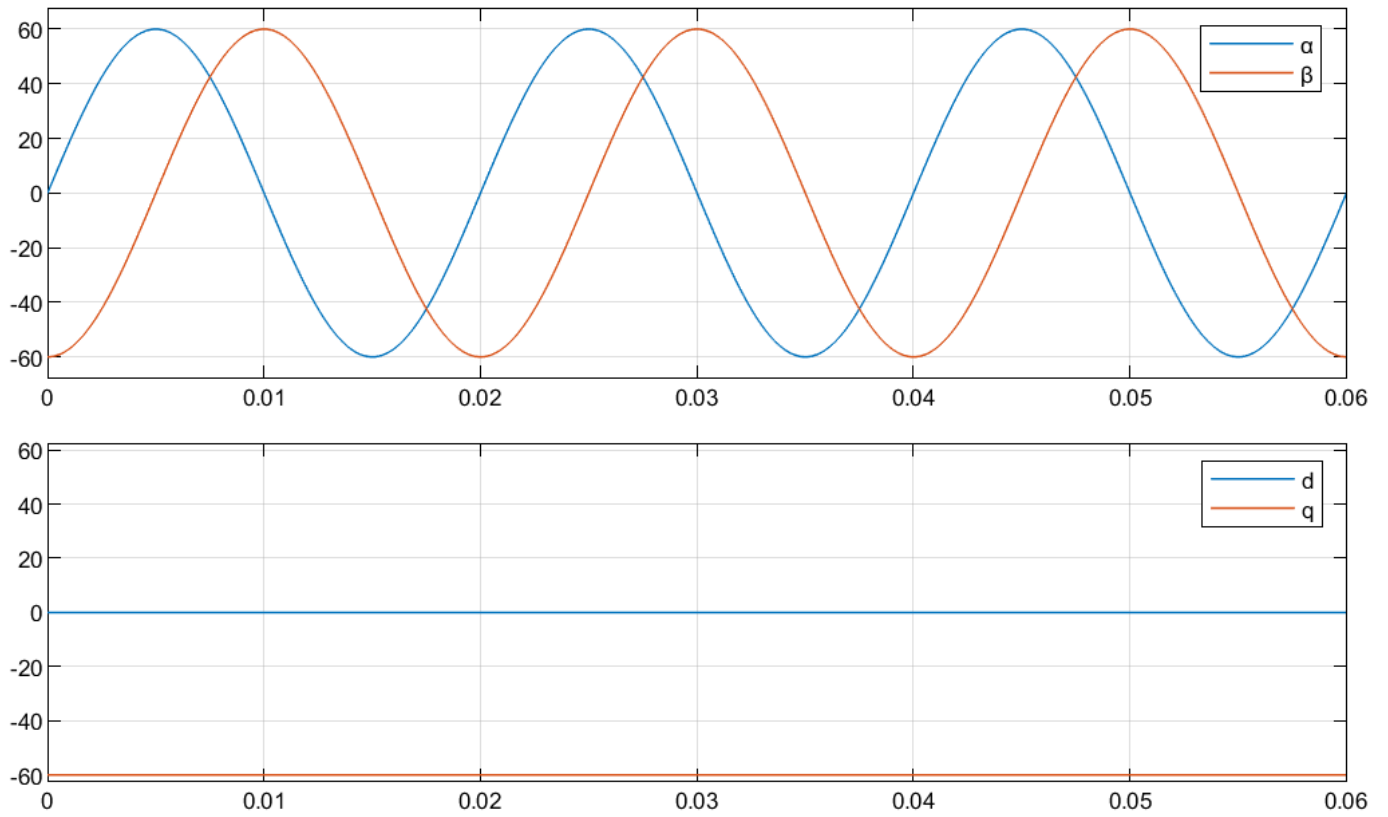


In both cases, the angle $\theta = \omega t$, where:

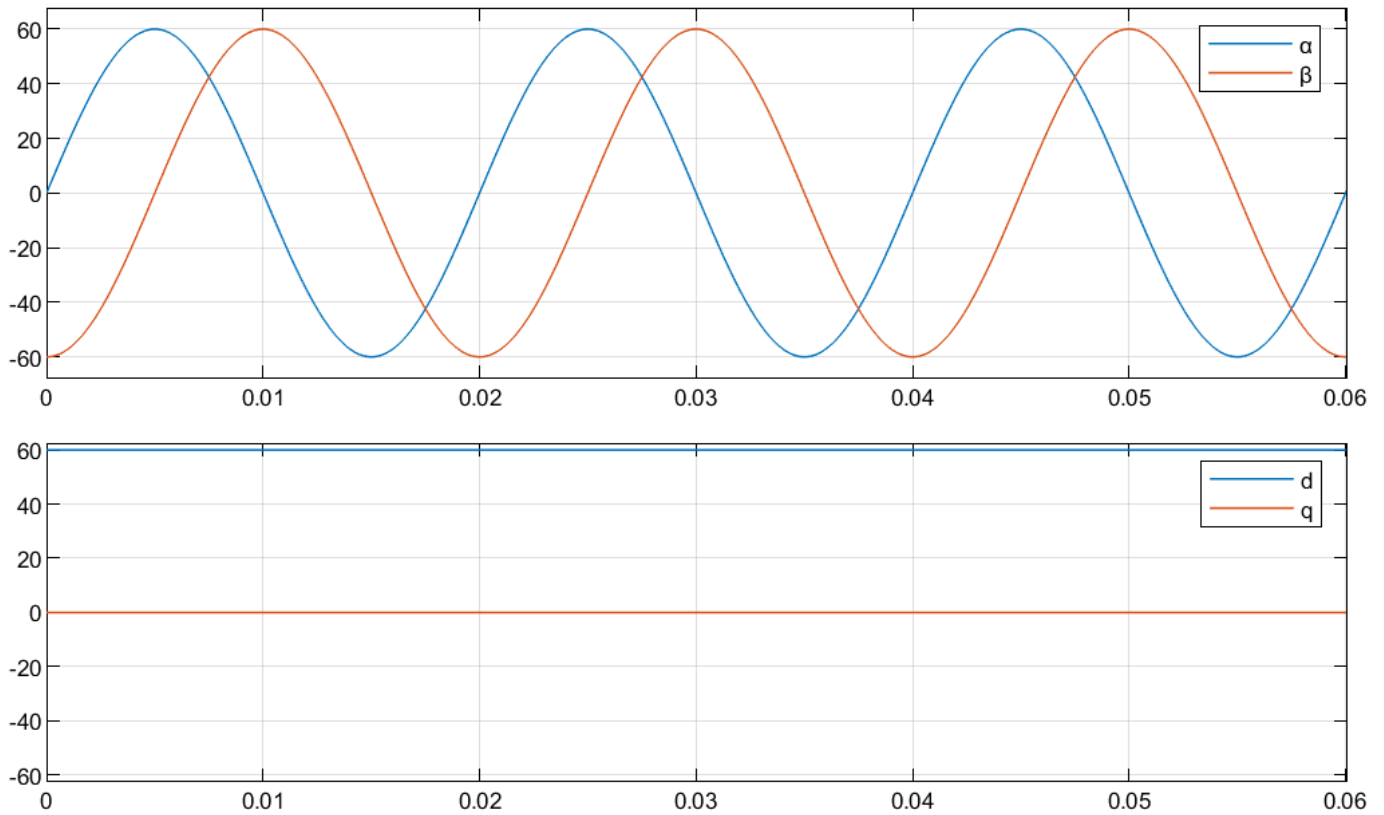
- θ is the angle between the α - and d -axes for the d -axis alignment or the angle between the α - and q -axes for the q -axis alignment. It indicates the angular position of the rotating dq reference frame with respect to the α -axis.
- ω is the rotational speed of the d - q reference frame.
- t is the time, in seconds, from the initial alignment.

The figures show the time-response of the individual components of the $\alpha\beta$ and dq reference frames when:

- The d -axis aligns with the α -axis.



- The q -axis aligns with the α -axis.



Equations

The following equations describe how the block implements Park transformation.

- When the d -axis aligns with the α -axis.

$$\begin{bmatrix} f_d \\ f_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix}$$

- When the q -axis aligns with the α -axis.

$$\begin{bmatrix} f_d \\ f_q \end{bmatrix} = \begin{bmatrix} \sin\theta & -\cos\theta \\ \cos\theta & \sin\theta \end{bmatrix} \begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix}$$

where:

- f_α and f_β are the two-phase orthogonal components in the stationary $\alpha\beta$ reference frame.
- f_d and f_q are the direct and quadrature axis orthogonal components in the rotating dq reference frame.

Ports

Input

α — Axis component
scalar

Alpha-axis component, α , in the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

β — Axis component
scalar

Beta-axis component, β , in the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

$\sin \theta_e$ — Sine value of rotational angle
scalar

Sine value of the angle of transformation, θ_e . θ_e is the angle between the rotating reference frame and the α -axis.

Data Types: `single` | `double` | `fixed point`

$\cos \theta_e$ — Cosine value of rotational angle
scalar

Cosine value of the angle of transformation, θ_e . θ_e is the angle between the rotating reference frame and the α -axis.

Data Types: `single` | `double` | `fixed point`

Output

d — Axis component
scalar

Direct axis component, d , in the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

q — Axis component
scalar

Quadrature axis component, q , in the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

Parameters

Alpha (phase-a) axis alignment — dq reference frame alignment
D-axis (default) | Q-axis

Align either the d - or q -axis of the rotating reference frame to the α -axis of the stationary reference frame.

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

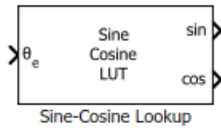
Inverse Park Transform | Clarke Transform | Sine-Cosine Lookup | PI Controller | ACIM Feed Forward Control | ACIM Torque Estimator | PMSM Feed Forward Control | PMSM Torque Estimator

Topics

“Open-Loop and Closed-Loop Control”
 “Field-Oriented Control (FOC)”

Sine-Cosine Lookup

Implement sine and cosine functions using lookup table approach



Libraries:

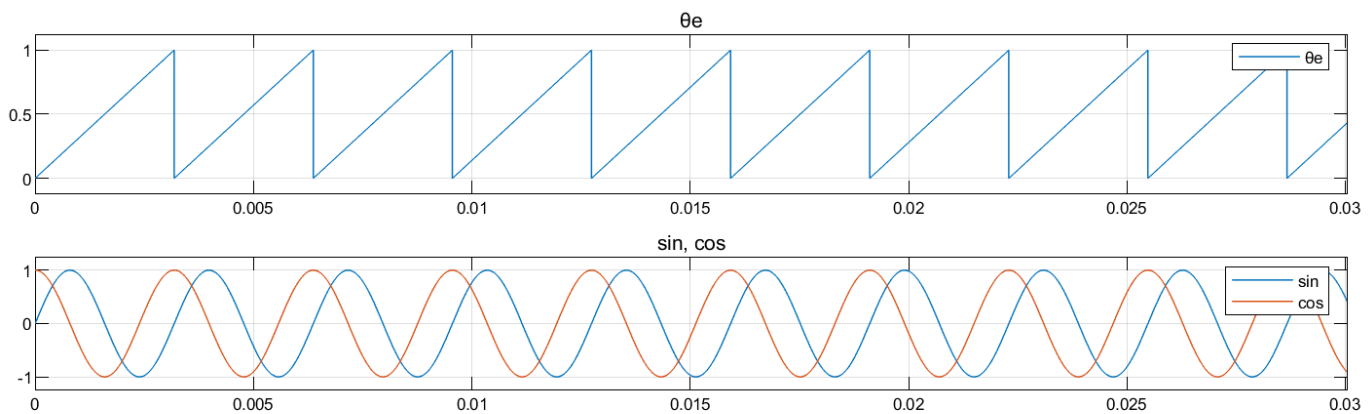
Motor Control Blockset / Controls / Math Transforms

Description

The Sine-Cosine Lookup block implements sine and cosine functions using the specified position or phase input signal.

The block uses the lookup table approach. This approach results in optimized code-execution when used with the model settings and configuration adopted by the examples shipped in Motor Control Blockset. You can specify the number of lookup table points in the **Number of data points for lookup table** parameter.

This figure shows the input position and the generated sine and cosine output signals:



Ports

Input

θ_e — Reference voltage position
scalar

Position or phase value of the reference voltage signal specified as scalar in either per-unit, radians, or degrees.

Data Types: single | double | fixed point

Output

sin — Sine voltage waveform
scalar

Sine waveform output with a frequency that is identical to the position or phase signal (θ_e) frequency.

Data Types: `single` | `double` | `fixed point`

cos — Cosine voltage waveform
scalar

Cosine waveform output with a frequency that is identical to the position or phase signal (θ_e) frequency.

Data Types: `single` | `double` | `fixed point`

Parameters

Theta units — Unit of θ_e
Per-unit (default) | Radians | Degrees

Unit of the input reference voltage position.

Number of data points for lookup table — Size of lookup table array
1024 (default) | scalar

Size of the lookup table array.

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Position Generator | Park Transform | Inverse Park Transform | Mechanical to Electrical Position

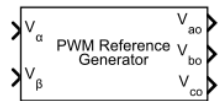
Topics

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

PWM Reference Generator

Generate modulated signals from phase voltages



PWM Reference Generator

Libraries:

Motor Control Blockset / Controls / Math Transforms

Motor Control Blockset HDL Support / Controls / Math Transforms

Description

The PWM Reference Generator block generates modulated voltage signals from the stator phase or reference voltages.

The block accepts either the phase voltages (V_{abc}) or the stator reference voltages ($V_{\alpha\beta}$) described by the α - β voltage components.

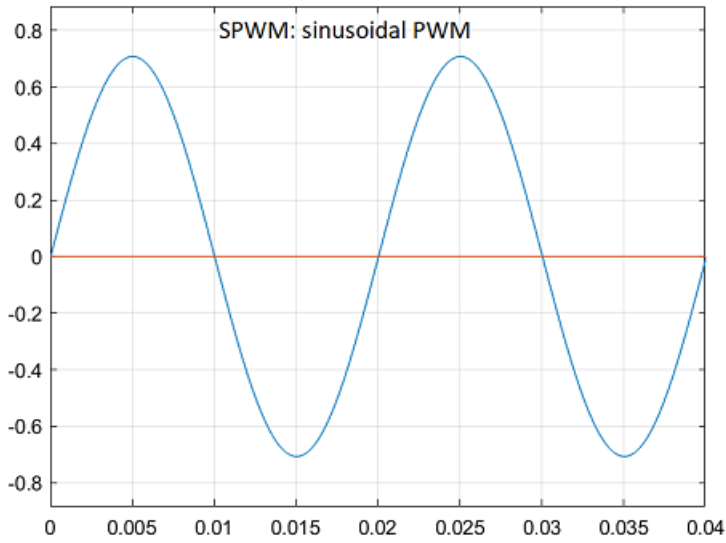
Use this block to perform sinusoidal PWM (SPWM) and space vector modulation (SVM) along with these discrete pulse-width modulation (DPWM) methods that reduce switching losses:

Note For the following modulation methods the block supports only per-unit (PU) input signals. For more information about the per-unit system, see “Per-Unit System”.

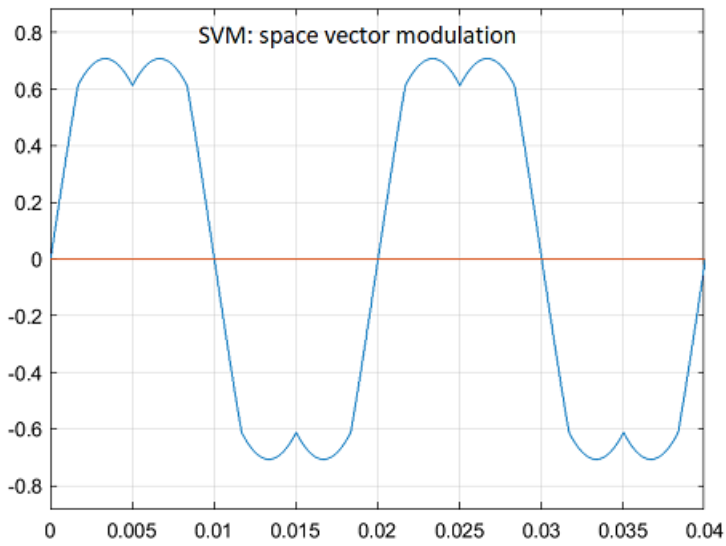
- 60 DPWM — 60 degree discontinuous PWM
- 60 DPWM (+30 degree shift) — +30 degree shift from 60 DPWM
- 60 DPWM (-30 degree shift) — -30 degree shift from 60 DPWM
- 30 DPWM — 30 degree discontinuous PWM
- 120 DPWM — Positive DC component
- 120 DPWM — Negative DC component

For discontinuous PWM (DPWM), the block clamps the modulation wave to the positive or negative DC rail for a total of 120 degrees during each fundamental period per phase. During each clamping interval, the modulation discontinues.

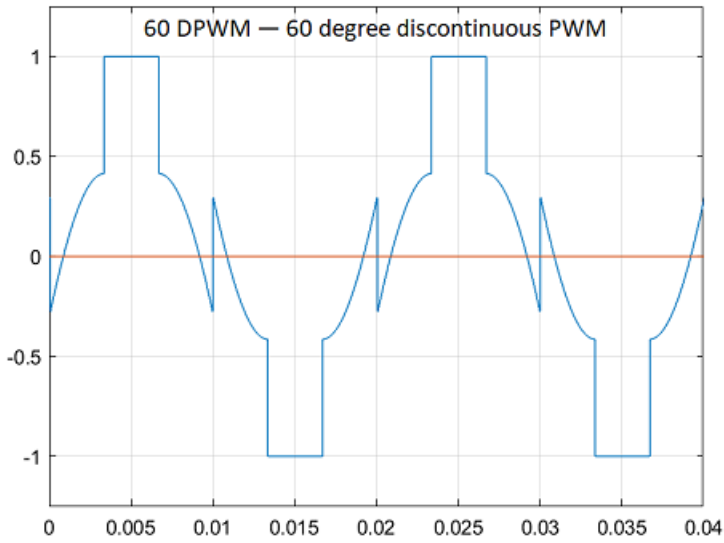
The figure shows the sinusoidal PWM (SPWM) waveform.



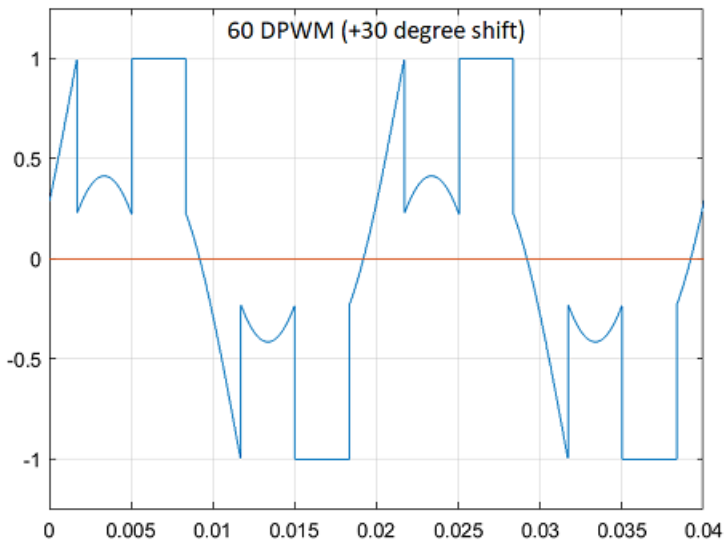
The figure shows the space vector modulation (SVM) waveform.



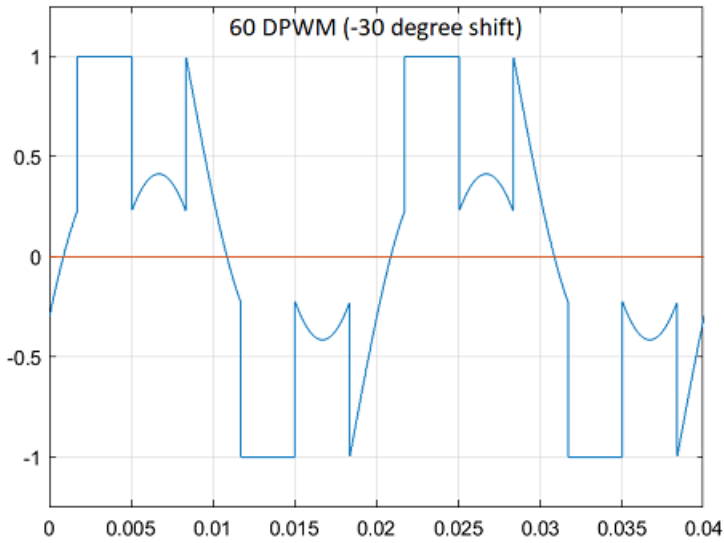
The figure shows a 60-degree DPWM waveform with two 60-degree clamped intervals per fundamental period.



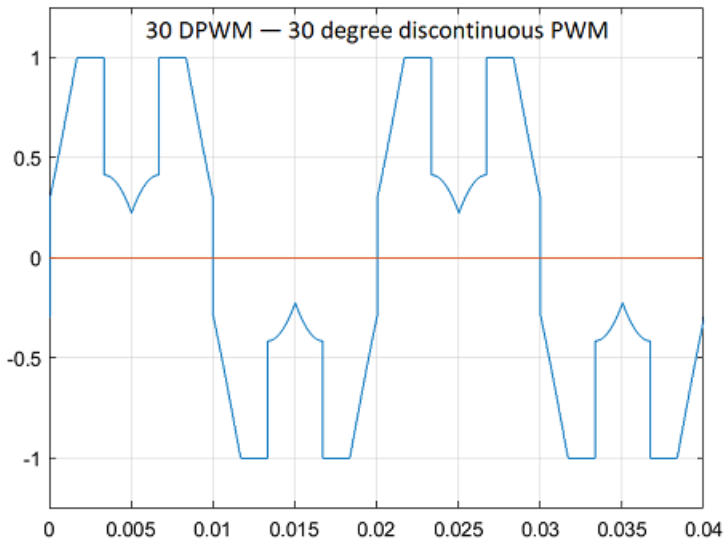
The figure shows a 60-degree DPWM waveform with a positive 30-degree phase shift.



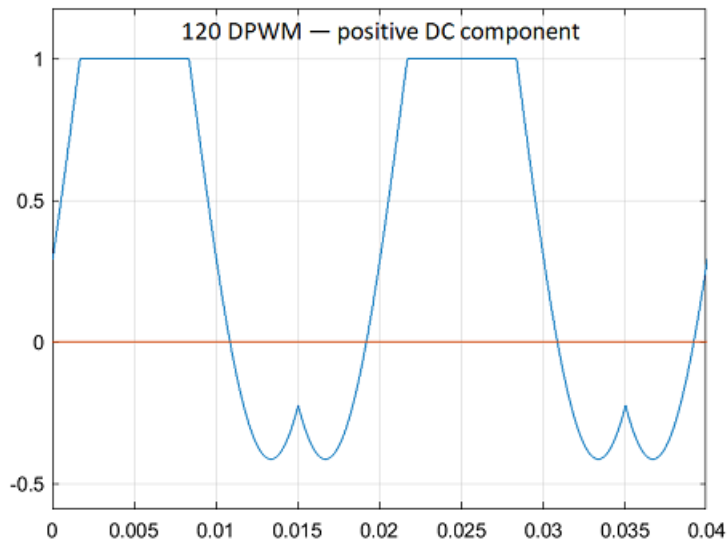
The figure shows a 60-degree DPWM waveform with a negative 30-degree phase shift.



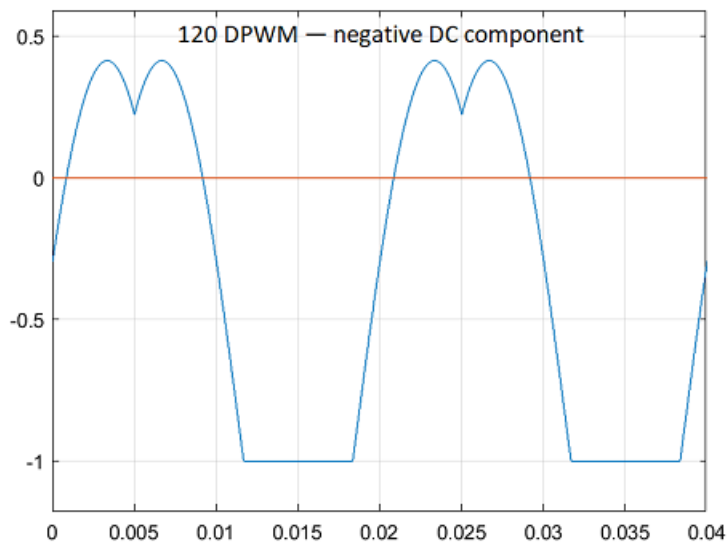
The figure shows a 30-degree DPWM waveform with four 30-degree clamped intervals per fundamental period.



The figure shows a 120-degree DPWM waveform with positive DC clamping.



The figure shows a 120-degree DPWM waveform with negative DC clamping.



Ports

Input

V_α — α -axis stator reference voltage component
scalar

Stator reference voltage component along α -axis of the $\alpha\beta$ reference frame.

Dependencies

To enable this port, set **Input type** to Valphabeta.

Data Types: single | double | fixed point

V_{β} — β -axis stator reference voltage component
scalar

Stator reference voltage component along β -axis of the $a\beta$ reference frame.

Dependencies

To enable this port, set **Input type** to Valphabeta.

Data Types: single | double | fixed point

V_a — Phase component
scalar

Component of the three-phase system in the abc reference frame.

Dependencies

To enable this port, set **Input type** to Vabc.

Data Types: single | double | fixed point

V_b — Phase component
scalar

Component of the three-phase system in the abc reference frame.

Dependencies

To enable this port, set **Input type** to Vabc.

Data Types: single | double | fixed point

V_c — Phase component
scalar

Component of the three-phase system in the abc reference frame.

Dependencies

To enable this port, set **Input type** to Vabc.

Data Types: single | double | fixed point

Output

V_{a0} — a -axis stator reference voltage component
scalar

Stator reference voltage component along a -axis of the abc reference frame.

Data Types: single | double | fixed point

V_{b0} — b -axis stator reference voltage component
scalar

Stator reference voltage component along b -axis of the abc reference frame.

Data Types: single | double | fixed point

V_{co} — c -axis stator reference voltage component
scalar

Stator reference voltage component along c -axis of the abc reference frame.

Data Types: single | double | fixed point

Parameters

Input type — Block input type
Valphabeta (default) | Vabc | Degrees

Type of three-phase stator voltage representation that the block uses as input. Select either the abc or $a\beta$ reference frame.

Modulation method — Pulse-width modulation (PWM) methods
SVM: space vector modulation (default) | SPWM: sinusoidal PWM | 60 DPWM — 60 degree discontinuous PWM | 60 DPWM (+30 degree shift) — +30 degree shift from 60 DPWM | 60 DPWM (-30 degree shift) — -30 degree shift from 60 DPWM | 30 DPWM — 30 degree discontinuous PWM | 120 DPWM — positive DC component | 120 DPWM — negative DC component

Pulse-width modulation (PWM) method that the block uses to modulate the input stator phase or reference voltages.

Version History

Introduced in R2020a

Extended Capabilities

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

HDL Code Generation
Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

Supported Block Parameters

For HDL code generation with the PWM Reference Generator block, set the **Modulation method** to SVM: space vector modulation or SPWM: sinusoidal PWM.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

--	--

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Inverse Park Transform

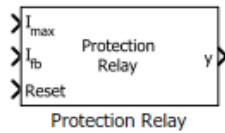
Topics

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

Protection Relay

Implement protection relay with definite minimum time (DMT) trip characteristics



Libraries:

Motor Control Blockset / Protection and Diagnostics

Description

The Protection Relay block implements a protection relay for the hardware and the motor with definite minimum time (DMT) trip characteristics using the reference limit, feedback, and reset input signals. In the event of a fault, the block generates a latched fault signal that you can use to protect the hardware and the motor. You can reset the fault latch using an external reset signal.

Ports

Input

I_{max} — Upper limit for current
scalar

Upper limit for current in the feedback loop, so as to provide overcurrent protection. The block generates a latched fault signal when the current in the feedback loop (I_{fb}) exceeds this value.

Dependencies

To enable this port, set **Select Protection** to Overcurrent.

Data Types: `single` | `double` | `fixed point`

I_{fb} — Actual current in feedback loop
scalar

Actual current in the feedback loop at a given time.

Dependencies

To enable this port, set **Select Protection** to Overcurrent.

Data Types: `single` | `double` | `fixed point`

$\omega_{m \max}$ — Rotor speed limit for overspeed protection
scalar

Speed limit of the rotor (in RPM). The block generates a latched fault signal when the rotor speed (ω_{fb}) exceeds this value.

Dependencies

To enable this port, set **Select Protection** to Overspeed.

Data Types: `single` | `double` | `fixed point`

$\omega_{m\text{ fb}}$ — Actual rotor speed
scalar

Actual rotor speed at a given time.

Dependencies

To enable this port, set **Select Protection** to Overspeed.

Data Types: `single` | `double` | `fixed point`

V_{max} — Upper voltage limit for overvoltage protection
scalar

Upper limit for voltage across the feedback loop. The block generates a latched fault signal when the voltage across the feedback loop (V_{fb}) exceeds this value.

Dependencies

To enable this port, set **Select Protection** to Overvoltage.

Data Types: `single` | `double` | `fixed point`

V_{min} — Lower voltage limit for undervoltage protection
scalar

Lower limit for voltage across the feedback loop. The block generates a latched fault signal when the voltage across the feedback loop (V_{fb}) is less than this value.

Dependencies

To enable this port, set **Select Protection** to Undervoltage.

Data Types: `single` | `double` | `fixed point`

V_{fb} — Actual voltage across feedback loop
scalar

Actual voltage across the feedback loop at a given time.

Dependencies

To enable this port, set **Select Protection** to either Overvoltage or Undervoltage.

Data Types: `single` | `double` | `fixed point`

Reset — External reset pulse
scalar

External pulse that resets the fault latch.

Data Types: `single` | `double` | `fixed point`

Output

y — Latched fault signal
scalar

Latched fault signal that the block generates during the overcurrent, overspeed, overvoltage, and undervoltage conditions to protect the hardware and the motor.

Data Types: single | double | fixed point

Parameters

Select Protection — Type of protection relay

Overcurrent (default) | Overspeed | Overvoltage | Undervoltage

Available protection types to configure block behavior during the overcurrent, overspeed, overvoltage, and undervoltage conditions.

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

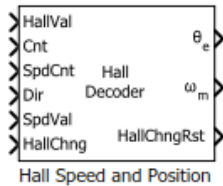
Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

Hall Speed and Position

Compute speed and estimate position of rotor by using Hall sensors



Libraries:

Motor Control Blockset / Sensor Decoders

Description

The Hall Speed and Position block computes the mechanical speed of the rotor by tracking changes in the Hall state. The block also estimates the electric position of the rotor by using the direction, Hall state, and external counter value inputs.

The block executes periodically after a fixed time interval that the controller algorithm defines.

Ports

Input

HallVal — Current Hall sensor output state
scalar

The Hall state at current time. For example, these are the possible valid Hall states (where the MSB represents the output of the first Hall sensor connected):

- 5 - (101)
- 4 - (100)
- 6 - (110)
- 2 - (010)
- 3 - (011)
- 1 - (001)

Data Types: uint8 | uint16 | uint32

Cnt — External counter value
scalar

The external counter value that the block uses to determine the time elapsed between the Hall state change and block execution.

Data Types: uint8 | uint16 | uint32

SpdCnt — Count at Hall state change
scalar

This value indicates the clock cycles (time) elapsed between two consecutive changes in the Hall state.

Data Types: uint8 | uint16 | uint32

Dir — Rotor spin direction during current Hall state
scalar

The direction of the rotor spin (either +1 or -1 indicating positive or negative direction of rotation, respectively) during the current Hall state.

Data Types: int8 | int16 | int32

SpdVal — Validity of current and previous Hall states and speed calculation
scalar

The port value indicates Hall state validity. The value zero indicates that the current or previous Hall state is invalid and that the block cannot calculate speed and position.

The value one indicates that both the current and previous Hall states are valid and that the block can calculate speed and position.

Data Types: uint8 | uint16 | uint32

HallChng — Value of Hall state change flag
scalar

The port value indicates Hall state change and block execution status. The value one indicates that the Hall state changed, but that the block execution is pending. The value zero indicates that the block has completed executing the last Hall state change.

Data Types: uint8 | uint16 | uint32

Output

θ_e — Electrical position of rotor
scalar

The estimated electrical position of the rotor based on the **Expected hall sequence in positive direction** parameter and the Direction, HallVal, and CounterValue inputs.

Dependencies

To enable this port, set **Block output** to either Position or Speed and position.

Data Types: single | double | fixed point

ω_m — Mechanical speed of rotor
scalar

The mechanical speed of the rotor in revolutions per minute. The block calculates this value by tracking the Hall state changes.

The port returns zero if the SpdVal input is zero.

Dependencies

To enable this port, set **Block output** to either Speed or Speed and position.

Data Types: `single` | `double` | `fixed point`

HallChngRst — Resets Hall state change flag to zero
scalar

The port outputs a value of zero (sets the Hall state change flag to zero) indicating that the block has successfully executed speed and position computations for the last Hall state change.

Data Types: `single` | `double` | `fixed point`

Parameters

General

Block output — Select output ports
`Speed and position (default)` | `Speed` | `Position`

Select the available block output ports as one of the following values:

- Speed and position
- Speed
- Position

Counter size — Size of external counter register
`32 bits (default)` | `8 bits` | `16 bits`

The register size of the external counter. The maximum counter value is $2^n - 1$, where n = counter size.

Counter clock frequency (Hz) — Clock frequency of external counter
`90e6 (default)` | scalar

The clock frequency of the external counter.

Discrete step size (s) — Sample time after which block executes again
`50e-6 (default)` | scalar

The time between two consecutive instances of block execution.

Number of pole pairs — Number of pole pairs available in motor
`8 (default)` | scalar

Number of pole pairs available in the motor.

Minimum detectable speed (RPM) — Minimum speed that block can detect
`20 (default)` | scalar

The block does not calculate position for speed below this value.

Speed measurement interval — Interval over which block measures speed
`Every 180 Degrees (default)` | `Every 60 Degrees`

Rotor angular displacement that represents the interval at which the SpdCnt port value was calculated.

Speed unit — Unit of rotor angular speed output
Radians/sec (default) | Degrees/sec | RPM | Per unit

Unit of the angular velocity or mechanical speed (ω_m) output.

Dependencies

To enable this parameter, set **Block output** to either Speed or Speed and position.

Speed datatype — Data type of rotor angular speed output
single (default) | double | fixdt(1,16,0) | fixdt(1,16,2^0,0) | <data type expression>

Data type of the rotor angular speed output.

Dependencies

To enable this parameter, set **Block output** to either Speed or Speed and position.

Position

Expected hall sequence in positive direction — Sequence indicating positive direction
ABC (default) | CBA | Custom sequence

The Hall sensor sequence that represents the positive direction of rotor spin.

Dependencies

To enable this parameter, set **Block output** to either Position or Speed and position.

Sequence — Custom sequence indicating positive direction
[5,4,6,2,3,1] (default) | scalar

The custom sequence that you can enter to represent rotor spin in the positive direction.

Dependencies

To enable this parameter:

- Set **Block output** to either Position or Speed and position.
- Set **Expected hall sequence in positive direction** to Custom sequence.

Order of extrapolation of position — Indicates precision in position computation
1st Order (default) | 2nd Order

The 1st Order option is less accurate in computing position, but quick. The 2nd Order option is more accurate, but needs more computation time. These equations describe the options:

$$\theta_{1st\ Order} = \theta_{sector} + \omega t$$

$$\theta_{2nd\ Order} = \theta_{sector} + \omega t + \frac{1}{2}\alpha t^2$$

where:

$\theta_{1st\ Order}$ = Position computed by using 1st order extrapolation.

$\theta_{2nd\ Order}$ = Position computed by using 2nd order extrapolation.

θ_{sector} = Sector angle defined by the Hall sensor output.

ω = Angular velocity of the rotor.

α = Angular acceleration of the rotor.

t = Time spent in a sector.

Dependencies

To enable this parameter, set **Block output** to either Position or Speed and position.

Position unit — Unit of angular speed output

Radians (default) | Degrees | Per unit

Unit of angular speed output.

Dependencies

To enable this parameter, set **Block output** to either Position or Speed and position.

Position datatype — Data type of angular speed output

single (default) | double | fixdt(1,16,0) | fixdt(1,16,2^0,0) | <data type expression>

Data type of angular speed output.

Dependencies

To enable this parameter, set **Block output** to either Position or Speed and position.

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Hall Validity | Mechanical to Electrical Position | PI Controller

Topics

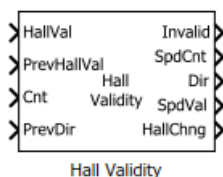
“Current Sensor ADC Offset and Position Sensor Calibration”

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

Hall Validity

Compute rotor spin direction and validity of Hall sensor sequence



Libraries:

Motor Control Blockset / Sensor Decoders

Description

The Hall Validity block checks and validates every state of the Hall sensor output sequence. The block identifies the condition when one or more Hall sensors are in an invalid state.

The block executes when a Hall sensor output state (or Hall state) changes.

Ports

Input

HallVal — Current Hall sensor output state
scalar

The Hall state at current time. These are the possible input values (three-bit numbers where the MSB represents the output of the first Hall connected):

- 5 - (101)
- 4 - (100)
- 6 - (110)
- 2 - (010)
- 3 - (011)
- 1 - (001)

Note The output port `Invalid` indicates a bad hall sensor condition.

Data Types: `uint8` | `uint16` | `uint32`

PrevHallVal — Previous Hall sensor output state
scalar

The Hall state prior to the current state.

Data Types: `uint8` | `uint16` | `uint32`

Cnt — External counter value
scalar

The external counter value that the block uses to determine the time elapsed between the Hall state change and block execution.

Note The counter must reset when a Hall state changes.

Data Types: `uint8` | `uint16` | `uint32`

PrevDir — Rotor spin direction during previous Hall state
scalar

The direction of rotor spin (either +1 or -1 indicating positive or negative direction of rotation, respectively) during the previous Hall state.

Data Types: `uint8` | `uint16` | `uint32`

Output

Invalid — Indicator of Hall state validity
scalar

The indicator of Hall sensor validity during the current or previous Hall state. The block checks the validity of the sensors by comparing the values of the `HallVal` and `PrevHallVal` input port with the value of the **Expected hall sequence in positive direction** parameter. The port can output these values:

- 1 - (001) Indicates that one (or more) sensors are bad.
- 0 - (000) Indicates that all sensors are good.

Data Types: `single` | `double` | `fixed point`

SpdCnt — Count at Hall state change
scalar

The value of the `Cnt` input port when a Hall state changes.

Note The counter must reset when a Hall state changes. Therefore, this port indicates the number of counts during the previous Hall state.

Data Types: `single` | `double` | `fixed point`

Dir — Rotor spin direction during current Hall state
scalar

The direction of the rotor spin (either +1 or -1 indicating positive or negative direction of rotation, respectively) during the current Hall state. The block computes the direction by comparing the values of the `HallVal` and `PrevHallVal` input ports with the value of the **Expected hall sequence in positive direction** parameter.

Data Types: `single` | `double` | `fixed point`

SpdVal — Validity of current and previous Hall states and speed calculation
scalar

The port outputs zero when either one or both conditions occur:

- The block detects a bad hall sensor state (in either `HallVal` or `PrevHallVal` input port values).
- The block detects a change in the rotor spin direction.

The zero value indicates that you cannot calculate the valid speed for the current Hall state because the current value of `SpdCnt` is invalid. The port outputs the value one to indicate that a valid speed calculation is possible.

Data Types: `single` | `double` | `fixed point`

HallChng — Set flag to one, indicating Hall state change
scalar

The port outputs the value one (and sets the Hall state change flag to one) after the Hall state changes and the block has completed execution.

Data Types: `single` | `double` | `fixed point`

Parameters

Expected hall sequence in positive direction — Sequence indicating positive direction
`ABC` (default) | `CBA` | `Custom sequence`

The Hall sensor sequence that represents the positive direction of rotor spin.

Sequence — Custom sequence indicating positive direction
`[5,4,6,2,3,1]` (default) | scalar

The custom sequence that you can enter to represent rotor spin in the positive direction.

Dependencies

To enable this parameter, set **Expected hall sequence in positive direction** to `Custom sequence`.

Counter size — Size of external counter register
`16 bits` (default) | `8 bits` | `32 bits`

The register size of the external counter. The maximum counter value is 2^n-1 , where n = counter size.

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Hall Speed and Position

Topics

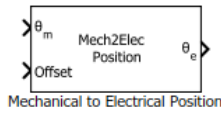
“Current Sensor ADC Offset and Position Sensor Calibration”

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

Mechanical to Electrical Position

Compute electrical position of rotor from mechanical position



Libraries:

Motor Control Blockset / Sensor Decoders

Motor Control Blockset HDL Support / Sensor Decoders

Description

The Mechanical to Electrical Position block computes the electrical position of rotor by using its mechanical position and mechanical offset value.

Ports

Input

θ_m — Mechanical position of rotor
scalar

The mechanical position of rotor (as output by the rotor position sensor) in either radians (0 to 2π), degrees (0 to 360), or per unit (0 to 1).

Data Types: `single` | `double` | `fixed point`

Offset — Mechanical position offset
scalar

The deviation of the rotor's electrical zero from the mechanical zero position. Unit of offset is identical to the unit of the mechanical position input.

Dependencies

- To enable this port, set **Specify offset via** to `Input` port.
- Inputs must be of the same data type.

Data Types: `single` | `double` | `fixed point`

Output

θ_e — Electrical position of rotor
scalar

The electrical position of the rotor with a range that is identical to that of the mechanical position input. Data type of the electrical position is identical to that of the input.

Data Types: `single` | `double` | `fixed point`

Parameters

Number of pole pairs — Number of pole pairs available in motor
4 (default) | scalar

Number of pole pairs available in the motor.

Input mechanical angle unit — Unit of mechanical position of rotor
Per unit (default) | Radians | Degrees

Unit of the mechanical position of the rotor.

Offset input type — Method to specify offset
Input port (default) | Specify via dialog

The method you want to use to specify the mechanical position offset. Select `Input port` to enable and use the input port `Offset`. Select `Specify via dialog` to provide the offset value using the dialog box.

Mechanical offset — Value of mechanical position offset
0 (default) | scalar

The unit of the offset is identical to that of the unit of the mechanical position input.

Dependencies

To enable this parameter, set **Specify offset via** to `Specify via dialog`.

Input data type — Data type of input ports
single (default) | double | fixed point

The data type that you want to use for the input ports.

Note The block runs faster, if you select either `fixdt(1,16,0)` or `fixdt(1,16,2^0,0)` input data type and provide fixed point values to the input ports.

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

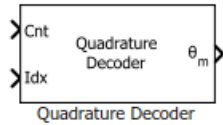
Hall Speed and Position | Quadrature Decoder | Position Generator | PI Controller | Sine-Cosine Lookup

Topics

“Open-Loop and Closed-Loop Control”
 “Field-Oriented Control (FOC)”

Quadrature Decoder

Compute position of quadrature encoder



Libraries:

Motor Control Blockset / Sensor Decoders

Motor Control Blockset HDL Support / Sensor Decoders

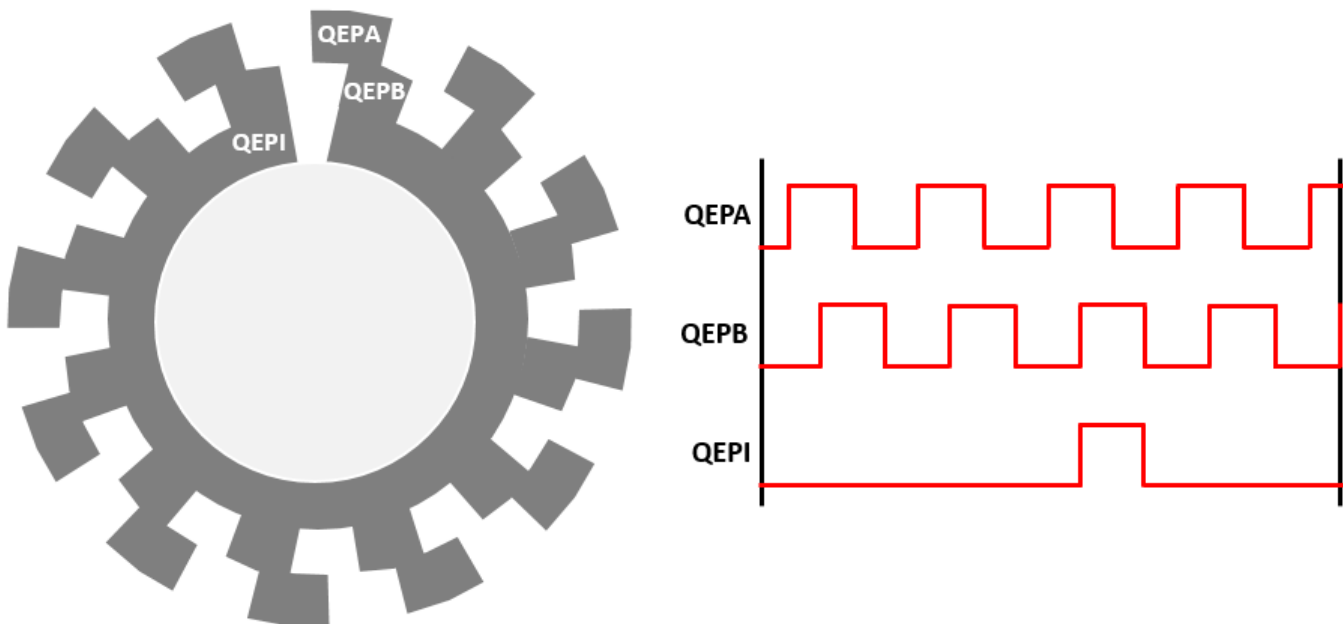
Description

The Quadrature Decoder block computes the position of the quadrature encoder.

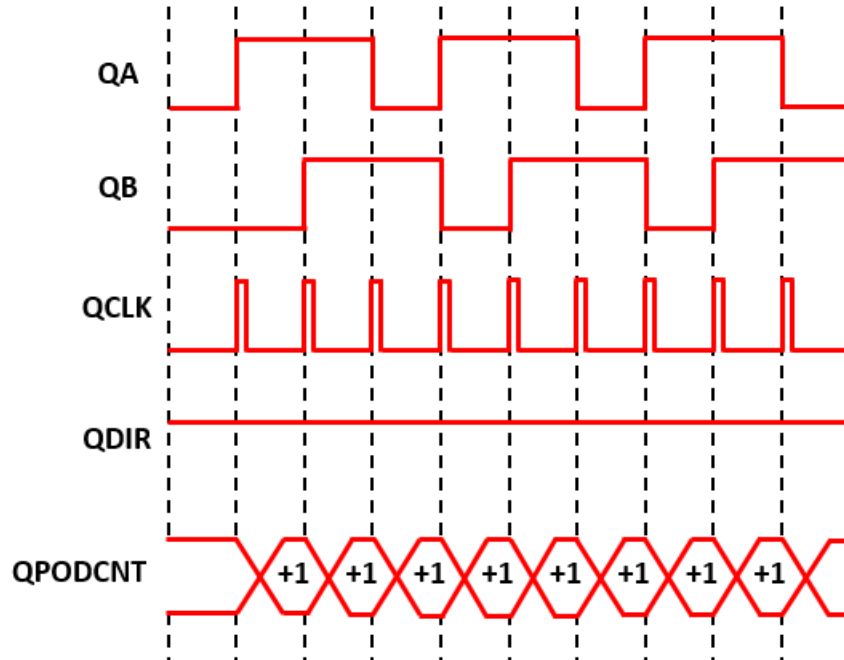
To calculate the angular position of the quadrature encoder (and the rotor) in either degrees, radians, or per-unit, the block uses one of the following methods.

- Difference between current encoder counter value and encoder counter value at the previous index pulse (when index pulse is available).
- Current encoder counter value (when index pulse is not available).

This figure shows a quadrature encoder disk with two channels (QEPA and QEPB) and an index pulse (QEPI):



In this example, the timer driven by the QEP increments by four for each slit:



Equations

The block computes the angular position (in counts) of the quadrature encoder as:

When the encoder rotates in the clockwise direction:

- If $Idx \leq Cnt$,
 $Position\ count = (Cnt - Idx)$
- If $Idx > Cnt$ and the shaft continues to rotate in the clockwise direction,
 $Position\ count = (Cnt - Idx)$
- If $Idx > Cnt$ and the shaft starts rotating in the anticlockwise direction,
 $Position\ count = Counts\ per\ revolution - (Idx - Cnt)$

When the encoder rotates in the anticlockwise direction:

- If $Idx \geq Cnt$,
 $Position\ count = Counts\ per\ revolution - (Idx - Cnt)$
- If $Idx < Cnt$ and the shaft continues to rotate in the anticlockwise direction,
 $Position\ count = Counts\ per\ revolution - (Idx - Cnt)$
- If $Idx < Cnt$ and the shaft starts rotating in the clockwise direction,
 $Position\ count = (Cnt - Idx)$

When you clear the **External index count** parameter, the **Idx** pulse resets **Cnt** to zero, therefore:

$$Position\ count = Cnt$$

where:

- *Position count* is the angular position of the quadrature encoder in counts.
- *Counts per revolution* is the number of counts in one rotation cycle of the quadrature encoder.

The block computes the output θ_m as:

$Position = 360 \times Position\ count / (Encoder\ slits \times Encoder\ counts\ per\ slit)$ (in degrees)

$Position = 2\pi \times Position\ count / (Encoder\ slits \times Encoder\ counts\ per\ slit)$ (in radians)

$Position = Cnt / (Encoder\ slits \times Encoder\ counts\ per\ slit)$ (in per-unit)

Ports

Input

Cnt — Quadrature encoder counter value
scalar

Value that the quadrature encoder counter generates with respect to the slit-position. The port only accepts a scalar unsigned integer based on the **Counter size** parameter. For example, if you select **8 bits** for **Counter size**, the input data type must be uint8.

Data Types: uint8 | uint16 | uint32

Idx — Quadrature encoder counter value at last index pulse
scalar

Value that the quadrature encoder counter generated with respect to the slit-position at the time of the last index pulse. The port only accepts a scalar unsigned integer based on the **Counter size** parameter. For example, if you select **8 bits** for **Counter size**, the input data type must be uint8.

Dependencies

To enable this port, select the **External index count** parameter.

Data Types: uint8 | uint16 | uint32

Note The input data types for both Cnt and Idx must be identical.

Output

θ_m — Angular position of quadrature encoder
scalar

Angular position that the block computes based on the Cnt and Idx inputs.

Data Types: single | double | fixed point

Parameters

Encoder slits — Number of slits per phase
1000 (default) | scalar

The number of slits available in each phase of the quadrature encoder.

Encoder counts per slit — Number of counts generated for every slit

4 (default) | 1 | 2

The number of counts that the quadrature encoder generates for every slit. A count indicates a slit position. For example, select 4 (quadrature mode) if you want the encoder to generate four counts corresponding to 00, 10, 11, and 01 slit positions or values. If you select the quadrature mode:

Encoder density, in counts per revolution (post-quadrature) = **Encoder counts per slit (4) × Encoder slits**

Counter size — Size of quadrature encoder counter

16 bits (default) | 8 bits | 32 bits

Counter size signifies the register size of the counter used by the processor to count the quadrature encoder pulses. It is the data type of the counter output of eQEP.

External index count — Enable Idx input port

on (default) | off

The block enables the Idx input port only if you select this parameter. The block expects that the Cnt input port value resets at the time of the Idx pulse.

Position unit — Unit of angular position output

Radians (default) | Degrees | Per unit

Unit of the angular position output.

Position data type — Data type of angular position output

single (default) | double | fixdt(1,16,0) | fixdt(1,16,2^0,0) | <data type expression>

The data type for the angular position output.

Note The Quadrature Decoder block may occasionally display the warning message 'Wrap on overflow detected.'

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Speed Measurement | Mechanical to Electrical Position

Topics

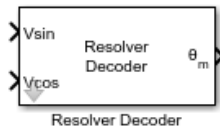
“Current Sensor ADC Offset and Position Sensor Calibration”

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

Resolver Decoder

Compute motor mechanical position and speed as well as sine and cosine values of motor electrical position

**Libraries:**

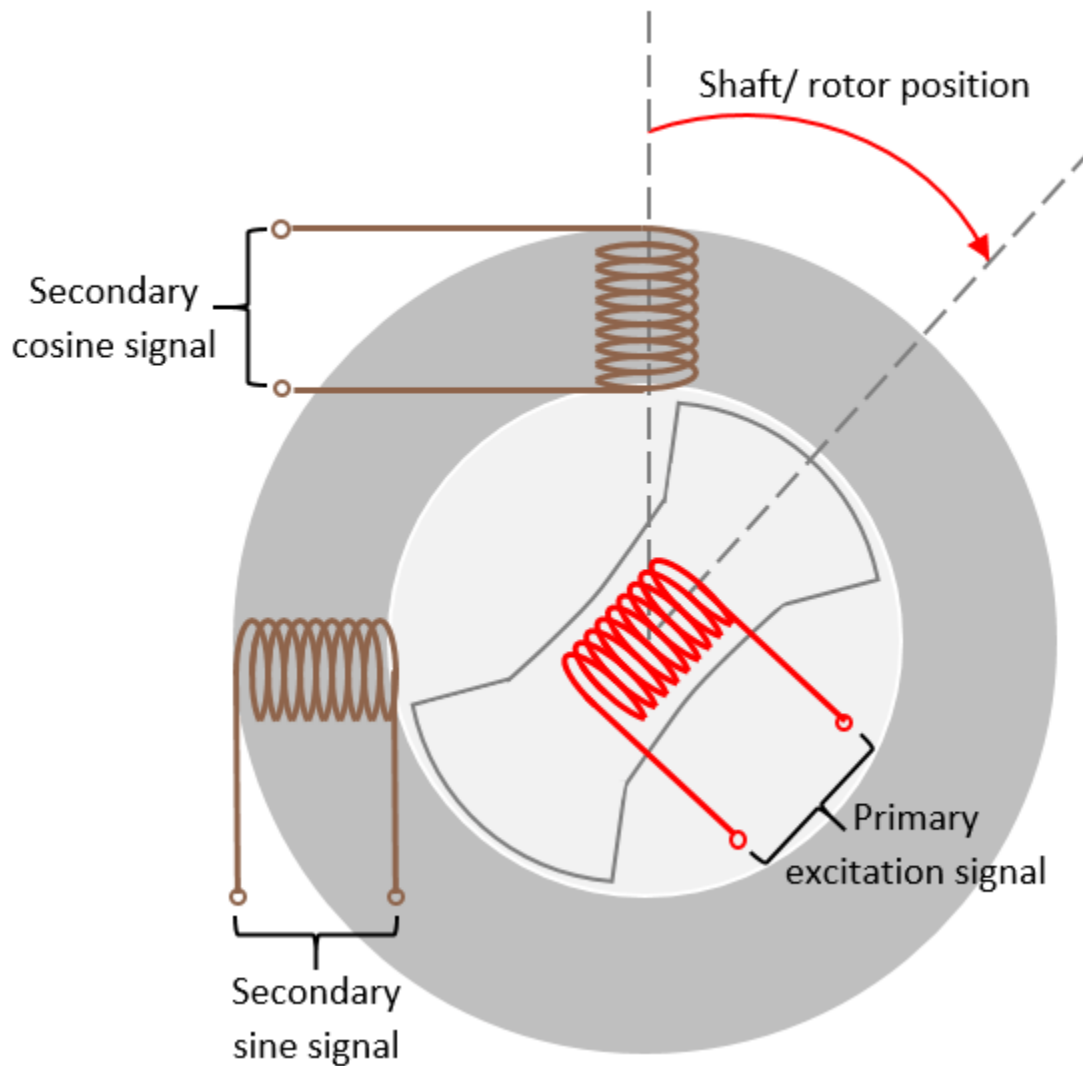
Motor Control Blockset / Sensor Decoders

Description

The Resolver Decoder block computes the following for a resolver connected to a motor shaft:

- Mechanical angular position of motor
- Sine and cosine of electrical angular position of motor
- Mechanical speed of motor

A resolver uses a primary excitation input signal to generate the modulated secondary sine and cosine waveforms, which is then sampled by the ADC. The resolver utilizes one winding to two winding transformations. The sine and cosine modulation occurs in the secondary windings because of the design and construction of these windings, which places them at positions that are 90 degrees apart.



For more details about the algorithm used by the block, see "Algorithm" on page 1-121.

Ports

Input

V Sin — Sampled secondary sine signal
vector

Secondary sine waveform output from the resolver that is sampled. When using sinusoidal excitation, this signal should be normalized within the range of [-1, 1] and centred at 0.

Data Types: `single` | `double` | `fixed point`

V Cos — Sampled secondary cosine signal
vector

Secondary cosine waveform output from the resolver that is sampled. When using sinusoidal excitation, this signal should be normalized within the range of [-1, 1] and centred at 0.

Data Types: `single` | `double` | `fixed point`

Output

θ_m — Motor mechanical position
scalar

Mechanical angular position of the resolver (and the motor) in either degrees, radians, or per-unit.

Data Types: `single` | `double` | `fixed point`

$\sin\theta_e$ — Sine of electrical motor position
scalar

Sine of electrical angular position of the motor.

Data Types: `single` | `double` | `fixed point`

$\cos\theta_e$ — Cosine of electrical motor position
scalar

Cosine of electrical angular position of the motor.

Data Types: `single` | `double` | `fixed point`

ω_m — Motor mechanical speed
scalar

Mechanical speed of the motor in either degrees/sec, radians/sec, RPM, or per-unit.

Data Types: `single` | `double` | `fixed point`

Parameters

Block Output — Output of block

`Mechanical position (default)` | `Sine and Cosine electrical position` | `Mechanical speed`

The output of the Resolver Decoder block:

- Mechanical position — Enable the block to compute motor mechanical position.
- Sine and Cosine electrical position — Enable the block to compute sine and cosine values of motor electrical position.
- Mechanical speed — Enable the block to compute the mechanical speed of the motor.

Input Parameters

Number of pole-pairs for resolver — Resolver pole pair count
1 (default) | scalar

The number of pole pairs available in the resolver.

Type of excitation method — Resolve excitation method
`Sinusoidal Excitation (default)` | `Square Pulse Excitation`

The resolver excitation method used to obtain secondary sine and cosine waveforms.

Enable input normalization — Enable block to normalize inputs
off (default) | on

When using square pulse excitation method, the block normalizes the secondary sine and cosine inputs only if you select this parameter.

Dependencies

To enable this parameter, set **Type of excitation method** to Square Pulse Excitation.

Discrete step size (s) — Sample time after which block executes again
50e-6 (default) | scalar

The fixed time interval (in seconds) between every two consecutive instances of block execution.

Dependencies

To enable this parameter, set **Block Output** to Mechanical speed.

Inputs for Sine and Cosine electrical position

Number of pole-pairs for motor — Motor pole pair count
3 (default) | scalar

The number of pole pairs available in the motor.

Dependencies

To enable this parameter, set **Block Output** to Sine and Cosine electrical position.

Position offset (mechanical radians) — Resolver mechanical position offset (in radians)
0 (default) | scalar

The offset between resolver mechanical position and motor mechanical position (in radians).

Dependencies

To enable this parameter, set **Block Output** to Sine and Cosine electrical position.

Integer rounding mode — Rounding mode for fixed-point operations
Zero (default) | Simplest

Select the rounding mode for fixed-point operations used when computing sine and cosine of motor electrical position. You can select:

- Simplest — Generates compact rounding code with faster computation. However, with time, it may add bias in sine and cosine electrical position output.
- Zero — Ensures that the rounding code does not add any bias in the sine and cosine electrical position output. However, this results in slower computation.

Dependencies

To enable this parameter, set **Block Output** to Sine and Cosine electrical position.

Inputs for sinusoidal excitation method

Phase delay (electrical radians) — Phase delay for input signals
0.1746 (default) | scalar

The phase delay that the block must add to the Sin and Cos input port signals.

Dependencies

To enable this parameter, set **Type of excitation method** to Sinusoidal Excitation.

Number of samples per excitation cycle — Samples per cycle of input signal
16 (default) | even scalar greater than zero

Number of samples available in one cycle of the Sin and Cos input port signals.

Dependencies

To enable this parameter, set **Type of excitation method** to Sinusoidal Excitation.

Output Parameters

Position unit — Unit of position output
Radians (default) | Degrees | Per-unit

The unit of the mechanical position output of the block.

Dependencies

To enable this parameter, set **Block Output** to Mechanical position.

Speed unit — Unit of speed output
Degrees/Sec (default) | Radians/Sec | RPM | Per-unit

The unit of the mechanical speed output of the block.

Dependencies

To enable this parameter, set **Block Output** to Mechanical speed.

Base speed (RPM) — Base speed of the motor (RPM)
2000 (default) | scalar

The rated speed of the motor (in RPM).

Dependencies

To enable this parameter, set **Speed unit** to Per-Unit and **Block Output** to Mechanical speed.

Algorithms

The block uses the correctly sampled and normalized version of secondary sine and cosine waveforms to demodulate the sine and cosine signals using which it determines the electrical position of the resolver. It converts this position into its mechanical equivalent according to the number of pole pairs available in the resolver. The resulting value indicates the mechanical position of the motor.

The block also uses the demodulated sine and cosine signals (sine and cosine of resolver electrical angle) to compute the motor speed as well as the sine and cosine values of the motor electrical position.

Resolver excitation methods

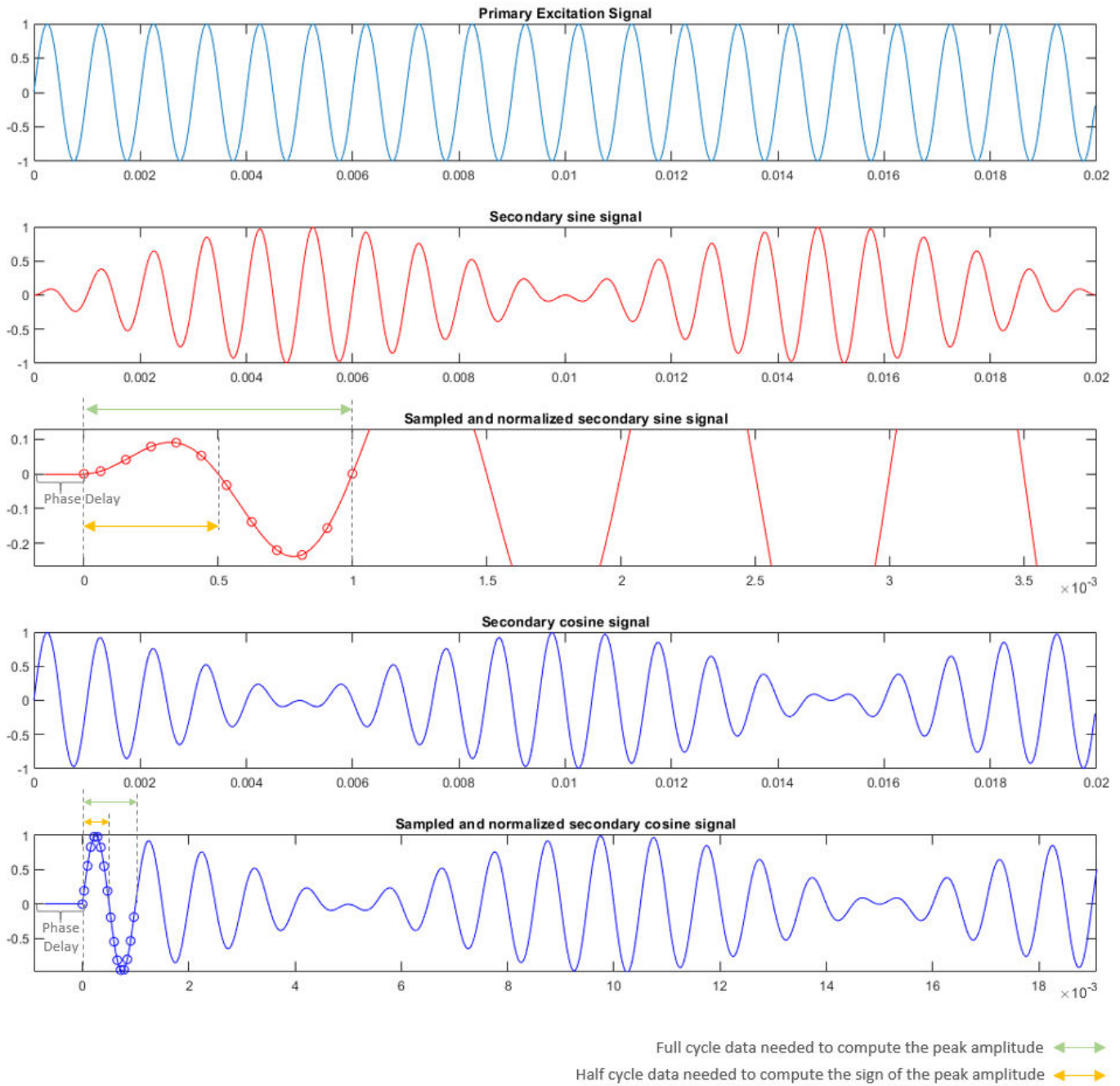
The block supports the following two excitation methods:

- Sinusoidal excitation — When the primary excitation signal is sinusoidal. This generates sinusoidal secondary waveforms after modulation.
- Square pulse excitation — When the primary excitation signal is a square pulse signal. This generates square pulse secondary signals after modulation.

Sinusoidal excitation

When you use sinusoidal excitation method, the block expects the secondary sine and cosine resolver signals that are sampled, by default, at the rate of 16 samples per excitation signal cycle, as shown below. It may also add a phase delay to the sampled sine and cosine signals with respect to the excitation signal.

When using sinusoidal excitation, the block does not normalize the modulated sine and cosine resolver output automatically. Normalize these modulated waveforms (within the range of [-1,1] and centred at 0) before you provide them to the block.



The block then demodulates the sampled signal. It computes the average, peak amplitude values, and the sign of the peak amplitude of a signal cycle as:

The block computes the average, peak amplitude values, and the sign of the peak amplitude of a signal cycle as

$$\hat{A}_{average} = \frac{1}{n} \sum_{i=0}^{n-1} (|\hat{A}_i|)$$

$$\hat{A}_{peak} = \hat{A}_{average} \times \frac{\pi}{2}$$

$$Sign \ of \ Peak = Sign \ of \ \left[\sum_{i = phase \ delay}^{\frac{n}{2} - 1 + phase \ delay} \hat{A}_i \right]$$

where:

- $\hat{A}_{average}$ is the average amplitude value of a signal cycle
- n is the number of samples per excitation cycle
- \hat{A}_{peak} is the peak amplitude value of a signal cycle

The block computes the electrical angular position of the resolver as

$$\theta = \text{atan2} \frac{u_{\sin_peak}}{u_{\cos_peak}}$$

where:

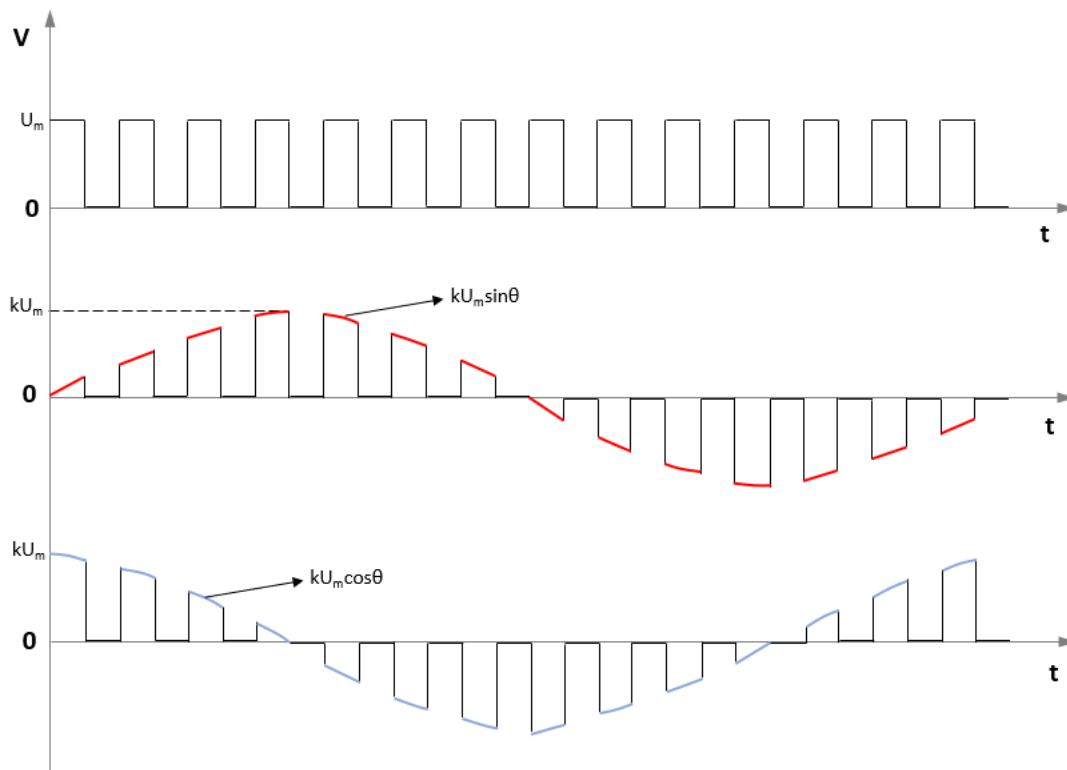
- u_{\sin_peak} is the \hat{A}_{peak} of the secondary sine signal
- u_{\cos_peak} is the \hat{A}_{peak} of the secondary cosine signal
- θ is the electrical angular position of the resolver

This enables the block to demodulate and extract the sine and cosine envelopes. It uses these demodulated envelop signals to compute the block outputs.

