Design the FOC of BLDC (PMSM)

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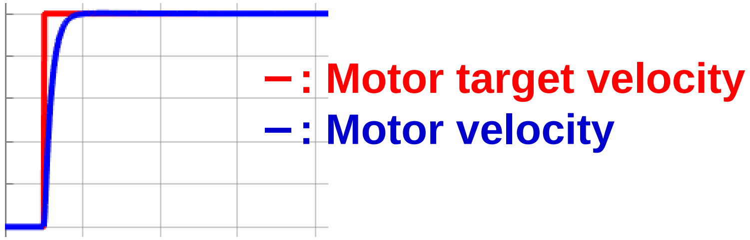
Terminology
- FOC: Field Oriented Control (or Vector Control)
- BLDC: Brush-less DC Motor
- PMSM: Permanent Magnet Synchronous Motor

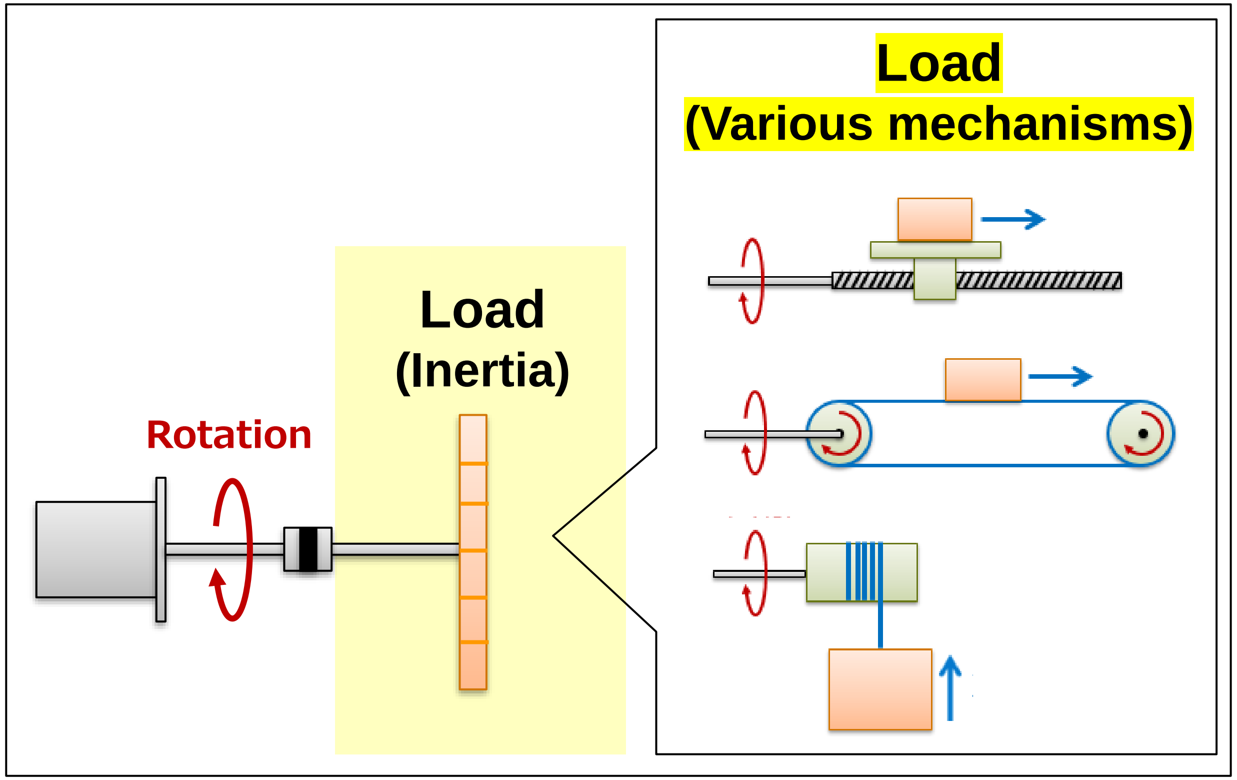
In this material, we suppose that BLDC is almost equal to PMSM.

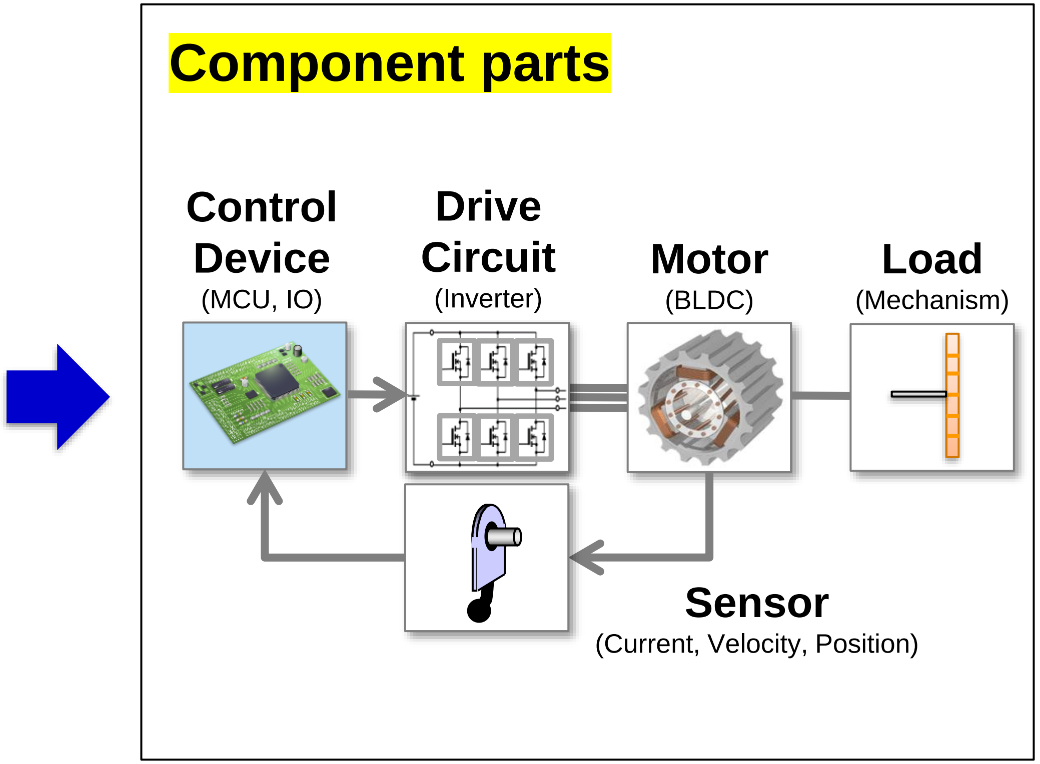
Ex) Velocity control system of BLDC (PMSM)

Purpose:
Construct FOC control logic and tune velocity control parameters to satisfy the following control specification.

Control Specification	Response for step signal of target velocity 1,000[rpm]
Rise time	20[msec]
Overshoot	5[%] (=1,000＋50[rpm])



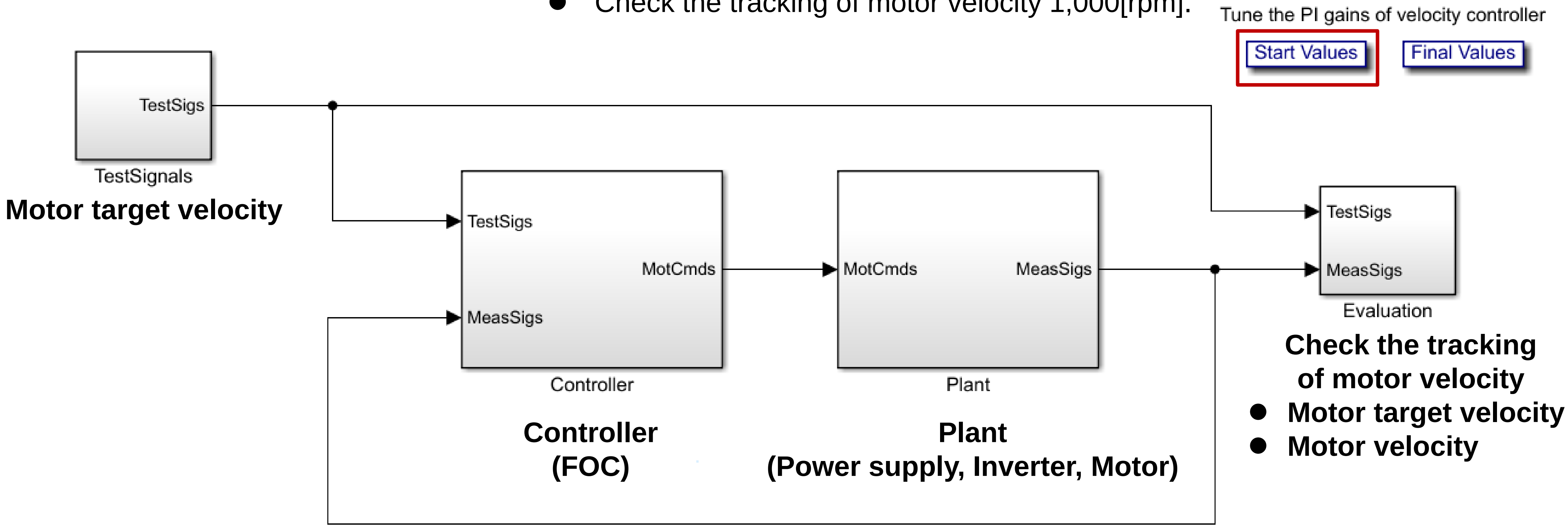




Model ① Electrical : Simple

Test Conditions

- Check the behavior of velocity control system during 1[sec].
- Input the step signal of target velocity 1,000[rpm] at t=0.05[sec].
- Input the step signal of load torque 0.2[Nm] at t=0.5[sec].
- Check the tracking of motor velocity 1,000[rpm].



