PSIM

TUTORIAL

Motor Control Design Suite

April 2017

The Motor Control Design Suite provides a total solution for motor drive system design. From system specifications, the Motor Control Design Suite automatically designs all the controllers with proper stability margins, and generates a complete system that is operational and ready to simulate.

The Motor Control Design Suite supports multiple sampling rates and per unit systems. That is:

- Multiple Sampling Rate: The sampling rate of the outer speed loop is often slower than the inner current loop. Different sampling rates are supported in the controller design.
- Per Unit System: Controllers can be designed in either real value or per unit value.

With the capability to put together quickly a motor drive system with detailed circuit models, the Motor Control Design Suite offers significant benefit and advantages to engineers in the following ways:

- It can help system engineers evaluate system requirements and understand the interactions among major subsystems such as dc bus, 3-phase voltage source inverter, and motor and controller. It can also help engineers derive detailed subsystem hardware/software specifications, and gain a better insight of the subsystem operations.
- It can help hardware engineer carry out hardware component selection and design, and help software/control engineers develop control algorithms and DSP control software.
- It can help system engineers integrate and test the system based on system requirements.

The Motor Control Design Suite provides a very quick design solution to the development of motor drive systems, and helps speed up the development process substantially.

Five design templates for sensored motor drives are provided in the Motor Control Design Suite:

- **PMSM (IPM) Drive**: Interior Permanent Magnet (IPM) motor drive system with maximum-torque-per-ampere control and field weakening control
- **PMSM (IPM) Drive (nonlinear)**: IPM motor drive system, with nonlinear motor, with maximum-torque-per-ampere control and field weakening control
- **PMSM (SPM) Drive**: Surface-mounted Permanent Magnet (SPM) motor drive system, with field weakening control
- **PMSM Drive**: IPM or SPM motor drive system with field oriented control
- **Induction Motor Drive**: Induction motor drive system with vector control and field weakening control

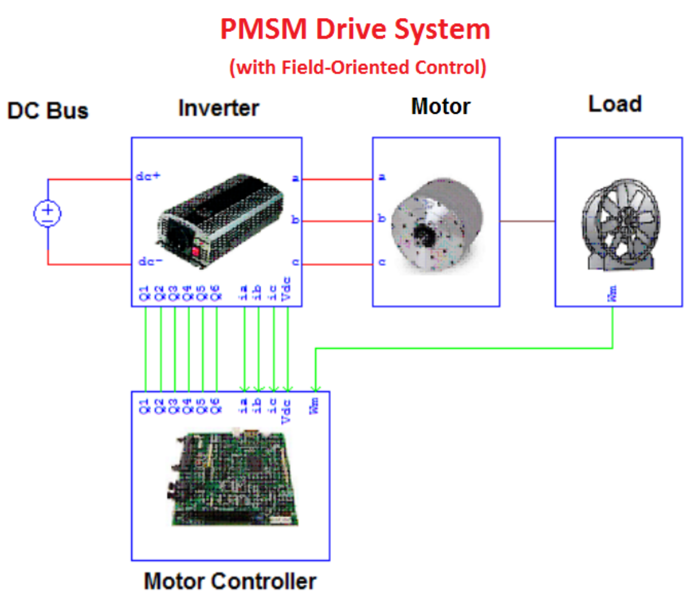
In addition, four design templates for sensorless PMSM motor drives are provided using TI's InstaSPIN technology:

- **PMSM (IPM) Sensorless Drive (InstaSPIN)**: Sensorless IPM motor drive system with maximum-torque-per-ampere control and field weakening control.
- **PMSM (SPM) Drive (InstaSPIN)**: Sensorless SPM motor drive system with field weakening control.
- **PMSM Sensorless Drive (InstaSPIN)**: Sensorless PMSM drive system (either IPM or SPM) using the same control structure as in TI InstaSPIN Motorware Lab 11.
- **PMSM Sensorless Drive (InstaSPIN SimCoder)**: Sensorless PMSM drive system (either IPM or SPM) using the same control structure as in TI InstaSPIN Motorware Lab 11, with SimCoder hardware library blocks for auto code generation.