Square pulse excitation

When using the square pulse excitation method, the block expects the secondary sine and cosine signals sampled at the rate of one sample every pulse as shown below.

If you select **Enable input normalization** field, then after receiving the discrete time sampled waveform, the block automatically normalizes the waveform (within the range of [-1,1] and centred at 0). To perform normalization within the block, ensure that both input signals have equal peak magnitudes.

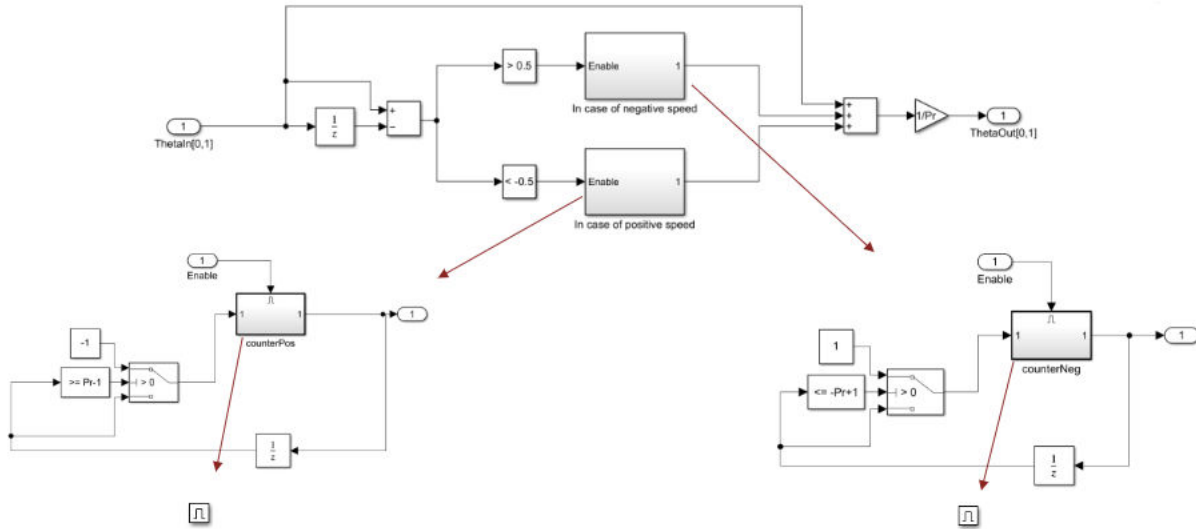


It demodulates the sine and cosine signals. It uses these demodulated signals to compute the block outputs.

Computation of motor mechanical position

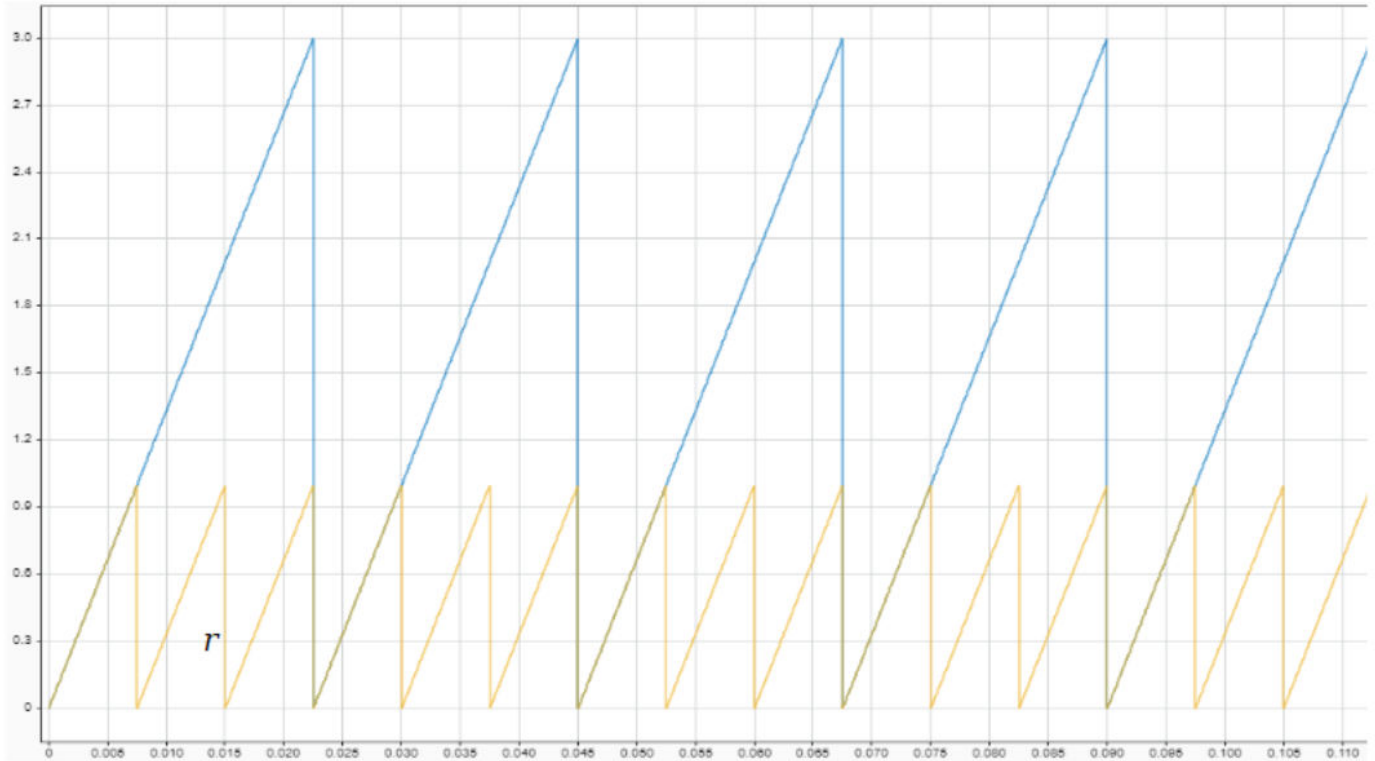
When using either sinusoidal or square pulse excitation, the block uses the demodulated waveforms to compute the electrical position of the resolver. This resolver position may vary using either a positive ramp (for clockwise rotation) or a negative ramp (for anti-clockwise rotation).

To correctly detect the wrap-around (from 0 PU to 1 PU or from 1 PU to 0 PU), the block measures the difference between the two consecutive samples. Because the input signal frequency is always less than $\frac{1}{2}$ of sampling frequency, a difference less than -0.5 PU indicates a positive ramp whereas a difference that is less than $+0.5$ PU indicates a negative ramp.

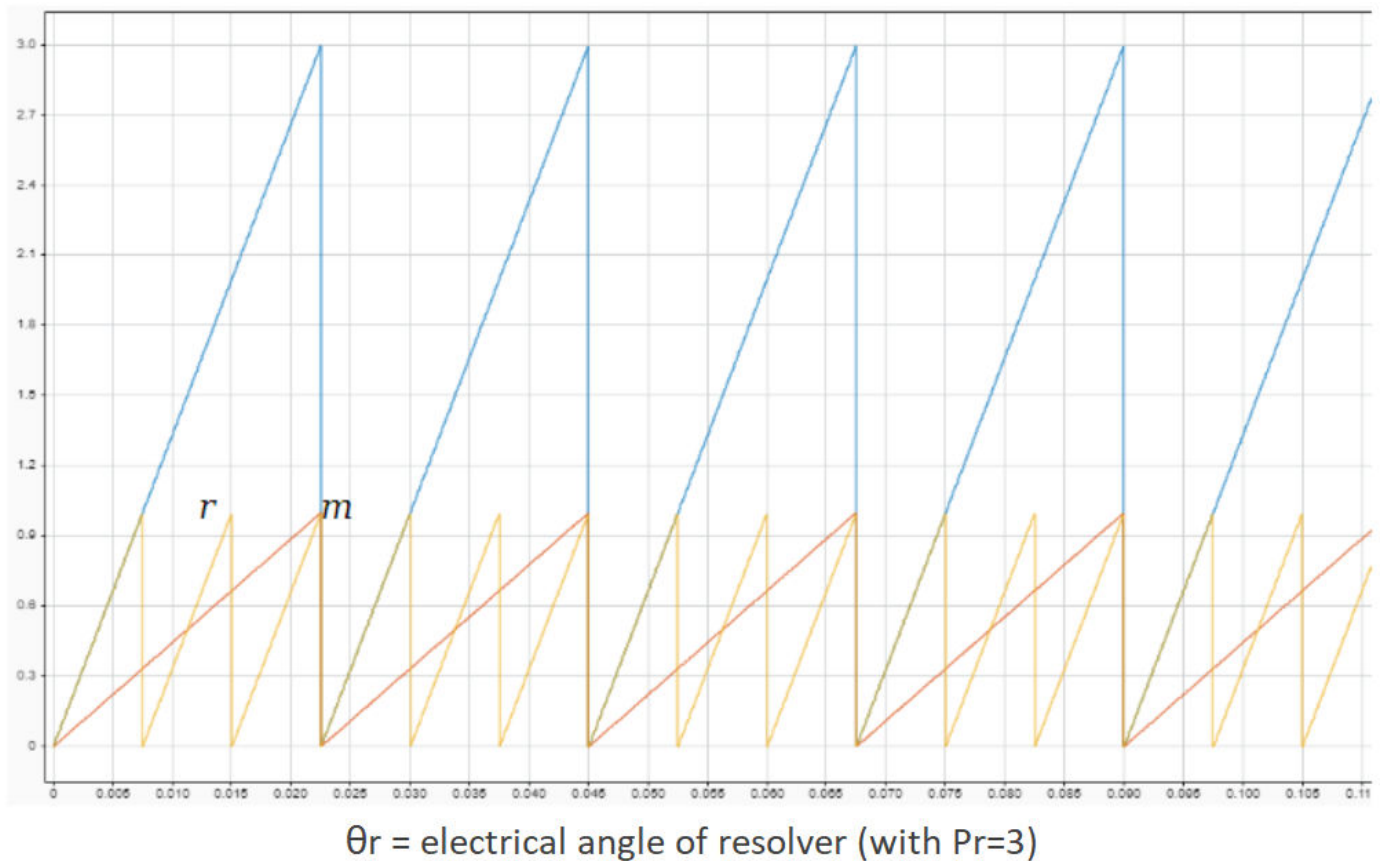


After identifying the resolver electrical position direction, the block uses the number of resolver pole pairs to compute the mechanical position of the resolver (and the motor) by extrapolating the ramp signal.

For example, for a 3-pole pair resolver, the block extrapolates the ramp to achieve a magnitude that is 3 times the original magnitude. It then performs a division by 3 to obtain the resolver mechanical position as shown below.



θ_r = electrical angle of resolver (with $P_r=3$)



Computation of sine and cosine of electrical motor position

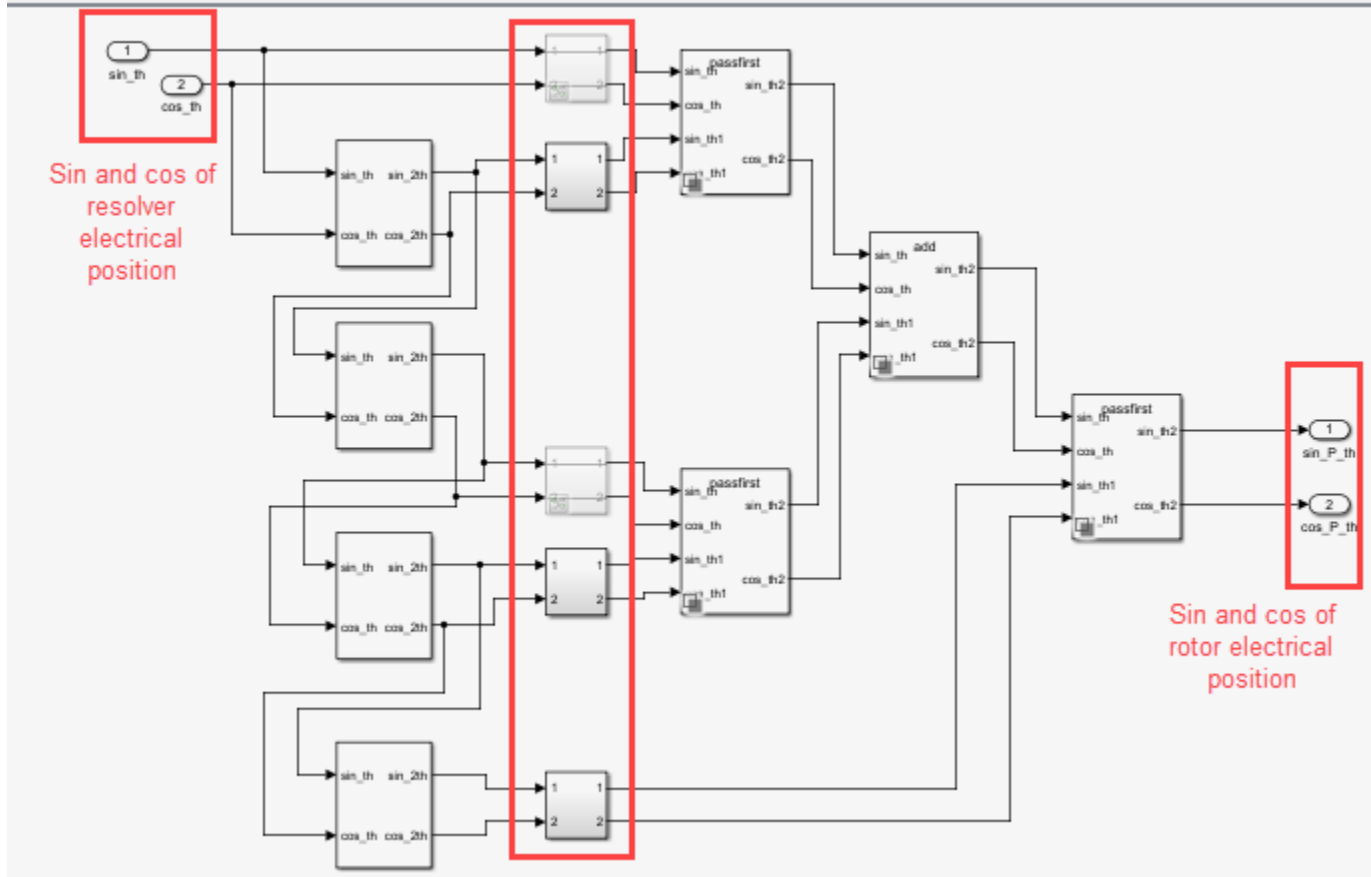
When using either sinusoidal or square pulse excitation, the block generates the demodulated sine and cosine waveforms (sine and cosine of resolver electrical position). From these demodulated waveforms, the block computes sine and cosine of motor electrical position using an arithmetic computation according to the ratio of motor and resolver pole pairs. To accommodate different possible ratios, the block utilizes unit blocks, which in turn use a generic binary-coded decimal (BCD) based structure.

For example, if the ratio of motor and resolver pole pairs (n) is 5, the following image indicates the BCD based algorithm that eventually generates sine and cosine of motor electrical position.

Therefore, $n = \text{number of motor pole pairs} / \text{number of resolver pole pairs} = 5$.

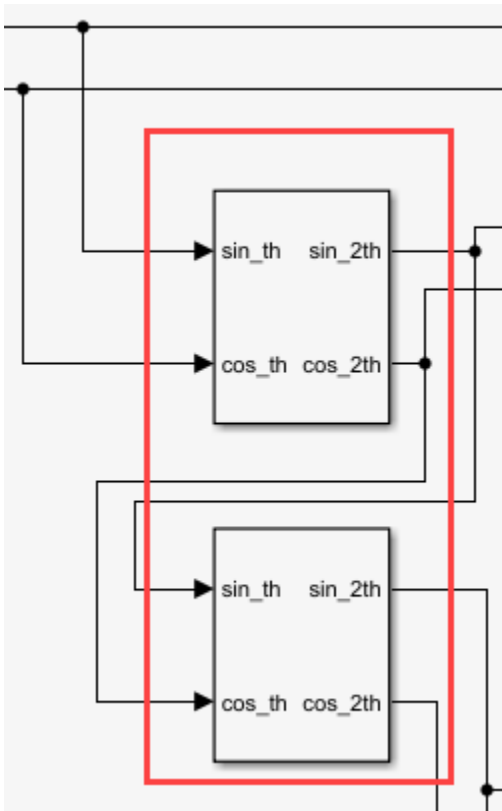
BCD code for $n = 5$ is $[0 \ 0 \ 1 \ 0 \ 1]$ or $[2^4 \ 2^3 \ 2^2 \ 2^1 \ 2^0]$. The block configures the algorithm for this sequence as shown below.

Resolver Decoder ▶ Decoder Algorithm ▶ Resolver Elec to Motor Elec Conversion

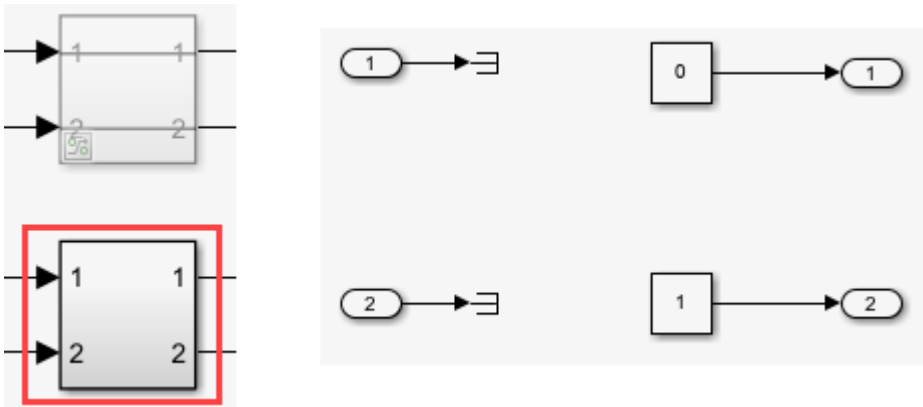


The block supports values of n (integers) ranging from 1 to 31.

Note The block optimizes the computation according to the ratio n . For example, if $n = 5$, the block only computes $\sin_{2\theta}$ and $\cos_{2\theta}$ twice by utilizing the following two subsystems only.



Similarly, whenever a switch does not bypass the signals, it terminates them as shown below to ensure minimal and optimized code generation.



Computation of motor speed

When using either sinusoidal or square pulse excitation, the block generates the demodulated sine and cosine waveforms (sine and cosine of resolver electrical position). From these waveforms, the block computes the motor mechanical speed using the algorithm shown below.

At first, it computes the difference between the two samples of these discrete time sampled signals and adds them:

In the ideal scenario, when using continuous time signals:

$$\frac{d}{dt}\sin\theta = \omega_r \cos\omega_r t$$

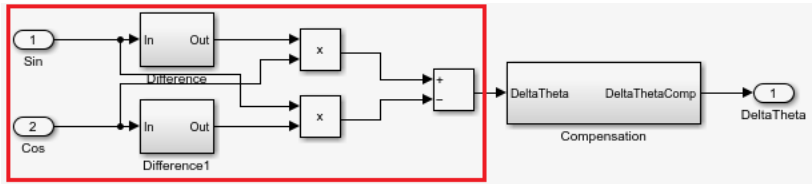
$$\frac{d}{dt}\cos\theta = -\omega_r \sin\omega_r t$$

$$\cos\theta \frac{d}{dt}\sin\theta - \sin\theta \frac{d}{dt}\cos\theta = \omega_r \cos^2\theta + \omega_r \sin^2\theta = \omega_r$$

$$\theta = \omega_r t$$

Where, ω_r is constant with respect to time.

Because we use discrete time sampled signals:



$$\cos\theta \frac{\Delta\sin\theta}{\Delta t} - \sin\theta \frac{\Delta\cos\theta}{\Delta t}$$

$$\sin\theta = \sin\omega_r T_s n$$

$$\cos\theta = \cos\omega_r T_s n$$

$$\frac{\Delta\sin\theta}{\Delta t} = \frac{\sin\omega_r T_s n - \sin[\omega_r T_s (n-1)]}{T_s}$$

$$\frac{\Delta\cos\theta}{\Delta t} = \frac{\cos\omega_r T_s n - \cos[\omega_r T_s (n-1)]}{T_s}$$

$$\cos\theta \frac{\Delta\sin\theta}{\Delta t} - \sin\theta \frac{\Delta\cos\theta}{\Delta t} = \frac{\sin\omega_r T_s}{T_s}$$

$$\Delta t = T_s$$

$$\frac{\cos\theta \cdot \Delta\sin\theta}{T_s} - \frac{\sin\theta \cdot \Delta\cos\theta}{T_s} = \frac{\sin\omega_r T_s}{T_s}$$

$$\cos\theta \cdot \Delta\sin\theta - \sin\theta \cdot \Delta\cos\theta = \sin\omega_r T_s$$

If $\omega_r T_s$ is very small, then $\sin\omega_r T_s$ approximately equals to $\omega_r T_s$. This is speed \times time, therefore, this term indicates position difference for a sample duration $\Delta\theta$.

$$\cos\theta \cdot \Delta\sin\theta - \sin\theta \cdot \Delta\cos\theta = \Delta\theta = \sin\omega_r T_s \approx \omega_r T_s$$

$$\omega_r = \frac{1}{T_s} \sin^{-1} \Delta\theta$$

$$\omega_r \approx \frac{\Delta\theta}{T_s}$$

To obtain a more accurate speed, we use the Taylor series expansion of \sin^{-1} to add the following compensation of $\frac{\Delta\theta^3}{6}$.

$$\omega_r = \frac{1}{T_s} \sin^{-1} \Delta\theta$$

$$\Rightarrow \omega_r \approx \frac{1}{T_s} \left[\Delta\theta + \frac{\Delta\theta^3}{6} \right]$$

Because the error is negligible, the preceding ω_r value can be considered accurate. Therefore, we can state:

$$\omega_r = \frac{1}{T_s} \left[\Delta\theta + \frac{\Delta\theta^3}{6} \right]$$

$$\omega_r = \left(\frac{g}{T_s} \right) \left[\Delta\theta + \frac{\Delta\theta^3}{6} \right]$$

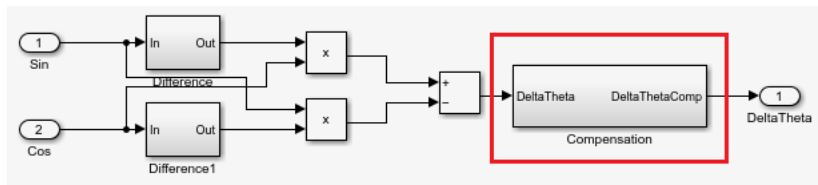
$$\omega = \frac{\omega_r}{P_r}$$

$$\omega = \left(\frac{g}{T_s P_r} \right) \left[\Delta\theta + \frac{\Delta\theta^3}{6} \right]$$

Where, P_r is the number of pole pairs of resolver.

The block multiplies the gain of $\left(\frac{g}{T_s P_r} \right)$ separately to avoid data overflow when using fixed point data type.

Here, $\frac{\Delta\theta^3}{6}$ is the approximate compensation that the block applies to the computed speed as shown below to obtain more accurate version of the actual mechanical speed.



Where:

- g is the speed conversion factor.
- θ is the electrical position of the resolver.
- ω_r is the electrical speed of the resolver.
- $\Delta\theta$ is the resolver electrical position difference per sample.
- ω is the mechanical speed of the resolver (or motor).
- T_s is the sampling time of the sine and cosine envelop signals.

Note The block inputs should have identical amplitude and data types (either signed fixed or floating point).

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

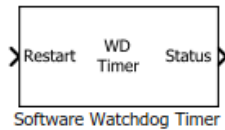
Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

Software Watchdog Timer

Output true until counter reaches maximum count limit



Libraries:

Motor Control Blockset / Sensor Decoders

Description

The Software Watchdog Timer block increments the counter value until either the block receives a Restart input pulse, or the count reaches the value of the **Maximum count** parameter.

On receiving the Restart pulse, the block restarts the counter and starts incrementing the counter value again when the Restart pulse falls.

The block maintains the true Status output until the counter value remains less than the value of **Maximum count** parameter. When the counter reaches **Maximum count**, the block stops the counter and turns the Status false.

Ports

Input

Restart — Pulse to restart watchdog timer counter

scalar

The pulse (true value) that restarts the watchdog timer counter. The counter resumes counting when the pulse falls (false value).

Data Types: single | double | int8 | int16 | int32 | uint8 | uint16 | uint32 | Boolean

Output

Status — Watchdog timer status

scalar

The watchdog timer status indicated as one of the following:

- True indicates that the counter value is less than the value of the **Maximum count** parameter.
- False indicates that the counter value is equal to the value of the **Maximum count** parameter and the block has stopped the counter.

Data Types: single | double | fixed point

Parameters

Maximum count — Maximum limit of watchdog timer value

10 (default) | scalar

The maximum limit of the watchdog timer counter value that causes the block to stop the counter and turn the watchdog timer status to false.

Counter data type — Data type of Status output
uint8 (default) | uint16 | uint32

The data type of the watchdog timer status output.

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

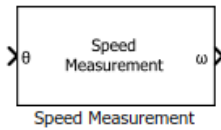
Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

Speed Measurement

Compute speed from rotor angular position



Libraries:

Motor Control Blockset / Sensor Decoders

Motor Control Blockset HDL Support / Sensor Decoders

Description

The Speed Measurement block calculates the angular speed from the angular position of the rotor by calculating the change in the angular position with respect to time.

Ports

Input

θ — Angular position of rotor
scalar

Angular position of the rotor specified in either radians, degrees, or per-unit.

Data Types: `single` | `double` | `fixed point`

Output

ω — Angular speed of rotor
scalar

Angular speed that the block computes based on the angular position input.

Data Types: `single` | `double` | `fixed point`

Parameters

Position unit — Unit of angular position
`Radians (default)` | `Degrees` | `Per unit`

The unit of the angular position θ .

Position scaling datatype — Range for mapping input position
`uint32 (default)` | `uint16` | `uint64`

Range used to map input position internally to fit in the unsigned integer datatype. For example, the block scales an input in the range $(\theta - 2\pi)$ to $(\theta - (2^{32}-1))$ for `uint32` datatype.

Speed calculation criteria — Method of speed calculation
`Maximum application speed (default)` | `Speed resolution` | `Time interval for speed calculation`

The speed calculation method used in the block. The selected method determines the range of the rotor speed that the block can measure.

These parameters change values according to the **Speed calculation criteria** parameter:

Parameter name	Maximum application speed	Speed Resolution	Time interval for speed calculation
Delays for speed calculation (number of samples)	299	28	28
Maximum measurable speed (RPM)	1000	10344.8276	10713.2857
Measurable speed resolution (RPM)	4.6566e-07	4.9892e-06	4.9892e-06

Discrete step size (s) — Sample time after which block executes again
100e-6 (default) | scalar

The fixed time interval (in seconds) between every two consecutive instances of block execution.

These parameters change values according to the **Discrete step size (s)** parameter value:

- **Delays for speed calculation (number of samples)**
- **Maximum measurable speed (RPM)**
- **Measurable speed resolution (RPM)**

Maximum application speed (RPM) — Maximum measurable rotor speed
1000 (default) | scalar

The maximum rotor speed (in rotations per minute) that the block can measure.

These parameters change values according to the **Maximum application speed (RPM)** parameter value:

- **Delays for speed calculation (number of samples)**
- **Maximum measurable speed (RPM)**
- **Measurable speed resolution (RPM)**

Dependencies

To enable this parameter, set **Speed calculation criteria** to Maximum application speed.

Speed Resolution (RPM) — Minimum detectable speed
5e-6 (default) | scalar

The minimum value of change in the θ input per unit time that the block can detect.

These parameters change values according to the **Speed Resolution (RPM)** parameter value:

- **Delays for speed calculation (number of samples)**
- **Maximum measurable speed (RPM)**

- **Measurable speed resolution (RPM)**

Dependencies

To enable this parameter, set **Speed calculation criteria** to Speed resolution.

Delays for speed calculation (number of samples) — Number of angular position samples measured
299 or 28 (default) | scalar

The number of samples of the angular position input that the block measures to compute the average position value.

These parameters change values according to the **Delays for speed calculation (number of samples)** parameter value:

- **Maximum measurable speed (RPM)**
- **Measurable speed resolution (RPM)**

Dependencies

To enable this parameter, set **Speed calculation criteria** to Time interval for speed calculation.

Maximum measurable speed (RPM) — Maximum measurable speed
1000 or 10344.8276 or 10713.2857 (default) | scalar

The absolute maximum speed that the block can measure.

This parameter is not configurable and uses a value that is internally computed using other parameters.

Measurable speed resolution (RPM) — Minimum speed resolution used for speed computation
4.6566e-07 or 4.9892e-06 (default) | scalar

The minimum speed resolution that the block uses for speed computation. It is always less than or equal to **Speed Resolution (RPM)**.

This parameter is not configurable and uses a value that is internally computed using other parameters.

Speed unit — Unit of angular speed output
RPM (default) | Degrees/Sec | Radians/Sec | Per unit based on maximum measurable speed | Per unit based on dialog

Unit of the angular speed output.

Per unit speed (RPM) — Speed (in RPM) for per-unit calculation
1000 (default)

Specify the speed in RPM for per-unit calculation.

Dependencies

This parameter appears only if Per unit based on dialog is selected for **Speed unit**.

Speed data type — Data type of angular speed output
 single (default) | double | fixed point

The data type of the angular speed output ω .

Note The Speed Measurement block may occasionally display the warning message 'Wrap on overflow detected.'

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has a single, default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see "ConstrainedOutputPipeline" (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see "InputPipeline" (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see "OutputPipeline" (HDL Coder).

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

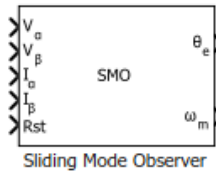
Quadrature Decoder | Position Generator | PI Controller | ACIM Feed Forward Control | ACIM Torque Estimator | PMSM Feed Forward Control | PMSM Torque Estimator

Topics

“Open-Loop and Closed-Loop Control”
“Field-Oriented Control (FOC)”

Sliding Mode Observer

Compute electrical position and mechanical speed of rotor



Libraries:
mcbpositiondecoderlib / Archive

Description

The Sliding Mode Observer block computes the electrical position and mechanical speed of a PMSM by using the per unit voltage and current values along the α - and β -axes of the stationary $\alpha\beta$ reference frame.

Equations

These equations describe the computation of the electrical position and mechanical speed by the block.

$$\frac{di_{\alpha\beta}}{dt} = \Phi i_{\alpha\beta} + \Gamma V_{\alpha\beta} - \Gamma e_{\alpha\beta}$$

$$i_{\alpha\beta} = [i_{\alpha} \ i_{\beta}]^T$$

$$V_{\alpha\beta} = [V_{\alpha} \ V_{\beta}]^T$$

$$e_{\alpha\beta} = [e_{\alpha} \ e_{\beta}]^T = \begin{bmatrix} -\psi\omega_e \sin\theta_e \\ \psi\omega_e \cos\theta_e \end{bmatrix}$$

$$\Phi = \begin{bmatrix} -\frac{R}{L} & 0 \\ 0 & -\frac{R}{L} \end{bmatrix}$$

$$\Gamma = \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & \frac{1}{L} \end{bmatrix}$$

These equations describe the discrete-time sliding mode observer operation by using per-unit values:

$$\hat{i}_{\alpha\beta(k+1)P.U} = A \hat{i}_{\alpha\beta(k)P.U} + \frac{V_{rated}}{I_{rated}} B (v_{\alpha\beta(k)P.U} - \vartheta_{\alpha\beta(k)P.U})$$

$$\vartheta_{\alpha\beta(k+1)P.U} = \vartheta_{\alpha\beta(k)P.U} + 2\pi f_0 \times (\mathbf{Z}(I_{rated}(\hat{i}_{\alpha\beta(k)P.U} - i_{\alpha\beta(k)P.U})) - \vartheta_{\alpha\beta(k)P.U})$$

$$A = e^{\Phi T_s}$$

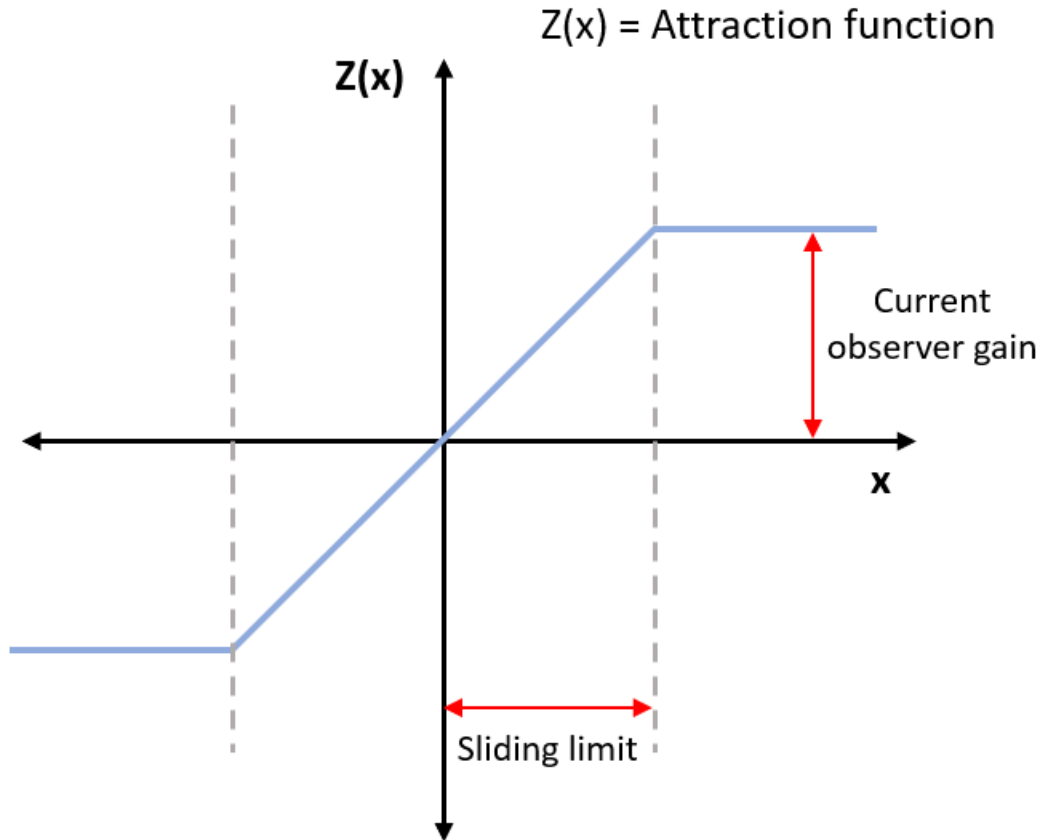
$$B = \int_0^{T_s} e^{\Phi\tau} d\tau$$

$$f_0 = \frac{F_0}{F_s}$$

$$F_s = \frac{1}{T_s}$$

where:

- e_α, i_α are the stator back EMF and current for the α axis.
- e_β, i_β are the stator back EMF and current for the β axis.
- v_α, v_β are the stator supply voltages.
- R is the stator resistance.
- L is the stator inductance.
- ψ is the flux linkage due to permanent magnet.
- ω_e is the electrical angular velocity.
- θ_e is the electrical position of the rotor.
- t is the time.
- T_s is the sampling period.
- k is the sample count.
- V_{rated} is the nominal voltage corresponding to 1 per-unit.
- I_{rated} is the nominal current corresponding to 1 per-unit.
- Z is the attraction function.



- f_0 is the cut-off frequency of the filter in cycles per sample.
- F_0 is the cut-off frequency in cycles per second.
- F_s is the sample frequency in samples per second.
- $\vartheta_{\alpha\beta(k)}$ is the estimated back EMF.

Tuning

Use the **Current observer gain** and **Sliding surface limit** parameters to tune the block.

- To improve stability, increase the **Sliding surface limit** or reduce the **Current observer gain**.
- To reduce distortion, decrease the **Current observer gain** or increase the **Sliding surface limit**.

Ports

Input

V_α — α -axis voltage
scalar

Per-unit voltage component along the α -axis of the stationary $\alpha\beta$ reference frame.

Data Types: single | double | fixed point

V_β — β -axis voltage
scalar

Per-unit voltage component along the β -axis of the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

I_α — α -axis current
scalar

Per-unit current component along the α -axis of the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

I_β — β -axis current
scalar

Per-unit current component along the β -axis of the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

Rst — Reset the block
scalar

The pulse (true value) that resets and restarts the processing of the block algorithm.

Data Types: `single` | `double` | `fixed point`

Output

θ_e — Electrical position of PMSM
scalar

The estimated electrical position of the rotor.

Data Types: `single` | `double` | `fixed point`

ω_m — Mechanical speed of PMSM
scalar

The estimated mechanical speed of the rotor.

Data Types: `single` | `double` | `fixed point`

Parameters

Observer parameters

Current observer gain — Sliding mode observer gain for current
1.1 (default) | scalar

The attraction function gain.

Sliding surface limit — Maximum limit of sliding surface of SMO
0.15 (default) | scalar

The boundary layer limit of the attraction function's domain.

Position unit — Unit of position output
Radians (default) | Degrees | Per unit

Unit of the position output.

Position data type — Data type of position output
single (default) | double | fixdt(1,16) | fixdt(1,16,0) | fixdt(1,16,2^0,0) | <data type expression>

Data type of the position output.

Speed unit — Unit of speed output
RPM (default) | Degrees/sec | Radians/sec | Per unit

Unit of the speed output.

Speed data type — Data type of speed output
single (default) | double | fixdt(1,16) | fixdt(1,16,0) | fixdt(1,16,2^0,0) | <data type expression>

Data type of the speed output.

Discrete step size (s) — Sample time after which block executes again
50e-6 (default) | scalar

The fixed time interval (in seconds) between every two consecutive instances of block execution.

Motor parameters

Stator resistance (ohm) — Resistance
0.4836 (default) | scalar

Stator phase winding resistance (in ohm).

Stator inductance (H) — Inductance
1e-3 (default) | scalar

Stator phase winding inductance (in Henry).

Maximum application speed (RPM) — Maximum supported speed value
6000 (default) | scalar

Maximum value of speed (in RPM) that the block can support. For a speed beyond this value, the block generates incorrect outputs.

Number of pole pairs — Number of pole pairs available in motor
4 (default) | scalar

Number of pole pairs available in the motor.

Base voltage — Nominal voltage corresponding to one per unit
68 (default) | scalar

The maximum phase voltage applied to PMSM. For details, see “Per-Unit System”.

Base current — Nominal current corresponding to one per unit
10 (default) | scalar

The maximum measurable current supplied to PMSM. For details, see “Per-Unit System”.

Note The Sliding Mode Observer block may occasionally display the warning message 'Wrap on overflow detected.'

Version History

Introduced in R2020a

References

- [1] Y. Kung, N. V. Quynh, C. Huang and L. Huang, "Design and simulation of adaptive speed control for SMO-based sensorless PMSM drive," *2012 4th International Conference on Intelligent and Advanced Systems (ICIAS2012), Kuala Lumpur, 2012*, pp. 439-444 (doi: 10.1109/ICIAS.2012.6306234)
- [2] Zhang Yan and V. Utkin, "Sliding mode observers for electric machines-an overview," *IEEE 2002 28th Annual Conference of the Industrial Electronics Society. IECON 02, Sevilla, 2002*, pp. 1842-1847 vol.3. (doi: 10.1109/IECON.2002.1185251)
- [3] T. Bernardes, V. F. Montagner, H. A. Gründling and H. Pinheiro, "Discrete-Time Sliding Mode Observer for Sensorless Vector Control of Permanent Magnet Synchronous Machine," in *IEEE Transactions on Industrial Electronics*, vol. 61, no. 4, pp. 1679-1691, April 2014 (doi: 10.1109/TIE.2013.2267700)
- [4] Z. Guo and S. K. Panda, "Design of a sliding mode observer for sensorless control of SPMSM operating at medium and high speeds," *2015 IEEE Symposium on Sensorless Control for Electrical Drives (SLED), Sydney, NSW, 2015*, pp. 1-6. (doi: 10.1109/SLED.2015.7339255)

See Also

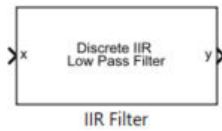
Flux Observer | Clarke Transform | Inverse Park Transform | Sine-Cosine Lookup | PI Controller

Topics

“Open-Loop and Closed-Loop Control”
“Field-Oriented Control (FOC)”

IIR Filter

Implement infinite impulse response (IIR) filter



Libraries:

Motor Control Blockset / Signal Management

Motor Control Blockset HDL Support / Signal Management

Description

The IIR Filter block implements a discrete first-order infinite impulse response (IIR) filter on the specified input signal. The block supports fixed-point and floating-point data types. The block is also optimized for code generation when used with the model settings and configuration adopted by the examples shipped in Motor Control Blockset.

We recommend that you use fixed-step discrete solver for this block to enable code generation and ensure accurate simulation.

Equations

You can configure the IIR filter by using the filter coefficient (a) block parameter for a given cutoff frequency (f_c).

This equation describes computation of the filter coefficient from the cutoff frequency:

$$a = \left(\frac{2\pi T_s f_c}{2\pi T_s f_c + 1} \right)$$

Alternatively, the block also computes the theoretical cutoff frequency for the given sample time using a filter coefficient:

$$f_c = \left(\frac{a}{(1-a) \cdot 2\pi \cdot T_s} \right)$$

Use the **Filter type** parameter to configure the block either as a low-pass or high-pass filter.

Low-pass filter:

$$y(k) = a \cdot x_k + (1 - a) \cdot y_{k-1}$$

High-pass filter:

$$y(k) = (1 - a) \cdot x_k - (1 - a) \cdot x_{k-1} + (1 - a) \cdot y_{k-1}$$

where:

- f_c is the cutoff frequency of the IIR filter.
- a is the filter coefficient in the range (0, 1].
- $y(k)$ is the filtered output value at time k .
- y_{k-1} is the filtered output value at time $k - 1$.

- x_k is the sampled input value at time k .
- x_{k-1} is the filtered output value at time $k-1$.
- T_s is the sample time of the IIR Filter block.

Ports

Input

x — Sampled input signal
scalar

Sampled values of the raw input signal in the time domain.

Data Types: `single` | `double` | `fixed point`

Output

y — Filtered output signal
scalar

Filtered output signal returned by the IIR Filter block in the time domain.

Data Types: `single` | `double` | `fixed point`

Parameters

Filter type — IIR filter type
`Low-pass (default)` | `High-pass`

Type of the IIR filter.

Filter co-efficient — Filter coefficient of IIR filter
`0.01 (default)` | scalar in the range $(0, 1]$

Filter coefficient of the IIR filter. The data type of this parameter is the same as that of the input signal. We suggest that you check the precision of the parameter value in this data type.

Display cutoff frequency — Display the cutoff frequency parameters
`off (default)` | `on`

Select this parameter for the block to display the **Discrete step size (s)** and **Theoretical cutoff frequency (Hz)** parameters.

Discrete step size (s) — Step size of discrete-time filter
`50e-6 (default)` | scalar

Step size of the discrete-time computation (in seconds) used by the IIR filter.

Dependencies

To display this parameter, select the **Display cutoff frequency** parameter.

Theoretical cutoff frequency (Hz) — Theoretical cutoff frequency of IIR filter
`32.1525` | scalar

Theoretical cutoff frequency (in Hertz) of the IIR filter. This parameter is not configurable.

Dependencies

To display this parameter, select the **Display cutoff frequency** parameter.

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

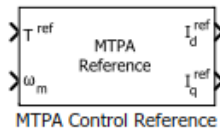
ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

MTPA Control Reference

Compute reference currents for Maximum Torque Per Ampere (MTPA) and field-weakening operation



Libraries:

Motor Control Blockset / Controls / Control Reference

Description

The MTPA Control Reference block computes the d -axis and q -axis reference current values for maximum torque per ampere (MTPA) and field-weakening operations. The computed reference current values result in efficient output for the permanent magnet synchronous motor (PMSM).

The block accepts the reference torque and feedback mechanical speed and outputs the corresponding d - and q -axes reference current values for MTPA and field-weakening operations. For a given mechanical speed, in addition to the highest possible torque values, the block also supports reference torque values that are less than the rated torque of a PMSM.

The block computes the reference current values by solving mathematical relationships. The calculations use SI unit system. When working with the Per-Unit (PU) system, the block converts PU input signals to SI units to perform computations, and converts them back to PU values at the output.

In addition, the **Vdc input method** parameter configures the block to either accept a fixed reference DC voltage through the **DC voltage (V)** parameter or accept a variable reference DC voltage through a separate input port V_{dc} .

These equations describe the computation of reference d -axis and q -axis current values by the block:

Mathematical Model of PMSM

These model equations describe dynamics of PMSM in the rotor flux reference frame:

$$v_d = i_d R_s + \frac{d\lambda_d}{dt} - \omega_e L_q i_q$$

$$v_q = i_q R_s + \frac{d\lambda_q}{dt} + \omega_e L_d i_d + \omega_e \lambda_{pm}$$

$$\lambda_d = L_d i_d + \lambda_{pm}$$

$$\lambda_q = L_q i_q$$

$$T_e = \frac{3}{2} p (\lambda_{pm} i_q + (L_d - L_q) i_d i_q)$$

$$T_e - T_L = J \frac{d\omega_m}{dt} + B \omega_m$$

where:

- v_d is the d -axis voltage (Volts).
- v_q is the q -axis voltage (Volts).
- i_d is the d -axis current (Amperes).
- i_q is the q -axis current (Amperes).
- R_s is the stator phase winding resistance (Ohms).
- λ_{pm} is the permanent magnet flux linkage (Weber).
- λ_d is the d -axis flux linkage (Weber).
- λ_q is the q -axis flux linkage (Weber).
- ω_e is the electrical speed corresponding to frequency of stator voltages (Radians/ sec).
- ω_m is the rotor mechanical speed (Radians/ sec).
- L_d is the d -axis winding inductance (Henry).
- L_q is the q -axis winding inductance (Henry).
- T_e is the electromechanical torque produced by the PMSM (Nm).
- T_L is the load torque (Nm).
- p is the number of motor pole pairs.
- J is the inertia coefficient (kg-m²).
- B is the friction coefficient (kg-m²/ sec).

Base Speed

Base speed is the maximum motor speed at the rated voltage and rated load, outside the field-weakening region. These equations describe the computation of the motor base speed.

The inverter voltage constraint is defined by computing the d -axis and q -axis voltages:

$$v_{d0} = -\omega_e L_q i_q$$

$$v_{q0} = \omega_e (L_d i_d + \lambda_{pm})$$

$$v_{max} = \frac{v_{dc}}{\sqrt{3}} - R_s i_{max} \geq \sqrt{v_{d0}^2 + v_{q0}^2}$$

The current limit circle defines the current constraint which can be considered as:

$$i_{max}^2 = i_d^2 + i_q^2$$

In the preceding equation, i_d is zero for surface PMSMs. For interior PMSMs, values of i_d and i_q corresponding to MTPA are considered.

Using the preceding relationships, we can compute the base speed as:

$$\omega_{base} = \frac{1}{p} \cdot \frac{v_{max}}{\sqrt{(L_q i_q)^2 + (L_d i_d + \lambda_{pm})^2}}$$

where:

- ω_e is the electrical speed corresponding to frequency of stator voltages (Radians/ sec).
- ω_{base} is the mechanical base speed of the motor (Radians/ sec).
- i_d is the d -axis current (Amperes).
- i_q is the q -axis current (Amperes).
- v_{d0} is the d -axis voltage when i_d is zero (Volts).
- v_{q0} is the q -axis voltage when i_q is zero (Volts).
- L_d is the d -axis winding inductance (Henry).
- L_q is the q -axis winding inductance (Henry).
- R_s is the stator phase winding resistance (Ohms).
- λ_{pm} is the permanent magnet flux linkage (Weber).
- v_d is the d -axis voltage (Volts).
- v_q is the q -axis voltage (Volts).
- v_{max} is the maximum fundamental line to neutral voltage (peak) supplied to the motor (Volts).
- v_{dc} is the dc voltage supplied to the inverter (Volts).
- i_{max} is the maximum phase current (peak) of the motor (Amperes).
- p is the number of motor pole pairs.

Surface PMSM

For a surface PMSM, you can achieve maximum torque by using zero d -axis current when the motor is below the base speed. For field-weakening operation, the reference d -axis current is computed by constant-voltage-constant-power control (CVCP) algorithm defined by these equations:

If $\omega_m \leq \omega_{base}$:

- $i_{d_mtpa} = 0$
- $i_{q_mtpa} = \frac{T^{ref}}{\frac{3}{2} \cdot p \cdot \lambda_{pm}}$
- $i_{d_sat} = i_{d_mtpa} = 0$
- $i_{q_sat} = \text{sat}(i_{q_mtpa}, i_{max})$

If $\omega_m > \omega_{base}$:

- $i_{d_fw} = \frac{(\omega_e \text{ base} - \omega_e)\lambda_{pm}}{\omega_e L_d}$
- $i_{d_sat} = \max(i_{d_fw}, -i_{max})$
- $i_{q_fw} = \frac{T^{ref}}{\frac{3}{2} \cdot p \cdot \lambda_{pm}}$
- $i_{q_lim} = \sqrt{i_{max}^2 - i_{d_sat}^2}$
- $i_{q_sat} = \text{sat}(i_{q_fw}, i_{q_lim})$

The saturation function used to compute i_{q_sat} is described below:

$$\text{If } i_{q_fw} < -i_{q_lim},$$

$$i_{q_sat} = -i_{q_lim}$$

$$\text{If } i_{q_fw} > i_{q_lim},$$

$$i_{q_sat} = i_{q_lim}$$

$$\text{If } -i_{q_lim} \leq i_{q_fw} \leq i_{q_lim},$$

$$i_{q_sat} = i_{q_fw}$$

The block outputs the following values:

$$I_d^{ref} = i_{d_sat}$$

$$I_q^{ref} = i_{q_sat}$$

where:

- ω_e is the electrical speed corresponding to frequency of stator voltages (Radians/ sec).
- ω_m is the rotor mechanical speed (Radians/ sec).
- ω_{base} is the mechanical base speed of the motor (Radians/ sec).
- ω_{e_base} is the electrical base speed of the motor (Radians/ sec).
- i_{d_mtpa} is the d -axis phase current corresponding to MTPA (Amperes).
- i_{q_mtpa} is the q -axis phase current corresponding to MTPA (Amperes).
- T^{ref} is the reference torque (Nm).
- p is the number of motor pole pairs.
- λ_{pm} is the permanent magnet flux linkage (Weber).
- i_{d_fw} is the d -axis field weakening current (Amperes).
- i_{q_fw} is the q -axis field weakening current (Amperes).
- L_d is the d -axis winding inductance (Henry).
- i_{max} is the maximum phase current (peak) of the motor (Amperes).
- i_{d_sat} is the d -axis saturation current (Amperes).
- i_{q_sat} is the q -axis saturation current (Amperes).
- I_d^{ref} is the d -axis current corresponding to the reference torque and reference speed (Amperes).
- I_q^{ref} is the q -axis current corresponding to the reference torque and reference speed (Amperes).

Interior PMSM

For an interior PMSM, you can achieve maximum torque by computing the d -axis and q -axis reference currents from the torque equation. For field-weakening operation, the reference d -axis current is computed by voltage and current limited maximum torque control (VCLMT) algorithm.

The reference currents for MTPA and field weakening operations are defined by these equations:

$$\begin{aligned}
 i_{m_ref} &= \frac{2 \cdot T^{ref}}{3 \cdot p \cdot \lambda_{pm}} \\
 i_m &= \min(i_{m_ref}, i_{max}) \\
 i_{d_mtpa} &= \frac{\lambda_{pm}}{4(L_q - L_d)} - \sqrt{\frac{\lambda_{pm}^2}{16(L_q - L_d)^2} + \frac{i_m^2}{2}} \\
 i_{q_mtpa} &= \sqrt{i_m^2 - (i_{d_mtpa})^2} \\
 v_{d0} &= -\omega_e L_q i_q \\
 v_{q0} &= \omega_e (L_d i_d + \lambda_{pm}) \\
 v_{d0}^2 + v_{q0}^2 &= v_{max}^2 \\
 (L_q i_q)^2 + (L_d i_d + \lambda_{pm})^2 &\leq \frac{v_{max}^2}{\omega_e^2} \\
 i_q &= \sqrt{i_{max}^2 - i_d^2} \\
 (L_d^2 - L_q^2) i_d^2 + 2\lambda_{pm} L_d i_d + \lambda_{pm}^2 + L_q^2 i_{max}^2 - \frac{v_{max}^2}{\omega_e^2} &= 0
 \end{aligned}$$

The following two equations describe the computation of field-weakening currents for maximum possible torque corresponding to a given speed value:

$$\begin{aligned}
 i_{d_fw} &= \frac{-\lambda_{pm} L_d + \sqrt{(\lambda_{pm} L_d)^2 - (L_d^2 - L_q^2) \left(\lambda_{pm}^2 + L_q^2 i_{max}^2 - \frac{v_{max}^2}{\omega_e^2} \right)}}{(L_d^2 - L_q^2)} \\
 i_{q_fw} &= \sqrt{i_{max}^2 - i_{d_fw}^2}
 \end{aligned}$$

The following two equations describe computation of field-weakening currents for a given speed and torque value.

$$\begin{aligned}
 9p^2(L_d - L_q)^2 L_q^2 \omega_e^2 i_{q_fw}^4 + (9p^2 \lambda_{pm}^2 L_q^2 \omega_e^2 - 9p^2(L_d - L_q)^2 v_{max}^2) i_{q_fw}^2 - 12T^{ref} p \lambda_{pm} L_d L_q \omega_e^2 i_{q_fw} \\
 + 4(T^{ref})^2 L_d^2 \omega_e^2 &= 0 \\
 i_{d_fw} &= -\frac{\lambda_{pm}}{L_d} + \frac{1}{L_d} \sqrt{\frac{v_{max}^2}{\omega_e^2} - (L_q i_{q_fw})^2}
 \end{aligned}$$

To reduce the computation time, the block uses approximations to solve the preceding polynomial.

If $\omega_m \leq \omega_{base}$,

$$I_d^{ref} = i_{d_mtpa}$$

$$I_q^{ref} = i_{q_mtpa}$$

If $\omega_m > \omega_{base}$,

$$I_d^{ref} = \max(i_{d_fw}, -i_{max})$$

$$i_{q_fw} = \sqrt{i_{max}^2 - i_{d_fw}^2}$$

If $i_{q_fw} < i_m$,

$$I_q^{ref} = i_{q_fw}$$

If $i_{q_fw} \geq i_m$,

$$I_q^{ref} = i_m$$

For negative reference torque values, the sign of i_m and I_q^{ref} are updated and equations are modified accordingly.

where:

- i_{m_ref} is the estimated maximum current to produce the reference torque (Amperes).
- i_m is the saturated value of estimated maximum current (Amperes).
- i_{d_max} is the maximum d -axis phase current (peak) (Amperes).
- i_{q_max} is the maximum q -axis phase current (peak) (Amperes).
- T^{ref} is the reference torque (Nm).
- I_d^{ref} is the d -axis current component corresponding to the reference torque and reference speed (Amperes).
- I_q^{ref} is the q -axis current component corresponding to the reference torque and reference speed (Amperes).
- p is the number of motor pole pairs.
- λ_{pm} is the permanent magnet flux linkage (Weber).
- i_{d_mtpa} is the d -axis phase current corresponding to MTPA (Amperes).
- i_{q_mtpa} is the q -axis phase current corresponding to MTPA (Amperes).
- L_d is the d -axis winding inductance (Henry).
- L_q is the q -axis winding inductance (Henry).
- i_{max} is the maximum phase current (peak) of the motor (Amperes).
- v_{max} is the maximum fundamental line to neutral voltage (peak) supplied to the motor (Volts).
- v_{d0} is the d -axis voltage when i_d is zero (Volts).
- v_{q0} is the q -axis voltage when i_q is zero (Volts).
- ω_e is the electrical speed corresponding to frequency of stator voltages (Radians/ sec).

- i_d is the d -axis current (Amperes).
- i_q is the q -axis current (Amperes).
- i_{d_fw} is the d -axis field weakening current (Amperes).
- i_{q_fw} is the q -axis field weakening current (Amperes).
- ω_{base} is the mechanical base speed of the motor (Radians/ sec).

Ports

Input

T^{ref} — Reference torque value
scalar

Reference torque input value for which the block computes the reference current.

Data Types: single | double | fixed point

ω_m — Mechanical speed
scalar

Reference mechanical speed value for which the block computes the reference current.

Data Types: single | double | fixed point

V_{dc} — DC bus voltage
scalar

Variable DC bus voltage (in Volts).

Dependencies

To enable this port, set **Type of motor** to Interior PMSM and **Vdc input method** to Input port.

Data Types: single | double | fixed point

Output

I_d^{ref} — Reference d -axis current
scalar

Reference d -axis phase current that can efficiently generate the input torque and speed values.

Data Types: single | double | fixed point

I_q^{ref} — Reference q -axis current
scalar

Reference q -axis phase current that can efficiently generate the input torque and speed values.

Data Types: single | double | fixed point

Parameters

Motor Parameters

Type of motor — Type of PMSM

Interior PMSM (default) | Surface PMSM

Type of PMSM based on the location of the permanent magnets.

Number of pole pairs — Number of available pole pairs

4 (default) | scalar

Number of pole pairs available in the motor.

Stator resistance per phase (Ohm) — Resistance of stator phase winding (Ohms)

0.36 (default) | scalar

Resistance of the stator phase winding (in Ohms).

Dependencies

To enable this parameter, set **Type of motor** to Interior PMSM.

Stator d-axis inductance (H) — *d*-axis stator winding inductance

0.2e-3 (default) | scalar

Stator winding inductance (in Henry) along the *d*-axis of the rotating *dq* reference frame.

Stator q-axis inductance (H) — *q*-axis stator winding inductance

0.4e-3 (default) | scalar

Stator winding inductance (in Henry) along the *q*-axis of the rotating *dq* reference frame.

Dependencies

To enable this parameter, set **Type of motor** to Interior PMSM.

Permanent magnet flux linkage (Wb) — Magnetic flux linkage of permanent magnets

6.4e-3 (default) | scalar

Magnetic flux linkage (in Weber) between the stator windings and permanent magnets on the rotor (weber).

Max current (A) — Maximum phase current limit for motor (Amperes)

7.1 (default) | scalar

Maximum phase current limit for the motor (in Amperes).

Vdc input method — Input method for Vdc

Specify via dialog (default) | Input port

Method used to specify Vdc input.

- Specify via dialog — Specify the fixed reference voltage *Vdc* using the parameter **DC voltage (V)**.
- Input port — Specify the variable reference voltage *Vdc* using the input port Vdc.

Note If you select the Input port input method for V_{dc} , ensure that you configure the **Base voltage (V)** parameter in the **Input Units** tab.

Dependencies

To enable this parameter, set **Type of motor** to Interior PMSM.

DC voltage (V) — DC bus voltage (Volts)

24 (default) | scalar

DC bus voltage (in Volts).

Dependencies

To enable this parameter, set **Type of motor** to Interior PMSM and **Vdc input method** to Specify via dialog.

Input Units

Input signal units — Unit of block input values

Per-Unit (PU) (default) | SI Units

Unit of the block input values.

Base speed (rpm) — Base speed of motor (rpm)

4107 (default) | scalar

Speed of the motor (in rpm) at the rated voltage and rated current outside the field weakening region.

Dependencies

To enable this parameter, set **Input signal units** to Per-Unit (PU).

Base current (A) — Base current for per-unit conversion (Amperes)

19.3 (default) | scalar

Current (in Amperes) corresponding to 1 per-unit. We recommend that you use the maximum current detected by an Analog to Digital Converter (ADC) as the base current.

Dependencies

To enable this parameter, set **Input signal units** to Per-Unit (PU).

Base torque (Nm) — Base torque for per-unit conversion (Nm)

0.74112 (default) | scalar

Torque (in Nm) corresponding to 1 per-unit. See “Per-Unit System” page for more details.

This parameter is not configurable and uses a value that is internally computed using other parameters.

Dependencies

To display this parameter, set **Input signal units** to Per-Unit (PU).

Base voltage (V) — Base voltage for per-unit conversion (Volts)

$24/\sqrt{3}$ (default) | scalar

Voltage (in Volts) corresponding to 1 per-unit. See “Per-Unit System” page for more details.

This parameter is not configurable and uses a value that is internally computed using other parameters.

Dependencies

To display this parameter, set **Input signal units** to Per-Unit (PU).

Implementation

Prioritise execution time — Scale down computations to reduce algorithm execution time
on (default) | off

If you select this field, the block follows computational approximations to prioritize and reduce the algorithm execution time. Clear this field to run the block algorithms iteratively without using approximations.

Version History

Introduced in R2020a

References

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- [2] Morimoto, Shigeo, Masayuka Sanada, and Yoji Takeda. "Wide-speed operation of interior permanent magnet synchronous motors with high-performance current regulator." *IEEE Transactions on Industry Applications*, Vol. 30, Issue 4, July/August 1994, pp. 920-926.
- [3] Li, Muyang. "Flux-Weakening Control for Permanent-Magnet Synchronous Motors Based on Z-Source Inverters." *Master's Thesis, Marquette University, e-Publications@Marquette*, Fall 2014.
- [4] Briz, Fernando, Michael W. Degner, and Robert D. Lorenz. "Analysis and design of current regulators using complex vectors." *IEEE Transactions on Industry Applications*, Vol. 36, Issue 3, May/June 2000, pp. 817-825.
- [5] Lorenz, Robert D., Thomas Lipo, and Donald W. Novotny. "Motion control with induction motors." *Proceedings of the IEEE*, Vol. 82, Issue 8, August 1994, pp. 1215-1240.
- [6] Briz, Fernando, et al. "Current and flux regulation in field-weakening operation [of induction motors]." *IEEE Transactions on Industry Applications*, Vol. 37, Issue 1, Jan/Feb 2001, pp. 42-50.
- [7] TI Application Note, "Sensorless-FOC With Flux-Weakening and MTPA for IPMSM Motor Drives."
- [8] 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.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

PI Controller

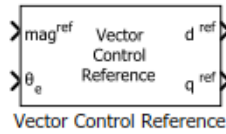
Topics

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

Vector Control Reference

Compute d and q axis components of reference vector



Libraries:

Motor Control Blockset / Controls / Control Reference

Description

The Vector Control Reference block calculates the d -axis and q -axis components of the reference voltage, current, or flux vector that you provide as an input to the block.

The block accepts magnitude and position of the reference vector as inputs. The block outputs the reference vector components along the direct and quadrature axes of the rotating dq reference frame.

Equations

The block uses these equations to compute the d -axis and q -axis vector component outputs.

$$d^{ref} = mag^{ref} \times \cos\theta_e$$

$$q^{ref} = mag^{ref} \times \sin\theta_e$$

where:

- d^{ref} is the d -axis component of the reference vector.
- q^{ref} is the q -axis component of the reference vector.
- mag^{ref} is the magnitude of the reference vector.
- θ_e is the electrical position of the reference vector.

Ports

Input

mag^{ref} — Magnitude of reference vector
scalar

Magnitude of the reference voltage, current, or flux vector that you provide as an input to the block.

Data Types: `single` | `double` | `fixed point`

θ_e — Electrical position of reference vector
scalar

Electrical position of the reference voltage, current, or flux vector that you provide as an input to the block.

Data Types: `single` | `double` | `fixed point`

Output

d^{ref} — d -axis component of reference vector
scalar

Reference voltage, current, or flux vector component along the direct axis of the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

q^{ref} — q -axis component of reference vector
scalar

Reference voltage, current, or flux vector component along the quadrature axis of the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

Parameters

Alpha (phase-a) axis alignment — dq reference frame alignment
`D-axis` (default) | `Q-axis`

Align either the d - or q -axis of the rotating reference frame to the α -axis of the stationary reference frame.

Theta units — Unit of input position value
`Per-unit` (default) | `Radians` | `Degrees`

Unit of the input electrical position of the reference voltage, current, or flux vector.

Number of data points for trigonometric lookup table — Size of lookup table array
`1024` (default) | `scalar`

Size of the lookup table array.

Version History

Introduced in R2020a

Extended Capabilities

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

Fixed-Point Conversion
Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

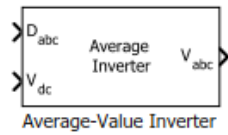
Speed Measurement | MTPA Control Reference

Topics

“Open-Loop and Closed-Loop Control”
“Field-Oriented Control (FOC)”

Average-Value Inverter

Compute three-phase AC voltage from inverter DC voltage



Libraries:

Motor Control Blockset / Electrical Systems / Inverters

Description

The Average-Value Inverter block models an average-value and full-wave inverter. It computes the three-phase AC voltage output from inverter DC voltage by using the duty cycle information.

Equations

These equations describe how the block computes the three-phase AC voltage.

$$D_0 = \frac{(D_a + D_b + D_c)}{3}$$

$$V_a = V_{dc} \times (D_a - D_0)$$

$$V_b = V_{dc} \times (D_b - D_0)$$

$$V_c = V_{dc} \times (D_c - D_0)$$

where:

- D_a , D_b , and D_c are the modulation indices ranging between 0 and 1.
- V_{dc} is the DC bus voltage of the inverter (Volts).
- V_a , V_b , and V_c are the output three-phase voltages (Volts).

Ports

Input

D_{abc} — Duty cycle for three-phase voltage
scalar

Three-phase modulation indices in the range [0,1] for generating voltages that run the motor.

Data Types: `single` | `double` | `fixed point`

V_{dc} — Inverter DC voltage
scalar

DC bus voltage input to the inverter.

Data Types: `single` | `double` | `fixed point` | `uint8` | `uint16` | `uint32`

Output

V_{abc} — Three-phase voltage output
scalar

Three-phase voltage (Volts) corresponding to the input duty cycle that runs the motor.

Data Types: `single` | `double` | `fixed point`

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Space Vector Generator | Induction Motor | Interior PMSM | Surface Mount PMSM

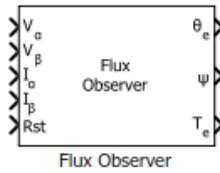
Topics

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

Flux Observer

Compute electrical position, magnetic flux, and electrical torque of rotor



Libraries:
Motor Control Blockset / Sensorless Estimators

Description

The Flux Observer block computes the electrical position, magnetic flux, and electrical torque of a PMSM or an induction motor by using the per unit voltage and current values along the α - and β -axes in the stationary $\alpha\beta$ reference frame.

The block also accepts 16-bit fixed-point datatype inputs. To perform mathematical operations on 16-bit fixed-point datatype signals, the block uses optimized implementation of equations for maintaining the best possible precision.

Equations

These equations describe how the block computes the electrical position, magnetic flux, and electrical torque for a PMSM.

$$\psi_{\alpha} = \int (V_{\alpha} - I_{\alpha}R)dt - (L_s \cdot I_{\alpha})$$

$$\psi_{\beta} = \int (V_{\beta} - I_{\beta}R)dt - (L_s \cdot I_{\beta})$$

If $(V_{\alpha} - I_{\alpha}R) = v_1(t)$ and $(V_{\beta} - I_{\beta}R) = v_2(t)$

Then, the following Laplace transforms represent the integral terms available in Ψ_{α} and Ψ_{β} :

$$L\left(\int v_1(t)dt\right) = \frac{1}{s}L(v_1(t)) = \frac{1}{s}v_1(s)$$

$$L\left(\int v_2(t)dt\right) = \frac{1}{s}L(v_2(t)) = \frac{1}{s}v_2(s)$$

The block uses low-pass filter (LPF) based integrator to compute these integral terms.

If the input electrical speed of the motor (ω_e) is much greater than the speed corresponding to the cut-off frequency of LPF-based integrator (ω_c), then

$$L \left(\int v_1(t) dt \right) = \frac{1}{(s + \omega_c)} v_1(s)$$

$$L \left(\int v_2(t) dt \right) = \frac{1}{(s + \omega_c)} v_2(s)$$

The LPF-based integrator that the block uses eliminates any DC offset that the block may have. For example, consider an input function $X(s)=k/s$. Using the preceding transfer function of

$G(s) = \frac{1}{(s + \omega_c)}$, we obtain:

$$Y(s) = G(s)X(s) = \frac{k}{s(s + \omega_c)} = \frac{k}{\omega_c} \left(\frac{1}{s} \right) - \frac{k}{\omega_c} \left(\frac{1}{s + \omega_c} \right)$$

$$Y(t) = \frac{k}{\omega_c} u(t) - \frac{k}{\omega_c} \exp(-\omega_c t) u(t)$$

The preceding equation shows that the DC component in the resulting output $Y(t)$ reduces exponentially with time. Therefore, the LPF-based integrator enables the block to eliminate any DC component available in the system.

$$\psi = \sqrt{\psi_\alpha^2 + \psi_\beta^2}$$

$$T_e = \frac{3}{2} P (\psi_\alpha I_\beta - \psi_\beta I_\alpha)$$

$$\theta_e = \tan^{-1} \frac{\psi_\beta}{\psi_\alpha}$$

These equations describe how the block computes the rotor electrical position, rotor magnetic flux, and electrical torque for an induction motor.

$$\psi_\alpha = \frac{L_r}{L_m} \left(\int (V_\alpha - I_\alpha R) dt - \sigma L_s I_\alpha \right)$$

$$\psi_\beta = \frac{L_r}{L_m} \left(\int (V_\beta - I_\beta R) dt - \sigma L_s I_\beta \right)$$

As explained previously, the LPF-based integrator enables the block to eliminate any DC component available in ψ_α and ψ_β .

$$\sigma = 1 - \frac{L_m^2}{L_r \cdot L_s}$$

$$\psi = \sqrt{\psi_\alpha^2 + \psi_\beta^2}$$

$$T_e = \frac{3}{2} \cdot P \cdot \frac{L_m}{L_r} (\psi_\alpha I_\beta - \psi_\beta I_\alpha)$$

$$\theta_e = \tan^{-1} \frac{\psi_\beta}{\psi_\alpha}$$

where:

- V_α and V_β are the α -axis and β -axis voltages (Volts).
- I_α and I_β are the α -axis and β -axis current (Amperes).
- R is the stator resistance of the motor (Ohms).
- L_s is the stator inductance of the motor (Henry).
- L_r is the rotor inductance of the motor (Henry).
- L_m is the magnetizing inductance of the motor (Henry).
- σ is the total leakage factor of the induction motor.
- P is the number of motor pole pairs.
- ψ is the rotor magnetic flux (Weber).
- ψ_α and ψ_β are the rotor magnetic fluxes along the α - and β -axes (Weber).
- T_e is the electrical torque of the rotor (Nm).
- θ_e is the electrical position of the rotor (Radians).