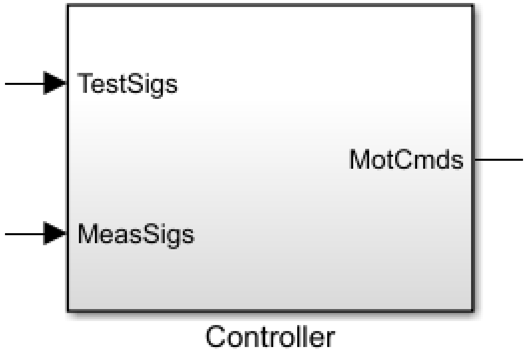
Check the tracking of motor velocity

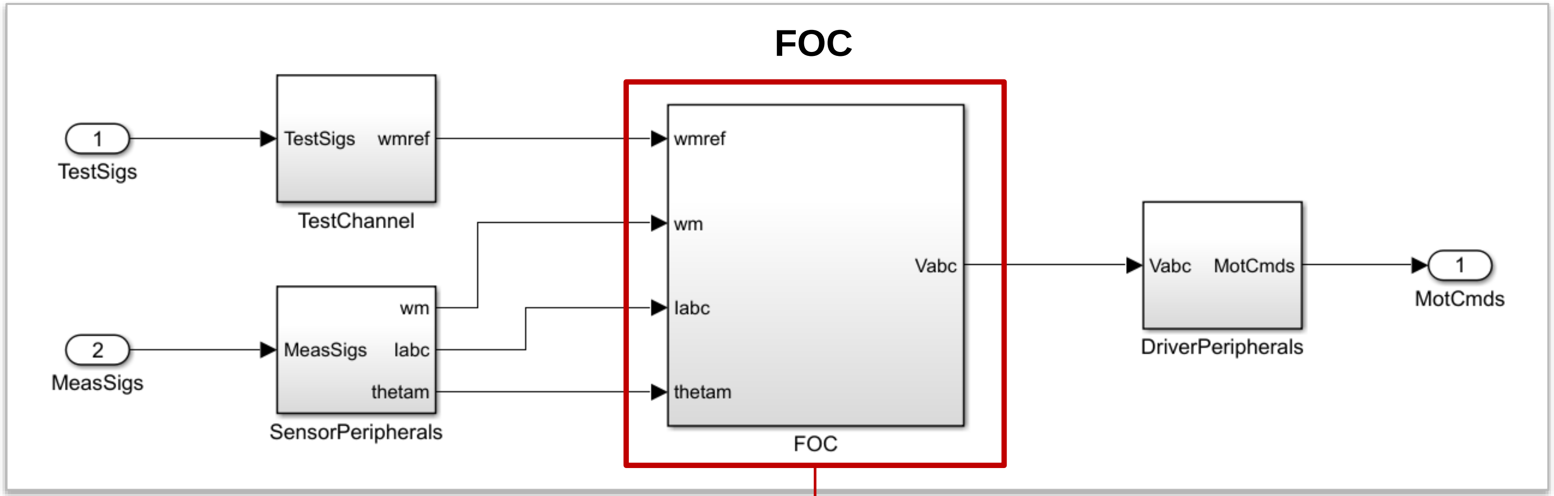
- **Motor target velocity**
- **Motor velocity**

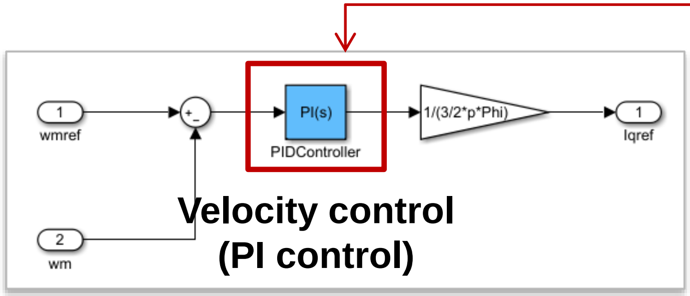
Procedure to run the sample model

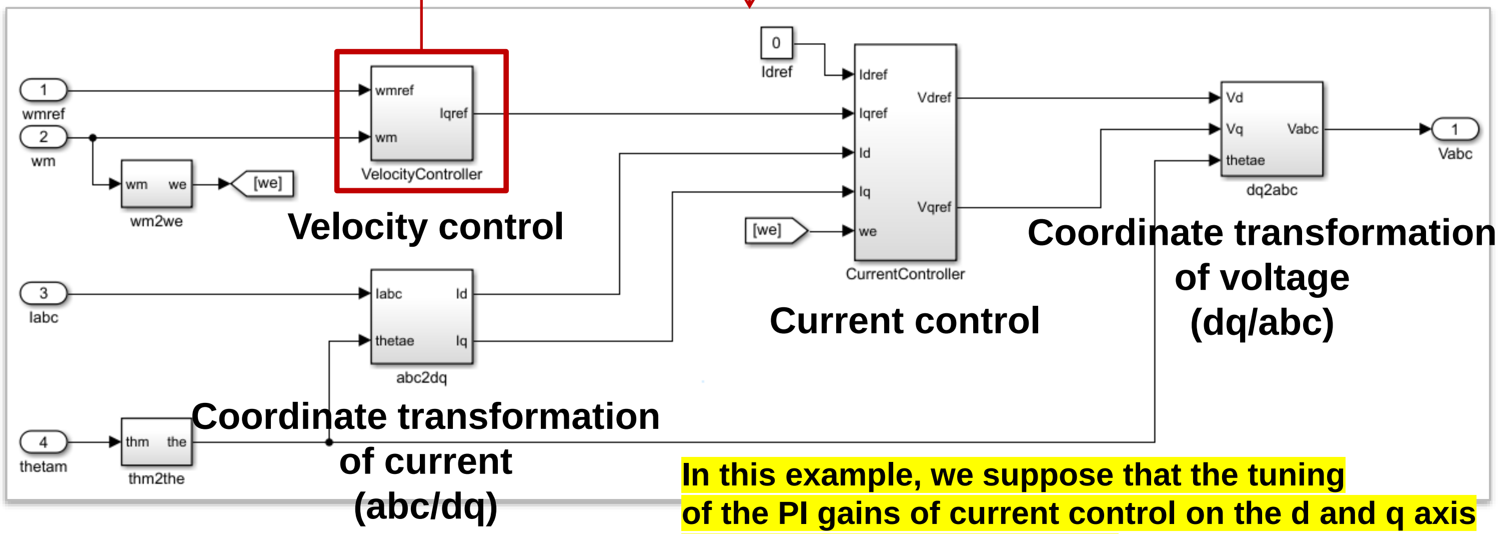
#1) Execute the m-file (**"foc_controlsystem_param.m"**).
#2) Open the slx-file (**"foc_controlsystem_average.slx"**), and click "**Start Values**" and simulate it. Then, check that the result of p.6 is got.

Controller





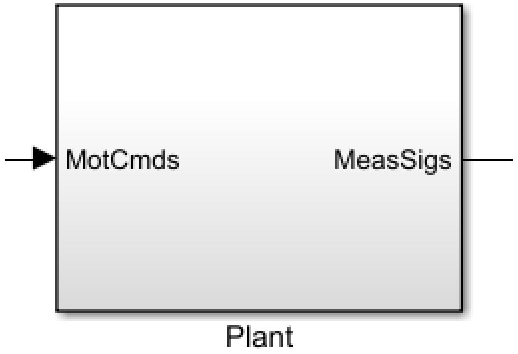


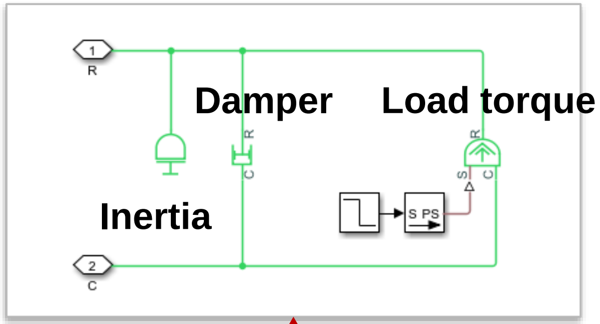


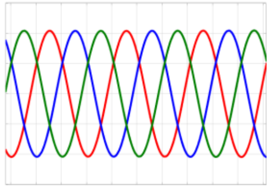
Tune the PI gains of velocity control
(---> Please see the p.7)

In this example, we suppose that the tuning of the PI gains of current control on the d and q axis has already been completed.

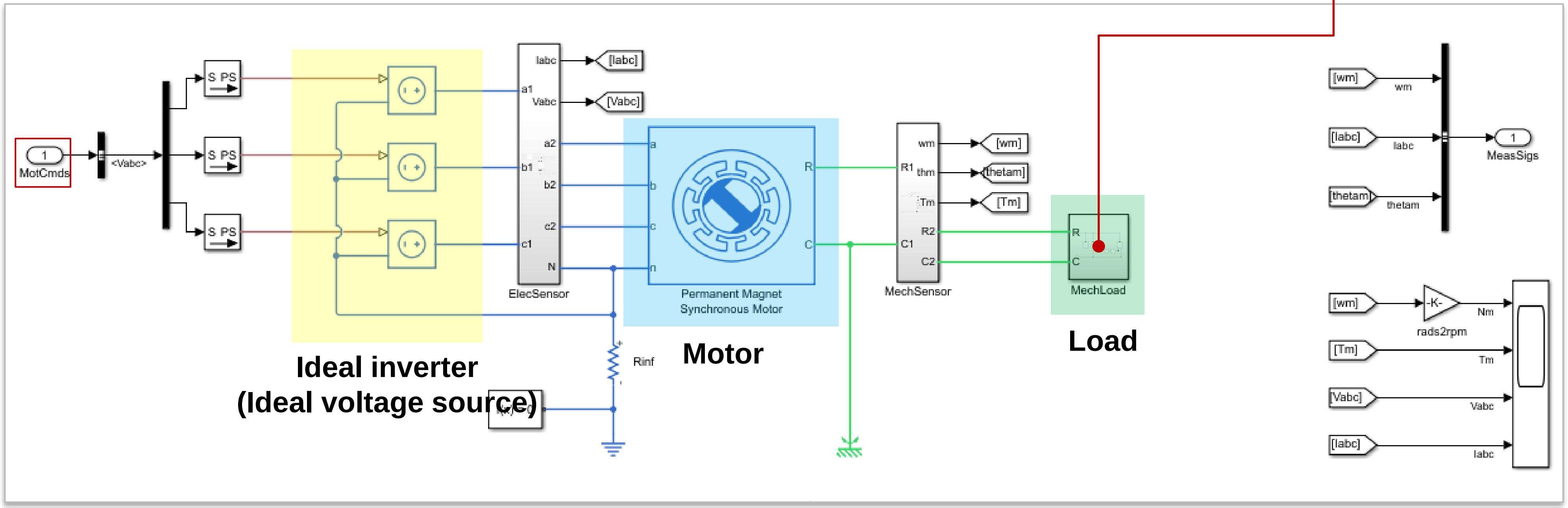
Plant





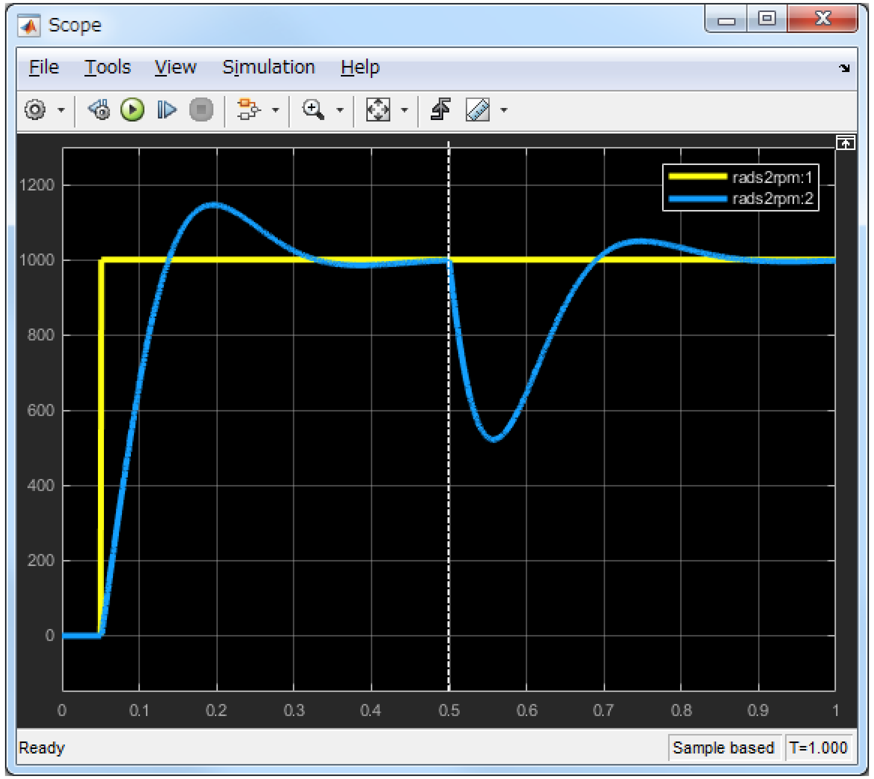


3-phase voltage



Result (Electrical: Simple / Before tuning the PI gains of velocity control)

