



RT Box

Tutorial

From Offline to Real-Time

Steps to deploy a PLECS model in real-time

Tutorial Version 1.0

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1 Introduction

Hardware-in-the-loop (HIL) simulation is used to verify the real controller hardware behavior with a virtual “Plant” model running on a real-time simulator. Prior to the HIL test, an offline simulation is usually carried out with both the controller and plant modeled in the virtual environment. The PLECS toolchain together with the RT Box real-time simulator make possible that the user can operate the same model file for both offline and real-time simulation. However, to make an “offline” model “real-time” capable, one needs to apply some modifications to it. This document takes a conventional offline model as an example and demonstrates the steps and conventions to prepare it for real-time use.

2 Original Model

A permanent magnetic synchronous motor (PMSM) drive is taken as the starting point, as shown in Fig. 1. The power circuit is supplied by a grid-connected diode rectifier, and a DC-link capacitor is further connected to a full bridge inverter driving a PMSM. The classical vector control in the dq frame is used with the q-axis current reference provided as a step function. The switching frequency of the PWM gating signals is 10 kHz.

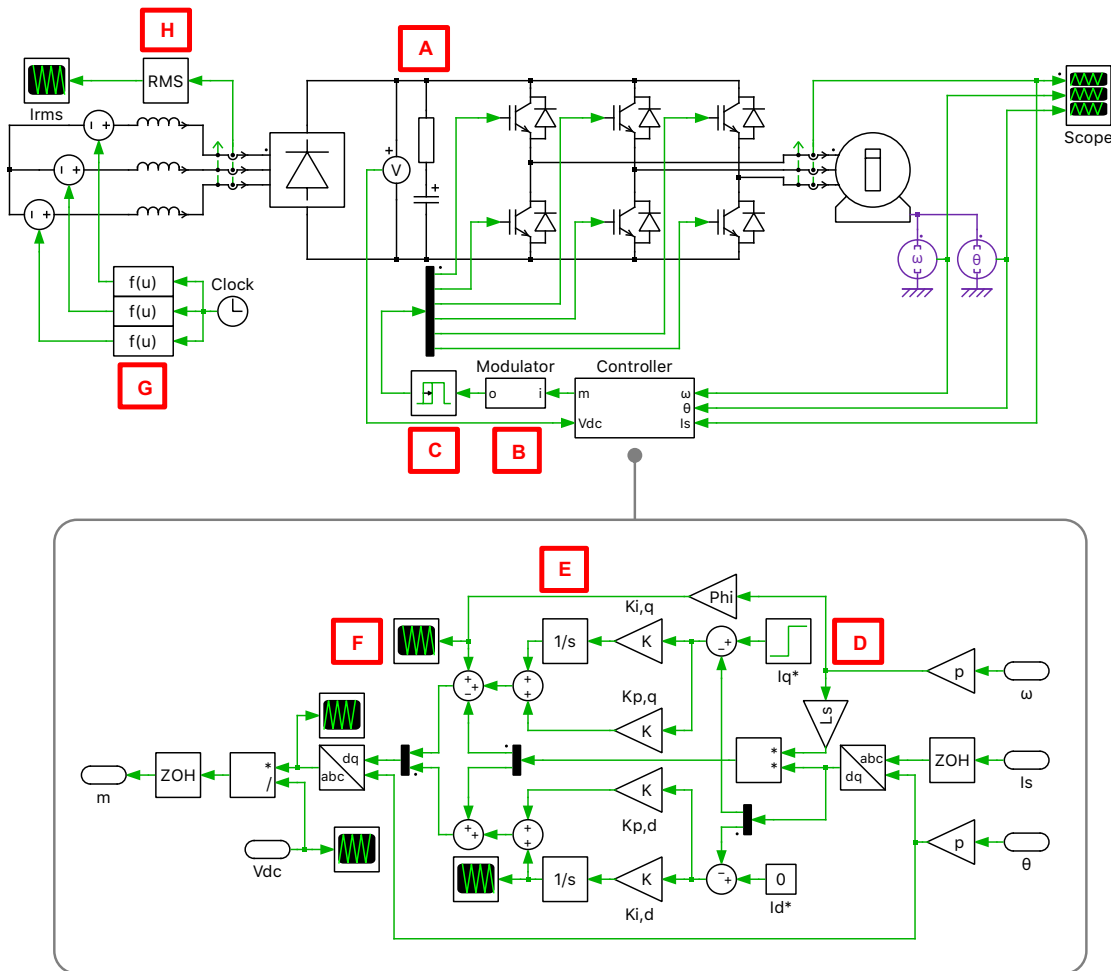


Figure 1: Schematic of the original offline simulation model

A benefit of offline simulation is that one can investigate certain aspects in as much detail as possible. With real-time simulation, however, two main constraints prevent the user from adding more details:

- **Computational power:** A HIL simulator only has a limited time window in which to update the model for the next sample step.
- **I/O sampling:** The control output of the controller under test, which is typically the PWM gate signal, has to be captured with adequate accuracy to actuate the plant model.