Ports

Input

V_α — α -axis voltage
scalar

Voltage component along the α -axis in the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

V_β — β -axis voltage
scalar

Voltage component along the β -axis in the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

I_α — α -axis current
scalar

Current along the α -axis in the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

I_β — β -axis current
scalar

Current along the β -axis in the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

Rst — Reset block

scalar

The pulse (true value) that resets the block algorithm.

Data Types: `single` | `double` | `fixed point`

Output

θ_e — Electrical position of motor

scalar

The electrical position of the rotor as estimated by the block.

Dependencies

To enable this port, set **Block output** to Position.

Data Types: `single` | `double` | `fixed point`

Ψ — Rotor flux of motor

scalar

The magnetic flux of the rotor as estimated by the block.

Dependencies

To enable this port, set **Block output** to Flux.

Data Types: `single` | `double` | `fixed point`

T_e — Electrical torque of motor

scalar

The electrical torque of the rotor as estimated by the block.

Dependencies

To enable this port, set **Block output** to Torque.

Data Types: `single` | `double` | `fixed point`

Parameters

Motor parameters

Motor selection — Type of motor

PMSM (default) | ACIM

Select the type of motor that the block supports.

Support 16-bit fixedpoint datatype — Support the datatype of 16-bit fixed-point

on (default) | off

To process 16-bit fixed-point inputs and perform computation using 16-bit fixed-point data type, select this parameter. To use a data type other than 16-bit fixed point, clear this parameter.

Dependencies

If you select this parameter:

- The block sets the **Input unit** parameter to Per-unit because 16-bit datatype does not work with SI units.
- The block selects only **Position** option for the **Block output** parameter because it cannot generate flux or torque output using 16-bit datatype.

Input unit — Unit of voltage and current inputs

SI unit (default) | Per-unit

Select the unit of the α and β -axes voltage and current input values.

Base voltage (V) — Nominal voltage corresponding to one per unit

13.86 (default) | scalar

The maximum phase voltage applied to the PMSM. For details, see “Per-Unit System”.

Dependencies

To enable this parameter, set **Input unit** to Per-unit.

Base current (A) — Nominal current corresponding to one per unit

19.3 (default) | scalar

The maximum measurable current supplied to the PMSM. For details, see “Per-Unit System”.

Dependencies

To enable this parameter, set **Input unit** to Per-unit.

Block output — Select outputs that block should compute

Position (default) | Flux | Torque

Select one or more quantities that the block should compute and display in the block output.

Note You must select at least one value. The block displays an error message if you click **Ok** or **Apply** without selecting any value.

Pole pairs — Number of pole pairs available in motor

4 (default) | scalar

Number of pole pairs available in the motor.

Dependencies

To enable this parameter, set **Block output** to Torque.

Stator resistance (ohm) — Stator winding resistance

0.36 (default) | scalar

Stator phase winding resistance of the motor in ohms.

Stator d-axis inductance (H) — Stator winding inductance along d -axis
 $0.2e-3$ (default) | scalar

Stator winding inductance of the motor along d -axis in Henry.

Dependencies

To enable this parameter, set **Motor selection** to PMSM.

Stator leakage inductance (H) — Leakage inductance of stator winding
 0.0068 (default) | scalar

Leakage inductance of the induction motor stator winding in Henry.

Dependencies

To enable this parameter, set **Motor selection** to ACIM.

Rotor leakage inductance (H) — Leakage inductance of rotor winding
 0.0068 (default) | scalar

Leakage inductance of the induction motor rotor winding in Henry.

Dependencies

To enable this parameter, set **Motor selection** to ACIM.

Magnetizing inductance (H) — Magnetizing inductance of induction motor
 0.0300 (default) | scalar

Magnetizing inductance of the induction motor in Henry.

Dependencies

To enable this parameter, set **Motor selection** to ACIM.

Cutoff frequency (Hz) — Cutoff frequency of internal high-pass filter
 3.1863 (default) | scalar

Cutoff frequency of the internal high-pass filter (that filters noise) in Hertz.

The Flux Observer block uses an internal first order IIR high-pass filter. You should set the **Cutoff frequency (Hz)** for this filter to a value that is lower than the lowest frequency corresponding to the minimum speed of the motor. For example, you can enter a value that is one-tenth of the lowest electrical frequency of the stator voltages and the currents. However, you can adjust this value to determine a more accurate cutoff frequency that generates the desired block output.

Discrete step size (s) — Sample time after which block executes again
 $50e-6$ (default) | scalar

The fixed time interval in seconds between two consecutive instances of block execution.

Datatypes

Position unit — Unit of electrical position output
 Radians (default) | Degrees | Per-unit

Unit of the electrical position output.

Dependencies

To enable this parameter, set **Block output** to Position.

Position datatype — Data type of electrical position output
`single (default) | double | fixed point`

Data type of the electrical position output.

Dependencies

To enable this parameter, set **Block output** to Position.

Flux unit — Unit of magnetic flux output
`Weber (default) | Per-unit`

Unit of the magnetic flux output.

Dependencies

To enable this parameter, set **Block output** to Flux.

Flux datatype — Data type of magnetic flux output
`single (default) | double | fixed point`

Data type of the magnetic flux output.

Dependencies

To enable this parameter, set **Block output** to Flux.

Torque unit — Unit of electrical torque output
`Nm (default) | Per-unit`

Unit of the electrical torque output.

Dependencies

To enable this parameter, set **Block output** to Torque.

Torque datatype — Data type of electrical torque output
`single (default) | double | fixed point`

Data type of the electrical torque output.

Dependencies

To enable this parameter, set **Block output** to Torque.

Version History

Introduced in R2020a

References

- [1] A. Podder and D. Pandit, "Study of Sensorless Field-Oriented Control of SPMSM Using Rotor Flux Observer & Disturbance Observer Based Discrete Sliding Mode Observer," 2021 IEEE 22nd

- Workshop on Control and Modelling of Power Electronics (COMPEL), 2021, pp. 1-8. (doi: 10.1109/COMPEL52922.2021.9645939)*
- [2] O. Sandre-Hernandez, J. J. Rangel-Magdaleno and R. Morales-Caporal, "Simulink-HDL cosimulation of direct torque control of a PM synchronous machine based FPGA," *2014 11th International Conference on Electrical Engineering, Computing Science and Automatic Control (CCE), Campeche, 2014, pp. 1-6. (doi: 10.1109/ICEEE.2014.6978298)*
- [3] Y. Inoue, S. Morimoto and M. Sanada, "Control method suitable for direct torque control based motor drive system satisfying voltage and current limitations," *The 2010 International Power Electronics Conference - ECCE ASIA -, Sapporo, 2010, pp. 3000-3006. (doi: 10.1109/IPEC.2010.5543698)*

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see "ConstrainedOutputPipeline" (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see "InputPipeline" (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see "OutputPipeline" (HDL Coder).

Restrictions

- The block supports HDL code generation only when you set the **Motor selection** parameter to PMSM.
- The block does not support HDL code generation when:

- Input or output signals have mixed datatypes.
- The parameter **Support 16-bit fixedpoint datatype** is selected.
- Input or output signals have fixed point datatype of size less than 16 bits.
- The block needs native floating point library to support fixed point datatype with HDL code generation.
- If you run third-party (3p) simulation, the block may show a minor mismatch (of the order $1e-7$) in the simulation results because of an internal trigonometric function that uses the floating point datatype.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Sliding Mode Observer | Clarke Transform | Inverse Park Transform | Speed Measurement

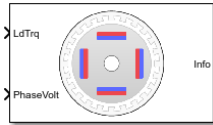
Topics

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

Interior PMSM

Three-phase interior permanent magnet synchronous motor with sinusoidal back electromotive force



Libraries:

Powertrain Blockset / Propulsion / Electric Motors and Inverters
Motor Control Blockset / Electrical Systems / Motors

Description

The Interior PMSM block implements a three-phase interior permanent magnet synchronous motor (PMSM) with sinusoidal back electromotive force. The block uses the three-phase input voltages to regulate the individual phase currents, allowing control of the motor torque or speed.

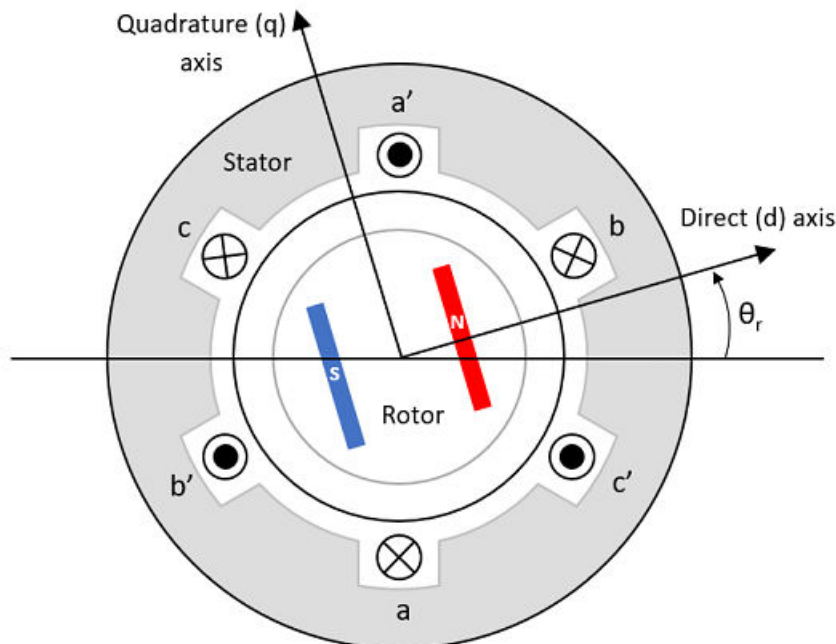
By default, the block sets the **Simulation type** parameter to **Continuous** to use a continuous sample time during simulation. If you want to generate code for fixed-step double- and single-precision targets, considering setting the parameter to **Discrete**. Then specify a **Sample Time, Ts** parameter.

On the **Parameters** tab, if you select **Back-emf**, the block implements this equation to calculate the permanent flux linkage constant.

$$\lambda_{pm} = \frac{1}{\sqrt{3}} \cdot \frac{K_e}{1000P} \cdot \frac{60}{2\pi}$$

Motor Construction

This figure shows the motor construction with a single pole pair on the motor.



The motor magnetic field due to the permanent magnets creates a sinusoidal rate of change of flux with motor angle.

For the axes convention, the a -phase and permanent magnet fluxes are aligned when motor angle θ , is zero.

Three-Phase Sinusoidal Model Electrical System

The block implements these equations, expressed in the motor flux reference frame (dq frame). All quantities in the motor reference frame are referred to the stator.

$$\omega_e = P\omega_m$$

$$\frac{d}{dt}i_d = \frac{1}{L_d}v_d - \frac{R}{L_d}i_d + \frac{L_q}{L_d}P\omega_m i_q$$

$$\frac{d}{dt}i_q = \frac{1}{L_q}v_q - \frac{R}{L_q}i_q - \frac{L_d}{L_q}P\omega_m i_d - \frac{\lambda_{pm}P\omega_m}{L_q}$$

$$T_e = 1.5P[\lambda_{pm}i_q + (L_d - L_q)i_d i_q]$$

The L_q and L_d inductances represent the relation between the phase inductance and the motor position due to the saliency of the motor.

The equations use these variables.

L_q, L_d	q- and d-axis inductances (H)
R	Resistance of the stator windings (ohm)
i_q, i_d	q- and d-axis currents (A)
v_q, v_d	q- and d-axis voltages (V)
ω_m	Angular mechanical velocity of the motor (rad/s)
ω_e	Angular electrical velocity of the motor (rad/s)
λ_{pm}	Permanent flux linkage constant (Wb)
K_e	Back electromotive force (EMF) (Vpk_LL/krpm, where Vpk_LL is the peak voltage line-to-line measurement)
P	Number of pole pairs
T_e	Electromagnetic torque (Nm)
Θ_e	Electrical angle (rad)

Mechanical System

The motor angular velocity is given by:

$$\frac{d}{dt}\omega_m = \frac{1}{J}(T_e - T_f - F\omega_m - T_m)$$

$$\frac{d\theta_m}{dt} = \omega_m$$

The equations use these variables.

J	Combined inertia of motor and load (kgm ²)
F	Combined viscous friction of motor and load (N·m/(rad/s))
θ_m	Motor mechanical angular position (rad)
T_m	Motor shaft torque (Nm)
T_e	Electromagnetic torque (Nm)
T_f	Motor shaft static friction torque (Nm)
ω_m	Angular mechanical velocity of the motor (rad/s)

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Variable	Equations	
PwrInfo	PwrTrnsfrd — Power transferred between blocks	PwrMtr	Mechanical power	P_{mot}	$P_{mot} = -\omega_m T_e$
	<ul style="list-style-type: none"> Positive signals indicate flow into block Negative signals indicate flow out of block 	PwrBus	Electrical power	P_{bus}	$P_{bus} = v_{an}i_a + v_{bn}i_b + v_{cn}i_c$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred	PwrElecLoss	Resistive power loss	P_{elec}	$P_{elec} = -\frac{3}{2}(R_s i_{sd}^2 + R_s i_{sq}^2)$
	<ul style="list-style-type: none"> Positive signals indicate an input Negative signals indicate a loss 	PwrMechLoss	Mechanical power loss	P_{mech}	<p>When Port Configuration is set to Torque:</p> $P_{mech} = -(\omega_m^2 F + \omega_m T_f)$ <p>When Port Configuration is set to Speed:</p> $P_{mech} = 0$
PwrStored — Stored energy rate of change	PwrMtrStored	Stored motor power	P_{str}	$P_{str} = P_{bus} + P_{mot} + P_{elec} + P_{mech}$	
<ul style="list-style-type: none"> Positive signals indicate an increase Negative signals indicate a decrease 					

The equations use these variables.

R_s	Stator resistance (ohm)
-------	-------------------------

i_a, i_b, i_c	Stator phase a, b, and c current (A)
i_{sq}, i_{sd}	Stator q- and d-axis currents (A)
v_{an}, v_{bn}, v_{cn}	Stator phase a, b, and c voltage (V)
ω_m	Angular mechanical velocity of the rotor (rad/s)
F	Combined motor and load viscous damping (N·m/(rad/s))
T_e	Electromagnetic torque (Nm)
T_f	Combined motor and load friction torque (Nm)

Amplitude invariant dq transformation

The block uses these equations to implement amplitude invariant dq transformation to ensure that the dq and three phase amplitudes are equal.

$$\begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos(\theta_{da}) & \cos(\theta_{da} - \frac{2\pi}{3}) & \cos(\theta_{da} + \frac{2\pi}{3}) \\ -\sin(\theta_{da}) & -\sin(\theta_{da} - \frac{2\pi}{3}) & -\sin(\theta_{da} + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} \cos(\theta_{da}) & -\sin(\theta_{da}) \\ \cos(\theta_{da} - \frac{2\pi}{3}) & -\sin(\theta_{da} - \frac{2\pi}{3}) \\ \cos(\theta_{da} + \frac{2\pi}{3}) & -\sin(\theta_{da} + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix}$$

The equations use these variables.

θ_{da}	dq stator electrical angle with respect to the rotor a -axis (rad)
v_{sq}, v_{sd}	Stator q - and d -axis voltages (V)
i_{sq}, i_{sd}	Stator q - and d -axis currents (A)
v_a, v_b, v_c	Stator voltage phases a, b, c (V)
i_a, i_b, i_c	Stator currents phases a, b, c (A)

Ports

Input

LdTrq — Load torque on motor
scalar

Load torque on the motor shaft, T_m , in N·m.

Dependencies

To create this port, select Torque for the **Port Configuration** parameter.

Spd — Motor shaft speed
scalar

Angular velocity of the motor, ω_m , in rad/s.

Dependencies

To create this port, select Speed for the **Port Configuration** parameter.

PhaseVolt — Stator terminal voltages

1-by-3 array

Stator terminal voltages, V_a , V_b , and V_c , in V.

Dependencies

To create this port, select Speed or Torque for the **Port Configuration** parameter.

Output**Info** — Bus signal

bus

The bus signal contains these block calculations.

Signal		Description	Variable	Units	
IaStator		Stator phase current A	i_a	A	
IbStator		Stator phase current B	i_b	A	
IcStator		Stator phase current C	i_c	A	
IdSync		Direct axis current	i_d	A	
IqSync		Quadrature axis current	i_q	A	
VdSync		Direct axis voltage	v_d	V	
VqSync		Quadrature axis voltage	v_q	V	
MtrSpd		Angular mechanical velocity of the motor	ω_m	rad/s	
MtrPos		Motor mechanical angular position	θ_m	rad	
MtrTrq		Electromagnetic torque	T_e	N·m	
PwrInfo	PwrTrnsfrd	PwrMtr	Mechanical power	P_{mot}	W
		PwrBus	Electrical power	P_{bus}	W
	PwrNotTrnsfrd	PwrElecLoss	Resistive power loss	P_{elec}	W
		PwrMechLoss	Mechanical power loss	P_{mech}	W
	PwrStored	PwrMtrStored	Stored motor power	P_{str}	W

PhaseCurr — Phase a, b, c current

1-by-3 array

Phase a, b, c current, i_a , i_b , and i_c , in A.

MtrTrq — Motor torque

scalar

Motor torque, T_{mtr} , in N·m.

Dependencies

To create this port, select Speed for the **Mechanical input configuration** parameter.

MtrSpd — Motor speed
scalar

Angular speed of the motor, ω_{mtr} , in rad/s.

Dependencies

To create this port, select Torque for the **Mechanical input configuration** parameter.

Parameters

Block Options

Mechanical input configuration — Select port configuration
Torque (default) | Speed

This table summarizes the port configurations.

Port Configuration	Creates Input Port	Creates Output Port
Torque	LdTrq	MtrSpd
Speed	Spd	MtrTrq

Simulation type — Select simulation type
Continuous (default) | Discrete

By default, the block uses a continuous sample time during simulation. If you want to generate code for single-precision targets, considering setting the parameter to Discrete.

Dependencies

Setting **Simulation type** to Discrete creates the **Sample Time, Ts** parameter.

Sample Time (Ts) — Sample time for discrete integration
0.001 (default) | scalar

Integration sample time for discrete simulation, in s.

Dependencies

Setting **Simulation type** to Discrete creates the **Sample Time, Ts** parameter.

Load Parameters

File — Path to motor parameter ".m" or ".mat" file
file name

Enter the path to the motor parameter ".m" or ".mat" file that you saved using the Motor Control Blockset parameter estimation tool. You can also click the **Browse** button to navigate and select the ".m" or ".mat" file, and update **File** parameter with the file name and path. For details related to the

motor parameter estimation process, see “Estimate PMSM Parameters Using Recommended Hardware”.

- **Load from file** - Click this button to read the estimated motor parameters from the ".m" or ".mat" file (indicated by the **File** parameter) and load them to the motor block.
- **Save to file** - Click this button to read the motor parameters from the motor block and save them into a ".m" or ".mat" file (with a file name and location that you specify in the **File** parameter).

Note Before you click **Save to file** button, ensure that the target file name in the **File** parameter has either ".m" or ".mat" extension. If you use any other file extension, the block displays an error message.

Parameters

Number of pole pairs (P) — Pole pairs

4 (default) | scalar

Motor pole pairs, P .

Stator phase resistance per phase (Rs) — Resistance

0.02 (default) | scalar

Stator phase resistance per phase, R_s , in ohm.

Stator d-axis and q-axis inductance (Ldq) — Inductance

[1.7e-3 3.2e-3] (default) | vector

Stator d-axis and q-axis inductance, L_d , L_q , in H.

Permanent flux linkage constant (lambda_pm) — Flux

0.2205 (default) | scalar

Permanent flux linkage constant, λ_{pm} , in Wb.

Back-emf constant (Ke) — Back electromotive force

scalar

Back electromotive force, EMF, K_e , in Vpk_LL/krpm. Vpk_LL is the peak voltage line-to-line measurement.

To calculate the permanent flux linkage constant, the block implements this equation.

$$\lambda_{pm} = \frac{1}{\sqrt{3}} \cdot \frac{K_e}{1000P} \cdot \frac{60}{2\pi}$$

Physical inertia, viscous damping, and static friction (mechanical) — Inertia, damping, friction

[0.002700, 4.924e-4, 0] (default) | vector

Mechanical properties of the motor:

- Inertia, J , in kg.m²
- Viscous damping, F , in N·m/(rad/s)

- Static friction, T_f , in N·m

Dependencies

To enable this parameter, select the Torque configuration parameter.

Initial Values

Initial d-axis and q-axis current (idq0) — Current
[0 0] (default) | `vector`

Initial q- and d-axis currents, i_q, i_d , in A.

Initial mechanical position (theta_init) — Angle
 θ (default) | `scalar`

Initial motor angular position, θ_{m0} , in rad.

Initial mechanical speed (omega_init) — Speed
 θ (default) | `scalar`

Initial angular velocity of the motor, ω_{m0} , in rad/s.

Dependencies

To enable this parameter, select the Torque configuration parameter.

Version History

Introduced in R2017a

References

- [1] Kundur, P. *Power System Stability and Control*. New York, NY: McGraw Hill, 1993.
- [2] Anderson, P. M. *Analysis of Faulted Power Systems*. Hoboken, NJ: Wiley-IEEE Press, 1995.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

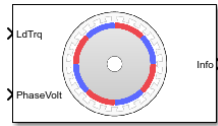
See Also

Topics

“Estimate Motor Parameters Using Motor Control Blockset Parameter Estimation Tool”

Surface Mount PMSM

Three-phase exterior permanent magnet synchronous motor with sinusoidal back electromotive force



Libraries:

Powertrain Blockset / Propulsion / Electric Motors and Inverters
Motor Control Blockset / Electrical Systems / Motors

Description

The Surface Mount PMSM block implements a three-phase exterior permanent magnet synchronous motor (PMSM) with sinusoidal back electromotive force. The block uses the three-phase input voltages to regulate the individual phase currents, allowing control of the motor torque or speed.

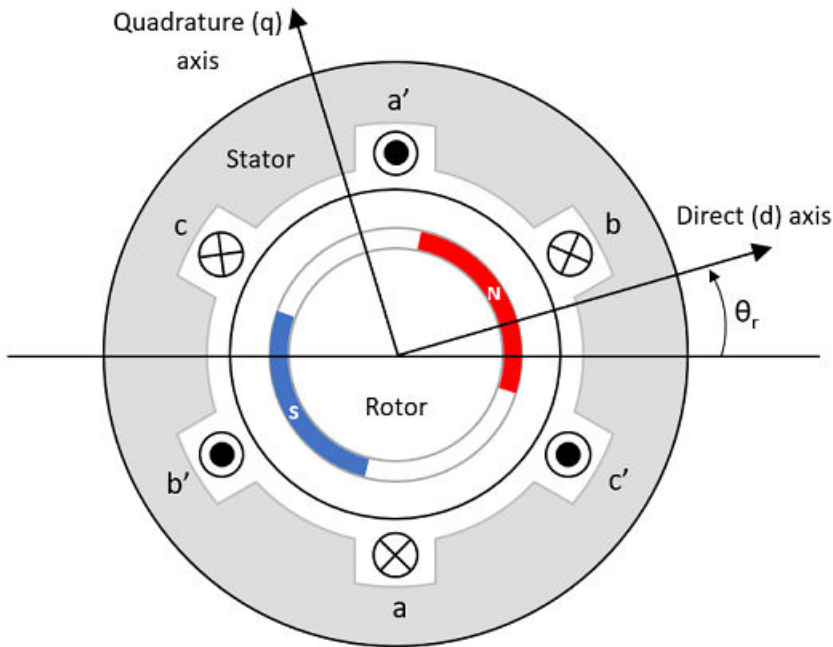
By default, the block sets the **Simulation type** parameter to `Continuous` to use a continuous sample time during simulation. If you want to generate code for fixed-step double- and single-precision targets, considering setting the parameter to `Discrete`. Then specify a **Sample Time, Ts** parameter.

On the **Parameters** tab, if you select `Back-emf` or `Torque` constant, the block implements one of these equations to calculate the permanent flux linkage constant.

Setting	Equation
Back-emf	$\lambda_{pm} = \frac{1}{\sqrt{3}} \cdot \frac{K_e}{1000P} \cdot \frac{60}{2\pi}$
Torque constant	$\lambda_{pm} = \frac{2}{3} \cdot \frac{K_t}{P}$

Motor Construction

This figure shows the motor construction with a single pole pair on the motor.



The motor magnetic field due to the permanent magnets creates a sinusoidal rate of change of flux with motor angle.

For the axes convention, the *a*-phase and permanent magnet fluxes are aligned when motor angle θ_r is zero.

Three-Phase Sinusoidal Model Electrical System

The block implements these equations, expressed in the motor flux reference frame (dq frame). All quantities in the motor reference frame are referred to the stator.

$$\omega_e = P\omega_m$$

$$\frac{d}{dt}i_d = \frac{1}{L_d}v_d - \frac{R}{L_d}i_d + \frac{L_q}{L_d}P\omega_m i_q$$

$$\frac{d}{dt}i_q = \frac{1}{L_q}v_q - \frac{R}{L_q}i_q - \frac{L_d}{L_q}P\omega_m i_d - \frac{\lambda_{pm}P\omega_m}{L_q}$$

$$T_e = 1.5P[\lambda_{pm}i_q + (L_d - L_q)i_d i_q]$$

The L_q and L_d inductances represent the relation between the phase inductance and the motor position due to the saliency of the motor magnets. For the surface mount PMSM, $L_d = L_q$.

The equations use these variables.

L_q, L_d	q- and d-axis inductances (H)
R	Resistance of the stator windings (ohm)
i_q, i_d	q- and d-axis currents (A)
v_q, v_d	q- and d-axis voltages (V)

ω_m	Angular mechanical velocity of the motor (rad/s)
ω_e	Angular electrical velocity of the motor (rad/s)
λ_{pm}	Permanent magnet flux linkage (Wb)
K_e	Back electromotive force (EMF) (Vpk_LL/krpm, where Vpk_LL is the peak voltage line-to-line measurement)
K_t	Torque constant (N·m/A)
P	Number of pole pairs
T_e	Electromagnetic torque (Nm)
Θ_e	Electrical angle (rad)

Mechanical System

The motor angular velocity is given by:

$$\frac{d}{dt}\omega_m = \frac{1}{J}(T_e - T_f - F\omega_m - T_m)$$

$$\frac{d\theta_m}{dt} = \omega_m$$

The equations use these variables.

J	Combined inertia of motor and load (kgm ²)
F	Combined viscous friction of motor and load (N·m/(rad/s))
θ_m	Motor mechanical angular position (rad)
T_m	Motor shaft torque (Nm)
T_e	Electromagnetic torque (Nm)
T_f	Motor shaft static friction torque (Nm)
ω_m	Angular mechanical velocity of the motor (rad/s)

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Variable	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks	PwrMtr	Mechanical power	$P_{mot} = -\omega_m T_e$
	<ul style="list-style-type: none"> Positive signals indicate flow into block Negative signals indicate flow out of block 	PwrBus	Electrical power	$P_{bus} = v_{an}i_a + v_{bn}i_b + v_{cn}i_c$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred	PwrElecLoss	Resistive power loss	$P_{elec} = -\frac{3}{2}(R_s i_{sd}^2 + R_s i_{sq}^2)$

Bus Signal		Description	Variable	Equations
<ul style="list-style-type: none"> Positive signals indicate an input Negative signals indicate a loss 	PwrMechLoss	Mechanical power loss	P_{mech}	When Port Configuration is set to Torque: $P_{mech} = -(\omega_m^2 F + \omega_m T_f)$ When Port Configuration is set to Speed: $P_{mech} = 0$
PwrStored — Stored energy rate of change <ul style="list-style-type: none"> Positive signals indicate an increase Negative signals indicate a decrease 	PwrMtrStored	Stored motor power	P_{str}	$P_{str} = \frac{P_{bus} + P_{mot} + P_{elec} + P_{mech}}$

The equations use these variables.

- R_s Stator resistance (ohm)
- i_a, i_b, i_c Stator phase a, b, and c current (A)
- i_{sq}, i_{sd} Stator q- and d-axis currents (A)
- v_{an}, v_{bn}, v_{cn} Stator phase a, b, and c voltage (V)
- ω_m Angular mechanical velocity of the motor (rad/s)
- F Combined motor and load viscous damping N·m/(rad/s)
- T_e Electromagnetic torque (Nm)
- T_f Combined motor and load friction torque (Nm)

Ports

Input

LdTrq — Load torque on motor
scalar

Load torque on the motor shaft, T_m , in N·m.

Dependencies

To create this port, select Torque for the **Port Configuration** parameter.

Spd — Motor shaft speed
scalar

Angular velocity of the motor, ω_m , in rad/s.

Dependencies

To create this port, select Speed for the **Port Configuration** parameter.

PhaseVolt — Stator terminal voltages

1-by-3 array

Stator terminal voltages, V_a , V_b , and V_c , in V.

Output**Info** — Bus signal

bus

The bus signal contains these block calculations.

Signal		Description	Variable	Units	
IaStator		Stator phase current A	i_a	A	
IbStator		Stator phase current B	i_b	A	
IcStator		Stator phase current C	i_c	A	
IdSync		Direct axis current	i_d	A	
IqSync		Quadrature axis current	i_q	A	
VdSync		Direct axis voltage	v_d	V	
VqSync		Quadrature axis voltage	v_q	V	
MtrSpd		Angular mechanical velocity of the motor	ω_m	rad/s	
MtrPos		Motor mechanical angular position	θ_m	rad	
MtrTrq		Electromagnetic torque	T_e	N·m	
PwrInfo	PwrTrnsfrd	PwrMtr	Mechanical power	P_{mot}	W
		PwrBus	Electrical power	P_{bus}	W
	PwrNotTrnsfrd	PwrElecLoss	Resistive power loss	P_{elec}	W
		PwrMechLoss	Mechanical power loss	P_{mech}	W
	PwrStored	PwrMtrStored	Stored motor power	P_{str}	W

PhaseCurr — Phase a, b, c current

1-by-3 array

Phase a, b, c current, i_a , i_b , and i_c , in A.

MtrTrq — Motor torque

scalar

Motor torque, T_{mtr} , in N·m.

Dependencies

To create this port, select Speed for the **Mechanical input configuration** parameter.

MtrSpd — Motor speed
scalar

Angular speed of the motor, ω_{mtr} in rad/s.

Dependencies

To create this port, select Torque for the **Mechanical input configuration** parameter.

Parameters**Block Options**

Mechanical input configuration — Select port configuration
Torque (default) | Speed

This table summarizes the port configurations.

Port Configuration	Creates Input Port	Creates Output Port
Torque	LdTrq	MtrSpd
Speed	Spd	MtrTrq

Simulation type — Select simulation type
Continuous (default) | Discrete

By default, the block uses a continuous sample time during simulation. If you want to generate code for single-precision targets, considering setting the parameter to **Discrete**.

Dependencies

Setting **Simulation type** to **Discrete** creates the **Sample Time, Ts** parameter.

Sample Time (Ts) — Sample time for discrete integration
0.001 (default) | scalar

Integration sample time for discrete simulation, in s.

Dependencies

Setting **Simulation type** to **Discrete** creates the **Sample Time, Ts** parameter.

Load Parameters

File — Path to motor parameter ".m" or ".mat" file
file name

Enter the path to the motor parameter ".m" or ".mat" file that you saved using the Motor Control Blockset parameter estimation tool. You can also click the **Browse** button to navigate and select the ".m" or ".mat" file, and update **File** parameter with the file name and path. For details related to the motor parameter estimation process, see "Estimate PMSM Parameters Using Recommended Hardware".

- **Load from file** - Click this button to read the estimated motor parameters from the ".m" or ".mat" file (indicated by the **File** parameter) and load them to the motor block.
- **Save to file** - Click this button to read the motor parameters from the motor block and save them into a ".m" or ".mat" file (with a file name and location that you specify in the **File** parameter).

Note Before you click **Save to file** button, ensure that the target file name in the **File** parameter has either ".m" or ".mat" extension. If you use any other file extension, the block displays an error message.

Parameters

Number of pole pairs (P) — Pole pairs
4 (default) | scalar

Motor pole pairs, P .

Stator phase resistance per phase (Rs) — Resistance
0.02 (default) | scalar

Stator phase resistance per phase, R_s , in ohm.

Stator d-axis inductance (Ldq_) — Inductance
1.7e-3 (default) | scalar

Stator inductance, L_{dq} , in H.

Permanent flux linkage constant (lambda_pm) — Flux
0.2205 (default) | scalar

Permanent flux linkage constant, λ_{pm} , in Wb.

Back-emf constant (Ke) — Back electromotive force
scalar

Back electromotive force, EMF, K_e , in peak $V_{pk_LL}/krpm$. V_{pk_LL} is the peak voltage line-to-line measurement.

To calculate the permanent flux linkage constant, the block implements this equation.

$$\lambda_{pm} = \frac{1}{\sqrt{3}} \cdot \frac{K_e}{1000P} \cdot \frac{60}{2\pi}$$

Torque constant (Kt) — Torque constant
scalar

Torque constant, K_t , in N·m/A.

To calculate the permanent flux linkage constant, the block implements this equation.

$$\lambda_{pm} = \frac{2}{3} \cdot \frac{K_t}{P}$$

Physical inertia, viscous damping, and static friction (mechanical) — Inertia, damping, friction
[0.002700, 4.924e-4, 0] (default) | vector

Mechanical properties of the motor:

- Inertia, J , in $\text{kg}\cdot\text{m}^2$
- Viscous damping, F , in $\text{N}\cdot\text{m}/(\text{rad}/\text{s})$
- Static friction, T_f , in $\text{N}\cdot\text{m}$

Dependencies

To enable this parameter, select the Torque configuration parameter.

Initial Values

Initial d-axis and q-axis current (**idq0**) — Current

$[0 \ 0]$ (default) | `vector`

Initial q- and d-axis currents, i_q , i_d , in A.

Initial mechanical position (**theta_init**) — Angle

0 (default) | `scalar`

Initial motor angular position, θ_{m0} , in rad.

Initial mechanical speed (**omega_init**) — Speed

0 (default) | `scalar`

Initial angular velocity of the motor, ω_{m0} , in rad/s.

Dependencies

To enable this parameter, select the Torque configuration parameter.

Version History

Introduced in R2017a

References

- [1] Kundur, P. *Power System Stability and Control*. New York, NY: McGraw Hill, 1993.
- [2] Anderson, P. M. *Analysis of Faulted Power Systems*. Hoboken, NJ: Wiley-IEEE Press, 1995.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

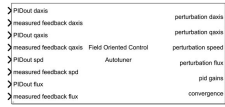
See Also

Topics

“Estimate Motor Parameters Using Motor Control Blockset Parameter Estimation Tool”

Field Oriented Control Autotuner

Automatically and sequentially tune multiple PID control loops in field-oriented control application



Libraries:

Motor Control Blockset / Controls / Controllers

Description

The Field Oriented Control Autotuner block allows you to automatically tune PID control loops in your field-oriented control (FOC) application in real time. For more information on field-oriented control, see “Field-Oriented Control (FOC)”.

You can automatically tune PID controllers associated with the following loops:

- Direct-axis (d-axis) current loop
- Quadrature-axis (q-axis) current loop
- Speed loop
- Flux loop

For each loop the block tunes, the Field Oriented Control Autotuner block performs the autotuning experiment in closed-loop without a parametric model associated with that loop. The block allows you to specify the order in which the control loops are tuned. When the tuning experiment is running for one loop, the block has no effect on the other loops. During the experiment, the block:

- 1 Injects a test signal into the plant associated with that loop to collect plant input-output data and estimate frequency response in real time. The test signal is combination of sinusoidal perturbation signals added on top of the plant input.
- 2 At the end of the experiment, tunes PID controller parameters based on estimated plant frequency responses near the target bandwidth.
- 3 Writes updated PID gains at the block output, allowing you to transfer the new gains to existing controllers and validate the closed-loop performance.

You can use the Field Oriented Control Autotuner block to tune the existing PID controllers in your FOC structure. If you do not have the initial PID controllers, you can use the “Estimate Control Gains and Use Utility Functions” workflow to obtain them. You can then use the Field Oriented Control Autotuner block for refinement or retuning.

If you have a code-generation product such as Simulink Coder™, you can generate code that implements the tuning algorithm on hardware, letting you tune in real time, using or without using Simulink to manage the autotuning process.

If you have a machine modeled in Simulink with Motor Control Blockset and an initial FOC structure with PID controllers, you can perform closed-loop PID autotuning against the modeled machine. Doing so lets you preview the plant response and adjust the settings for PID autotuning before tuning the controller in real time.

The block supports code generation with Simulink Coder, Embedded Coder®, and Simulink PLC Coder™. It does not support code generation with HDL Coder. For real-time applications, deploy the generated code on a rapid prototyping hardware such as Speedgoat® real-time target machine.

For more information about using the Field Oriented Control Autotuner block, see “How to Use Field Oriented Control Autotuner Block”.

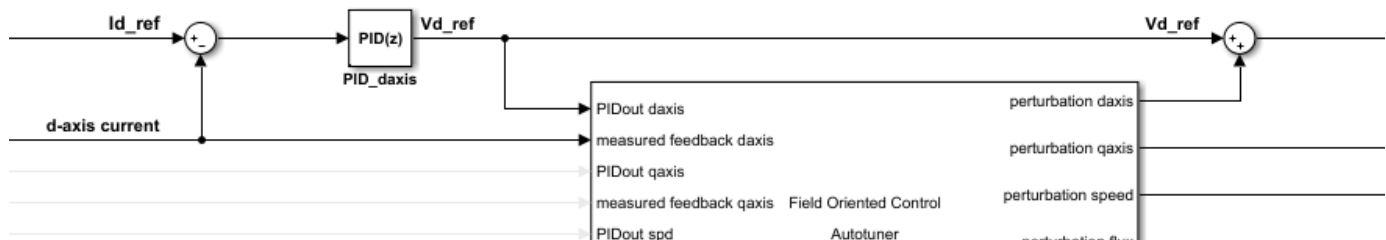
This block requires Simulink Control Design software.

Ports

Input

PIDout daxis — Signal from direct-axis current controller
scalar

This port accepts the output of the d-axis controller `PID_daxis`, which is the output of PID controller that regulates the d-axis current of the motor. The controller generates the d-axis voltage reference `Vd_ref`, while the FOC autotuner block generates perturbations used during the tuning experiment for the d-axis current loop.



Dependencies

To enable this port, select **Tune D-axis current loop**.

Data Types: `single` | `double`

measured feedback daxis — Measured direct-axis current
scalar

This port accepts the d-axis current obtained from the measured (sensed or estimated) motor currents.

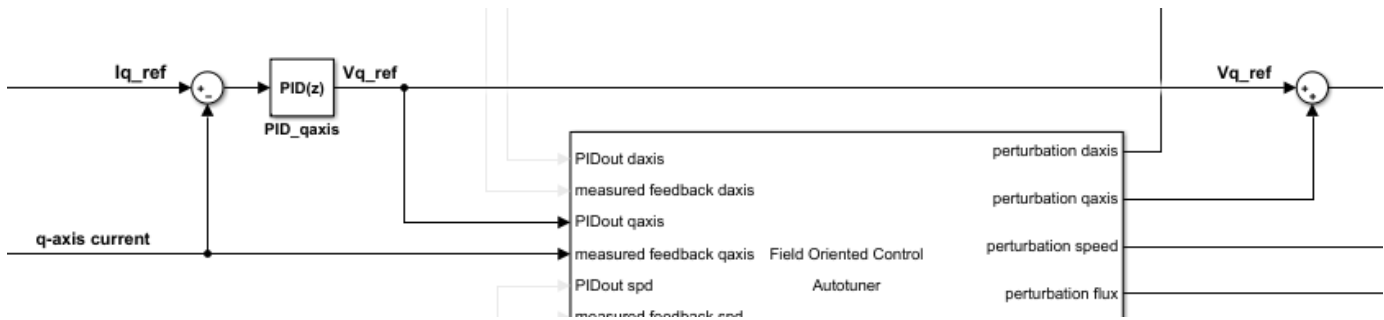
Dependencies

To enable this port, select **Tune D-axis current loop**.

Data Types: `single` | `double`

PIDout qaxis — Signal from quadrature-axis current controller
scalar

This port accepts the output of the q-axis controller `PID_qaxis`, which is the output of PID controller that regulates the q-axis current of the motor. The controller generates the q-axis voltage reference `Vq_ref`, while the FOC autotuner block generates perturbations used during the tuning experiment for the q-axis current loop.



Dependencies

To enable this port, select **Tune Q-axis current loop**.

Data Types: single | double

measured feedback qaxis — Measured quadrature-axis current scalar

This port accepts the q-axis current obtained from the measured (sensed or estimated) motor currents.

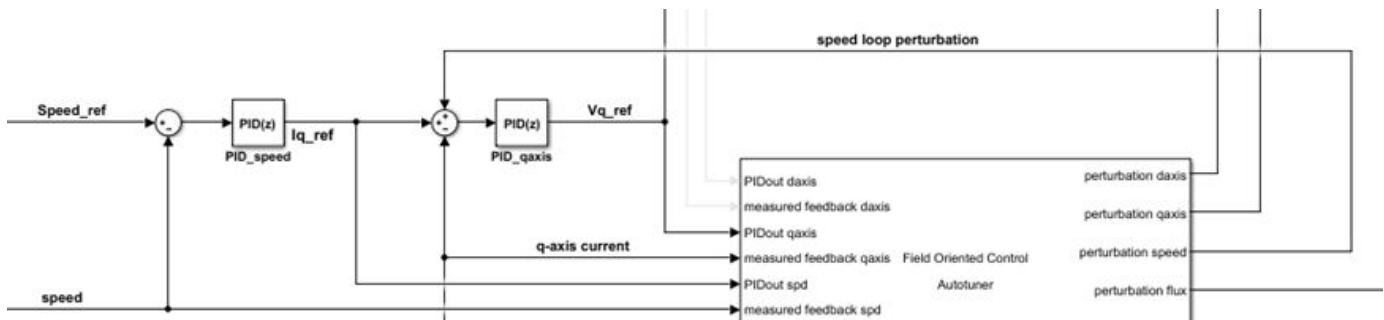
Dependencies

To enable this port, select **Tune Q-axis current loop**.

Data Types: single | double

PIDout spd — Signal from speed controller scalar

This port accepts the output of the speed controller `PID_speed`, which is the output of PID controller that regulates the speed of the motor. The controller generates the q-axis current reference `Iq_ref`, while the FOC autotuner block generates perturbations used during the tuning experiment for the speed loop.



Dependencies

To enable this port, select **Tune speed loop**.

Data Types: single | double

measured feedback spd — Measured speed scalar

This port accepts the measured (sensed or estimated) speed from the motor.

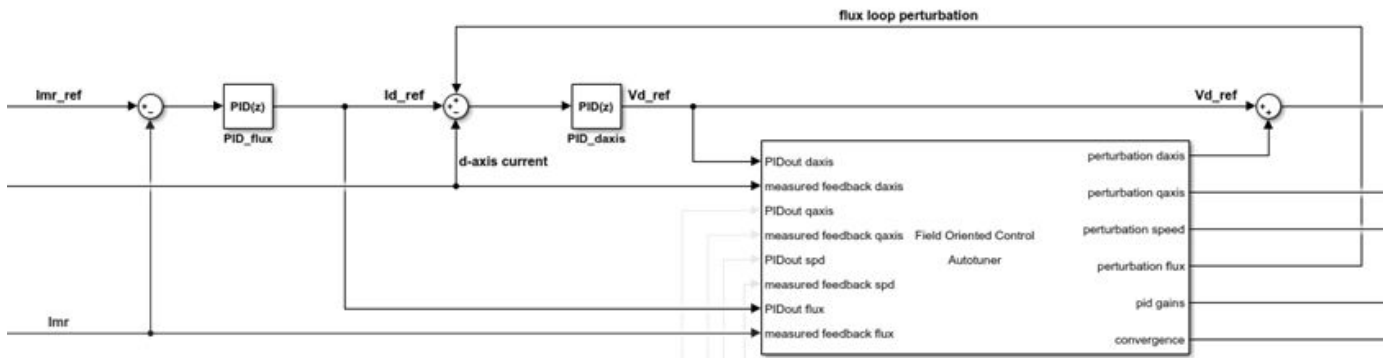
Dependencies

To enable this port, select **Tune speed loop**.

Data Types: `single` | `double`

PIDout flux — Signal from flux controller
scalar

This port accepts the output of the flux controller `PID_flux`, which is the output of PID controller that regulates the flux of the motor. The controller generates the d-axis current reference `Id_ref`, while the FOC autotuner block generates perturbations used during the tuning experiment for the flux loop.



For a permanent magnet synchronous motor (PMSM), there is no flux loop controller as the rotor flux is fixed and `Id_ref` is set to zero. In some applications you can provide a negative `Id_ref` value to implement field-weakening control and achieve higher rotor speeds at the cost of a higher current.

Dependencies

To enable this port, select **Tune flux loop**.

Data Types: `single` | `double`

measured feedback flux — Measured flux
scalar

This port accepts the measured (sensed or estimated) flux from the motor.

Dependencies

To enable this port, select **Tune flux loop**.

Data Types: `single` | `double`

start/stop — Start and stop autotuning experiment
scalar

To externally start and stop the autotuning process, provide a signal at the `start/stop` port and the `ActiveLoop` port.

- The experiment starts when the value of the signal changes from negative or zero to positive.

- The experiment stops when the value of the signal changes from positive to negative or zero.

For the duration of the experiment, for each loop, the block injects sinusoidal perturbations at the plant input associated with the loop, near the nominal operating point, to collect input-output data and estimate frequency response. When the experiment stops, the block computes PID gains based on the plant frequency responses estimated near the target bandwidth.

When the experiment is not running, the block does not inject any perturbations at the plant inputs. In this state, the block has no impact on plant or controller behavior.

Typically, you can use a signal that changes from 0 to 1 to start the experiment, and from 1 to 0 to stop it. Consider the following when you configure the `start/stop` signal.

- Start the experiment when the motor is at the desired equilibrium operating point. Use the initial controller to drive the motor to the operating point.
- Avoid any input or output disturbance on the motor during the experiment. If your existing closed-loop system has good disturbance rejection, then the experiment can handle small disturbances. Otherwise, large disturbances can distort the plant output and reduce the accuracy of the frequency-response estimation.
- Let the experiment run long enough for the algorithm to collect sufficient data for a good estimate at all frequencies it probes. There are two ways to determine when to stop the experiment:
 - Determine the experiment duration in advance. A conservative estimate for the experiment duration is $200/\omega_c$ in superposition experiment mode or $550/\omega_c$ in sinestream experiment mode, where ω_c is your target bandwidth.
 - Observe the signal at the convergence output, and stop the experiment when the signal stabilizes near 100%.
- When you stop the experiment, the block computes tuned PID gains and updates the signal at the `pid gains` port.

You can configure any logic appropriate for your application to control the start and stop times of the experiment. The `start/stop` signal is specified along with `ActiveLoop`. `ActiveLoop` takes integer values 1 to 4 and specifies which loop to tune.

Alternatively, if you are tuning in simulation or external mode, you can specify the tuning experiment sequence, start time and duration in the block parameters.

Dependencies

To enable this port, on the Block tab under **Parameters Source**, select **Use external source for start/stop of experiment**.

Data Types: `single` | `double`

ActiveLoop — Specify active loop for autotuning experiment
scalar

Set the `ActiveLoop` value to specify which loop to tune when providing an external source for the start and stop times of the tuning experiment.

ActiveLoop Value	Loop to Tune
1	D-axis current loop

ActiveLoop Value	Loop to Tune
2	Q-axis current loop
3	Speed loop
4	Flux loop

You can configure any logic appropriate for your application along with the `start/stop` port to control the sequence and the time at which the loop tuning experiment runs. `ActiveLoop` takes integer values from 1 to 4 and specifies which loop to tune. Any other number will result in no tuning taking place regardless of the `start/stop` signal. For example, when you supply a constant value 2 at `ActiveLoop` and the signal at `start/stop` rises, the block starts the tuning experiment for the q-axis current loop.

Alternatively, you can specify the tuning experiment sequence, start time, and duration in the block parameters.

Dependencies

To enable this port, on the Block tab under **Parameters Source**, select **Use external source for start/stop of experiment**.

Data Types: `single` | `double`

bandwidth — Target bandwidth for tuning
 scalar | vector | bus

Supply the values for the `Target bandwidth (rad/sec)` parameter for each loop to be tuned. If you are tuning multiple loops, you can specify the bandwidth as a vector or bus, entries of which correspond to the target bandwidth for the loops in this order:

- D-axis current loop
- Q-axis current loop
- Speed loop
- Flux loop

The vector signal must be specified as a N-by-1 or 1-by-N signal or if specified as a bus must have N elements, where N is the number of loops to be tuned. For instance, if you are tuning the q-axis current loop and the speed loop, and you specify a vector [5000, 200] at this port, the block tunes the q-axis current controller with the target bandwidth 5000 rad/sec and the speed loop controller with the target bandwidth 200 rad/sec.

If you are tuning multiple loops and specify a scalar value at this port, then the block uses the same target bandwidth to tune all the controllers. For effective cascade control, the inner control loops (d-axis and q-axis) must respond much faster than the outer control loops (flux and speed). Therefore, you must supply the target bandwidth as a vector or bus signal when tuning multiple loops.

Alternatively, you can specify target bandwidth for individual loops in block parameters. For more information on how to choose a bandwidth, see that parameter description.

Dependencies

To enable this port, on the Block tab under **Parameters Source**, select **Use external source for bandwidth**.

Data Types: `single` | `double`

target PM — Target phase margin for tuning

scalar | vector | bus

Supply a value for the `Target phase margin (degrees)` parameter for each loop to be tuned. If you are tuning multiple loops, you can specify `target PM` as a vector or bus, entries of which correspond to the target phase margin for the loops in this order:

- D-axis current loop
- Q-axis current loop
- Speed loop
- Flux loop

The vector signal must be specified as a N-by-1 or 1-by-N signal or if specified as a bus must have N elements, where N is the number of loops to be tuned. For instance, if you are tuning q-axis current loop and speed loop, and you specify a vector [60, 45] at this port, the block tunes q-axis current controller with target phase margin 60 degrees and speed loop controller with target phase margin 45 degrees.

If you are tuning multiple loops and specify a scalar value at this port, then the block uses the same target phase margin to tune all the controllers.

Alternatively, you can specify target phase margin for individual loops in block parameters. For more information on how to choose a target phase margin, see that parameter description.

Dependencies

To enable this port, on the Block tab under **Parameters Source**, select **Use external source for target phase margin**.

Data Types: single | double

sine Amp — Amplitudes of injected sinusoidal perturbation signals

vector | matrix

Supply a value for the `Sine Amplitudes` parameter for each loop to be tuned. Specify one of the following:

- Vector of length 5 to specify a different amplitude at each of $[1/10, 1/3, 1, 3, 10]\omega_c$, where ω_c is the target bandwidth for tuning.
- N-by-5 matrix, where N is the number of loops to be tuned. Each row entry must be of length 5 to specify a different amplitude at each of $[1/10, 1/3, 1, 3, 10]\omega_c$.

If you are tuning multiple loops and specify a vector of length 5 at this port, then the block uses the specified amplitude for all the loops at each of $[1/10, 1/3, 1, 3, 10]\omega_c$ corresponding to that loop.

Alternatively, you can specify the sinusoidal perturbation amplitude for individual loops in block parameters. For more information, see the parameter description.

Dependencies

To enable this port, on the Block tab under **Parameters Source**, select **Use external source for sine amplitudes**.

Data Types: single | double

Output

perturbation daxis — Direct-axis current input perturbation
scalar

Perturbation signal input used for estimating the frequency-response data model associated with the d-axis current control loop. Inject the perturbation signal from this port by using a sum block to the output of the PID controller that regulates the d-axis current.

- When the experiment is running, the block generates perturbation signals at this port.
- When the experiment is not running, the signal at this port is zero. In this state, the block has no effect on the plant.

Dependencies

To enable this port, select **Tune D-axis current loop**.

Data Types: `single` | `double`

perturbation qaxis — Quadrature-axis current input perturbation
scalar

Perturbation signal input used for estimating the frequency-response data model associated with the q-axis current control loop. Inject this perturbation signal from this port by using a sum block to the output of the PID controller that regulates the q-axis current.

- When the experiment is running, the block generates perturbation signals at this port.
- When the experiment is not running, the signal at this port is zero. In this state, the block has no effect on the plant.

Dependencies

To enable this port, select **Tune Q-axis current loop**.

Data Types: `single` | `double`

perturbation spd — Speed input perturbation
scalar

Perturbation signal input used for estimating the frequency-response data model associated with the motor speed control loop. Inject this perturbation signal from this port by using a sum block with the output of the PID controller that regulates the speed of the motor.

- When the experiment is running, the block generates perturbation signals at this port.
- When the experiment is not running, the signal at this port is zero. In this state, the block has no effect on the plant.

Dependencies

To enable this port, select **Tune speed loop**.

Data Types: `single` | `double`

perturbation flux — Flux input perturbation
scalar

Perturbation signal input used for estimating the frequency-response data model associated with the motor flux control loop. Inject this perturbation signal from this port by using a sum block to the output of the PID controller that regulates the flux linkage of the motor.

- When the experiment is running, the block generates perturbation signals at this port.
- When the experiment is not running, the signal at this port is zero. In this state, the block has no effect on the plant.

Dependencies

To enable this port, select **Tune flux loop**.

Data Types: `single` | `double`

pid gains — Tuned PID coefficients
bus

This 4-element bus signal contains the tuned PID gains P , I , D , and the filter coefficient N for each control loop the block tunes. These values correspond to the P , I , D , and N parameters in the expressions given in the `Form` parameter. Initially, the values are 0, 0, 0, and 100, respectively. The block updates the values when the experiment ends. The bus signal corresponding to each loop the block tunes always has four elements, even if you are not tuning a PIDF controller.

Data Types: `single` | `double`

convergence — Convergence of FRD estimation during experiment
scalar

The block uses perturbation signals to estimate the frequency response of the plant associated with each loop at several frequencies around the target bandwidth for tuning. `convergence` indicates how close to completion the estimation of the plant frequency response is. Typically, this value quickly rises to about 90% after the experiment begins, and then gradually converges to a higher value. Stop the experiment when it levels off near 100%.

Data Types: `single` | `double`

estimated PM — Estimated phase margin for most recently tuned loop
scalar

This port outputs the estimated phase margin achieved by the tuned controller for the most recently tuned loop, in degrees. The block updates this value when the tuning experiment ends for each loop. The estimated phase margin is calculated from the angle of $G(j\omega_c)C(j\omega_c)$, where G is the estimated plant for that loop, C is the tuned controller, and ω_c is the crossover frequency (bandwidth). The estimated phase margin might differ from the target phase margin specified by the `Target phase margin (degrees)` parameter. It is an indicator of the robustness and stability achieved by the tuned system.

- Typically, the estimated phase margin is near the target phase margin. In general, the larger the value, the more robust is the tuned system, and the less overshoot there is.
- A negative phase margin indicates that the closed-loop system might be unstable.

Dependencies

To enable this port, on the Block tab, select **Estimated phase margin achieved by tuned controllers**.

Data Types: `single` | `double`

frd — Estimated frequency response for most recently tuned loop
vector

This port outputs the frequency-response data estimated by the experiment for most recently tuned loop. Initially, the value at `frd` is `[0, 0, 0, 0, 0]`. During the experiment, the block injects signals at frequencies `[1/10, 1/3, 1, 3, 10] ω_c` , where ω_c is the target bandwidth. At each sample time during the experiment, the block updates `frd` with a vector containing the complex frequency response at each of these frequencies. You can use the progress of the response as an alternative to `convergence` to examine the convergence of the estimation. When the experiment stops, the block updates `frd` with the final estimated frequency response used for computing the PID gains.

Dependencies

To enable this port, on the Block tab, select **Plant frequency responses near bandwidth**.

Data Types: `single` | `double`

nominal — Plant input and output at nominal operating point for most recently tuned loop
vector

This port outputs a vector containing the plant input and plant output for the most recently tuned loop or the loop currently being tuned. These values are the plant input and output at the nominal operating point at which the block performs the experiment.

Dependencies

To enable this port, on the Block tab, select **Plant nominal input and output**.

Data Types: `single` | `double`

loop startstops — Active loop
bus

This 4-element bus signal indicates whether the tuning experiment for each loop tuned by the block is active or not. For each signal in the bus, the port outputs the logical value `1` (`true`) for the loop when the tuning experiment is running. The value is logical `0` (`false`) when the experiment is over or has not yet started. You can use this port to trigger updates of PID gains for individual loops.

Dependencies

To enable this port, on the Block tab, disable **Use external source for start/stop of experiment** and select **Start/stop of autotuning process**.

Data Types: `single` | `double`

Parameters

Tune D-axis current loop — Enable d-axis current loop tuning
`on` (default) | `off`

Use this parameter to enable or disable d-axis current loop autotuning.

Programmatic Use

Block Parameter: `TuneDaxisLoop`

Type: character vector

Values: 'on' | 'off'

Default: 'on'

Tune Q-axis current loop — Enable q-axis current loop tuning

on (default) | off

Use this parameter to enable or disable q-axis current loop autotuning.

Programmatic Use

Block Parameter: TuneQaxisLoop

Type: character vector

Values: 'on' | 'off'

Default: 'on'

Tune speed loop — Enable speed loop tuning

on (default) | off

Use this parameter to enable or disable speed loop autotuning.

Programmatic Use

Block Parameter: TuneSpeedLoop

Type: character vector

Values: 'on' | 'off'

Default: 'on'

Tune flux loop — Enable flux loop tuning

on (default) | off

Use this parameter to enable or disable flux loop autotuning.

Programmatic Use

Block Parameter: TuneSpeedLoop

Type: character vector

Values: 'on' | 'off'

Default: 'on'

Use same settings for current loop controllers (D-axis + Q-axis) — Enable same tuning and experiment settings for direct-axis and quadrature-axis current loops

off (default) | on

Select this parameter to enable the same tuning and experiment settings for d-axis and q-axis current loops. When enabled, the block uses the same controller settings, target bandwidth, phase margin, and other experiment settings to tune d-axis and q-axis current loops.

Programmatic Use

Block Parameter: UseSameSettingsInner

Type: character vector

Values: 'off' | 'on'

Default: 'off'

Use same settings for outer loop controllers (Speed + Flux) — Enable same tuning and experiment settings for speed and flux loops

off (default) | on

Select this parameter to enable the same tuning and experiment settings for speed and flux loops. When enabled, the block uses the same controller settings, target bandwidth, phase margin, and other experiment settings to tune speed and flux loops.

Programmatic Use**Block Parameter:** UseSameSettingsOuter**Type:** character vector**Values:** 'off' | 'on'**Default:** 'off'**Experiment sample time** — Sample time of frequency response estimation experiment
-1 (default) | positive scalar

Specify the sample time of the frequency response estimation experiment performed by the block in seconds.

By default, the experiment sample time is set to inherited (-1) and the block performs the frequency response estimation experiment, for each loop, at the inherited sample time. Use this parameter to specify a sample time for the frequency response estimation experiment that is different from the tuning and PID gain calculation sample rates. For each loop that you tune, the frequency responses are estimated at the sample time specified in this parameter.

When you specify different sample times for tuning, experiment, and loops, you can configure Simulink to treat each block module rate as a separate task to enable multitasking execution for your model. This multitasking mode helps improve performance on hardware. For more information, see [Treat each discrete rate as a separate task](#).

Programmatic Use**Block Parameter:** TsExperiment**Type:** scalar**Value:** positive scalar**Default:** -1 (inherited)**Tuning Tab****Use different sample time for tuning** — Enable tuning at different sample time from loop PID controller and experiment
off (default) | on

By default, the block runs tuning for each loop at the same sample time that you specify in the **Controller sample time (sec)** parameter for that loop. Enable this parameter to run tuning at a sample rate that is different from the sample rate of the PID controllers you are tuning and the frequency response estimation experiment performed by the block. The PID gain tuning algorithm is computationally intensive, and when you want to deploy the block to hardware and tune a controller with a fast sample time, some hardware might not complete the PID gain calculation in a single time step. To reduce the hardware throughput requirements, specify a tuning sample time slower than the controller sample time using the **Tuning sample time (sec)** parameter.

Programmatic Use**Block Parameter:** UseTuningTs**Type:** character vector**Value:** 'off' | 'on'**Default:** 'off'**Tuning sample time (sec)** — Sample time of tuning algorithm
0.2 (default) | positive scalar

Specify the sample time of the tuning algorithm in seconds.

If you intend to deploy the block on hardware with limited processing power and want to tune a controller with a fast sample time, specify a sample time such that the tuning algorithm runs at a slower rate than the PID controllers you are tuning. For each loop that you tune, after the frequency response estimation experiment ends, controller tuning occurs at the sample time specified in this parameter.

Dependencies

To enable this parameter, select **Use different sample time for tuning**.

Programmatic Use

Block Parameter: TsTuning

Type: scalar

Value: positive scalar

Default: 0.2

D-axis Current Loop

Type — D-axis current loop PID controller actions

PI (default) | PID | PIDF | ...

Specify the type of PID controller associated with the d-axis current control loop.

The controller type indicates what actions are present in the controller that regulates the loop. The following controller types are available for PID autotuning:

- P — Proportional only
- I — Integral only
- PI — Proportional and integral
- PD — Proportional and derivative
- PDF — Proportional and derivative with derivative filter
- PID — Proportional, integral, and derivative
- PIDF — Proportional, integral, and derivative with derivative filter

Make sure the controller type matches the controller that regulates the loop.

Programmatic Use

Block Parameter: PIDTypeDaxis

Type: character vector

Values: 'P' | 'I' | 'PI' | 'PD' | 'PDF' | 'PID' | 'PIDF'

Default: 'PI'

Form — D-axis current loop PID controller form

Parallel (default) | Ideal

Specify the PID controller form associated with your d-axis current control loop.

The controller form determines the interpretation of the PID coefficients P , I , D , and N .

- **Parallel** — In **Parallel** form, the transfer function of a discrete-time PIDF controller is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

where $F_i(z)$ and $F_d(z)$ are the integrator and filter formulas (see `Integrator` method and `Filter` method).

Other controller actions amount to setting P , I , or D to zero.

- `Ideal` — In `Ideal` form, the transfer function of a discrete-time PIDF controller is

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

Other controller actions amount to setting D to zero or setting I to `Inf`. (In ideal form, the controller must have proportional action.)

Make sure the controller form matches the controller that regulates the loop.

Tunable: Yes

Programmatic Use

Block Parameter: `PIDFormDaxis`

Type: character vector

Values: `'Parallel'` | `'Ideal'`

Default: `'Parallel'`

Controller sample time (sec) — D-axis current loop PID controller sample time

0.001 (default) | positive scalar | -1

Specify the sample time of your PID controller associated with the d-axis current control loop in seconds. This parameter sets the sample time used to calculate the PID controller gains for the loop.

To perform PID tuning, the block measures frequency-response information up to a frequency of 10 times the target bandwidth. To ensure that this frequency is less than the Nyquist frequency, the target bandwidth ω_c must satisfy $\omega_c T_s \leq 0.3$, where T_s ω_c is the controller sample time that you specify with the `Controller sample time (sec)` parameter.

Make sure the controller sample time matches the controller that regulates the loop.

Tips

If you want to run the deployed block with different sample times in your application, set this parameter to -1 and put the block in a Triggered Subsystem. Then, trigger the subsystem at the desired sample time. If you do not plan to change the sample time after deployment, specify a fixed and finite sample time.

Programmatic Use

Block Parameter: `TsDaxis`

Type: scalar

Value positive scalar | -1

Default: 0.001

Integrator method — D-axis current loop controller discrete integration formula for integrator term

`Forward Euler` (default) | `Backward Euler` | `Trapezoidal`

Specify the discrete integration formula for the integrator term in your controller. In discrete time, the PID controller transfer function assumed by the block is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

in parallel form, or in ideal form,

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

For a controller sample time T_s , the **Integrator method** parameter determines the formula F_i as follows.

Integrator method	F_i
Forward Euler	$\frac{T_s}{z - 1}$
Backward Euler	$\frac{T_s z}{z - 1}$
Trapezoidal	$\frac{T_s z + 1}{2 z - 1}$

For more information about the relative advantages of each method, see the Discrete PID Controller block reference page.

Make sure the controller integrator method matches the controller that regulates the loop.

Tunable: Yes

Dependencies

This parameter is enabled when the controller includes integral action.

Programmatic Use

Block Parameter: IntegratorMethodDaxis

Type: character vector

Values: 'Forward Euler' | 'Backward Euler' | 'Trapezoidal'

Default: 'Forward Euler'

Filter method — D-axis current loop controller discrete integration formula for derivative filter term
Forward Euler (default) | Backward Euler | Trapezoidal

Specify the discrete integration formula for the derivative filter term in your controller. In discrete time, the PID controller transfer function assumed by the block is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

in parallel form, or in ideal form,

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

For a controller sample time T_s , the **Filter method** parameter determines the formula F_d as follows.

Filter method	F_d
Forward Euler	$\frac{T_s}{z-1}$
Backward Euler	$\frac{T_s z}{z-1}$
Trapezoidal	$\frac{T_s z + 1}{2 z - 1}$

For more information about the relative advantages of each method, see the Discrete PID Controller block reference page.

Make sure the controller derivative filter method matches the controller that regulates the loop.

Tunable: Yes

Dependencies

This parameter is enabled when the controller includes derivative action with a derivative filter term.

Programmatic Use

Block Parameter: FilterMethodDaxis

Type: character vector

Values: 'Forward Euler' | 'Backward Euler' | 'Trapezoidal'

Default: 'Forward Euler'

Target bandwidth (rad/sec) — D-axis current loop target crossover frequency of tuned response
100 (default) | positive scalar

The target bandwidth is the target value for the 0 dB gain crossover frequency of the tuned open-loop response CP , where P is the plant response associated with the loop, and C is the controller response. This crossover frequency roughly sets the control bandwidth. For a rise time τ seconds, a good guess for the target bandwidth is $2/\tau$ rad/sec.

To perform PID tuning, the autotuner block measures frequency-response information up to a frequency of 10 times the target bandwidth. To ensure that this frequency is less than the Nyquist frequency, the target bandwidth ω_c must satisfy $\omega_c T_s \leq 0.3$, where T_s is the controller sample time that you specify with the **Controller sample time (sec)** parameter. Because of this condition, the fastest rise time you can enforce for tuning is about $6.67T_s$. If this rise time does not meet your design goals, consider reducing T_s .

For best results, use a target bandwidth that is within about a factor of 10 of the bandwidth with the initial PID controller. To tune a controller for a larger change in bandwidth, tune incrementally using smaller changes.

To provide the target bandwidth by using an input port, on the Block tab, select **Use external source for bandwidth**.

Programmatic Use

Block Parameter: BandwidthDaxis

Type: positive scalar

Default: 100

Target phase margin (degrees) — D-axis current loop target minimum phase margin
60 (default) | scalar in range 0–90

Specify a target minimum phase margin for the tuned open-loop response associated with the d-axis current control loop at the crossover frequency.

The target phase margin reflects the desired robustness of the tuned system. Typically, choose a value in the range of about 45°-60°. In general, a higher phase margin reduces overshoot, but can limit the response speed. The default value 60° tends to balance performance and robustness, yielding about 5-10% overshoot, depending on the characteristics of your plant.

To provide the target phase margin by using an input port, on the Block tab, select **Use external source for target phase margins**.

Tunable: Yes

Programmatic Use

Block Parameter: TargetPMDaxis

Type: scalar

Values: 0-90

Default: 60

Q-axis Current Loop

Type — Q-axis current loop PID controller actions

PI (default) | PID | PIDF | ...

Specify the type of PID controller associated with the q-axis current control loop.

The controller type indicates what actions are present in the controller that regulates the loop. The following controller types are available for PID autotuning:

- P — Proportional only
- I — Integral only
- PI — Proportional and integral
- PD — Proportional and derivative
- PDF — Proportional and derivative with derivative filter
- PID — Proportional, integral, and derivative
- PIDF — Proportional, integral, and derivative with derivative filter

Make sure the controller type matches the controller that regulates the loop.

Programmatic Use

Block Parameter: PIDTypeQaxis

Type: character vector

Values: 'P' | 'I' | 'PI' | 'PD' | 'PDF' | 'PID' | 'PIDF'

Default: 'PI'

Form — Q-axis current loop PID controller form

Parallel (default) | Ideal

Specify the PID controller form associated with your q-axis current control loop.