Motor
target velocity
N_{m_ref} [rpm]
Motor velocity
N_m [rpm]



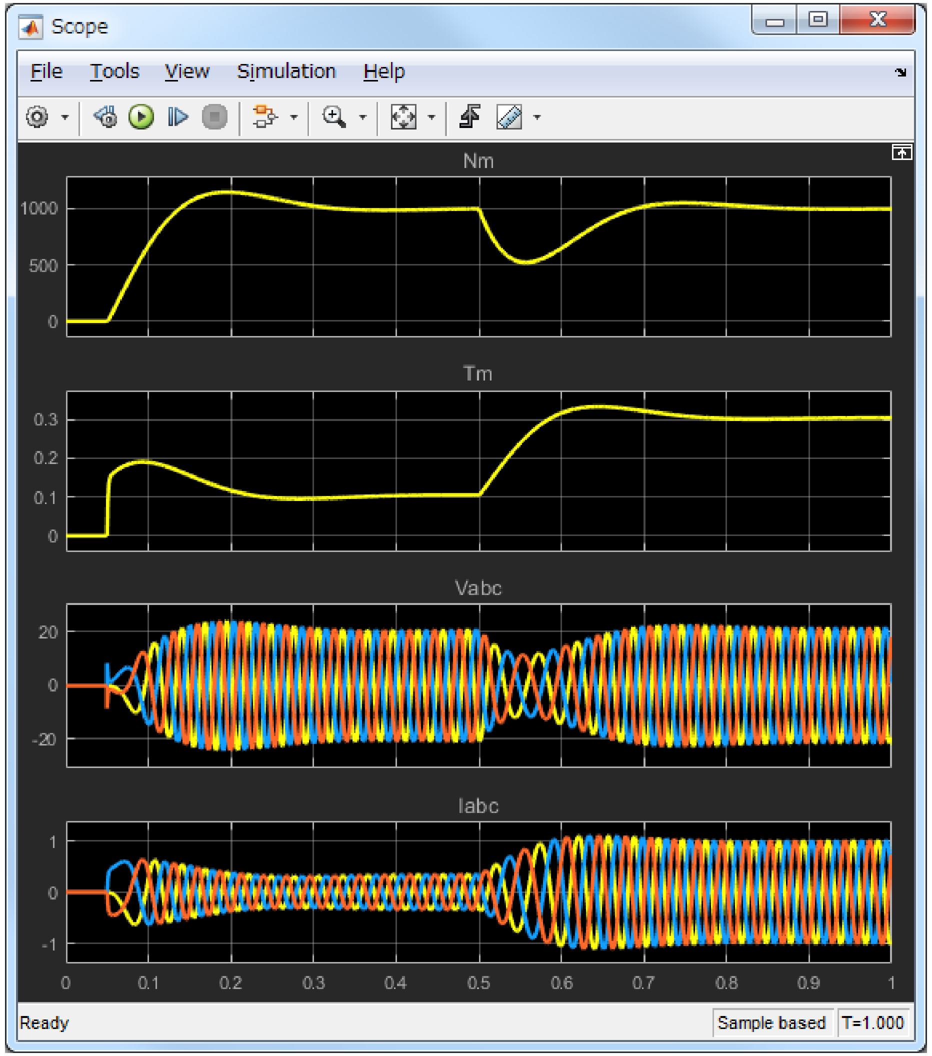
The velocity has overshoot, but it tracks to the target velocity.
And, when the disturbance of the load torque at t=0.5[sec] is caused, the velocity behaves similarly to the above.

Motor
velocity
N_m [rpm]

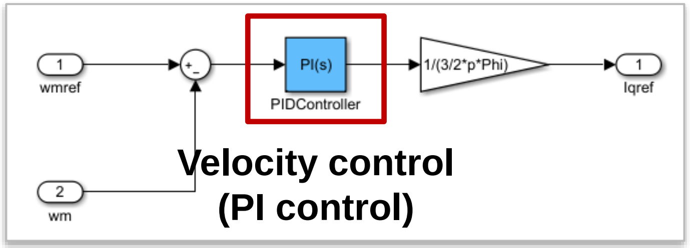
Motor
torque
T_m [Nm]

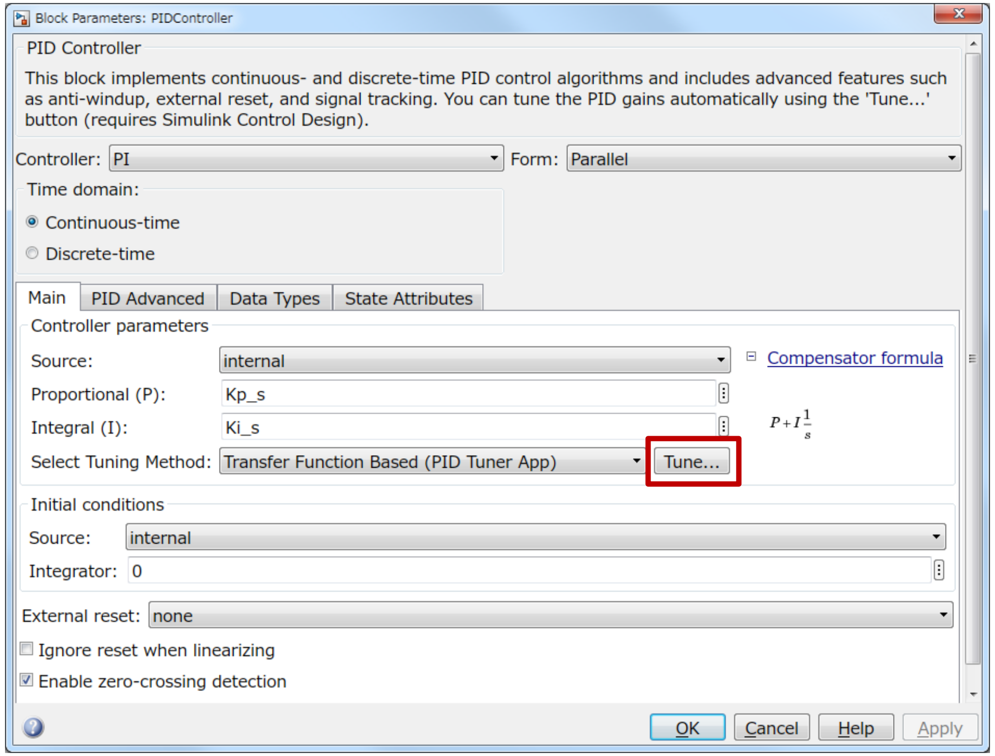
Motor
phase voltage
V_a V_b V_c [V]

Motor
phase current
I_a I_b I_c [A]