Note that the four sensorless motor design templates use the PIL block (InstaSPIN). As the PIL block (InstaSPIN) is part of the PIL Module, one needs the PIL Module in the PSIM license in order to run these four templates. For further information on how to run the sensorless motor drive templates, refer to "Tutorial – PMSM drive with sensorless control.pdf".

In an IPM motor, the q-axis inductance is greater than the d-axis inductance, i.e. Lq > Ld. In a SPM motor, the d-axis and q-axis inductances are equal, i.e. Ld = Lq. In a nonlinear IPM motor, Ld, Lq, and back EMF constant vary as a function of the motor currents.

A typical motor drive system consists of a dc bus, 3-phase voltage source inverter, motor, motor controller, and mechanical load. The overall structure of the PMSM Drive template, for example, is shown below:



After parameters are entered for each block, all controller parameters will be designed automatically based on the operating conditions, and the entire circuit is ready to simulate.

This tutorial describes how to use the sensored motor drive templates in the Motor Control Design Suite. We will use the PMSM Drive template and the following motor as an example to illustrate the process.

PMSM motor: 900 W, 220 V, 4 poles, 1700 rpm, 5 N*m

Parameters: Rs = 4.3 Ohm; Ld = 27 mH; Lq = 67 mH; Back EMF constant = 98.67 Vpk/krpm

Moment of inertia = 1.79 kg* m^2

Maximum ratings: 1400 W; 10 N*m; 3000 rpm

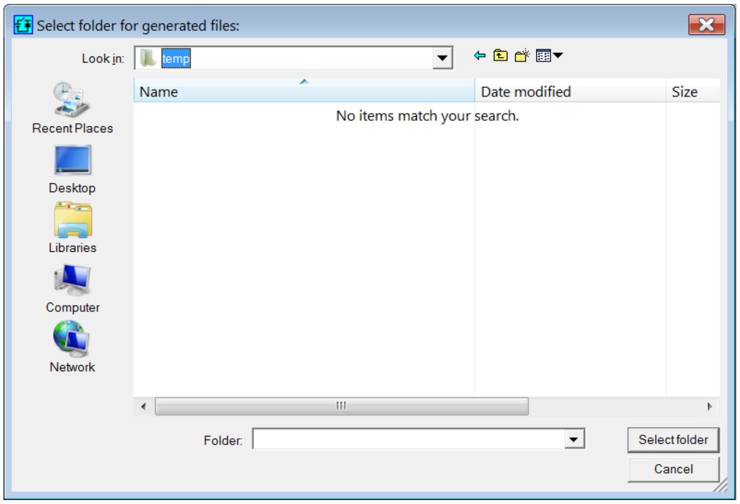
Based on the motor, the dc bus voltage is set at 500V. The inverter will operate at a switching frequency of 10kHz. The current loop sampling frequency will be set at 10kHz, and the speed loop sampling frequency will be 2kHz. The current loop bandwidth will be set at 1kHz, and the speed loop bandwidth will be set at 200Hz.

Running the Motor Control Design Suite involves two steps: defining system parameters, and updating the parameter file.