The controller form determines the interpretation of the PID coefficients P , I , D , and N .

- **Parallel** — In **Parallel** form, the transfer function of a discrete-time PIDF controller is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

where $F_i(z)$ and $F_d(z)$ are the integrator and filter formulas (see `Integrator` method and `Filter` method).

Other controller actions amount to setting P , I , or D to zero.

- **Ideal** — In `Ideal` form, the transfer function of a discrete-time PIDF controller is

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

Other controller actions amount to setting D to zero or setting I to `Inf`. (In ideal form, the controller must have proportional action.)

Make sure the controller form matches the controller that regulates the loop.

Tunable: Yes

Programmatic Use

Block Parameter: `PIDFormQaxis`

Type: character vector

Values: `'Parallel'` | `'Ideal'`

Default: `'Parallel'`

Controller sample time (sec) — Q-axis current loop PID controller sample time

0.001 (default) | positive scalar | -1

Specify the sample time of your PID controller associated with the q-axis current control loop in seconds. This parameter sets the sample time used to calculate the PID controller gains for the loop.

To perform PID tuning, the block measures frequency-response information up to a frequency of 10 times the target bandwidth. To ensure that this frequency is less than the Nyquist frequency, the target bandwidth ω_c must satisfy $\omega_c T_s \leq 0.3$, where T_s ω_c is the controller sample time that you specify with the `Controller sample time (sec)` parameter.

Make sure the controller sample time matches the controller that regulates the loop.

Tips

If you want to run the deployed block with different sample times in your application, set this parameter to -1 and put the block in a `Triggered Subsystem`. Then, trigger the subsystem at the desired sample time. If you do not plan to change the sample time after deployment, specify a fixed and finite sample time.

Programmatic Use

Block Parameter: `TsQaxis`

Type: scalar

Value positive scalar | -1

Default: 0.001

Integrator method — Q-axis current loop controller discrete integration formula for integrator term

`Forward Euler` (default) | `Backward Euler` | `Trapezoidal`

Specify the discrete integration formula for the integrator term in your controller. In discrete time, the PID controller transfer function assumed by the block is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

in parallel form, or in ideal form,

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

For a controller sample time T_s , the **Integrator** method parameter determines the formula F_i as follows.

Integrator method	F_i
Forward Euler	$\frac{T_s}{z - 1}$
Backward Euler	$\frac{T_s z}{z - 1}$
Trapezoidal	$\frac{T_s z + 1}{2 z - 1}$

For more information about the relative advantages of each method, see the Discrete PID Controller block reference page.

Make sure the controller integrator method matches the controller that regulates the loop.

Tunable: Yes

Dependencies

This parameter is enabled when the controller includes integral action.

Programmatic Use

Block Parameter: IntegratorMethodQaxis

Type: character vector

Values: 'Forward Euler' | 'Backward Euler' | 'Trapezoidal'

Default: 'Forward Euler'

Filter method — Q-axis current loop controller discrete integration formula for derivative filter term

Forward Euler (default) | Backward Euler | Trapezoidal

Specify the discrete integration formula for the derivative filter term in your controller. In discrete time, the PID controller transfer function assumed by the block is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

in parallel form, or in ideal form,

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

For a controller sample time T_s , the **Filter** method parameter determines the formula F_d as follows.

Filter method	F_d
Forward Euler	$\frac{T_s}{z-1}$
Backward Euler	$\frac{T_s z}{z-1}$
Trapezoidal	$\frac{T_s z + 1}{2 z - 1}$

For more information about the relative advantages of each method, see the Discrete PID Controller block reference page.

Make sure the controller derivative filter method matches the controller that regulates the loop.

Tunable: Yes

Dependencies

This parameter is enabled when the controller includes derivative action with a derivative filter term.

Programmatic Use

Block Parameter: FilterMethodQaxis

Type: character vector

Values: 'Forward Euler' | 'Backward Euler' | 'Trapezoidal'

Default: 'Forward Euler'

Target bandwidth (rad/sec) — Q-axis current loop target crossover frequency of tuned response
100 (default) | positive scalar

The target bandwidth is the target value for the 0 dB gain crossover frequency of the tuned open-loop response CP , where P is the plant response associated with the loop, and C is the controller response. This crossover frequency roughly sets the control bandwidth. For a rise time τ seconds, a good guess for the target bandwidth is $2/\tau$ rad/sec.

To perform PID tuning, the autotuner block measures frequency-response information up to a frequency of 10 times the target bandwidth. To ensure that this frequency is less than the Nyquist frequency, the target bandwidth ω_c must satisfy $\omega_c T_s \leq 0.3$, where T_s is the controller sample time that you specify with the **Controller sample time (sec)** parameter. Because of this condition, the fastest rise time you can enforce for tuning is about $6.67T_s$. If this rise time does not meet your design goals, consider reducing T_s .

For best results, use a target bandwidth that is within about a factor of 10 of the bandwidth with the initial PID controller. To tune a controller for a larger change in bandwidth, tune incrementally using smaller changes.

To provide the target bandwidth by using an input port, on the Block tab, select **Use external source for bandwidth**.

Programmatic Use

Block Parameter: BandwidthQaxis

Type: positive scalar

Default: 100

Target phase margin (degrees) — Q-axis current loop target minimum phase margin
60 (default) | scalar in range 0–90

Specify a target minimum phase margin for the tuned open-loop response associated with the q-axis current control loop at the crossover frequency.

The target phase margin reflects the desired robustness of the tuned system. Typically, choose a value in the range of about 45°-60°. In general, a higher phase margin reduces overshoot, but can limit the response speed. The default value 60° tends to balance performance and robustness, yielding about 5-10% overshoot, depending on the characteristics of your plant.

To provide the target phase margin by using an input port, on the Block tab, select **Use external source for target phase margins**.

Tunable: Yes

Programmatic Use

Block Parameter: TargetPMQaxis

Type: scalar

Values: 0-90

Default: 60

Speed Loop

Type — Speed loop PID controller actions

PI (default) | PID | PIDF | ...

Specify the type of PID controller associated with the speed control loop.

The controller type indicates what actions are present in the controller that regulates the loop. The following controller types are available for PID autotuning:

- P — Proportional only
- I — Integral only
- PI — Proportional and integral
- PD — Proportional and derivative
- PDF — Proportional and derivative with derivative filter
- PID — Proportional, integral, and derivative
- PIDF — Proportional, integral, and derivative with derivative filter

Make sure the controller type matches the controller that regulates the loop.

Programmatic Use

Block Parameter: PIDTypeSpeed

Type: character vector

Values: 'P' | 'I' | 'PI' | 'PD' | 'PDF' | 'PID' | 'PIDF'

Default: 'PI'

Form — Speed loop PID controller form

Parallel (default) | Ideal

Specify the PID controller form associated with your speed control loop.

The controller form determines the interpretation of the PID coefficients P , I , D , and N .

- `Parallel` — In `Parallel` form, the transfer function of a discrete-time PIDF controller is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

where $F_i(z)$ and $F_d(z)$ are the integrator and filter formulas (see `Integrator` method and `Filter` method).

Other controller actions amount to setting P , I , or D to zero.

- **Ideal** — In `Ideal` form, the transfer function of a discrete-time PIDF controller is

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

Other controller actions amount to setting D to zero or setting I to `Inf`. (In ideal form, the controller must have proportional action.)

Make sure the controller form matches the controller that regulates the loop.

Tunable: Yes

Programmatic Use

Block Parameter: `PIDFormSpeed`

Type: character vector

Values: `'Parallel'` | `'Ideal'`

Default: `'Parallel'`

Controller sample time (sec) — Speed loop PID controller sample time

0.1 (default) | positive scalar | -1

Specify the sample time of your PID controller associated with the speed control loop in seconds. This parameter sets the sample time used to calculate the PID controller gains for the loop.

To perform PID tuning, the block measures frequency-response information up to a frequency of 10 times the target bandwidth. To ensure that this frequency is less than the Nyquist frequency, the target bandwidth ω_c must satisfy $\omega_c T_s \leq 0.3$, where T_s ω_c is the controller sample time that you specify with the `Controller sample time (sec)` parameter.

Make sure the controller sample time matches the controller that regulates the loop.

Tips

If you want to run the deployed block with different sample times in your application, set this parameter to -1 and put the block in a `Triggered Subsystem`. Then, trigger the subsystem at the desired sample time. If you do not plan to change the sample time after deployment, specify a fixed and finite sample time.

Programmatic Use

Block Parameter: `TsSpeed`

Type: scalar

Value positive scalar | -1

Default: 0.1

Integrator method — Speed loop controller discrete integration formula for integrator term

`Forward Euler` (default) | `Backward Euler` | `Trapezoidal`

Specify the discrete integration formula for the integrator term in your controller. In discrete time, the PID controller transfer function assumed by the block is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

in parallel form, or in ideal form,

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

For a controller sample time T_s , the **Integrator** method parameter determines the formula F_i as follows.

Integrator method	F_i
Forward Euler	$\frac{T_s}{z - 1}$
Backward Euler	$\frac{T_s z}{z - 1}$
Trapezoidal	$\frac{T_s z + 1}{2 z - 1}$

For more information about the relative advantages of each method, see the Discrete PID Controller block reference page.

Make sure the controller integrator method matches the controller that regulates the loop.

Tunable: Yes

Dependencies

This parameter is enabled when the controller includes integral action.

Programmatic Use

Block Parameter: IntegratorMethodSpeed

Type: character vector

Values: 'Forward Euler' | 'Backward Euler' | 'Trapezoidal'

Default: 'Forward Euler'

Filter method — Speed loop controller discrete integration formula for derivative filter term

Forward Euler (default) | Backward Euler | Trapezoidal

Specify the discrete integration formula for the derivative filter term in your controller. In discrete time, the PID controller transfer function assumed by the block is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

in parallel form, or in ideal form,

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

For a controller sample time T_s , the **Filter** method parameter determines the formula F_d as follows.

Filter method	F_d
Forward Euler	$\frac{T_s}{z-1}$
Backward Euler	$\frac{T_s z}{z-1}$
Trapezoidal	$\frac{T_s z + 1}{2 z - 1}$

For more information about the relative advantages of each method, see the Discrete PID Controller block reference page.

Make sure the controller derivative filter method matches the controller that regulates the loop.

Tunable: Yes

Dependencies

This parameter is enabled when the controller includes derivative action with a derivative filter term.

Programmatic Use

Block Parameter: FilterMethodSpeed

Type: character vector

Values: 'Forward Euler' | 'Backward Euler' | 'Trapezoidal'

Default: 'Forward Euler'

Target bandwidth (rad/sec) — Speed loop target crossover frequency of tuned response
1 (default) | positive scalar

The target bandwidth is the target value for the 0 dB gain crossover frequency of the tuned open-loop response CP , where P is the plant response associated with the loop, and C is the controller response. This crossover frequency roughly sets the control bandwidth. For a rise time τ seconds, a good guess for the target bandwidth is $2/\tau$ rad/sec.

To perform PID tuning, the autotuner block measures frequency-response information up to a frequency of 10 times the target bandwidth. To ensure that this frequency is less than the Nyquist frequency, the target bandwidth ω_c must satisfy $\omega_c T_s \leq 0.3$, where T_s is the controller sample time that you specify with the **Controller sample time (sec)** parameter. Because of this condition, the fastest rise time you can enforce for tuning is about $6.67T_s$. If this rise time does not meet your design goals, consider reducing T_s .

For best results, use a target bandwidth that is within about a factor of 10 of the bandwidth with the initial PID controller. To tune a controller for a larger change in bandwidth, tune incrementally using smaller changes.

To provide the target bandwidth by using an input port, on the Block tab, select **Use external source for bandwidth**.

Programmatic Use

Block Parameter: BandwidthSpeed

Type: positive scalar

Default: 1

Target phase margin (degrees) — Speed loop target minimum phase margin
60 (default) | scalar in range 0–90

Specify a target minimum phase margin for the tuned open-loop response associated with the speed control loop at the crossover frequency.

The target phase margin reflects the desired robustness of the tuned system. Typically, choose a value in the range of about 45°–60°. In general, a higher phase margin reduces overshoot, but can limit the response speed. The default value 60° tends to balance performance and robustness, yielding about 5–10% overshoot, depending on the characteristics of your plant.

To provide the target phase margin by using an input port, on the Block tab, select **Use external source for target phase margins**.

Tunable: Yes

Programmatic Use

Block Parameter: TargetPMSpeed

Type: scalar

Values: 0–90

Default: 60

Flux Loop

Type — Flux loop PID controller actions

PI (default) | PID | PIDF | ...

Specify the type of PID controller associated with the flux control loop.

The controller type indicates what actions are present in the controller that regulates the loop. The following controller types are available for PID autotuning:

- P — Proportional only
- I — Integral only
- PI — Proportional and integral
- PD — Proportional and derivative
- PDF — Proportional and derivative with derivative filter
- PID — Proportional, integral, and derivative
- PIDF — Proportional, integral, and derivative with derivative filter

Make sure the controller type matches the controller that regulates the loop.

Programmatic Use

Block Parameter: PIDTypeFlux

Type: character vector

Values: 'P' | 'I' | 'PI' | 'PD' | 'PDF' | 'PID' | 'PIDF'

Default: 'PI'

Form — Flux loop PID controller form

Parallel (default) | Ideal

Specify the PID controller form associated with your flux control loop.

The controller form determines the interpretation of the PID coefficients P , I , D , and N .

- `Parallel` — In `Parallel` form, the transfer function of a discrete-time PIDF controller is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

where $F_i(z)$ and $F_d(z)$ are the integrator and filter formulas (see `Integrator` method and `Filter` method).

Other controller actions amount to setting P , I , or D to zero.

- **Ideal** — In `Ideal` form, the transfer function of a discrete-time PIDF controller is

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

Other controller actions amount to setting D to zero or setting I to `Inf`. (In ideal form, the controller must have proportional action.)

Make sure the controller form matches the controller that regulates the loop.

Tunable: Yes

Programmatic Use

Block Parameter: `PIDFormFlux`

Type: character vector

Values: `'Parallel'` | `'Ideal'`

Default: `'Parallel'`

Controller sample time (sec) — Flux loop PID controller sample time

0.1 (default) | positive scalar | -1

Specify the sample time of your PID controller associated with the flux control loop in seconds. This parameter sets the sample time used to calculate the PID controller gains for the loop.

To perform PID tuning, the block measures frequency-response information up to a frequency of 10 times the target bandwidth. To ensure that this frequency is less than the Nyquist frequency, the target bandwidth ω_c must satisfy $\omega_c T_s \leq 0.3$, where T_s ω_c is the controller sample time that you specify with the `Controller sample time (sec)` parameter.

Make sure the controller sample time matches the controller that regulates the loop.

Tips

If you want to run the deployed block with different sample times in your application, set this parameter to -1 and put the block in a `Triggered Subsystem`. Then, trigger the subsystem at the desired sample time. If you do not plan to change the sample time after deployment, specify a fixed and finite sample time.

Programmatic Use

Block Parameter: `TsFlux`

Type: scalar

Value positive scalar | -1

Default: 0.1

Integrator method — Flux loop controller discrete integration formula for integrator term

`Forward Euler` (default) | `Backward Euler` | `Trapezoidal`

Specify the discrete integration formula for the integrator term in your controller. In discrete time, the PID controller transfer function assumed by the block is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

in parallel form, or in ideal form,

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

For a controller sample time T_s , the **Integrator** method parameter determines the formula F_i as follows.

Integrator method	F_i
Forward Euler	$\frac{T_s}{z - 1}$
Backward Euler	$\frac{T_s z}{z - 1}$
Trapezoidal	$\frac{T_s z + 1}{2 z - 1}$

For more information about the relative advantages of each method, see the Discrete PID Controller block reference page.

Make sure the controller integrator method matches the controller that regulates the loop.

Tunable: Yes

Dependencies

This parameter is enabled when the controller includes integral action.

Programmatic Use

Block Parameter: IntegratorMethodFlux

Type: character vector

Values: 'Forward Euler' | 'Backward Euler' | 'Trapezoidal'

Default: 'Forward Euler'

Filter method — Flux loop controller discrete integration formula for derivative filter term

Forward Euler (default) | Backward Euler | Trapezoidal

Specify the discrete integration formula for the derivative filter term in your controller. In discrete time, the PID controller transfer function assumed by the block is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

in parallel form, or in ideal form,

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

For a controller sample time T_s , the **Filter** method parameter determines the formula F_d as follows.

Filter method	F_d
Forward Euler	$\frac{T_s}{z-1}$
Backward Euler	$\frac{T_s z}{z-1}$
Trapezoidal	$\frac{T_s z + 1}{2 z - 1}$

For more information about the relative advantages of each method, see the Discrete PID Controller block reference page.

Make sure the controller derivative filter method matches the controller that regulates the loop.

Tunable: Yes

Dependencies

This parameter is enabled when the controller includes derivative action with a derivative filter term.

Programmatic Use

Block Parameter: FilterMethodFlux

Type: character vector

Values: 'Forward Euler' | 'Backward Euler' | 'Trapezoidal'

Default: 'Forward Euler'

Target bandwidth (rad/sec) — Flux loop target crossover frequency of tuned response
1 (default) | positive scalar

The target bandwidth is the target value for the 0 dB gain crossover frequency of the tuned open-loop response CP , where P is the plant response associated with the loop, and C is the controller response. This crossover frequency roughly sets the control bandwidth. For a rise time τ seconds, a good guess for the target bandwidth is $2/\tau$ rad/sec.

To perform PID tuning, the autotuner block measures frequency-response information up to a frequency of 10 times the target bandwidth. To ensure that this frequency is less than the Nyquist frequency, the target bandwidth ω_c must satisfy $\omega_c T_s \leq 0.3$, where T_s is the controller sample time that you specify with the **Controller sample time (sec)** parameter. Because of this condition, the fastest rise time you can enforce for tuning is about $6.67T_s$. If this rise time does not meet your design goals, consider reducing T_s .

For best results, use a target bandwidth that is within about a factor of 10 of the bandwidth with the initial PID controller. To tune a controller for a larger change in bandwidth, tune incrementally using smaller changes.

To provide the target bandwidth by using an input port, on the Block tab, select **Use external source for bandwidth**.

Programmatic Use

Block Parameter: BandwidthFlux

Type: positive scalar

Default: 1

Target phase margin (degrees) — Flux loop target minimum phase margin
60 (default) | scalar in range 0–90

Specify a target minimum phase margin for the tuned open-loop response associated with the flux control loop at the crossover frequency.

The target phase margin reflects the desired robustness of the tuned system. Typically, choose a value in the range of about 45°–60°. In general, a higher phase margin reduces overshoot, but can limit the response speed. The default value 60° tends to balance performance and robustness, yielding about 5–10% overshoot, depending on the characteristics of your plant.

To provide the target phase margin by using an input port, on the Block tab, select **Use external source for target phase margins**.

Tunable: Yes

Programmatic Use

Block Parameter: TargetPMFlux

Type: scalar

Values: 0–90

Default: 60

Current Loops (Q-axis + D-axis)

Type — Current loop PID controller actions

PI (default) | PID | PIDF | ...

Specify the type of PID controller associated with the current control loops.

The controller type indicates what actions are present in the controller that regulates the loop. The following controller types are available for PID autotuning:

- P — Proportional only
- I — Integral only
- PI — Proportional and integral
- PD — Proportional and derivative
- PDF — Proportional and derivative with derivative filter
- PID — Proportional, integral, and derivative
- PIDF — Proportional, integral, and derivative with derivative filter

Make sure the controller type matches the controller that regulates the loop.

Programmatic Use

Block Parameter: PIDTypeAllInner

Type: character vector

Values: 'P' | 'I' | 'PI' | 'PD' | 'PDF' | 'PID' | 'PIDF'

Default: 'PI'

Form — Current loop PID controller form

Parallel (default) | Ideal

Specify the PID controller form associated with your current control loops.

The controller form determines the interpretation of the PID coefficients P , I , D , and N .

- `Parallel` — In `Parallel` form, the transfer function of a discrete-time PIDF controller is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

where $F_i(z)$ and $F_d(z)$ are the integrator and filter formulas (see `Integrator` method and `Filter` method).

Other controller actions amount to setting P , I , or D to zero.

- **Ideal** — In `Ideal` form, the transfer function of a discrete-time PIDF controller is

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

Other controller actions amount to setting D to zero or setting I to `Inf`. (In ideal form, the controller must have proportional action.)

Make sure the controller form matches the controller that regulates the loop.

Tunable: Yes

Programmatic Use

Block Parameter: `PIDFormAllInner`

Type: character vector

Values: `'Parallel'` | `'Ideal'`

Default: `'Parallel'`

Controller sample time (sec) — Current loop PID controller sample time

0.001 (default) | positive scalar | -1

Specify the sample time of your PID controllers associated with the current control loops in seconds. This parameter sets the sample time used to calculate the PID controller gains for the loop.

To perform PID tuning, the block measures frequency-response information up to a frequency of 10 times the target bandwidth. To ensure that this frequency is less than the Nyquist frequency, the target bandwidth ω_c must satisfy $\omega_c T_s \leq 0.3$, where T_s ω_c is the controller sample time that you specify with the `Controller sample time (sec)` parameter.

Make sure the controller sample time matches the controller that regulates the loop.

Tips

If you want to run the deployed block with different sample times in your application, set this parameter to -1 and put the block in a `Triggered Subsystem`. Then, trigger the subsystem at the desired sample time. If you do not plan to change the sample time after deployment, specify a fixed and finite sample time.

Programmatic Use

Block Parameter: `TsAllInner`

Type: scalar

Value positive scalar | -1

Default: 0.001

Integrator method — Current loop controller discrete integration formula for integrator term

`Forward Euler` (default) | `Backward Euler` | `Trapezoidal`

Specify the discrete integration formula for the integrator term in your controller. In discrete time, the PID controller transfer function assumed by the block is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

in parallel form, or in ideal form,

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

For a controller sample time T_s , the **Integrator** method parameter determines the formula F_i as follows.

Integrator method	F_i
Forward Euler	$\frac{T_s}{z - 1}$
Backward Euler	$\frac{T_s z}{z - 1}$
Trapezoidal	$\frac{T_s z + 1}{2 z - 1}$

For more information about the relative advantages of each method, see the Discrete PID Controller block reference page.

Make sure the controller integrator method matches the controller that regulates the loop.

Tunable: Yes

Dependencies

This parameter is enabled when the controller includes integral action.

Programmatic Use

Block Parameter: IntegratorMethodAllInner

Type: character vector

Values: 'Forward Euler' | 'Backward Euler' | 'Trapezoidal'

Default: 'Forward Euler'

Filter method — Current loop controller discrete integration formula for derivative filter term

Forward Euler (default) | Backward Euler | Trapezoidal

Specify the discrete integration formula for the derivative filter term in your controller. In discrete time, the PID controller transfer function assumed by the block is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

in parallel form, or in ideal form,

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

For a controller sample time T_s , the **Filter** method parameter determines the formula F_d as follows.

Filter method	F_d
Forward Euler	$\frac{T_s}{z-1}$
Backward Euler	$\frac{T_s z}{z-1}$
Trapezoidal	$\frac{T_s z + 1}{2 z - 1}$

For more information about the relative advantages of each method, see the Discrete PID Controller block reference page.

Make sure the controller derivative filter method matches the controller that regulates the loop.

Tunable: Yes

Dependencies

This parameter is enabled when the controller includes derivative action with a derivative filter term.

Programmatic Use

Block Parameter: FilterMethodAllInner

Type: character vector

Values: 'Forward Euler' | 'Backward Euler' | 'Trapezoidal'

Default: 'Forward Euler'

Target bandwidth (rad/sec) — Current loop target crossover frequency of tuned responses
100 (default) | positive scalar

The target bandwidth is the target value for the 0 dB gain crossover frequency of the tuned open-loop response CP , where P is the plant response associated with the loop, and C is the controller response. This crossover frequency roughly sets the control bandwidth. For a rise time τ seconds, a good guess for the target bandwidth is $2/\tau$ rad/sec.

To perform PID tuning, the autotuner block measures frequency-response information up to a frequency of 10 times the target bandwidth. To ensure that this frequency is less than the Nyquist frequency, the target bandwidth ω_c must satisfy $\omega_c T_s \leq 0.3$, where T_s is the controller sample time that you specify with the **Controller sample time (sec)** parameter. Because of this condition, the fastest rise time you can enforce for tuning is about $6.67T_s$. If this rise time does not meet your design goals, consider reducing T_s .

For best results, use a target bandwidth that is within about a factor of 10 of the bandwidth with the initial PID controller. To tune a controller for a larger change in bandwidth, tune incrementally using smaller changes.

To provide the target bandwidth by using an input port, on the Block tab, select **Use external source for bandwidth**.

Programmatic Use

Block Parameter: BandwidthAllInner

Type: positive scalar

Default: 1

Target phase margin (degrees) — Current loop target minimum phase margins
60 (default) | scalar in range 0–90

Specify target minimum phase margin for the tuned open-loop responses associated with the current control loops at the crossover frequency.

The target phase margin reflects the desired robustness of the tuned system. Typically, choose a value in the range of about 45°–60°. In general, a higher phase margin reduces overshoot, but can limit the response speed. The default value 60° tends to balance performance and robustness, yielding about 5–10% overshoot, depending on the characteristics of your plant.

To provide the target phase margin by using an input port, on the Block tab, select **Use external source for target phase margins**.

Tunable: Yes

Programmatic Use

Block Parameter: TargetPMAAllInner

Type: scalar

Values: 0–90

Default: 60

Outer Loops (Speed + Flux)

Type — Outer loop PID controller actions

PI (default) | PID | PIDF | ...

Specify the type of PID controllers associated with the outer control loops.

The controller type indicates what actions are present in the controller that regulates the loop. The following controller types are available for PID autotuning:

- P — Proportional only
- I — Integral only
- PI — Proportional and integral
- PD — Proportional and derivative
- PDF — Proportional and derivative with derivative filter
- PID — Proportional, integral, and derivative
- PIDF — Proportional, integral, and derivative with derivative filter

Make sure the controller type matches the controller that regulates the loop.

Programmatic Use

Block Parameter: PIDTypeAllOuter

Type: character vector

Values: 'P' | 'I' | 'PI' | 'PD' | 'PDF' | 'PID' | 'PIDF'

Default: 'PI'

Form — Outer loop PID controller form

Parallel (default) | Ideal

Specify the PID controller form associated with your outer control loops.

The controller form determines the interpretation of the PID coefficients P , I , D , and N .

- **Parallel** — In **Parallel** form, the transfer function of a discrete-time PIDF controller is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

where $F_i(z)$ and $F_d(z)$ are the integrator and filter formulas (see `Integrator` method and `Filter` method).

Other controller actions amount to setting P , I , or D to zero.

- **Ideal** — In `Ideal` form, the transfer function of a discrete-time PIDF controller is

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

Other controller actions amount to setting D to zero or setting I to `Inf`. (In ideal form, the controller must have proportional action.)

Make sure the controller form matches the controller that regulates the loop.

Tunable: Yes

Programmatic Use

Block Parameter: `PIDFormAllOuter`

Type: character vector

Values: `'Parallel'` | `'Ideal'`

Default: `'Parallel'`

Controller sample time (sec) — Outer loop PID controller sample time

0.1 (default) | positive scalar | -1

Specify the sample time of your PID controllers associated with the outer control loop in seconds. This parameter sets the sample time used to calculate the PID controller gains for the loop.

To perform PID tuning, the block measures frequency-response information up to a frequency of 10 times the target bandwidth. To ensure that this frequency is less than the Nyquist frequency, the target bandwidth ω_c must satisfy $\omega_c T_s \leq 0.3$, where T_s ω_c is the controller sample time that you specify with the `Controller sample time (sec)` parameter.

Make sure the controller sample time matches the controller that regulates the loop.

Tips

If you want to run the deployed block with different sample times in your application, set this parameter to -1 and put the block in a `Triggered Subsystem`. Then, trigger the subsystem at the desired sample time. If you do not plan to change the sample time after deployment, specify a fixed and finite sample time.

Programmatic Use

Block Parameter: `TsAllOuter`

Type: scalar

Value positive scalar | -1

Default: 0.1

Integrator method — Outer loop controller discrete integration formula for integrator term

`Forward Euler` (default) | `Backward Euler` | `Trapezoidal`

Specify the discrete integration formula for the integrator term in your controller. In discrete time, the PID controller transfer function assumed by the block is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

in parallel form, or in ideal form,

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

For a controller sample time T_s , the **Integrator** method parameter determines the formula F_i as follows.

Integrator method	F_i
Forward Euler	$\frac{T_s}{z - 1}$
Backward Euler	$\frac{T_s z}{z - 1}$
Trapezoidal	$\frac{T_s z + 1}{2 z - 1}$

For more information about the relative advantages of each method, see the Discrete PID Controller block reference page.

Make sure the controller integrator method matches the controller that regulates the loop.

Tunable: Yes

Dependencies

This parameter is enabled when the controller includes integral action.

Programmatic Use

Block Parameter: IntegratorMethodAllOuter

Type: character vector

Values: 'Forward Euler' | 'Backward Euler' | 'Trapezoidal'

Default: 'Forward Euler'

Filter method — Outer loop controller discrete integration formula for derivative filter term

Forward Euler (default) | Backward Euler | Trapezoidal

Specify the discrete integration formula for the derivative filter term in your controller. In discrete time, the PID controller transfer function assumed by the block is

$$C = P + IF_i(z) + D \left[\frac{N}{1 + NF_d(z)} \right],$$

in parallel form, or in ideal form,

$$C = P \left[1 + IF_i(z) + D \left(\frac{N}{1 + NF_d(z)} \right) \right].$$

For a controller sample time T_s , the **Filter** method parameter determines the formula F_d as follows.

Filter method	F_d
Forward Euler	$\frac{T_s}{z-1}$
Backward Euler	$\frac{T_s z}{z-1}$
Trapezoidal	$\frac{T_s z + 1}{2 z - 1}$

For more information about the relative advantages of each method, see the Discrete PID Controller block reference page.

Make sure the controller derivative filter method matches the controller that regulates the loop.

Tunable: Yes

Dependencies

This parameter is enabled when the controller includes derivative action with a derivative filter term.

Programmatic Use

Block Parameter: FilterMethodAllOuter

Type: character vector

Values: 'Forward Euler' | 'Backward Euler' | 'Trapezoidal'

Default: 'Forward Euler'

Target bandwidth (rad/sec) — Outer loop target crossover frequency of tuned responses
1 (default) | positive scalar

The target bandwidth is the target value for the 0 dB gain crossover frequency of the tuned open-loop response CP , where P is the plant response associated with the loop, and C is the controller response. This crossover frequency roughly sets the control bandwidth. For a rise time τ seconds, a good guess for the target bandwidth is $2/\tau$ rad/sec.

To perform PID tuning, the autotuner block measures frequency-response information up to a frequency of 10 times the target bandwidth. To ensure that this frequency is less than the Nyquist frequency, the target bandwidth ω_c must satisfy $\omega_c T_s \leq 0.3$, where T_s is the controller sample time that you specify with the **Controller sample time (sec)** parameter. Because of this condition, the fastest rise time you can enforce for tuning is about $6.67T_s$. If this rise time does not meet your design goals, consider reducing T_s .

For best results, use a target bandwidth that is within about a factor of 10 of the bandwidth with the initial PID controller. To tune a controller for a larger change in bandwidth, tune incrementally using smaller changes.

To provide the target bandwidth by using an input port, on the Block tab, select **Use external source for bandwidth**.

Programmatic Use

Block Parameter: BandwidthAllOuter

Type: positive scalar

Default: 1

Target phase margin (degrees) — Outer loop target minimum phase margins
60 (default) | scalar in range 0–90

Specify a target minimum phase margin for the tuned open-loop responses associated with the outer control loops at the crossover frequency.

The target phase margin reflects the desired robustness of the tuned system. Typically, choose a value in the range of about 45°–60°. In general, a higher phase margin reduces overshoot, but can limit the response speed. The default value 60° tends to balance performance and robustness, yielding about 5–10% overshoot, depending on the characteristics of your plant.

To provide the target phase margin by using an input port, on the Block tab, select **Use external source for target phase margins**.

Tunable: Yes

Programmatic Use

Block Parameter: TargetPMAllOuter

Type: scalar

Values: 0–90

Default: 60

Experiment Tab

Experiment Start/Stop

D-axis current loop start time (sec) — Specify direct-axis current loop tuning experiment start time
1 (default)

Specify the simulation time when the d-axis current loop tuning experiment starts.

Programmatic Use

Block Parameter: StartTimeDaxis

Type: positive scalar

Default: 1

D-axis current loop experiment duration (sec) — Specify direct-axis current loop tuning experiment duration
0.05 (default)

Specify the d-axis current loop tuning experiment duration.

Programmatic Use

Block Parameter: DurationDaxis

Type: positive scalar

Default: 0.05

Q-axis current loop start time (sec) — Specify quadrature-axis current loop tuning experiment start time
1.1 (default)

Specify the simulation time when the q-axis current loop tuning experiment starts.

Programmatic Use

Block Parameter: StartTimeQaxis

Type: positive scalar

Default: 1.1

Q-axis current loop experiment duration (sec) — Specify quadrature-axis current loop tuning experiment duration
0.05 (default)

Specify the q-axis current loop tuning experiment duration.

Programmatic Use

Block Parameter: DurationQaxis

Type: positive scalar

Default: 0.05

Speed loop start time (sec) — Specify speed loop tuning experiment start time
2 (default)

Specify the simulation time when the speed loop tuning experiment starts.

Programmatic Use

Block Parameter: StartTimeSpeed

Type: positive scalar

Default: 2

Speed loop experiment duration (sec) — Specify speed loop tuning experiment duration
3 (default)

Specify the speed loop tuning experiment duration.

Programmatic Use

Block Parameter: DurationSpeed

Type: positive scalar

Default: 3

Flux loop start time (sec) — Specify flux loop tuning experiment start time
6 (default)

Specify the simulation time when the flux tuning experiment starts.

Programmatic Use

Block Parameter: StartTimeFlux

Type: positive scalar

Default: 6

Flux loop experiment duration (sec) — Specify flux loop tuning experiment duration
3 (default)

Specify the flux loop tuning experiment duration.

Programmatic Use

Block Parameter: DurationFlux

Type: positive scalar

Default: 3

Loop Experiment Settings

Experiment Mode — Sinusoidal perturbation signal type
Superposition (default) | Sinestream

Specify whether the perturbation at each frequency is applied sequentially (**Sinestream**) or simultaneously (**Superposition**).

- **Sinestream** — In this mode, the block applies perturbation at each frequency separately. For more information about sinestream signals for estimation, see “Sinestream Input Signals” (Simulink Control Design).
- **Superposition** — In this mode, the perturbation signal includes all specified frequencies at once. For frequency response estimation at a vector of frequencies $\omega = [\omega_1, \dots, \omega_N]$ at amplitudes $A = [A_1, \dots, A_N]$, the perturbation signal is:

$$\Delta u = \sum_i A_i \sin(\omega_i t).$$

Sinestream mode can be more accurate and can also be less intrusive, because the total size of the perturbation is never bigger than the values specified by the **Sine Amplitudes** parameter. However, due to the sequential nature of the sinestream perturbation, each frequency point you add increases the recommended experiment time (see the **start/stop** input port for details). Thus, the estimation experiment is typically much faster in **Superposition** mode with satisfactory results.

Sinestream signals reduce the execution time compared to superposition input signals, but also take longer to estimate the frequency response. Frequency response estimation using sinestream signals is useful when you have limited processing power and you want to reduce the execution time.

Programmatic Use

Block Parameter: ExperimentMode

Type: character vector

Values: 'Superposition' | 'Sinestream'

Default: 'Superposition'

D-axis Current Loop

Plant Type — Stability of direct-axis current plant

Stable (default) | Integrating

Specify whether the plant associated with the d-axis current control loop is stable or integrating. If the plant has one or more integrators, select Integrating.

Programmatic Use

Block Parameter: PlantTypeDaxis

Type: character vector

Values: 'Stable' | 'Integrating'

Default: 'Stable'

Plant Sign — Sign of direct-axis current plant

Positive (default) | Negative

Specify whether the plant associated with the d-axis current control loop is positive or negative. If a positive change in the plant input at the nominal operating point results in a positive change in the plant output, specify Positive. Otherwise, specify negative. For stable plants, the sign of the plant is the sign of the plant DC gain.

Programmatic Use

Block Parameter: PlantSignDaxis

Type: character vector

Values: 'Positive' | 'Negative'

Default: 'Positive'

Sine Amplitudes — Amplitude of sinusoidal perturbations in direct-axis current loop

1 (default) | scalar | vector of length 5

During the experiment, the block injects a sinusoidal signal into the plant associated with the loop at the frequencies $[1/10, 1/3, 1, 3, 10]\omega_c$, where ω_c is the target bandwidth for tuning. Use **Sine Amplitudes** to specify the amplitude of each of these injected signals. Specify a:

- Scalar value to inject the same amplitude at each frequency
- Vector of length 5 to specify a different amplitude at each of $[1/10, 1/3, 1, 3, 10]\omega_c$

In a typical plant with typical target bandwidth, the magnitudes of the plant responses at the experiment frequencies do not vary widely. In such cases, you can use a scalar value to apply the same magnitude perturbation at all frequencies. However, if you know that the response decays sharply over the frequency range, consider decreasing the amplitude of the lower frequency inputs and increasing the amplitude of the higher frequency inputs. It is numerically better for the estimation experiment when all the plant responses have comparable magnitudes.

The perturbation amplitudes must be:

- Large enough that the perturbation overcomes any deadband in the plant actuator and generates a response above the noise level
- Small enough to keep the plant running within the approximately linear region near the nominal operating point, and to avoid saturating the plant input or output

When **Experiment mode** is **Superposition**, the sinusoidal signals are superimposed. Thus, the perturbation can be at least as large as the sum of all amplitudes. Make sure that the largest possible perturbation is within the range of your plant actuator. Saturating the actuator can introduce errors into the estimated frequency response.

To provide the sine amplitudes by using an input port, on the Block tab, select **Use external source for sine amplitudes**.

Tunable: Yes

Programmatic Use

Block Parameter: AmpSineDaxis

Type: scalar, vector of length 5

Default: 1

Q-axis Current Loop

Plant Type — Stability of quadrature-axis current plant

Stable (default) | Integrating

Specify whether the plant associated with the q-axis current control loop is stable or integrating. If the plant has one or more integrators, select **Integrating**.

Programmatic Use

Block Parameter: PlantTypeQaxis

Type: character vector

Values: 'Stable' | 'Integrating'

Default: 'Stable'

Plant Sign — Sign of quadrature-axis current plant

Positive (default) | Negative

Specify whether the plant associated with the q-axis current control loop is positive or negative. If a positive change in the plant input at the nominal operating point results in a positive change in the plant output, specify **Positive**. Otherwise, specify negative. For stable plants, the sign of the plant is the sign of the plant DC gain.

Programmatic Use**Block Parameter:** PlantSignQaxis**Type:** character vector**Values:** 'Positive' | 'Negative'**Default:** 'Positive'**Sine Amplitudes** — Amplitude of sinusoidal perturbations in quadrature-axis current loop

1 (default) | scalar | vector of length 5

During the experiment, the block injects a sinusoidal signal into the plant associated with the loop at the frequencies $[1/10, 1/3, 1, 3, 10]\omega_c$, where ω_c is the target bandwidth for tuning. Use **Sine Amplitudes** to specify the amplitude of each of these injected signals. Specify a:

- Scalar value to inject the same amplitude at each frequency
- Vector of length 5 to specify a different amplitude at each of $[1/10, 1/3, 1, 3, 10]\omega_c$

In a typical plant with typical target bandwidth, the magnitudes of the plant responses at the experiment frequencies do not vary widely. In such cases, you can use a scalar value to apply the same magnitude perturbation at all frequencies. However, if you know that the response decays sharply over the frequency range, consider decreasing the amplitude of the lower frequency inputs and increasing the amplitude of the higher frequency inputs. It is numerically better for the estimation experiment when all the plant responses have comparable magnitudes.

The perturbation amplitudes must be:

- Large enough that the perturbation overcomes any deadband in the plant actuator and generates a response above the noise level
- Small enough to keep the plant running within the approximately linear region near the nominal operating point, and to avoid saturating the plant input or output

When **Experiment mode** is **Superposition**, the sinusoidal signals are superimposed. Thus, the perturbation can be at least as large as the sum of all amplitudes. Make sure that the largest possible perturbation is within the range of your plant actuator. Saturating the actuator can introduce errors into the estimated frequency response.

To provide the sine amplitudes by using an input port, on the Block tab, select **Use external source for sine amplitudes**.

Tunable: Yes**Programmatic Use****Block Parameter:** AmpSineQaxis**Type:** scalar, vector of length 5**Default:** 1

Speed Loop

Plant Type — Stability of speed loop plant
Stable (default) | Integrating

Specify whether the plant associated with the speed control loop is stable or integrating. If the plant has one or more integrators, select **Integrating**.

Programmatic Use

Block Parameter: PlantTypeSpeed

Type: character vector

Values: 'Stable' | 'Integrating'

Default: 'Stable'

Plant Sign — Sign of speed loop plant
Positive (default) | Negative

Specify whether the plant associated with the speed control loop is positive or negative. If a positive change in the plant input at the nominal operating point results in a positive change in the plant output, specify **Positive**. Otherwise, specify **Negative**. For stable plants, the sign of the plant is the sign of the plant DC gain.

Programmatic Use

Block Parameter: PlantSignSpeed

Type: character vector

Values: 'Positive' | 'Negative'

Default: 'Positive'

Sine Amplitudes — Amplitude of sinusoidal perturbations in speed loop
1 (default) | scalar | vector of length 5

During the experiment, the block injects a sinusoidal signal into the plant associated with the loop at the frequencies $[1/10, 1/3, 1, 3, 10]\omega_c$, where ω_c is the target bandwidth for tuning. Use **Sine Amplitudes** to specify the amplitude of each of these injected signals. Specify a:

- Scalar value to inject the same amplitude at each frequency
- Vector of length 5 to specify a different amplitude at each of $[1/10, 1/3, 1, 3, 10]\omega_c$

In a typical plant with typical target bandwidth, the magnitudes of the plant responses at the experiment frequencies do not vary widely. In such cases, you can use a scalar value to apply the same magnitude perturbation at all frequencies. However, if you know that the response decays sharply over the frequency range, consider decreasing the amplitude of the lower frequency inputs and increasing the amplitude of the higher frequency inputs. It is numerically better for the estimation experiment when all the plant responses have comparable magnitudes.

The perturbation amplitudes must be:

- Large enough that the perturbation overcomes any deadband in the plant actuator and generates a response above the noise level
- Small enough to keep the plant running within the approximately linear region near the nominal operating point, and to avoid saturating the plant input or output

When **Experiment mode** is **Superposition**, the sinusoidal signals are superimposed. Thus, the perturbation can be at least as large as the sum of all amplitudes. Make sure that the largest possible

perturbation is within the range of your plant actuator. Saturating the actuator can introduce errors into the estimated frequency response.

To provide the sine amplitudes by using an input port, on the Block tab, select **Use external source for sine amplitudes**.

Tunable: Yes

Programmatic Use

Block Parameter: AmpSineSpeed

Type: scalar, vector of length 5

Default: 1

Flux Loop

Plant Type — Stability of flux loop plant

Stable (default) | Integrating

Specify whether the plant associated with the flux control loop is stable or integrating. If the plant has one or more integrators, select **Integrating**.

Programmatic Use

Block Parameter: PlantTypeFlux

Type: character vector

Values: 'Stable' | 'Integrating'

Default: 'Stable'

Plant Sign — Sign of flux loop plant

Positive (default) | Negative

Specify whether the plant associated with the flux control loop is positive or negative. If a positive change in the plant input at the nominal operating point results in a positive change in the plant output, specify **Positive**. Otherwise, specify **negative**. For stable plants, the sign of the plant is the sign of the plant DC gain.

Programmatic Use

Block Parameter: PlantSignFlux

Type: character vector

Values: 'Positive' | 'Negative'

Default: 'Positive'

Sine Amplitudes — Amplitude of sinusoidal perturbations in flux loop

1 (default) | scalar | vector of length 5

During the experiment, the block injects a sinusoidal signal into the plant associated with the loop at the frequencies $[1/10, 1/3, 1, 3, 10]\omega_c$, where ω_c is the target bandwidth for tuning. Use **Sine Amplitudes** to specify the amplitude of each of these injected signals. Specify a:

- Scalar value to inject the same amplitude at each frequency
- Vector of length 5 to specify a different amplitude at each of $[1/10, 1/3, 1, 3, 10]\omega_c$

In a typical plant with typical target bandwidth, the magnitudes of the plant responses at the experiment frequencies do not vary widely. In such cases, you can use a scalar value to apply the same magnitude perturbation at all frequencies. However, if you know that the response decays sharply over the frequency range, consider decreasing the amplitude of the lower frequency inputs

and increasing the amplitude of the higher frequency inputs. It is numerically better for the estimation experiment when all the plant responses have comparable magnitudes.

The perturbation amplitudes must be:

- Large enough that the perturbation overcomes any deadband in the plant actuator and generates a response above the noise level
- Small enough to keep the plant running within the approximately linear region near the nominal operating point, and to avoid saturating the plant input or output

When **Experiment mode** is **Superposition**, the sinusoidal signals are superimposed. Thus, the perturbation can be at least as large as the sum of all amplitudes. Make sure that the largest possible perturbation is within the range of your plant actuator. Saturating the actuator can introduce errors into the estimated frequency response.

To provide the sine amplitudes by using an input port, on the Block tab, select **Use external source for sine amplitudes**.

Tunable: Yes

Programmatic Use

Block Parameter: AmpSineFlux

Type: scalar, vector of length 5

Default: 1

Current Loops (D-axis + Q-axis)

Plant Type — Stability of current loop plants

Stable (default) | Integrating

Specify whether the plants associated with the current control loops are stable or integrating. If the plant has one or more integrators, select Integrating.

Programmatic Use

Block Parameter: PlantTypeAllInner

Type: character vector

Values: 'Stable' | 'Integrating'

Default: 'Stable'

Plant Sign — Sign of current loop plants

Positive (default) | Negative

Specify whether the plants associated with the current control loops are positive or negative. If a positive change in the plant input at the nominal operating point results in a positive change in the plant output, specify Positive. Otherwise, specify negative. For stable plants, the sign of the plant is the sign of the plant DC gain.

Programmatic Use

Block Parameter: PlantSignAllInner

Type: character vector

Values: 'Positive' | 'Negative'

Default: 'Positive'

Sine Amplitudes — Amplitude of sinusoidal perturbations in current loops

1 (default) | scalar | vector of length 5

During the experiment, the block injects a sinusoidal signal into the plant associated with the loop at the frequencies $[1/10, 1/3, 1, 3, 10]\omega_c$, where ω_c is the target bandwidth for tuning. Use **Sine Amplitudes** to specify the amplitude of each of these injected signals. Specify a:

- Scalar value to inject the same amplitude at each frequency
- Vector of length 5 to specify a different amplitude at each of $[1/10, 1/3, 1, 3, 10]\omega_c$

In a typical plant with typical target bandwidth, the magnitudes of the plant responses at the experiment frequencies do not vary widely. In such cases, you can use a scalar value to apply the same magnitude perturbation at all frequencies. However, if you know that the response decays sharply over the frequency range, consider decreasing the amplitude of the lower frequency inputs and increasing the amplitude of the higher frequency inputs. It is numerically better for the estimation experiment when all the plant responses have comparable magnitudes.

The perturbation amplitudes must be:

- Large enough that the perturbation overcomes any deadband in the plant actuator and generates a response above the noise level
- Small enough to keep the plant running within the approximately linear region near the nominal operating point, and to avoid saturating the plant input or output

When **Experiment mode** is **Superposition**, the sinusoidal signals are superimposed. Thus, the perturbation can be at least as large as the sum of all amplitudes. Make sure that the largest possible perturbation is within the range of your plant actuator. Saturating the actuator can introduce errors into the estimated frequency response.

To provide the sine amplitudes by using an input port, on the Block tab, select **Use external source for sine amplitudes**.

Tunable: Yes

Programmatic Use

Block Parameter: AmpSineAllInner

Type: scalar, vector of length 5

Default: 1

Outer Loops (Speed + Flux)

Plant Type — Stability of outer loop plants

Stable (default) | Integrating

Specify whether the plants associated with the outer control loops are stable or integrating. If the plant has one or more integrators, select Integrating.

Programmatic Use

Block Parameter: PlantTypeAllOuter

Type: character vector

Values: 'Stable' | 'Integrating'

Default: 'Stable'

Plant Sign — Sign of outer loop plants

Positive (default) | Negative

Specify whether the plants associated with the outer control loops are positive or negative. If a positive change in the plant input at the nominal operating point results in a positive change in the

plant output, specify **Positive**. Otherwise, specify negative. For stable plants, the sign of the plant is the sign of the plant DC gain.

Programmatic Use

Block Parameter: PlantSignAllOuter

Type: character vector

Values: 'Positive' | 'Negative'

Default: 'Positive'

Sine Amplitudes — Amplitude of sinusoidal perturbations in outer loops

1 (default) | scalar | vector of length 5

During the experiment, the block injects a sinusoidal signal into the plant associated with the loop at the frequencies $[1/10, 1/3, 1, 3, 10]\omega_c$, where ω_c is the target bandwidth for tuning. Use **Sine Amplitudes** to specify the amplitude of each of these injected signals. Specify a:

- Scalar value to inject the same amplitude at each frequency
- Vector of length 5 to specify a different amplitude at each of $[1/10, 1/3, 1, 3, 10]\omega_c$

In a typical plant with typical target bandwidth, the magnitudes of the plant responses at the experiment frequencies do not vary widely. In such cases, you can use a scalar value to apply the same magnitude perturbation at all frequencies. However, if you know that the response decays sharply over the frequency range, consider decreasing the amplitude of the lower frequency inputs and increasing the amplitude of the higher frequency inputs. It is numerically better for the estimation experiment when all the plant responses have comparable magnitudes.

The perturbation amplitudes must be:

- Large enough that the perturbation overcomes any deadband in the plant actuator and generates a response above the noise level
- Small enough to keep the plant running within the approximately linear region near the nominal operating point, and to avoid saturating the plant input or output

When **Experiment mode** is **Superposition**, the sinusoidal signals are superimposed. Thus, the perturbation can be at least as large as the sum of all amplitudes. Make sure that the largest possible perturbation is within the range of your plant actuator. Saturating the actuator can introduce errors into the estimated frequency response.

To provide the sine amplitudes by using an input port, on the Block tab, select **Use external source for sine amplitudes**.

Tunable: Yes

Programmatic Use

Block Parameter: AmpSineAllOuter

Type: scalar, vector of length 5

Default: 1

Block Tab

Use external source for bandwidths — Supply external signal for target bandwidths

off (default) | on

Select this parameter to enable the `bandwidth` input port of the block. You can specify the target bandwidth for all the loops the block tunes at this port. When this parameter is disabled, specify the target bandwidths at the block parameters. For more details, see the `bandwidth` port description.

Programmatic Use

Block Parameter: `UseExternalWc`

Type: character vector

Values: 'off' | 'on'

Default: 'off'

Use external source for target phase margins — Supply external signal for target phase margin
off (default) | on

Select this parameter to enable the `target PM` input port of the block. You can specify the target phase margin for all the loops the block tunes at this port. When this parameter is disabled, specify the target phase margins at the block parameters. For more details, see the `target PM` port description.

Programmatic Use

Block Parameter: `UseExternalPM`

Type: character vector

Values: 'off' | 'on'

Default: 'off'

Use external source for start/stops of experiment — Supply external signal for start and stop of tuning experiment
off (default) | on

Select this parameter to enable the `start/stop` and `ActiveLoop` input ports of the block. You can specify the start and stop of the experiment and which loop the block tunes at these ports. When this parameter is disabled, specify the start time and duration of the tuning experiment at the block parameters. For more details, see the `start/stop` and `ActiveLoop` port descriptions.

Programmatic Use

Block Parameter: `UseExternalSourceStartStop`

Type: character vector

Values: 'off' | 'on'

Default: 'off'

Use external source for sine amplitudes — Supply external signal for sinusoidal perturbation amplitude
off (default) | on

Select this parameter to enable the `sine Amp` input port of the block. You can specify sinusoidal perturbation amplitude for all the loops the block tunes at this port. When this parameter is disabled, supply the sine amplitudes at block parameters. For more details, see the `sine Amp` port description.

Programmatic Use

Block Parameter: `UseExternalAmpSine`

Type: character vector

Values: 'off' | 'on'

Default: 'off'

Data Type — Floating point precision
double (default) | single

Specify the floating-point precision based on the simulation environment or hardware requirements.

Programmatic Use

Block Parameter: BlockDataType

Type: character vector

Values: 'double' | 'single'

Default: 'double'

Estimated phase margin achieved by tuned controllers — Phase margin achieved by most recently tuned loop

off (default) | on

Select this parameter to enable the `estimated` PM output port of the block. The block returns the phase margin achieved by the tuned controller of the most recently tuned loop. When this parameter is disabled, you can see the tuning results by using the **Export to MATLAB** parameter. For more details, see the `estimated` PM port description.

Programmatic Use

Block Parameter: UseExternalAchievedPM

Type: character vector

Values: 'off' | 'on'

Default: 'off'

Plant frequency responses near bandwidth — Estimated frequency response for most recently tuned loop

off (default) | on

Select this parameter to enable the `frd` output port of the block. The block returns the phase margin achieved by the tuned controller of the most recently tuned loop. When this parameter is disabled, you can see the tuning results by using the **Export to MATLAB** parameter. For more details, see the `frd` port description.

Programmatic Use

Block Parameter: UseExternalFRD

Type: character vector

Values: 'off' | 'on'

Default: 'off'

Plant nominal input and output — Plant input and output at nominal operating point

off (default) | on

Select this parameter to enable the `nominal` output port of the block. The block returns the plant input and output at the nominal operating point of the most recently tuned loop. When this parameter is disabled, you can see the tuning results by using the **Export to MATLAB** parameter. For more details, see the port description.

Programmatic Use

Block Parameter: UseExternalU0

Type: character vector

Values: 'off' | 'on'

Default: 'off'

Start/stop of autotuning process — Signal indicating start and end of experiment for each tuned loop

off (default) | on

Select this parameter to enable `loop_start/stops` output port of the block. The block returns a signal indicating the times at which the autotuning experiment started and ended for each loop tuned by the block. When this parameter is disabled, you can see the tuning results by using the **Export to MATLAB** parameter. For more details, see the `loop_start/stops` port description.

Programmatic Use

Block Parameter: `UseExternalActiveLoop`

Type: character vector

Values: 'off' | 'on'

Default: 'off'

Export to MATLAB — Send experiment and tuning results to MATLAB workspace
button

When you click this button, the block creates a structure in the MATLAB workspace containing the experiment and tuning results. This structure, `FOCTuningResult`, contains the tuning results for each loop the block tunes.

- `Daxis` — D-axis current loop tuning results
- `Qaxis` — Q-axis current loop tuning results
- `Speed` — Speed loop tuning results
- `Flux` — Flux loop tuning results

For each loop tuned by the block, the result contains the following fields:

- `P, I, D, N` — Tuned PID gains. The structure contains whichever of these fields are necessary for the controller type you are tuning. For instance, if you are tuning a PI controller, the structure contains `P` and `I`, but not `D` and `N`.
- `TargetBandwidth` — The value you specified in the `Target bandwidth (rad/sec)` parameter of the block.
- `TargetPhaseMargin` — The value you specified in the `Target phase margin (degrees)` parameter of the block.
- `EstimatedPhaseMargin` — Estimated phase margin achieved by the tuned system.
- `Controller` — The tuned PID controller, returned as a `pid` (for parallel form) or `pidstd` (for ideal form) model object.
- `Plant` — The estimated plant, returned as an `frd` model object. This `frd` contains the response data obtained at the experiment frequencies $[1/10, 1/3, 1, 3, 10]\omega_c$.
- `PlantNominal` — The plant input and output at the nominal operating point when the experiment begins, specified as a structure with the fields `u` (input) and `y` (output).

You can export to the MATLAB workspace while the simulation is running, including when running in external mode.

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

The generated code for this block can be resource heavy. For real-time applications, deploying the code on rapid prototyping hardware, such as the Speedgoat real-time target machine, is recommended.

PLC Code Generation

Generate Structured Text code using Simulink® PLC Coder™.

See Also

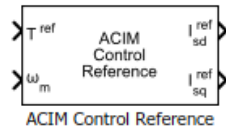
[Park Transform](#) | [PI Controller](#) | [DQ Limiter](#) | [Speed Measurement](#) | [Inverse Park Transform](#)

Topics

[“How to Use Field Oriented Control Autotuner Block”](#)

ACIM Control Reference

Compute reference currents for field-oriented control of induction motor



Libraries:

Motor Control Blockset / Controls / Control Reference

Motor Control Blockset HDL Support / Controls / Control Reference

Description

The ACIM Control Reference block computes the d -axis and q -axis reference currents for the field-oriented control (and field-weakening) operation.

The block accepts the reference torque and feedback mechanical speed and outputs the corresponding d - and q -axes reference currents.

The block computes the reference current values by solving mathematical relationships. The calculations use the SI unit system. When working with the Per-Unit (PU) system (with the **Input units** parameter set to Per-Unit (PU)), the block converts PU input signals to SI units to perform the computations and converts them back to PU values at the output.

These equations describe how the block computes the reference d -axis and q -axis current values.

Mathematical Model of Induction Motor

These model equations describe the dynamics of induction motor in the rotor flux reference frame:

The machine inductances are represented as,

$$L_s = L_{ls} + L_m$$

$$L_r = L_{lr} + L_m$$

$$\sigma = 1 - \left(\frac{L_m^2}{L_s \cdot L_r} \right)$$

Stator voltages are represented as,

$$v_{sd} = R_s i_{sd} + \sigma L_s \frac{di_{sd}}{dt} + \frac{L_m}{L_r} \frac{d\lambda_{rd}}{dt} - \omega_e \sigma L_s i_{sq}$$

$$v_{sq} = R_s i_{sq} + \sigma L_s \frac{di_{sq}}{dt} + \frac{L_m}{L_r} \omega_e \lambda_{rd} + \omega_e \sigma L_s i_{sd}$$

In the preceding equations, the flux linkages can be represented as,

$$\lambda_{sd} = \frac{L_m}{L_r} \lambda_{rd} + \sigma L_s i_{sd}$$

$$\lambda_{sq} = \sigma L_s i_{sq}$$

$$\tau_r \frac{d\lambda_{rd}}{dt} + \lambda_{rd} = L_m i_{sd}$$

If we keep the rotor flux as constant and the d -axis is aligned to the rotor flux reference frame, then we can imply:

$$\lambda_{rd} = L_m i_{sd}$$

$$\lambda_{rq} = 0$$

These equations describe the mechanical dynamics,

$$T_e = \frac{3}{2} p \left(\frac{L_m}{L_r} \right) \lambda_{rd} i_{sq}$$

$$T_e - T_L = J \frac{d\omega_m}{dt} + B\omega_m$$

These equations describe the slip speed,

$$\tau_r = \left(\frac{L_r}{R_r} \right)$$

$$\omega_{e_slip} = \left(\frac{L_m \cdot i_{sq}^{ref}}{\tau_r \cdot \lambda_{rd}} \right)$$

$$\omega_e = \omega_r + \omega_{e_slip}$$

$$\theta_e = \int \omega_e \cdot dt = \int (\omega_r + \omega_{e_slip}) \cdot dt = \theta_r + \theta_{slip}$$

Reference Current Computation

These equations show computation of the reference currents,

$$i_{sd_0} = \frac{\lambda_{rd}}{L_m}$$

$$i_{sq_req} = \frac{T^{ref}}{\frac{3}{2} p \left(\frac{L_m}{L_r} \right) \lambda_{rd}}$$

The reference currents are computed differently for operation below base speed and field weakening region,

If $\omega_m \leq \omega_{rated}$:

$$i_{sd_sat} = \min(i_{sd_0}, i_{max})$$

If $\omega_m > \omega_{rated}$:

$$i_{sd_fw} = i_{sd_0} \left(\frac{\omega_{rated}}{\omega_m} \right)$$

$$i_{sd_sat} = \min(i_{sd_fw}, i_{max})$$

These equations indicate the q -axis current computation,

$$i_{sq_lim} = \sqrt{i_{max}^2 - i_{sd_sat}^2}$$

$$i_{sq_sat} = sat(i_{sq_lim}, i_{sq_req})$$

The block outputs the following values,

$$i_{sd}^{ref} = i_{sd_sat}$$

$$i_{sq}^{ref} = i_{sq_sat}$$

where:

- p is the number of pole pairs of the motor.
- R_s is the stator phase winding resistance (Ohms).
- R_r is the rotor resistance referred to stator (Ohms).
- L_{ls} is the stator leakage inductance (Henry).
- L_{lr} is the rotor leakage inductance (Henry).
- L_s is the stator inductance (Henry).
- L_m is the magnetizing inductance (Henry).
- L_r is the rotor inductance referred to stator (Henry).
- σ is the total leakage factor of the induction motor.
- τ_r is the rotor time constant (sec).
- v_{sd} and v_{sq} are the stator d - and q -axis voltages (Volts).
- i_{sd} and i_{sq} are the stator d - and q -axis currents (Amperes).
- i_{sd_0} is the rated d -axis current of the stator also known as magnetizing current (Amperes).
- i_{max} is the maximum phase current (peak) of the motor (Amperes).
- λ_{sd} is the d -axis flux linkage of the stator (Weber).
- λ_{sq} is the q -axis flux linkage of the stator (Weber).
- λ_{rd} is the d -axis flux linkage of the rotor (Weber).
- λ_{rq} is the q -axis flux linkage of the rotor (Weber).
- ω_{e_slip} is the electrical slip speed of the rotor (Radians/ sec).
- ω_{slip} is the mechanical slip speed of the rotor (Radians/ sec).
- ω_e is the electrical speed corresponding to frequency of stator voltages (Radians/ sec).
- ω_m is the rotor mechanical speed (Radians/ sec).
- ω_r is the rotor electrical speed (Radians/ sec).
- ω_{rated} is the rated mechanical speed of the motor (Radians/ sec).
- T_e is the electromechanical torque produced by the motor (Nm).

Ports

Input

T^{ref} — Reference torque value
scalar

Reference torque input value for which the block computes the reference current.

Data Types: `single` | `double` | `fixed point`

ω_m — Mechanical speed
scalar

Reference mechanical speed value for which the block computes the reference current.

Data Types: `single` | `double` | `fixed point`

Output

I_{sd}^{ref} — Reference d -axis stator current
scalar

Reference d -axis stator current value.

Data Types: `single` | `double` | `fixed point`

I_{sq}^{ref} — Reference q -axis stator current
scalar

Reference q -axis stator current value.

Data Types: `single` | `double` | `fixed point`

Parameters

Number of pole pairs — Number of pole pairs available in motor
2 (default) | scalar

Number of pole pairs available in the induction motor.

Rotor leakage inductance (H) — Leakage inductance of rotor winding
6.81e-3 (default) | scalar

Inductance due to leakage flux linked to the rotor winding (in Henry).

Magnetizing Inductance (H) — Magnetizing inductance of induction motor
30e-3 (default) | scalar

Inductance due to the magnetizing flux (in Henry).

Rated Flux (Wb) — Rated flux of motor
38.2e-3 (default) | scalar

Rated flux of the induction motor (in Weber).

Rated Speed (rpm) — Rated speed of motor
1150 (default) | scalar

Rated speed of the induction motor according to motor data sheet (in rpm).

Synchronous Speed (rpm) — Synchronous speed of motor
1500 (default) | scalar

Synchronous speed of the induction motor (in rpm).

Max current (A) — Maximum phase current limit for motor (amperes)
3 (default) | scalar

Maximum phase current limit for the induction motor (amperes).

Input units — Unit of input values
Per-Unit (PU) (default) | SI Units

Unit of the input values.

Base Current (A) — Base current for per-unit system
5.3611 (default) | scalar

Base current (in Amperes) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Base torque (Nm) — Base torque for per-unit system
0.50072 (default) | scalar

Base torque (in Nm) for per-unit system. See “Per-Unit System” page for more details.

This parameter is not configurable and uses a value that is internally computed using other parameters.

Dependencies

To display this parameter, set **Input units** to Per-Unit (PU).

Version History

Introduced in R2020b

References

- [1] B. Bose, *Modern Power Electronics and AC Drives*. Prentice Hall, 2001. ISBN-0-13-016743-6.
- [2] Lorenz, Robert D., Thomas Lipo, and Donald W. Novotny. "Motion control with induction motors." *Proceedings of the IEEE*, Vol. 82, Issue 8, August 1994, pp. 1215-1240.
- [3] W. Leonhard, *Control of Electrical Drives*, 3rd ed. Secaucus, NJ, USA:Springer-Verlag New York, Inc., 2001.

- [4] Briz, Fernando, Michael W. Degner, and Robert D. Lorenz. "Analysis and design of current regulators using complex vectors." *IEEE Transactions on Industry Applications*, Vol. 36, Issue 3, May/June 2000, pp. 817-825.
- [5] Briz, Fernando, et al. "Current and flux regulation in field-weakening operation [of induction motors]." *IEEE Transactions on Industry Applications*, Vol. 37, Issue 1, Jan/Feb 2001, pp. 42-50.
- [6] R. M. Prasad and M. A. Mulla, "A novel position-sensorless algorithm for field oriented control of DFIG with reduced current sensors," *IEEE Trans. Sustain. Energy*, vol. 10, no. 3, pp. 1098-1108, July 2019.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see "ConstrainedOutputPipeline" (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see "InputPipeline" (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see "OutputPipeline" (HDL Coder).

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

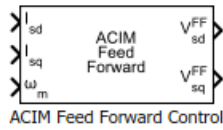
MTPA Control Reference | ACIM Slip Speed Estimator | PI Controller | Speed Measurement

Topics

“Open-Loop and Closed-Loop Control”
“Field-Oriented Control (FOC)”

ACIM Feed Forward Control

Decouple d -axis and q -axis current to eliminate disturbance



Libraries:

Motor Control Blockset / Controls / Control Reference

Motor Control Blockset HDL Support / Controls / Control Reference

Description

The ACIM Feed Forward Control block decouples d -axis and q -axis current controls and generates the corresponding feed-forward voltage gains for field-oriented control of the induction motor.

The block accepts feedback values of d -axis and q -axis currents and the mechanical speed of the rotor.

Equations

If you select Per-Unit (PU) in the **Input units** parameter, the block converts the inputs to SI units before performing any computation. After calculating the output, the block converts the values back to per-unit (PU) values.

The machine inductances and stator flux are represented as,

$$L_s = L_{ls} + L_m$$

$$L_r = L_{lr} + L_m$$

$$\sigma = 1 - \left(\frac{L_m^2}{L_s \cdot L_r} \right)$$

$$\lambda_{sd} = \frac{L_m}{L_r} \lambda_{rd} + \sigma L_s i_{sd}$$

$$\lambda_{sq} = \sigma L_s i_{sq}$$

These equations describe how the block computes the feed-forward gain.

$$V_{sd}^{FF} = \omega_e \lambda_{sd}$$

$$V_{sq}^{FF} = -\omega_e \lambda_{sq}$$

For detailed set of equations and assumptions, see “Mathematical Model of Induction Motor” on page 1-241.

where:

- ω_e is the electrical speed corresponding to frequency of stator voltages (Radians/ sec).
- L_{ls} is the stator leakage inductance (Henry).

- L_{lr} is the rotor leakage inductance (Henry).
- L_s is the stator inductance (Henry).
- L_r is the rotor inductance (Henry).
- L_m is the magnetizing inductance of the motor (Henry).
- σ is the total leakage factor of the induction motor.
- λ_{sd} is the d -axis flux linkage of the stator (Weber).
- λ_{sq} is the q -axis flux linkage of the stator (Weber).
- λ_{rd} is the d -axis flux linkage of the rotor (Weber).
- i_{sd} and i_{sq} are the stator d - and q -axis currents (Amperes).

Ports

Input

\mathbf{I}_{sd} — D-axis stator current
scalar

Stator current along the d -axis of the rotating dq reference frame.

Data Types: single | double | fixed point

\mathbf{I}_{sq} — Q-axis stator current
scalar

Stator current along the q -axis of the rotating dq reference frame.

Data Types: single | double | fixed point

ω_m — Mechanical speed of rotor
scalar

Mechanical speed of the rotor.

Data Types: single | double | fixed point

Output

\mathbf{V}_{sd}^{FF} — D-axis feed-forward voltage
scalar

Feed-forward voltage along the d -axis of the rotating dq reference frame.

Data Types: single | double | fixed point

\mathbf{V}_{sq}^{FF} — Q-axis feed-forward voltage
scalar

Feed-forward voltage along the q -axis of the rotating dq reference frame.

Data Types: single | double | fixed point

Parameters

Number of pole pairs — Number of pole pairs available in motor
2 (default) | scalar

Number of pole pairs available in the induction motor.

Stator leakage inductance (H) — Leakage inductance of stator winding
6.81e-3 (default) | scalar

Inductance due to leakage flux linked to the stator winding (in Henry).

Rotor leakage inductance (H) — Leakage inductance of rotor winding
6.81e-3 (default) | scalar

Inductance due to leakage flux linked to the rotor winding (in Henry).

Magnetizing Inductance (H) — Magnetizing inductance of induction motor
30e-3 (default) | scalar

Inductance due to the magnetizing flux (in Henry).

Rated Flux (Wb) — Rated flux of motor
38.2e-3 (default) | scalar

Rated flux of the induction motor (in Weber).

Output Saturation (V) — Saturation limit for output values
24/sqrt(3) (default) | scalar

Saturation limit (in Volts) for the block outputs V_{sd}^{FF} and V_{sq}^{FF} .

