RT Box

DEMO MODEL

Vector Control of an Induction Machine

Last updated in RT Box Target Support Package 3.0.3

1 Overview

This demo model features an induction motor drive system with field oriented control. The drive is fed by a DC voltage of $400\,\mathrm{V}$ and produces $200\,\mathrm{Nm}$ of torque. The model consists of one subsystem called “Plant + Controller”. The subsystem contains the drive system and the controller using a vector control scheme. The following sections provide a brief description of the model and instructions on how to simulate it.

Real-time execution on the RT Box requires the model to execute using a fixed-step solver. The discretization step size parameter specifies the base sample time of the generated code and is used to discretize the physical model and control domain state-space equations. The execution time represents the actual time it takes to execute one discrete step of the PLECS model on the RT Box hardware. The chosen discretization step sizes and average execution times for each core in this demo model are shown in Tab. 1.

Table 1: Discretization step size and average execution time of the demo on one RT Box

	Core 0: exec. time / step size	Core 1: exec. time / step size
RT Box 2 or 3	$3\,\mu\mathrm{s}$ / $5\,\mu\mathrm{s}$	$2\,\mu\mathrm{s}$ / $100\,\mu\mathrm{s}$
RT Box 1	$3.4\,\mu\mathrm{s}$ / $5\,\mu\mathrm{s}$	N/A

1.1 Requirements

To run this demo model, the following items are needed (available at `www.plexim.com`):

- One PLECS RT Box and one PLECS and PLECS Coder license
- The RT Box Target Support Package
- Follow the step-by-step instructions on configuring PLECS and the RT Box in the Quick Start guide of the RT Box User Manual.
- Two 37 pin Sub-D cables to connect the box in loop-back setup at the front panel.

Note that this demo model is primarily showcasing the `multi-tasking` mode, which can run on an RT Box 1, 2 or 3.

- When the target is an RT Box 2 or 3, the main CPU core (Core 0) runs the plant as “Base task” with a sample time of `Ts_plant`. Another core (Core 1) runs closed-loop controls in “Controller” task in parallel with a sample time of `Ts_controller`, which is much slower and usually equals the switching period of the converter. In this way, the multi-core feature of the RT Box 2 or 3 is showcased by splitting the computational effort onto different cores. Besides, the setup can easily transition to a HIL or RCP test later on.
- However if the user has only a single RT Box 1 available, this model can also run with the multitasking feature onto the only CPU core of the RT Box 1, but in a pre-emptive multi-tasking fashion. In this case, the “Base task” is doing the plant calculation with the highest priority with a sample time of `Ts_plant`. The “Controller” task is executed as a background task with lower priority at the sample time of `Ts_controller`.

Please check the setting under **Scheduling** tab of the **Coder options...** window.

Note This model contains model initialization commands that are accessible from:
PLECS Standalone: The menu **Simulation + Simulation Parameters... + Initializations**
PLECS Blockset: Right click in the **Simulink model window + Model Properties + Callbacks + InitFcn***

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2 Model

The top-level schematic contains one subsystem including both plant and controller models, as shown in Fig. 1. The subsystem is enabled for code generation from the **Edit + Subsystem + Execution settings...** menu. This step is necessary to generate the model code for the RT Box.

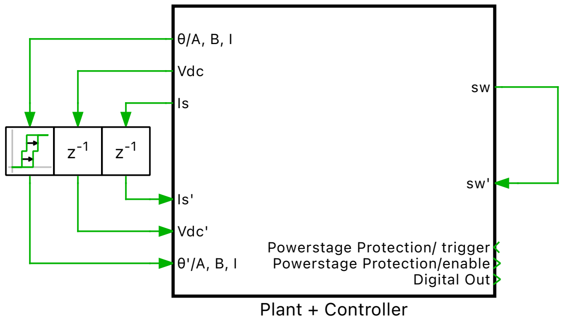

Figure 1: Top-level schematic of the induction machine drive system model

2.1 Power Circuit

The power circuit includes an induction machine (IM) and a three-phase full bridge voltage source inverter (VSI). The mechanical interface of the IM is loaded by a linear friction block via a gear box. The DC voltage source V_i with $V_\mathrm{dc} = 400\,\mathrm{V}$ supplies the VSI, which is represented by three IGBT Half Bridge power modules.

The six switching signals are brought into the subsystem by a PWM Capture block from the PLECS RT Box component library. The measurements of the DC voltage and the AC current are exported out of the subsystem by Analog Output ports. The rotor angular position and rotational speed are converted by the Incremental Encoder block into digital orthogonal pulses, which can be measured outside of the subsystem.

