Motor Control Blockset™

Sensorless Field-Oriented Control (FOC) of PMSM Using NXP™ S32K344 Development Kit

MATLAB®

R2024b

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About This Example

Introduction

This example implements a motor control system using the NXP MCSPTE1AK344 hardware. The MCSPTE1AK344 development kit, based on the 32-bit Arm® Cortex®-M7 S32K3 microcontroller and the GD3000 pre-driver, can run motor control applications designed for either a three-phase brushless DC (BLDC) or three-phase permanent magnet synchronous motor (PMSM). For more details about the hardware, see *MCSPTE1AK344 development kit*.

You can use this example to implement a sensorless field-oriented control (FOC) algorithm for the three-phase PMSM available in the MCSPTE1AK344 development kit.

This example also helps you:

- Verify your hardware setup using an open-loop control algorithm and check the integrity of the hardware, motor, and current measurement.
- Perform sensorless FOC of the three-phase PMSM.

The control algorithm available in the example needs these offset values to optimally run the PMSM.

Follow the example workflows in this order to successfully run the PMSM using FOC:

Sequence	Workflow Title
Workflow - 1	Run 3-Phase PMSM in Open-Loop Control and Validate Hardware Condition
Workflow - 2	Sensorless Field-Oriented Control of PMSM

For information regarding the FOC algorithm that is used in this example, see *Field-Oriented Control (FOC)*.

Hardware Specifications

MCSPTE1AK344 development kit:

- Uses 32-bit Arm® Cortex®-M7 S32K3 microcontroller and the GD3000 pre-driver.
- Uses 12 V DC power supply.
- Provides USB connectivity.
- Includes a three-phase PMSM (BLDC).

For detailed specifications, see *MCSPTE1AK344 development kit*.

Software Requirements

This section lists the software products from MathWorks® and NXP that you need to simulate and run the example models on the MCSPTE1AK344 development kit.

Required MathWorks Products

To simulate an example model:

- Motor Control Blockset

To generate code and deploy an example model:

- Motor Control Blockset
- Embedded Coder®

Required NXP Products

To simulate or deploy an example model:

- NXP Model-Based Design Toolbox (MBDT)

For instructions to download and install NXP MBDT, see *NXP Model-Based Design Toolbox (MBDT)*.

Contents of Downloaded ZIP Folder

The ZIP folder that you downloaded from the GitHub® repository, includes:

File Name	Description	
`mcb_nxp_MCSPTE1AK344_example_doc.pdf`	This document.	
`Open loop speed control\s32k344_mcb_open_loop_s32ct.mdl`	Target model	for Workflow - 1 (Run 3-Phase PMSM in Open-Loop Control and Validate Hardware Condition)

`Open loop speed control\s32k344Data.m`
 	
`Open loop speed control\mcbOpenLoopData.m`
	Target model Initialization scripts	

`Open loop speed control\OpenLoopControlHost.slx`	Host model	
`Sensorless closed loop speed control\s32k344_mcb_sensorless_s32ct.mdl`	Target model	for Workflow - 2 (Sensorless Field-Oriented Control of PMSM)

`Sensorless closed loop speed control\s32k344Data.m`
 	
`Sensorless closed loop speed control\mcbSensorlessData.m`
	Target model Initialization scripts	

`Sensorless closed loop speed control\SensorlessFocHost.slx`	Host model	

Each workflow in this example uses a host and a target model. The host model is a user interface to the controller hardware board. You can run the host model on the host computer. The prerequisite to use the host model is to deploy the target model to the controller hardware board. The host model uses serial communication to command the target Simulink® model and run the motor either in an open-loop or closed-loop control. For more details about the host and target model setup, see *Host-Target Communication*.

To learn more about configuring the target model initialization script, see *Estimate Control Gains from Motor Parameters*.

Run 3-Phase PMSM in Open-Loop Control and Validate Hardware Condition

Introduction

This workflow uses open-loop control (also known as scalar control or Volts/Hz control) to run the permanent magnet synchronous motor (PMSM) available in the MCSPTE1AK344 development kit. This technique varies the stator voltage and frequency to control the rotor speed without using any feedback from the motor. You can use this technique to check the integrity of the hardware connections of the MCSPTE1AK344 development kit. A constant speed application of open-loop control uses a fixed-frequency motor power supply. An adjustable speed application of open-loop control needs a variable-frequency power supply to control the rotor speed. To ensure a constant stator magnetic flux, keep the supply voltage amplitude proportional to its frequency.

Open-loop motor control does not have the ability to consider the external conditions that can affect the motor speed. Therefore, the control system cannot automatically correct the deviation between the desired and the actual motor speed.

This workflow helps you run the motor by using an open-loop motor control algorithm. It helps you get started with Motor Control Blockset™ and verify the hardware setup by running the motor.

You can use this model to:

- Check connectivity with the target.
- Check serial communication with the target.
- Verify the hardware and software environment.
- Run a new motor with an inverter and target setup for the first time.

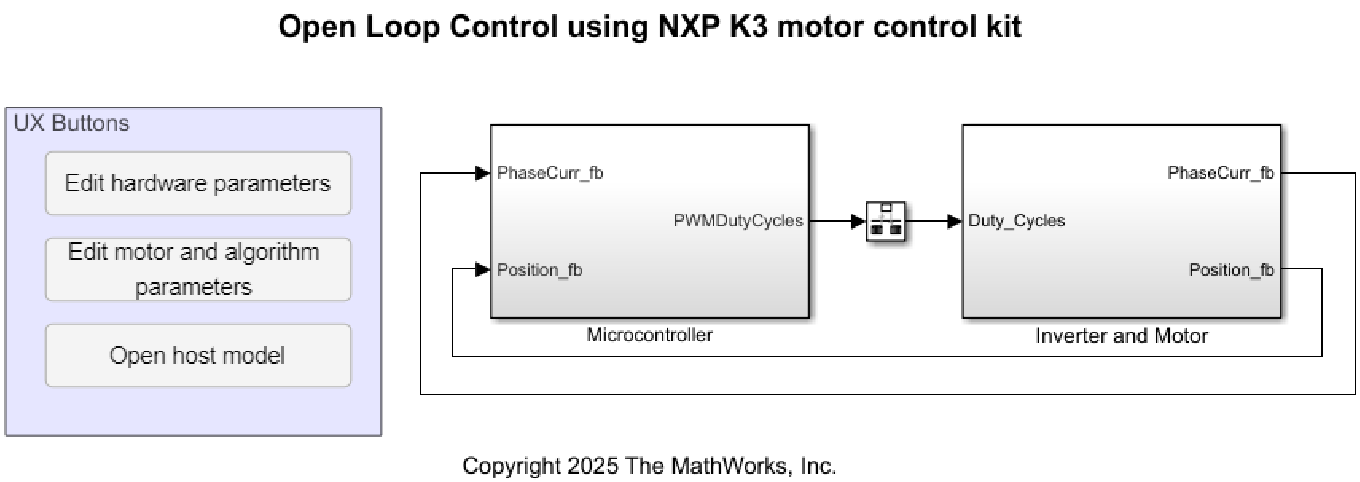
Models

The example includes these models:

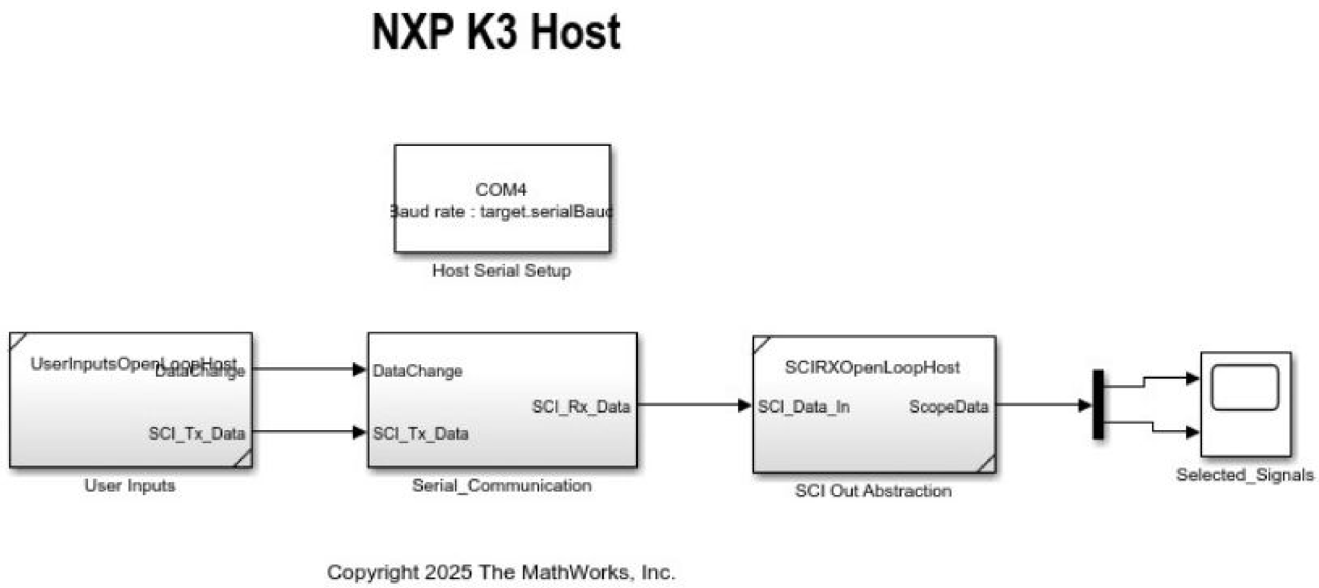
- s32k344_mcb_open_loop_s32ct.mdl (target model)
- OpenLoopControlHost.slx (host model)

You can use these models for both simulation and code generation. You can use the `open_system` command (or use the target model name) at the MATLAB command prompt to open the target and host models.

```
open_system('s32k344_mcb_open_loop_s32ct.mdl');
```




```
open_system('OpenLoopControlHost.slx');
```


NXP K3 Host
COM4
Baud rate : target.serialBaud
Host Serial Setup
UserInputsOpenLoopHost
DataChange
SCI_Tx_Data
User Inputs
DataChange
SCI_Tx_Data
SCI_Rx_Data
Serial_Communication
SCIRXOpenLoopHost
SCI_Data_In
ScopeData
SCI Out Abstraction
Selected_Signals
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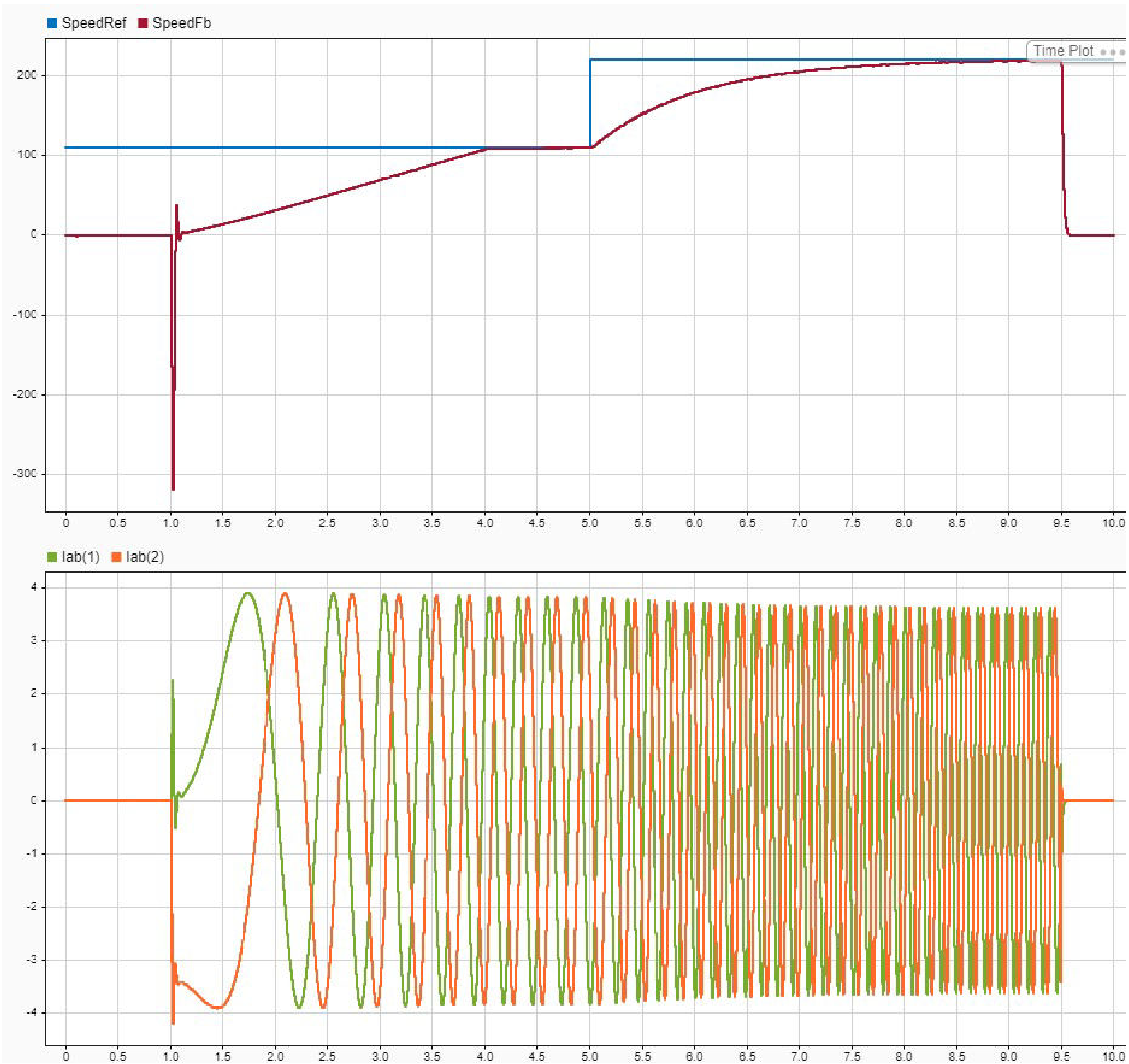
Simulate Target Model

This example supports simulation. Follow these steps to simulate the model.

