



**RT Box**

***DEMO MODEL***

## **Vector Control of an Induction Machine**

Last updated in RT Box Target Support Package 2.1.7

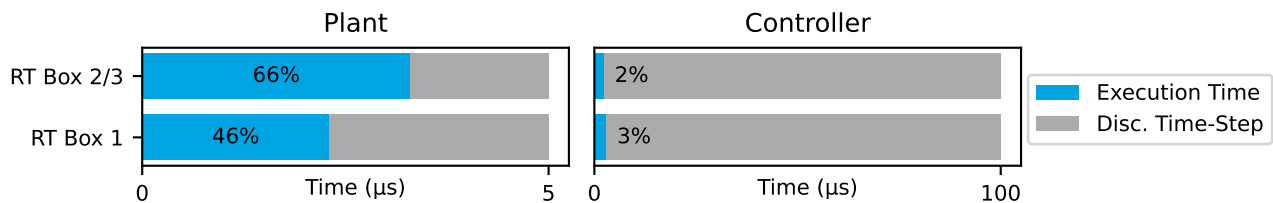
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- ▶ Request a PLECS and PLECS Coder trial license
- ▶ Get the latest RT Box Target Support Package
- ▶ Check the PLECS and RT Box documentation

# 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 V and produces 200 Nm of torque. The model is split into two distinct subsystems called “Plant” and “Controller”. The plant contains the drive system and the controller employs a vector control scheme. These subsystems can then be independently built on the PLECS RT Box either for Hardware-in-the-loop (HIL) testing of an external controller, or for rapid control prototyping (RCP). 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 subsystem in this demo model are shown in Fig. 1.



**Figure 1: Performance overview for the execution on two RT Boxes**

## 1.1 Requirements

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

- Two PLECS RT Boxes 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.
- Three 37 pin Sub-D cables to connect the boxes front-to-front.

Note that this demo model is targeted at two RT Boxes application, with one running the Plant and the other running the Controller. In this way, the execution time of each real-time target is minimized. Besides, the setup can easily transition to a HIL or RCP test later on.

However if the user has only one RT Box available, please check the corresponding models targeted for one RT Box application. In this case, two 37 pin Sub-D cables are still needed to connect in front Analog Out interface with Analog In interface, and Digital Out interface with Digital In interface.

- For RT Box 2 and 3, by default the multi-tasking feature is enabled in this demo. “Controller” part is circled with a Task frame block, and runs in one core. The rest of the circuit on the schematic belongs to the “Base task”, and runs in another core. In this way the computational effort is split onto different cores. Please check the default setting under **Scheduling** tab of the **Coder options...** window.
- For RT Box 1, single-tasking should be used which runs both the Plant and the Controller on the same one core of the RT Box 1.

**Note** This model contains model initialization commands that are accessible from:

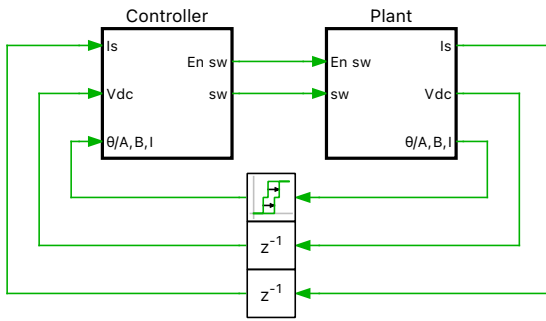
*PLECS Standalone:* The menu **Simulation + Simulation Parameters... + Initializations**

*PLECS Blockset:* Right click in the **Simulink model window + Model Properties + Callbacks + InitFcn\***

## 2 Model

The top level schematic contains two separate subsystems representing the controller and plant models, as shown in Fig. 2. Both subsystems are enabled for code generation from the **Edit + Subsystem + Execution settings...** menu. This step is necessary to generate the model code for the RT Box.

Vector Control of an Induction Machine deployable on the RT Box



**Figure 2: Top level schematic of the plant and the controller subsystems**

### 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  $V_{dc} = 400$  V supplies the VSI, which is represented by three IGBT Half Bridge power modules.