Input units — Unit of input values
Per-Unit (PU) (default) | SI Units

Unit of the input values.

Base Voltage (V) — Base voltage for per-unit system
24/sqrt(3) (default) | scalar

Base voltage (in Volts) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Base Current (A) — Base current for per-unit system
5.3611 (default) | scalar

Base current (in Amperes) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Base Speed (rpm) — Base speed for per-unit system
1500 (default) | scalar

Base speed (in rpm) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Version History

Introduced in R2020b

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

PMSM Feed Forward Control | Park Transform | Speed Measurement | DQ Limiter | PI Controller

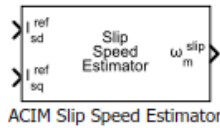
Topics

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

ACIM Slip Speed Estimator

Calculate slip speed of AC induction motor



Libraries:

Motor Control Blockset / Controls / Control Reference

Motor Control Blockset HDL Support / Controls / Control Reference

Description

The ACIM Slip Speed Estimator block computes the mechanical slip speed (difference between the synchronous speed and rotor speed) of the induction motor.

The block accepts the reference values of d - and q -axis currents and outputs the computed slip speed of the induction motor.

Equations

These equations describe the utilization of the slip speed value for field-oriented control (FOC) of the induction motor:

$$\tau_r = \left(\frac{L_r}{R_r} \right)$$

$$\omega_{e_slip} = \left(\frac{L_m \cdot i_{sq}^{ref}}{\tau_r \cdot \lambda_{rd}} \right)$$

$$\omega_e = \omega_r + \omega_{e_slip}$$

$$\theta_e = \int \omega_e \cdot dt = \int (\omega_r + \omega_{e_slip}) \cdot dt = \theta_r + \theta_{slip}$$

If we keep the rotor flux as constant and the d -axis is aligned to the rotor flux reference frame, then we can imply:

$$\lambda_{rd} = L_m i_{sd}$$

This block implements the preceding calculations as:

$$\omega_{slip} = \left(\frac{1}{p} \right) \left(\frac{1}{\tau_r} \right) \left(\frac{i_{sq}^{ref}}{i_{sd}^{ref}} \right)$$

For detailed set of equations and assumptions, see “Mathematical Model of Induction Motor” on page 1-241.

where:

- ω_{e_slip} is the electrical slip speed of the rotor (Radians/ sec).
- ω_{slip} is the mechanical slip speed of the rotor (Radians/ sec).

- ω_e is the electrical speed corresponding to frequency of stator voltages (Radians/ sec).
- ω_m is the rotor mechanical speed (Radians/ sec).
- ω_r is the rotor electrical speed (Radians/ sec).
- L_m is the magnetizing inductance of the motor (Henry).
- R_r is the rotor resistance referred to stator (Ohms).
- i_{sd}^{ref} and i_{sq}^{ref} are the reference stator d - and q -axis currents (Amperes).
- τ_r is the rotor time constant (sec).
- λ_{rd} is the d -axis flux linkage of the rotor (Weber).

Ports

Input

I_{sd}^{ref} — Reference d -axis stator current
scalar

Reference d -axis stator current.

Data Types: `single` | `double` | `fixed point`

I_{sq}^{ref} — Reference q -axis stator current
scalar

Reference q -axis stator current.

Data Types: `single` | `double` | `fixed point`

Output

ω_m^{slip} — Slip speed of induction motor
scalar

Mechanical slip speed of the rotor that the block computes.

Data Types: `single` | `double` | `fixed point`

Parameters

Number of pole pairs — Number of pole pairs available in motor
2 (default) | scalar

Number of pole pairs available in the induction motor.

Rotor resistance (Ohm) — Rotor resistance of motor
1.05 (default) | scalar

Rotor resistance of the induction motor in Ohms.

Rotor leakage inductance (H) — Leakage inductance of rotor winding
6.81e-3 (default) | scalar

Inductance due to leakage flux linked to the rotor winding (in Henry).

Magnetizing inductance (H) — Magnetizing inductance of induction motor
30e-3 (default) | scalar

Inductance due to the magnetizing flux (in Henry).

Output saturation (rpm) — Saturation value for the block output
150 (default) | scalar

Saturation value for the block output (in rpm).

Input units — Unit of input values
Per-Unit (PU) (default) | SI Units

Unit of the input values.

Base speed (rpm) — Base speed for per-unit system
1500 (default) | scalar

Base speed (in rpm) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Version History

Introduced in R2020b

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
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InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Position Generator | Speed Measurement | ACIM Control Reference

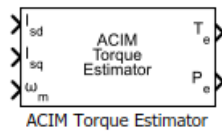
Topics

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

ACIM Torque Estimator

Estimate electromechanical torque and power



Libraries:

Motor Control Blockset / Controls / Control Reference

Motor Control Blockset HDL Support / Controls / Control Reference

Description

The ACIM Torque Estimator block generates electromechanical torque and power estimates for an induction motor. The block outputs the mathematically computed electromechanical torque for constant motor parameters. To measure an accurate torque value, we recommend that you use a physical sensor.

The block accepts feedback values of d - and q -axis stator current and mechanical speed as inputs.

Equations

If you select Per-Unit (PU) in the **Input units** parameter, the block converts the inputs to SI units before performing any computation. After calculating the output, the block converts the output back to per unit values.

These equations describe the computation of electromechanical torque and power estimates by the block.

$$T_e = \frac{3}{2}p \left(\frac{L_m}{L_r} \right) \lambda_{rd} i_{sq}$$

$$P_e = T_e \cdot \omega_m$$

For detailed set of equations and assumptions, see “Mathematical Model of Induction Motor” on page 1-241.

where:

- p is the number of pole pairs available in the motor.
- L_m is the magnetizing inductance of the motor (Henry).
- L_r is the rotor inductance (Henry).
- λ_{rd} is the d -axis flux linkage of the rotor (Weber).
- i_{sq} is the stator q -axis current (Amperes).
- ω_m is the mechanical speed of the rotor (Radians/ sec).

Ports

Input

I_{sd} — D-axis stator current
scalar

Stator current along the d -axis of the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

I_{sq} — Q-axis stator current
scalar

Stator current along the q -axis of the rotating dq reference frame.

Data Types: `single` | `double` | `fixed point`

ω_m — Mechanical speed of rotor
scalar

Mechanical speed of the rotor.

Data Types: `single` | `double` | `fixed point`

Output

T_e — Electromechanical torque
scalar

Electromechanical torque of the rotor.

Data Types: `single` | `double` | `fixed point`

P_e — Electromechanical power
scalar

Electromechanical power of the rotor.

Data Types: `single` | `double` | `fixed point`

Parameters

Number of pole pairs — Number of pole pairs available in motor
2 (default) | scalar

Number of pole pairs available in the induction motor.

Stator leakage inductance (H) — Leakage inductance of stator winding
6.81e-3 (default) | scalar

Inductance due to leakage flux linked to the stator winding (in Henry).

Rotor leakage inductance (H) — Leakage inductance of rotor winding
6.81e-3 (default) | scalar

Inductance due to leakage flux linked to the rotor winding (in Henry).

Magnetizing Inductance (H) — Magnetizing inductance of induction motor
30e-3 (default) | scalar

Inductance due to the magnetizing flux (in Henry)..

Rated Flux (Wb) — Rated flux of motor
38.2e-3 (default) | scalar

Rated flux of the induction motor (in Weber).

Input units — Unit of input values
Per-Unit (PU) (default) | SI Units

Unit of the input values.

Base Voltage (V) — Base voltage for per-unit system
24/sqrt(3) (default) | scalar

Base voltage (in Volts) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Base Current (A) — Base current for per-unit system
5.3611 (default) | scalar

Base current (in Amperes) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Base Speed (rpm) — Base speed for per-unit system
1500 (default) | scalar

Base speed (in rpm) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Base torque (Nm) — Base torque for per-unit system
0.50072 (default) | scalar

Base torque (in Nm) for per-unit system. See “Per-Unit System” page for more details.

This parameter is not configurable and uses a value that is internally computed using other parameters.

Dependencies

To display this parameter, set **Input units** to Per-Unit (PU).

Base power (W) — Base power for per-unit system
111.4284 (default) | scalar

Base power (in W) for per-unit system. See “Per-Unit System” page for more details.

This parameter is not configurable and uses a value that is internally computed using other parameters.

Dependencies

To display this parameter, set **Input units** to Per-Unit (PU).

Version History

Introduced in R2020b

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Park Transform | Speed Measurement

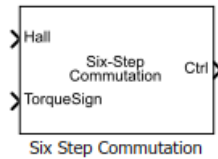
Topics

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

Six Step Commutation

Generate switching sequence for six-step commutation of brushless DC (BLDC) motor



Libraries:

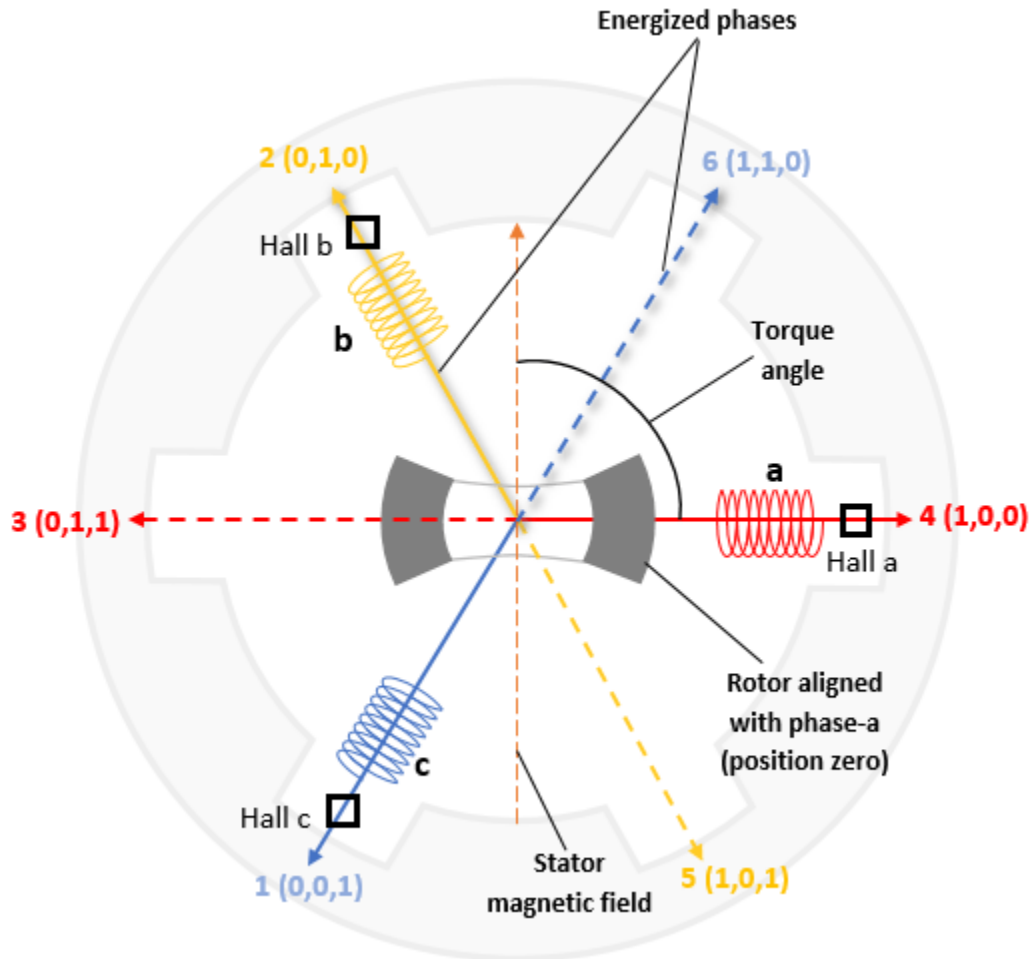
Motor Control Blockset / Controls / Control Reference

Description

The Six Step Commutation block uses a 120-degree conduction mode to generate a switching sequence to implement six-step commutation (or trapezoidal commutation) on a three-phase BLDC motor. You can use the switching signals to operate switches and control the stator currents, and therefore, control motor speed and direction of rotation.

The block accepts the Hall sequence number or rotor position (from a position sensor such as a Hall or a quadrature encoder sensor) and the direction of torque as inputs. It uses the Hall sequence or position input to determine the sector where the rotor is present. The block computes the switching sequence such that it energizes the corresponding phases to maintain the torque angle (angle between rotor d-axis and stator magnetic field) of 90 degrees (with a deviation of 30 degrees). For example, as shown in the below figure, for hall state 5, phase B and phase C are triggered to spin the motor.

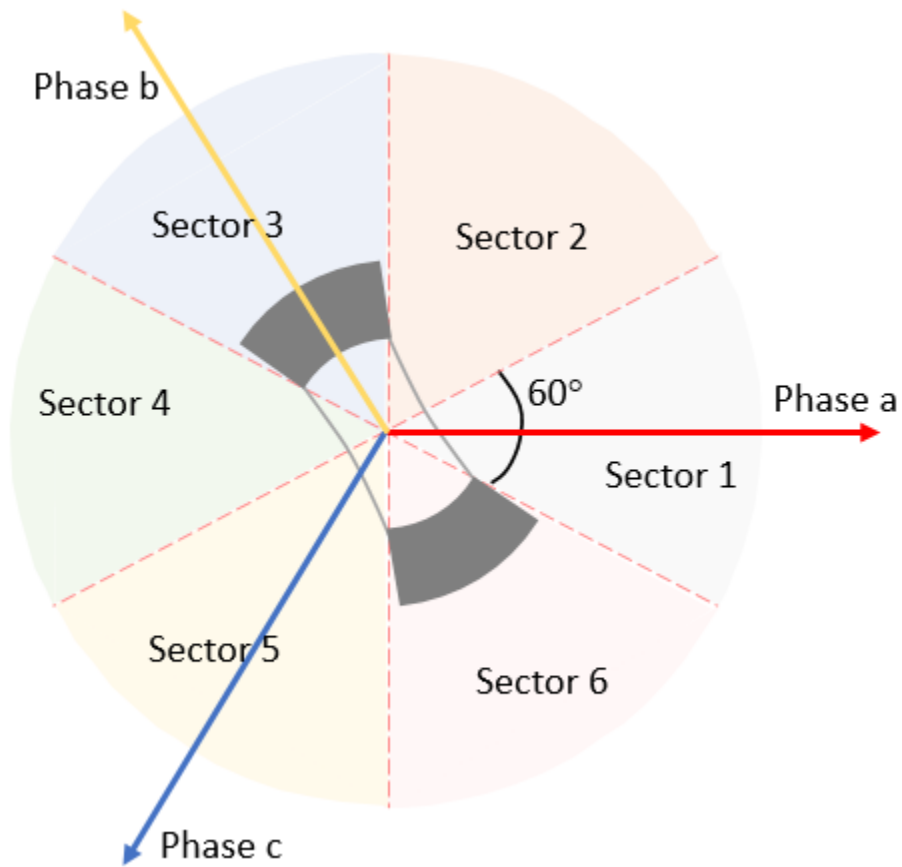
This figure is an example that shows the stator magnetic field phasors along with their default Hall sequence. It is recommended that you use "Hall Sensor Sequence Calibration of BLDC Motor" to obtain hall sequence and use this hall sequence with the block to achieve the six step commutation.



The block uses a commutation logic based on the Hall sequence to generate switching sequences.

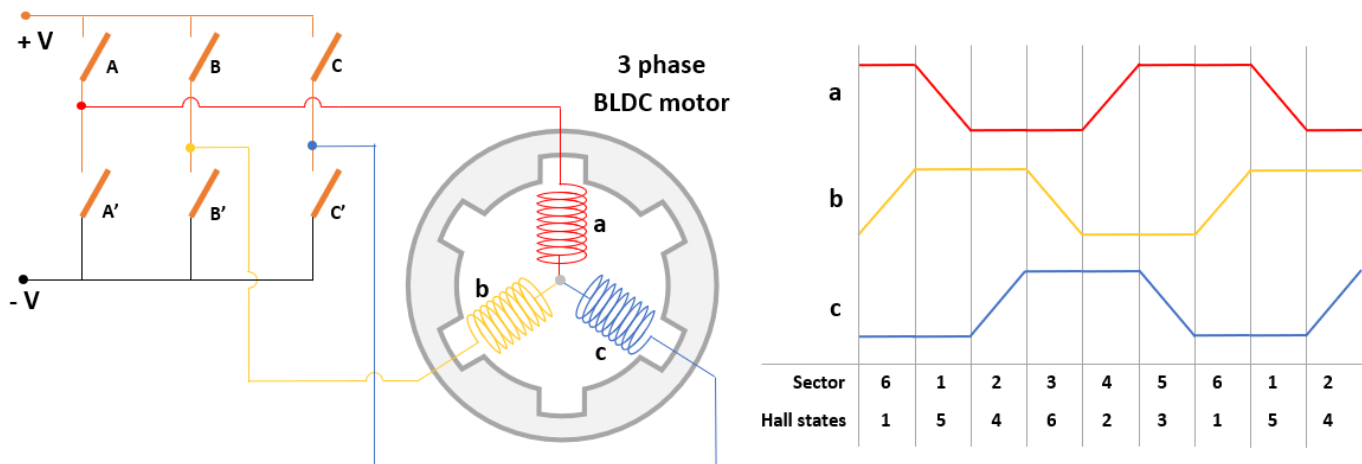
Hall State (Hall a, Hall b, Hall c)	Switching Sequence (AA' BB' CC')		
	AA'	BB'	CC'
4 (100)	00	10	01
6 (110)	01	10	00
2 (010)	01	00	10
3 (011)	00	01	10
1 (001)	10	01	00
5 (101)	10	00	01

This figure shows the stator magnetic field phasors along with the possible sectors (determined from the input rotor position).



The block uses a commutation logic based on the position sensor signals to generate switching sequences.

Position (θ)	Sector	Switching Sequence (AA' BB' CC')		
		AA'	BB'	CC'
$(-30^\circ, 30^\circ]$	1	00	10	01
$(30^\circ, 90^\circ]$	2	01	10	00
$(90^\circ, 150^\circ]$	3	01	00	10
$(150^\circ, 210^\circ]$	4	00	01	10
$(210^\circ, 270^\circ]$	5	10	01	00
$(270^\circ, 330^\circ]$	6	10	00	01



Ports

Input

Hall — Hall sensor sequence
scalar

The Hall sensor sequence. If the Hall sensors are placed 120 degrees apart, the sequence number is between 1 to 6. For a custom Hall sensor sequence (when the Hall sensors are placed 60 degrees apart), the sequence number is between 0 to 7.

Note If you provide an invalid Hall sequence to this port, the block sets the output port **Ctrl** to zero.

Dependencies

To enable this port, set **Input type** to Hall.

Data Types: single | double | fixed point

Position — Rotor position
scalar

Position detected by either the Hall or quadrature encoder sensor in radians (0 to 2π), degrees (0 to 360), or per unit (0 to 1).

Dependencies

To enable this port, set **Input type** to Position.

Data Types: single | double | fixed point

TorqueSign — Direction of rotation
scalar

Torque sign (+1 or -1) indicating the direction of rotation of the BLDC motor.

Data Types: single | double | int8 | int16 | int32

Output

Ctrl — Motor control switching sequence
scalar

Switching sequence signals to implement six-step commutation (or trapezoidal commutation) on the BLDC motor.

Data Types: `single` | `double` | `fixed point`

Parameters

Input type — Block input type
`Hall` (default) | `Position`

Type of position sensor feedback connected to the block input.

Position Unit — Unit of position input
`Per-unit` (default) | `Degrees` | `Radians`

Unit of position feedback input.

Dependencies

To enable this parameter, set **Input type** to `Position`.

Hall Sequence number — Hall sequence
`[5,4,6,2,3,1]` (default) | `vector`

Customized Hall sequence.

If the Hall sensors are placed 120 degrees apart, the sequence number is between 1 to 6. If the Hall sensors are placed 60 degrees apart, the sequence number is between 0 to 7.

Dependencies

To enable this parameter, set **Input type** to `Hall`.

Enable custom commutation — Enable **Commutation switching** parameter
`off` (default) | `on`

Select this parameter for the block to enable the **Commutation switching** parameter.

Dependencies

To enable this parameter, set **Input type** to `Hall`.

Commutation switching — Commutation switching sequence
`[0 0 1 0 0 1;0 1 1 0 0 0;0 1 0 0 1 0;0 0 0 1 1 0;1 0 0 1 0 0;1 0 0 0 0 1]`
(default) | `vector`

Customized switching sequence for commutation of the BLDC motor.

Dependencies

To enable this parameter, set **Input type** to `Hall` and select **Enable custom commutation** parameter.

Version History

Introduced in R2020b

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Mechanical to Electrical Position | PI Controller

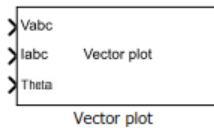
Topics

“Open-Loop and Closed-Loop Control”

“Six-Step Commutation”

Vector Plot

Plot vectors in space domain



Libraries:

Motor Control Blockset / Signal Management

Description

The Vector Plot block plots and tracks the changes in vectors in the space domain. You can use the block to visualize vectors for electrical quantities (such as voltage and current) and track their changes in real time by using the trace left behind by the vector tip.

The block accepts vector magnitudes and their angles (in radians, per-unit, or degrees) as inputs and provides a pictorial representation of the vectors. The block also traces the plot history of the vector tip according to the selected number of points.

For details about how to use the Vector Plot block, see the model `mcb_pmsm_foc_qep_f28379d` in “Field-Oriented Control of PMSM Using Quadrature Encoder”.

Ports

Input

Vabc — Three-phase voltages
vector

Voltage components in the three-phase system in the *abc* reference frame. The port accepts three voltage components multiplexed by using Mux.

Dependencies

To enable this port, set **Select input types** to `Vabc Iabc Theta`.

Data Types: `single | double`

Iabc — Three-phase currents
vector

Current components in the three-phase system in the *abc* reference frame. The port accepts three current components multiplexed by using Mux.

Dependencies

To enable this port, set **Select input types** to `Vabc Iabc Theta`.

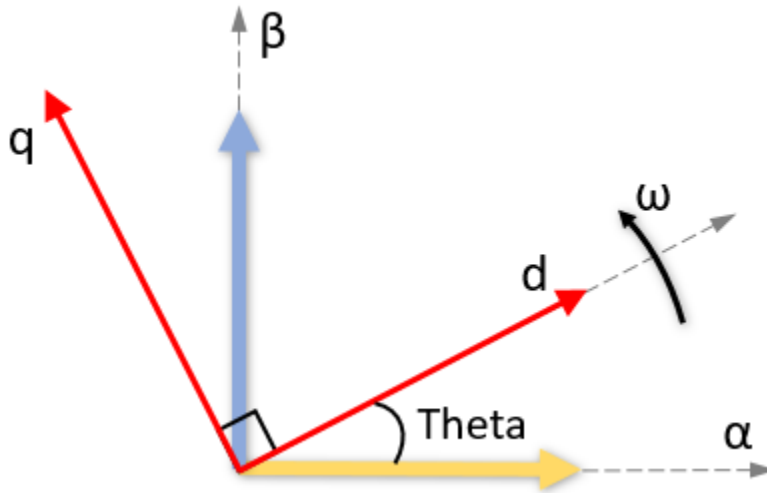
Data Types: `single | double`

Theta — Angle of transformation
scalar

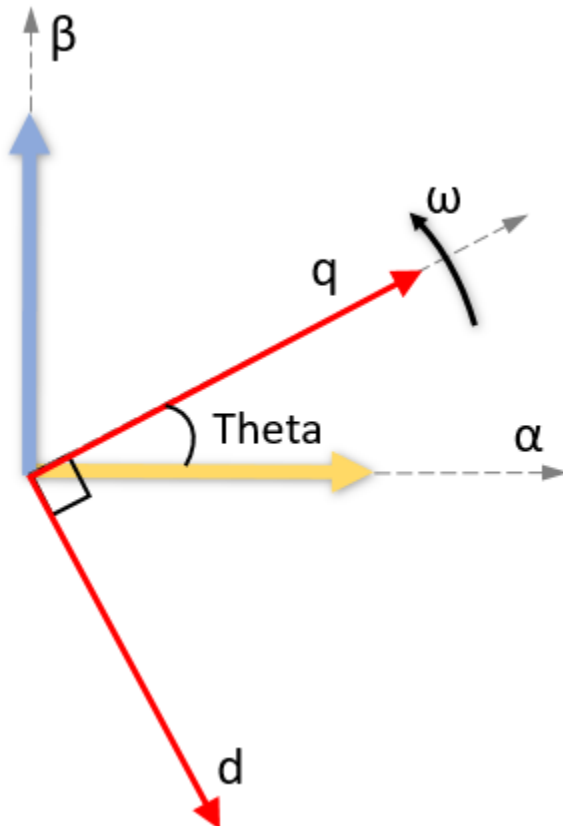
Angle value (in radians, per-unit, or degrees for V_{abc} and I_{abc}) between the rotating reference frame and the α -axis.

The figures show the angle of transformation when:

- The d -axis aligns with the α -axis.



- The q -axis aligns with the α -axis.



In both cases, the angle is $\theta = \omega t$, where:

- θ is the angle between the α - and d -axes for the d -axis alignment or the angle between the α - and q -axes for the q -axis alignment. It indicates the angular position of the rotating dq reference frame with respect to the α -axis.
- ω is the rotational speed in the d - q reference frame.
- t is the time in seconds from the initial alignment.

Dependencies

To enable this port, set **Select input types** to `Vabc Iabc Theta` and set **Select reference frame** to `Rotating Reference Frame`.

Data Types: `single | double`

Vdq — Voltages in dq reference frame
vector

Direct and quadrature axis voltage components in the rotating dq reference frame. The port accepts two voltage components multiplexed by using `Mux`.

Dependencies

To enable this port, set **Select input types** to `Vdq Idq`.

Data Types: `single | double`

Idq — Currents in dq reference frame
vector

Direct and quadrature axis current components in the rotating dq reference frame. The port accepts two currents components multiplexed by using `Mux`.

Dependencies

To enable this port, set **Select input types** to `Vdq Idq`.

Data Types: `single | double`

Magnitude — Vector magnitudes
vector

Magnitudes of vectors that you want to plot. The port accepts up to six vector magnitudes multiplexed by using `Mux`. The vector magnitudes correspond to the angle values input to the **Angle** port.

Note The number of multiplexed vector magnitudes should be same as the number of multiplexed angles input to the **Angle** port.

Dependencies

To enable this port, set **Select input types** to `Mag Angle`.

Data Types: `single | double`

Angle — Vector angle
vector

Angle values (in radians, per-unit, or degrees) of vectors that you want to plot. The port accepts up to six vector angles multiplexed by using Mux. The angle values correspond to the vector magnitudes input to the **Magnitude** port.

Note The number of multiplexed vector angles should be same as the number of multiplexed magnitudes input to the **Magnitude** port.

Dependencies

To enable this port, set **Select input types** to Mag Angle.

Data Types: single | double

Parameters

Select input types — Input port types

Vabc Iabc Theta (default) | Vdq Idq | Mag Angle

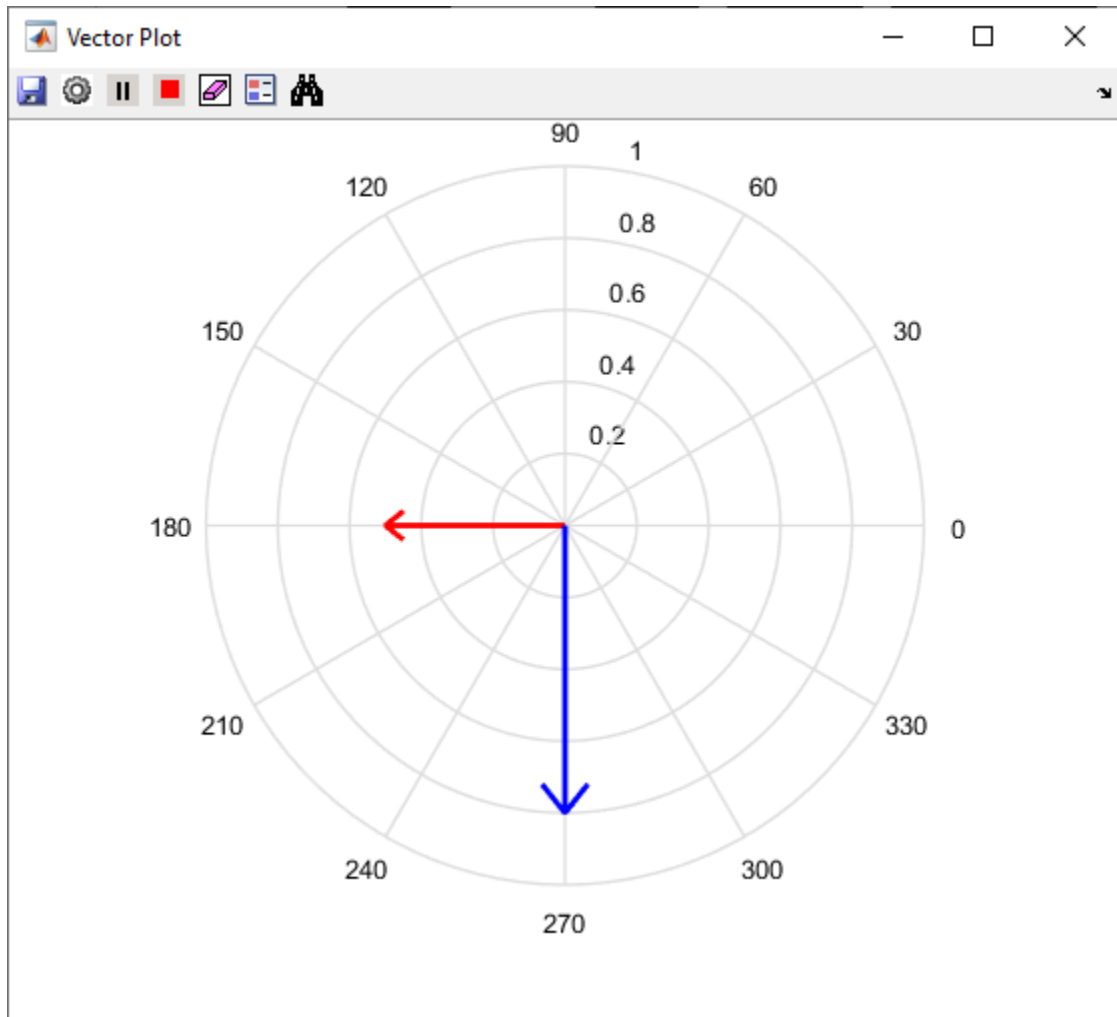
Types of input ports available for the block.

Select reference frame — Reference frame for vectors

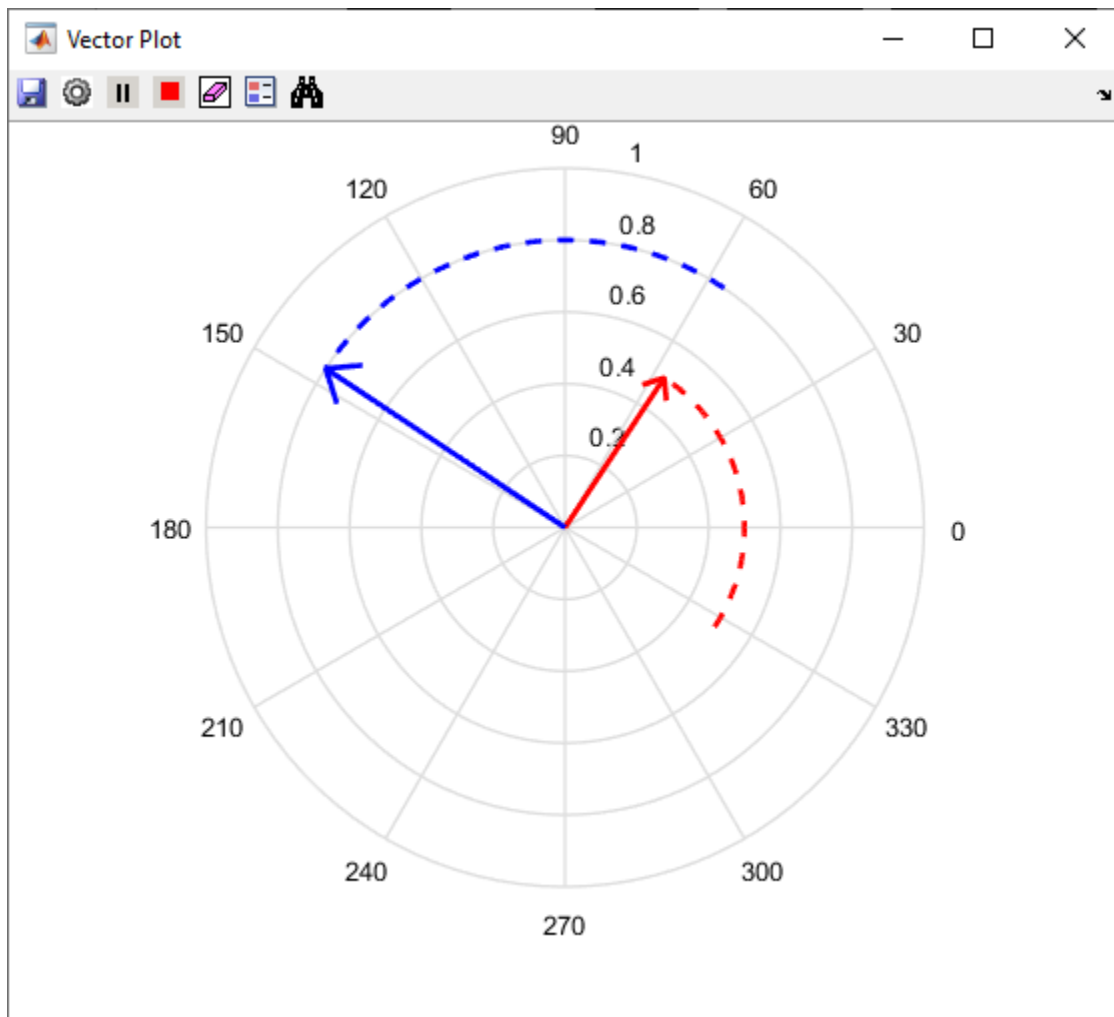
Rotating Reference Frame (default) | Stationary Reference Frame

Select type of reference frame that the block uses to plot the input vectors:

- **Rotating Reference Frame** — Select this option to plot the three-phase voltage and current vectors in the rotating dq reference frame.



- Stationary Reference Frame — Select this option to plot the three-phase voltage and current vectors in the stationary $\alpha\beta$ reference frame.



Dependencies

To enable this parameter, set **Select input types** to Vabc Iabc Theta.

Alpha (phase-a) axis alignment — dq reference frame alignment

D-axis (default) | Q-axis

Align either the d - or q -axis of the rotating reference frame to the α -axis of the stationary reference frame.

Dependencies

To enable this parameter, set **Select input types** to Vabc Iabc Theta and **Select reference frame** to Rotating Reference Frame.

Theta units — Unit of Theta input

Radians (default) | Degrees | Per-unit

Unit of **Theta** input value.

Dependencies

To enable this parameter, set **Select input types** to Vabc Iabc Theta and **Select reference frame** to Rotating Reference Frame.

Angle units — Unit of Angle input
Radians (default) | Degrees | Per-unit

Unit of **Angle** input value.

Dependencies

To enable this parameter, set **Select input types** to Mag Angle.

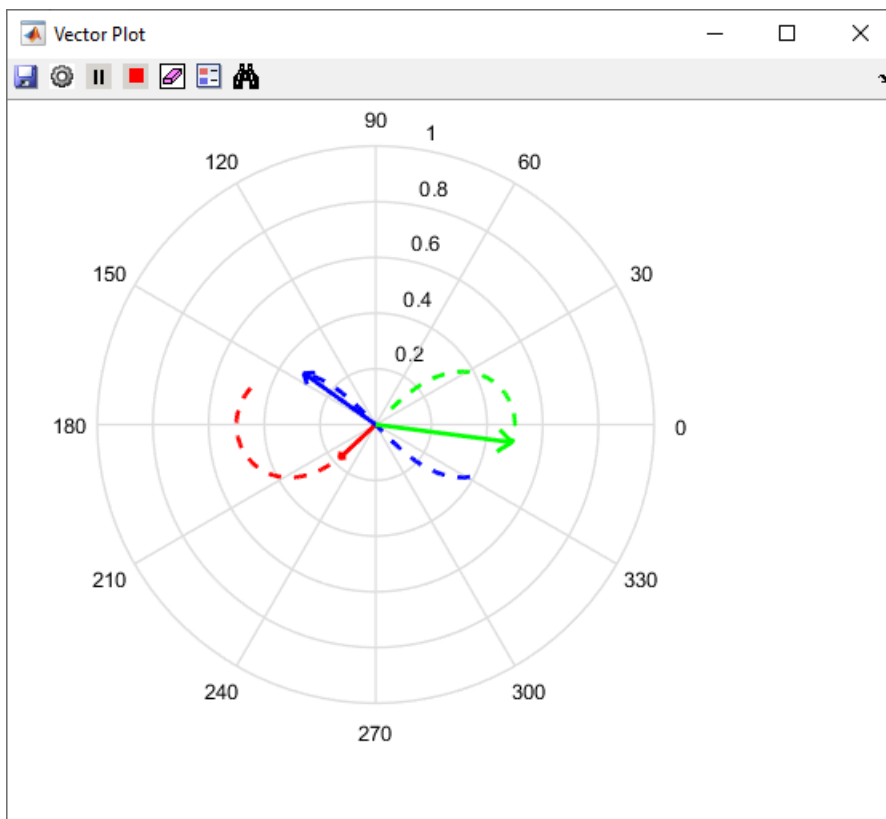
Open plot at simulation start — Open vector plot at simulation start
on (default) | off

Select this parameter to automatically open the vector plot window when simulation begins.








Showplot — Click this button to open the vector plot window.


Vector Plot Window

This example shows the plot when you set **Select input types** to Mag Angle and provide three multiplexed magnitudes and three multiplexed angles as inputs.



You can use these buttons on the Vector Plot window:

-  (Save Figure) — Click to save the plot to an image.
-  (Preferences) — Click to open the Preferences dialog box.
 - **Display traces (samples)** — Enter the number of samples that you want to trace for the vector tip. By default, the field uses the value 100.
 - **Auto-Scale** — Select this field to automatically scale the axes limit. The block performs auto-scaling every at every 1000 points of simulation.
 - **Axes limit** — Enter the maximum value of the x and y axis that the plot should use. By default, the field uses the value 1. If you select **Auto-Scale** and the vector magnitude increases beyond the selected axes limit, the limit on the Vector Plot window extends automatically to accommodate the vector magnitude.
-  (Run Simulation) — Click to simulate the model that contains the Vector Plot block.
-  (Pause Simulation) — Click to pause simulation.
-  (Stop Simulation) — Click to stop simulation.
-  (Clear Data History) — Click to clear the vector tracing history.
-  (Insert Legend) — Click to insert or remove the legend describing the vectors. You can manually change the default legend description.

	data1
	data2
	data3
-  (Auto Scale) — Click to turn on or turn off the auto-scale function.

Version History

Introduced in R2020b

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

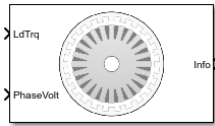
See Also

Topics

“Field-Oriented Control of PMSM Using Quadrature Encoder”

Induction Motor

Three-phase induction motor

**Libraries:**

Powertrain Blockset / Propulsion / Electric Motors and Inverters
Motor Control Blockset / Electrical Systems / Motors

Description

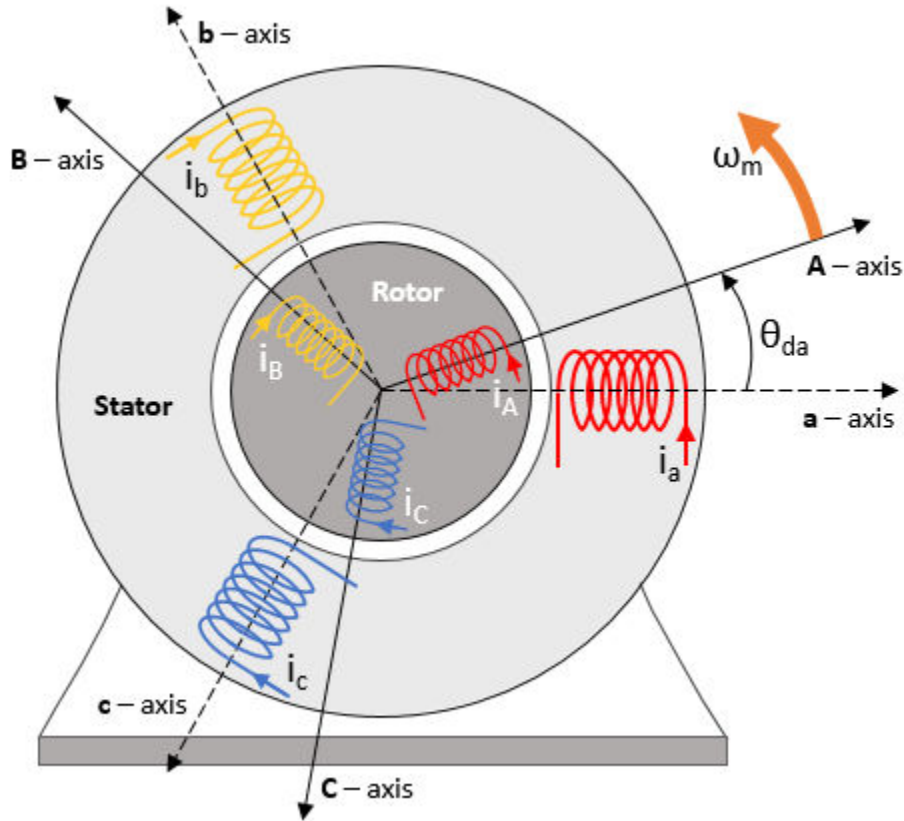
The Induction Motor block implements a three-phase induction motor. The block uses the three-phase input voltages to regulate the individual phase currents, allowing control of the motor torque or speed.

Note The block parameters use per-phase values of a star-equivalent induction motor.

By default, the block sets the **Simulation Type** parameter to `Continuous` to use a continuous sample time during simulation. If you want to generate code for fixed-step double- and single-precision targets, considering setting the parameter to `Discrete`. Then specify a **Sample Time, Ts** parameter.

Three-Phase Sinusoidal Model Electrical System

The block implements equations that are expressed in a stationary rotor reference (dq) frame. The d-axis aligns with the a-axis. All quantities in the rotor reference frame are referred to the stator.



The block uses these equations to calculate the electrical speed (ω_{em}) and slip speed (ω_{slip}).

$$\omega_{em} = P\omega_m$$

$$\omega_{slip} = \omega_{syn} - \omega_{em}$$

To calculate the dq rotor electrical speed with respect to the rotor A-axis (dA), the block uses the difference between the stator a-axis (da) speed and slip speed:

$$\omega_{dA} = \omega_{da} - \omega_{em}$$

To simplify the equations for the flux, voltage, and current transformations, the block uses a stationary reference frame:

$$\omega_{da} = 0$$

$$\omega_{dA} = -\omega_{em}$$

Calculation	Equation
Flux	$\frac{d}{dt} \begin{bmatrix} \lambda_{sd} \\ \lambda_{sq} \end{bmatrix} = \begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} - R_s \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} - \omega_{da} \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \lambda_{sd} \\ \lambda_{sq} \end{bmatrix}$ $\frac{d}{dt} \begin{bmatrix} \lambda_{rd} \\ \lambda_{rq} \end{bmatrix} = \begin{bmatrix} v_{rd} \\ v_{rq} \end{bmatrix} - R_r \begin{bmatrix} i_{rd} \\ i_{rq} \end{bmatrix} - \omega_{dA} \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \lambda_{rd} \\ \lambda_{rq} \end{bmatrix}$ $\begin{bmatrix} \lambda_{sd} \\ \lambda_{sq} \\ \lambda_{rd} \\ \lambda_{rq} \end{bmatrix} = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix}$
Current	$\begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix} = \left(\frac{1}{L_m^2 - L_r L_s} \right) \begin{bmatrix} -L_r & 0 & L_m & 0 \\ 0 & -L_r & 0 & L_m \\ L_m & 0 & -L_s & 0 \\ 0 & L_m & 0 & -L_s \end{bmatrix} \begin{bmatrix} \lambda_{sd} \\ \lambda_{sq} \\ \lambda_{rd} \\ \lambda_{rq} \end{bmatrix}$
Inductance	$L_s = L_{ls} + L_m$ $L_r = L_{lr} + L_m$
Electromagnetic torque	$T_e = PL_m(i_{sq}i_{rd} - i_{sd}i_{rq})$
Power invariant dq transformation to ensure that the dq and three phase powers are equal	$\begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} = \sqrt{\frac{2}{3}}$ $\begin{bmatrix} \cos(\theta_{da}) & \cos(\theta_{da} - \frac{2\pi}{3}) & \cos(\theta_{da} + \frac{2\pi}{3}) \\ -\sin(\theta_{da}) & -\sin(\theta_{da} - \frac{2\pi}{3}) & -\sin(\theta_{da} + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$ $\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta_{da}) & -\sin(\theta_{da}) \\ \cos(\theta_{da} - \frac{2\pi}{3}) & -\sin(\theta_{da} - \frac{2\pi}{3}) \\ \cos(\theta_{da} + \frac{2\pi}{3}) & -\sin(\theta_{da} + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix}$

The equations use these variables.

- ω_m Angular velocity of the rotor (rad/s)
- ω_{em} Electrical rotor speed (rad/s)
- ω_{slip} Electrical rotor slip speed (rad/s)
- ω_{syn} Synchronous rotor speed (rad/s)
- ω_{da} dq stator electrical speed with respect to the rotor a-axis (rad/s)
- ω_{dA} dq stator electrical speed with respect to the rotor A-axis (rad/s)
- θ_{da} dq stator electrical angle with respect to the rotor a-axis (rad)
- θ_{dA} dq stator electrical angle with respect to the rotor A-axis (rad)
- L_q, L_d q- and d-axis inductances (H)

L_s	Stator inductance (H)
L_r	Rotor inductance (H)
L_m	Magnetizing inductance (H)
L_{ls}	Stator leakage inductance (H)
L_{lr}	Rotor leakage inductance (H)
v_{sq}, v_{sd}	Stator q- and d-axis voltages (V)
i_{sq}, i_{sd}	Stator q- and d-axis currents (A)
$\lambda_{sq}, \lambda_{sd}$	Stator q- and d-axis flux (Wb)
i_{rq}, i_{rd}	Rotor q- and d-axis currents (A)
$\lambda_{rq}, \lambda_{rd}$	Rotor q- and d-axis flux (Wb)
v_a, v_b, v_c	Stator voltage phases a, b, c (V)
i_a, i_b, i_c	Stator currents phases a, b, c (A)
R_s	Resistance of the stator windings (Ohm)
R_r	Resistance of the rotor windings (Ohm)
P	Number of pole pairs
T_e	Electromagnetic torque (Nm)

Mechanical System

The motor angular velocity is given by:

$$\frac{d}{dt}\omega_m = \frac{1}{J}(T_e - T_f - F\omega_m - T_m)$$

$$\frac{d\theta_m}{dt} = \omega_m$$

The equations use these variables.

J	Combined inertia of motor and load (kgm ²)
F	Combined viscous friction of motor and load (N·m/(rad/s))
θ_m	Motor mechanical angular position (rad)
T_m	Motor shaft torque (Nm)
T_e	Electromagnetic torque (Nm)
T_f	Motor shaft static friction torque (Nm)
ω_m	Angular mechanical velocity of the motor (rad/s)

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Variable	Equations
PwrIn fo	PwrTrnsfrd — Power transferred between blocks	PwrMtr	P_{mot}	$P_{mot} = -\omega_m T_e$

Bus Signal		Description	Variable	Equations
<ul style="list-style-type: none"> Positive signals indicate flow into block Negative signals indicate flow out of block 	PwrBus	Electrical power	P_{bus}	$P_{bus} = v_{an}i_a + v_{bn}i_b + v_{cn}i_c$
PwrNotTrnsfrd — Power crossing the block boundary, but not transferred	PwrElecLoss	Resistive power loss	P_{elec}	$P_{elec} = -(R_s i_{sd}^2 + R_s i_{sq}^2 + R_r i_{rd}^2 + R_r i_{rq}^2)$
<ul style="list-style-type: none"> Positive signals indicate an input Negative signals indicate a loss 	PwrMechLoss	Mechanical power loss	P_{mech}	<p>When Port Configuration is set to Torque:</p> $P_{mech} = -(\omega_m^2 F + \omega_m T_f)$ <p>When Port Configuration is set to Speed:</p> $P_{mech} = 0$
PwrStored — Stored energy rate of change <ul style="list-style-type: none"> Positive signals indicate an increase Negative signals indicate a decrease 	PwrMtrStored	Stored motor power	P_{str}	$P_{str} = P_{bus} + P_{mot} + P_{elec} + P_{mech}$

The equations use these variables.

R_s	Stator resistance (Ohm)
R_r	Rotor resistance (Ohm)
i_a, i_b, i_c	Stator phase a, b, and c current (A)
i_{sq}, i_{sd}	Stator q- and d-axis currents (A)
v_{an}, v_{bn}, v_{cn}	Stator phase a, b, and c voltage (V)
ω_m	Angular mechanical velocity of the rotor (rad/s)
F	Combined viscous damping of motor and load (N·m/(rad/s))
T_e	Electromagnetic torque (Nm)
T_f	Combined friction torque of motor and load (Nm)

Ports

Input

LdTrq — Load torque on motor
scalar

Load torque on the motor shaft, T_m , in N·m.

Dependencies

To create this port, select Torque for the **Port configuration** parameter.

Spd — Rotor shaft speed

scalar

Angular velocity of the rotor, ω_m , in rad/s.

Dependencies

To create this port, select Speed for the **Port configuration** parameter.

PhaseVolt — Stator terminal voltages

1-by-3 array

Stator terminal voltages, V_a , V_b , and V_c , in V.

Output

Info — Bus signal

bus

The bus signal contains these block calculations.

Signal		Description	Variable	Units	
IaStator		Stator phase current A	i_a	A	
IbStator		Stator phase current B	i_b	A	
IcStator		Stator phase current C	i_c	A	
IdSync		Direct axis current	i_d	A	
IqSync		Quadrature axis current	i_q	A	
VdSync		Direct axis voltage	v_d	V	
VqSync		Quadrature axis voltage	v_q	V	
MtrSpd		Angular mechanical velocity of the rotor	ω_m	rad/s	
MtrMechPos		Rotor mechanical angular position	θ_m	rad	
MtrPos		Rotor electrical angular position	θ_e	rad	
MtrTrq		Electromagnetic torque	T_e	N·m	
PwrInfo	PwrTrnsfrd	PwrMtr	Mechanical power	P_{mot}	W
		PwrBus	Electrical power	P_{bus}	W
	PwrNotTrnsfrd	PwrElecLoss	Resistive power loss	P_{elec}	W
		PwrMechLoss	Mechanical power loss	P_{mech}	W
	PwrStored	PwrMtrStored	Stored motor power	P_{str}	W

PhaseCurr — Phase a, b, c current
1-by-3 array

Phase a, b, c current, i_a , i_b , and i_c , in A.

MtrTrq — Motor torque
scalar

Motor torque, T_{mtr} , in N·m.

Dependencies

To create this port, select Speed for the **Port configuration** parameter.

MtrSpd — Motor speed
scalar

Angular speed of the motor, ω_{mtr} , in rad/s.

Dependencies

To create this port, select Torque for the **Port configuration** parameter.

Parameters

Block Options

Simulation type — Select simulation type
Continuous (default) | Discrete

By default, the block uses a continuous sample time during simulation. If you want to generate code for single-precision targets, considering setting the parameter to Discrete.

Dependencies

Setting **Simulation Type** to Discrete creates the **Sample Time, Ts** parameter.

Sample time, Ts — Sample time for discrete integration
0.001 (default) | scalar

Integration sample time for discrete simulation, in s.

Dependencies

Setting **Simulation Type** to Discrete creates the **Sample Time, Ts** parameter.

Port configuration — Select port configuration
Torque (default) | Speed

This table summarizes the port configurations.

Port Configuration	Creates Input Port	Creates Output Port
Torque	LdTrq	MtrSpd
Speed	Spd	MtrTrq

Load Parameter Values

File — Path to motor parameter ".m" or ".mat" file
scalar

Enter the path to the motor parameter ".m" or ".mat" file that you saved using the Motor Control Blockset parameter estimation tool. You can also click the **Browse** button to navigate and select the ".m" or ".mat" file, and update **File** parameter with the file name and path. For details related to the motor parameter estimation process, see "Estimate PMSM Parameters Using Recommended Hardware".

- **Load from file** - Click this button to read the estimated motor parameters from the ".m" or ".mat" file (indicated by the **File** parameter) and load them to the motor block.
- **Save to file** - Click this button to read the motor parameters from the motor block and save them into a ".m" or ".mat" file (with a file name and location that you specify in the **File** parameter).

Note Before you click **Save to file** button, ensure that the target file name in the **File** parameter has either ".m" or ".mat" extension. If you use any other file extension, the block displays an error message.

Parameters

Number of pole pairs, P — Pole pairs
2 (default) | scalar

Motor pole pairs, P .

Stator resistance and leakage inductance, Zs — Resistance and inductance
[1.77 0.0139] (default) | vector

Stator resistance, R_s , in ohms and leakage inductance, L_{ls} , in H.

Rotor resistance and leakage inductance, Zr — Resistance and inductance
[1.34 0.0121] (default) | vector

Rotor resistance, R_r , in ohms and leakage inductance, L_{lr} , in H.

Magnetizing inductance, Lm — Inductance
0.3687 (default) | scalar

Magnetizing inductance, L_m , in H.

Physical inertia, viscous damping, static friction, mechanical — Inertia, damping, friction
[0.001 0 0] (default) | vector

Mechanical properties of the rotor:

- Inertia, J , in $\text{kg}\cdot\text{m}^2$
- Viscous damping, F , in $\text{N}\cdot\text{m}/(\text{rad}/\text{s})$
- Static friction, T_f , in $\text{N}\cdot\text{m}$

Dependencies

To enable this parameter, select Torque for the **Port configuration**.

Initial Values

Initial mechanical position, theta_init — Angular position
 θ (default) | scalar

Initial rotor angular position, θ_{m0} , in rad.

Initial mechanical speed, omega_init — Angular speed
 ω (default) | scalar

Initial angular velocity of the rotor, ω_{m0} , in rad/s.

Dependencies

To enable this parameter, select Torque for the **Port configuration**.

Version History

Introduced in R2020b

References

[1] Mohan, Ned. *Advanced Electric Drives: Analysis, Control and Modeling Using Simulink*. Minneapolis, MN: MNPERE, 2001.

Extended Capabilities**C/C++ Code Generation**

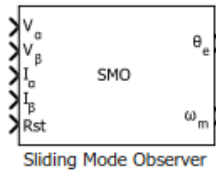
Generate C and C++ code using Simulink® Coder™.

See Also**Topics**

“Estimate Motor Parameters Using Motor Control Blockset Parameter Estimation Tool”

Sliding Mode Observer

Compute electrical position and mechanical speed of a surface-mount PMSM



Libraries:

Motor Control Blockset / Sensorless Estimators

Description

The Sliding Mode Observer block computes the electrical position and mechanical speed of a Surface Mount PMSM by using the voltage and current values along the α - and β -axes of the stationary $\alpha\beta$ reference frame.

Equations

These equations describe the discrete-time operation of a PMSM:

$$i_{\alpha\beta(k+1)} = Ai_{\alpha\beta(k)} + Bv_{\alpha\beta(k)} - Be_{\alpha\beta(k)}$$

$$e_{\alpha\beta(k+1)} = e_{\alpha\beta(k)} + T_s \omega_e(k) J e_{\alpha\beta(k)}$$

$$J = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$$

$$\Phi = \begin{bmatrix} -\frac{R}{L} & 0 \\ 0 & -\frac{R}{L} \end{bmatrix}$$

$$A = e^{\Phi T_s}$$

$$B = \int_0^{T_s} e^{\Phi \tau} d\tau = \begin{bmatrix} b & 0 \\ 0 & b \end{bmatrix}$$

$$b = \frac{1 - e^{-RT_s/L}}{R}$$

These equations describe the discrete-time sliding mode observer operation of a surface mount PMSM:

$$\hat{i}_{\alpha\beta(k+1)} = A\hat{i}_{\alpha\beta(k)} + Bv_{\alpha\beta(k)} - B\hat{e}_{\alpha\beta(k)} - \eta \text{Sign}(\tilde{i}_{\alpha\beta(k)})$$

$$\hat{e}_{\alpha\beta(k+1)} = \hat{e}_{\alpha\beta(k)} + B^{-1}g(\tilde{i}_{\alpha\beta(k)} - A\tilde{i}_{\alpha\beta(k-1)} + \eta \text{Sign}(\tilde{i}_{\alpha\beta(k-1)}))$$

$$\tilde{i}_{\alpha\beta(k)} = \hat{i}_{\alpha\beta(k)} - i_{\alpha\beta(k)}$$

$$\tilde{e}_{\alpha\beta(k)} = \hat{e}_{\alpha\beta(k)} - e_{\alpha\beta(k)}$$

If the back EMF observer fulfils the conditions $|e_{\alpha\beta(k+1)} - e_{\alpha\beta(k)}| \leq m$ and $g \in (0, 1)$, there exists a k_0 , such that:

$$\tilde{e}_{\alpha\beta(k)} < \frac{m}{g}$$

If the sliding mode observer fulfils these conditions:

- $g \in (0, 1)$
- $|e_{\alpha\beta(k+1)} - e_{\alpha\beta(k)}| \leq m$
- $\eta > b \frac{m}{g}$

then there exists a $k=k_0$, such that for $k \geq k_0$:

$$|\tilde{i}_{\alpha\beta(k)}| \leq \eta + b \frac{m}{g}$$

where:

- e_α and i_α are the stator back EMF and current for the α axis
- e_β and i_β are the stator back EMF and current for the β axis
- \tilde{e}_α and \tilde{i}_α are the errors in the stator back EMF and current for the α axis
- \tilde{e}_β and \tilde{i}_β are the errors in the stator back EMF and current for the β axis
- v_α and v_β are the stator supply voltages
- R is the stator resistance
- L is the stator inductance
- g is the back EMF observer gain
- η is the current observer gain
- ω_e is the electrical angular velocity
- T_s is the sampling period
- k is the sample count

Tuning

Use these steps to tune the block using the **Current observer gain** (η) and **Back-emf observer gain** (g) parameters.

- Select a back-emf observer gain (g) value such that $g \in (0, 1)$. Bringing g close to the value 1, results in less error in the estimated back-emf. However, this makes convergence slow.
- Select a value of m based on the block sample time and maximum slope of the operating back-emf (such that $|e_{\alpha\beta(k+1)} - e_{\alpha\beta(k)}| \leq m$).
- Select a current observer gain (η) value based on b , m , and g (such that $\eta > b \frac{m}{g}$).

Note The block functions correctly when you tune the sliding mode observer gains.

When using open-loop control to run a motor, compute the rotor position using both sliding mode observer and an actual sensor hardware and compare the computed position values. If the difference is acceptable, the block functions correctly. Otherwise, manually tune the sliding mode observer gains to ensure that the block functions accurately.

The transition from open-loop control to closed-loop control may fail due to noise in the currents and voltages. To make a successful transition, try reducing the value of the **Filter cut-off frequency (Hz)** parameter.

Ports

Input

V_α — α -axis voltage
scalar

Voltage component along the α -axis of the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

V_β — β -axis voltage
scalar

Voltage component along the β -axis of the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

I_α — α -axis current
scalar

Current component along the α -axis of the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

I_β — β -axis current
scalar

Current component along the β -axis of the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

Rst — Reset the block
scalar

The pulse (true value) that resets and restarts the processing of the block algorithm.

Data Types: `single` | `double` | `fixed point`

Output

θ_e — Electrical position of PMSM
scalar

The estimated electrical position of the rotor.

Data Types: `single` | `double` | `fixed point`

ω_m — Mechanical speed of PMSM
scalar

The estimated mechanical speed of the rotor.

Data Types: `single` | `double` | `fixed point`

Parameters

Input units — Unit of block inputs
`SI unit` (default) | `Per-unit`

Unit of the input voltage and current components along the α -axis and β -axis of the stationary $\alpha\beta$ reference frame.

Discrete step size (s) — Sample time after which block executes again
`50e-6` (default) | scalar

The fixed time interval (in seconds) between every two consecutive instances of block execution.

Motor parameters

Stator resistance (ohm) — Resistance
`0.36` (default) | scalar

Stator phase winding resistance (in ohm).

Stator inductance (H) — Inductance
`0.2e-3` (default) | scalar

Stator phase winding inductance (in Henry).

Maximum application speed (RPM) — Maximum supported mechanical speed
`6000` (default) | scalar

Maximum mechanical speed (in RPM) that the block can support. For a speed beyond this value, the block generates incorrect outputs.

Note The block uses this parameter to filter out noise in the estimated speed signal.

Number of pole pairs — Number of pole pairs available in motor
`4` (default) | scalar

Number of pole pairs available in the motor.

Base voltage (V) — Nominal voltage corresponding to one per unit
`13.8564` (default) | scalar

The maximum phase voltage applied to the PMSM. For details, see “Per-Unit System”.

Base current (A) — Nominal current corresponding to one per unit
`21.4286` (default) | scalar

The maximum measurable current supplied to the PMSM. For details, see “Per-Unit System”.

Note The Sliding Mode Observer block might occasionally display the warning message 'Wrap on overflow detected.'

Observer Parameters

Back-emf observer gain — Sliding mode observer gain for back-emf
0.9 (default) | scalar

The gain that ensures the convergence of the back-emf observer.

Current observer gain — Sliding mode observer gain for current
0.50881 (default) | scalar

The gain that ensures the convergence of the current observer.

Filter cut-off frequency (Hz) — Cut-off frequency of internal filter
1200 (default) | scalar

The cut-off frequency of the internal low-pass IIR filter. The cut-off frequency value must be greater than or equal to the maximum electrical frequency.

Click **Compute default parameters** to calculate approximate observer gains and the filter coefficient and update these fields. For this calculation, we set g to 0.9, computed m at twice the rated speed, and set η to $1.1\left(b\frac{m}{g}\right)$.

Datatypes

Position unit — Unit of position output
Radians (default) | Degrees | Per unit

Unit of the position output.

Position data type — Data type of position output
single (default) | double | fixdt(1,16) | fixdt(1,16,0) | fixdt(1,16,2^0,0) | <data type expression>

Data type of the position output.

Speed unit — Unit of speed output
RPM (default) | Degrees/sec | Radians/sec | Per unit

Unit of the speed output.

Speed data type — Data type of speed output
single (default) | double | fixdt(1,16) | fixdt(1,16,0) | fixdt(1,16,2^0,0) | <data type expression>

Data type of the speed output.

Version History

Introduced in R2021b

References

- [1] A. Podder and D. Pandit, "Study of Sensorless Field-Oriented Control of SPMSM Using Rotor Flux Observer & Disturbance Observer Based Discrete Sliding Mode Observer," *2021 IEEE 22nd Workshop on Control and Modelling of Power Electronics (COMPEL)*, 2021, pp. 1-8. (doi: 10.1109/COMPEL52922.2021.9645939)
- [2] T. Bernardes, V. F. Montagner, H. A. Gründling, and H. Pinheiro, "Discrete-Time Sliding Mode Observer for Sensorless Vector Control of Permanent Magnet Synchronous Machine," in *IEEE Transactions on Industrial Electronics*, vol. 61, no. 4, pp. 1679-1691, 2014
- [3] B. Bose, *Modern Power Electronics and AC Drives*. Prentice Hall, 2001. ISBN-0-13-016743-6.
- [4] J. Liu and X. Wan, "Advanced Sliding Mode Control for Mechanical Systems". Springer-Verlag Berlin Heidelberg, 2011.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Flux Observer | Clarke Transform | Inverse Park Transform | Sine-Cosine Lookup | PI Controller

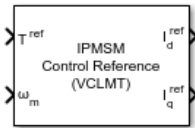
Topics

"Open-Loop and Closed-Loop Control"

"Field-Oriented Control (FOC)"

LUT based PMSM Control Reference

Generate lookup-table-based control reference currents for field-oriented control of permanent magnet synchronous motor



Libraries:

Motor Control Blockset / Controls / Control Reference

Description

The LUT based PMSM Control Reference block generates the d -axis and q -axis reference currents for field-oriented control and field-weakening control of a permanent magnet synchronous motor (PMSM). The block accepts reference torque and feedback mechanical speed and outputs the corresponding reference current values. The block also supports the maximum torque per ampere (MTPA) and maximum torque per voltage (MTPV) operating regions.

The block uses $i_d(T, \omega)$ and $i_q(T, \omega)$ lookup tables (LUTs) to generate reference current values. Depending on the input method you use to specify the motor parameters, the block can either generate LUTs or use the data you provide.

You can specify the motor parameters using one of these methods.

- Lumped parameters with L_d , L_q , and $FluxPM$

This method uses the lumped parameters to compute the i_d and i_q LUTs. The block obtains i_d and i_q for the given ω and T inputs by solving the equations associated with the following curves.

Maximum torque per ampere (MTPA) line (IPMSM),

$$i_d^2 + \frac{i_d \psi_m}{(L_d - L_q)} = i_q^2.$$

MTPA line (SPMSM), $i_d = 0$.

Constant torque trajectory

$$i_q = \frac{T}{1.5P_p(\psi_m + (L_d - L_q)i_d)}.$$

Current limit curve

$$i_d^2 + i_q^2 = i_{\max}^2.$$

Voltage limit curve

$$\left(\frac{V_{DC}}{\sqrt{3}}\right)^2 = (i_d R_s - \omega_e L_q i_q)^2 + (i_q R_s + \omega_e L_d i_d + \omega_e \psi_m)^2.$$

- When the motor is operating within the voltage constraints, the block solves for the intersection of MTPA line and constant torque trajectory.
- When the motor is operating beyond the voltage constraints, the block solves for the intersection of voltage constraint curve and the constant torque trajectory.

After computing the i_d and i_q tables from a grid of ω and T values, the block uses interpolation to find i_d^{ref} and i_q^{ref} for any ω and T inputs that lie within the range of table values. The table values are clipped for ω and T values beyond the boundaries.

- Nonlinear model with d -axis and q -axis stator winding inductances and permanent magnet flux linkage lookup tables

This method uses an approach similar to the previous method, except that the block updates the values for $L_d(i_d, i_q)$, $L_q(i_d, i_q)$, and $FluxPM(i_d, i_q)$ with every iteration it computes i_d and i_q . The block iterates these computations until the i_d and i_q values converge.

- Nonlinear model with d -axis and q -axis flux linkage lookup tables

Use this option when you want to manually provide the $i_d(T, \omega)$ and $i_q(T, \omega)$ tables. Typically, you obtain these tables through simulations or dyno tests. You can also generate these tables using the `mcbGenerateTables` function provided with the Motor Control Blockset software.

For a detailed set of equations and assumptions that Motor Control Blockset uses for a PMSM, see “Mathematical Model of PMSM” on page 1-150.

In addition, the **Vdc input method** parameter configures the block to either accept a fixed reference DC voltage through the **DC bus voltage, Vdc (V)** parameter or accept a variable reference DC voltage through a separate input port V_{dc} .

Based on the selected **Motor parameter input method** parameter value, you can use either the lumped parameters or a non-linear model to compute the reference currents as shown below:

Motor parameter input method	Vdc input method	Technique used to compute reference currents
Linear model with lumped parameters	Specify via dialog	The block uses the lumped parameters to compute the i_d and i_q LUT for a fixed voltage specified by the DC bus voltage, Vdc (V) parameter, from which it determines the reference currents.
	Input port - use 3D LUT (voltage slice based)	The block uses the lumped parameters to compute a 3D i_d and i_q LUT containing data for different voltages (or voltage slices specified by the DC bus voltage breakpoint vector, Vdc (V) parameter). It uses this data to determine the reference currents corresponding to the voltage provided at the input port V_{dc} .

Motor parameter input method	Vdc input method	Technique used to compute reference currents
	Input port - use 2D LUT (scaled-w based)	The block uses the lumped parameters to compute a 2D i_d and i_q LUT for a fixed voltage specified by the DC bus voltage, Vdc (V) parameter. It uses this LUT to compute the reference currents (corresponding to the voltage provided at the input port V_{dc}) by scaling the speed (ω).
Non-linear model with L_d , L_q , and FluxPM LUTs	Specify via dialog	The block computes the reference currents by using the given L_d , L_q , and permanent magnet flux linkage LUT for a fixed voltage specified by the DC bus voltage, Vdc (V) parameter.
	Input port - use 3D LUT (voltage slice based)	The block uses the given 3D L_d , L_q , and permanent magnet flux linkage LUT containing data for different voltages (or voltage slices specified by the DC bus voltage breakpoint vector, Vdc (V) parameter). It uses this LUT to compute the reference currents corresponding to the voltage provided at the input port V_{dc} .
	Input port - use 2D LUT (scaled-w based)	The block uses the given 2D L_d , L_q , and permanent magnet flux linkage LUT for a fixed voltage specified by the DC bus voltage, Vdc (V) parameter. It uses this LUT to compute the reference currents (corresponding to the voltage provided at the input port V_{dc}) by scaling the speed (ω).
Non-linear model with i_d and i_q LUTs	Specify via dialog	The block determines the reference currents by using the given i_d , i_q LUT for a fixed voltage specified by the DC bus voltage, Vdc (V) parameter.