1. Open the target model included in this workflow.
2. Click **Run** on the **Simulation** tab to simulate the model.
3. Click **Data Inspector** on the **Simulation** tab to view and analyze the simulation results.



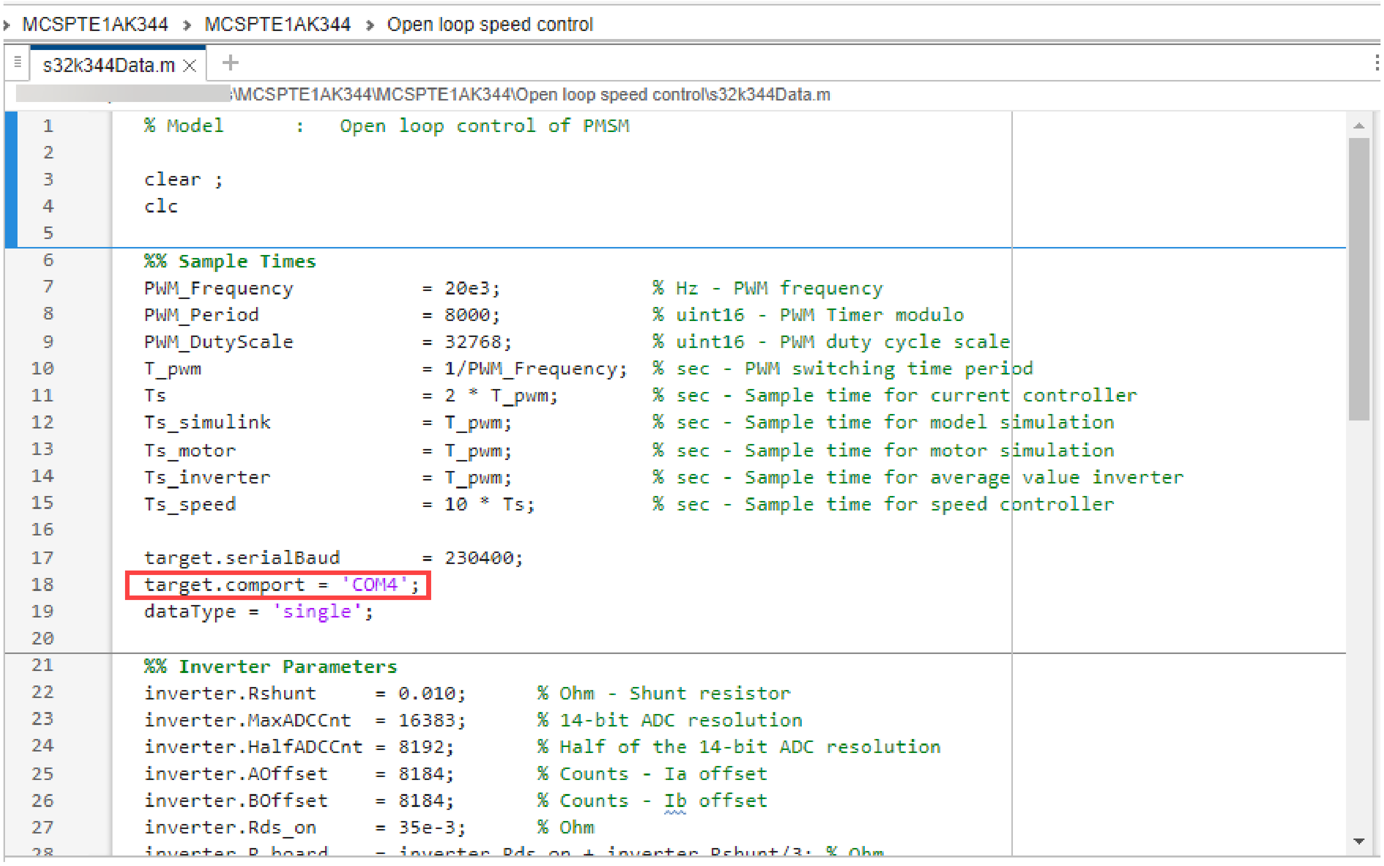
Generate Code and Deploy Model to Target Hardware for Open-Loop Control

This section explains how to generate code and run the motor by using open-loop control. The example uses a host and a target model. The host model is a user interface to the controller hardware board. You can run the host model on the host computer. The prerequisite to use the host model is to deploy the target model to the controller hardware board. The host model uses serial communication to command the target Simulink model and run the motor in a open-loop control.

Generate Code and Run Model to Implement Open-Loop Control

1. Simulate the target model and observe the simulation results.
2. Connect the MCSPTE1AK344 development kit to the host computer.
3. Open the target model.
4. Click the **Edit hardware parameters** button available in the target model to open the target model's hardware initialization script, `s32k344Data.m`. Use this script to:

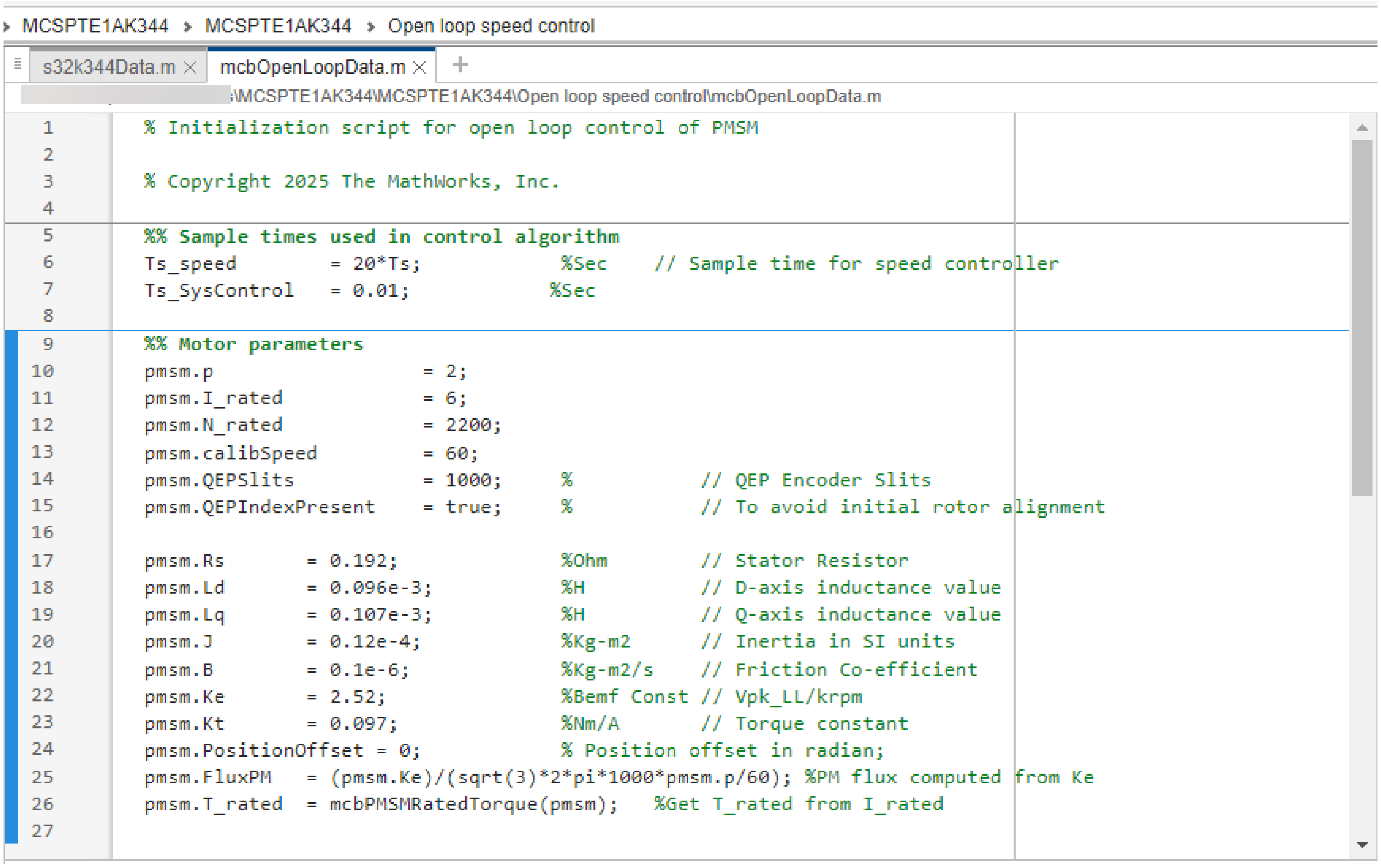
   - Update the device driver specifications (for example, PWM values, communication baud rate, and so on) as well as the inverter configuration parameters (for example, inverter voltage, current sense gain, and so on).
   - Update the target hardware device COM port to match the hardware connection by using the variable `target.comport`. The example uses this variable to update the Port parameter in the Host Serial Setup, Host Serial Receive, and Host Serial Transmit blocks in the host model.



5 Click the **Edit motor and algorithm parameters** button available in the target model to open the target model initialization script, `mcbOpenLoopData.m`. You can also use this command to open the initialization script.

```
edit mcbOpenLoopData.m
```

6 Verify and edit the motor and inverter parameters that are pre-configured in the model initialization script `mcbOpenLoopData.m`. You can replace the parameter values with the values obtained from either the motor datasheet or other sources.

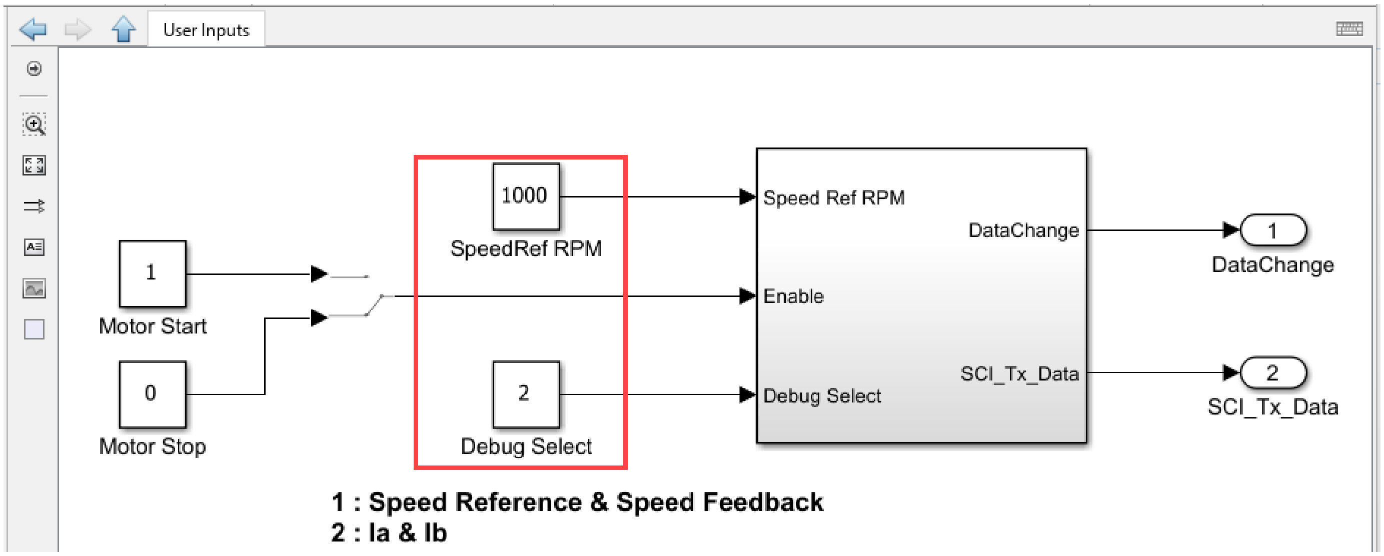


For instructions to configure the script, see *Estimate Control Gains from Motor Parameters*.

7. Click **Build, Deploy & Start** on the **Hardware** tab to deploy the target model to the hardware.
8. Verify the variables updated by the target model in the MATLAB base workspace.
9. Click the **Open host model** button in the target model to open the associated host model, `OpenLoopControlHost.slx`. You can also use the `open_system` command to open the host model.