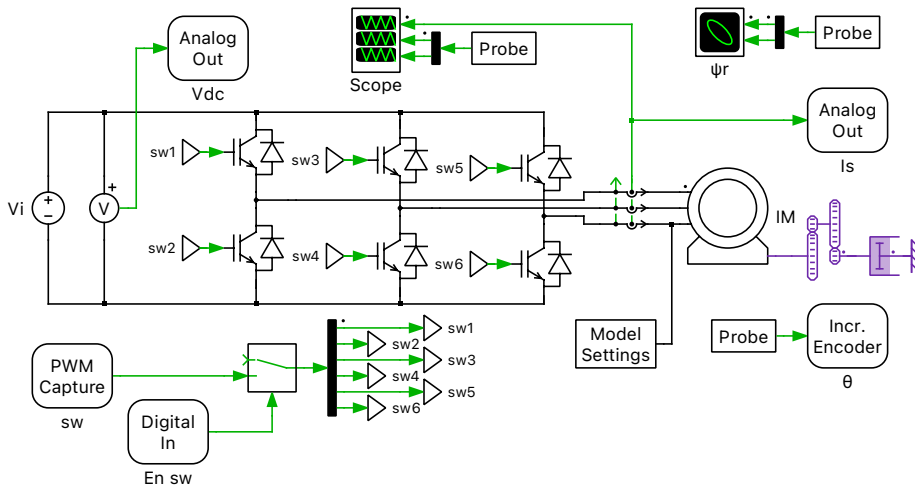
The six switching signals are brought into the subsystem by a PWM Capture block from the PLECS RT Box component library. The measurements of the DC voltage and the AC current are exported out of the subsystem by Analog Output ports. The rotor angular position and rotational speed are converted by the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

### 2.2 Controls

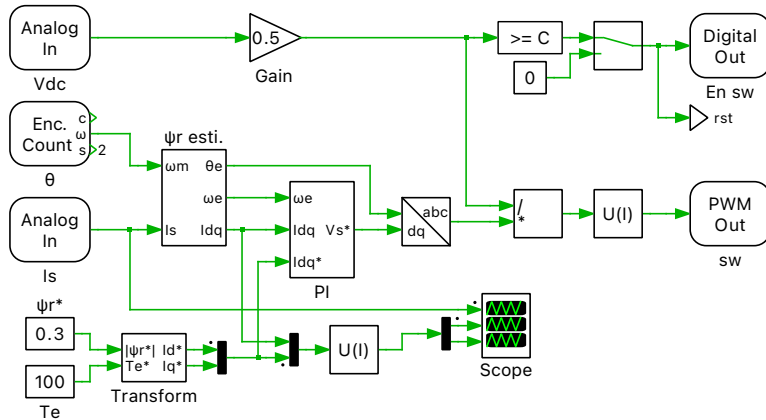
In the controller subsystem, the measurements of the DC-link voltage and the stator currents are imported by Analog In blocks. The mechanical angular speed of the rotor is obtained from the Quadrature Encoder Counter block, which converts the orthogonal digital pulses.

Rotor-field oriented control is applied to the drive system and the basic structure is shown in Fig. 4, where the stator current is regulated in the dq frame.

Fig. 5 shows the equivalent circuit of the induction machine in the dq frame, which rotates synchronously with the rotor flux. The values of  $L_M$ ,  $L_{\sigma S}$  and  $R_R$  are calculated from the original machine