Some common modeling approaches and configurations in offline simulation that can become problematic in real-time simulation are summarized below (and numbered alphabetically in Fig. 1).

- **A:** Parasitic components
- **B:** PWM generator with the carrier-compare logic in the model
- **C:** Blocks that require extra small steps (e.g., Blanking Time)
- **D:** Blocks that use absolute time
- **E:** Components that lead to numerical overflow
- **F:** Excessive observation instruments (e.g., Scopes)
- **G:** Non-linear function calls
- **H:** Computationally-expensive post-processing

These topics will be discussed in the following chapters.

3 Modifications

3.1 Simplification

The offline model needs to be simplified so that the HIL simulator is able to accomplish each update within a reasonable model step size, which is preliminarily defined as $5\ \mu\text{s}$. The following changes are recommended and highlighted in Fig. 2:



Your Task:

- 1 Remove parasitic components, as the resulting time constants or resonant frequencies shouldn't be included.
- 2 Split the model at the DC-link capacitor by introducing a cross-coupled controlled current source and controlled voltage source pair. This reduces the number of matrices and their size.
- 3 Remove the $0.5\ \mu\text{s}$ Turn-on Delay block, as it cannot be resolved by the minimum step size of the RT Box.
- 4 Remove excessive Scopes, whose data acquisition may slow down the real-time simulation.
- 5 Replace the Function block used for sinusoidal grid voltage reference by a Sine Wave Generator block, as the latter uses a special algorithm to reduce the computational effort of a regular sinusoidal function call.
- 6 Remove the RMS Value block, as the same post-processing can be done in the PLECS Scope. When the RT Box External Mode is activated during a real-time simulation, the RMS calculation is done on the host computer instead of on the RT Box.



After making the aforementioned modifications to *from_offline_to_realtime_1.plecs*, your model should now be identical to *from_offline_to_realtime_2.plecs*.