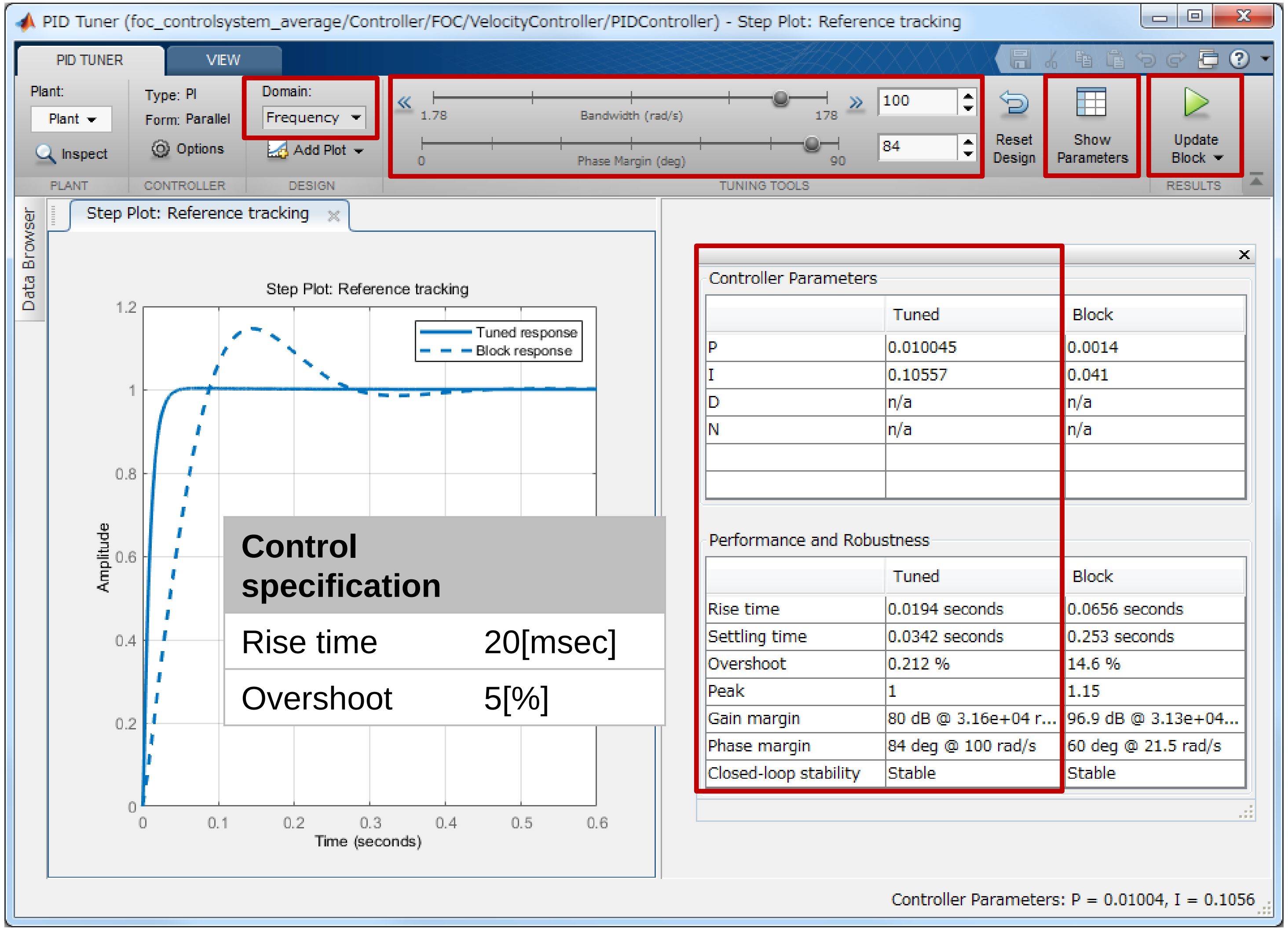
Tune the PI gains of velocity control





Procedure to run the sample model

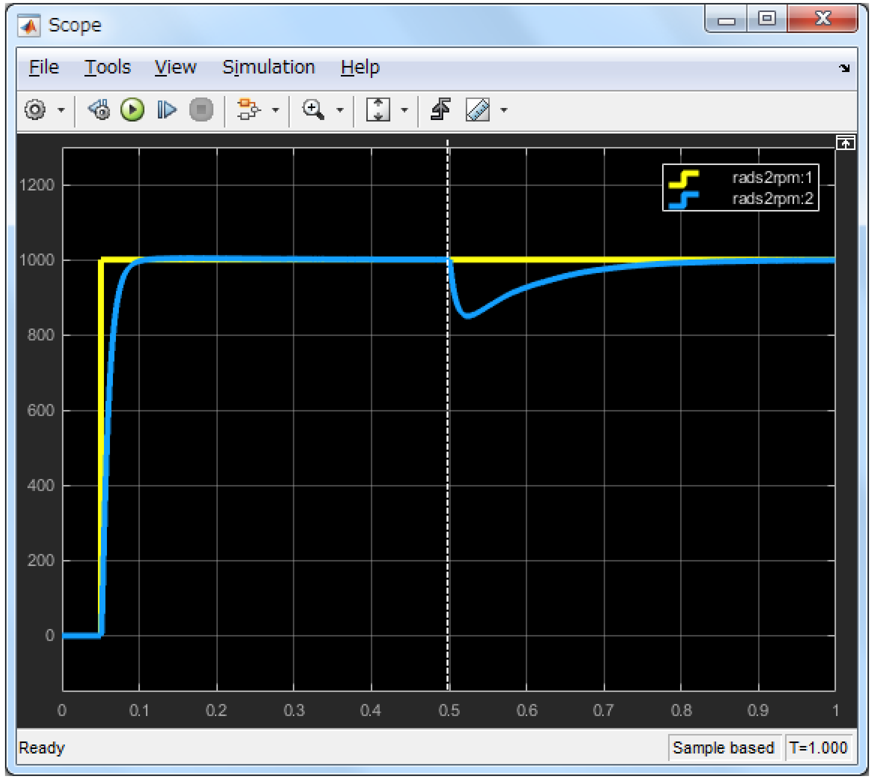
#1) Click the **"Tune"** in the **PID Controller** block, and open the specific UI (**"PID Tuner"**).
#2) Click the **"Show Parameters"**, and display the PI gains and control performance items.
#3) Select the "**Domain: Frequency"**, and tune the gauges of "Bandwidth" and "Phase Margin".
#4) After tuning of the PI gains, click the **"Update Block"**.



Control specification	
Rise time	20[msec]
Overshoot	5[%]

Result (Electrical: Simple / After tuning the PI gains of velocity control)

Motor
target velocity
N_{m_ref} [rpm]
Motor velocity
N_m [rpm]

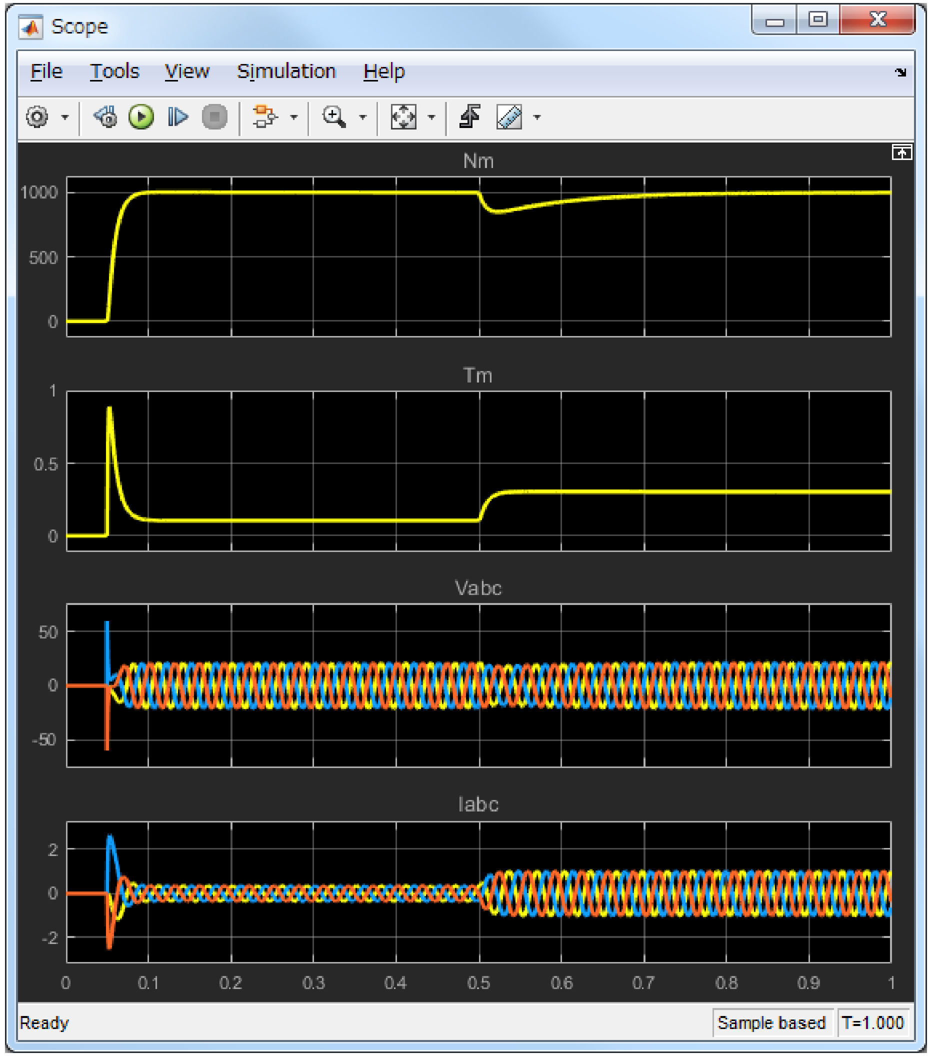


Motor
velocity
N_m [rpm]

Motor
torque
T_m [Nm]

Motor
phase voltage
V_a V_b V_c [V]

Motor
phase current
I_a I_b I_c [A]

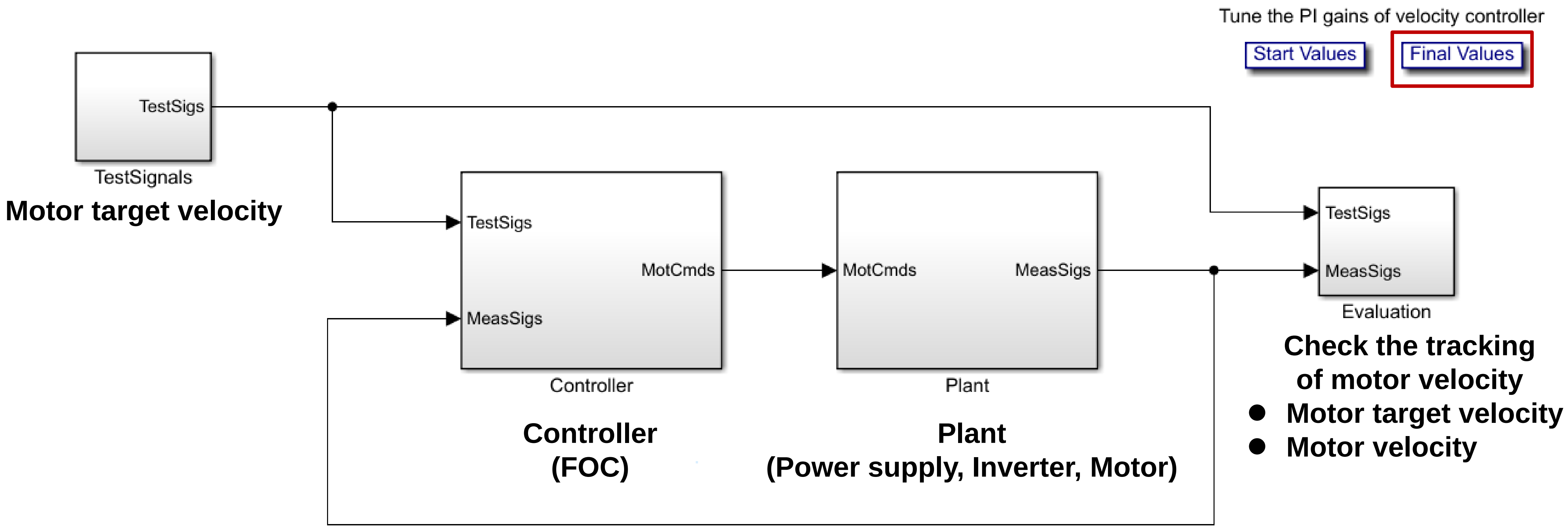


The velocity doesn't have overshoot, and it tracks to the target velocity.
And, when the disturbance of the load torque at t=0.5[sec] is caused,
the velocity behaves similarly to the above.

Procedure to run the sample model

#1) After tuning the PI gains of velocity control, simulate the model of p.3. Then, check that the result of this slide is got.

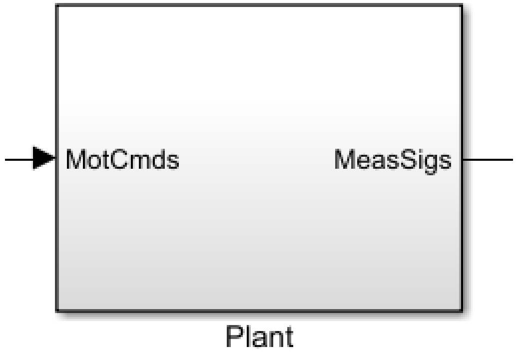
Model ②
Electrical: Detailed

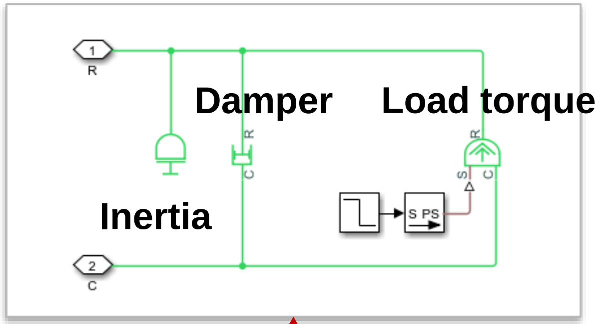


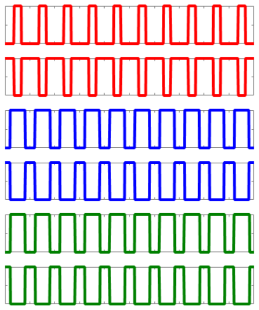
Procedure to run the sample model

#1) Open the slx-file (**"foc_controlsystem_pwm.slx"**), and simulate it.
(If we click the **"Final Values"**, we can set the PI gains that have been tuned in p.7.)
Check that the result of p.11 is got.