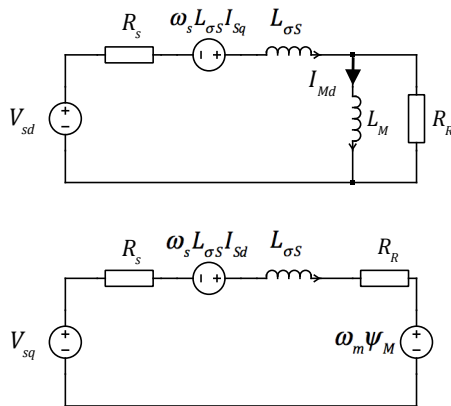


**Figure 3: Power circuit of the induction machine drive system**



**Figure 4: Controller model of the induction machine drive system**

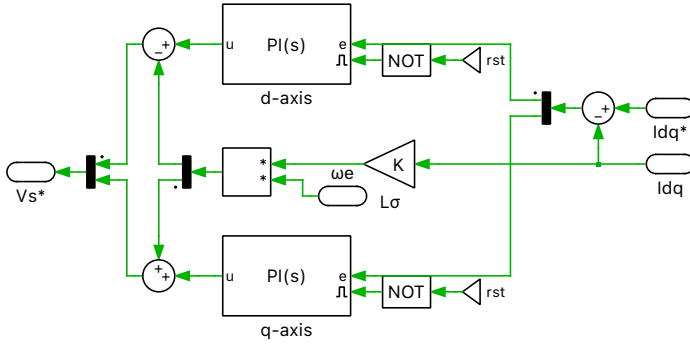
parameters, which can be found in the initialization commands of the model, (see Note above in Section 1).



**Figure 5: 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. 6. 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..

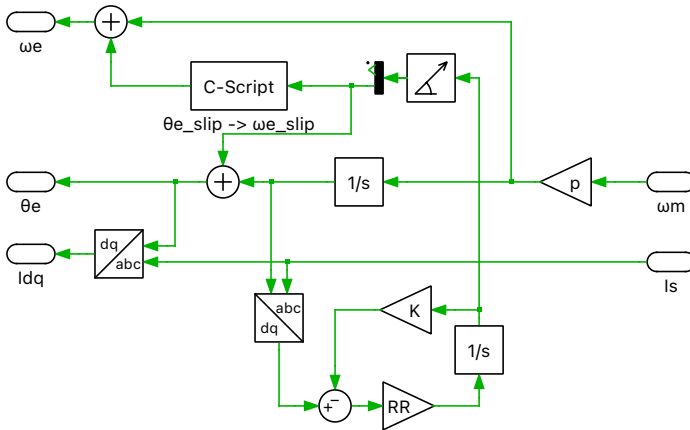


**Figure 6: PI controller in the dq frame**

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

$$\frac{d\vec{\Psi}_{r,xy}}{dt} = R_R \left( \frac{-d\vec{\Psi}_{r,xy}}{L_M} \right) + \vec{I}_{s,xy} \quad (1)$$

Following the differential equation,  $d\vec{\Psi}_{r,xy}$  can be calculated using  $\vec{I}_{s,xy}$  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  $\theta$ .  $\theta$  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. 7.



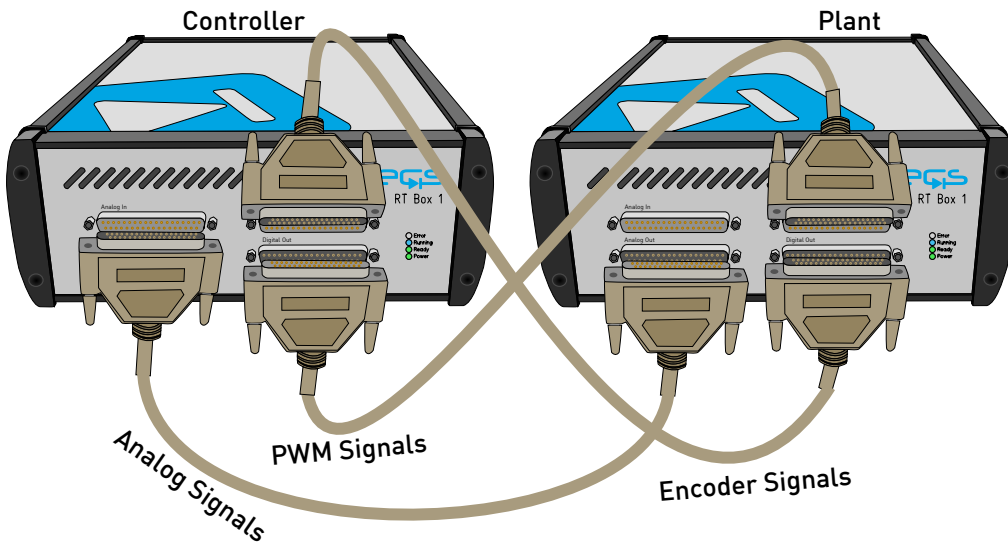
**Figure 7: Structure of the rotor flux estimator**

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, two RT Boxes (referred to as “Plant” and “Controller”) need to be set up as

demonstrated in Fig. 8 using three DB37 cables.