1. Defining System Parameters

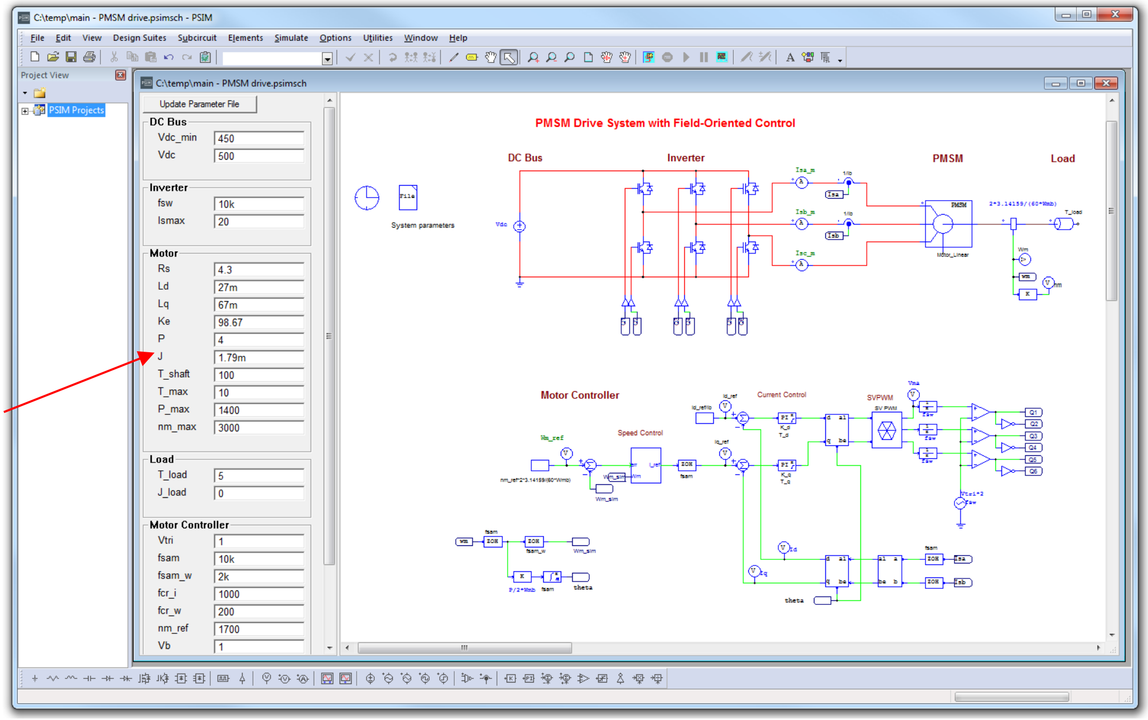
To run the PMSM Drive template, follow the steps below:

- In PSIM, go to **Design Suites** >> **Motor Control Design Suite**, and select **PMSM Drive**. The **Select folder** dialog window will appear as follows to specify the folder for the schematic files:



- In this example, the files will be placed in “c:\temp”. Navigate into this folder, and click on the button **Select folder**. The schematic file and parameter file, with the default values, will be generated and placed in this folder. The schematic file will be loaded into PSIM automatically, as shown below.

Parameter Panel



At the left of the schematic is the Parameter Panel. The panel defines the system parameters (such as dc bus voltage, inverter frequency, motor parameters) and control design parameters (such as current and speed loop bandwidth). For this example, enter the values as below.

For *DC Bus*:

Minimum DC Bus Voltage (Vdc_min):	450.
Operating DC Bus Voltage (Vdc):	500.

For *Inverter*:

Switching Frequency (fsw):	10k
Maximum Inverter Current (Ismax):	20.

For *Motor*:

Stator Resistance (Rs):	4.3
d-axis Inductance (Ld):	27m
q-axis Inductance (Lq):	67m
Back EMF Constant (Ke):	98.67
Number of Poles (P):	4
Moment of Inertia (J)	1.79m
Shaft Time Constant (T_shaft)	100
Maximum Torque (T_max):	10
Maximum Power (P_max):	1400
Maximum Speed (nm_max):	3000

For *Load*:

Load Torque (T_load):	5.

Load Moment of Inertia (J_load): 0

For *Motor Controller*:

PWM Carrier Amplitude (Vtri): 1
Current Loop Sampling Frequency (fsam): 10k
Speed Loop Sampling Frequency (fsam_w): 2k
Current Loop Crossover Frequency (fcr_i): 1000
Speed Loop Crossover Frequency (fcr_w): 200.
Motor Speed Reference (nm_ref): 1700.
Base Voltage Value (Vb): 1.
Base Current Value (Ib): 1.
Base Mechanical Speed (Wmb): 1.
Base Torque Value (Tb): 1.

The variables in the brackets are the names used in the parameter file of the circuit.

Beside using the Parameter Panel, another way to enter the design parameters is to use the template interface, as shown in Page 3. To display the template interface, select **Design Suites** >> **Show Design File**. Double click on each block to enter the parameters.

The control circuit quantities are in per unit values, with the base values as Vb, Ib, Wmb, and Tb. If the base values are all set to 1 (such as in this case), the control circuit quantities are in real values.

2. Updating Parameter File

After all the parameters are entered in the Parameter Panel, click on the button **Update Parameter File** to update the parameter file "parameters-main.txt" in the schematic. This parameter file contains the parameters entered by the user and the ones calculated by the Motor Control Design Suite. One big advantage of the Design Suite is that parameters of the current loop controller and the speed loop controller are calculated automatically, saving users the effort and trouble of designing the controllers.