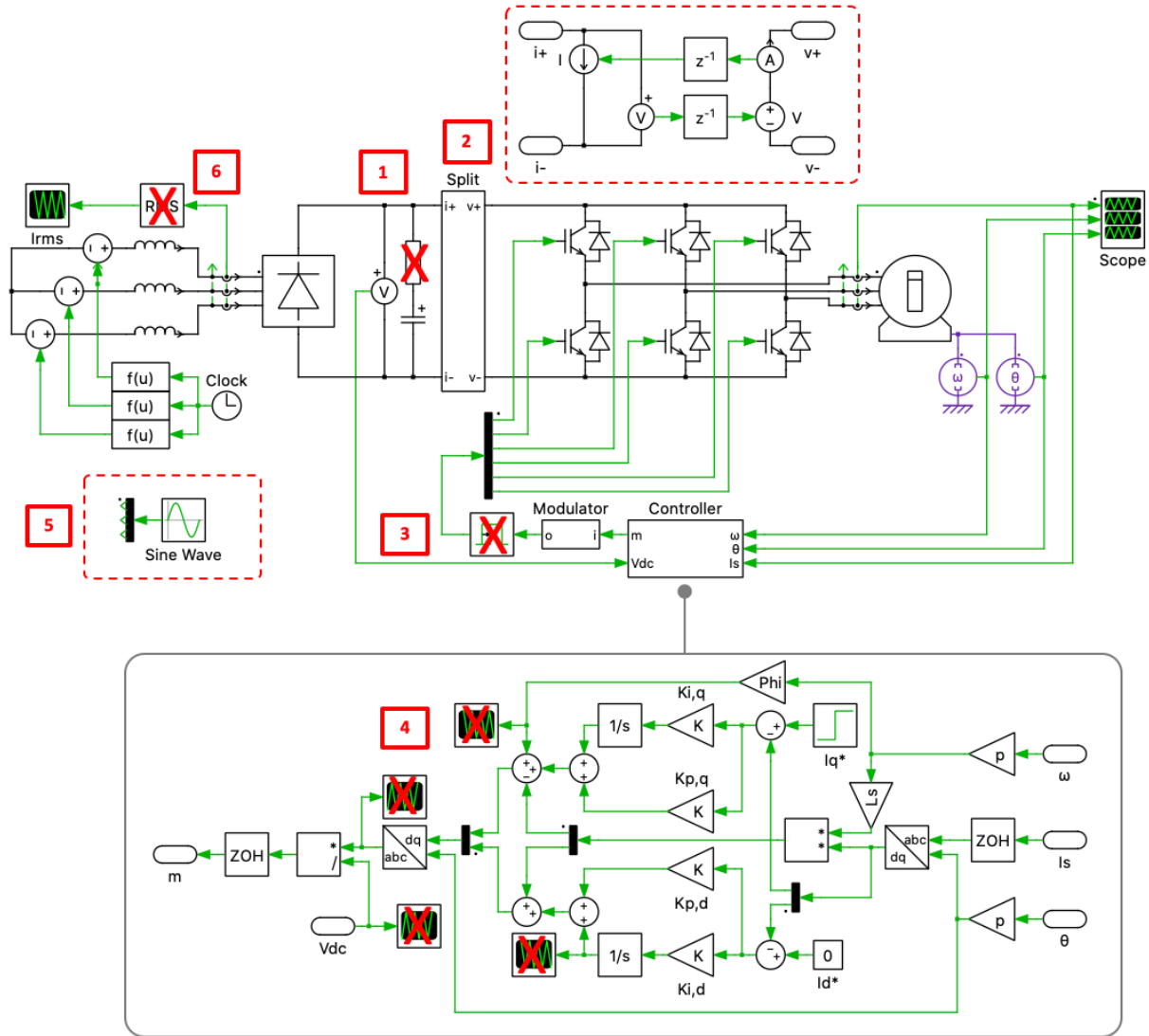


Figure 2: Model simplification recommendations

3.2 PWM Sampling

Start an offline simulation using the model *from_offline_to_realtime_2.plecs* and observe the motor stator current displayed in the Scope block. It should exhibit a smooth sinusoidal shape with switching ripple. Upload the model onto the RT Box, activate the External Mode and observe the current waveforms again. Although in the offline model the stator current can be well regulated, in the real-time model running on the RT Box, however, it is distorted significantly, as shown in Fig. 3. The reason is that the “Modulator” subsystem has the carrier-compare logic inside the model and is resolved within the window of the model step size of $5\ \mu\text{s}$, which is too little time considering the switching frequency.

To resolve the PWM gating signal with adequate accuracy, the solution is to use the PWM Out block to physically generate the PWM signal on the digital out port of the RT Box, connect the digital out and digital in ports together using a D-Sub 37 pin cable, then capture the physical PWM signals back into the box using the PWM Capture block. With this approach, the gating signal is sampled with a resolution of $7.5\ \text{ns}$, and sub-cycle averaged over the model step size of $5\ \mu\text{s}$.