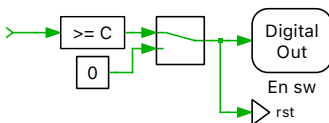


**Figure 8: Hardware configuration for the real-time operation of the demo model**

Please follow the instructions below to run a real-time model on two RT Boxes:

- From the **System** tab of the **Coder options...** window, select the “Plant” and **Build** it onto the “Plant” RT Box. Then, select “Controller” and **Build** it onto the “Controller” RT Box.
- Once the models are uploaded, from the **External Mode** tab of the **Coder options...** window, **Connect** to both RT Boxes and **Activate autotriggering**.

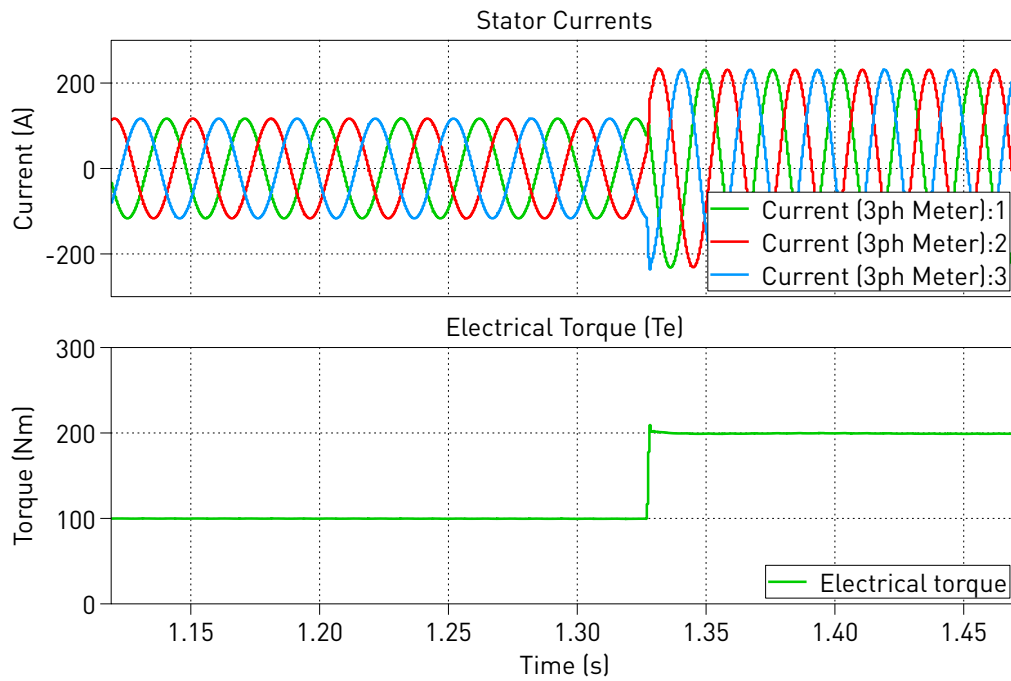
**Note** As shown below, during runtime the Manual Signal Switch before the Digital Out named “En sw” in the “Controller” subsystem in its default Up position enables switching. Change it to the Down position disables switching and also resets the id-iq PI Controller integral part.



The stator current, rotational speed and electrical torque are shown in the scope of the “Plant” subsystem. In the XY plot  $\Psi_r$  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 Nm to 200 Nm, please further follow the scenario below:

- Make sure that the External Mode and **Activate autotriggering** of both RT Boxes are enabled.
- Switch the **Trigger channel** parameter to [Electrical torque] in the **External Mode** tab of the “Plant” subsystem’s **Coder options...** window.
- Setup the **Trigger level** parameter to be 150 and **Trigger delay [steps]** to be -50000.
- Open the controller subsystem and change the Constant block “Te” from the default value of 100 to 200.

The step change will be captured by the scope in the “Plant” subsystem, as shown in Fig. 9.



**Figure 9: Transient response of a step change of the torque reference in the controller**

## 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

## Revision History:

RT Box Target Support Package 1.8.5	First release
RT Box Target Support Package 2.1.5	Turn on Assertions in IGBT Half Bridges and add deadtime in the PWM Out block
RT Box Target Support Package 2.1.7	Add the enable/disable switching scheme and use the PI Controller component from the library

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### *RT Box Demo Model*

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