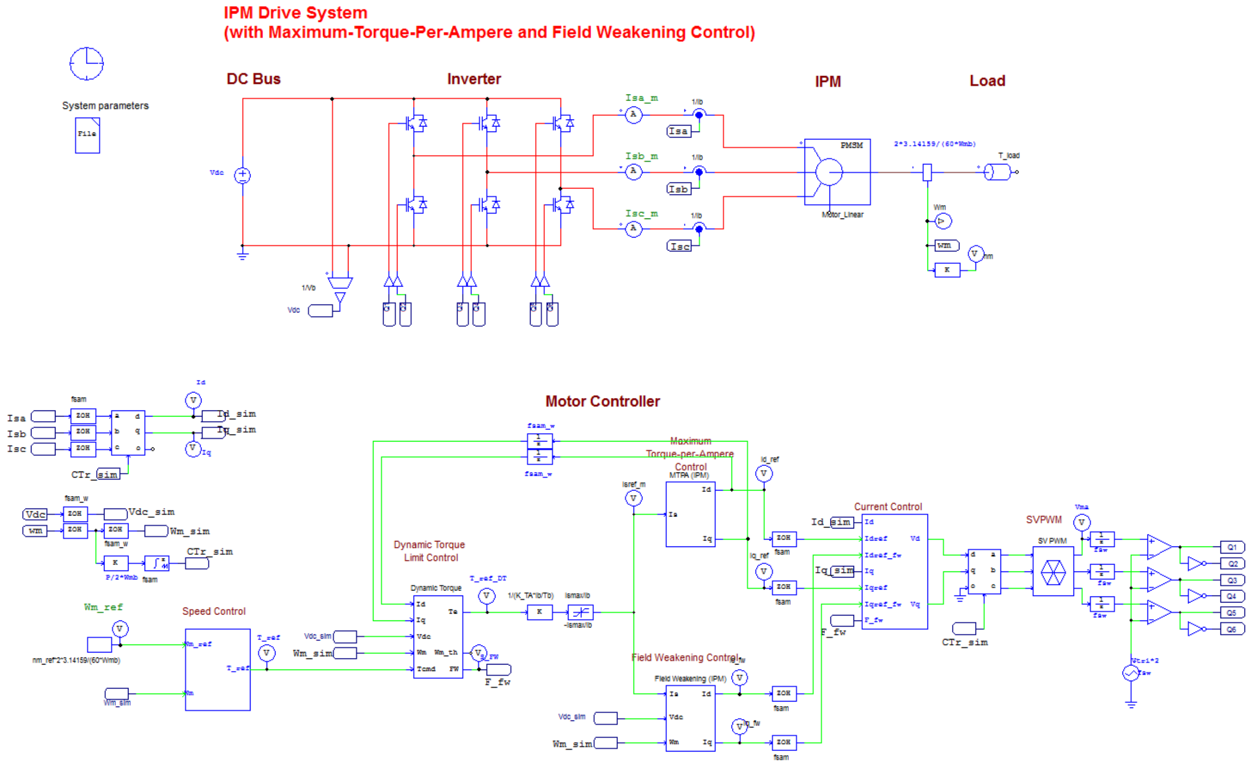
If any of the parameters in the Parameter Panel are changed, the parameter file in the schematic needs to be updated.

3. Design Templates

The use of the five sensored motor drive design templates are described below.

PMSM (IPM) Drive Template

The PMSM (IPM) Drive design template consists of a linear IPM motor drive system with maximum-torque-per-ampere control and field weakening control. The circuit is shown below.