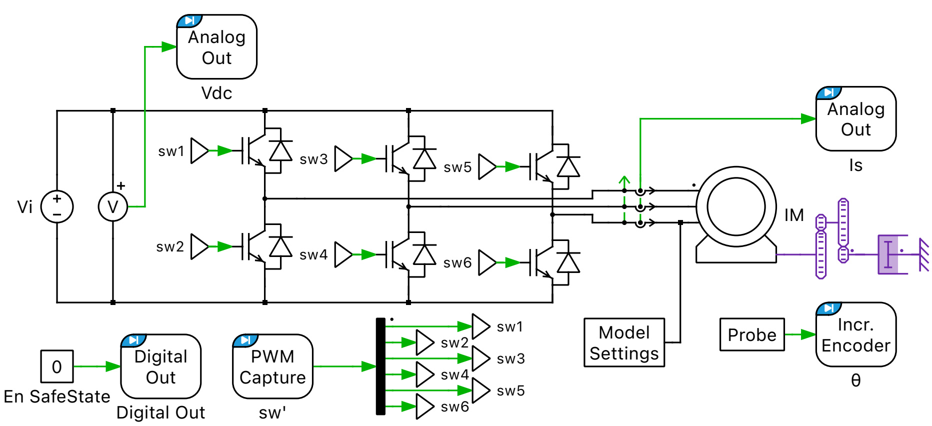

Figure 2: Power circuit of the induction machine drive system

2.2 Controls

In the controller part, the measurements of the DC-link voltage and the stator currents are imported by Analog In blocks. The mechanical angular speed of the rotor is obtained from the Quadrature Encoder Counter block, which converts the orthogonal digital pulses.

Rotor-field oriented control is applied to the drive system and the basic structure is shown in Fig. 3, where the stator current is regulated in the dq frame.

The voltage reference generated in dq-frame is converted to abc-frame, and then passes through a 3-Phase Index-Based Modulation block to generate three-phase modulation indices. Inside the 3-Phase Index-Based Modulation block mask dialog, one can choose the simple Sinusoidal PWM or other Space Vector PWM modulation methods.

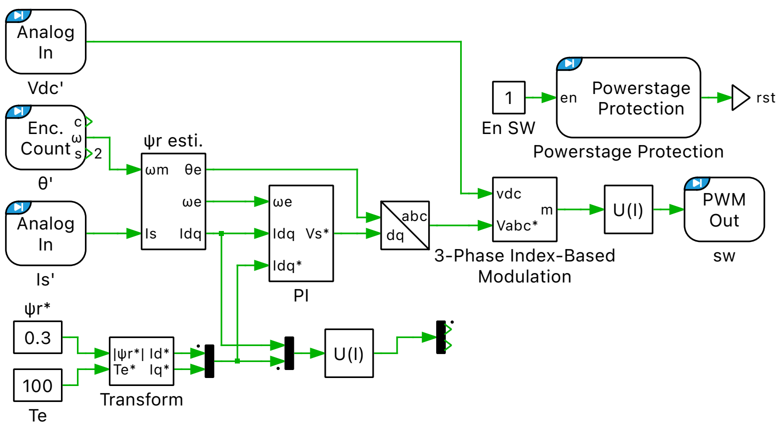

Figure 3: Controller model of the induction machine drive system

Fig. 4 shows the equivalent circuit of the induction machine in the dq frame, which rotates synchronously with the rotor flux. The values of L_M, $L_{\sigma\mathrm{S}}$ and R_R are calculated from the original machine parameters, which can be found in the initialization commands of the model, (see Note above in Section 1).

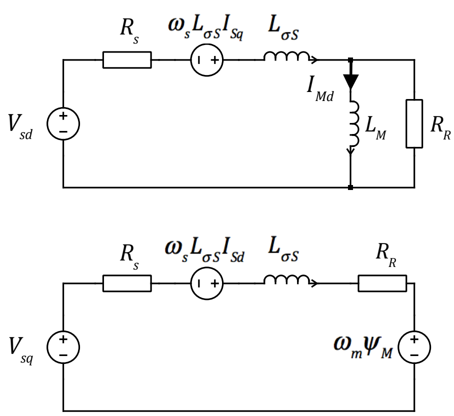

Figure 4: Equivalent circuit of the induction machine in the dq frame

The PI controllers for the d and q axis currents are included in the subsystem “PI”, as shown in Fig. 5. The proportional and integral gains are designed following the “Optimum Magnitude” method, which is described in more detail in the “Boost Converter” demo model of the RT Box Target Support Package.