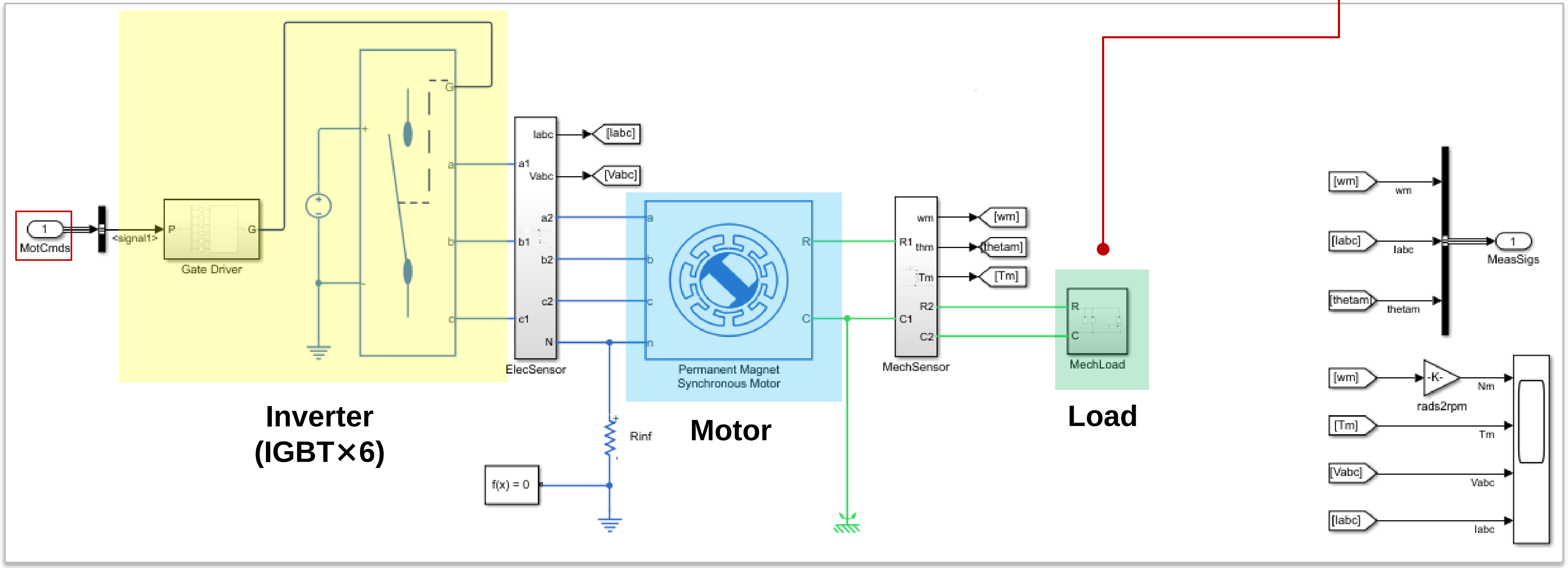
Plant





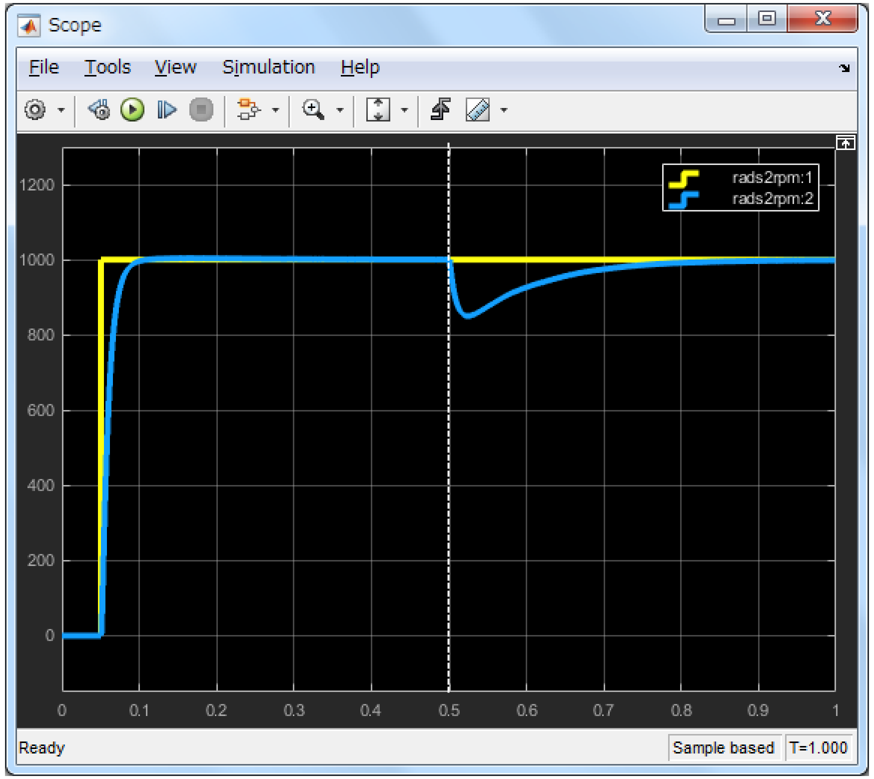


Gate signals
(×6)



Result (Electrical: Detailed / After tuning the PI gains of velocity control)

Motor
target velocity
N_{m_ref} [rpm]
Motor velocity
N_m [rpm]



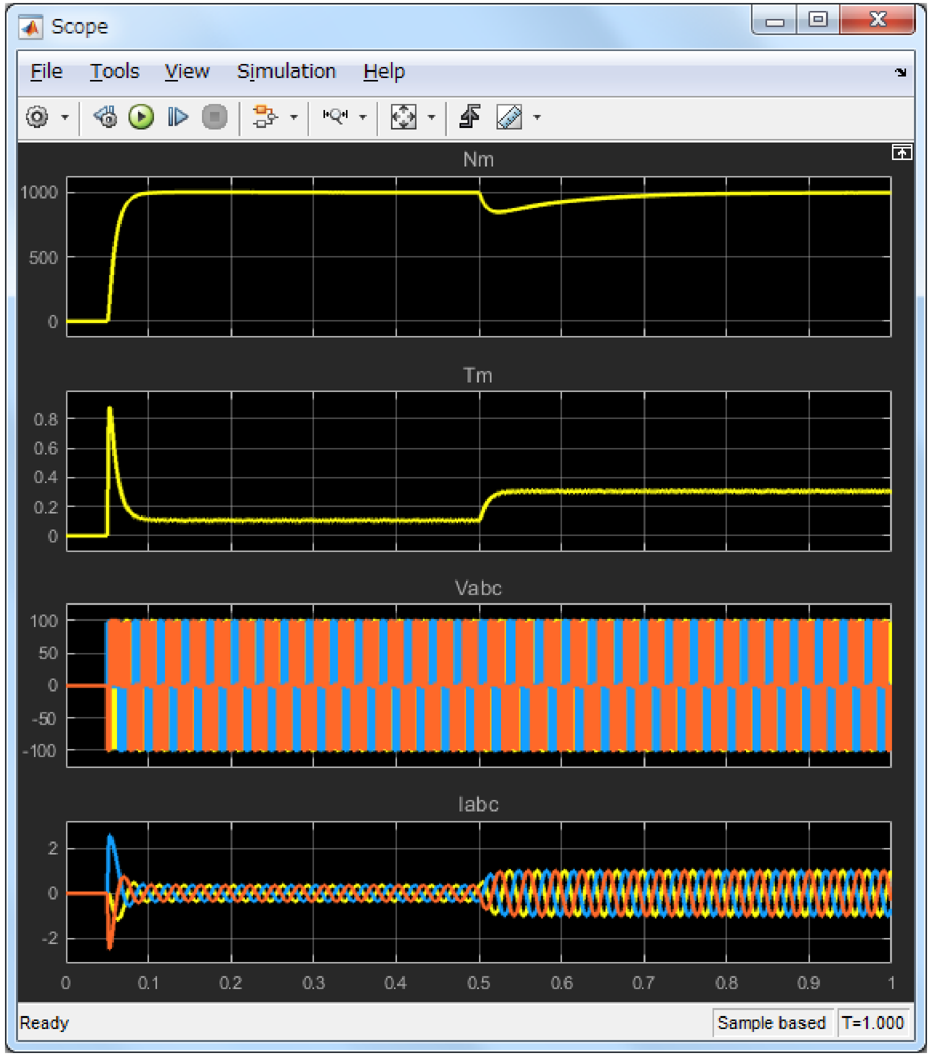
The velocity doesn’t have overshoot, and it tracks to the target velocity.
And, when the disturbance of the load torque at t=0.5[sec] is caused, the velocity behaves similarly to the above.

Motor
velocity
N_m [rpm]

Motor
torque
T_m [Nm]

Motor
line voltage
V_{ab} V_{bc} V_{ca} [V]

Motor
phase current
I_a I_b I_c [A]



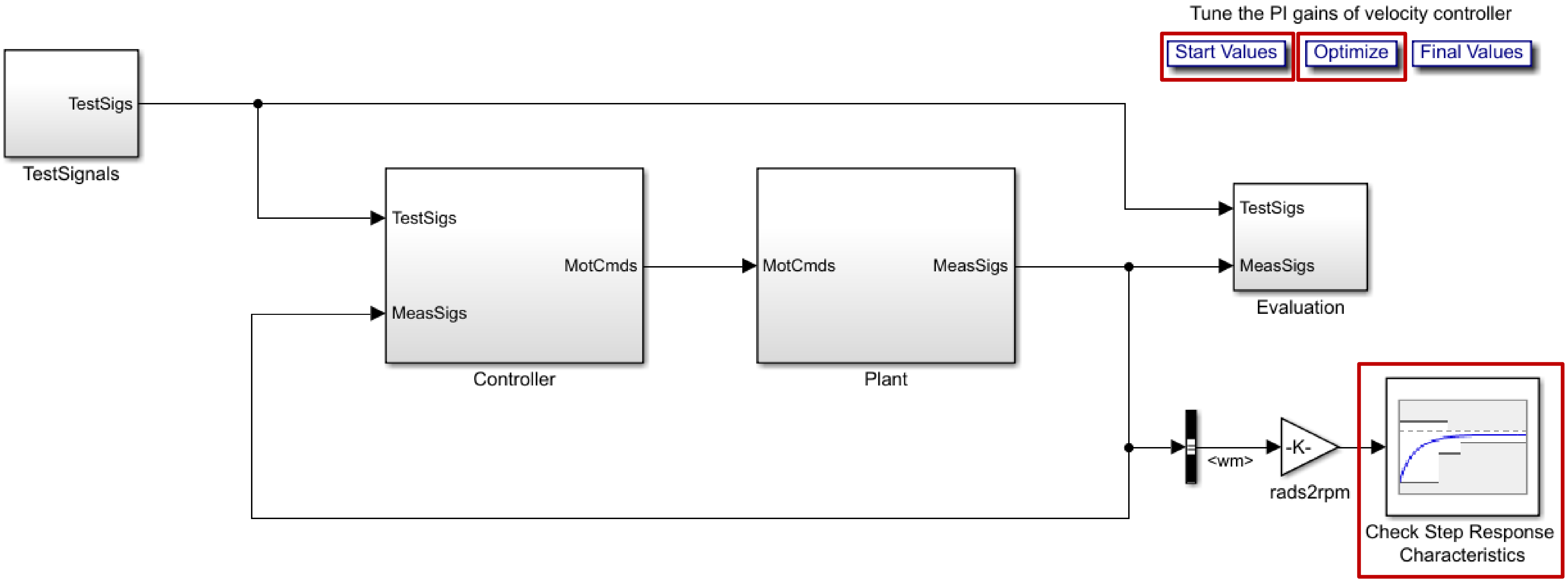
Appendix

- Auto-tuning of control parameters in model including switching control

- Two types of libraries of **Simscape Power Systems™**
  - **Specialized Technology (Simulink based library)**
  - **Simscape Components (Simscape Language based library)**

<Notes>
From R2018b, **Simscape Power Systems™** and **Simscape Electronics™** are integrated as one electrical modeling tool. The new tool's name is **Simscape Electrical™**.