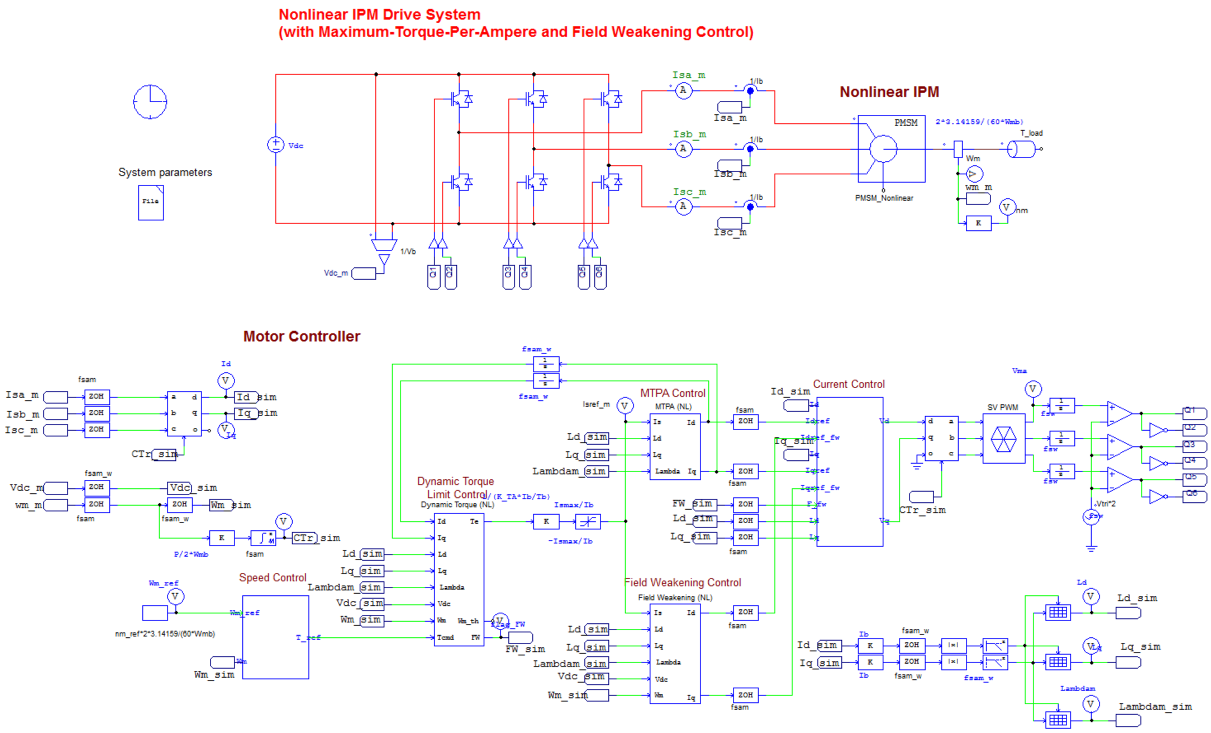
The control scheme is in the dq frame. It consists of the d-axis and q-axis current loops and a speed loop. The speed loop establishes the torque reference. Based on the torque reference and other operating conditions, the Dynamic Torque Limit Control block determines if the system operates in field weakening control, and adjusts the torque reference accordingly.

The torque reference is converted to the current reference and is sent to the Maximum-Torque-Per-Ampere Control (MTPA) block and the Field Weakening Control block. If the motor speed is below the threshold speed *Wm_th* (calculated by the Dynamic Torque Limit Control block), the system operates in the constant torque region and the MTPA outputs are used as the current loop references. Otherwise, the system operates in field weakening in the constant power region, and the Field Weakening Control block outputs are used as the references.

The current loops and the speed loop can have different sampling rates.

PMSM (IPM) Drive (Nonlinear) Template

The PMSM Drive (nonlinear) design template consists of a nonlinear IPM motor drive system with maximum-torque-per-ampere control and field weakening control. The template circuit is shown below.



Similar to the PMSM (IPM) Drive template, the control scheme is in the dq frame. It consists of the d-axis and q-axis current loops and a speed loop. The speed loop establishes the torque reference. Based on the torque reference and other operating conditions, the Dynamic Torque Limit Control block determines if the system operates in field weakening control, and adjusts the torque reference accordingly.

The torque reference is then converted to the current reference and is sent to the Maximum-Torque-Per-Ampere Control block and the Field Weakening Control block. If the motor speed is below the threshold speed *Wm_th* (calculated by the Dynamic Torque Limit Control block), the system operates in the constant torque region and the MTPA outputs are used as the current loop references. Otherwise, the system operates in field weakening in the constant power region, and the Field Weakening Control block outputs are used as the references.