To avoid the use of an embedded flux sensor, a magnetic flux estimator introduced on page 322 of [1] is employed in the subsystem “Ψ_r esti.”. Making use of the measured mechanical angular speed ω_m, the stator current is transformed into the rotor reference frame (RRF) as $\vec{I}_{\mathrm{s,xy}}$. The rotor flux $d\vec{\Psi}_{\mathrm{r,xy}}$ in the RRF is governed by the differential equation below:

$$\frac{d\vec{\Psi}_{\mathrm{r,xy}}}{dt} = R_\mathrm{R}(\frac{-d\vec{\Psi}_{\mathrm{r,xy}}}{L_\mathrm{M}}) + \vec{I}_{\mathrm{r,xy}} \tag{1}$$

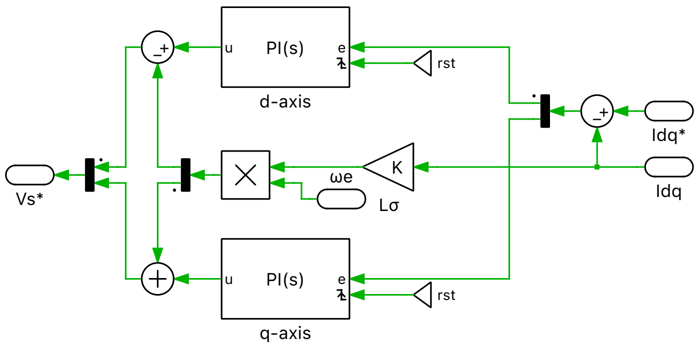

Figure 5: PI controller in the dq frame

Following the differential equation, $d\vec{\Psi}_{\mathrm{r,xy}}$ can be calculated using $\vec{I}_{\mathrm{s,xy}}$ as the input. Processing the "x" and "y" components of the rotor flux in the RRF by a Rectangular to Polar transformation block, yields the slip angular position. Summing up the slip angular position and the rotor electrical angular position, one can obtain the rotational flux angular position θ_{e}. θ_{e} is further used to transform the stator currents from the abc frame to the dq frame. The structure of the rotor flux estimator is demonstrated in Fig. 6.

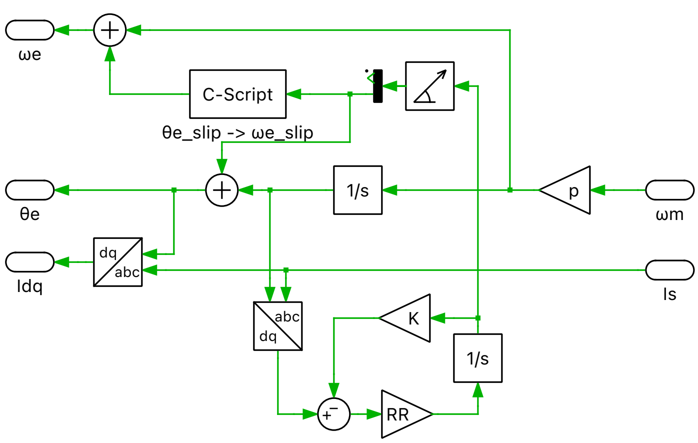

Figure 6: Structure of the rotor flux estimator

The current reference in the dq frame is converted from the torque and flux reference by the subsystem "Transform".

3 Simulation

This model can run both, in offline mode on a computer or in real-time mode on the PLECS RT Box. For the real-time operation, one RT Box (referred to as "Plant + Controller") needs to be set up as demonstrated in Fig. 7.

Please follow the instructions below to run a real-time model on a single RT Box:

1 Connect the Analog Out interface to the Analog In interface with one DB37 cable, and the Digital Out interface to the Digital In interface with another DB37 cable (as shown in Fig. 7).

2 From the **System** tab of the **Coder options...** window, select the "Plant + Controller" subsystem and **Build** it onto the RT Box.

3 Once the model is uploaded, from the **External Mode** tab of the **Coder options...** window, **Connect** to the RT Box and **Activate autotriggering**.

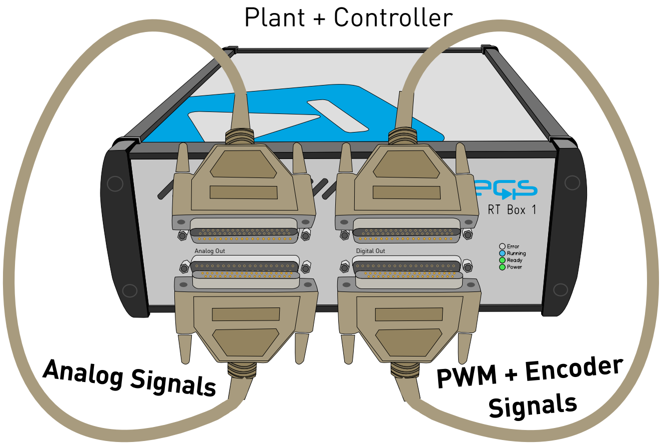

Figure 7: Hardware configuration for the real-time operation of the demo model

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Note On the plant side, the “En SafeState” Constant value `0` is output through DO-9 and received on the “Controller” task Power Stage Protection block DI-9 via a DB37 cable. Therefore all PWMs on the “Controller” task are in normal operation mode upon startup.