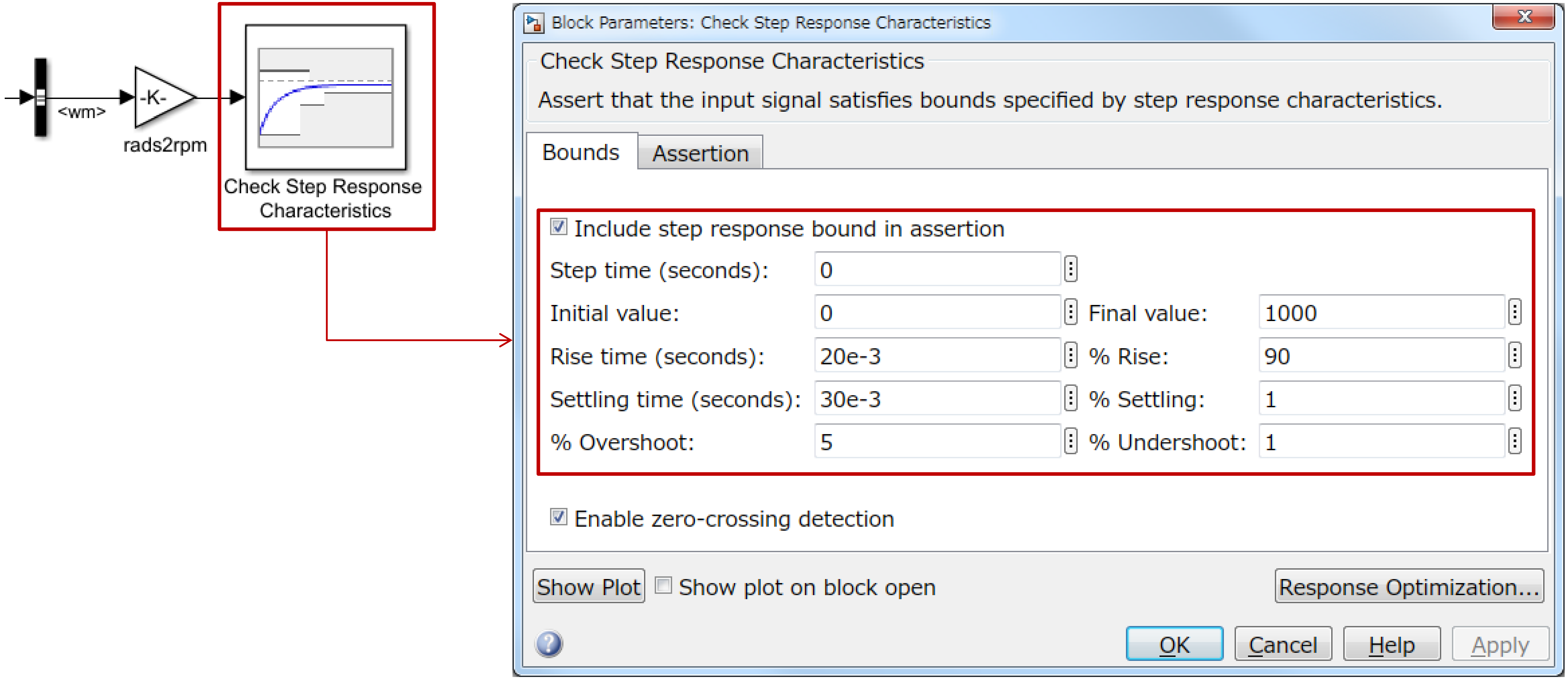
Model



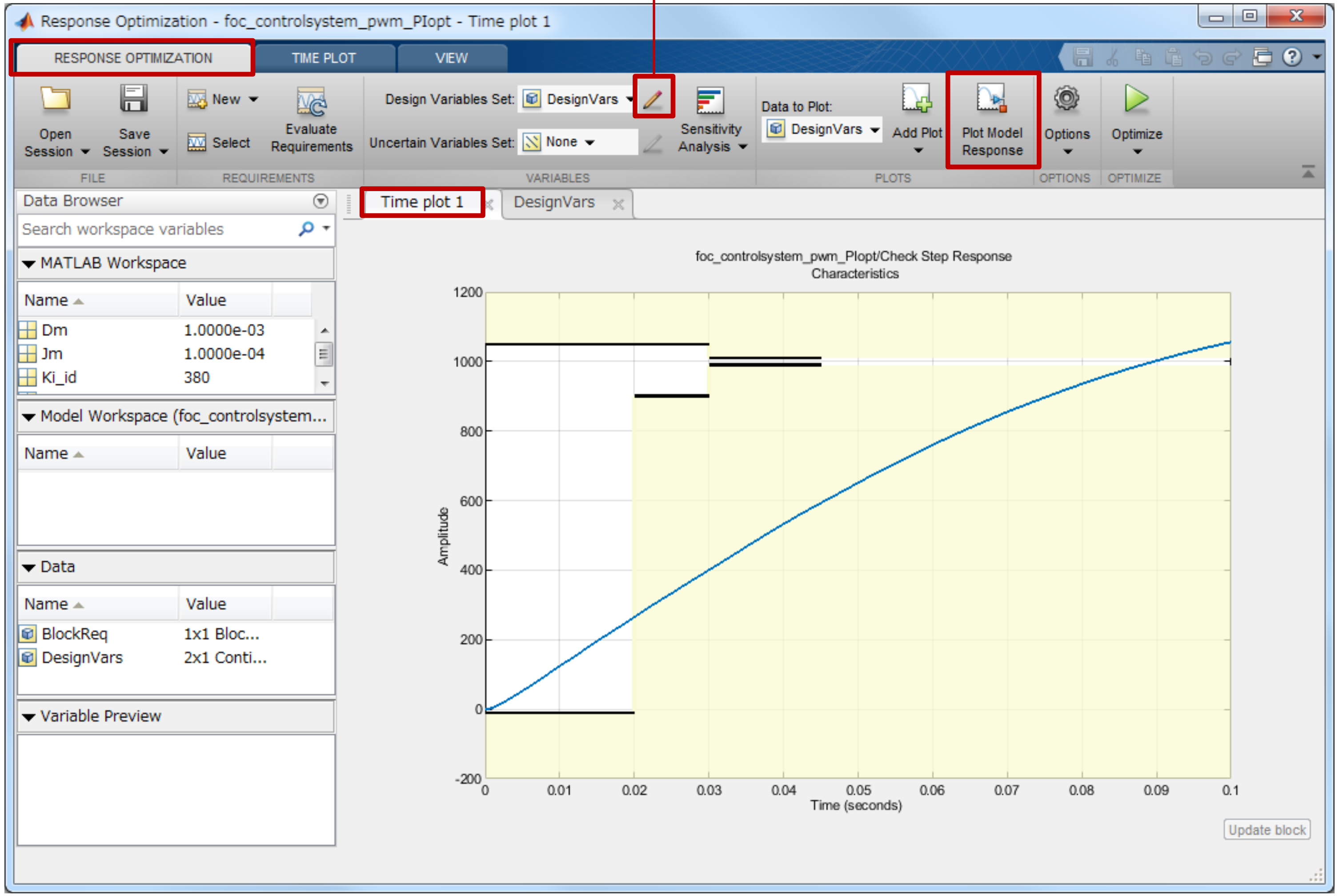
Procedure to run the sample model

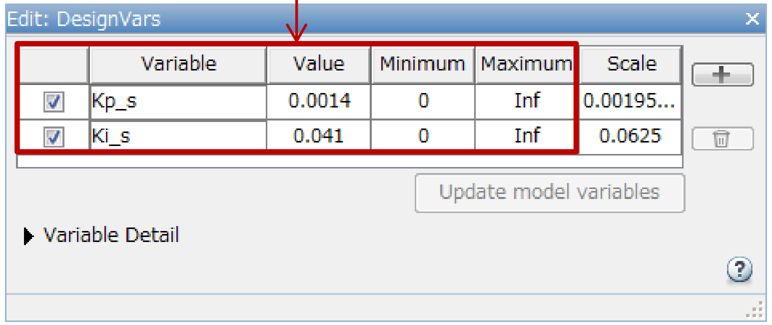
#1) Execute the m-file (**“foc_controlsystem_param.m”**).
#2) Open the slx-file (**“foc_controlsystem_pwm_PIopt.slx”**), and click **“Start Values”** and **“Optimize”**.
Then, open the specific UI of parameter optimization.
#3) For the subsequent procedures, please see the pages of p.14-17.

Set the constraints about the time response of motor velocity



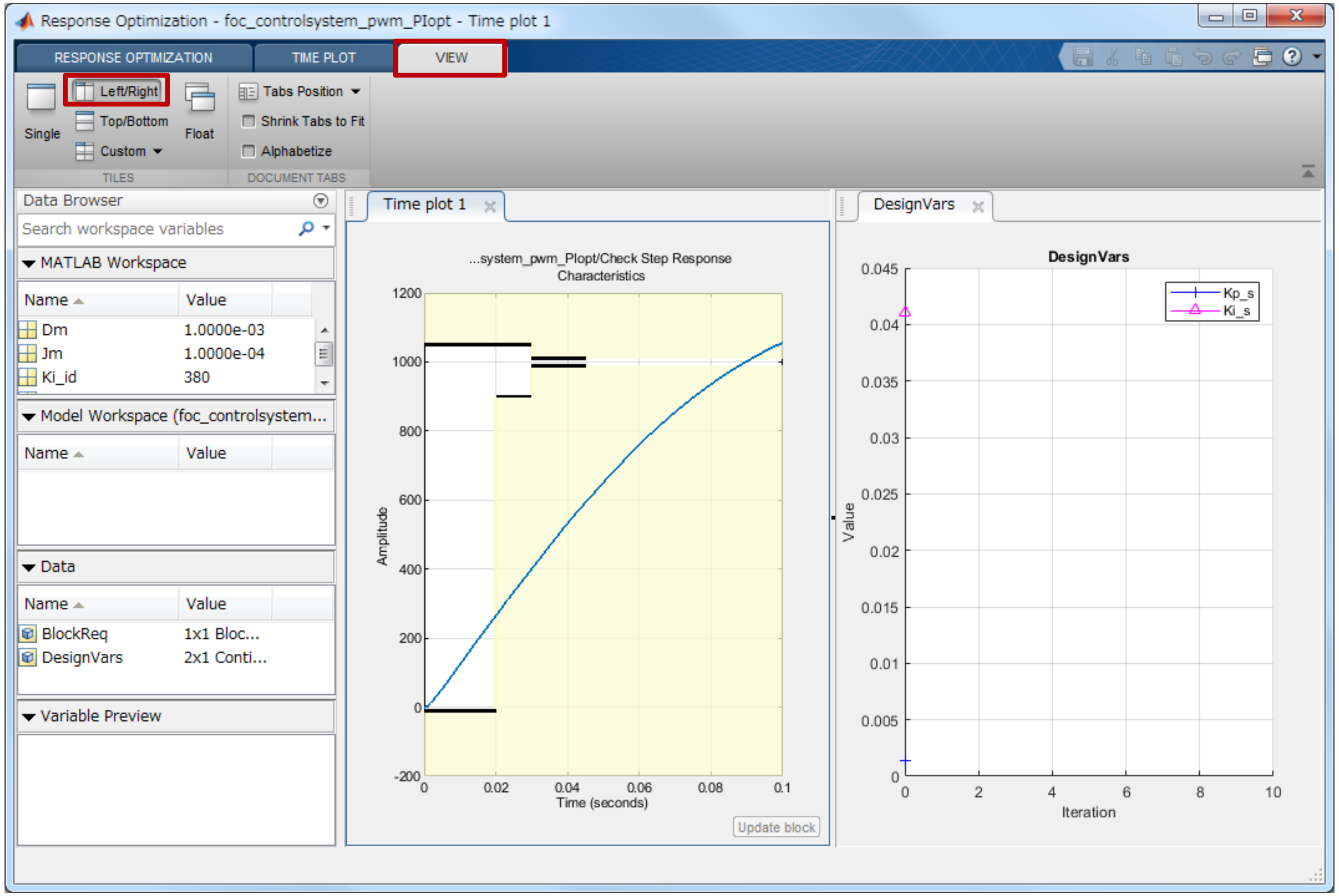
Set and check the parameters to be tuned, and check the time response of motor velocity before tuning