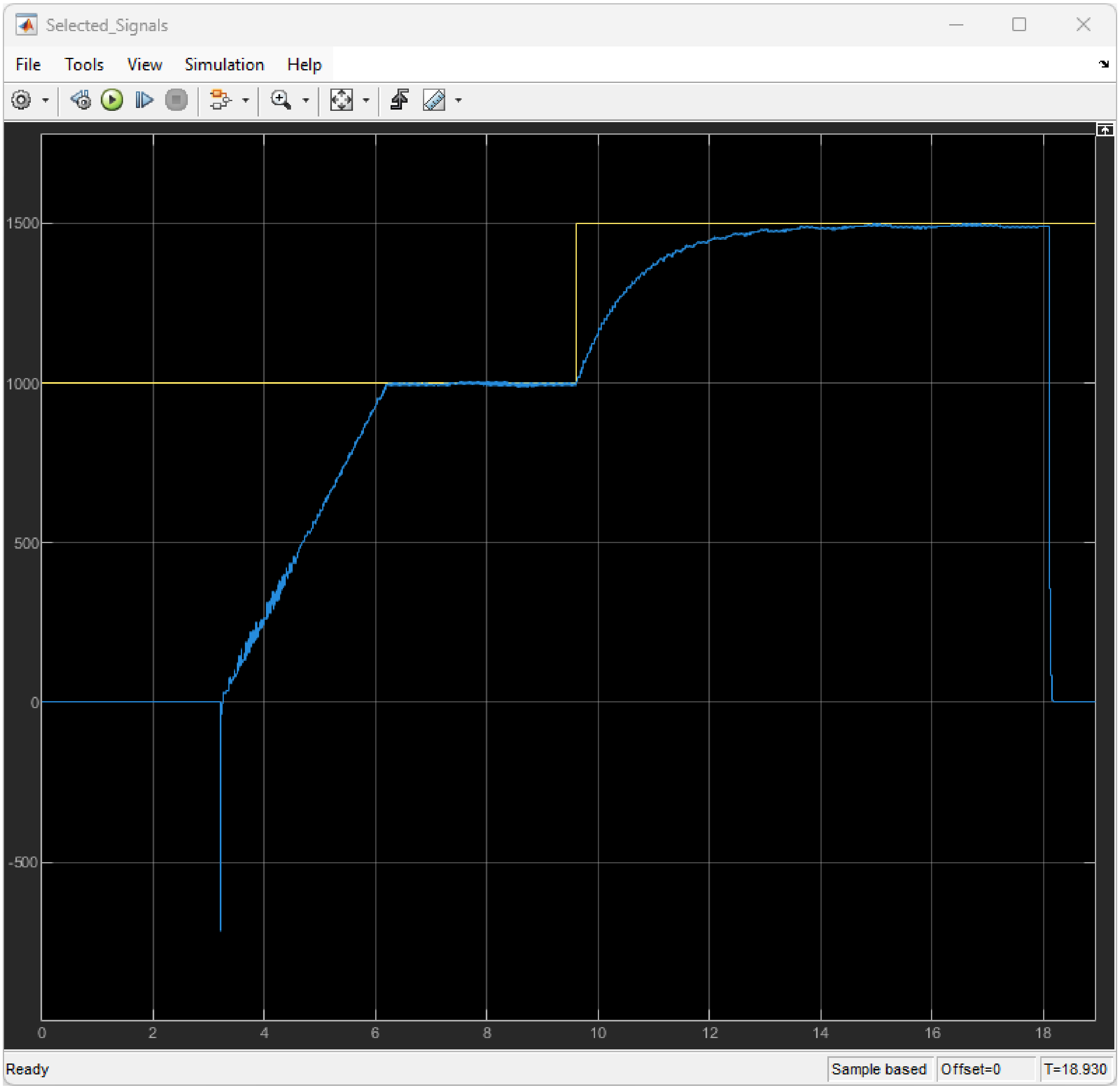
   For details about the serial communication between the host and target models, see *Host-Target Communication*.
10. Go to `OpenLoopControlHost/User Inputs` subsystem and verify that the value for `SpeedRef RPM` Constant block is set to `1000`, and the value of Debug Select Constant block is set to `2`.

Note It is recommended that you always limit the reference speed to 1000 RPM during open-loop run.



11 Click **Run** on the **Simulation** tab to run the host model.

12 After the motor starts running, observe the I_a and I_b phase currents in the Time Scope to verify a successful open-loop control using MCSPTE1AK344 development kit. This image shows the speed response using open loop model.



You can now proceed to sensorless FOC of the PMSM using MCSPTE1AK344 development kit, which uses an I-F control-based startup followed by transition from I-F to closed-loop control and from closed-loop to I-F control.

Sensorless Field-Oriented Control of PMSM

Introduction

This workflow implements the sensorless field-oriented control (FOC) technique to control the speed of a three-phase permanent magnet synchronous motor (PMSM) available in the MCSPTE1AK344 development kit. The FOC algorithm requires rotor position feedback, which is obtained by the sensorless position estimators. The PMSM starts using the I-F control algorithm (using the I-F Controller block) followed by transition from I-F to closed-loop control and from closed-loop to I-F control. For details about FOC, see *Field-Oriented Control (FOC)*.

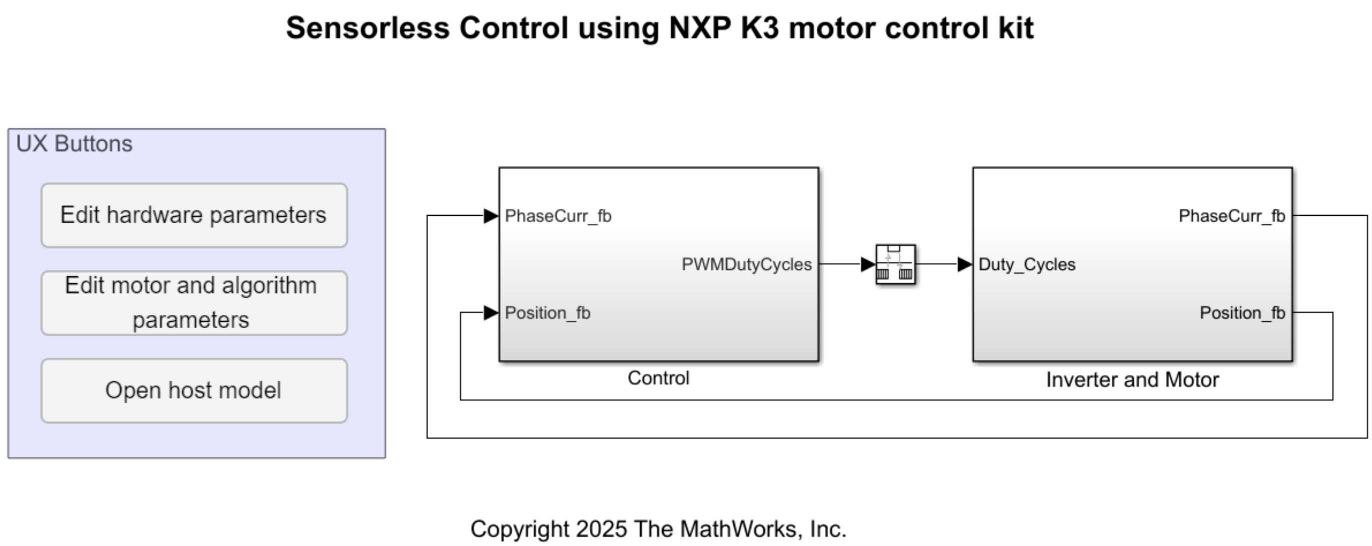
Models

The example includes these models for sensorless closed loop control of PMSM using MCSPTE1AK344 development kit:

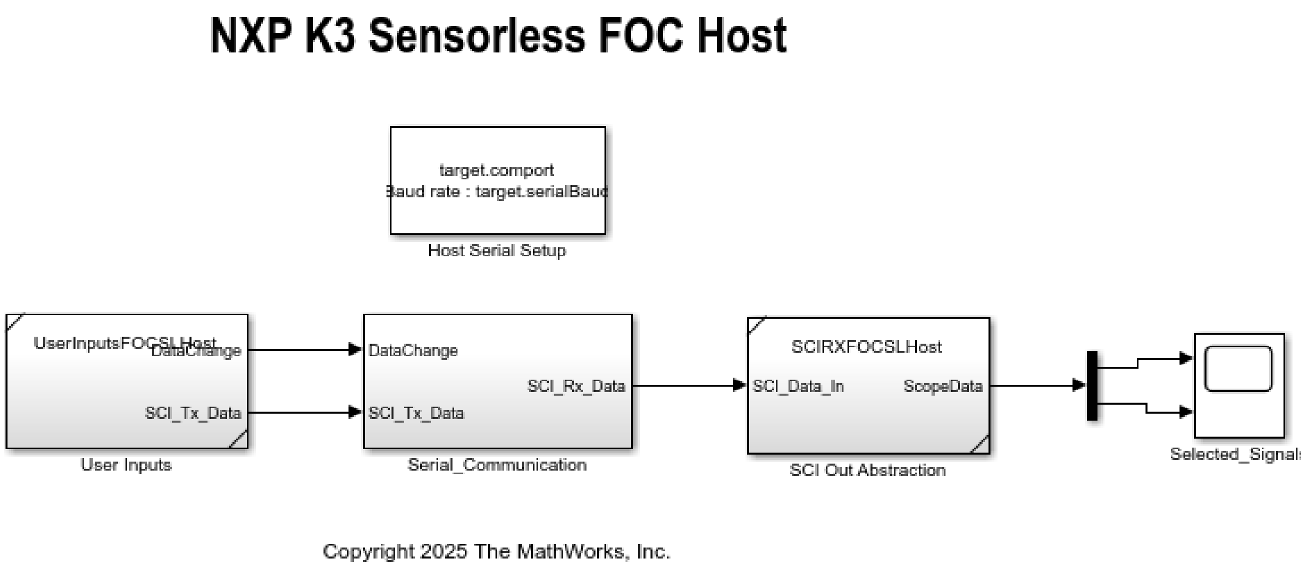
- s32k344_mcb_sensorless_s32ct.mdl (target model)
- SensorlessFocHost.slx (host model)

You can use these models for both simulation and code generation. You can use the `open_system` command (or use the target model name) at the MATLAB command prompt to open the target and host models.

```
open_system('s32k344_mcb_sensorless_s32ct.mdl');
```




```
open_system('SensorlessFocHost.slx');
```


NXP K3 Sensorless FOC Host
target.comport
Baud rate : target.serialBaud
Host Serial Setup
UserInputsFOCSLHost
DataChange
SCI_Tx_Data
User Inputs
DataChange
SCI_Tx_Data
SCI_Rx_Data
Serial_Communication
SCIRXFOCSLHost
SCI_Data_In
ScopeData
SCI Out Abstraction
Selected_Signals
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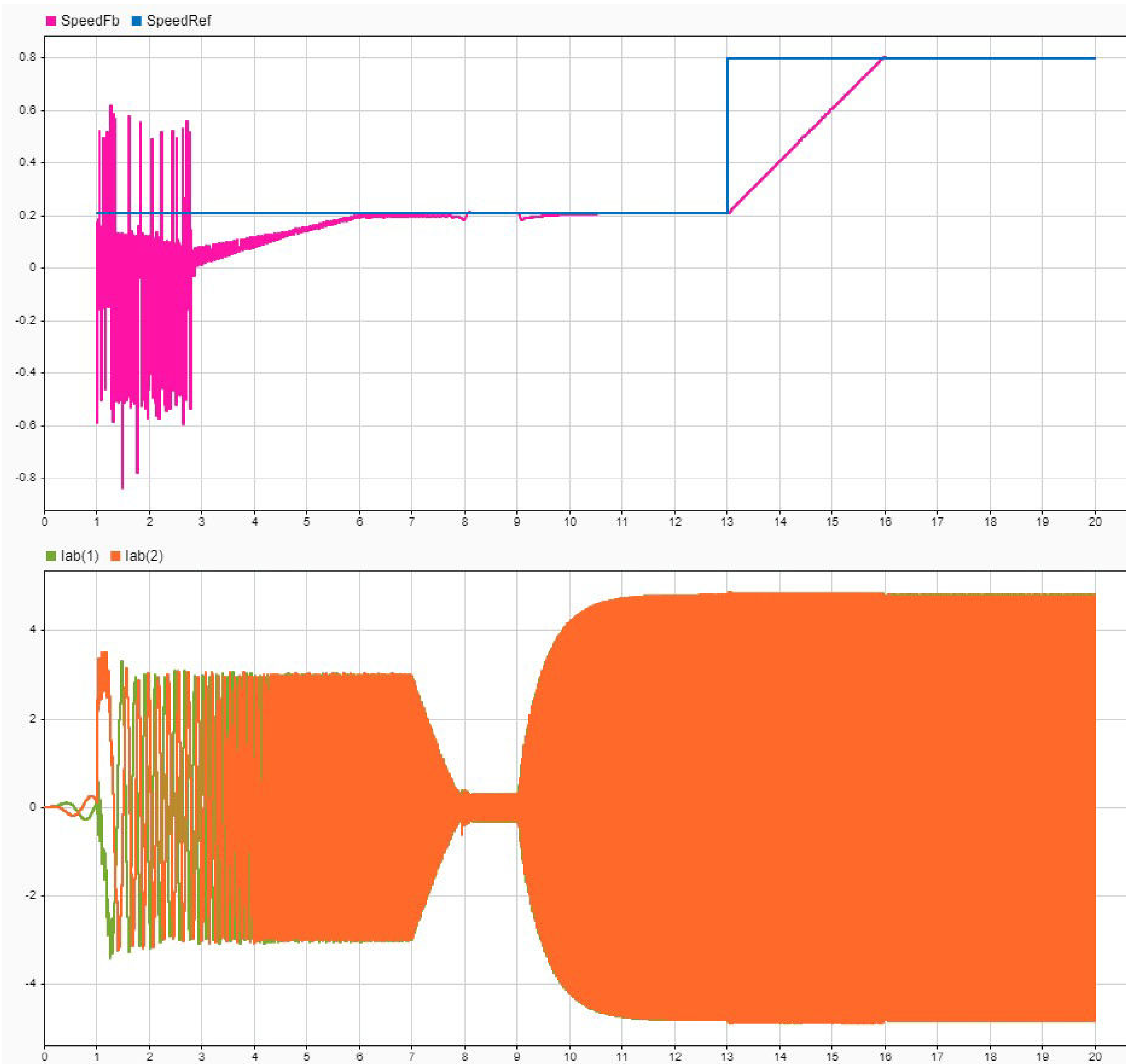
Simulate Target Model