Unlike in the linear PMSM drive system, however, the motor in this system is nonlinear, and d-axis and q-axis inductances and stator flux linkage are a function of the motor currents *Id* and *Iq*. Through 2-dimensional lookup tables, the inductances Ld and Lq and the stator flux linkage Lambda are obtained and are fed back to various control blocks.

Once created, the three lookup table files need to be placed in a different folder from the folder for the generated circuit schematic. This is because a default set of lookup tables will be placed in the folder of the generated circuit schematic. For example, if the generated circuit schematic is to be placed in "c:\temp", your lookup table files should be placed in a folder other than "c:\temp".

Otherwise your lookup table files will be overwritten by the default lookup table files. To define the lookup table file locations, in the Design Suite template interface, for example, define

Ld Lookup Table "temp1\Ld_Idq.tbl" [The file is in the subfolder "temp1"]

Ld Lookup Table "..\temp1\Ld_Idq.tbl" [The file is in the folder "temp1" in parallel to the schematic file folder]

Ld Lookup Table "c:\temp2\Ld_Idq.tbl" [The file is in the folder "c:\temp2\tables"]

All the controller parameters are calculated automatically by the Design Suite with proper stability margins. The current loops and the speed loop can have different sampling rates.

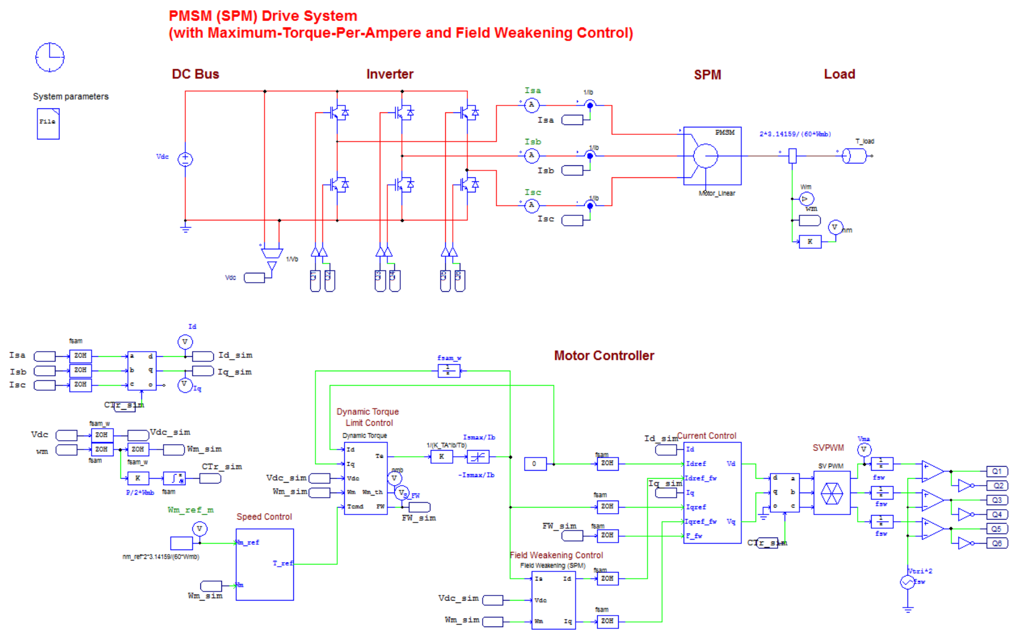
Controller design involving nonlinear machines is a particularly difficult and challenging task, and this is made considerably easier with the Motor Control Design Suite.

PMSM (SPM) Drive Template

The PMSM (SPM) Drive design template consists of a linear SPM motor drive system with field weakening control. The template circuit is shown below.

The control scheme is in the dq frame. It consists of the d-axis and q-axis current loops and a speed loop. The speed loop establishes the torque reference. Based on the torque reference and other operating conditions, the Dynamic Torque Limit Control block determines if the system operates in field weakening control, and adjusts the torque reference accordingly.