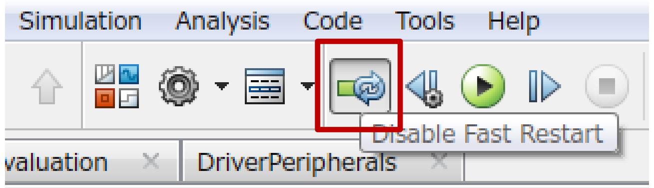


	Variable	Value	Minimum	Maximum	Scale
☑	Kp_s	0.0014	0	Inf	0.00195...
☑	Ki_s	0.041	0	Inf	0.0625

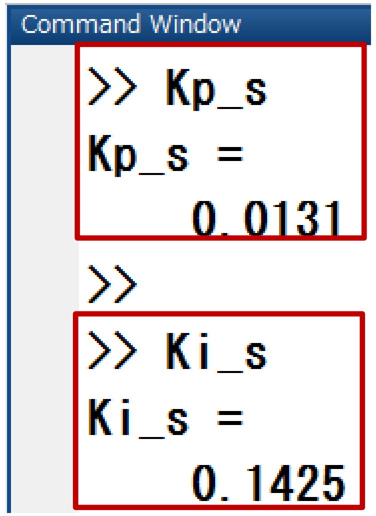
Display the graphs about the time response of motor velocity (left side) and the tuned parameters (right side)

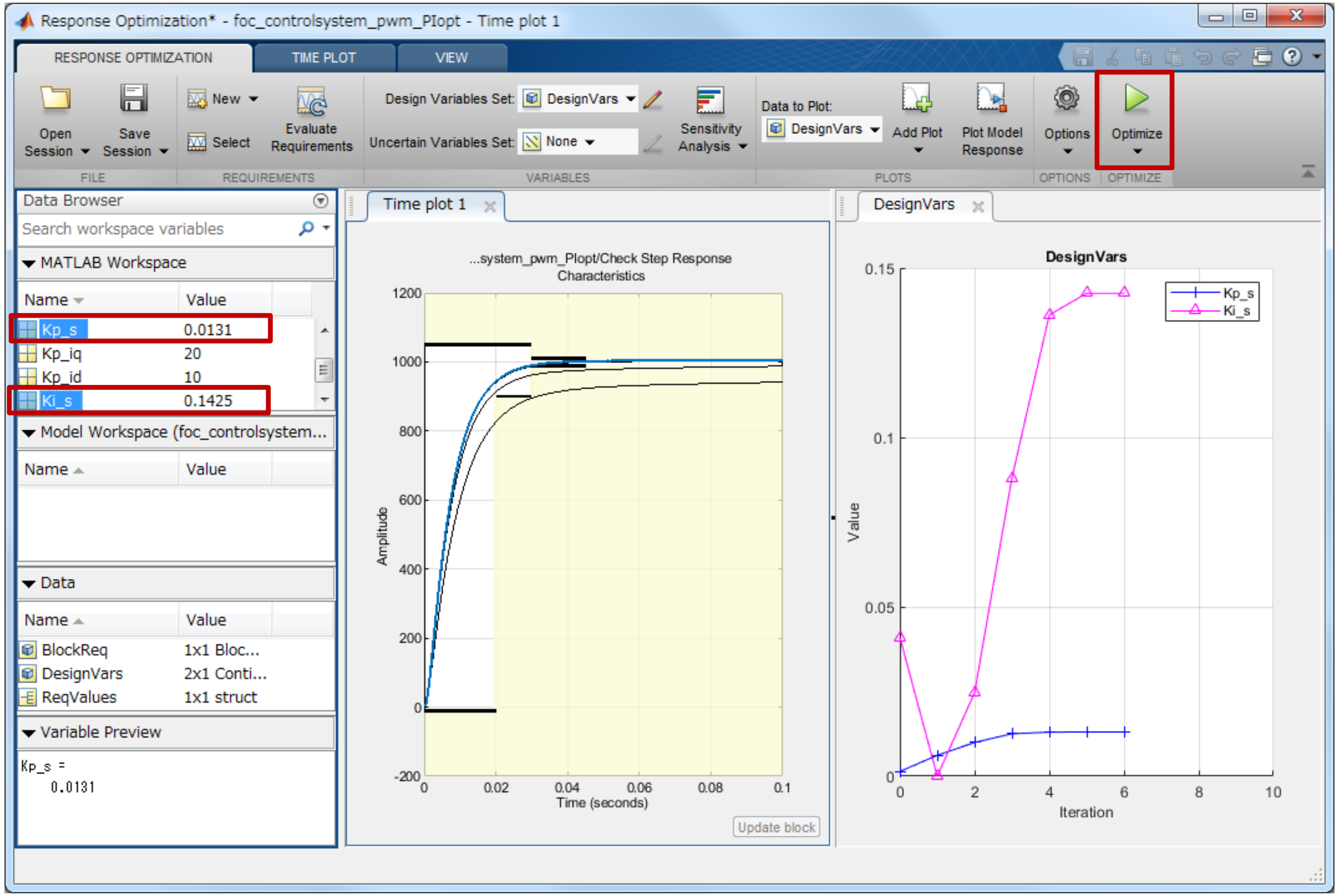


Optimize the tuning parameters



#1) Now, set **"Fast Restart"** to **"Enable"** in order to accelerate to tune the parameters.
#2) When we want to edit the model, set **"Fast Restart"** to **"Disable"**.





Appendix

- Auto-tuning of control parameters in model including switching control

- Two types of libraries of **Simscape Power Systems™**
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  - **Simscape Components (Simscape Language based library)**

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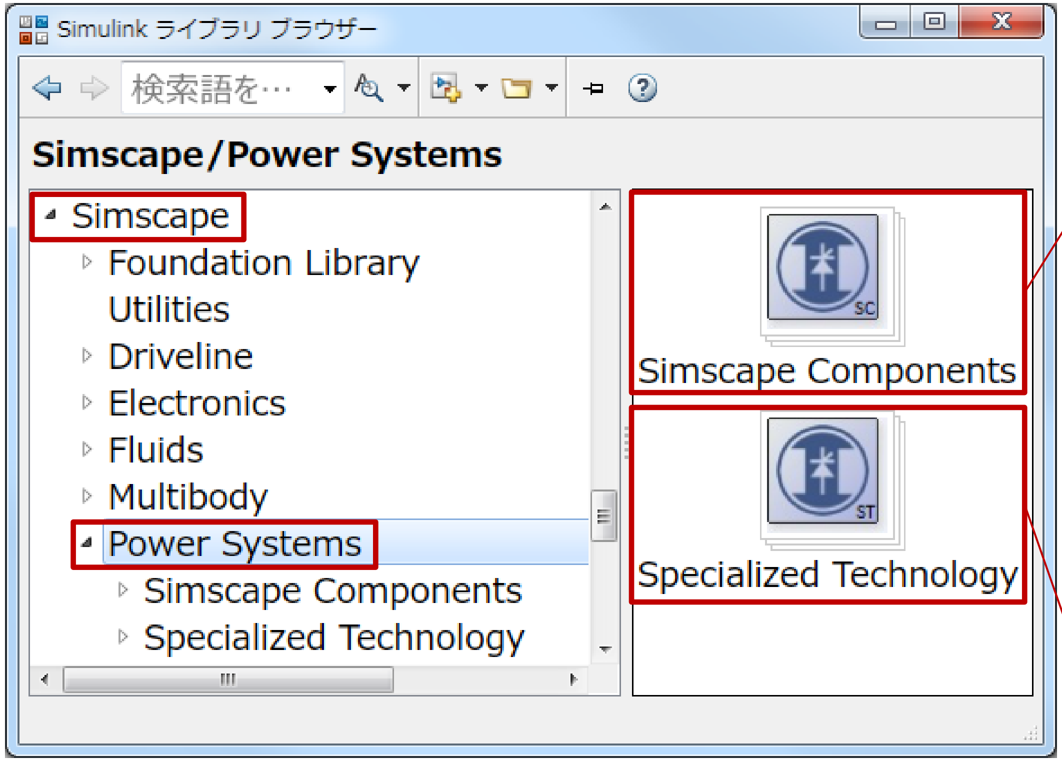
Simscape Power Systems™ - Two types of libraries



1 The library released from R2013b

2 The traditional existing powerful library

1 Simscape Components

- Provide electrical components based Simscape Language
- Recommend to analyze power electronics system by mixing various kinds and fidelities of electrical components of Simscape™ and Simscape Electronics™
  (Multi-domain analysis such as electrical, thermal, and mechanical)

R2013b

2 Specialized Technology

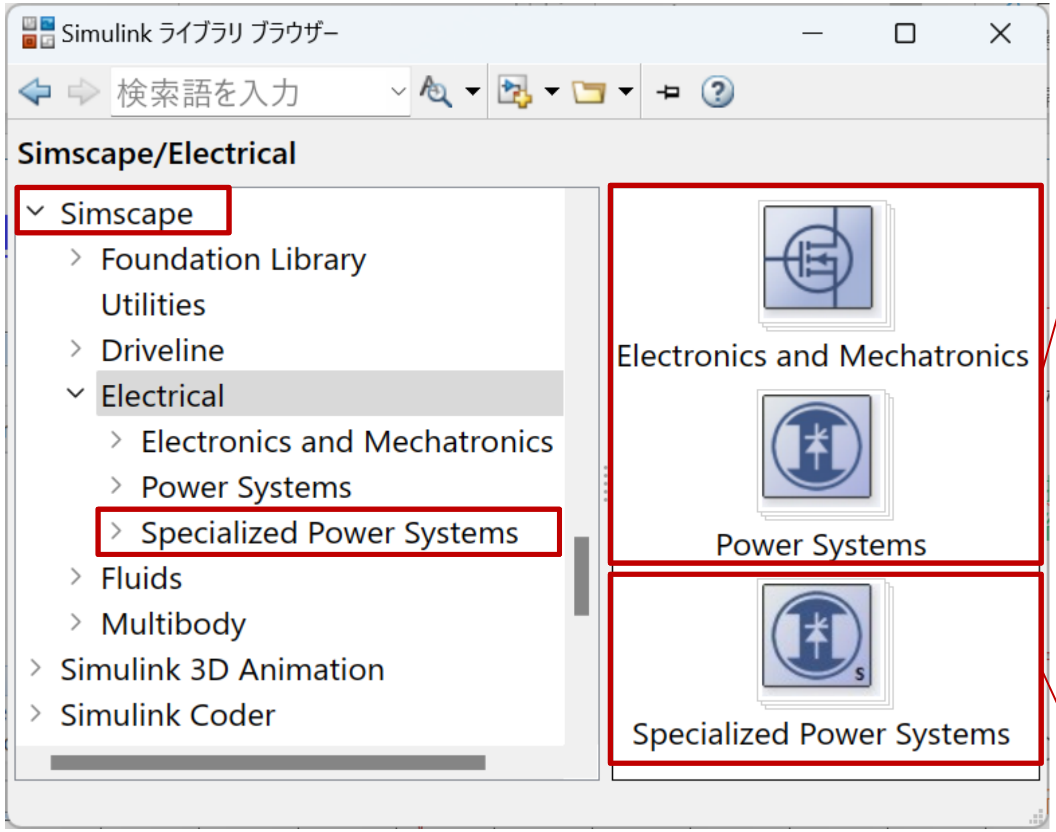
- Provide electrical components based Simulink
- Recommend to analyze power electronics and power network speedily

#1) Various calculation methods of power electronics
(Ideal switching mode, Continuous mode, Discrete mode)

#2) Calculation method and analysis of power network
(By phasor method, initialization, load flow, and long period simulation of power network.)