Motor parameter input method	Vdc input method	Technique used to compute reference currents
	Input port - use 3D LUT (voltage slice based)	The block uses the given 3D i_d , i_q LUT containing data for different voltages (or voltage slices specified by the DC bus voltage breakpoint vector, Vdc (V) parameter). It uses this LUT to determine the reference currents corresponding to the voltage provided at the input port V_{dc} .
	Input port - use 2D LUT (scaled-w based)	The block uses the given 2D i_d , i_q LUT for a fixed voltage specified by the DC bus voltage, Vdc (V) parameter. It uses this LUT to compute the reference currents (corresponding to the voltage provided at the input port V_{dc}) by scaling the speed (ω).

Ports

Input

T^{ref} — Reference torque value
scalar

Reference torque input value (in Nm) for which the block computes the reference current.

Data Types: single | double | fixed point

ω_m — Mechanical speed
scalar

Reference mechanical speed value (in rpm) for which the block computes the reference current.

Data Types: single | double | fixed point

V_{dc} — DC bus voltage
scalar

Variable DC bus voltage (in Volts).

Dependencies

To enable this port, set **Vdc input method** to either Input port - use 3D LUT (voltage slice based) or Input port - use 2D LUT (scaled-w based).

Data Types: single | double | fixed point

Output

I_d^{ref} — Reference d -axis current
scalar

Reference d -axis phase current (in Amperes).

Data Types: single | double | fixed point

I_q^{ref} — Reference q -axis current
scalar

Reference q -axis phase current (in Amperes).

Data Types: single | double | fixed point

Parameters

Motor parameters

Motor topology — Type of PMSM
Interior PMSM (default) | Surface PMSM

Type of PMSM based on the placement of the permanent magnets.

Field weakening control method — Type of field weakening control
CVCP (default) | CCCP | VCLMT | NONE

Type of field weakening control, specified as one of these:

- CVCP — Constant voltage constant power (CVCP) control method.
- CCCP — Constant current constant power (CCCP) control method.
- VCLMT — Voltage and current limited maximum torque (VCLMT) control method.

You can configure this parameter only in surface PMSMs with the motor parameters specified as linear lumped parameters. For all other configurations, the block uses the VCLMT control method.

Dependencies

To enable this parameter, set **Motor topology** to Surface PMSM and set **Motor parameter input method** to either Linear model with lumped parameters or Non-linear model with L_d, L_q and FluxPM LUTs.

Number of pole pairs — Number of pole pairs available in motor
4 (default) | scalar

Number of pole pairs available in the motor.

Stator resistance per phase, R_s (Ohm) — Resistance of stator phase winding (Ohms)
0.36 (default) | scalar

Resistance of the stator phase winding (in Ohms).

Vdc input method — Input method for Vdc
Specify via dialog (default) | Input port - use 3D LUT (voltage slice based) |
Input port - use 2D LUT (scaled-w based)

Method used to specify V_{dc} input.

- **Specify via dialog** — Specify the fixed reference voltage V_{dc} using the parameter **DC bus voltage, V_{dc} (V)**.
- **Input port - use 3D LUT (voltage slice based)** — Specify the variable reference voltage V_{dc} using the input port V_{dc} . When using this option, the block computes the reference current data for the given voltage by using a 3-D lookup table (LUT) based on voltage slicing.
- **Input port - use 2D LUT (scaled-w based)** — Specify the variable reference voltage V_{dc} using the input port V_{dc} . When using this option, the block computes the reference current data for the given voltage by using a 2-D LUT based on motor speed (ω) scaling.

DC bus voltage, V_{dc} (V) — DC bus voltage (Volts)

24 (default) | scalar

DC bus voltage (in Volts).

Dependencies

To enable this parameter, set **V_{dc} input method** to either **Specify via dialog** or **Input port - use 2D LUT (scaled-w based)**.

DC bus voltage breakpoint vector, V_{dc} (V) — DC bus voltage lookup vector (Volts)

[18, 30] (default) | vector

DC bus voltage lookup vector used in i_d and i_q lookup tables (in Volts).

Dependencies

To enable this parameter, set **V_{dc} input method** to **Input port - use 3D LUT (voltage slice based)**.

Current Limit, I_{limit} (A) — Maximum phase current limit for motor (Amperes)

7.1 (default) | scalar

Maximum phase current limit for the motor (in Amperes).

Viscous damping coefficient, B_v (Nm-s/rad) — Viscous damping coefficient

2.636875217824e-6 (default) | scalar

Viscous damping coefficient B_v of the motor in N·m/(rad/s).

Motor parameter input method — Type of motor parameters

Linear model with lumped parameters (default) | Non-linear model with L_d , L_q , and FluxPM LUTs | Non-linear model with i_d and i_q LUTs

Motor parameters that the block uses to generate the control reference currents.

- **Linear model with lumped parameters** — Generate current reference tables using lumped-circuit values for motor parameters L_d , L_q , and $FluxPM$.
- **Non-linear model with L_d , L_q , and FluxPM LUTs** — Generate current reference tables using L_d , L_q , and $FluxPM$ lookup tables.
- **Non-linear model with i_d and i_q LUTs** — Determine current reference using the i_d and i_q lookup tables.

Linear Model with Lumped Parameters

Stator d-axis inductance, L_d (H) — D-axis stator winding inductance

0.2e-3 (default) | scalar

Stator winding inductance (in Henry) along the direct-axis of the rotating dq reference frame.

Dependencies

To enable this parameter, set **Motor parameter input method** to Linear model with lumped parameters.

Stator q-axis inductance, L_q (H) — Q-axis stator winding inductance

0.4e-3 (default) | scalar

Stator winding inductance (in Henry) along the quadrature-axis of the rotating dq reference frame.

Dependencies

To enable this parameter, set **Motor topology** to Interior PMSM and **Motor parameter input method** to Linear model with lumped parameters.

Permanent magnet flux linkage (Wb) — Permanent magnet flux linkage

6.4e-3 (default) | scalar

Peak permanent magnet flux linkage (in Weber).

Dependencies

To enable this parameter, select the Linear model with lumped parameters option in the **Motor parameter input method** parameter.

Non-linear Model with L_d , L_q , and FluxPM Lookup Tables

D-axis current breakpoint vector, id (A) — D-axis current lookup vector

[-40, -20, 0, 20] (default) | vector

D-axis current vector (in Amperes) used in the L_d , L_q , and *FluxPM* lookup tables.

Dependencies

To enable this parameter, select the Non-linear model with L_d , L_q and FluxPM LUTs option in the **Motor parameter input method** parameter.

Q-axis current breakpoint vector, iq (A) — Q-axis current lookup vector

[-40, -20, 0, 20, 40] (default) | vector

Q-axis current vector (in Amperes) used in the L_d , L_q , and *FluxPM* lookup tables.

Dependencies

To enable this parameter, select the Non-linear model with L_d , L_q and FluxPM LUTs option in the **Motor parameter input method** parameter.

L_d LUT, $L_d(id,iq)$ (H) — D-axis inductance lookup data

0.2e-3 * ones(4, 5) (default) | matrix

D-axis inductance lookup table data (in Henry).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with Ld,Lq and FluxPM LUTs.

Lq LUT, Lq(id,iq) (H) — Q-axis inductance lookup data

$0.4e-3 * \text{ones}(4, 5)$ (default) | matrix

Q-axis inductance lookup table data (in Henry).

Dependencies

To enable this parameter, set **Motor topology** to Interior PMSM and **Motor parameter input method** to Non-linear model with Ld,Lq and FluxPM LUTs.

PM flux linkage LUT, FluxPM(id,iq) (Wb) — Permanent magnet flux linkage lookup data

$6.4e-3 * \text{ones}(4, 5)$ (default) | matrix

Permanent magnet flux linkage lookup table data (in Weber).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with Ld,Lq and FluxPM LUTs.

Non-linear Model with id and iq Lookup Tables

Reference torque breakpoint vector, Tref (Nm) — Torque reference lookup vector

$[0 \ 0.15 \ 0.3]$ (default) | vector

Torque reference lookup vector used in i_d and i_q lookup tables (in Nm).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with id and iq LUTs.

Mechanical speed breakpoint vector, wrpm (rpm) — Rotor speed lookup vector

$[0 \ 1000 \ 2000 \ 6000]$ (default) | vector

Rotor speed lookup vector used in i_d and i_q lookup tables (in rpm).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with id and iq LUTs.

Reference id LUT, id(Tref,wrpm) (A) — Reference d-axis current lookup data

$[0,0,0, -7.1;0,0,0, -7.1;0,0,0, -7.1]$ (default) | matrix

D-axis current reference 2D lookup table data (in Amperes).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with id and iq LUTs and **Vdc input method** to Input port - use 2D LUT (scaled-w based).

Reference id LUT, $id(T_{ref}, w_{rpm}, V_{dc})$ (A) — Reference d-axis current lookup data

`cat(3, [0,0,0,-7.1;-0.4579,-0.4579,-0.4579,-7.1;-1.4457,-1.4457,-1.4457,-7.1], [0,0,0,0;-0.4579,-0.4579,-0.4579,-1.2581;-1.4457,-1.4457,-1.4457,-4.5085])`
(default) | matrix

D-axis current reference 3D lookup table data (in Amperes).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with id and iq LUTs and **Vdc input method** to Input port - use 3D LUT (voltage slice based).

Reference iq LUT, $iq(T_{ref}, w_{rpm})$ (A) — Reference q-axis current lookup data

`[0,0,0,0;3.9091,3.9091,3.9091,0;7.1,7.1,7.1,0]` (default) | matrix

Q-axis current reference 2D lookup table data (in Amperes).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with id and iq LUTs and **Vdc input method** to Input port - use 2D LUT (scaled-w based).

Reference iq LUT, $iq(T_{ref}, w_{rpm}, V_{dc})$ (A) — Reference q-axis current lookup data

`cat(3, [0,0,0,0;3.8539,3.8539,3.8539,0;6.9513,6.9513,6.9513,0], [0,0,0,0;3.8539,3.8539,3.8539,3.7611;6.9513,6.9513,6.9513,5.4848])` (default) | matrix

Q-axis current reference 3D lookup table data (in Amperes).

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with id and iq LUTs and **Vdc input method** to Input port - use 3D LUT (voltage slice based).

Input units

Input units — Unit of block input values

Per-Unit (PU) (default) | SI Units

Unit of the block input values.

Base voltage (V) — Nominal voltage limit

$24/\sqrt{3}$ (default) | scalar

Base voltage (in Volts) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Base current (A) — Nominal current limit

19.3 (default) | scalar

Base current (in Amperes) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Base speed (rpm) — Nominal speed limit
4107 (default) | scalar

Base speed (in rpm) for per-unit system.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Base torque (Nm) — Nominal torque limit
0.74112 (default)

Torque (in Nm) corresponding to 1 per-unit. See “Per-Unit System” page for more details.

You cannot configure this parameter. Its value is internally computed using the other parameters.

Dependencies

To enable this parameter, set **Input units** to Per-Unit (PU).

Allow scaled-down motor parameters with CodeGen (higher precision with Fixed-Point data type) — Scale down internal parameters to match per-unit scale
on (default) | off

Option to scale down internal parameters to match per-unit scale when generating code.

- When you enable this option, the block scales down the internal constants and coefficients to match the per-unit scale. This allows for higher precision when you use the fixed-point data type. If you use this option with the single or double data type, some precision loss can occur depending on the number of bits allotted to the integer portion.
- When you disable this option, the block converts all the constants and coefficients used for internal calculations to SI units and then converts them back to the PU scale. This allows you to update the lookup table values in the generated code, typically, for applications such as controller tuning or end-of-line operations. You can also update the values manually for debugging or reusing previously generated code.

Dependencies

To enable this parameter, set **Motor parameter input method** to Non-linear model with id and iq LUTs and **Input units** to Per-Unit (PU).

Version History

Introduced in R2022b

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

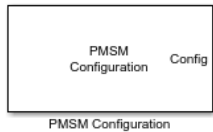
Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

PMSM FeedForward Control | PMSM Torque Estimator

PMSM Configuration

Configure PMSM system parameters



Libraries:

Motor Control Blockset HDL Support / Electrical Systems / Motors

Description

The PMSM Configuration block generates the configuration signal for a permanent magnet synchronous machine/motor (PMSM). This signal can be used to update parameters of PMSM blocks that support FPGA deployment, for example, PMSM HDL.

Ports

Output

Config — Block configuration signal vector

Configuration signal for permanent magnet synchronous machine/motor (PMSM).

Data Types: `single` | `double` | `fixed point`

Parameters

Block Options

Mechanical input configuration — Select port configuration
Torque (default) | Speed

This table summarizes the port configurations.

Port Configuration	Creates Input Port	Creates Output Port
Torque	LdTrq	MtrSpd
Speed	Spd	MtrTrq

Sample Time (Ts) — Sample time for discrete integration
1e-6 (default) | scalar

Integration sample time for discrete simulation, in s.

Parameters

Number of pole pairs — Pole pairs
4 (default) | scalar

Motor pole pairs, P .

Stator phase resistance per phase (Ohm) — Resistance
 0.02 (default) | scalar

Stator phase resistance per phase, R_s , in ohm.

Stator d-axis inductance (H) — Inductance
 $1.7e-3$ (default) | scalar

Stator inductance, L_d , in H.

Stator q-axis inductance (H) — Inductance
 $3.2e-3$ (default) | scalar

Stator inductance, L_q , in H.

Permanent flux linkage constant (lambda_pm) — Flux
 0.2205 (default) | scalar

Permanent flux linkage constant, λ_{pm} , in Wb.

Inertia (kgm^2) — Physical Inertia
 0.0027 (default) | scalar

Physical inertia of the motor, J , in $\text{kg}\cdot\text{m}^2$.

Viscous damping (Nm/rad/s) — Viscous damping
 $4.924e-4$ (default) | scalar

Viscous damping of the motor, F , in $\text{N}\cdot\text{m}/(\text{rad}/\text{s})$.

Static friction (Nm) — Static friction
 0 (default) | scalar

Static friction of the motor, T_f , in $\text{N}\cdot\text{m}$.

Version History

Introduced in R2022b

See Also

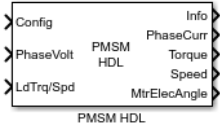
PMSM HDL | Interior PMSM | Surface Mount PMSM

Topics

“Open-Loop and Closed-Loop Control”
 “Field-Oriented Control (FOC)”

PMSM HDL

Three-phase permanent magnet synchronous motor with sinusoidal back electromotive force



Libraries:

Motor Control Blockset HDL Support / Electrical Systems / Motors

Description

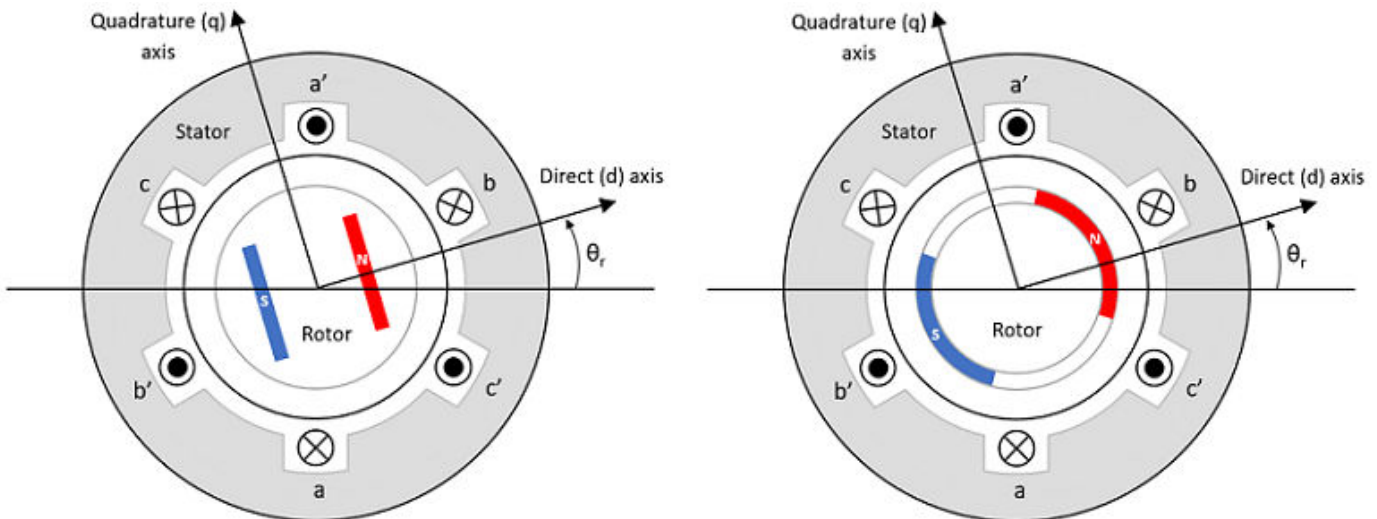
The PMSM HDL block implements a three-phase permanent magnet synchronous motor (PMSM) with sinusoidal back electromotive force. The block uses the three-phase input voltages to regulate the individual phase currents, allowing control of the motor torque or speed.

The block generates code for fixed-step double- and single-precision targets using the **Sample Time (s)** parameter. It supports code generation for FPGA deployment. The block generates HDL compatible code.

The block accepts the PMSM parameters and mode of operation using the **Config** input port. Optionally, you may use the PMSM Configuration block to generate the required configuration signal for the **Config** input port.

Motor Construction

These figures show the interior and surface-mount PMSM construction with a single pole pair on the motor.



The motor magnetic field due to the permanent magnets creates a sinusoidal rate of change of flux with motor angle.

For the axes convention, the a-phase and permanent magnet fluxes are aligned when motor angle θ_r is zero.

Three-Phase Sinusoidal Model Electrical System

The block implements these equations, expressed in the motor flux reference frame (dq frame). All quantities in the motor reference frame are referred to the stator.

$$\omega_e = P\omega_m$$

$$\frac{d}{dt}i_d = \frac{1}{L_d}v_d - \frac{R}{L_d}i_d + \frac{L_q}{L_d}P\omega_m i_q$$

$$\frac{d}{dt}i_q = \frac{1}{L_q}v_q - \frac{R}{L_q}i_q - \frac{L_d}{L_q}P\omega_m i_d - \frac{\lambda_{pm}P\omega_m}{L_q}$$

$$T_e = 1.5P[\lambda_{pm}i_q + (L_d - L_q)i_d i_q]$$

The L_q and L_d inductances represent the relation between the phase inductance and the motor position due to the saliency of the motor magnets. For the surface mount PMSM, $L_d = L_q$.

The equations use these variables.

L_q, L_d	q- and d-axis inductances (H)
R	Resistance of the stator windings (ohm)
i_q, i_d	q- and d-axis currents (A)
v_q, v_d	q- and d-axis voltages (V)
ω_m	Angular mechanical velocity of the motor (rad/s)
ω_e	Angular electrical velocity of the motor (rad/s)
λ_{pm}	Permanent magnet flux linkage (Wb)
K_e	Back electromotive force (EMF) (Vpk_LL/krpm, where Vpk_LL is the peak voltage line-to-line measurement)
K_t	Torque constant (N·m/A)
P	Number of pole pairs
T_e	Electromagnetic torque (Nm)
Θ_e	Electrical angle (rad)

Mechanical System

The motor angular velocity is given by:

$$\frac{d}{dt}\omega_m = \frac{1}{J}(T_e - T_f - F\omega_m - T_m)$$

$$\frac{d\theta_m}{dt} = \omega_m$$

The equations use these variables.

J	Combined inertia of motor and load (kgm ²)
F	Combined viscous friction of motor and load (N·m/(rad/s))
θ_m	Motor mechanical angular position (rad)

T_m	Motor shaft torque (Nm)
T_e	Electromagnetic torque (Nm)
T_f	Motor shaft static friction torque (Nm)
ω_m	Angular mechanical velocity of the motor (rad/s)

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Variable	Equations	
PwrInfo	PwrTrnsfrd — Power transferred between blocks	PwrMtr	Mechanical power	P_{mot}	$P_{mot} = -\omega_m T_e$
	<ul style="list-style-type: none"> Positive signals indicate flow into block Negative signals indicate flow out of block 	PwrBus	Electrical power	P_{bus}	$P_{bus} = v_{an}i_a + v_{bn}i_b + v_{cn}i_c$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred	PwrElecLoss	Resistive power loss	P_{elec}	$P_{elec} = -\frac{3}{2}(R_s i_{sd}^2 + R_s i_{sq}^2)$
	<ul style="list-style-type: none"> Positive signals indicate an input Negative signals indicate a loss 	PwrMechLoss	Mechanical power loss	P_{mech}	<p>When Port Configuration is set to Torque:</p> $P_{mech} = -(\omega_m^2 F + \omega_m T_f)$ <p>When Port Configuration is set to Speed:</p> $P_{mech} = 0$
PwrStored — Stored energy rate of change	PwrMtrStored	Stored motor power	P_{str}	$P_{str} = P_{bus} + P_{mot} + P_{elec} + P_{mech}$	
<ul style="list-style-type: none"> Positive signals indicate an increase Negative signals indicate a decrease 					

The equations use these variables.

R_s	Stator resistance (ohm)
i_a, i_b, i_c	Stator phase a, b, and c current (A)
i_{sq}, i_{sd}	Stator q- and d-axis currents (A)
v_{an}, v_{bn}, v_{cn}	Stator phase a, b, and c voltage (V)

ω_m	Angular mechanical velocity of the motor (rad/s)
F	Combined motor and load viscous damping N·m/(rad/s)
T_e	Electromagnetic torque (Nm)
T_f	Combined motor and load friction torque (Nm)

Ports

Input

Config — Block configuration signal
vector

Configuration signal for the PMSM HDL block containing block configuration parameters.

Data Types: `single` | `double` | `fixed point`

PhaseVolt — Stator terminal voltages
1-by-3 array

Stator terminal voltages, V_a , V_b , and V_c , in V.

Data Types: `single` | `double` | `fixed point`

LdTrq/Spd — Load torque on motor or speed of motor shaft
scalar

This port supports one of these inputs:

- Load torque on the motor shaft, T_m , in N·m.
- Angular velocity of the motor, ω_m , in rad/s.

Data Types: `single` | `double` | `fixed point`

Output

Info — Bus signal
bus

The bus signal contains these block calculations.

Signal	Description	Variable	Units
IaStator	Stator phase current A	i_a	A
IbStator	Stator phase current B	i_b	A
IcStator	Stator phase current C	i_c	A
IdSync	Direct axis current	i_d	A
IqSync	Quadrature axis current	i_q	A
VdSync	Direct axis voltage	v_d	V
VqSync	Quadrature axis voltage	v_q	V

Signal			Description	Variable	Units
MtrSpd			Angular mechanical velocity of the motor	ω_m	rad/s
MtrPos			Motor mechanical angular position	θ_m	rad
MtrTrq			Electromagnetic torque	T_e	N·m
PwrInfo	PwrTrnsfrd	PwrMtr	Mechanical power	P_{mot}	W
		PwrBus	Electrical power	P_{bus}	W
	PwrNotTrnsfrd	PwrElecLoss	Resistive power loss	P_{elec}	W
		PwrMechLoss	Mechanical power loss	P_{mech}	W
	PwrStored	PwrMtrStored	Stored motor power	P_{str}	W

PhaseCurr — Phase a, b, c current
1-by-3 array

Phase a, b, c current, i_a , i_b , and i_c , in A.

Torque — Motor torque
scalar

Motor torque, T_{mtr} , in N·m.

Speed — Motor speed
scalar

Angular speed of the motor, ω_{mtr} , in rad/s.

MtrElecAngle — Motor electrical angle
scalar

Electrical position of the motor, θ_e , in rad.

Data Types: `single` | `double` | `fixed point`

Parameters

Block Options

Sample time (s) — Sample time after which block executes again
1e-6 (default) | scalar

The fixed time interval (in seconds) between every two consecutive instances of block execution.

Version History

Introduced in R2022b

Extended Capabilities

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).
OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).

See Also

PMSM Configuration | Interior PMSM | Surface Mount PMSM

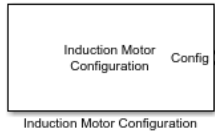
Topics

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

Induction Motor Configuration

Configure induction motor system parameters



Libraries:

Motor Control Blockset HDL Support / Electrical Systems / Motors

Description

The Induction Motor Configuration block generates the configuration signal for an induction machine/motor. This signal can be used to update parameters of induction motor blocks that support FPGA deployment, for example, Induction Motor HDL.

Ports

Output

Config — Block configuration signal vector

Configuration signal for induction machine/motor.

Data Types: `single` | `double` | `fixed point`

Parameters

Block Options

Port configuration — Select port configuration
Torque (default) | Speed

This table summarizes the port configurations.

Port Configuration	Creates Input Port	Creates Output Port
Torque	LdTrq	MtrSpd
Speed	Spd	MtrTrq

Sample Time (Ts) — Sample time for discrete integration
1e-6 (default) | scalar

Integration sample time for discrete simulation, in s.

Parameters

Number of pole pairs — Pole pairs
2 (default) | scalar

Motor pole pairs, P .

Stator resistance (Ohm) — Stator resistance

1.77 (default) | scalar

Stator resistance, R_s , in ohm.

Leakage inductance (H) — Stator leakage inductance

0.0139 (default) | scalar

Stator leakage inductance, L_{ls} , in H.

Rotor resistance (Ohm) — Rotor resistance

1.34 (default) | scalar

Rotor resistance, R_r , in ohm.

Leakage inductance (H) — Rotor leakage inductance

0.0121 (default) | scalar

Rotor leakage inductance, L_{lr} , in H.

Magnetizing inductance (H) — Inductance

0.3876 (default) | scalar

Magnetizing inductance, L_m , in H.

Physical Inertia (kg·m²) — Physical inertia

0.001 (default) | scalar

Physical inertia of the motor, J , in kg·m².

Viscous damping (N·m/rad/s) — Viscous damping

0 (default) | scalar

Viscous damping of the motor, F , in N·m/(rad/s).

Static friction (N·m) — Static friction

0 (default) | scalar

Static friction of the motor, T_f , in N·m.

Version History

Introduced in R2022b

See Also

Induction Motor HDL | Induction Motor

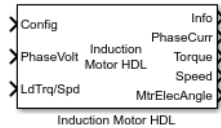
Topics

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

Induction Motor HDL

Three-phase induction motor



Libraries:

Motor Control Blockset HDL Support / Electrical Systems / Motors

Description

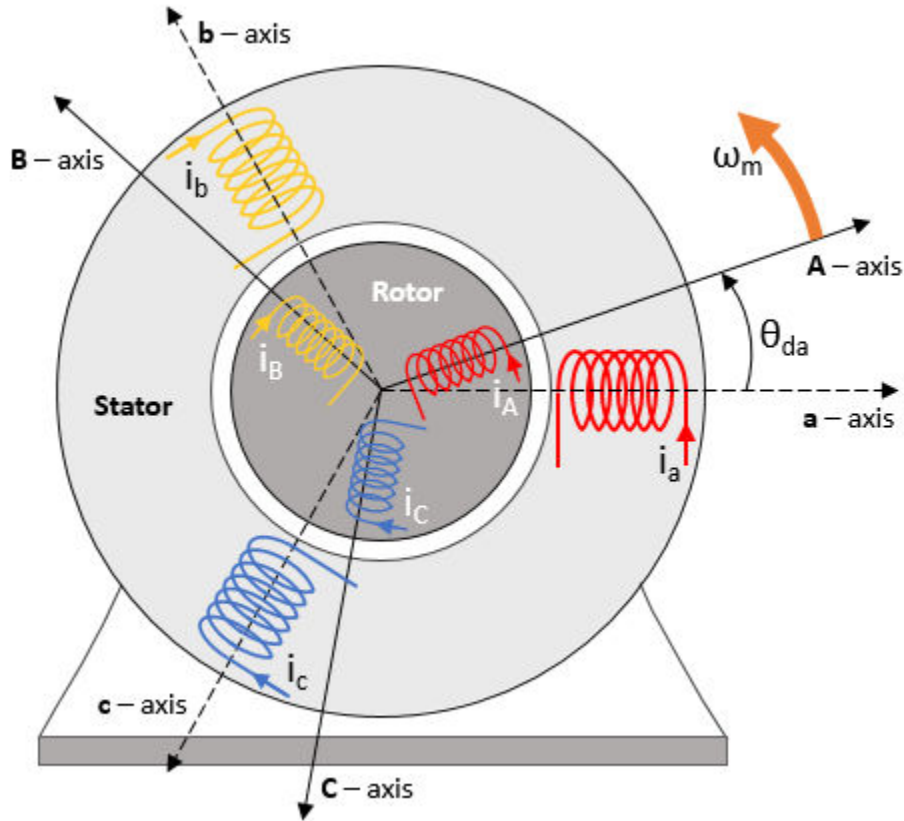
The Induction Motor HDL block implements a three-phase induction motor. The block uses the three-phase input voltages to regulate the individual phase currents, allowing control of the motor torque or speed.

The block generates code for fixed-step double- and single-precision targets using the **Sample Time (s)** parameter. It supports code generation for FPGA deployment. The block generates HDL compatible code.

The block accepts the induction motor parameters and mode of operation using the **Config** input port. Optionally, you may use the Induction Motor Configuration block to generate the required configuration signal for the **Config** input port.

Three-Phase Sinusoidal Model Electrical System

The block implements equations that are expressed in a stationary rotor reference (dq) frame. The d-axis aligns with the a-axis. All quantities in the rotor reference frame are referred to the stator.



The block uses these equations to calculate the electrical speed (ω_{em}) and slip speed (ω_{slip}).

$$\omega_{em} = P\omega_m$$

$$\omega_{slip} = \omega_{syn} - \omega_{em}$$

To calculate the dq rotor electrical speed with respect to the rotor A-axis (dA), the block uses the difference between the stator a-axis (da) speed and slip speed:

$$\omega_{dA} = \omega_{da} - \omega_{em}$$

To simplify the equations for the flux, voltage, and current transformations, the block uses a stationary reference frame:

$$\omega_{da} = 0$$

$$\omega_{dA} = -\omega_{em}$$

Calculation	Equation
Flux	$\frac{d}{dt} \begin{bmatrix} \lambda_{sd} \\ \lambda_{sq} \end{bmatrix} = \begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} - R_s \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} - \omega_{da} \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \lambda_{sd} \\ \lambda_{sq} \end{bmatrix}$ $\frac{d}{dt} \begin{bmatrix} \lambda_{rd} \\ \lambda_{rq} \end{bmatrix} = \begin{bmatrix} v_{rd} \\ v_{rq} \end{bmatrix} - R_r \begin{bmatrix} i_{rd} \\ i_{rq} \end{bmatrix} - \omega_{dA} \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \lambda_{rd} \\ \lambda_{rq} \end{bmatrix}$ $\begin{bmatrix} \lambda_{sd} \\ \lambda_{sq} \\ \lambda_{rd} \\ \lambda_{rq} \end{bmatrix} = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix}$
Current	$\begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix} = \left(\frac{1}{L_m^2 - L_r L_s} \right) \begin{bmatrix} -L_r & 0 & L_m & 0 \\ 0 & -L_r & 0 & L_m \\ L_m & 0 & -L_s & 0 \\ 0 & L_m & 0 & -L_s \end{bmatrix} \begin{bmatrix} \lambda_{sd} \\ \lambda_{sq} \\ \lambda_{rd} \\ \lambda_{rq} \end{bmatrix}$
Inductance	$L_s = L_{ls} + L_m$ $L_r = L_{lr} + L_m$
Electromagnetic torque	$T_e = PL_m(i_{sq}i_{rd} - i_{sd}i_{rq})$
Power invariant dq transformation to ensure that the dq and three phase powers are equal	$\begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} = \sqrt{\frac{2}{3}}$ $\begin{bmatrix} \cos(\theta_{da}) & \cos(\theta_{da} - \frac{2\pi}{3}) & \cos(\theta_{da} + \frac{2\pi}{3}) \\ -\sin(\theta_{da}) & -\sin(\theta_{da} - \frac{2\pi}{3}) & -\sin(\theta_{da} + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$ $\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta_{da}) & -\sin(\theta_{da}) \\ \cos(\theta_{da} - \frac{2\pi}{3}) & -\sin(\theta_{da} - \frac{2\pi}{3}) \\ \cos(\theta_{da} + \frac{2\pi}{3}) & -\sin(\theta_{da} + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix}$

The equations use these variables.

- ω_m Angular velocity of the rotor (rad/s)
- ω_{em} Electrical rotor speed (rad/s)
- ω_{slip} Electrical rotor slip speed (rad/s)
- ω_{syn} Synchronous rotor speed (rad/s)
- ω_{da} dq stator electrical speed with respect to the rotor a-axis (rad/s)
- ω_{dA} dq stator electrical speed with respect to the rotor A-axis (rad/s)
- θ_{da} dq stator electrical angle with respect to the rotor a-axis (rad)
- θ_{dA} dq stator electrical angle with respect to the rotor A-axis (rad)
- L_q, L_d q- and d-axis inductances (H)

L_s	Stator inductance (H)
L_r	Rotor inductance (H)
L_m	Magnetizing inductance (H)
L_{ls}	Stator leakage inductance (H)
L_{lr}	Rotor leakage inductance (H)
v_{sq}, v_{sd}	Stator q- and d-axis voltages (V)
i_{sq}, i_{sd}	Stator q- and d-axis currents (A)
$\lambda_{sq}, \lambda_{sd}$	Stator q- and d-axis flux (Wb)
i_{rq}, i_{rd}	Rotor q- and d-axis currents (A)
$\lambda_{rq}, \lambda_{rd}$	Rotor q- and d-axis flux (Wb)
v_a, v_b, v_c	Stator voltage phases a, b, c (V)
i_a, i_b, i_c	Stator currents phases a, b, c (A)
R_s	Resistance of the stator windings (Ohm)
R_r	Resistance of the rotor windings (Ohm)
P	Number of pole pairs
T_e	Electromagnetic torque (Nm)

Mechanical System

The motor angular velocity is given by:

$$\frac{d}{dt}\omega_m = \frac{1}{J}(T_e - T_f - F\omega_m - T_m)$$

$$\frac{d\theta_m}{dt} = \omega_m$$

The equations use these variables.

J	Combined inertia of motor and load (kgm ²)
F	Combined viscous friction of motor and load (N·m/(rad/s))
θ_m	Motor mechanical angular position (rad)
T_m	Motor shaft torque (Nm)
T_e	Electromagnetic torque (Nm)
T_f	Motor shaft static friction torque (Nm)
ω_m	Angular mechanical velocity of the motor (rad/s)

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Variable	Equations
PwrIn		Mechanical power	P_{mot}	$P_{mot} = -\omega_m T_e$
fo				
	PwrMtr			

Bus Signal		Description	Variable	Equations
	PwrBus	Electrical power	P_{bus}	$P_{bus} = v_{an}i_a + v_{bn}i_b + v_{cn}i_c$
	PwrElec Loss	Resistive power loss	P_{elec}	$P_{elec} = -(R_s i_{sd}^2 + R_s i_{sq}^2 + R_r i_{rd}^2 + R_r i_{rq}^2)$
	PwrMech Loss	Mechanical power loss	P_{mech}	When Port Configuration is set to Torque: $P_{mech} = -(\omega_m^2 F + \omega_m T_f)$ When Port Configuration is set to Speed: $P_{mech} = 0$
	PwrMtrStored	Stored motor power	P_{str}	$P_{str} = P_{bus} + P_{mot} + P_{elec} + P_{mech}$

The equations use these variables.

R_s	Stator resistance (Ohm)
R_r	Rotor resistance (Ohm)
i_a, i_b, i_c	Stator phase a, b, and c current (A)
i_{sq}, i_{sd}	Stator q- and d-axis currents (A)
v_{an}, v_{bn}, v_{cn}	Stator phase a, b, and c voltage (V)
ω_m	Angular mechanical velocity of the rotor (rad/s)
F	Combined viscous damping of motor and load (N·m/(rad/s))
T_e	Electromagnetic torque (Nm)
T_f	Combined friction torque of motor and load (Nm)

Ports

Input

Config — Block configuration signal vector

Configuration signal for the Induction Motor HDL block containing block configuration parameters.

Data Types: single | double | fixed point

PhaseVolt — Stator terminal voltages
1-by-3 array

Stator terminal voltages, V_a , V_b , and V_c , in V.

Data Types: single | double | fixed point

LdTrq/Spd — Load torque on motor or speed of motor shaft
scalar

This port supports one of these inputs:

- Load torque on the motor shaft, T_m , in N·m.
- Angular velocity of the motor, ω_m , in rad/s.

Data Types: single | double | fixed point

Output

Info — Bus signal
bus

The bus signal contains these block calculations.

Signal	Description	Variable	Units		
IaStator	Stator phase current A	i_a	A		
IbStator	Stator phase current B	i_b	A		
IcStator	Stator phase current C	i_c	A		
IdSync	Direct axis current	i_d	A		
IqSync	Quadrature axis current	i_q	A		
VdSync	Direct axis voltage	v_d	V		
VqSync	Quadrature axis voltage	v_q	V		
MtrSpd	Angular mechanical velocity of the rotor	ω_m	rad/s		
MtrMechPos	Rotor mechanical angular position	θ_m	rad		
MtrPos	Rotor electrical angular position	θ_e	rad		
MtrTrq	Electromagnetic torque	T_e	N·m		
PwrInfo	PwrTrnsfrd	PwrMtr	Mechanical power	P_{mot}	W
		PwrBus	Electrical power	P_{bus}	W
	PwrNotTrnsfrd	PwrElecLoss	Resistive power loss	P_{elec}	W
		PwrMechLoss	Mechanical power loss	P_{mech}	W
	PwrStored	PwrMtrStored	Stored motor power	P_{str}	W

PhaseCurr — Phase a, b, c current
1-by-3 array

Phase a, b, c current, i_a , i_b , and i_c , in A.

Torque — Motor torque
scalar

Motor torque, T_{mtr} , in N·m.

Speed — Motor speed
scalar

Angular speed of the motor, ω_{mtr} , in rad/s.

MtrElecAngle — Motor electrical angle
scalar

Electrical position of the motor, θ_{dq} , in rad.

Data Types: `single` | `double` | `fixed point`

Parameters

Sample time (s) — Sample time after which block executes again
`1e-6` (default) | scalar

The fixed time interval (in seconds) between every two consecutive instances of block execution.

Version History

Introduced in R2022b

Extended Capabilities

HDL Code Generation

Generate Verilog and VHDL code for FPGA and ASIC designs using HDL Coder™.

HDL Coder provides additional configuration options that affect HDL implementation and synthesized logic.

HDL Architecture

This block has one default HDL architecture.

HDL Block Properties

ConstrainedOutputPipeline	Number of registers to place at the outputs by moving existing delays within your design. Distributed pipelining does not redistribute these registers. The default is 0. For more details, see “ConstrainedOutputPipeline” (HDL Coder).
InputPipeline	Number of input pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “InputPipeline” (HDL Coder).

OutputPipeline	Number of output pipeline stages to insert in the generated code. Distributed pipelining and constrained output pipelining can move these registers. The default is 0. For more details, see “OutputPipeline” (HDL Coder).
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See Also

Induction Motor Configuration | Induction Motor

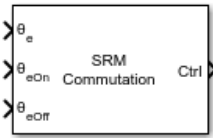
Topics

“Open-Loop and Closed-Loop Control”

“Field-Oriented Control (FOC)”

SRM Commutation

Generate switching sequences for n -phase switched reluctance motor (SRM)



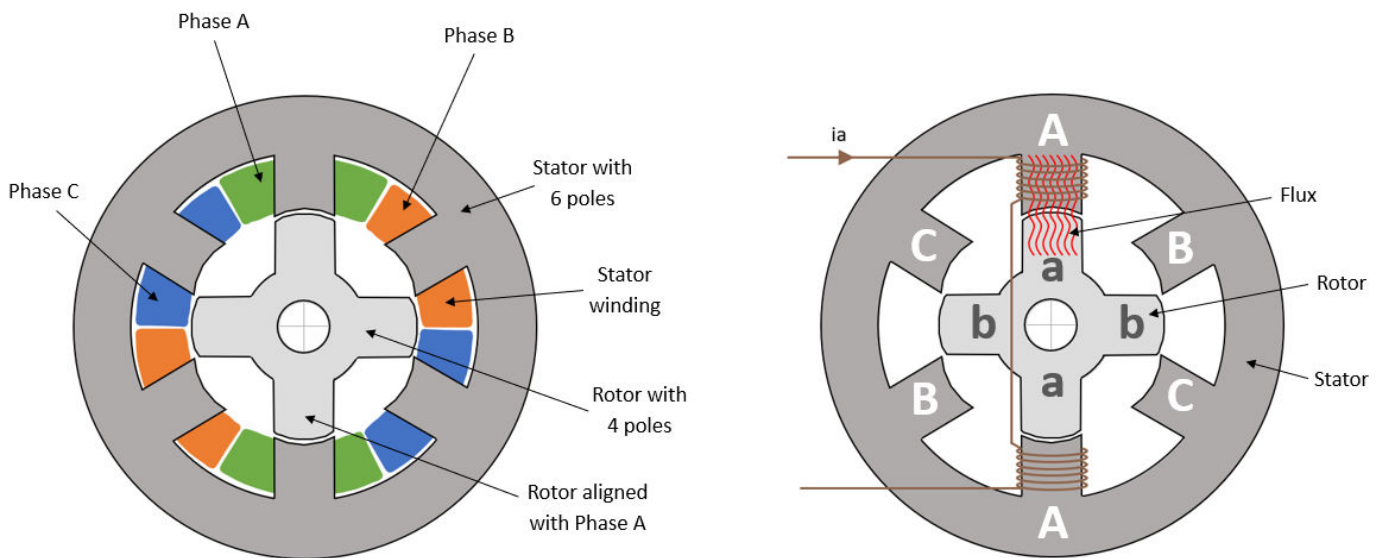
Libraries:

Motor Control Blockset / Controls / Control Reference

Description

The SRM Commutation block implements a commutation system that generates switching sequences to energize the stator windings of an n -phase SRM.

The block supports either a three-, four-, five-, or six-phase SRM.



6/4 switched reluctance motor (SRM)

For more details about the algorithm used by the block, see “Algorithm” on page 1-321.

Ports

Input

θ_e — Electrical motor position
scalar

Electrical position of the motor measured with respect to phase a , the first phase of the motor. The value should lie between $0 - 2\pi$ radians or $0 - 360$ degrees or $0 - 1$ per-unit.

Data Types: single | double | fixed point

θ_{eOn} — Turn on electrical motor position
scalar

Motor electrical position for phase a (phase used by θ_e input) at which the switching sequence turns 0 to 1 and energizes the corresponding phase. The value should lie between 0- 2π radians or 0-360 degrees or 0-1 per-unit.

Data Types: single | double | fixed point

θ_{eOff} — Turn off electrical motor position
scalar

Motor electrical position for phase a (phase used by θ_e input) at which the switching sequence turns 1 to 0 and de-energizes the corresponding phase. The value should lie between 0- 2π radians or 0-360 degrees or 0-1 per-unit.

Data Types: single | double | fixed point

Output

Ctrl — Control signal
vector

Combination of switching sequences that you can use to switch each phase On and Off to drive the motor.

Data Types: Boolean

Parameters

Number of motor phases — Number of phases in SRM
3 (default) | 4 | 5 | 6

The number of phases in the stator windings of SRM.

Input position units — Unit of position inputs
Radians (default) | Per unit | Degrees

Units used by the θ_e , θ_{eOn} , and θ_{eOff} inputs.

Algorithms

The block uses the electrical motor position (θ_e), electrical turn-on position (θ_{eOn}), and electrical turn-off position (θ_{eOff}) to generate n switching sequences (a vector of size n) for an n -phase SRM.

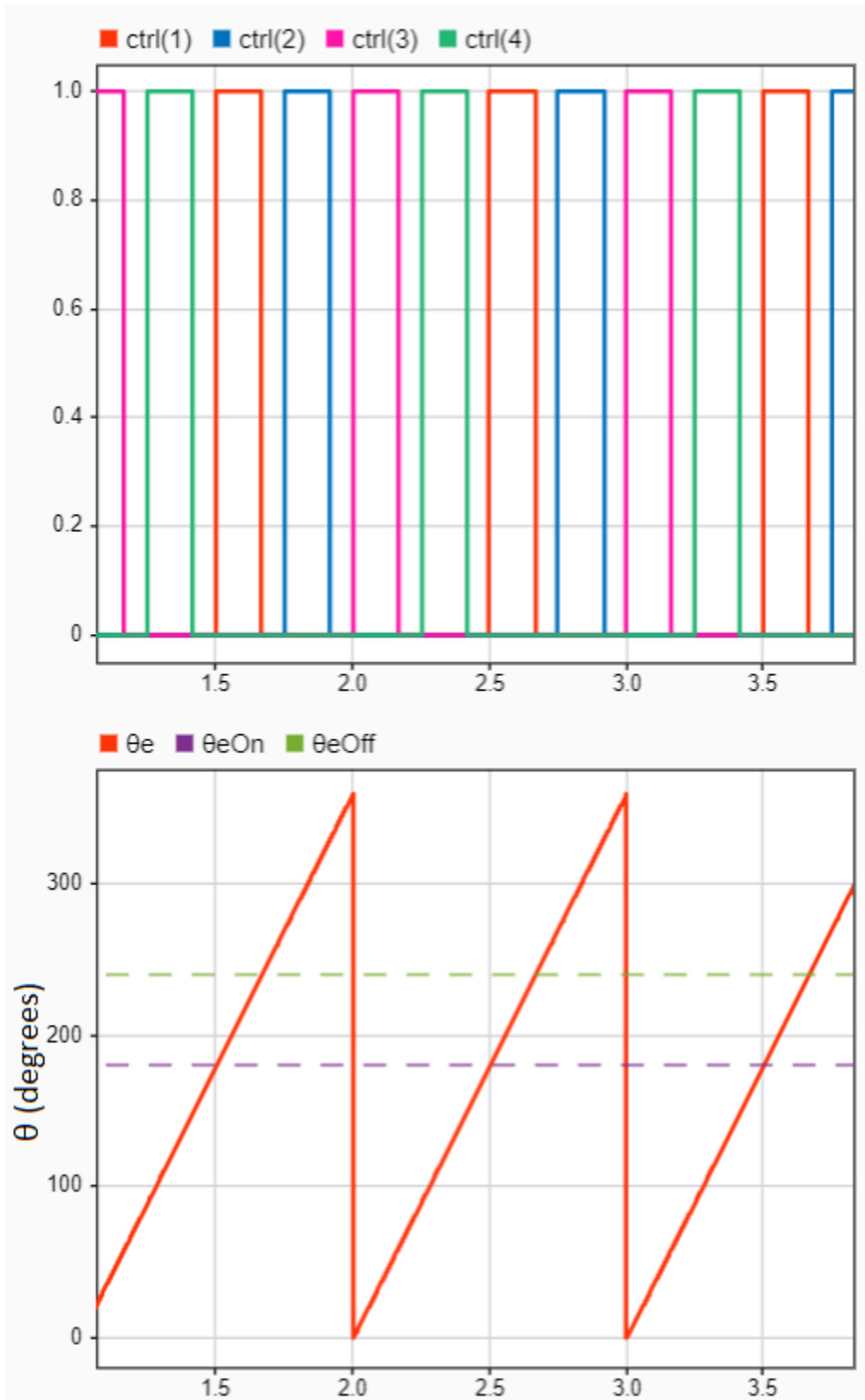
Each switching sequence (that forms a pulse train) can be used to control (turn on or off) the corresponding motor phase.

Each pulse in a switching sequence represents the activation period of the phase. The range of motor positions for which a phase activates is known as the dwell angle, $\theta_{dwell} = \theta_{eOff} - \theta_{eOn}$. When the motor electrical position falls within the dwell angle of a phase, the block outputs 1 to activate this phase.

For the first stator phase or phase A is as follows.

Block output	Condition
0	if $\theta_e < \theta_{eOn}$ or $\theta_e > \theta_{eOff}$
1	if $\theta_{eOn} \leq \theta_e \leq \theta_{eOff}$

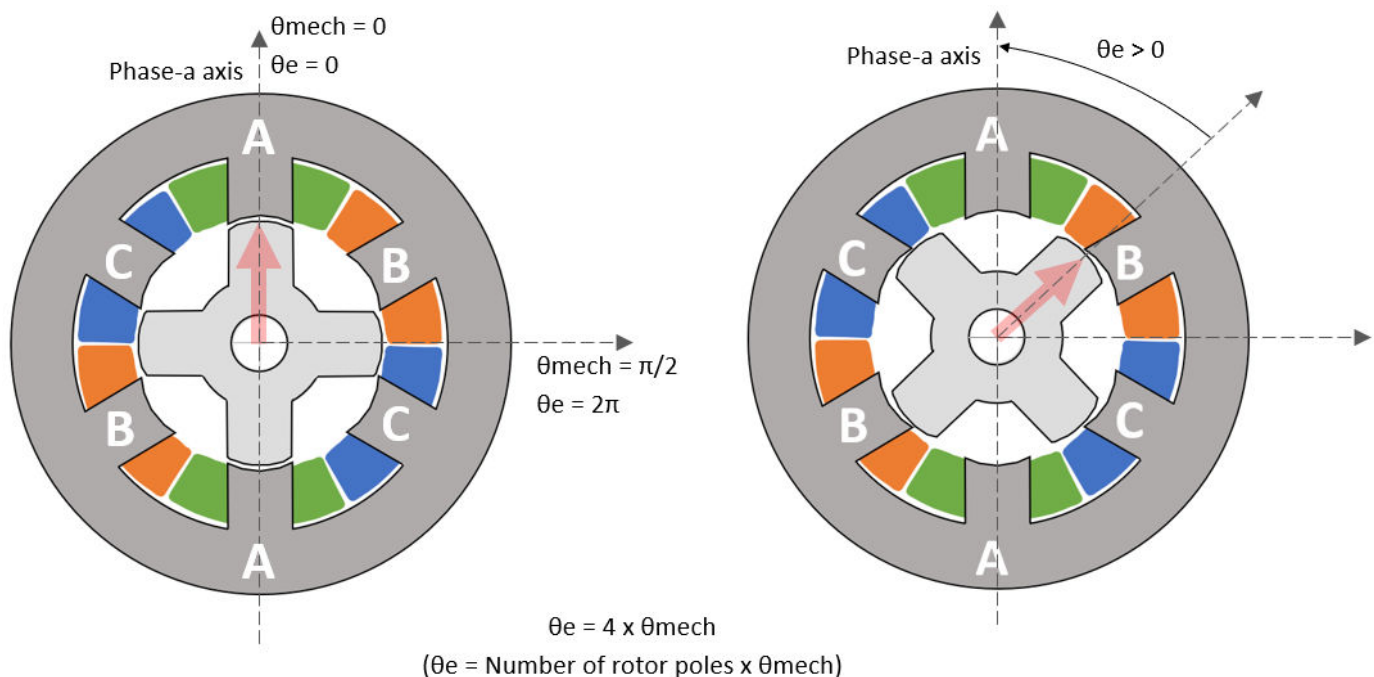
For subsequent phases, the block output (switching sequence) has an offset of $(m \times 2\pi) / n$ for the m^{th} motor phase (m is a value between 0 and n and n is the total number of motor phases).



Therefore, for an n -phase SRM, the block output is a combination of n such sequences (or pulse trains) that can be used with position sensor feedback and control loops to control the motor speed.

The direction in which the motor rotates depends on the sequence in which you excite the stator phases. You can use the block output to change this excitation sequence by providing appropriate inputs at θ_{eOn} and θ_{eOff} .

The block expects that the electrical motor position (θ_e) input is aligned with the first phase of the SRM (phase a or phase 1). The block internally computes the remaining electrical positions aligned with the subsequent phases and generates switching sequences for them. For example, for a 3-phase SRM, if you derive the θ_e input from the mechanical motor position aligned with motor phase a , then the block internally computes the required electrical positions for phases b and c and generates the commutation outputs for each of the three phases.



Note The block inputs should have the same position units.

Version History

Introduced in R2022b

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

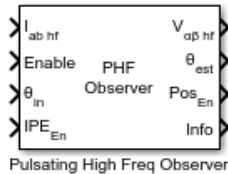
PI Controller | Switched Reluctance Machine

Topics

“Open-Loop and Closed-Loop Control”

Pulsating High Freq Observer

Estimate initial rotor electrical position of interior PMSM using pulsating high frequency (PHF) injection



Libraries:

Motor Control Blockset / Sensorless Estimators

Description

The PHF Observer block estimates the initial position (in electrical radians) of a stationary interior PMSM by using pulsating high-frequency (PHF) injection and dual-pulse (DP) techniques. In addition, the block also detects real-time position when the rotor runs using (low-speed) closed-loop control.

For more details about the algorithm used by the block, see “Algorithm” on page 1-333.

Ports

Input

$I_{ab\ hf}$ — PHF current response
vector

The high-frequency (phase a and b) current feedback from motor in response to the PHF voltage injection, in Amperes or per-unit.

Data Types: `single` | `double` | `fixed point`

Enable — Enable block
scalar

Port for signal to enable block. It supports one of the following input signals:

- 1 — Enable block operation
- 0 — Disable the block

Data Types: `Boolean`

θ_{in} — Initial rotor position
scalar

Initial rotor position input when the block skips the stage 1 initial position estimation (IPE) operation, in radians, degrees, or per-unit.

The unit depends on the **Position unit** parameter.

Data Types: `single` | `double` | `fixed point`

IPE_{En} — Enable stage 1 initial position estimation (IPE) operation
scalar

Port for signal to enable stage 1 IPE operation. It supports one of the following inputs:

- 1 — Enable the block to run stage 1 IPE followed by stage 2 closed-loop pulsating high-frequency (PHF) injection.
- 0 — Enable the block to skip stage 1 and directly run stage 2 closed-loop PHF injection.

Data Types: Boolean

Output

V_{αβ hf} — PHF output
scalar

Pulsating high-frequency voltage (in $\alpha\beta$ reference frame) output, in per-unit.

Data Types: single | double | fixed point

θ_{est} — Estimated rotor position
scalar

The rotor position estimated by the block, in radians, degrees, or per-unit.

The unit depends on the **Position unit** parameter.

Data Types: single | double | fixed point

Pos_{En} — Status of θ_{est} port
scalar

The port provides one of the following outputs:

- 1 — Indicates that stage 1 initial position estimation (IPE) is successfully complete and the θ_{est} port output is accurate.
- 0 — Indicates that stage 1 IPE is in progress (θ_{est} port output is not accurate as yet) or estimation has failed.

Data Types: single | double | fixed point

Info — Bus signal
bus

The bus signal contains these block calculations.

Signal	Description	Units
$\sin \theta_{est}$ and $\cos \theta_{est}$	Sine and cosine of estimated rotor position	-
I_d and I_q	Stator direct axis and quadrature axis currents	A

Signal		Description	Units
Convergence		Difference between current and previous sample of θ_{est} output. A value closer to zero indicates saturation of θ_{est} .	rad
Status	0	Block is not enabled (Enable input port is 0)	-
	1	Block is finding the best possible initial estimate (stage 1 part A)	-
	2	Block is running the PHF method (stage 1 part B)	-
	3	Block is running the DP Method (stage 1 part C)	-
	4	Block has successfully completed stage 1 and has started stage 2 closed-loop PHF injection	-
	5	Stage 1 part B failed due to a large error in the estimated rotor position	-

Parameters

Discrete step size (s) — Sample time after which block executes again
50e-6 (default) | scalar

The time between two consecutive instances of block execution.

Input units — Unit of block inputs
Per-unit (default) | SI

Units for the block inputs.

Datatype — Input and output data type
single (default) | double | fixdt(1,16) | fixdt(1,16,0) | fixdt(1,16,2^0,0) | <data type expression>

Data type of the block inputs and outputs.

Compute PHF parameters automatically using motor parameters — Automatically compute PHF parameters
off (default) | on

Selecting this parameter enables the block to automatically compute the following PHF parameters (available in the **PHF Parameters** tab) using the specified motor parameters:

- **PHF frequency (Hz)**
- **LP filter cutoff frequency (Hz)**
- **Proportional gain**
- **Integral gain**

- **Expected settling time (s)**
- **Expected damping ratio**
- **Open loop duration (s)**
- **Close loop duration (s)**
- **Idle time (s)**

For more details about computation of these PHF parameters, see “Compute PHF Parameters” on page 1-343.

Dependencies

If you select this parameter, the block disables the **Compute PHF parameters** button.

Compute DP parameters automatically using motor parameters — Automatically compute DP parameters

off (default) | on

Selecting this parameter enables the block to automatically compute the DP parameter **Pulse duration (s)** (available in the **DP Parameters** tab) using the specified motor parameters.

For more details about computation of the DP parameter, see “Compute DP Parameters” on page 1-344.

Dependencies

If you select this parameter, the block disables the **Compute DP parameters** button.

Motor Parameters

Stator resistance (ohm) — Motor resistance

0.1458 (default) | scalar

Resistance of the stator (in Ohms).

Stator d-axis inductance (H) — Motor inductance

0.00013016 (default) | scalar

Inductance of stator along *d*-axis of the *d-q* reference frame.

Stator q-axis inductance (H) — Motor inductance

0.00014098 (default) | scalar

Inductance of stator along *q*-axis of the *d-q* reference frame.

Base voltage (V) — Rated voltage

13.8564 (default) | scalar

Rated voltage of the motor (in Volts).

Base current (A) — Rated current

21.4286 (default) | scalar

Rated current of the motor (in Amperes).

Compute PHF parameters — Compute PHF parameters manually
button

When you click this button, the block computes the following PHF parameters (available in the **PHF Parameters** tab) manually using the specified motor parameters:

- **PHF frequency (Hz)**
- **LP filter cutoff frequency (Hz)**
- **Proportional gain**
- **Integral gain**
- **Expected settling time (s)**
- **Expected damping ratio**
- **Open loop duration (s)**
- **Close loop duration (s)**
- **Idle time (s)**

For more details about computation of these PHF parameters, see “Compute PHF Parameters” on page 1-343.

Dependencies

To enable this parameter, clear the **Compute PHF parameters automatically using motor parameters** parameter.

Compute DP parameters — Compute DP parameters manually
button

When you click this button, the block computes the DP parameter **Pulse duration (s)** (available in the **PHF Parameters** tab) manually using the specified motor parameters:

For more details about computation of the DP parameter, see “Compute DP Parameters” on page 1-344.

Dependencies

To enable this parameter, clear the **Compute DP parameters automatically using motor parameters** parameter.

PHF Parameters

PHF peak voltage (PU) — Peak voltage of PHF
0.2 (default) | scalar

Peak amplitude of the PHF voltage applied by the block, in Volts.

PHF frequency (Hz) — PHF voltage frequency
2000 (default) | scalar

Frequency of the PHF voltage applied by the block, in Hz.

LP filter cutoff frequency (Hz) — Cutoff frequency for lowpass filter of PHF
131.9037 (default) | scalar

Cutoff frequency of the lowpass filter for the PHF applied by the block, in Hz.

Select tuning parameters — Select control parameters for manual tuning
Controller gains (default) | Time response variables

Select the control parameters that you want to manually tune.

- **Controller gains** — Select this value to enable the following control parameters for editing:
 - **Proportional gain**
 - **Integral gain**

Note Selecting **Controller gains** disables the time response variables.

- **Time response variables** — Select this value to enable the following control parameters for editing:
 - **Expected settling time (s)**
 - **Expected damping ratio**

Note Selecting **Time response variables** disables the control gains variables.

To see the effects of the tuned parameters on the disabled control parameters, you can click the **Compute Control Parameters** button. For more details, see “Compute Control Parameters” on page 1-0 .

Proportional gain — Proportional gain for PI controller of PHF
1954.6647 (default) | scalar

Proportional PI controller gain K_p for the PHF applied by the block.

Dependencies

To enable this parameter, set **Select tuning parameters** parameter to **Controller gains**.

Integral gain — Integral gain for PI controller of PHF
7392.5303 (default) | scalar

Integral PI controller gain K_i for the PHF applied by the block.

Dependencies

To enable this parameter, set **Select tuning parameters** parameter to **Controller gains**.

Expected settling time (s) — Expected settling time of estimated position
0.66794 (default) | scalar

The expected time for the block output θ_{est} to saturate during Part B.

Dependencies

To enable this parameter, set **Select tuning parameters** parameter to **Time response variables**.

Expected damping ratio — Expected damping ratio of block output θ_{est}
0.99 (default) | scalar

The expected damping ratio of the block output θ_{est} dynamics.

Dependencies

To enable this parameter, set **Select tuning parameters** parameter to Time response variables.

Compute Control Parameters — Compute disabled control parameters button

Compute the control parameters that are disabled in the **Control Parameters** section. This button helps you update the disabled control parameters according to the edits that you make to the enabled control parameters. The following table describes the equations that the block uses to compute the disabled control parameters:

Control Parameter	Expression or Value	Remarks
Proportional gain, k_p	$\frac{\ln(20000)}{G \cdot T_{settling}}$	The Compute Control Parameters button computes these values when you enable the time response variables for manual edits.
Integral gain, k_i	$\frac{G(k_p)^2}{4\delta^2}$	
Expected settling time (s), $T_{settling}$	$\frac{\ln(20000)}{G \cdot k_p}$, when $\delta \leq 1$ $\frac{\ln(20000)}{G \cdot k_p} \left(\frac{2\delta}{(\delta - \sqrt{\delta^2 - 1})} \right)$, when $\delta > 1$	The Compute Control Parameters button computes these values when you enable the controller gains for manual edits.
Expected damping ratio, δ	$\frac{k_p \sqrt{G}}{2 \sqrt{k_i}}$	

where:

- $G = \frac{V_{phf}(L_q - L_d)}{4\pi f_h L_d L_q}$
- V_{phf} is the peak amplitude value of the injected high frequency voltage signal (in Volts).
- L_d and L_q are the d and q axis stator inductances (in Henry).
- f_h is the frequency of injected high frequency voltage.

Note The expressions in the preceding table use elements and values based on the reference papers as well as experimental data.

Open loop duration (s) — Duration of open-loop PHF injection during stage 1 part A
0.0066794 (default) | scalar

Duration of the open-loop PHF injection during stage 1 part A, in seconds.

Close loop duration (s) — Duration of closed-loop PHF injection during stage 1 part B
0.66794 (default) | scalar

Duration of the closed-loop PHF injection during stage 1 part B, in seconds.

Idle time (s) — Duration between algorithm steps

0.0066794 (default) | scalar

Duration (in seconds) between steps in the algorithm related to stage 1 part A and stage 1 part B that allow for fading of transient dynamics. For example, this block stops operating (for this duration) between each PHF injection (open-loop or closed-loop).

Error threshold (rad) — Minimum error threshold for θ_{err}

4e-4 (default) | scalar

The minimum error value θ_{err} at which the convergence of estimated rotor position θ_{est} completes.

DP Parameters

Pulse voltage (PU) — Amplitude of injected pulses

0.5 (default) | scalar

Voltage amplitude of the injected pulses, in Volts.

Pulse duration (s) — Duration of injected pulses

0.00066955 (default) | scalar

Duration of the injected pulses, in seconds.

Idle time (s) — Duration between two pulses during dual-pulse injection

50e-3 (default) | scalar

Duration (in seconds) between two pulses during dual-pulse injection (stage 1 part C).

Algorithms

The block determines the best possible initial estimation for the rotor position using open-loop PHF injection, which it uses to run closed-loop PHF.

The block executes closed-loop PHF by injecting a high-frequency signal into the estimated rotor position to determine the actual rotor position without spinning the motor. This technique works when the motor saliency ratio (L_q/L_d) is greater than 1. Due to a limitation in the PHF method, the estimated position can show ambiguity equal to the value of π (pi). The dual-pulse (DP) method uses polarity detection to resolve the ambiguity of π and applies a compensation of π if there is an error. The estimated rotor position ranges from 0 to 2π electrical radians.

The block can run in these two stages:

- 1 Stage 1 - Initial position estimation (IPE), which includes three parts.
- 2 Stage 2 - Closed-loop pulsating high-frequency (PHF) injection.

After Stage 1 completes, you can continue to run the block in Stage 2 where it computes the rotor position while the motor runs using closed loop control (for example, field-oriented control or FOC). Using the Stage 2 algorithm (closed-loop PHF injection), the block can continue to inject pulsating high frequency (as described in Part B) and use the numerical analysis of the resulting stator current response to compute and track the rotor position during closed-loop operation.

Stage 1 focuses on determining the initial position of the rotor when it is stationary. This stage includes the following three parts.

Part A: Find Best Possible Initial Estimation

The block uses the PHF injection technique. PHF injection needs initial estimation to start the algorithm.

If you use only one initial estimation, θ_{i_est} , (for PHF) for all possible actual rotor positions, the block algorithm might not work accurately for certain actual rotor positions when the motor has low saliency. These ambiguous positions are:

- 1 When θ_{actual} lies in the range $\left[\left(\theta_{i_est} + \frac{\pi}{2} - 0.1\right), \left(\theta_{i_est} + \frac{\pi}{2} + 0.1\right)\right]$
- 2 When θ_{actual} lies in the range $\left[\left(\theta_{i_est} - \frac{\pi}{2} - 0.1\right), \left(\theta_{i_est} - \frac{\pi}{2} + 0.1\right)\right]$
- 3 When θ_{actual} lies in the range $\left[\left(\theta_{i_est} + \pi - 0.1\right), \left(\theta_{i_est} + \pi + 0.1\right)\right]$

To make PHF work for motors with low saliency, the block picks different initial estimation for different actual rotor positions.

The block picks the best possible initial estimation from these three alternatives:

- 1 $\theta_{i_est} = 0$
- 2 $\theta_{i_est} = 2\pi/3$
- 3 $\theta_{i_est} = -2\pi/3$

Therefore, the block sequentially injects three high-frequency voltage signals (that have the same peak amplitude V_{phf} and the same frequency f_h) across the preceding 3 θ_{i_est} values and measures the resulting i_q currents.

Note In Part A, each high frequency voltage signal injection happens for a fixed time duration (**Open loop duration (s)** parameter). In addition, two consecutive injections have a fixed delay between them (**Idle time (s)** parameter).

The following equations describe the injected voltages in the estimated d - q reference frame:

$$\begin{aligned} v_{d_est} &= V_{phf} \sin(2\pi f_h t) \\ v_{q_est} &= 0 \end{aligned}$$

The following equations describe the injected voltages in the estimated α - β reference frame:

$$\begin{aligned} v_{\alpha} &= V_{phf} \cos(\theta_{i_est}) \sin(2\pi f_h t) \\ v_{\beta} &= V_{phf} \sin(\theta_{i_est}) \sin(2\pi f_h t) \end{aligned}$$

The following equations describe the injected voltages in the actual d - q reference frame:

$$\begin{aligned} v_d &= V_{phf} \cos(\theta_{err}) \sin(2\pi f_h t) \\ v_q &= -V_{phf} \sin(\theta_{err}) \sin(2\pi f_h t) \end{aligned}$$

We can derive the following equation for the resulting i_q current using the IPMSM motor dynamic equations:

$$i_q = \frac{V_{phf}(L_d - L_q)\sin(2\theta_{err})}{4\pi f_h L_d L_q} \cos(2\pi f_h t)$$

$$i_{q_peak} \propto |\sin(2\theta_{err})|$$

Therefore, $i_{q_peak} \propto |\sin(2(\theta_{actual} - \theta_{i_est}))|$

, where

θ_{i_est} — Initial estimation of rotor position (which can be either 0 , $2\pi/3$, or $-2\pi/3$) (in degrees, per-unit, or radians).

θ_{actual} — Actual rotor position (in degrees, per-unit, or radians)

$\theta_{err} = \theta_{actual} - \theta_{i_est}$ (in degrees, per-unit, or radians).

L_d and L_q are the d and q axis inductances of the IPMSM.

V_{d_est} and V_{q_est} are the voltages injected across the d and q axes of the estimated d - q reference frame.

V_d and V_q are the voltages injected across the d and q axes of the actual d - q reference frame.

V_α and V_β are the voltages injected across the α and β axes of the stationary α - β reference frame.

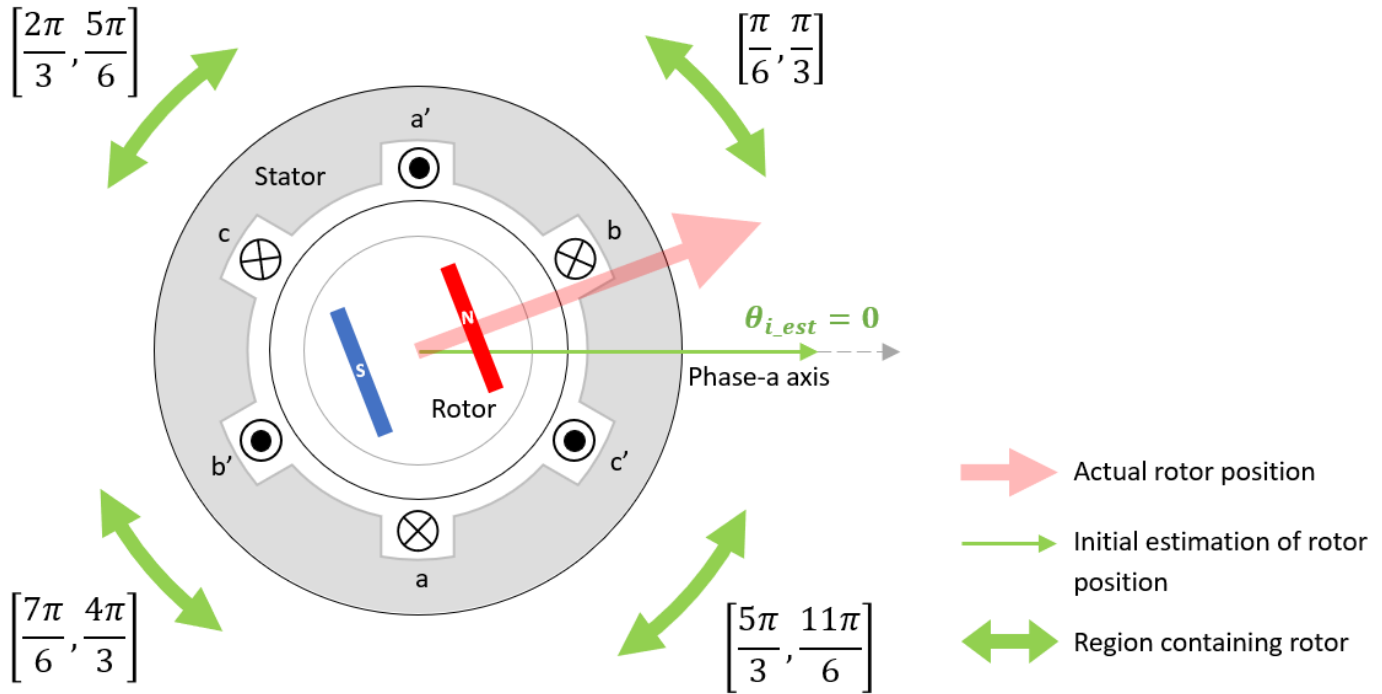
With

$$i_{q1} = i_{q_peak} \text{ for } \theta_{i_est} = 0$$

$$i_{q2} = i_{q_peak} \text{ for } \theta_{i_est} = 2\pi/3$$

$$i_{q3} = i_{q_peak} \text{ for } \theta_{i_est} = -2\pi/3$$

For $\theta_{i_est} = 0$, when you vary θ_{actual} from 0 to 2π , $i_{q1} \propto |\sin 2(\theta_{actual} - 0)|$ is the maximum value between the i_{q1} , i_{q2} , and i_{q3} current peak values when the rotor lies in the following four highlighted regions.