This example supports simulation. Follow these steps to simulate the model.

1. Open the target model `s32k344_mcb_sensorless_s32ct.mdl`.
2. Click **Run** on the **Simulation** tab to simulate the model.
3. Click **Data Inspector** on the **Simulation** tab to view and analyze the simulation results.



Generate Code and Deploy Model to Target Hardware for Sensorless FOC

This section explains how to generate code and run the sensorless FOC algorithm on the target hardware.

This example uses a host and a target model. The host model is a user interface to the controller hardware board. You can run the host model on the host computer. The prerequisite to use the host model is to deploy the target model to the controller hardware board. The host model uses serial communication to command the target Simulink model and run the motor in a closed-loop control.

Follow these steps to deploy and run the target model on the MCSPTE1AK344 development kit.

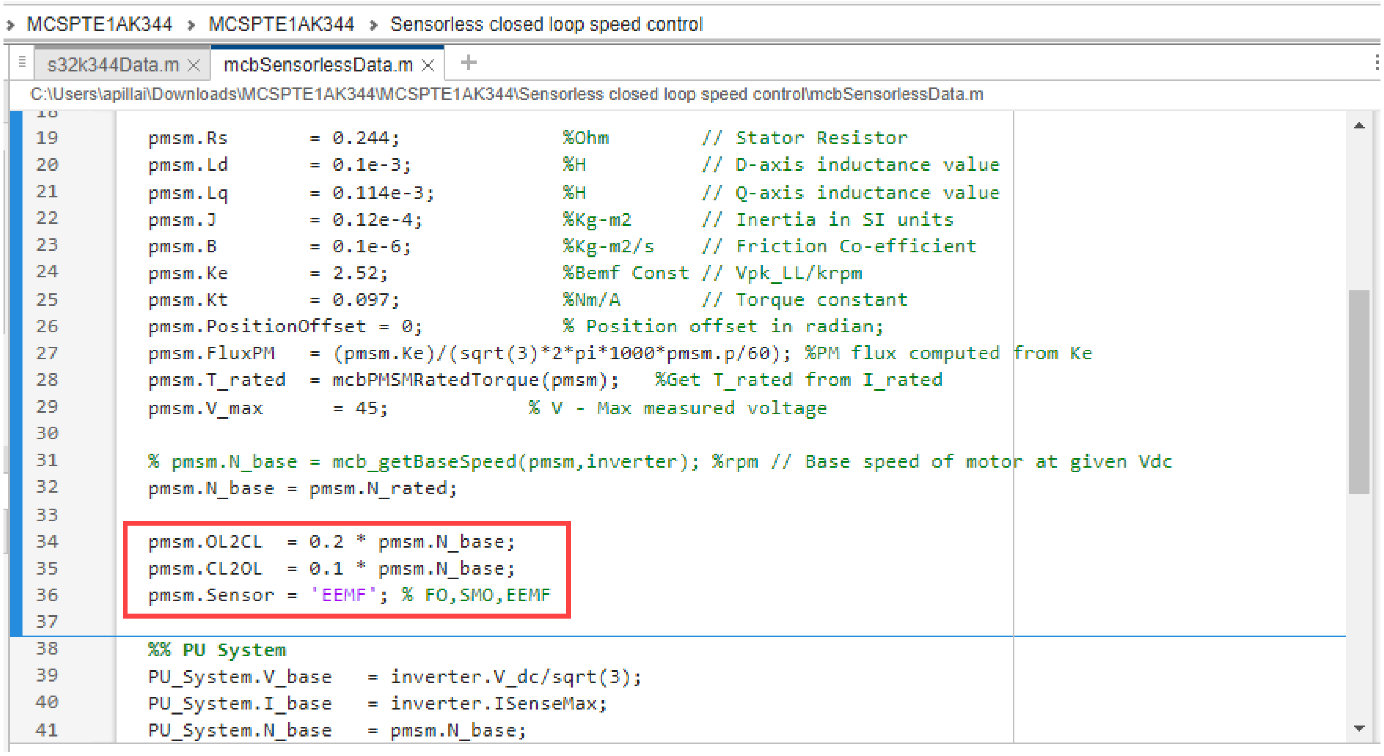
1. Simulate the target model `s32k344_mcb_sensorless_s32ct.mdl`, and observe the simulation results.
2. Connect the MCSPTE1AK344 development kit to the host computer.
3. Open the target model.
4. Click the **Edit hardware parameters** button available in the target model to open the target model's hardware initialization script, `s32k344Data.m`. Ensure that this script is the same one that you modified in the open-loop control phase (as described in Step 4 of *Generate Code and Run Model to Implement Open-Loop Control* section).
5. Click the **Edit motor and algorithm parameters** button available in the target model to open the target model initialization script, `mcbSensorlessData.m`. You can also use this command to open the initialization script.

   ```
   edit mcbSensorlessData.m
   ```

   The example implements field-oriented control (FOC) using sensorless position estimation and I-F control-based startup to control the speed of PMSM. The PMSM starts using the I-F control algorithm (using the I-F Controller block in) followed by transition from I-F to closed-loop control and from closed-loop to I-F control.

   Therefore, the `mcbSensorlessData.m` script allows you to specify the speed at which those transitions occur. Change the values, if required.

   To estimate the position feedback for the FOC algorithm, the script also allows you to select one of the three options: flux observer (FO), extended EMF observer (EEMF) or sliding mode observer (SMO). By default, this example uses EEMF.