Under external mode of the RT Box, first change the “En SafeState” Constant value from `0` to `1`. This brings all PWMs into the corresponding safe state, as specified under the **Protection** tab of the PWM Out block.

To get out of the safe state, first change the “En SafeState” Constant value from `1` back to `0`. Next change the “En SW” Constant value in the “Controller” task from `1` to `0` and back to `1`. This enables again the normal switching operation and meanwhile resets the integral part of the PI controller.

For more detailed explanation, please refer to the Help page of the Powerstage Protection block.

The stator current, rotational speed and electrical torque are shown in the scope of the plant side. In the XY plot Ψ_{r} the rotor flux is displayed and it should be a circle in steady-state operation. To observe a transient behavior of the system, e.g. a step change of the torque reference from $100\,\mathrm{Nm}$ to $200\,\mathrm{Nm}$, please further follow the scenario below:

- Make sure that the External Mode and **Activate autotriggering** of the RT Box is enabled.
- Switch the **Trigger channel** parameter to `[Electrical torque]` in the **External Mode** tab of the subsystem’s **Coder options...** window.
- Setup the **Trigger level** parameter to be 150 and **Trigger delay [steps]** to be -50000.
- Change the Constant block “T_{e}” in the “Controller” task from the default value of 100 to 200.

The step change will be captured by the scope on the plant topology, as shown in Fig. 8.

4 Conclusion

This model demonstrates an induction machine drive system which can run in both offline simulation and real-time operation for Hardware-in-the-loop testing and rapid control prototyping.

References

[1] R. De Doncker, D. Pulle and A. Veltman, “Advanced electrical drives”, Springer, 2011

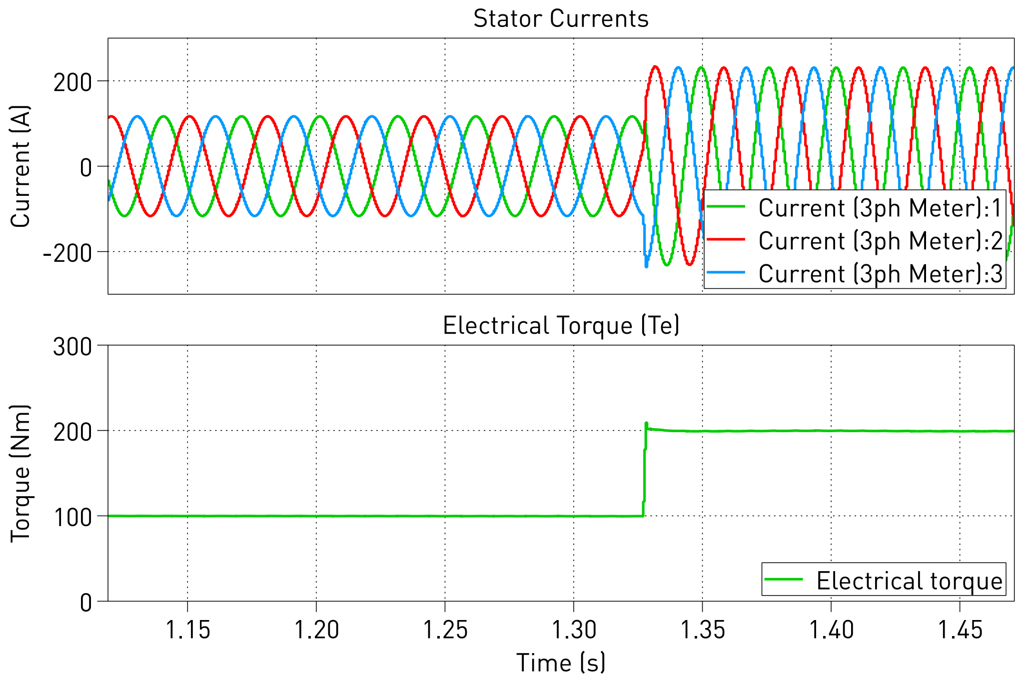

Figure 8: Transient response of a step change of the torque reference in the controller task

Revision History:

RT Box TSP 1.8.5	First release
RT Box TSP 2.1.5	Turn on Assertions in IGBT Half Bridges and add deadtime in the PWM Out block
RT Box TSP 2.1.7	Add the enable/disable switching scheme and use the PI Controller component from the library
RT Box TSP 2.2.1	Use the Powerstage Protection block to enable/disable switching
RT Box TSP 3.0.1	Use the 3-Phase Index-Based Modulation block to provide more three-phase inverter modulation strategies, also update the single box model to use the multi-tasking feature on RT Box 1
RT Box TSP 3.0.3	Remove the model with two separate RT Boxes and keep only the single RT Box model using multi-tasking feature

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