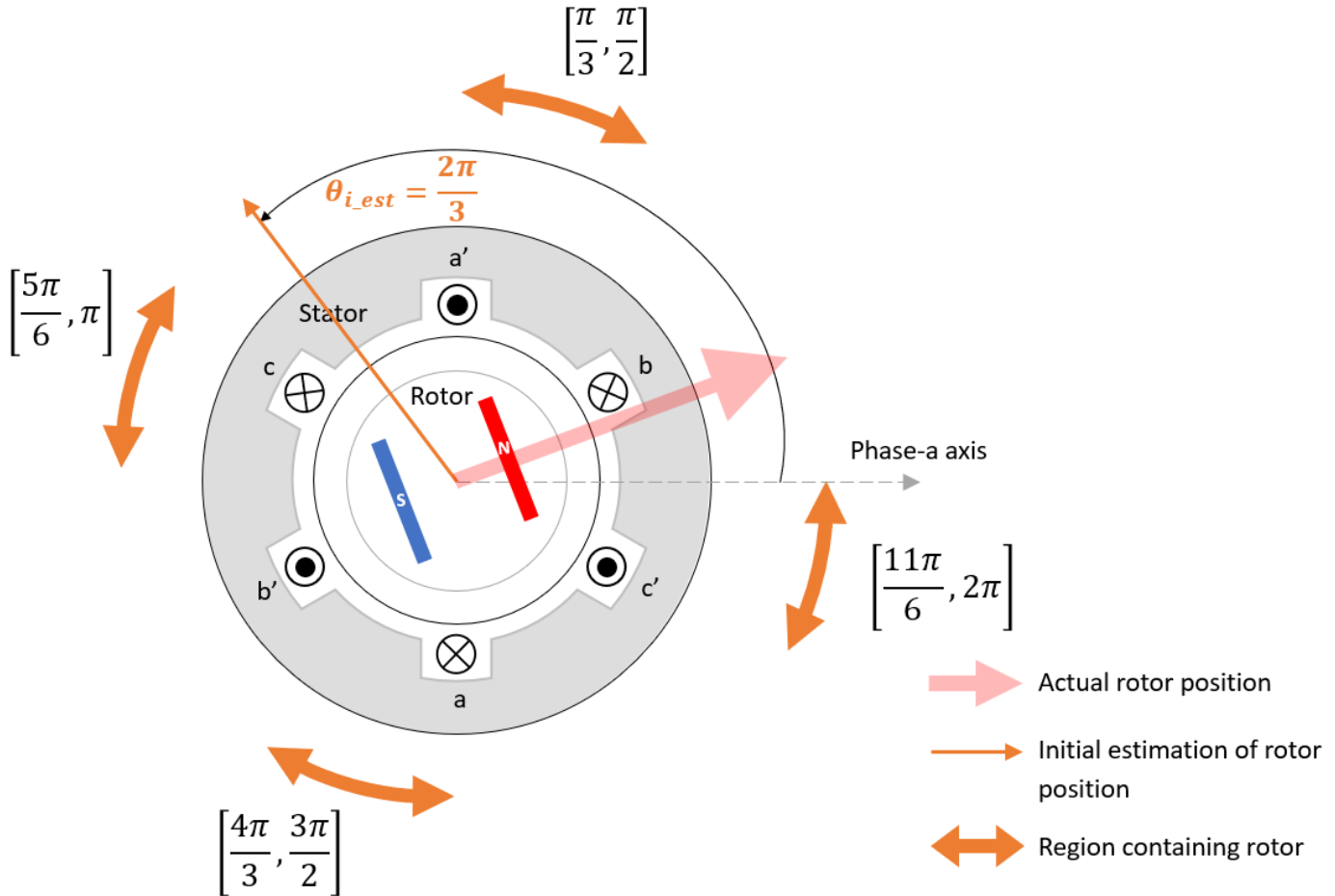


If $\theta_{i_est} = 0$ is used for all $\theta_{actual} = 0$ to 2π , the algorithm fails for following ambiguous regions (when motor saliency is low):

- 1 θ_{actual} lies in the range $\left[\left(0 + \frac{\pi}{2} - 0.1\right), \left(0 + \frac{\pi}{2} + 0.1\right)\right]$
- 2 θ_{actual} lies in the range $\left[\left(0 - \frac{\pi}{2} - 0.1\right), \left(0 - \frac{\pi}{2} + 0.1\right)\right]$
- 3 θ_{actual} lies in the range $\left[\left(0 + \pi - 0.1\right), \left(0 + \pi + 0.1\right)\right]$

Because these ambiguous regions are not present in the preceding four regions, you can eliminate the regions where the algorithm might fail.

For $\theta_{i_est} = (2\pi/3)$, when you vary θ_{actual} from 0 to 2π , $i_{q2} \propto \left| \sin 2\left(\theta_{actual} - \frac{2\pi}{3}\right) \right|$ is the maximum value between the i_{q1} , i_{q2} , and i_{q3} current peak values when the rotor lies in the following four highlighted regions.

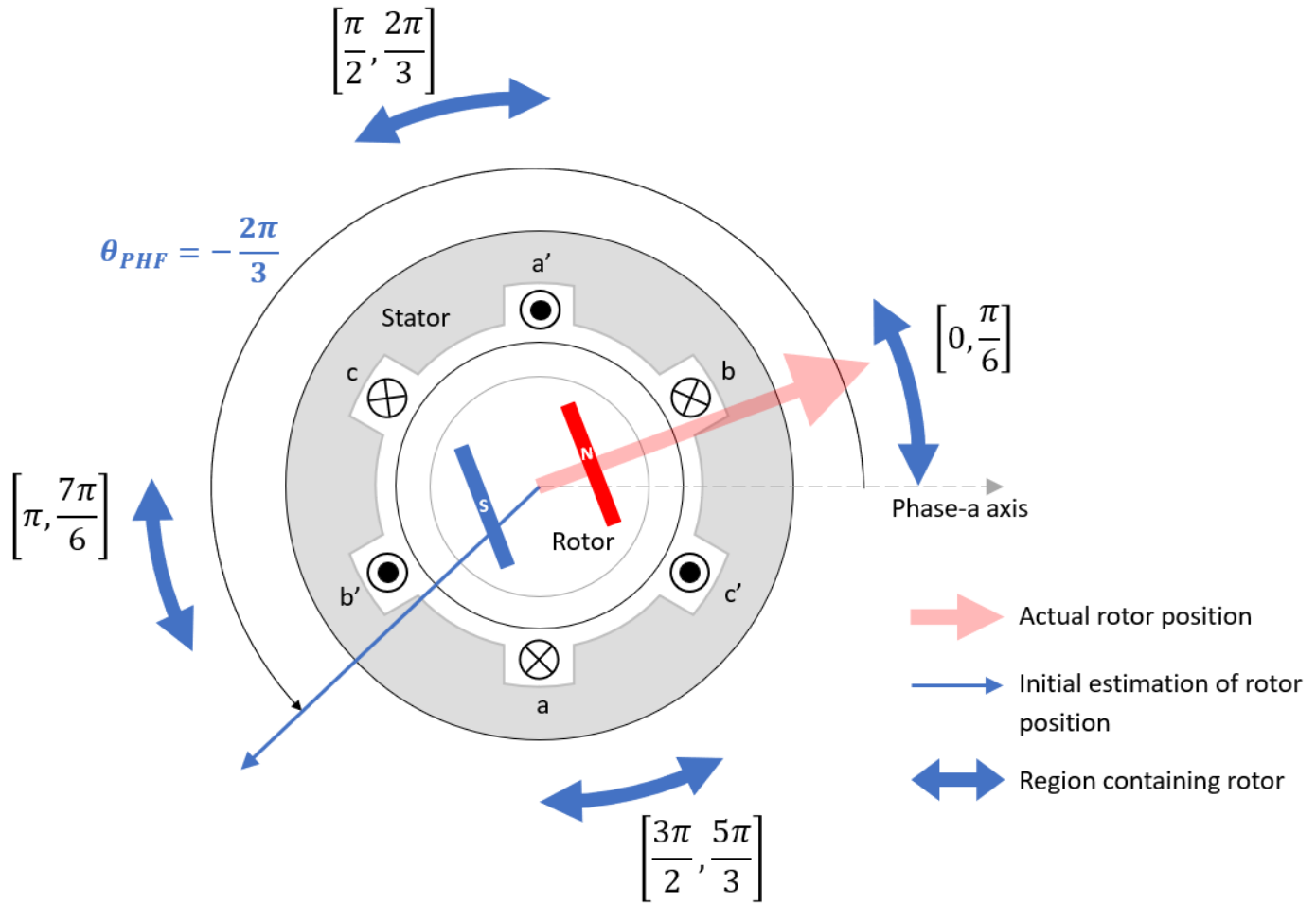


If $\theta_{i_est} = (2\pi/3)$ is used for all $\theta_{actual} = \theta$ to 2π , the algorithm fails for following ambiguous regions (when motor saliency is low):

- 1 θ_{actual} lies in the range $\left[\left(\frac{2\pi}{3} + \frac{\pi}{2} - 0.1\right), \left(\frac{2\pi}{3} + \frac{\pi}{2} + 0.1\right)\right]$
- 2 θ_{actual} lies in the range $\left[\left(\frac{2\pi}{3} - \frac{\pi}{2} - 0.1\right), \left(\frac{2\pi}{3} - \frac{\pi}{2} + 0.1\right)\right]$
- 3 θ_{actual} lies in the range $\left[\left(\frac{2\pi}{3} + \pi - 0.1\right), \left(\frac{2\pi}{3} + \pi + 0.1\right)\right]$

Because these ambiguous regions are not present in the preceding four regions, you can eliminate the regions where the algorithm might fail.

For $\theta_{i_est} = -(2\pi/3)$, when you vary θ_{actual} from θ to 2π , $i_{q3} \propto \left| \sin 2(\theta_{actual} - (-\frac{2\pi}{3})) \right|$ is the maximum value between i_{q1} , i_{q2} , and i_{q3} current peak values when the rotor lies in the following four highlighted regions.

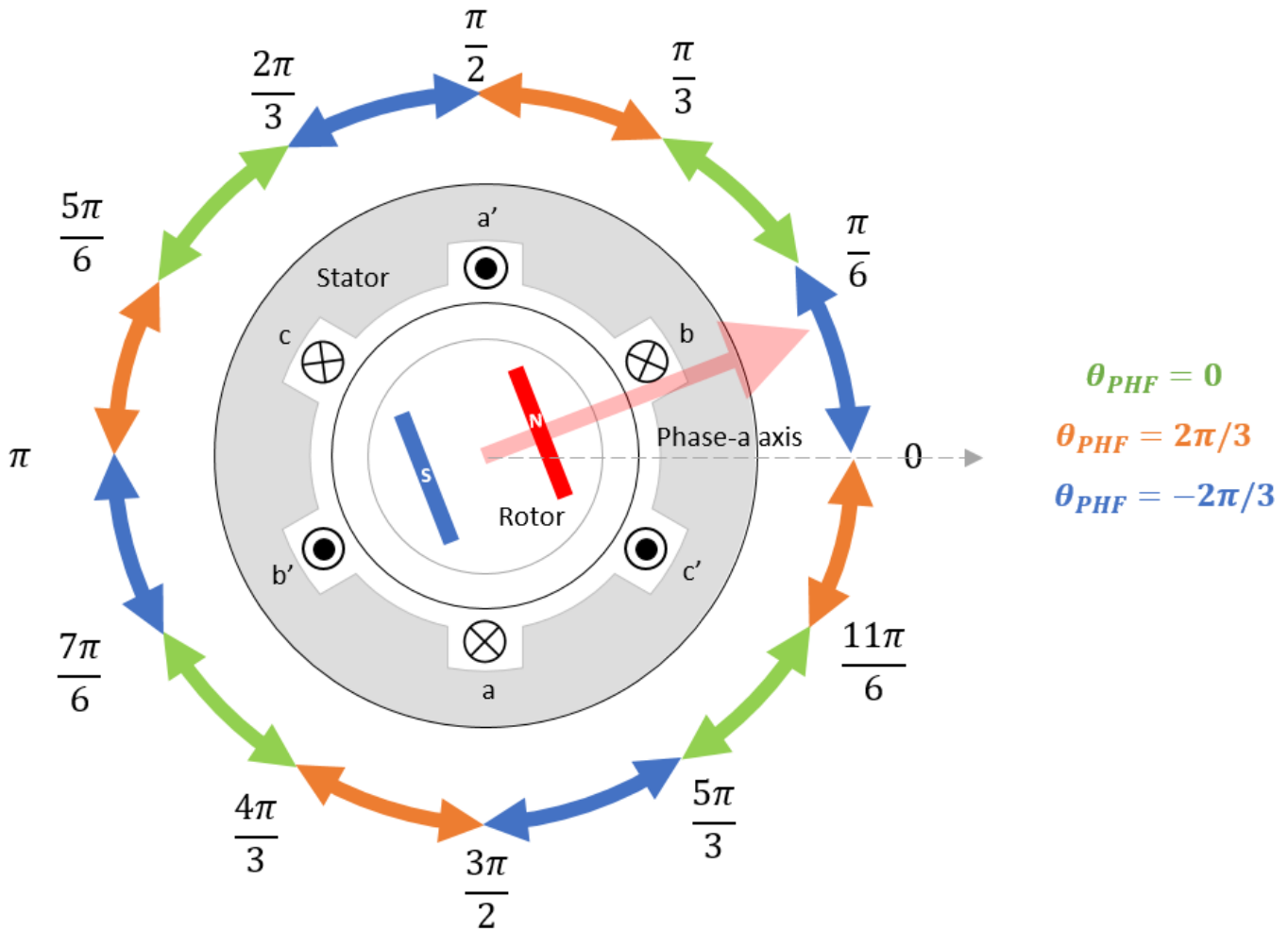


If $\theta_{i_est} = -(2\pi/3)$ is used for all $\theta_{actual} = 0$ to 2π , the algorithm fails for following ambiguous regions (when motor saliency is low):

- 1 θ_{actual} lies in the range $\left[\left(-\frac{2\pi}{3} + \frac{\pi}{2} - 0.1 \right), \left(-\frac{2\pi}{3} + \frac{\pi}{2} + 0.1 \right) \right]$
- 2 θ_{actual} lies in the range $\left[\left(-\frac{2\pi}{3} - \frac{\pi}{2} - 0.1 \right), \left(-\frac{2\pi}{3} - \frac{\pi}{2} + 0.1 \right) \right]$
- 3 θ_{actual} lies in the range $\left[\left(-\frac{2\pi}{3} + \pi - 0.1 \right), \left(-\frac{2\pi}{3} + \pi + 0.1 \right) \right]$

Because these ambiguous regions are not present in the preceding four regions, you can eliminate the regions where the algorithm might fail.

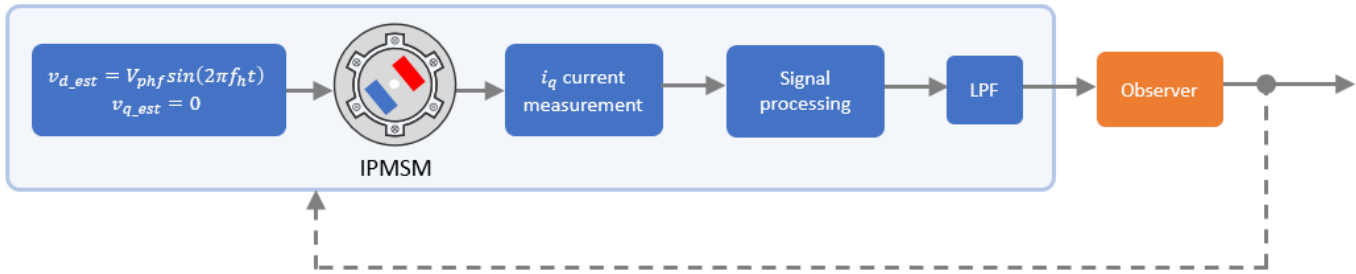
Therefore, using this approach you have three sets of regions corresponding to three different initial estimates. These three sets or regions cover all the motor sectors where the rotor can lie:



In part A, the block picks the θ_{i_est} corresponding to the maximum i_q peak current value between i_{q1} , i_{q2} , and i_{q3} for Part B.

Part B: Pulsating High-Frequency (PHF) Method

After determining the best possible initial estimate θ_{i_est} , the block injects a sinusoidal high-frequency voltage (with peak amplitude V_{phf} and frequency f_h) along the finalized $(\theta_{est} | t = 0) = \theta_{i_est}$ and reads the q -axis current response of the motor as described in Part A. However, in addition, it applies signal processing routines on the q -axis current response to make corrections to θ_{est} using a PI controller in a closed-loop configuration as shown below:



Model 1: PHF injection and current measurement

The following steps describe the signal processing routines used by the block:

- 1 Multiply the measured i_q with cosine signal (with unit amplitude and frequency f_h) to obtain the following signal:
 $i_q \cos(\omega_h t)$
- 2 Apply low-pass filter (LPF) to extract the bias term in the preceding result.
- 3 Negate the output of step 2.

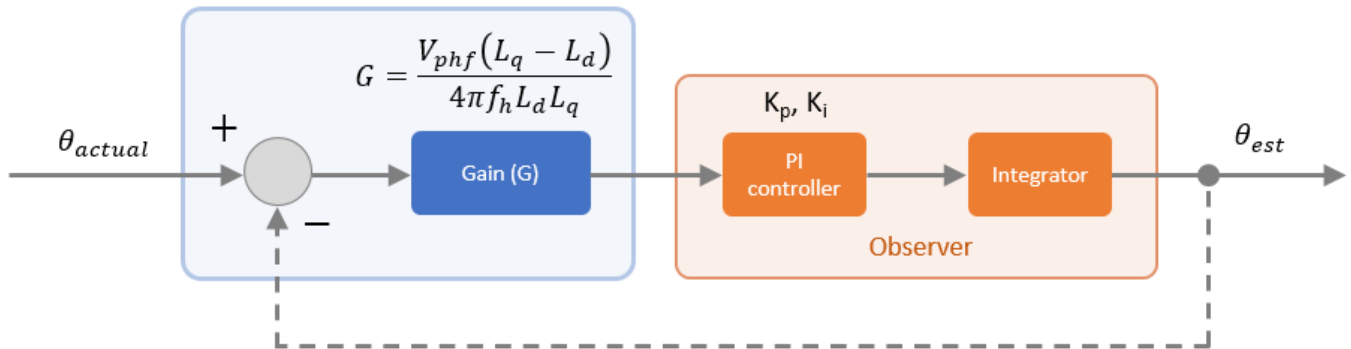
From the output of the preceding 3 steps, we can derive the following error signal:

$$Error_signal = \frac{V_{phf}(L_q - L_d)\sin(2\theta_{err})}{8\pi f_h L_d L_q}$$

Because we can approximate $\sin(\theta)$ to θ (when θ is close to zero), we can derive the following approximated error signal after considering that θ_{err} is close to zero:

$$Error_signal_approximated = \frac{V_{phf}(L_q - L_d)}{4\pi f_h L_d L_q} \theta_{err} = \frac{V_{phf}(L_q - L_d)}{4\pi f_h L_d L_q} (\theta_{actual} - \theta_{est}) = G(\theta_{actual} - \theta_{est})$$

Therefore, using the preceding result, we can simplify model 1 as shown below:



Model 2: Simplified model with approximations

The following term represents the transfer function (simplified) of the entire model:

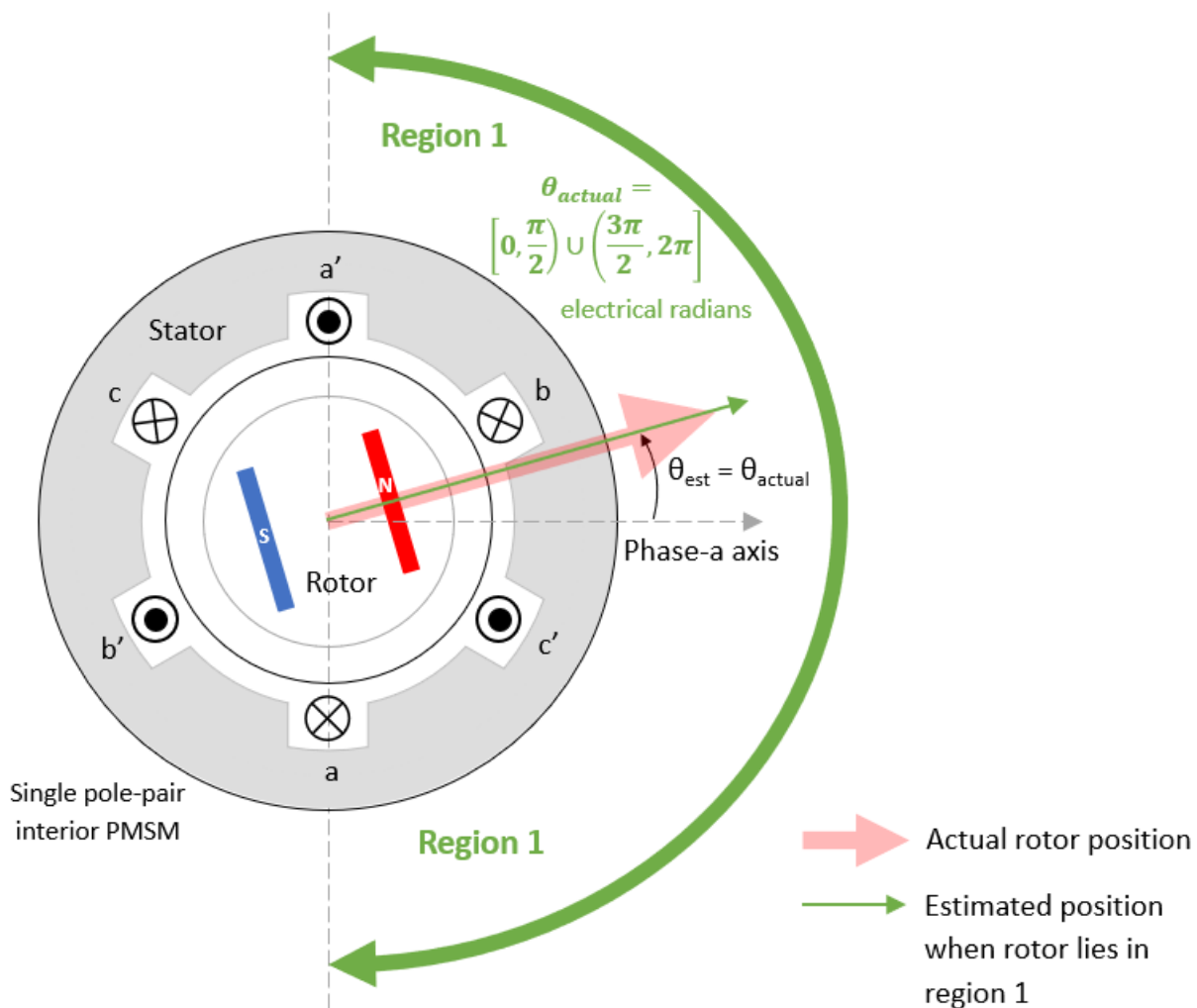
$$\frac{Gk_p s + Gk_i}{s^2 + Gk_p s + Gk_i}$$

where, k_p and k_i proportional and integral gains of the PI controller.

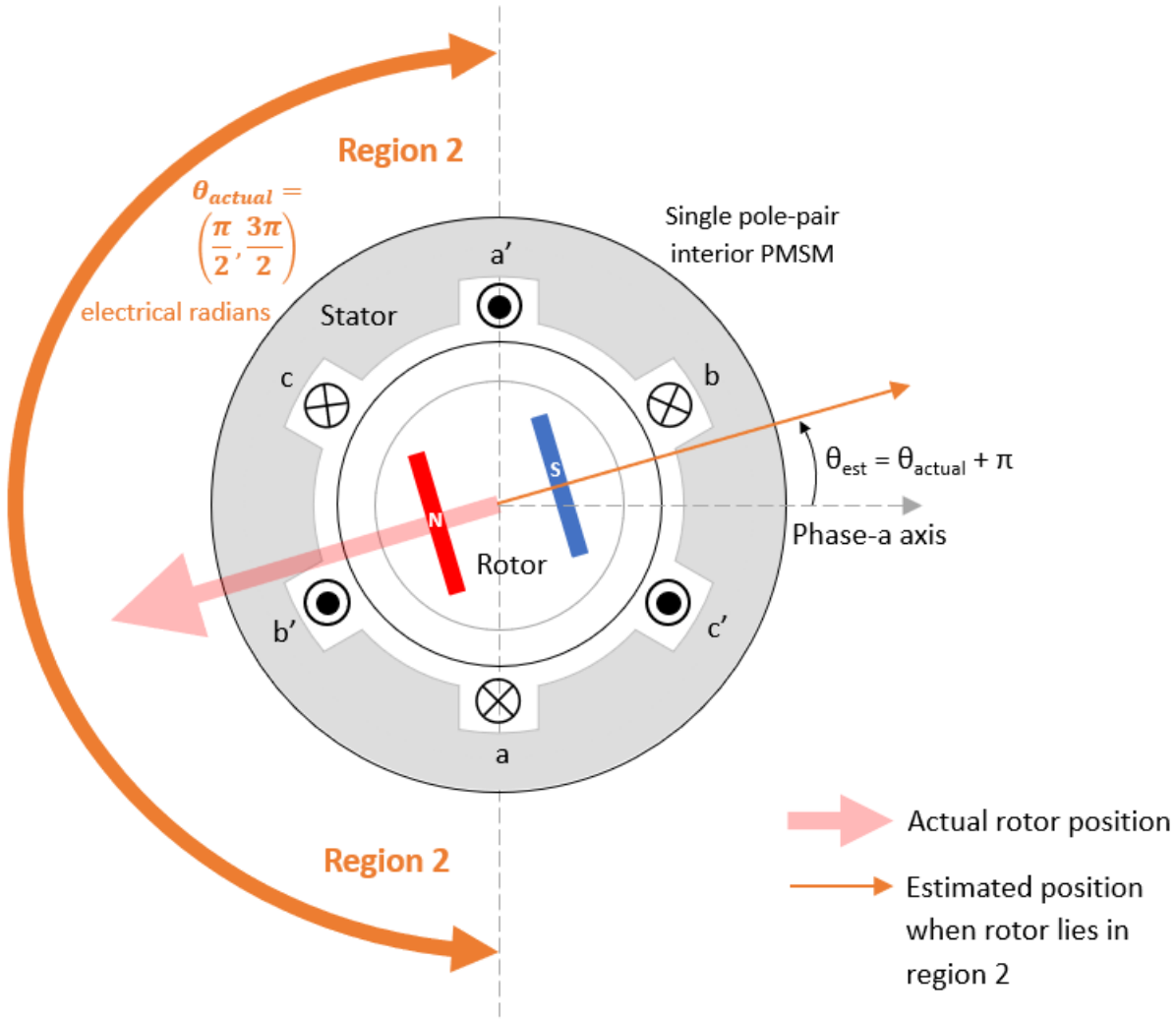
Therefore, when the block executes, the estimated position is initially θ_{i_est} , but it rises steadily (dynamically according to G , k_p , and k_i gains) to saturate at a certain angle (with respect to a -axis) such that $Error_signal$ is close to zero.

Note In Part B, the high frequency voltage signal injection happens for a given time duration (**Close loop duration (s)** parameter). Select this time duration such that the dynamics of θ_{est} reaches saturation.

The approximation used earlier introduces a limitation in the PHF method due to which the algorithm might compute the rotor position with an ambiguity of π . If the rotor lies in the range $\theta_{actual} = \left(0, \frac{\pi}{2}\right) \cup \left[\frac{3\pi}{2}, 2\pi\right)$ electrical radians (region 1), the estimated position is accurate (π compensation is not required).



If the rotor lies in the range $\theta_{actual} = \left(\frac{\pi}{2}, \frac{3\pi}{2}\right)$ electrical radians (region 2), the estimated position shows an ambiguity of π (π compensation is required).



Therefore, the block uses the dual-pulse method to determine if the estimated position needs π compensation.

Part C: Dual-Pulse (DP) Method

The block injects two very short duration voltage pulses (with the same width and magnitude) in the following positions:

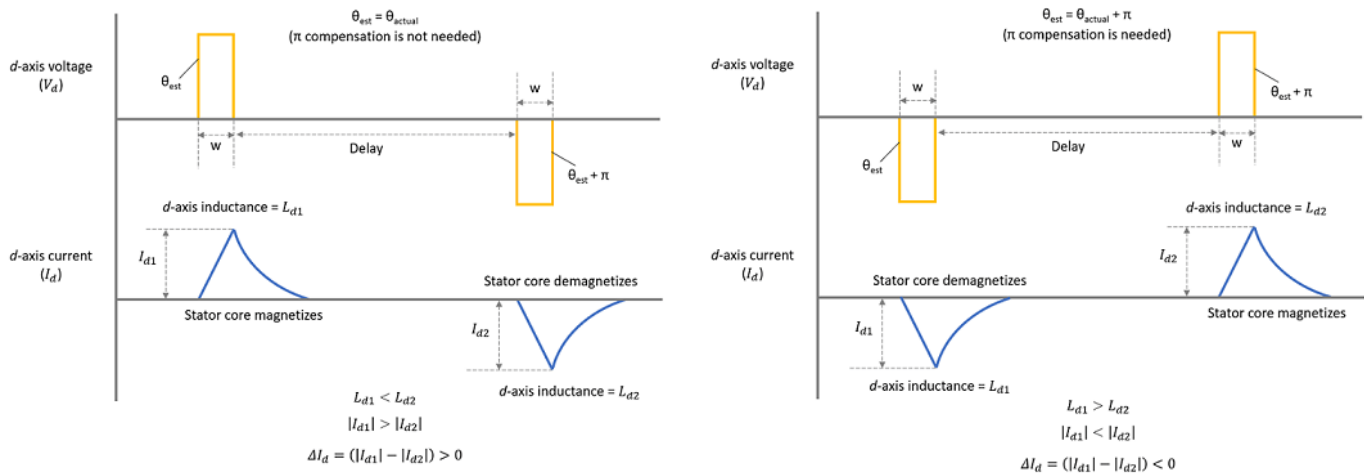
- Pulse 1 at the rotor position estimated in Part B
- Pulse 2 at the rotor position estimated in Part B + π

Because pulse width is very short, the motor does not run, and the rotor remains stationary after pulse injection.

The interaction between the resulting stator magnetic flux and the rotor permanent magnets results in two current impulses along the d -axis of the rotor that rise and fall quickly.

Because the stator core is saturated, it shows nonlinear behaviour. A small L_d results in higher current I_d , and a high L_d results in smaller current I_d . Therefore, the I_d current impulses generated by Pulse 1 and Pulse 2 show different peak values.

Note The pulse duration of the injected voltage pulses is large enough to obtain a measurable difference between the peak current values. At the same time, the duration is not too high, because, when the pulse duration exceeds a certain limit, the rotor may start spinning.



The block computes the difference between the peak values of the two current impulses ΔI_d to determine if the position estimated in Part A needs π compensation.

$$\Delta I_d = |I_{d1}| - |I_{d2}|$$

PHF injection benefits use cases that require the rotor to remain stationary or that require position estimation without starting the motor. The PHF injection technique also benefits use cases where you need to avoid open loop runs to estimate position (before transitioning to closed-loop speed control) or where you require the motor to start directly in the closed-loop mode. The block algorithm in stage 1 algorithm addresses these use cases by estimating the position while keeping the rotor stationary and avoiding an open-loop run.

Compute Algorithm Parameters Using Motor Parameters

Compute PHF Parameters

The following table describes how the block computes the PHF parameters when you select **Compute PHF parameters automatically using motor parameters** or when you click the **Compute PHF parameters** button:

PHF Parameter	Expression or Value	Remarks
PHF frequency (Hz), f_h	$\frac{1}{10T_s}$	Used in both Part A and Part B.

PHF Parameter	Expression or Value	Remarks
LP filter cutoff frequency (Hz)	$4\pi f_h \frac{r}{\sqrt{1-r^2}}$ where, $r = \frac{\pi f_h L_d L_q I_{base}}{500 \cdot V_{phf} (L_q - L_d)}$	Used in Part B.
Proportional gain, k_p	$\frac{\ln(20000)}{G \cdot T_{settling}}$	Used in Part B.
Integral gain, k_i	$\frac{G(k_p)^2}{4\delta^2}$	Used in Part B.
Expected settling time (s), $T_{settling}$	$\frac{100\ln(1000)L_q}{R_s}$	Used in Part B.
Expected damping ratio, δ	0.99	Used in Part B.
Open loop duration (s)	$\frac{\ln(1000)L_q}{R_s}$	Used in Part A.
Close loop duration (s)	$\frac{100\ln(1000)L_q}{R_s}$	Used in Part B.
Idle time (s)	$\frac{\ln(1000)L_q}{R_s}$	Used in both Part A and Part B.

where:

- T_s is the block sampling time (in seconds).
- L_d and L_q are the d and q axis stator inductances (in Henry).
- I_{base} is the base current of the motor (in Amperes).
- V_{phf} is the peak amplitude value of the injected high frequency voltage signal (in Volts).
- R_s is the motor resistance (in Ohms).

Note The expressions in the preceding table use elements and values based on the reference papers as well as experimental data.

Compute DP Parameters

The following table describes how the block computes the DP parameters when you select **Compute DP parameters automatically using motor parameters** or when you click the **Compute DP parameters** button:

DP Parameter	Expression or Value	Remarks
Pulse duration (s), w	$\frac{0.75L_d}{R_s}$	Used in Part C.

where:

- L_d is the d -axis stator inductance (in Henry).

- R_s is the motor resistance (in Ohms).

Note The expression in the preceding table uses elements and values based on the reference papers as well as experimental data.

Version History

Introduced in R2022b

References

- [1] W. Zine, L. Idkhajine, E. Monmasson, Z. Makni, P. Chauvenet, B. Condamin, and A. Bruyere, "Optimisation of HF signal injection parameters for EV applications based on sensorless IPMSM drives", *IET Electric Power Applications*, Volume 12, Issue 3, March 2018, p. 347 - 356 (doi:10.1049/iet-epa.2017.0228).
- [2] Gaolin Wang, Guoqiang Zhang, and Dianguo Xu, "Position Sensorless Control Techniques for Permanent Magnet Synchronous Machine Drives", Springer, Singapore, 2020 p. 41 - 43 (doi: <https://doi.org/10.1007/978-981-15-0050-3>).

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

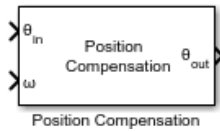
Inverse Clarke Transform

Topics

"Open-Loop and Closed-Loop Control"
"Field-Oriented Control (FOC)"

Position Compensation

Compensate for position offset due to different types of delays



Libraries:

Motor Control Blockset / Signal Management

Description

The Position Compensation block compensates for position offset due to different types of delays in a system.

Motor control algorithms may introduce offsets in the computed position because of different algorithmic entities such as delays and filters. These offsets affect the accuracy of motor control algorithms like field-oriented control (FOC) and direct torque control (DTC). This block compensates for these offsets in the motor control algorithms.

The block uses following computations for sample delay compensation:

$$\text{Offset introduced by delay} = \text{Applied compensation} = (- \text{Sample time}) \times (\text{Number of delay}) \times (\text{angular velocity}) \text{ radians}$$

The block uses following computations for 1st order Butterworth high-pass and low-pass filter compensation:

- For high-pass filter

$$\text{Phase_offset} = \frac{\pi}{2} - \arctan\left(\frac{\omega_{\text{speed}}}{\omega_{\text{cutoff}}}\right) = \arctan\left(\frac{\omega_{\text{cutoff}}}{\omega_{\text{speed}}}\right)$$

$$\text{Phase_compensation} = - \arctan\left(\frac{\omega_{\text{cutoff}}}{\omega_{\text{speed}}}\right)$$

- For low-pass filter

$$\text{Phase_offset} = - \arctan\left(\frac{\omega_{\text{speed}}}{\omega_{\text{cutoff}}}\right)$$

$$\text{Phase_compensation} = \arctan\left(\frac{\omega_{\text{speed}}}{\omega_{\text{cutoff}}}\right)$$

Ports

Input

θ_{in} — Position input value
scalar

Position input value that needs offset correction. This port supports the following range of values:

- -2π to $+2\pi$ radians
- 0 to 1 per-unit
- -360 to $+360$ degrees

Data Types: single | double | fixed point

ϕ — Position offset
scalar

Position offset value that is externally computed. This value must have same unit as that of θ_{in} input. This port supports the following range of values:

- -2π to $+2\pi$ radians
- 0 to 1 per-unit
- -360 to $+360$ degrees

Dependencies

To enable this port, select `External delay` for the **Nature of offset** parameter.

Data Types: single | double | fixed point

ω — Angular velocity
scalar

Externally computed angular velocity. This value indicates change in θ_{in} input.

Dependencies

To enable this port, select `Sample delay`, `High-pass filter delay`, or `Low-pass filter delay` for the **Nature of offset** parameter.

Data Types: single | double | fixed point

Output

θ_{out} — Position output value
scalar

Position output value that is corrected for offset.

Data Types: single | double | fixed point

Parameters

Nature of offset — Type of offset

Sample delay (default) | Constant delay | External delay | High-pass filter delay | Low-pass filter delay

Type of delay or offset in the system that you want to compensate for. You can select one of the following values:

- `Constant delay` — Compensate for a fixed delay or offset.
- `External delay` — Compensate for a constant delay using an externally computed position offset value.

- Sample delay — Compensate for the delay based on discrete step size or block execution time.
- High-pass filter delay — Compensate for delay from 1st order Butterworth high-pass filter using a cut-off frequency value.
- Low-pass filter delay — Compensate for delay from 1st order Butterworth low-pass filter using a cut-off frequency value.

Offset value — Position offset value

0.1 (default) | scalar

Position offset for constant delay in a system.

Dependencies

To enable this parameter, set **Nature of offset** to Constant delay.

Number of sample delay — Number of block execution time samples

1 (default) | scalar

Number of block execution time samples that the block should use for position offset compensation.

Dependencies

To enable this parameter, set **Nature of offset** to Sample delay.

Discrete step size (s) — Sample time after which block executes again

50e-6 (default) | scalar

The fixed time interval (in seconds) between every two consecutive instances of block execution.

Dependencies

To enable this parameter, set **Nature of offset** to Sample delay.

Cut-off frequency (Hz) — Filter cut-off frequency

9.578 (default) | scalar

Cut-off frequency of the 1st order Butterworth high-pass or low-pass filter.

Dependencies

To enable this parameter, set **Nature of offset** to either High-pass filter delay or Low-pass filter delay.

Position unit — Unit of position input

Radians (default) | Degrees | Per unit

Unit of position input, θ_{in} of block.

Speed unit — Unit of angular velocity input

RPM (default) | Degrees/Sec | Radians/Sec | Per unit

Unit of angular velocity input, ω of block.

Dependencies

To enable this parameter, set **Nature of offset** to either Sample delay, High-pass filter delay, or Low-pass filter delay.

Maximum application speed (RPM) — Upper limit of angular velocity
4000 (default) | scalar

Upper limit or maximum possible value of angular velocity input, ω , in RPM.

Dependencies

To enable this parameter, set **Nature of offset** to either Sample delay, High-pass filter delay, or Low-pass filter delay.

Version History

Introduced in R2022b

Extended Capabilities

C/C++ Code Generation

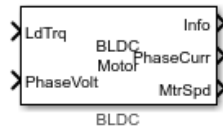
Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

BLDC

Three-phase brushless dc motor with trapezoidal flux distribution



Libraries:

Motor Control Blockset / Electrical Systems / Motors

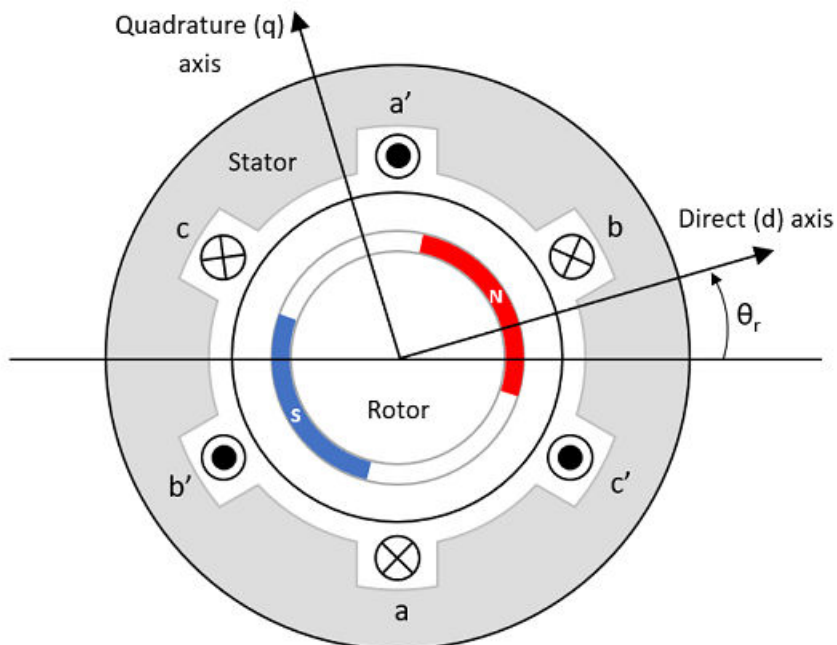
Description

The BLDC block implements a three-phase brushless DC (BLDC) motor with trapezoidal back electromotive force that remains constant for a position-range of 120 electrical degrees. The block uses the three-phase input voltages to regulate the individual phase currents, allowing control of the motor torque or speed.

By default, the block sets the **Simulation type** parameter to **Continuous** to use a continuous sample time during simulation. If you want to use the block for fixed-step simulation, considering setting the parameter to **Discrete**. Then specify a **Sample Time, T_s** parameter.

Motor Construction

This figure shows the motor construction with a single pole pair on the motor.



The motor magnetic field due to the permanent magnets creates a trapezoidal rate of change of flux with motor angle.

For the axes convention, the a -phase and permanent magnet fluxes are aligned when motor angle θ_r is zero.

Three-Phase Sinusoidal Model Electrical System

Instead of the standard dq reference frame, the block uses $d'q'$ reference frame which is defined by the following transformation equations.

$$v_{d'} = \frac{2}{3} \left((v_a - Ri_a - E_a) \cos \theta_e + (v_b - Ri_b - E_b) \cos \left(\theta_e - \frac{2\pi}{3} \right) + (v_c - Ri_c - E_c) \cos \left(\theta_e + \frac{2\pi}{3} \right) \right)$$

$$v_{q'} = -\frac{2}{3} \left((v_a - Ri_a - E_a) \sin \theta_e + (v_b - Ri_b - E_b) \sin \left(\theta_e - \frac{2\pi}{3} \right) + (v_c - Ri_c - E_c) \sin \left(\theta_e + \frac{2\pi}{3} \right) \right)$$

$$E_a = P\omega_m \frac{\partial \psi_a}{\partial \theta_e}$$

$$E_b = P\omega_m \frac{\partial \psi_b}{\partial \theta_e}$$

$$E_c = P\omega_m \frac{\partial \psi_c}{\partial \theta_e}$$

$$i_a = i_{d'} \cos \theta_e - i_{q'} \sin \theta_e$$

$$i_b = i_{d'} \cos \left(\theta_e - \frac{2\pi}{3} \right) - i_{q'} \sin \left(\theta_e - \frac{2\pi}{3} \right)$$

$$i_c = i_{d'} \cos \left(\theta_e + \frac{2\pi}{3} \right) - i_{q'} \sin \left(\theta_e + \frac{2\pi}{3} \right)$$

The block implements the following equations, expressed in dq as well as $d'q'$ reference frame of the BLDC motor. All quantities in the motor reference frame are with respect to the stator phase A.

$$\omega_e = P\omega_m$$

$$\frac{d}{dt} i_{d'} = \frac{1}{L_d} v_{d'} + \frac{L_q}{L_d} P\omega_m i_{q'}$$

$$\frac{d}{dt} i_{q'} = \frac{1}{L_q} v_{q'} - \frac{L_d}{L_q} P\omega_m i_{d'}$$

$$T_e = 1.5P((L_d - L_q)i_{d'}i_{q'}) + P \left(\frac{\partial \psi_a}{\partial \theta_e} i_a + \frac{\partial \psi_b}{\partial \theta_e} i_b + \frac{\partial \psi_c}{\partial \theta_e} i_c \right)$$

The equations use these variables.

$L_{q'}$, L_d	q- and d-axis inductances (H)
R	Resistance of the stator windings (ohm)
$i_{q'}$, $i_{d'}$	q'- and d'-axis currents (A)
$v_{q'}$, $v_{d'}$	q'- and d'-axis voltages (V)
ω_m	Angular mechanical velocity of the motor (rad/s)
ω_e	Angular electrical velocity of the motor (rad/s)
P	Number of pole pairs
T_e	Electromagnetic torque (Nm)
θ_e	Electrical angle (rad)

V_a, V_b, V_c	Stator phase A, B, and C voltages (V)
i_a, i_b, i_c	Stator phase A, B, and C currents (A)
E_a, E_b, E_c	Back EMF of stator phases A, B, and C (V/m/s)
Ψ_a, Ψ_b, Ψ_c	Total fluxes linking each stator winding (Wb)

Mechanical System

The motor angular velocity is given by:

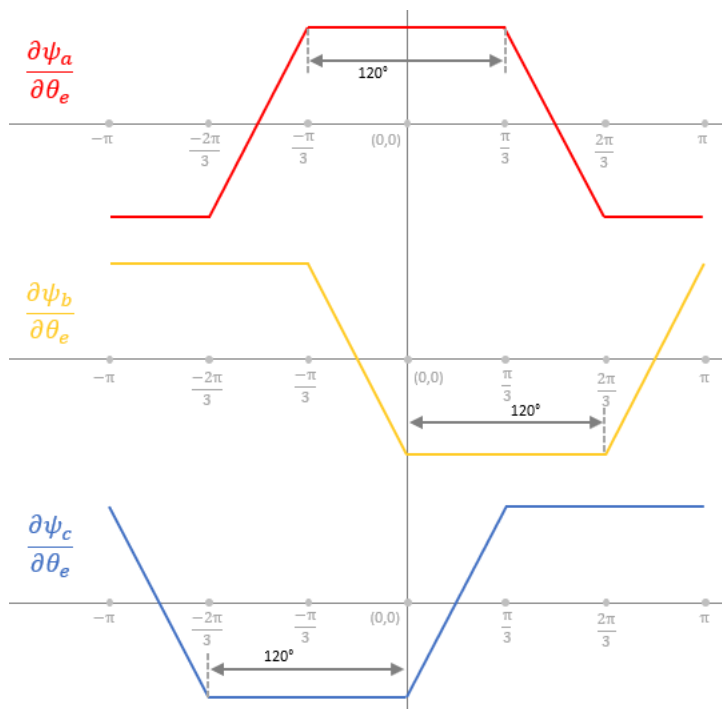
$$\frac{d}{dt}\omega_m = \frac{1}{J}(T_e - T_f - F\omega_m - T_m)$$
$$\frac{d\theta_m}{dt} = \omega_m$$

The equations use these variables.

J	Combined inertia of motor and load (kgm^2)
F	Combined viscous friction of motor and load ($\text{N}\cdot\text{m}/(\text{rad/s})$)
θ_m	Motor mechanical angular position (rad)
T_m	Motor shaft torque (Nm)
T_e	Electromagnetic torque (Nm)
T_f	Motor shaft static friction torque (Nm)
ω_m	Angular mechanical velocity of the motor (rad/s)

Trapezoidal Rate of Change of Flux

The rotor magnetic field due to the permanent magnets create a trapezoidal rate of change of flux with rotor angle. The figure shows this rate of change of flux for three phases of a 3-phase BLDC motor.



Ports

Input

LdTrq — Load torque on motor
scalar

Load torque on the motor shaft, T_m , in N·m.

Dependencies

To create this port, select Torque for the **Mechanical input configuration** parameter.

Spd — Motor shaft speed
scalar

Angular velocity of the motor, ω_m , in rad/s.

Dependencies

To create this port, select Speed for the **Mechanical input configuration** parameter.

PhaseVolt — Stator terminal voltages
1-by-3 array

Stator terminal voltages, V_a , V_b , and V_c , in V.

Output

Info — Bus signal
bus

The bus signal contains these block calculations.

Signal	Description	Variable	Units
IaStator	Stator phase current A	i_a	A
IbStator	Stator phase current B	i_b	A
IcStator	Stator phase current C	i_c	A
IdSync	d' axis current	$i_{d'}$	A
IqSync	q' axis current	$i_{q'}$	A
VdSync	d' axis voltage	$v_{d'}$	V
VqSync	q' axis voltage	$v_{q'}$	V
MtrSpd	Angular mechanical velocity of the motor	ω_m	rad/s
MtrPos	Motor mechanical angular position	θ_m	rad
MtrTrq	Electromagnetic torque	T_e	N·m
MtrHall	Hall sensor output	-	-
BackEMF	Back EMF generated in motor	E_a, E_b, E_c	V/m/s

PhaseCurr — Phase a, b, c current
1-by-3 array

Phase a, b, c current, i_a , i_b , and i_c , in A.

MtrTrq — Motor torque
scalar

Motor torque, T_{mtr} , in N·m.

Dependencies

To create this port, select Speed for the **Mechanical input configuration** parameter.

MtrSpd — Motor speed
scalar

Angular speed of the motor, ω_{mtr} , in rad/s.

Dependencies

To create this port, select Torque for the **Mechanical input configuration** parameter.

Parameters

Block Options

Mechanical input configuration — Select port configuration
Torque (default) | Speed

This table summarizes the port configurations.

Port Configuration	Creates Input Port	Creates Output Port
Torque	LdTrq	MtrSpd
Speed	Spd	MtrTrq

Simulation type — Select simulation type
Continuous (default) | Discrete

By default, the block uses a continuous sample time during simulation. If you want to generate code for single-precision targets, considering setting the parameter to Discrete.

Dependencies

Setting **Simulation type** to Discrete enables the **Sample time (s)** parameter.

Sample time (s) — Sample time for discrete integration
25e-6 (default) | scalar

Integration sample time for discrete simulation, in s.

Dependencies

To enable this parameter, set **Simulation type** to Discrete.

Parameters

Number of pole pairs — Pole pairs of motor
4 (default) | scalar

Motor pole pairs, P .

Stator resistance per phase (Ohm) — Stator resistance in each phase
0.36 (default) | scalar

Stator resistance per phase, R_s , in ohm.

Stator d-axis inductance (H) — Stator inductance across d-axis
2e-4 (default) | scalar

Stator inductance across d-axis, L_d , in H.

Stator q-axis inductance (H) — Stator inductance across q-axis
2e-4 (default) | scalar

Stator inductance across q-axis, L_q , in H.

Permanent flux linkage constant (Wb) — Flux-linkage constant
0.0064 (default) | scalar

Permanent flux linkage constant, λ_{pm} , in Wb.

Inertia (kgm²) — Rotor inertia
7.0616e-06 (default) | scalar

Rotor inertia, J , in kg.m².

Viscous damping (Nm/rad/s) — Viscous damping

2.6369e-06 (default) | scalar

Viscous damping, F , in N·m/(rad/s).**Static friction (Nm)** — Static friction

0 (default) | scalar

Static friction, T_f , in N·m.**Initial Values****Initial d-axis current (A)** — Initial current across d' -axis

0 (default) | scalar

Initial d-axis current, $i_{d'}$, in A.**Initial q-axis current (A)** — Initial current across q' -axis

0 (default) | scalar

Initial q-axis current, $i_{q'}$, in A.**Initial rotor mechanical position (rad)** — Initial mechanical position of rotor

0 (default) | scalar

Initial angular position of motor, θ_{m0} , in rad.**Initial rotor mechanical speed (rad/s)** — Initial mechanical speed of rotor

0 (default) | scalar

Initial angular velocity of the motor, ω_{m0} , in rad/s.**Dependencies**To enable this parameter, set **Mechanical input configuration** to Torque.

Version History

Introduced in R2023a

See Also

BLDC Average-Value Inverter | Interior PMSM | Surface Mount PMSM | PMSM HDL

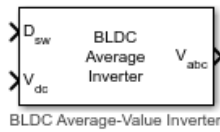
Topics

"Open-Loop and Closed-Loop Control"

"Six-Step Commutation"

BLDC Average-Value Inverter

Compute three-phase trapezoidal AC voltage from inverter DC voltage

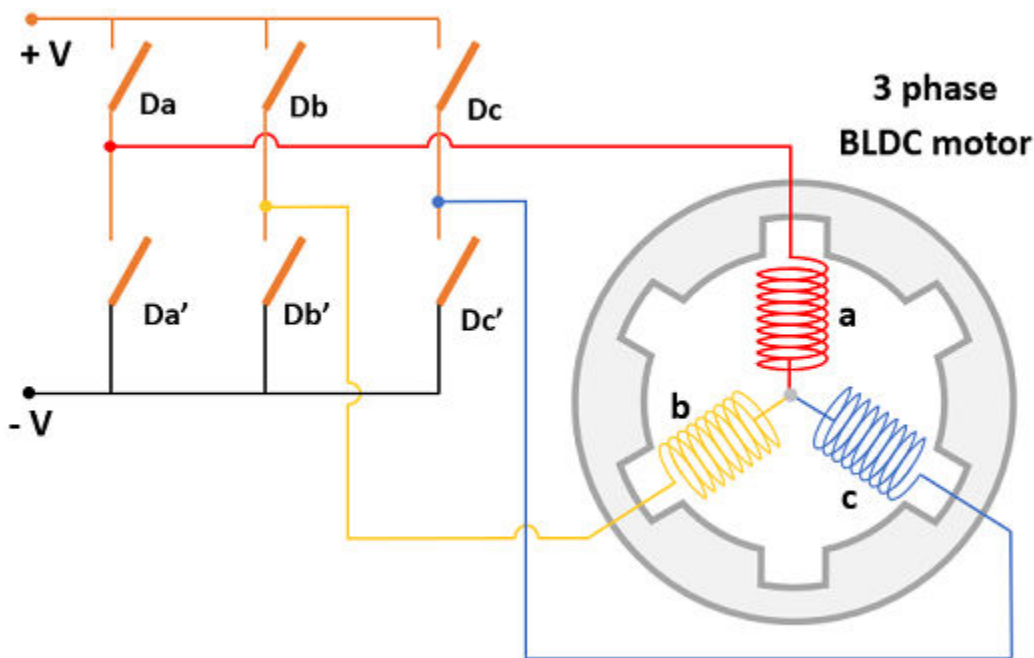


Libraries:

Motor Control Blockset / Electrical Systems / Inverters

Description

The BLDC Average-Value Inverter block models an average-value and full-wave inverter. It computes the three-phase trapezoidal voltage output from inverter DC voltage by using the 6 duty cycles corresponding to 6 inverter switches.



Equations

These equations describe how the block computes the three-phase AC voltage.

$$V_a = V_{dc} \times (D_a - D_{a'})$$

$$V_b = V_{dc} \times (D_b - D_{b'})$$

$$V_c = V_{dc} \times (D_c - D_{c'})$$

where:

- $D_a, D_b, D_c, D_{a'}, D_{b'},$ and $D_{c'}$ are the duty cycles (ranging between 0 and 1) corresponding to the six switches of the inverter (shown in the preceding figure).
- $V_a, V_b,$ and V_c are the output three-phase trapezoidal voltages (Volts).
- V_{dc} is the DC bus voltage of the inverter (Volts).

Ports

Input

D_{sw} — Duty cycles corresponding to 6 inverter switches
scalar

Six duty cycles in the range [0, 1] for generating the three-phase voltages that run the motor.

Data Types: `single` | `double` | `fixed point`

V_{dc} — Inverter DC voltage
scalar

DC bus voltage input to the inverter.

Data Types: `single` | `double` | `fixed point` | `uint8` | `uint16` | `uint32`

Output

V_{abc} — Three-phase voltage output
scalar

Three-phase trapezoidal voltage (Volts) corresponding to the input duty cycles that runs the motor.

Data Types: `single` | `double` | `fixed point`

Version History

Introduced in R2023a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Space Vector Generator | BLDC | Average-Value Inverter

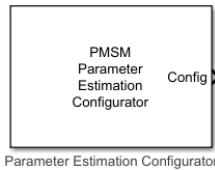
Topics

“Open-Loop and Closed-Loop Control”

“Six-Step Commutation”

PMSM Parameter Estimation Configurator

Generate configuration elements for PMSM parameter estimation



Libraries:

Motor Control Blockset / Parameter Estimation / PMSM Parameter Estimation

Description

The PMSM Parameter Estimation Configurator block generates the following configuration elements for estimating the parameters of a permanent magnet synchronous motor (PMSM):

- Elements for motor and inverter hardware
- Elements for estimating motor resistance (R_s)
- Elements for estimating motor inductances (L_d and L_q)
- Elements for estimating back EMF constant (K_e), motor inertia (J), and friction constant (B)

The block uses the parameters (available in the block parameters dialog box) to generate an output bus containing the preceding configuration elements, which are used by the following PMSM parameter estimation blocks:

- PMSM R_s Estimator
- L_d Estimator
- L_q Estimator
- PMSM Mechanical Parameter Estimator

Ports

Output

Config — Bus signal
bus

The bus signal includes these configuration elements:

Category	Configuration element	Units
Elements for motor and inverter hardware	Number of pole pairs	-
	Rated speed of motor	RPM
	Rated current of motor	A
	Maximum measurable inverter current	A
	Board resistance	ohm
	Current sense gain	A/ADC Count

Category	Configuration element	Units
	Voltage sense gain	V/ADC Count
Elements for estimating motor resistance (R_s)	Estimation time	sec
	V_d reference voltage	PU
Elements for estimating motor inductances (L_d and L_q)	Maximum frequency	Hz
	Minimum frequency	Hz
	Step for frequency sweep	Hz
	Frequency step size for estimation	Hz
	Rotor alignment duration	sec
	V_{dq} sine voltage	PU
	V_{dq} bias voltage	PU
Elements for estimating back EMF constant (K_e), motor inertia (J), and friction constant (B)	Back EMF estimation time	sec
	Back EMF estimation speed	RPM
	I_q Reference current for FOC	PU
	Proportional gain	-
	Integral gain	-
	Speed lower limit for inertia estimation	RPM
-	Parameter estimation sample time	sec

The preceding elements are analogous to the block parameters. For details about these elements, see “Parameters” on page 1-360.

Data Types: single

Parameters

Motor and Inverter

Number of pole pairs — Number of motor pole pairs
4 (default) | scalar

Number of pole pairs available in PMSM.

Rated speed (RPM) — Motor rated speed
4000 (default) | scalar

Rated speed of PMSM (in RPM).

Rated motor current (A) — Motor rated current
7 (default) | scalar

Rated current of PMSM (in Amperes).

Maximum inverter current (A) — Maximum measurable current
21 (default) | scalar

Maximum current (in Amperes) that the system (including inverter and controller) can measure.

Board resistance (ohm) — Inverter bridge resistance

0.0043 (default) | scalar

Resistance in the path of phase currents (excluding motor resistance). You can obtain this value from datasheet of the inverter hardware.

Current sense gain (A/ADC Count) — Current per ADC count

0.0105 (default) | scalar

Gain of the current sense circuit of the inverter. This value determines the current (in Amperes) corresponding to 1 analog-to-digital converter (ADC) count (resolution of the measurable current range).

Voltage sense gain (V/ADC Count) — Voltage per ADC count

0.0098 (default) | scalar

Gain of the voltage sense circuit of the inverter. This value determines the voltage (in Volts) corresponding to 1 analog-to-digital converter (ADC) count (resolution of the measurable voltage range).

Rs Estimation

Estimation time (sec) — Time to run Rs estimation algorithm

2 (default) | scalar

Time allotted to run motor resistance (R_s) estimation algorithm. This value defines the time duration for which the PMSM Rs Estimator block injects voltage to measure the motor resistance. For more details about R_s estimation, see PMSM Rs Estimator.

Vd reference voltage (PU) — Reference voltage for Rs estimation

0.1 (default) | scalar

Reference motor-phase voltage (in per-unit) that the PMSM Rs Estimator block uses for measuring motor resistance (R_s). By default, the block sets this field to 10 percent of the inverter DC voltage. For more details about R_s estimation, see PMSM Rs Estimator. For more details about the per-unit system, see “Per-Unit System”.

Ld and Lq Estimation

Maximum frequency (Hz) — Maximum frequency injected for frequency sweep

1000 (default) | scalar

Maximum frequency (in Hertz) injected by the Ld Estimator and Lq Estimator blocks to begin frequency sweep. For more details, see Ld Estimator and Lq Estimator.

Minimum frequency (Hz) — Minimum frequency injected for frequency sweep

400 (default) | scalar

Minimum frequency (in Hertz) injected by the Ld Estimator and Lq Estimator blocks to conclude frequency sweep. For more details, see Ld Estimator and Lq Estimator.

Step for frequency sweep (Hz) — Step size for frequency sweep

100 (default) | scalar

Step size (in Hertz) using which the Ld Estimator and Lq Estimator blocks decrement the frequency during the frequency sweep process. For more details, see Ld Estimator and Lq Estimator.

Frequency step size for estimation (Hz) — Frequency step size for L_d and L_q estimation

10 (default) | scalar

Step size (in Hertz) using which the Ld Estimator and Lq Estimator blocks increment the frequency during the L_d and L_q estimation process. For more details, see Ld Estimator and Lq Estimator.

Number of frequencies for estimation — Number of injected frequencies for L_d and L_q estimation

10 (default) | scalar

Number of frequencies (with a step size defined by the **Frequency step size for estimation (Hz)** parameter) that the Ld Estimator and Lq Estimator blocks inject after frequency sweep to estimate L_d and L_q parameters. For more details, see Ld Estimator and Lq Estimator.

Rotor alignment duration (sec) — Duration of Vdq bias voltage application for rotor alignment

1 (default) | scalar

Duration for which the Ld Estimator and Lq Estimator blocks apply V_{dq} bias voltage to align the rotor with zero position before frequency injection. A larger duration may result in greater heat generation. For more details, see Ld Estimator and Lq Estimator.

Vdq sine voltage (PU) — Injected sine voltage amplitude

0.05 (default) | scalar

Amplitude of the sinusoidal voltage signal (in per-unit) that the blocks Ld Estimator and Lq Estimator injects. For more details, see Ld Estimator and Lq Estimator. For details about the per-unit system, see “Per-Unit System”.

Vdq bias voltage (PU) — DC voltage aligned with injected sine signal

0.1 (default) | scalar

DC voltage (in per-unit) over which the injected sinusoidal voltage is aligned. For more details, see Ld Estimator and Lq Estimator. For details about the per-unit system, see “Per-Unit System”.

Ke, J, B Estimation

Back EMF estimation time (sec) — Motor run duration when estimating back emf

5 (default) | scalar

Duration (in seconds) for which the PMSM Mechanical Parameter Estimator block runs the motor using closed-loop control to estimate back emf, K_e . For more details, see PMSM Mechanical Parameter Estimator.

Back EMF estimation speed (RPM) — Motor speed when estimating back emf

3500 (default) | scalar

Speed (in RPM) at which the PMSM Mechanical Parameter Estimator block runs the motor using closed-loop control to estimate back emf, K_e . For more details, see PMSM Mechanical Parameter Estimator.

Iq reference current for FOC (PU) — Reference current for FOC when estimating K_e , J , and B

0.2 (default) | scalar

Reference current, I_q to achieve the reference speed specified by the **Back EMF estimation speed (RPM)** parameter. For more details, see PMSM Mechanical Parameter Estimator.

Specify current controller gains — Specify PI current controller gains

off (default) | on

Select this parameter to enable and display the following fields:

- **Proportional gain**
- **Integral gain**

You can use these fields to enter the proportional and integral gains of the PI current controllers that implement closed-loop control to estimate K_e , J , and B .

If you deselect this parameter, the block automatically computes the proportional and integral gains internally.

To know more about the estimation process, see PMSM Mechanical Parameter Estimator.

Proportional gain — Proportional gain of PI controller

1 (default) | scalar

Proportional gain, k_p , of the PI current controller that implements field-oriented control to run the motor in closed-loop control and estimate K_e , J , and B .

Dependencies

To enable and display this parameter, select the **Specify current controller gains** parameter.

Integral gain — Integral gain of PI controller

1000 (default) | scalar

Integral gain, k_i , of the PI current controller that implements field-oriented control to run the motor in closed-loop control and estimate K_e , J , and B .

Dependencies

To enable and display this parameter, select the **Specify current controller gains** parameter.

Speed lower limit for inertia estimation (RPM) — Lower speed limit during coast-down

1000 (default) | scalar

Lower speed limit during coast-down at which the PMSM Mechanical Parameter Estimation block registers the timestamp for estimating motor inertia. For more details about the estimation process, see PMSM Mechanical Parameter Estimator.

Parameter estimation sample time (sec) — Sample time for parameter estimation

50e-6 (default) | scalar

Sample time for the parameter estimation algorithm. This parameter defines the sample time for the following parameter estimation algorithm blocks:

- PMSM R_s Estimator
- L_d Estimator
- L_q Estimator

- PMSM Mechanical Parameter Estimator

Version History

Introduced in R2023a

Extended Capabilities

C/C++ Code Generation

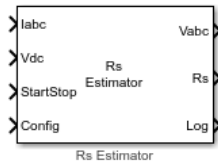
Generate C and C++ code using Simulink® Coder™.

See Also

[Rs Estimator](#) | [Ld Estimator](#) | [Lq Estimator](#) | [PMSM Mechanical Parameter Estimator](#)

PMSM Rs Estimator

Estimate stator resistance (R_s) of a permanent magnet synchronous motor (PMSM)



Libraries:

Motor Control Blockset / Parameter Estimation / PMSM Parameter Estimation

Description

The PMSM Rs Estimator block computes the stator resistance of a PMSM using the phase currents, DC voltage across the motor, and the test configuration elements.

The block injects a voltage across the motor phases and measures the current response to estimate the motor resistance.

Ports

Input

Iabc — Three-phase current response
scalar

The three-phase current response of the motor measured by the current sensors.

Note Providing phase-c current input is optional. Absence of phase-c current input has no impact on the block functionality.

Data Types: single

Vdc — DC link voltage
scalar

DC bus voltage that you provide to the inverter.

Data Types: single

StartStop — Control signal for R_s estimation
logical

Signal that either starts or stops R_s estimation:

- 1 (rising edge of a pulse) — This signal initiates R_s estimation.
- 0 (falling edge of a pulse) — This signal immediately stops R_s estimation process. If you interrupt the estimation process abruptly before completion, the block does not compute or output the R_s value.

Data Types: Boolean

Config — Bus signal input

bus

The following table summarizes the expected configuration elements in the bus signal input:

Category	Configuration element	Units
Elements for motor and inverter hardware	Number of pole pairs	-
	Rated speed of motor	RPM
	Rated current of motor	A
	Maximum measurable inverter current	A
	Board resistance	ohm
	Current sense gain	A/ADC Count
	Voltage sense gain	V/ADC Count
Elements for estimating motor resistance (R_s)	Estimation time	sec
	V_d reference voltage	PU
Elements for estimating motor inductances (L_d and L_q)	Maximum frequency	Hz
	Minimum frequency	Hz
	Step for frequency sweep	Hz
	Frequency step size for estimation	Hz
	Rotor alignment duration	sec
	V_{dq} sine voltage	PU
	V_{dq} bias voltage	PU
Elements for estimating back EMF constant (K_e), motor inertia (J), and friction constant (B)	Back EMF estimation time	sec
	Back EMF estimation speed	RPM
	I_q Reference current for FOC	PU
	Proportional gain	-
	Integral gain	-
	Speed lower limit for inertia estimation	RPM
-	Parameter estimation sample time	sec

You can connect this input port to the Config output port of the PMSM Parameter Estimation Configurator block.

Data Types: single

Output

Vabc — a , b , and c -axis stator reference voltage components

scalar

Stator reference voltage components along the a , b , and c axes of the abc reference frame.