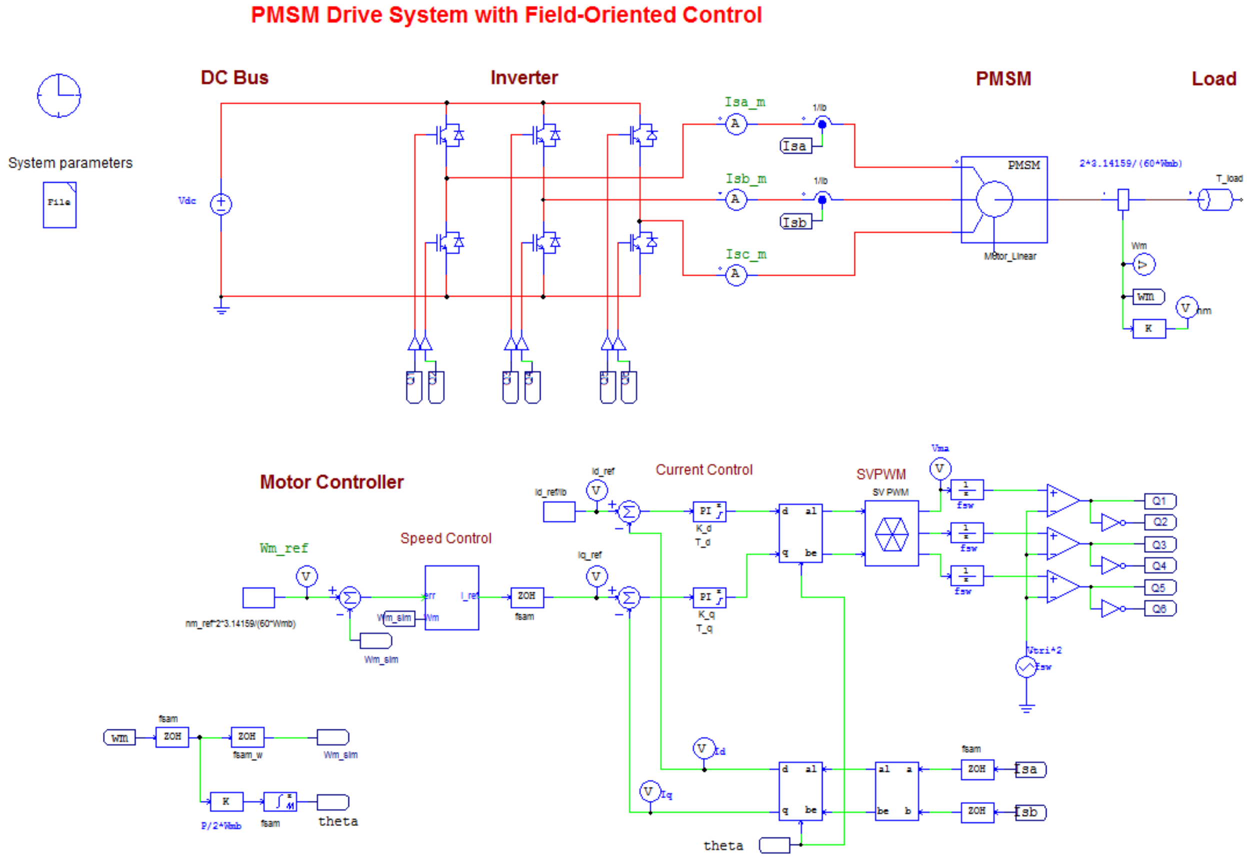
The torque reference is converted to the current reference and is sent to the Field Weakening Control block. If the motor speed is below the threshold speed *Wm_th* (calculated by the Dynamic Torque Limit Control block), the system operates in the constant torque region and the Dynamic Torque Limit Control block output is used as the q-axis current loop reference. Otherwise, the system operates in field weakening in the constant power region, and the Field Weakening Control block outputs are used as the references.



The current loops and the speed loop can have different sampling rates.

PMSM Drive Template

The PMSM Drive design template consists of a linear IPM or SPM motor drive system with field-oriented control. The template circuit is shown below.