R2018b

Simscape Electrical™ - Two types of libraries



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2 The traditional existing powerful library

1 Simscape Components

- Provide electrical components based Simscape Language
- Recommend to analyze power electronics system by mixing various kinds and fidelities of electrical components
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R2013b

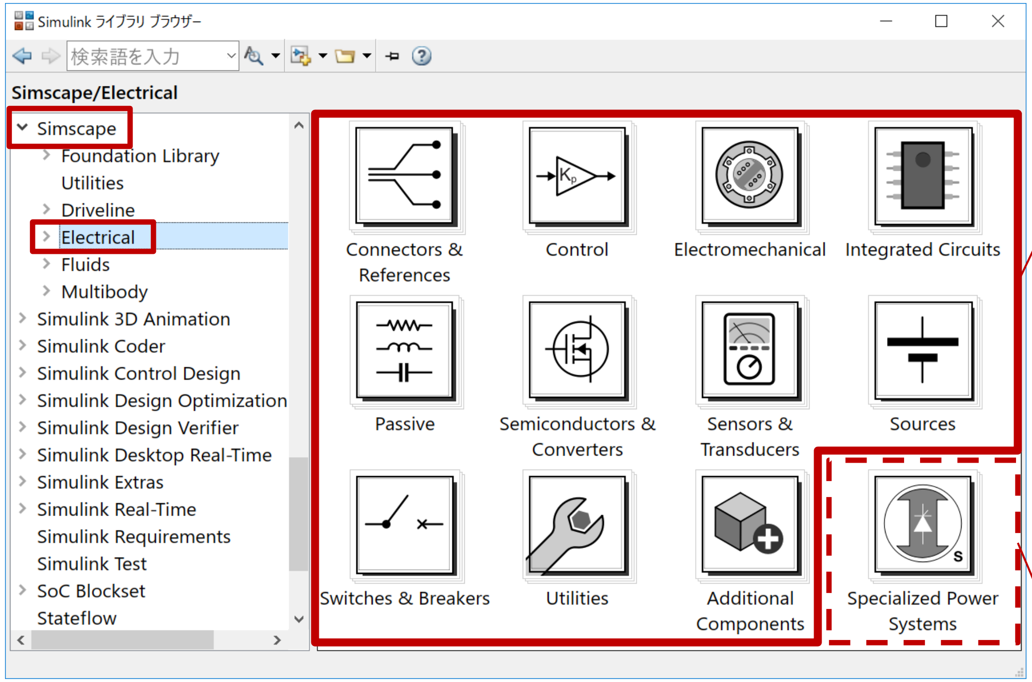
2 Specialized Power Systems

- Provide electrical components based Simulink
- Recommend to analyze power electronics and power network speedily

#1) Various calculation methods of power electronics
(Ideal switching mode, Continuous mode, Discrete mode)

#2) Calculation method and analysis of power network
(By phasor method, initialization, load flow, and long period simulation of power network.)

Simscape Electrical™ - Two types of libraries



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- Provide electrical components based Simscape Language
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- Provide electrical components based Simulink
- Recommend to analyze power electronics and power network speedily

#1) Various calculation methods of power electronics
(Ideal switching mode, Continuous mode, Discrete mode)

#2) Calculation method and analysis of power network
(By phasor method, initialization, load flow, and long period simulation of power network.)

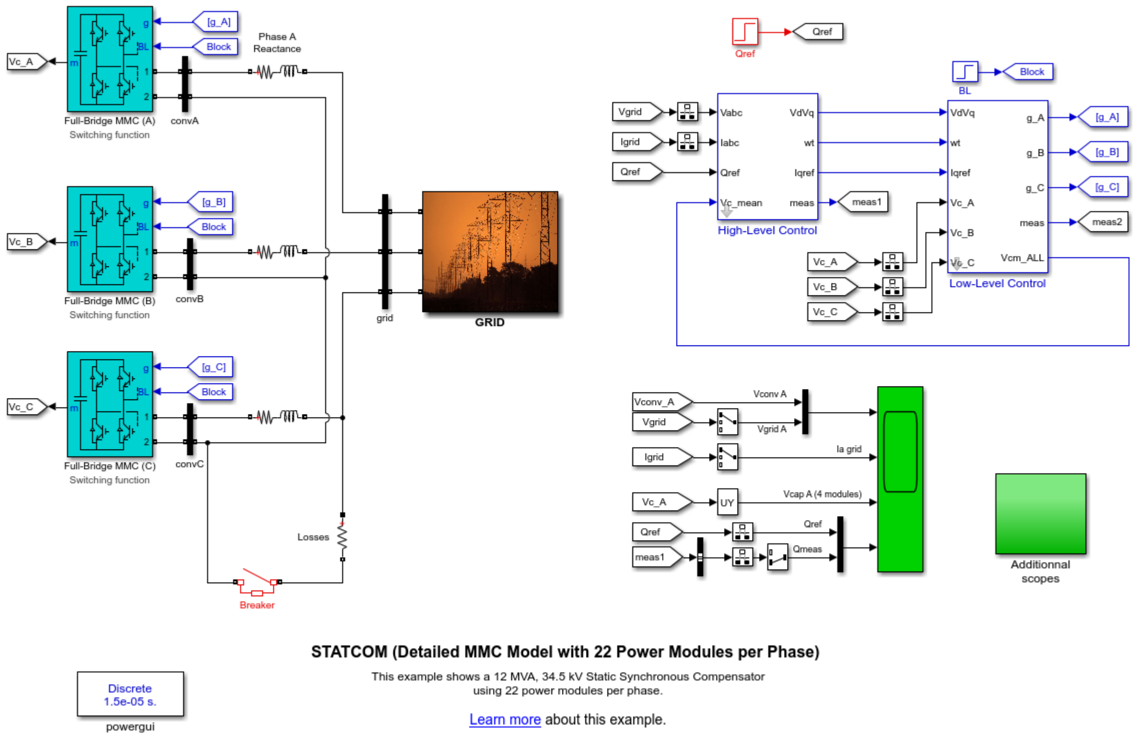
Simscape Electrical™ - Guideline for proper use of two types of libraries

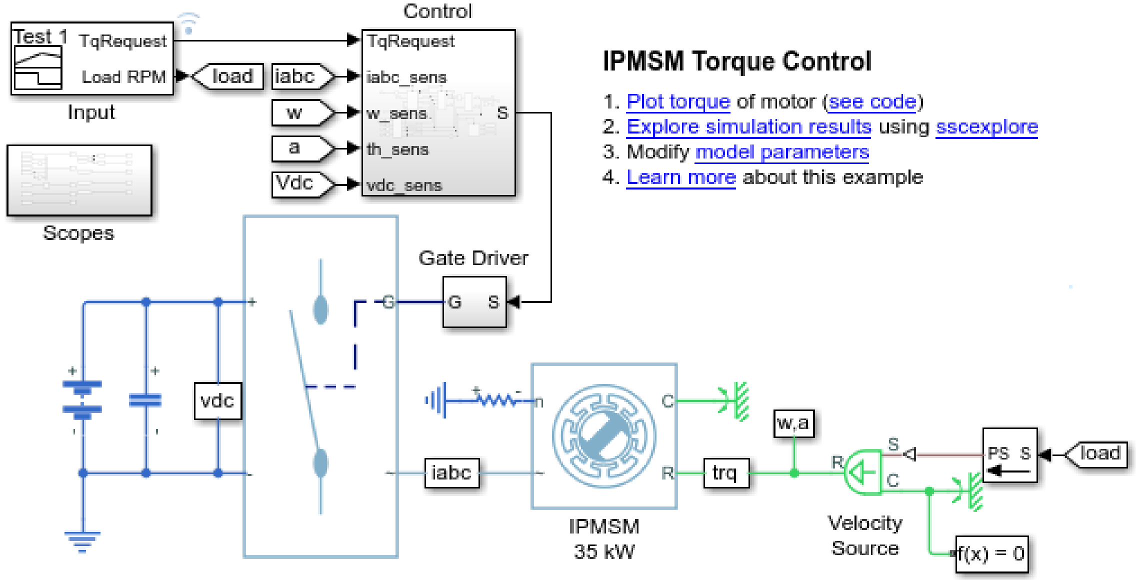
Specialized Technology (Specialized Power Systems)

- Analyze power electronics and power network speedily
- Analyze large scale power electronics system
- Analyze initialization, load flow and long period of power network

Simscape Components

- Analyze multi domain system (Ex: Electrical, Thermal, Mechanical)
- Analyze various fidelity levels of electrical components
- Analyze power loss and heat of motors and semiconductors





Simscape Electrical has the following high detailed electrical components.
・Semiconductor devices (Ex: N-Channel MOSFET)
・Motors (Ex: FEM-Parameterized PMSM)

STATCOM (Detailed MMC Model with 22 Power Modules per Phase)
https://www.mathworks.com/help/physmod/sps/examples/statcom-detailed-mmc-model-with-22-power-modules-per-phase.html

IPMSM Torque Control
https://www.mathworks.com/help/physmod/sps/examples/ipmsm-torque-control.html

“foc_controlsystem” folder

There are two folders. **“English”** folder and **“Japanese”** folder.
Original version is Japanese, and I translated it to English.

1. A set of sample models created with **Simscape Components**.
   Please see the files in the **“sps_sc”** folder.
   Save the sample models of the contents of p.2-17.

2. A set of sampel models created with **Specialized Technology (Specialized Power Systems)**.
   Please see the files in the **“sps_st”** folder.
   Save the sample models of the almost equal contents of p.2-17.

MATLAB products used in this material

- Basic environment
  - MATLAB®, Simulink®
- Plant modeling
  - Simscape™, Simscape Power Systems™
- Control design
  - Simulink Control Design™, Control System Toolbox™
- Parameter optimization
  - Simulink Design Optimization™, Optimization Toolbox™

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Accelerating the pace of engineering and science