Data Types: single

Rs — Estimated stator resistance
scalar

Estimated stator resistance (in ohms) of the PMSM.

Data Types: single

Log — Debug signals
bus

Debug signals that the block provides for examination. The bus includes these debug signals:

Debug signal		Description	Units
I_d		D -axis current	Amperes
V_d		D -axis voltage	Volts
$status$	0	R_s estimation did not complete	-
	1	R_s estimation completed successfully	-

Data Types: single

Version History

Introduced in R2023a

Extended Capabilities

C/C++ Code Generation

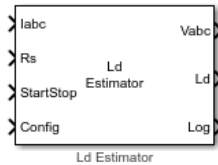
Generate C and C++ code using Simulink® Coder™.

See Also

PMSM Parameter Estimation Configurator | Ld Estimator | Lq Estimator | PMSM Mechanical Parameter Estimator

Ld Estimator

Estimate stator inductance (L_d) of a permanent magnet synchronous motor (PMSM)



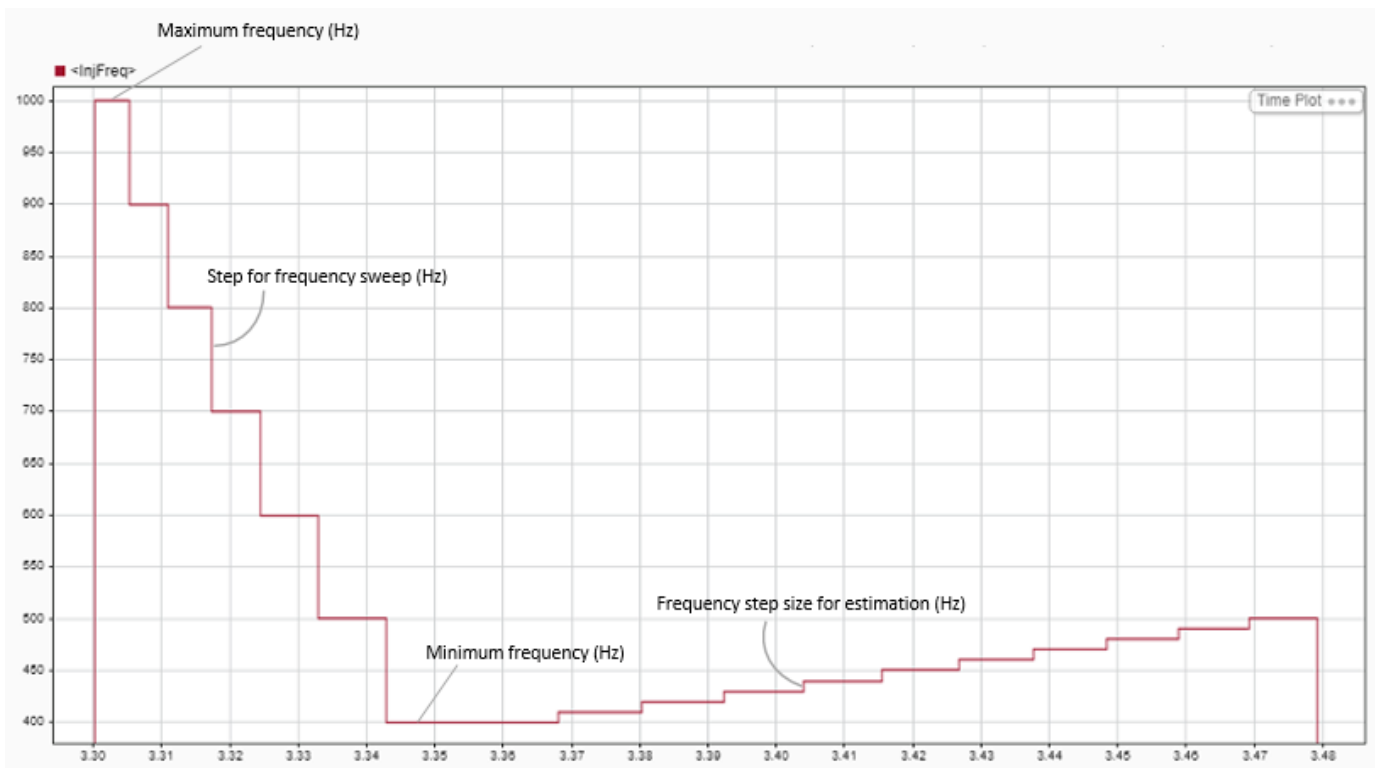
Libraries:

Motor Control Blockset / Parameter Estimation / PMSM Parameter Estimation

Description

The Ld Estimator block computes the d -axis stator inductance of a PMSM using the phase currents, stator resistance, and the test configuration elements.

To estimate d -axis stator inductance, the block injects a high-frequency voltage signal across the motor phases and then performs the frequency sweep process by gradually reducing the injected signal frequency to a minimum value. After the injected signal frequency reaches the minimum value, the block then injects the given number of signals with incremental rise in frequency using the given step size. The following image shows the frequency sweep and the incremental steps of increasing frequency.



The L_d estimation process uses the measured frequency sweep time duration as well as the step-size of the changing frequency to estimate the d -axis stator inductance, L_d .

Ports

Input

labc — Three-phase current response
scalar

The three-phase current response of the motor measured by the current sensors.

Note Providing phase-c current input is optional. Absence of phase-c current input has no impact on the block functionality.

Data Types: single

Rs — Estimated stator resistance
scalar

Estimated stator resistance of PMSM. You can either connect this input port to the Rs output of the PMSM Rs Estimator block or provide the resistance value manually using a Constant block.

Data Types: single

StartStop — Control signal for L_d estimation
logical

Signal that either starts or stops L_d estimation:

- 1 (rising edge of a pulse) — This signal initiates L_d estimation.
- 0 (falling edge of a pulse) — This signal immediately stops L_d estimation process. If you interrupt the estimation process abruptly before completion, the block does not compute or output the L_d value.

Data Types: Boolean

Config — Bus signal input
bus

The following table summarizes the expected configuration elements in the bus signal input:

Category	Configuration element	Units
Elements for motor and inverter hardware	Number of pole pairs	-
	Rated speed of motor	RPM
	Rated current of motor	A
	Maximum measurable inverter current	A
	Board resistance	ohm
	Current sense gain	A/ADC Count
	Voltage sense gain	V/ADC Count
Elements for estimating	Estimation time	sec

Category	Configuration element	Units
motor resistance (R_s)	V_d reference voltage	PU
Elements for estimating motor inductances (L_d and L_q)	Maximum frequency	Hz
	Minimum frequency	Hz
	Step for frequency sweep	Hz
	Frequency step size for estimation	Hz
	Rotor alignment duration	sec
	V_{dq} sine voltage	PU
	V_{dq} bias voltage	PU
Elements for estimating back EMF constant (K_e), motor inertia (J), and friction constant (B)	Back EMF estimation time	sec
	Back EMF estimation speed	RPM
	I_q Reference current for FOC	PU
	Proportional gain	-
	Integral gain	-
	Speed lower limit for inertia estimation	RPM
-	Parameter estimation sample time	sec

You can connect this input port to the Config output port of the PMSM Parameter Estimation Configurator block.

Data Types: single

Output

Vabc — a , b , and c -axis stator reference voltage components
scalar

Stator reference voltage components along the a , b , and c axes of the abc reference frame.

Data Types: single

Ld — Estimated d -axis stator inductance
scalar

Estimated d -axis stator inductance (in Henry).

Data Types: single

Log — Debug signals
bus

Debug signals that the block provides for examination. The bus includes these debug signals:

Debug signal	Description	Units
<i>InjFreq</i>	Frequency of signal injected most recently	Hertz

Debug signal		Description	Units
<i>status</i>	0	L_d estimation did not complete	-
	1	L_d estimation completed successfully	-
I_d		D-axis current	Amperes
V_d		D-axis voltage	Volts
<i>PhaseDiff_rad</i>		Phase difference between the injected voltage and current response	Radians

Data Types: single

Version History

Introduced in R2023a

Extended Capabilities

C/C++ Code Generation

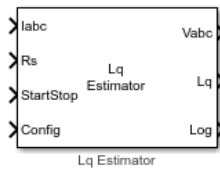
Generate C and C++ code using Simulink® Coder™.

See Also

PMSM Parameter Estimation Configurator | Rs Estimator | Lq Estimator | PMSM Mechanical Parameter Estimator

Lq Estimator

Estimate stator inductance (L_q) of a permanent magnet synchronous motor (PMSM)



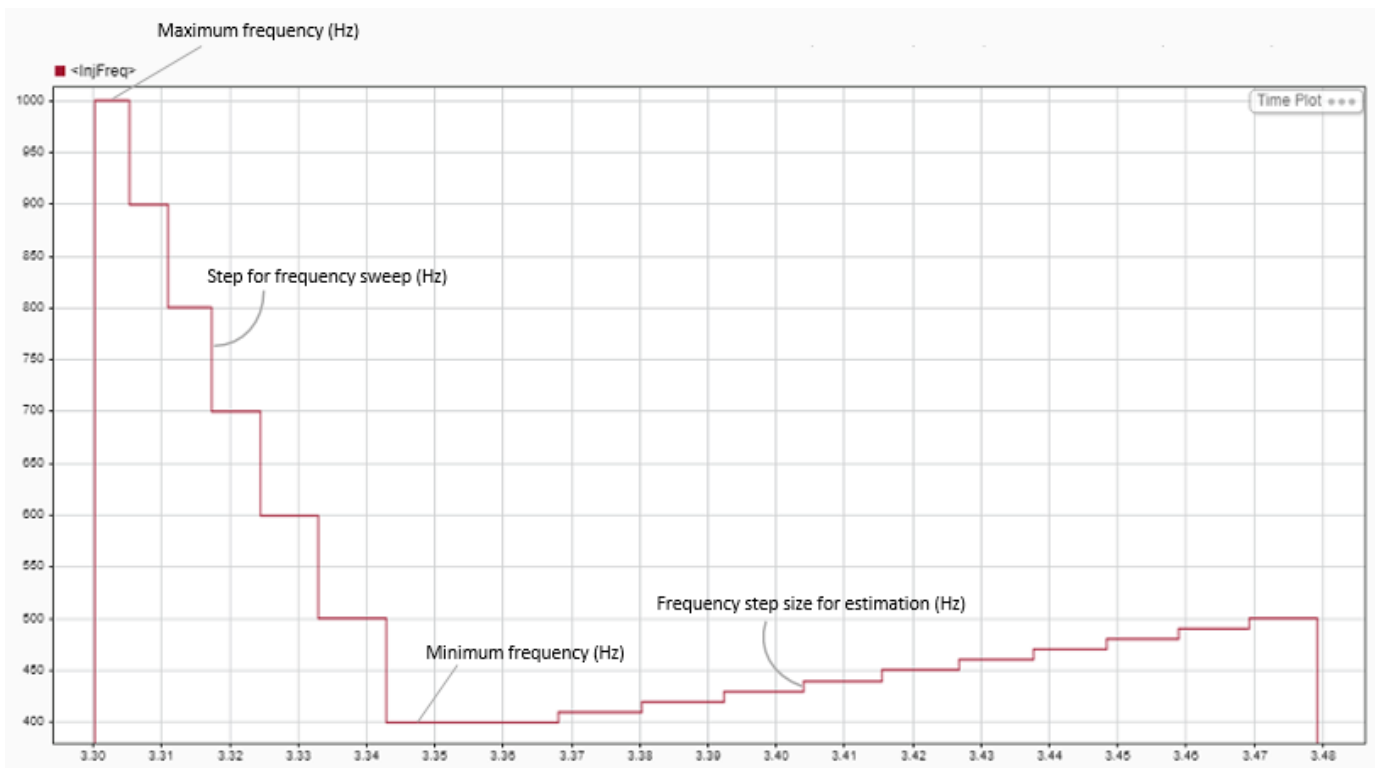
Libraries:

Motor Control Blockset / Parameter Estimation / PMSM Parameter Estimation

Description

The Lq Estimator block computes the q -axis stator inductance of a PMSM using the phase currents, stator resistance, and the test configuration elements.

To estimate q -axis stator inductance, the block injects a high-frequency voltage signal across the motor phases and then performs the frequency sweep process by gradually reducing the injected signal frequency to a minimum value. After the injected signal frequency reaches the minimum value, the block then injects the given number of signals with incremental rise in frequency using the given step size. The following image shows the frequency sweep and the incremental steps of increasing frequency.



The L_q estimation process uses the measured frequency sweep time duration as well as the step-size of the changing frequency to estimate the q -axis stator inductance, L_q .

Ports

Input

labc — Three-phase current response
scalar

The three-phase current response of the motor measured by the current sensors.

Note Providing phase-c current input is optional. Absence of phase-c current input has no impact on the block functionality.

Data Types: `single`

Rs — Estimated stator resistance
scalar

Estimated stator resistance of PMSM. You can either connect this input port to the Rs output of the PMSM Rs Estimator block or provide the resistance value manually using a Constant block.

Data Types: `single`

StartStop — Control signal for L_q estimation
logical

Signal that either starts or stops L_q estimation:

- 1 (rising edge of a pulse) — This signal initiates L_q estimation.
- 0 (falling edge of a pulse) — This signal immediately stops L_q estimation process. If you interrupt the estimation process abruptly before completion, the block does not compute or output the L_q value.

Data Types: `Boolean`

Config — Bus signal input
bus

The following table summarizes the expected configuration elements in the bus signal input:

Category	Configuration element	Units
Elements for motor and inverter hardware	Number of pole pairs	-
	Rated speed of motor	RPM
	Rated current of motor	A
	Maximum measurable inverter current	A
	Board resistance	ohm
	Current sense gain	A/ADC Count
	Voltage sense gain	V/ADC Count
Elements for estimating	Estimation time	sec

Category	Configuration element	Units
motor resistance (R_s)	V_d reference voltage	PU
Elements for estimating motor inductances (L_d and L_q)	Maximum frequency	Hz
	Minimum frequency	Hz
	Step for frequency sweep	Hz
	Frequency step size for estimation	Hz
	Rotor alignment duration	sec
	V_{dq} sine voltage	PU
	V_{dq} bias voltage	PU
Elements for estimating back EMF constant (K_e), motor inertia (J), and friction constant (B)	Back EMF estimation time	sec
	Back EMF estimation speed	RPM
	I_q Reference current for FOC	PU
	Proportional gain	-
	Integral gain	-
	Speed lower limit for inertia estimation	RPM
-	Parameter estimation sample time	sec

You can connect this input port to the Config output port of the PMSM Parameter Estimation Configurator block.

Data Types: single

Output

Vabc — a , b , and c -axis stator reference voltage components
scalar

Stator reference voltage components along the a , b , and c axes of the abc reference frame.

Data Types: single

Lq — Estimated q -axis stator inductance
scalar

Estimated q -axis stator inductance (in Henry).

Data Types: single

Log — Debug signals
bus

Debug signals that the block provides for examination. The bus includes these debug signals:

Debug signal	Description	Units
<i>InjFreq</i>	Frequency of signal injected most recently	Hertz

Debug signal		Description	Units
<i>status</i>	0	L_q estimation did not complete	-
	1	L_q estimation completed successfully	-
I_q		Q-axis current	Amperes
V_q		Q-axis voltage	Volts
<i>PhaseDiff_rad</i>		Phase difference between the injected voltage and current response	Radians

Data Types: single

Version History

Introduced in R2023a

Extended Capabilities

C/C++ Code Generation

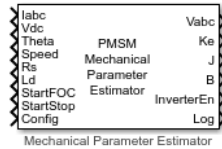
Generate C and C++ code using Simulink® Coder™.

See Also

PMSM Parameter Estimation Configurator | Rs Estimator | Ld Estimator | PMSM Mechanical Parameter Estimator

PMSM Mechanical Parameter Estimator

Estimate back EMF constant, rotor inertia, and viscous damping of a permanent magnet synchronous motor (PMSM)



Libraries:

Motor Control Blockset / Parameter Estimation / PMSM Parameter Estimation

Description

The PMSM Mechanical Parameter Estimator block uses the phase currents and voltages, DC voltage across the motor, motor position and speed, stator resistance, d -axis inductance, as well as the other test configuration elements to compute the following mechanical parameters of a PMSM:

- Back EMF constant (K_e)
- Rotor inertia (J)
- Viscous damping (B)

The block runs the motor using closed-loop field-oriented control (FOC) with a limited speed during which it runs the tests to estimate back-emf constant (K_e) and viscous damping (B). After a pre-configured duration, the block concludes these tests to compute K_e and B , and then, triggers coast-down by shutting down all six inverter switches. The coast-down results in gradual decline in motor speed which eventually reaches zero. The block measures and uses the time to reach zero-speed to calculate rotor inertia (J).

Ports

Input

Iabc — Three-phase current response
scalar

The three-phase current response of the motor measured by the current sensors.

Note Providing phase-c current input is optional. Absence of phase-c current input has no impact on the block functionality.

Data Types: single

Vdc — DC link voltage
scalar

DC bus voltage that you provide to the inverter.

Data Types: single

Theta — Rotor position
scalar

Current position of the rotor.

Data Types: `single`

Speed — Rotor speed
scalar

Current motor speed.

Data Types: `single`

Rs — Estimated stator resistance
scalar

Estimated stator resistance of PMSM. You can either connect this input port to the Rs output of the PMSM Rs Estimator block or provide the resistance value manually using a Constant block.

Data Types: `single`

Ld — Estimated *d*-axis stator inductance
scalar

Estimated *d*-axis stator inductance of PMSM. You can either connect this input port to the Ld output of the Ld Estimator block or provide the *d*-axis inductance value manually using a Constant block.

Data Types: `single`

StartFOC — Begin closed loop FOC
logical

Signal that starts running the motor in closed-loop FOC mode:

- 1 (rising edge of a pulse) — This signal initiates mechanical parameter estimation by running the motor in closed-loop using FOC.
- 0 (falling edge of a pulse) — This signal starts running the motor using open-loop control.

Data Types: `single`

StartStop — Control signal for mechanical parameter estimation
logical

Signal that either starts or stops block execution:

- 1 (rising edge of a pulse) — This signal initiates block execution.
- 0 (falling edge of a pulse) — This signal immediately stops block execution and any tests that the block is running. If you interrupt the estimation process abruptly before completion, the block does not compute or output the mechanical parameter values.

Data Types: `Boolean`

Config — Bus signal input
bus

The following table summarizes the expected configuration elements in the bus signal input:

Category	Configuration element	Units
Elements for motor and inverter hardware	Number of pole pairs	-
	Rated speed of motor	RPM
	Rated current of motor	A
	Maximum measurable inverter current	A
	Board resistance	ohm
	Current sense gain	A/ADC Count
	Voltage sense gain	V/ADC Count
Elements for estimating motor resistance (R_s)	Estimation time	sec
	V_d reference voltage	PU
Elements for estimating motor inductances (L_d and L_q)	Maximum frequency	Hz
	Minimum frequency	Hz
	Step for frequency sweep	Hz
	Frequency step size for estimation	Hz
	Rotor alignment duration	sec
	V_{dq} sine voltage	PU
	V_{dq} bias voltage	PU
Elements for estimating back EMF constant (K_e), motor inertia (J), and friction constant (B)	Back EMF estimation time	sec
	Back EMF estimation speed	RPM
	I_q Reference current for FOC	PU
	Proportional gain	-
	Integral gain	-
	Speed lower limit for inertia estimation	RPM
-	Parameter estimation sample time	sec

You can connect this input port to the Config output port of the PMSM Parameter Estimation Configurator block.

Data Types: single

Output

Vabc — a , b , and c -axis stator reference voltage components
scalar

Stator reference voltage components along the a , b , and c axes of the abc reference frame.

Data Types: single

Ke — Estimated back EMF constant
scalar

Estimated back EMF constant of PMSM (in V/m/s).

Data Types: `single`

J — Estimated rotor inertia
scalar

Estimated inertia of PMSM (in kg.m²).

Data Types: `single`

B — Estimated viscous damping
scalar

Estimated viscous damping of PMSM (in N.s/m).

Data Types: `single`

InverterEn — Inverter control signal
logical

Signal that switches the inverter either ON or OFF:

- 1 (logical high) — For the duration when this signal is high, all six switches of the inverter should be ON.
- 0 (logical low) — For the duration when this signal is low, all six switches of the inverter should be OFF.

Data Types: `single`

Log — Debug signals
bus

Debug signals that the block provides for examination. The bus includes these debug signals:

Debug signal		Description	Units
<i>status</i>	0	Mechanical parameter estimation did not complete	-
	1	Mechanical parameter estimation completed successfully	-
<i>CoastDownTime</i>		Measured coast-down time duration	seconds
<i>Vdq</i>		Voltages across <i>d</i> and <i>q</i> axes	Volts
<i>Idq</i>		Currents across <i>d</i> and <i>q</i> axes	Amperes

Debug signal	Description	Units
<i>VAlphaBeta</i>	Voltages and currents across α and β axes	Volts, Amperes

Data Types: single

Version History

Introduced in R2023a

Extended Capabilities

C/C++ Code Generation

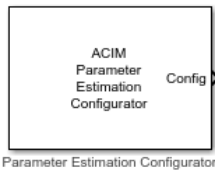
Generate C and C++ code using Simulink® Coder™.

See Also

PMSM Parameter Estimation Configurator | Rs Estimator | Ld Estimator | Lq Estimator

ACIM Parameter Estimation Configurator

Generate configuration elements for AC induction motor (ACIM) parameter estimation



Libraries:

Motor Control Blockset / Parameter Estimation / ACIM Parameter Estimation

Description

The ACIM Parameter Estimation Configurator block generates the following configuration elements for estimating the parameters of an AC induction motor (ACIM):

- Elements for motor and inverter hardware
- Elements for estimating magnetizing current I_{d0}
- Elements for estimating motor resistance (R_s)
- Elements for estimating:
 - Rotor resistance, R_r
 - Magnetizing inductance, L_m
 - Stator leakage inductance, L_{ls}
 - Rotor leakage inductance, L_{lr}
- Elements for estimating motor inertia (J) and friction constant (B)

The block uses the parameters (available in the block parameters dialog box) to generate an output bus containing the preceding configuration elements, which are used by the following ACIM parameter estimation blocks:

- Id0 Estimator
- ACIM Rs Estimator
- Rr L Estimator
- ACIM Mechanical Parameter Estimator

Ports

Output

Config — Bus signal
bus

The bus signal includes these configuration elements:

Category	Configuration element	Units
Elements for motor and	Number of pole pairs	-

Category	Configuration element	Units
inverter hardware	Rated frequency	Hz
	Nominal motor current	A
	Nominal voltage	V
	Maximum measurable inverter current	A
	Board resistance	ohm
	Current sense gain	A/ADC Count
	Voltage sense gain	V/ADC Count
Elements for estimating magnetizing current I_{d0}	Measurement time	sec
	Open-loop ramp time	sec
Elements for estimating motor resistance (R_s)	Estimation time	sec
	V_d reference voltage 1	PU
	V_d reference voltage 2	PU
Elements for estimating rotor resistance (R_r), magnetizing inductance (L_m), stator leakage inductance (L_{ls}), and rotor leakage inductance (L_{lr})	Frequency 1 as a ratio of rated frequency	PU
	Frequency 2 as a ratio of rated frequency	PU
	High frequency for L_m	Hz
	Voltage sweep start value voltage	PU
	Voltage sweep step value voltage	PU
	High frequency injection voltage	PU
Elements for estimating motor inertia (J) and friction constant (B)	Closed-loop speed duration	sec
	Closed-loop speed	RPM
	I_q Reference current for FOC	PU
	Proportional gain	-
	Integral gain	-
	Speed lower limit for inertia estimation	RPM
-	Parameter estimation sample time	sec

The preceding elements are analogous to the block parameters. For details about these elements, see “Parameters” on page 1-382.

Data Types: single

Parameters

Motor and Inverter

Number of pole pairs — Number of motor pole pairs
2 (default) | scalar

Number of pole pairs available in the induction motor.

Rated frequency (Hz) — Motor rated frequency
50 (default) | scalar

Rated frequency of the induction motor (in Hertz).

Nominal motor current (A) — Motor nominal current
2 (default) | scalar

Rated current of the induction motor (in Amperes).

Nominal voltage (V) — Motor nominal voltage
24 (default) | scalar

Rated voltage of the induction motor (in Volts).

Maximum inverter current (A) — Maximum measurable current
21 (default) | scalar

Maximum current (in Amperes) that the system (including inverter and controller) can measure.

Board resistance (ohm) — Inverter bridge resistance
0.0043 (default) | scalar

Resistance in the path of phase currents (excluding motor resistance). You can obtain this value from datasheet of the inverter hardware.

Current sense gain (A/ADC Count) — Current per ADC count
0.0105 (default) | scalar

Gain of the current sense circuit of the inverter. This value determines the current (in Amperes) corresponding to 1 analog-to-digital converter (ADC) count (resolution of the measurable current range).

Voltage sense gain (V/ADC Count) — Voltage per ADC count
0.0098 (default) | scalar

Gain of the voltage sense circuit of the inverter. This value determines the voltage (in Volts) corresponding to 1 analog-to-digital converter (ADC) count (resolution of the measurable voltage range).

Id0 Estimation

Measurement time (sec) — Time used to measure and average-out current
5 (default) | scalar

Time used to measure and average-out the peaks in the current response to the open-loop operation of the induction motor. For more details about I_{d0} estimation, see Id0 Estimator.

Open loop ramp time (sec) — Time allotted to ramp-up frequency
3 (default) | scalar

Time that you want to allot for the motor operation frequency to ramp-up and reach 90 percent of the motor rated frequency. For more details about I_{d0} estimation, see Id0 Estimator.

Rs Estimation

Estimation time (sec) — Time to run Rs estimation algorithm

2 (default) | scalar

Time allotted to run motor resistance (R_s) estimation algorithm. This value defines the time duration for which the ACIM Rs Estimator block injects each voltage to measure the motor resistance. For more details about R_s estimation, see ACIM Rs Estimator.

Vd reference voltage 1 (PU) — First reference voltage for Rs estimation

0.1 (default) | scalar

The first reference motor-phase voltage (in per-unit) that the ACIM Rs Estimator block uses for measuring motor resistance (R_s). By default, the block sets this field to 10 percent of the inverter DC voltage. For more details about R_s estimation, see ACIM Rs Estimator. For more details about the per-unit system, see “Per-Unit System”.

Vd reference voltage 2 (PU) — Second reference voltage for Rs estimation

0.2 (default) | scalar

The second reference motor-phase voltage (in per-unit) that the ACIM Rs Estimator block uses for measuring motor resistance (R_s). By default, the block sets this field to 20 percent of the inverter DC voltage. For more details about R_s estimation, see ACIM Rs Estimator. For more details about the per-unit system, see “Per-Unit System”.

Rr, Lm, Lls, Llr Estimation

Frequency 1 as a ratio of rated frequency (PU) — Ratio of first injected low frequency over rated frequency

0.1 (default) | scalar

Ratio of the first injected low frequency over the rated frequency of the induction motor (in per-unit). For more details about the estimation process, see RrL Estimator. For more details about the per-unit system, see “Per-Unit System”.

Frequency 2 as a ratio of rated frequency (PU) — Ratio of second injected low frequency over rated frequency

0.2 (default) | scalar

Ratio of the second injected low frequency over the rated frequency of the induction motor (in per-unit). For more details about the estimation process, see RrL Estimator. For more details about the per-unit system, see “Per-Unit System”.

High Frequency for Lm (Hz) — Frequency of third injected signal

200 (default) | scalar

Frequency of the third (high frequency) signal (in Hertz) injected by the block for mechanical parameter estimation. For more details about the estimation process, see RrL Estimator.

Voltage sweep start value voltage (PU) — Initial voltage at which voltage sweep begins

0.1 (default) | scalar

Initial voltage (of the first and second low-frequency signals that the block injects, in per-unit) at which the voltage sweep begins. For more details about the estimation process, see RrL Estimator. For more details about the per-unit system, see “Per-Unit System”.

Voltage sweep step value voltage (PU) — Step size for voltage sweep

0.0125 (default) | scalar

Step size that the block uses to perform voltage sweep on the two injected low frequency signals (in per-unit). For more details about the estimation process, see RrL Estimator. For more details about the per-unit system, see “Per-Unit System”.

High frequency injection voltage (PU) — Voltage of third injected signal

0.1 (default) | scalar

Voltage of the third (high frequency) signal (in per-unit) injected by the block for mechanical parameter estimation. For more details about the estimation process, see RrL Estimator. For more details about the per-unit system, see “Per-Unit System”.

J, B Estimation

Closed loop duration (sec) — Closed-loop motor run duration

5 (default) | scalar

Duration (in seconds) for which the ACIM Mechanical Parameter Estimator block runs the motor using closed-loop control before initiating coast-down. To know more about the estimation process, see ACIM Mechanical Parameter Estimator.

Closed loop speed (RPM) — Closed-loop motor speed

950 (default) | scalar

Speed (in RPM) at which the ACIM Mechanical Parameter Estimator block runs the motor using closed-loop control. To know more about the estimation process, see ACIM Mechanical Parameter Estimator.

I_q reference current for FOC (PU) — Reference current for FOC when estimating *J* and *B*

0.2 (default) | scalar

Reference current, I_q to achieve the reference speed specified by the **Closed loop speed (RPM)** parameter. To know more about the estimation process, see ACIM Mechanical Parameter Estimator.

Specify current controller gains — Specify PI current controller gains

off (default) | on

Select this parameter to enable and display the following fields:

- **Proportional gain**
- **Integral gain**

You can use these fields to enter the proportional and integral gains of the PI current controllers that implement closed-loop control to estimate *J* and *B*.

If you deselect this parameter, the block automatically computes the proportional and integral gains internally.

To know more about the estimation process, see ACIM Mechanical Parameter Estimator.

Proportional gain — Proportional gain of PI controller

1 (default) | scalar

Proportional gain, k_p , of the PI current controller that implements field-oriented control to run the motor in closed-loop control and estimate J and B .

Dependencies

To enable and display this parameter, select the **Specify current controller gains** parameter.

Integral gain — Integral gain of PI controller

1000 (default) | scalar

Integral gain, k_i , of the PI current controller that implements field-oriented control to run the motor in closed-loop control and estimate J and B .

Dependencies

To enable and display this parameter, select the **Specify current controller gains** parameter.

Speed lower limit for inertia estimation (RPM) — Lower speed limit during coast-down

100 (default) | scalar

Lower speed limit during coast-down at which the ACIM Mechanical Parameter Estimation block registers the timestamp for estimating motor inertia. For more details about the estimation process, see ACIM Mechanical Parameter Estimation.

Parameter estimation sample time (sec) — Sample time for parameter estimation

50e-6 (default) | scalar

Sample time for the parameter estimation algorithm. This parameter defines the sample time for the following parameter estimation algorithm blocks:

- Id0 Estimator
- ACIM Rs Estimator
- Rr L Estimator
- ACIM Mechanical Parameter Estimator

Version History

Introduced in R2023a

Extended Capabilities

C/C++ Code Generation

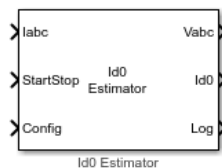
Generate C and C++ code using Simulink® Coder™.

See Also

Id0 Estimator | ACIM Rs Estimator | RrL Estimator | ACIM Mechanical Parameter Estimator

Id0 Estimator

Estimate magnetizing current (I_{d0}) of AC induction motor (ACIM)



Libraries:

Motor Control Blockset / Parameter Estimation / ACIM Parameter Estimation

Description

The Id0 Estimator block computes the magnetizing current of an induction motor using the phase currents and the test configuration elements.

The block runs the induction motor using open-loop control, during which it measures the peak current response values and averages them out over a given period. In addition, the block measures the time taken by motor to reach from zero to 90 percent of the rated frequency. It uses this time duration as well as the computed average current to estimate the magnetizing current of the induction motor.

Ports

Input

Iabc — Three-phase current response
scalar

The three-phase current response of the motor measured by the current sensors.

Note Providing phase-c current input is optional. Absence of phase-c current input has no impact on the block functionality.

Data Types: single

StartStop — Control signal for I_{d0} estimation
logical

Signal that either starts or stops Id0 estimation:

- 1 (rising edge of a pulse) — This signal initiates I_{d0} estimation.
- 0 (falling edge of a pulse) — This signal immediately stops I_{d0} estimation process. If you interrupt the estimation process abruptly before completion, the block does not compute or output the I_{d0} value.

Data Types: Boolean

Config — Bus signal input
bus

The following table summarizes the expected configuration elements in the bus signal input:

Category	Configuration element	Units
Elements for motor and inverter hardware	Number of pole pairs	-
	Rated frequency	Hz
	Nominal motor current	A
	Nominal voltage	V
	Maximum measurable inverter current	A
	Board resistance	ohm
	Current sense gain	A/ADC Count
	Voltage sense gain	V/ADC Count
Elements for estimating magnetizing current I_{d0}	Measurement time	sec
	Open-loop ramp time	sec
Elements for estimating motor resistance (R_s)	Estimation time	sec
	V_d reference voltage 1	PU
	V_d reference voltage 2	PU
Elements for estimating rotor resistance (R_r), magnetizing inductance (L_m), stator leakage inductance (L_{ls}), and rotor leakage inductance (L_{lr})	Frequency 1 as a ratio of rated frequency	PU
	Frequency 2 as a ratio of rated frequency	PU
	High frequency for L_m	Hz
	Voltage sweep start value voltage	PU
	Voltage sweep step value voltage	PU
	High frequency injection voltage	PU
Elements for estimating motor inertia (J) and friction constant (B)	Closed-loop speed duration	sec
	Closed-loop speed	RPM
	I_q Reference current for FOC	PU
	Proportional gain	-
	Integral gain	-
	Speed lower limit for inertia estimation	RPM
-	Parameter estimation sample time	sec

You can connect this input port to the Config output port of the ACIM Parameter Estimation Configurator block.

Data Types: single

Output

Vabc — a , b , and c -axis stator reference voltage components
scalar

Stator reference voltage components along the a , b , and c axes of the abc reference frame.

Data Types: single

Id0 — Estimated magnetizing current

scalar

Estimated magnetizing current (in Amperes).

Data Types: single

Log — Debug signals

bus

Debug signals that the block provides for examination. The bus includes these debug signals:

Debug signal		Description	Units
I_d		D -axis current	Amperes
$status$	0	I_{d0} estimation did not complete	-
	1	I_{d0} estimation completed successfully	-

Data Types: single

Version History

Introduced in R2023a

Extended Capabilities

C/C++ Code Generation

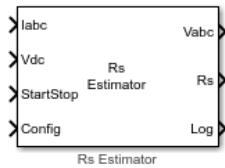
Generate C and C++ code using Simulink® Coder™.

See Also

ACIM Parameter Estimation Configurator | ACIM Rs Estimator | RrL Estimator | ACIM Mechanical Parameter Estimator

ACIM Rs Estimator

Estimate stator resistance (R_s) of an AC induction motor (ACIM)



Libraries:

Motor Control Blockset / Parameter Estimation / ACIM Parameter Estimation

Description

The ACIM Rs Estimator block computes the stator resistance of an induction motor using the phase currents, DC voltage across the motor, and the test configuration elements.

The block injects a voltage across the motor phases and measures the current response to estimate the motor resistance.

Ports

Input

Iabc — Three-phase current response
scalar

The three-phase current response of the motor measured by the current sensors.

Note Providing phase-c current input is optional. Absence of phase-c current input has no impact on the block functionality.

Data Types: single

Vdc — DC link voltage
scalar

DC bus voltage that you provide to the inverter.

Data Types: single

StartStop — Control signal for R_s estimation
logical

Signal that either starts or stops R_s estimation:

- 1 (rising edge of a pulse) — This signal initiates R_s estimation.
- 0 (falling edge of a pulse) — This signal immediately stops R_s estimation process. If you interrupt the estimation process abruptly before completion, the block does not compute or output the R_s value.

Data Types: Boolean

Config — Bus signal input

bus

The following table summarizes the expected configuration elements in the bus signal input:

Category	Configuration element	Units
Elements for motor and inverter hardware	Number of pole pairs	-
	Rated frequency	Hz
	Nominal motor current	A
	Nominal voltage	V
	Maximum measurable inverter current	A
	Board resistance	ohm
	Current sense gain	A/ADC Count
	Voltage sense gain	V/ADC Count
Elements for estimating magnetizing current I_{d0}	Measurement time	sec
	Open-loop ramp time	sec
Elements for estimating motor resistance (R_s)	Estimation time	sec
	V_d reference voltage 1	PU
	V_d reference voltage 2	PU
Elements for estimating rotor resistance (R_r), magnetizing inductance (L_m), stator leakage inductance (L_{ls}), and rotor leakage inductance (L_{lr})	Frequency 1 as a ratio of rated frequency	PU
	Frequency 2 as a ratio of rated frequency	PU
	High frequency for L_m	Hz
	Voltage sweep start value voltage	PU
	Voltage sweep step value voltage	PU
	High frequency injection voltage	PU
Elements for estimating motor inertia (J) and friction constant (B)	Closed-loop speed duration	sec
	Closed-loop speed	RPM
	I_q Reference current for FOC	PU
	Proportional gain	-
	Integral gain	-
	Speed lower limit for inertia estimation	RPM
-	Parameter estimation sample time	sec

You can connect this input port to the Config output port of the ACIM Parameter Estimation Configurator block.

Data Types: single

Output

Vabc — a , b , and c -axis stator reference voltage components
scalar

Stator reference voltage components along the a , b , and c axes of the abc reference frame.

Data Types: single

Rs — Estimated stator resistance
scalar

Estimated stator resistance (in ohms) of the induction motor.

Data Types: single

Log — Debug signals
bus

Debug signals that the block provides for examination. The bus includes these debug signals:

Debug signal		Description	Units
I_d		D -axis current	Amperes
V_d		D -axis voltage	Volts
$status$	0	R_s estimation did not complete	-
	1	R_s estimation completed successfully	-

Data Types: single

Version History

Introduced in R2023a

Extended Capabilities**C/C++ Code Generation**

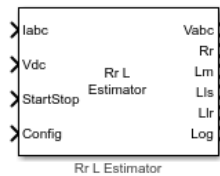
Generate C and C++ code using Simulink® Coder™.

See Also

ACIM Parameter Estimation Configurator | Id0 Estimator | RrL Estimator | ACIM Mechanical Parameter Estimator

RrL Estimator

Estimate rotor resistance (R_r), magnetizing inductance (L_m), stator leakage inductance (L_{ls}), and rotor leakage inductance (L_{lr}) of an AC induction motor (ACIM)



Libraries:

Motor Control Blockset / Parameter Estimation / ACIM Parameter Estimation

Description

The RrL Estimator block computes the rotor resistance (R_r), magnetizing inductance (L_m), stator leakage inductance (L_{ls}), and rotor leakage inductance (L_{lr}) of an AC induction motor (ACIM) using the phase currents, DC voltage across the motor, and the test configuration elements.

To estimate these values, the block injects the following 3 signals across the motor phases:

- First low-frequency signal (of varying voltage)
- Second low-frequency signal (of varying voltage)
- High-frequency signal (of fixed voltage)

Using the given initial voltage and the step size, the block performs voltage sweep on the first and second low-frequency signals until the resulting motor phase current becomes equal to 50 percent of the motor rated current. At this point, the block measures the phase difference between the injected voltage (of the low frequency signals) and the resulting current response to estimate R_r , L_m , L_{ls} , and L_{lr} .

Ports

Input

Iabc — Three-phase current response
scalar

The three-phase current response of the motor measured by the current sensors.

Note Providing phase-c current input is optional. Absence of phase-c current input has no impact on the block functionality.

Data Types: single

Vdc — DC link voltage
scalar

DC bus voltage that you provide to the inverter.

Data Types: single

StartStop — Control signal for L_d estimation

logical

Signal that either starts or stops the estimation process:

- 1 (rising edge of a pulse) — This signal initiates the estimation process.
- 0 (falling edge of a pulse) — This signal immediately stops the estimation process. If you interrupt the estimation process abruptly before completion, the block does not compute or output the R_r , L_m , L_{ls} , and L_{lr} values.

Data Types: Boolean

Config — Bus signal input

bus

The following table summarizes the expected configuration elements in the bus signal input:

Category	Configuration element	Units
Elements for motor and inverter hardware	Number of pole pairs	-
	Rated frequency	Hz
	Nominal motor current	A
	Nominal voltage	V
	Maximum measurable inverter current	A
	Board resistance	ohm
	Current sense gain	A/ADC Count
	Voltage sense gain	V/ADC Count
Elements for estimating magnetizing current I_{d0}	Measurement time	sec
	Open-loop ramp time	sec
Elements for estimating motor resistance (R_s)	Estimation time	sec
	V_d reference voltage 1	PU
	V_d reference voltage 2	PU
Elements for estimating rotor resistance (R_r), magnetizing inductance (L_m), stator leakage inductance (L_{ls}), and rotor leakage inductance (L_{lr})	Frequency 1 as a ratio of rated frequency	PU
	Frequency 2 as a ratio of rated frequency	PU
	High frequency for L_m	Hz
	Voltage sweep start value voltage	PU
	Voltage sweep step value voltage	PU
	High frequency injection voltage	PU
Elements for estimating	Closed-loop speed duration	sec
	Closed-loop speed	RPM

Category	Configuration element	Units
motor inertia (J) and friction constant (B)	I_q Reference current for FOC	PU
	Proportional gain	-
	Integral gain	-
	Speed lower limit for inertia estimation	RPM
-	Parameter estimation sample time	sec

You can connect this input port to the **Config** output port of the ACIM Parameter Estimation Configurator block.

Data Types: `single`

Output

Vabc — a , b , and c -axis stator reference voltage components
scalar

Stator reference voltage components along the a , b , and c axes of the abc reference frame.

Data Types: `single`

Rr — Estimated rotor resistance
scalar

Estimated rotor resistance of induction motor (in Ohms).

Data Types: `single`

Lm — Estimated magnetizing inductance
scalar

Estimated magnetizing inductance of induction motor (in Henry).

Data Types: `single`

Lls — Estimated stator leakage inductance
scalar

Estimated stator leakage inductance of induction motor (in Henry).

Data Types: `single`

Llr — Estimated rotor leakage inductance
scalar

Estimated rotor leakage inductance of induction motor (in Henry).

Data Types: `single`

Log — Debug signals
bus

Debug signals that the block provides for examination. The bus includes these debug signals:

Debug signal		Description	Units
I_d		<i>D</i> -axis current	Amperes
<i>InjFreq</i>		Frequency that the block currently injects	Hertz
<i>status</i>	0	Estimation did not complete	-
	1	Estimation completed successfully	-
V_d		<i>D</i> -axis voltage	Volts

Data Types: single

Version History

Introduced in R2023a

Extended Capabilities

C/C++ Code Generation

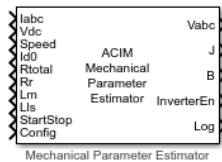
Generate C and C++ code using Simulink® Coder™.

See Also

ACIM Parameter Estimation Configurator | Id0 Estimator | ACIM Rs Estimator | ACIM Mechanical Parameter Estimator

ACIM Mechanical Parameter Estimator

Estimate rotor inertia and viscous damping of an AC induction motor (ACIM)



Libraries:

Motor Control Blockset / Parameter Estimation / ACIM Parameter Estimation

Description

The ACIM Mechanical Parameter Estimator block uses the phase currents and voltages, DC voltage across the motor, motor speed, magnetizing current, rotor and complete motor resistances, magnetizing and stator leakage inductances, as well as the other test configuration elements to compute the following mechanical parameters of an induction motor:

- Rotor inertia (J)
- Viscous damping (B)

The block runs the motor using closed-loop field-oriented control (FOC) with a limited speed during which it runs the tests to estimate viscous damping (B). After a pre-configured duration, the block concludes these tests to compute B , and then, triggers coast-down by shutting down all six inverter switches. The coast-down results in gradual decline in motor speed which eventually reaches zero. The block measures and uses the time to reach zero-speed to calculate rotor inertia (J).

Ports

Input

Iabc — Three-phase current response
scalar

The three-phase current response of the motor measured by the current sensors.

Note Providing phase- c current input is optional. Absence of phase- c current input has no impact on the block functionality.

Data Types: single

Vdc — DC link voltage
scalar

DC bus voltage that you provide to the inverter.

Data Types: single

Speed — Rotor speed
scalar

Current motor speed.

Data Types: `single`

Id0 — Estimated magnetizing current
scalar

Estimated magnetizing current of induction motor. You can either connect this input port to the Id0 output of the Id0 Estimator block or provide the magnetizing current value manually using a Constant block.

Data Types: `single`

Rtotal — Sum of stator and inverter-board resistances
scalar

Sum of estimated stator resistance R_s and inverter board resistance. You can either provide this input by utilizing the Rs output of the ACIM Rs Estimator block or provide this value manually using a Constant block.

Data Types: `single`

Rr — Estimated rotor resistance
scalar

Estimated rotor resistance of the induction motor. You can either connect this input port to the Rr output of the RrL Estimator block or provide the rotor resistance value manually using a Constant block.

Data Types: `single`

Lm — Estimated magnetizing inductance
scalar

Estimated magnetizing inductance of the induction motor. You can either connect this input port to the Lm output of the RrL Estimator block or provide the magnetizing inductance value manually using a Constant block.

Data Types: `single`

Lls — Estimated stator leakage inductance
scalar

Estimated stator leakage inductance of the induction motor. You can either connect this input port to the Lls output of the RrL Estimator block or provide the stator leakage inductance value manually using a Constant block.

Data Types: `single`

StartStop — Control signal for mechanical parameter estimation
logical

Signal that either starts or stops block execution:

- 1 (rising edge of a pulse) — This signal initiates block execution.
- 0 (falling edge of a pulse) — This signal immediately stops block execution and any tests that the block is running. If you interrupt the estimation process abruptly before completion, the block does not compute or output the mechanical parameter values.

Data Types: Boolean

Config — Bus signal input

bus

The following table summarizes the expected configuration elements in the bus signal input:

Category	Configuration element	Units
Elements for motor and inverter hardware	Number of pole pairs	-
	Rated frequency	Hz
	Nominal motor current	A
	Nominal voltage	V
	Maximum measurable inverter current	A
	Board resistance	ohm
	Current sense gain	A/ADC Count
	Voltage sense gain	V/ADC Count
Elements for estimating magnetizing current I_{d0}	Measurement time	sec
	Open-loop ramp time	sec
Elements for estimating motor resistance (R_s)	Estimation time	sec
	V_d reference voltage 1	PU
	V_d reference voltage 2	PU
Elements for estimating rotor resistance (R_r), magnetizing inductance (L_m), stator leakage inductance (L_{ls}), and rotor leakage inductance (L_{lr})	Frequency 1 as a ratio of rated frequency	PU
	Frequency 2 as a ratio of rated frequency	PU
	High frequency for L_m	Hz
	Voltage sweep start value voltage	PU
	Voltage sweep step value voltage	PU
	High frequency injection voltage	PU
Elements for estimating motor inertia (J) and friction constant (B)	Closed-loop speed duration	sec
	Closed-loop speed	RPM
	I_q Reference current for FOC	PU
	Proportional gain	-
	Integral gain	-
	Speed lower limit for inertia estimation	RPM
-	Parameter estimation sample time	sec

You can connect this input port to the Config output port of the ACIM Parameter Estimation Configurator block.

Data Types: single

Output

Vabc — *a*, *b*, and *c*-axis stator reference voltage components
 scalar

Stator reference voltage components along the *a*, *b*, and *c* axes of the *abc* reference frame.

Data Types: `single`

J — Estimated rotor inertia
 scalar

Estimated inertia of the induction motor (in kg.m²).

Data Types: `single`

B — Estimated viscous damping
 scalar

Estimated viscous damping of the induction motor (in N.s/m).

Data Types: `single`

InverterEn — Inverter control signal
 logical

Signal that switches the inverter either ON or OFF:

- 1 (logical high) — For the duration when this signal is high, all six switches of the inverter should be ON.
- 0 (logical low) — For the duration when this signal is low, all six switches of the inverter should be OFF.

Data Types: `single`

Log — Debug signals
 bus

Debug signals that the block provides for examination. The bus includes these debug signals:

Debug signal		Description	Units
<i>status</i>	0	Mechanical parameter estimation did not complete	-
	1	Mechanical parameter estimation completed successfully	-
<i>CoastDownTime</i>		Measured coast-down time duration	seconds

Debug signal	Description	Units
V_{dq}	Voltages across d and q axes	Volts
I_{dq}	Currents across d and q axes	Amperes
$VI\alpha\beta$	Voltages and currents across α and β axes	Volts, Amperes

Data Types: single

Version History

Introduced in R2023a

Extended Capabilities

C/C++ Code Generation

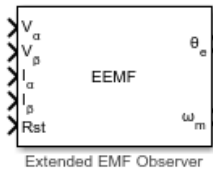
Generate C and C++ code using Simulink® Coder™.

See Also

ACIM Parameter Estimation Configurator | Id0 Estimator | ACIM Rs Estimator | RrL Estimator

Extended EMF Observer

Compute electrical position and mechanical speed of permanent magnet synchronous motor (PMSM)

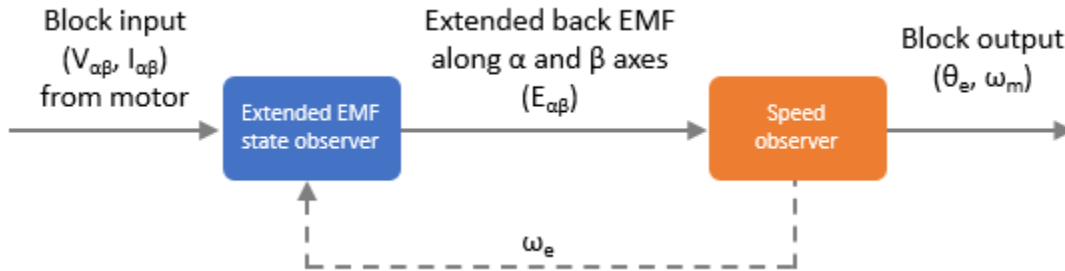


Libraries:
Motor Control Blockset / Sensorless Estimators

Description

The Extended EMF Observer block computes electrical position, θ_e (or $\sin \theta_e$ and $\cos \theta_e$) in addition to mechanical speed of PMSM from the measured voltage and current in the stationary $\alpha\beta$ reference frame.

The block includes a linear extended EMF state observer that estimates the extended back-emf. It uses a low-pass filter to remove any noise in the estimated back-emf value. In addition, the block includes a speed feed-forward-based quadrature phase-locked loop (PLL) that acts as a speed observer. The speed observer uses the computed extended back-emf to determine the motor speed. The feed-forward PLL calculates speed with zero error even during constant angular acceleration. The block then computes the position output from the estimated motor electrical speed.



Equations

The following is the IPMSM state equation:

$$\begin{bmatrix} \dot{i} \\ \dot{e} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ 0 & A_{22} \end{bmatrix} \begin{bmatrix} i \\ e \end{bmatrix} + \begin{bmatrix} B_1 \\ 0 \end{bmatrix} v + \begin{bmatrix} 0 \\ W \end{bmatrix}$$

$$i = C \begin{bmatrix} i \\ e \end{bmatrix}$$

The following equations describe the reduced order PMSM state model:

$$\dot{i} = A_{11}i + A_{12}e + B_1v$$

$$\dot{e} = A_{22}e$$

$$\text{Extended back-EMF, } e = \begin{bmatrix} (L_d - L_q)(\omega_{re}i_d - \dot{i}_q) + \omega_{re}K_E \\ \cos\theta_{re} \end{bmatrix} \begin{bmatrix} -\sin\theta_{re} \\ \cos\theta_{re} \end{bmatrix}$$

The following equation describes the reduced dimensional state observer:

$$\dot{\hat{e}} = (\hat{A}_{22} - \xi A_{12})\hat{e} + \xi(i - \hat{A}_{11}i - B_1v)$$

The following equations describe the extended EMF observer parameters:

$$A_{22} - \xi A_{12} = \omega_{re}J - (\alpha I + \beta J)\left(\frac{-1}{L_d}\right)I$$

$$\xi = (\alpha I + \beta J)$$

To ensure convergence, if we select $\beta = \omega_{re} \times L_d$ as well as select any negative value for α , then the extended EMF observer gain can be determined as:

$$\text{Extended EMF observer gain} = \frac{-\alpha}{L_d}$$

where:

- $i = \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$, $e = \begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix}$, and $v = \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix}$.
- $W = (L_d - L_q)\left(\omega_{re}\dot{i}_d - \dot{i}_q\right)\begin{bmatrix} -\sin\theta_{re} \\ \cos\theta_{re} \end{bmatrix}$
- $A = \begin{bmatrix} A_{11} & A_{12} \\ 0 & A_{22} \end{bmatrix}$, $B = \begin{bmatrix} B_1 \\ 0 \end{bmatrix}$, and $C = [I \ 0]$.
- $A_{11} = -\left(\frac{R}{L_d}\right)I + \left(\omega_{re}\frac{(L_d - L_q)}{L_d}\right)J$, $A_{12} = \left(\frac{-1}{L_d}\right)I$, and $A_{22} = \omega_{re}J$.
- $B_1 = \left(\frac{1}{L_d}\right)I$, $I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$, and $J = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$.

Note A and C are observable pair.

- "." and ".." are the first-order and second-order differential operators respectively.
- v_α and v_β are the stator voltages along the α - and β -axes respectively.
- i_α and i_β are the stator currents along the α - and β -axes respectively.
- e_α and e_β are the extended back-EMF along the α - and β -axes respectively.
- i_d and i_q are the stator currents along the d - and q -axes respectively.
- R is the stator resistance of PMSM.
- L_d and L_q are the stator inductances of PMSM across d and q axes respectively.
- K_E is the EMF constant
- ω_{re} is the angular velocity at electrical angle.
- θ_{re} is the rotor position at electrical angle.
- \hat{e} , \hat{A}_{22} , and \hat{A}_{11} are the estimated values.
- ξ is the feedback gain.

Ports

Input

V_α — α -axis voltage
scalar

Per-unit voltage component along the α -axis of the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

V_β — β -axis voltage
scalar

Per-unit voltage component along the β -axis of the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

I_α — α -axis current
scalar

Per-unit current component along the α -axis of the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

I_β — β -axis current
scalar

Per-unit current component along the β -axis of the stationary $\alpha\beta$ reference frame.

Data Types: `single` | `double` | `fixed point`

Rst — Reset the block
scalar

The pulse (true value) that resets and restarts the processing of the block algorithm.

Data Types: `single` | `double` | `fixed point`

Output

θ_e — Electrical position of PMSM
scalar

The estimated electrical position of the rotor.

Dependencies

To create this port, set the **Position output** parameter to `Electrical position`.

Data Types: `single` | `double` | `fixed point`

Sin θ_e — Sine of electrical position of PMSM
scalar

Sine of the estimated electrical position of the rotor.

Dependencies

To create this port, set the **Position output** parameter to Sine and Cosine electrical position.

Data Types: single | double | fixed point

Cos θ_e — Cosine of electrical position of PMSM
scalar

Cosine of the estimated electrical position of the rotor.

Dependencies

To create this port, set the **Position output** parameter to Sine and Cosine electrical position.

Data Types: single | double | fixed point

ω_m — Mechanical speed of PMSM
scalar

The estimated mechanical speed of the rotor.

Data Types: single | double | fixed point

Parameters

Input units — Units of block input
SI unit (default) | Per-unit

Units of inputs to the block.

Position output — Type of position output
Electrical position (default) | Sine and Cosine electrical position

Type of position output of the block.

- Electrical position — Select this value to enable θ_e port.
- Sine and Cosine electrical position — Select this value to enable the Sin θ_e and Cos θ_e ports.

Discrete step size (s) — Sample time after which block executes again
50e-6 (default) | scalar

The fixed time interval (in seconds) between two consecutive instances of block execution.

Motor Parameters

Stator resistance (ohm) — Resistance
0.36 (default) | scalar

Stator phase winding resistance (in ohm).

Stator d-axis inductance (H) — *D*-axis inductance
0.2e-3 (default) | scalar

Stator phase winding inductance (in Henry) along the d -axis of the rotating d - q reference frame.

Stator d-axis inductance (H) — Q -axis inductance

0.2e-3 (default) | scalar

Stator phase winding inductance (in Henry) along the q -axis of the rotating d - q reference frame.

Maximum application speed (RPM) — Maximum supported mechanical speed

6000 (default) | scalar

Maximum mechanical speed (in RPM) that the block can support. For a speed beyond this value, the block generates incorrect outputs.

Note The block uses this parameter to filter out noise in the estimated speed signal.

Number of pole pairs — Number of pole pairs available in motor

4 (default) | scalar

Number of pole pairs available in the motor.

Base voltage (V) — Nominal voltage corresponding to one per unit

13.8564 (default) | scalar

The maximum phase voltage applied to PMSM. For details, see “Per-Unit System”.

Base current (A) — Nominal current corresponding to one per unit

21.4286 (default) | scalar

The maximum measurable current supplied to PMSM. For details, see “Per-Unit System”.

Observer Parameters

EEMF observer gain — Extended EMF observer gain

10 (default) | scalar

Gain of the linear extended EMF state observer.

EEMF filter cutoff frequency (Hz) — Cut-off frequency of EEMF filter

7500 (default) | scalar

Cutoff frequency of the low-pass filter that the block uses to remove noise in the estimated back EMF.

Proportional (P) — Proportional gain of speed observer

250 (default) | scalar

Proportional gain of the speed observer used by the block.

Integral (I) — Integral gain of the speed observer

200000 (default) | scalar

Integral gain of the speed observer used by the block.

Number of data points for lookup table — Number of data points used for speed computation

1024 (default) | scalar

Number of data points in the lookup table that the speed observer uses to compute speed from the extended back emf value.

Speed filter cutoff frequency (Hz) — Cut-off filter of speed filter
15 (default) | scalar

Cutoff frequency of the low-pass filter that the block uses to remove noise in the estimated speed.

Datatypes

Position unit — Unit of position output
Degrees (default) | Radians | Per-unit

Unit of the position output.

Position data type — Data type of position output
single (default) | double | fixdt(1,16,0) | <data type expression>

Data type of the position output.

Speed unit — Unit of speed output
Degrees/sec (default) | Radians/sec | RPM | Per-unit

Unit of the speed output.

Speed data type — Data type of speed output
single (default) | double | fixdt(1,16,0) | <data type expression>

Data type of the speed output.

Version History

Introduced in R2023a

References

- [1] Zhiqian Chen, M. Tomita, S. Doki and S. Okuma, "An extended electromotive force model for sensorless control of interior permanent-magnet synchronous motors," in *IEEE Transactions on Industrial Electronics*, vol. 50, no. 2, pp. 288-295, April 2003, doi: 10.1109/TIE.2003.809391.
- [2] T. Ohnuma, S. Doki and S. Okuma, "Extended EMF observer for wide speed range sensorless control of salient-pole synchronous motor drives," *The XIX International Conference on Electrical Machines - ICEM 2010, Rome, Italy, 2010*, pp. 1-6, doi: 10.1109/ICELMACH.2010.5608087.
- [3] G. Liu, H. Zhang and X. Song, "Position-Estimation Deviation-Suppression Technology of PMSM Combining Phase Self-Compensation SMO and Feed-Forward PLL," in *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 9, no. 1, pp. 335-344, Feb. 2021, doi: 10.1109/JESTPE.2020.2967508.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

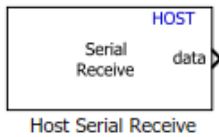
Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Sliding Mode Observer | Flux Observer | Inverse Park Transform | PWM Reference Generator | Sine-Cosine Lookup | Park Transform

Host Serial Receive

Configure host-side serial communications interface to receive data from serial port



Libraries:

Motor Control Blockset / Protection and Diagnostics

Description

The Host Serial Receive block specifies the configuration of the data that it receives from the target hardware.

The data package that the block receives is limited to 16 bytes of ASCII characters, including package headers and terminators. Calculate the size of a package by including the package header, or terminator, or both, and the data size. This table shows the number of bytes in each data type.

Data Type	Byte Count
single	4 bytes
int8 and uint8	1 byte
int16 and uint16	2 bytes
int32 and uint32	4 bytes

For example, if your data package has a package header 'S' (1 byte) and package terminator 'E' (1 byte), that leaves 14 bytes for the actual data. If your data is of type `int8`, there is space in the data package for 14 `int8`s. If your data is of type `uint16`, there is space in the data package for 7 `uint16`s. If your data is of type `int32`, there is space in the data package for only 3 `int32`s, with 2 bytes left over. Even though you could fit two `int8`s or one `uint16` in the remaining space, you should not, because you cannot mix data types in the same package.

The number of data types that can fit into a data package determine the data size. In the preceding example, the data size is 14 for `int8` and 7 for `uint16`. When the data size exceeds 16 bytes, unexpected behavior, including run-time errors, are likely to occur.

Ports

Output

data — Port to output received data

scalar

A first in, first out (FIFO) buffer receives the data. At every time step, the **data** port outputs the requested values from the buffer.

Data Types: `single` | `int8` | `uint8` | `int16` | `uint16` | `int32` | `uint32`

status — Transaction status

scalar

The status of the transaction. The status can be one of the following values:

- 0 — No errors
- 1 — A timeout occurred when the block was waiting to receive data
- 2 — There is an error in the received data (checksum error)
- 3 — SCI parity error flag — Occurs when a character is received with a mismatch
- 4 — SCI framing error flag — Occurs when an expected stop bit is not found

Dependencies

To enable this port, select the **Output receiving status** parameter.

Data Types: uint16

Parameters

Serial Connection — Serial port used for receiving data

Serial 1 (default) | Serial 2 | Serial 3 | Serial 4

Specify a serial port to receive communication from the target hardware. Select an available serial port from the list. You can configure the selected port using the Host Serial Setup block. If you do not configure a serial port, the block prompts you to do so. Each Host Serial Receive block must have a configured serial port. If you use multiple ports in your simulation, you must configure each port separately.

Additional package header — Package header data

'S' (default) | scalar

Specifies the data located at the front of the received data package, which is not part of the data being received, and generally indicates start of data. The additional package header must be an ASCII value. You can use a text value or a numeric value in the range (0-255). You must put single quotes around the text that you enter in this field, but the quotes are not received and they are not included in the total byte count.

Additional package terminator — Package terminator data

'E' (default) | scalar

Specifies the data located at the end of the received data package, which is not part of the data being received, and generally indicates end of data. The additional package terminator must be an ASCII value. You can use a text value or a numeric value in the range (0-255). You must put single quotes around text entered in this field, but the quotes are not received and they are not included in the total byte count.

Data type — Output data type

single (default) | int8 | uint8 | int16 | uint16 | int32 | uint32

Specifies the data type of the block output.

Data size — Output data size

1 (default) | scalar | matrix

Specifies the output data size or the number of values that should be read at every simulation time step.

Initial output — Default block output value

0 (default) | scalar

Specifies the initial or default output value of the block. This value is used, for example, if a connection timeout occurs and the **Action taken when connection times out** parameter is set to `Output the last received value`, but the block has not received any value yet.

Action taken when connection times out — Action taken by block when connection times out

`Output the last received value` (default) | `Output custom value` | `Error`

Specifies what to output if a connection timeout occurs.

- `Output the last received value` — The block outputs the value received at the preceding time step. If the block did not receive a value previously, it outputs the value of the **Initial output** parameter.
- `Output custom value` — The block outputs a user-defined value. Use the **Output value when connection times out** parameter to define this custom value.
- `Error` — The block outputs an error.

Output value when connection times out — Output custom value when the connection times out

0 (default) | scalar

Specifies a custom value that the block outputs when a connection timeout occurs.

Dependencies

To enable this parameter, set **Action taken when connection times out** to either `Output custom value` or `Error`.

Sample time — Sample time for block execution

-1 (default) | scalar

Determines how often the Host Serial Receive block is called (in seconds). When you set this value to -1, the model inherits the sample time of the model. To execute this block asynchronously, set **Sample time** to -1.

Output receiving status — Enable status output port

off (default) | on

Select this parameter to enable the **status** output port that provides the status of the transaction. If you clear this parameter, the block hides the **status** port.

Enable blocking mode — Block simulation while receiving data

on (default) | off

Select this parameter to block the simulation while receiving data. Clear this parameter if you do not want the read operation to block the simulation.

If you enable the blocking mode, the model blocks the simulation while it is waiting to receive the requested data. When you do not enable the blocking mode, the simulation runs continuously.

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

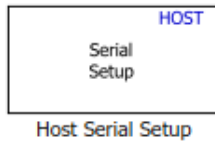
Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Host Serial Setup | Host Serial Transmit

Host Serial Setup

Configure communication ports used by Host Serial Receive and Host Serial Transmit blocks



Libraries:

Motor Control Blockset / Protection and Diagnostics

Description

The Host Serial Setup block is a standalone block that standardizes the serial communication (COM) port settings used by the Host Serial Receive and Host Serial Transmit blocks.

Setting the COM port configurations globally by using the Host Serial Setup block avoids conflicts. For example, the Host Serial Transmit block cannot use a COM1 port with settings different than those on the COM1 port of the Host Serial Receive block. You need to set the port configurations only once for each COM port.

Parameters

Port name — Port that you want to configure
'Please_select_a_port' (default) | 'COM3'

Select an available serial port that you want to configure. By default no port is selected and this field displays 'Please_select_a_port'. Use a configured port in the Host Serial Transmit and Host Serial Receive blocks. Both transmit and receive blocks must use a serial port that you configure using the Host Serial Setup block.

Baud rate — Baud rate for serial communication
115200 (default) | scalar

Enter the rate at which the model transmits the bits through the serial interface.

Number of stop bits — Number of stop bits
1 (default) | 2

Enter the number of bits that the model uses to indicate the end of a byte.

Parity mode — Method used to check parity bits
none (default) | odd | even

Specify how you want to check parity bits in the data bits that the model transmits through the serial port.

- none — Model does not perform parity check.
- odd — Model sets the parity bit to 0 if the number of ones in a given set of bits is even.
- even — Model sets the parity bit to 1 if the number of ones in a given set of bits is odd.

Timeout — Time interval before a one-way communication times out
1.0 (default) | scalar

Enter values greater than or equal to zero (seconds). When the COM port involved is using the protocol mode, this value indicates how long the transmitting side waits for an acknowledgement from the receiving side or how long the receiving side waits for data.

The system displays a warning message every n number of seconds, when the transmit or receive block exceeds the **Timeout** value of n seconds.

Byte order — Byte order for serial communication
LittleEndian (default) | BigEndian

Specify the byte order as either `LittleEndian` or `BigEndian`. If byte order is `LittleEndian`, the model stores the first byte in the first memory address. If byte order is `BigEndian`, the model stores the last byte in the first memory address. You should configure the byte order to an appropriate value before performing a read or write operation.

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

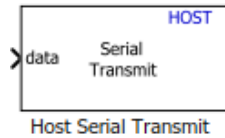
Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Host Serial Receive | Host Serial Transmit

Host Serial Transmit

Configure host-side serial communications interface to transmit data to serial port



Libraries:

Motor Control Blockset / Protection and Diagnostics

Description

The Host Serial Transmit block specifies the configuration of the data that it transmits to the target hardware.

The data package that the block sends is limited to 16 bytes of ASCII characters, including package headers and terminators. Calculate the size of a package by including the package header, or terminator, or both, and the data size. This table shows the number of bytes in each data type.

Data Type	Byte Count
single	4 bytes
int8 and uint8	1 byte
int16 and uint16	2 bytes
int32 and uint32	4 bytes

For example, if your data package has a package header 'S' (1 byte) and package terminator 'E' (1 byte), that leaves 14 bytes for the actual data. If your data is of type `int8`, there is space in the data package for 14 `int8`s. If your data is of type `uint16`, there is space in the data package for 7 `uint16`s. If your data is of type `int32`, there is space in the data package for only 3 `int32`s, with 2 bytes left over. Even though you could fit two `int8`s or one `uint16` in the remaining space, you should not, because you cannot mix data types in the same package.

The number of data types that can fit into a data package determine the data size. In the preceding example, the data size is 14 for `int8` and 7 for `uint16`. When the data size exceeds 16 bytes, unexpected behavior, including run-time errors, are likely to occur.

Ports

Input

data — Port to receive data to be transmitted
scalar

This port accepts both one-dimensional and matrix data for transmission to the target hardware.

Data Types: `single` | `int8` | `uint8` | `int16` | `uint16` | `int32` | `uint32`

Parameters

Serial Connection — Serial port used for transmitting data

Serial 1 (default) | Serial 2 | Serial 3 | Serial 4

Specify a serial port to transmit to the target hardware. Select an available serial port from the list. You can configure the selected port using the Host Serial Setup block. If you do not configure a serial port, the block prompts you to do so. Each Host Serial Transmit block must have a configured serial port. If you use multiple ports in your simulation, you must configure each port separately.

Additional package header — Package header data

'S' (default) | scalar

Specifies the data located at the front of the transmitted data package, which is not part of the data being transmitted, and generally indicates start of data. The additional package header must be an ASCII value. You can use a text value or a numeric value in the range (0–255). You must put single quotes around the text that you enter in this field, but the quotes are not transmitted and they are not included in the total byte count.

Additional package terminator — Package terminator data

'E' (default) | scalar

Specifies the data located at the end of the transmitted data package, which is not part of the data being transmitted, and generally indicates end of data. The additional package terminator must be an ASCII value. You can use a text value or a numeric value in the range (0–255). You must put single quotes around text entered in this field, but the quotes are not transmitted and they are not included in the total byte count.

Enable blocking mode — Block simulation while sending data

off (default) | on

Select this parameter to block the simulation while transmitting data. Clear this parameter if you do not want the write operation to block the simulation.

Version History

Introduced in R2020a

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

Fixed-Point Conversion

Design and simulate fixed-point systems using Fixed-Point Designer™.

See Also

Host Serial Setup | Host Serial Receive