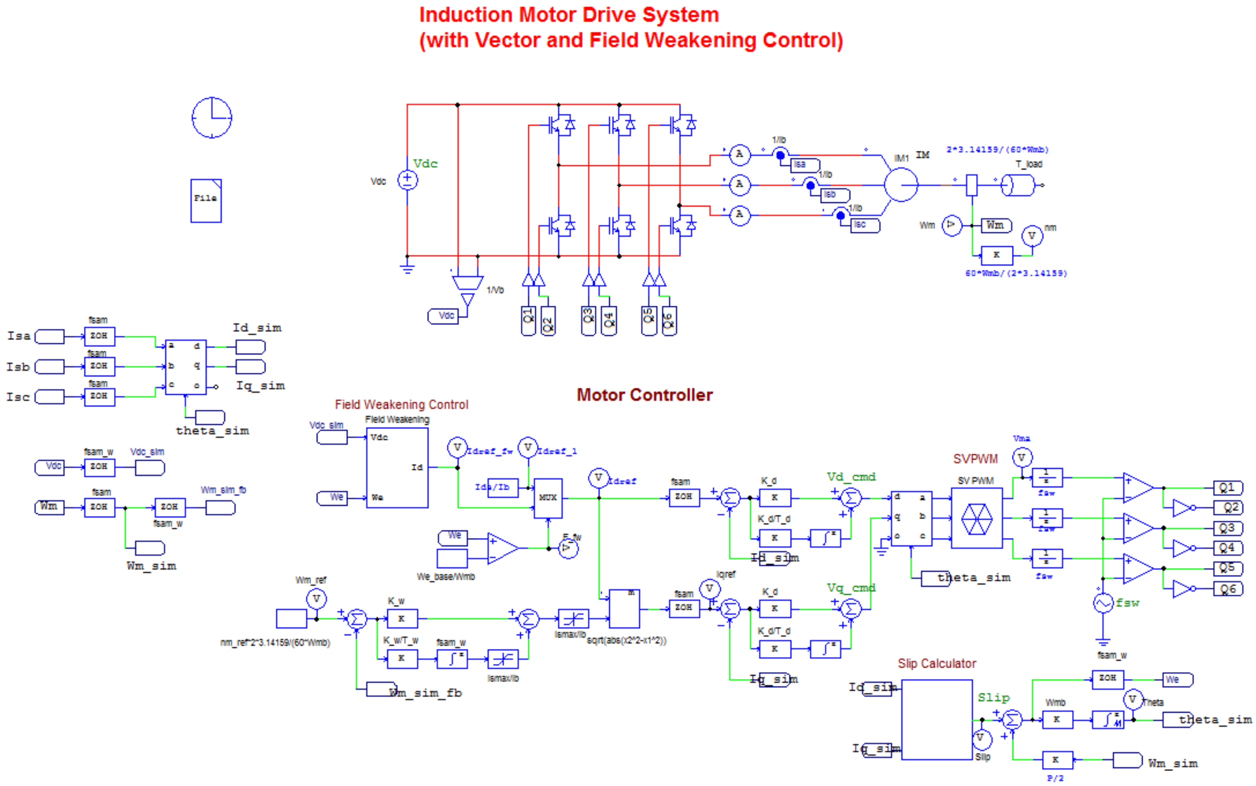


This control structure can be found in the application notes of many microcontroller unit manufacturers. The current Ia and Ib are converted to the alpha/beta frame through the Clarke transformation, and then to dc quantities Id and Iq through the Park transformation. The reference for the d-axis current Id is usually 0, but it should be set to a value other than 0 for higher torque output and for field weakening. The reference for the q-axis current Iq is determined by the outer speed loop.

Unlike the PMSM (IPM) Drive template circuit, maximum-torque-per-ampere control and field weakening control are not implemented. Users need to either use the PMSM (IPM) Drive template circuit or add their own circuits to achieve the maximum-torque-per-ampere control and field weakening control.

Induction Motor Drive Template

The Induction Motor Drive design template consists of an induction motor drive system with vector control and field weakening control. The template circuit is shown below.



The control scheme is in the dq frame, and the control circuit consists of d-axis and q-axis current loops and a speed loop. A slip calculator calculates the motor slip frequency. The current loops and the speed loop can have different sampling rates.

Based on the dc bus voltage and the stator frequency, a field weakening control block calculates the d-axis reference to achieve the constant power operation. This reference is used when the stator frequency is over the threshold frequency *We_base*. When the stator frequency is less than the threshold frequency, the calculated reference *Ids* is used to achieve the constant torque operation.

One big advantage of the Motor Control Design Suite is that the motor maximum current *Ismax*, the d-axis reference *Ids* (for maximum torque output) and the threshold stator frequency *We_base* are calculated automatically, ensuring the optimum operation of the system.