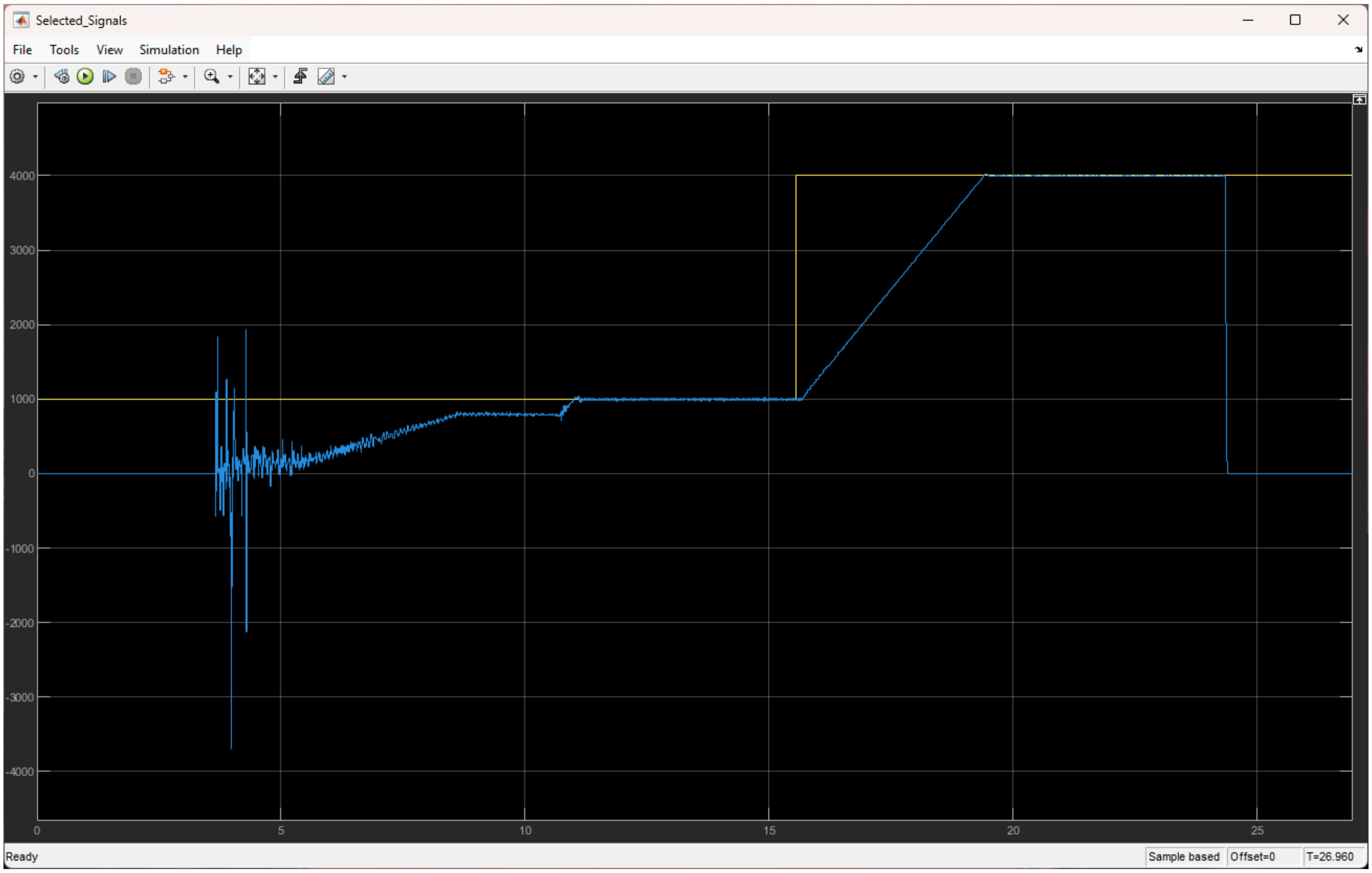



```
pmsm.Rs        = 0.244;              %Ohm        // Stator Resistor
pmsm.Ld        = 0.1e-3;             %H          // D-axis inductance value
pmsm.Lq        = 0.114e-3;           %H          // Q-axis inductance value
pmsm.J         = 0.12e-4;            %Kg-m2      // Inertia in SI units
pmsm.B         = 0.1e-6;             %Kg-m2/s    // Friction Co-efficient
pmsm.Ke        = 2.52;               %Bemf Const // Vpk_LL/krpm
pmsm.Kt        = 0.097;              %Nm/A       // Torque constant
pmsm.PositionOffset = 0;             % Position offset in radian;
pmsm.FluxPM    = (pmsm.Ke)/(sqrt(3)*2*pi*1000*pmsm.p/60); %PM flux computed from Ke
pmsm.T_rated   = mcbPMSMRatedTorque(pmsm);    %Get T_rated from I_rated
pmsm.V_max       = 45;            % V - Max measured voltage

% pmsm.N_base = mcb_getBaseSpeed(pmsm,inverter); %rpm // Base speed of motor at given Vdc
pmsm.N_base = pmsm.N_rated;

pmsm.OL2CL  = 0.2 * pmsm.N_base;
pmsm.CL2OL  = 0.1 * pmsm.N_base;
pmsm.Sensor = 'EEMF'; % FO,SMO,EEMF

%% PU System
PU_System.V_base   = inverter.V_dc/sqrt(3);
PU_System.I_base   = inverter.ISenseMax;
PU_System.N_base   = pmsm.N_base;
```

Additionally, verify and edit the motor and inverter parameters, if required. For instructions to configure the script, see *Estimate Control Gains from Motor Parameters*

6. After updating the initialization script, open the target model again, and click **Build, Deploy & Start** on the **Hardware** tab to deploy the target model to the hardware.
7. Verify the variables updated by the target model in the MATLAB base workspace.
8. Click the **Open host model** button in the target model to open the associated host model. You can also use the `open_system` command to open the host model, `SensorlessFocHost.slx`.

   For details about the serial communication between the host and target models, see *Host-Target Communication*.
9. Go to `SensorlessFocHost/User Inputs` subsystem and update the value for `SpeedRef RPM` Constant block to use a very low value (maximum 10% of base speed). The value of `Debug Select` Constant block is set to `1` to obtain the speed reference and speed feedback.
10. Click **Run** on the **Simulation** tab to run the host model. The motor starts rotating.
11. Increase the motor `SpeedRef RPM` in steps to exceed **Speed to exit I-F controller** (parameter of the I-F Controller block, which is same as `pmsm.OL2CL` variable) to switch from I-F control to closed-loop control.
12. During closed-loop operation, decrease the motor `SpeedRef RPM` such that it falls below **Speed to re-enter I-F controller** (parameter of the I-F Controller block, which is same as `pmsm.CL2OL` variable) to switch from closed-loop control to I-F control.
13. Observe the debug signals in the scope and display blocks available in the host model. This image shows the speed reference and speed feedback signals.


Selected_Signals
File Tools View Simulation Help
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
0
5
10
15
20
25
Ready
Sample based
Offset=0
T=26.960