The PWM Capture block has to be combined with the Half Bridge from Electrical/Power Modules component library to utilize the enhanced PWM sampling accuracy (other Power Modules may be more appropriate for different topologies). Replace the six individual IGBTs with three Half Bridge blocks,

and upload the model onto the RT Box again. One can now observe a more stable stator current.

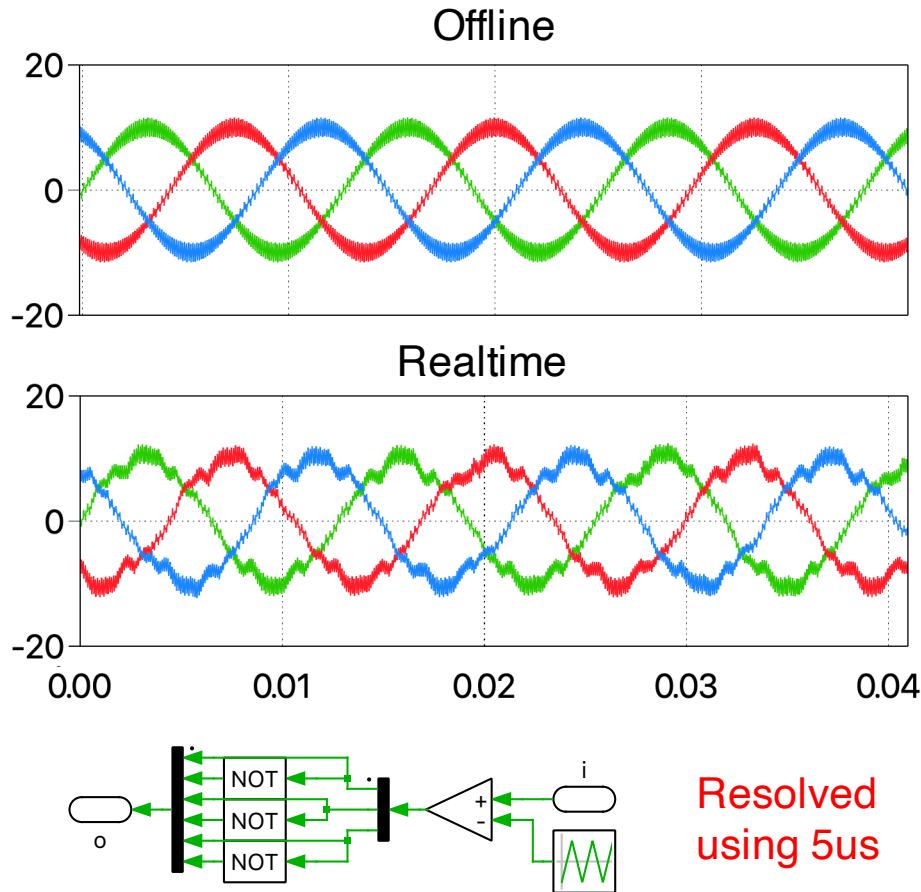


Figure 3: Distorted stator currents in real-time operation using ideal switches and model-based modulation logic



After making the aforementioned modifications in *from_offline_to_realtime_2.plecs*, your model should be identical to *from_offline_to_realtime_3.plecs*.

3.3 Transient Event

A step change has been configured for the q-axis current in the offline simulation, which occurs at 0.2 s. When running on the RT Box, however, it is not realistic to observe this transient event, as the model starts immediately after upload. The step change in real-time can be observed with the Parameter Inlining and External Mode features.

Replace the Step block for q-axis current reference with a Constant block and connect a Scope to its output, as shown in Fig. 5. Open the “Coder Options” window, and drag the Constant block into the blank area inside the “Parameter Inlining” tab. Upload the model again to the RT Box. After the upload, activate the External Mode and setup the trigger channel to the scope channel on the Constant block output. Configure the trigger delay to be approximately in the middle of the time axis and the level to be slightly higher than 0. Finally, change the q-axis current reference to be 10 with External Mode activated, and then observe the result of the step change in all the scopes, as shown in Fig. 6.

[illegible]

Figure 1 consists of two side-by-side plots. The left plot shows a green line representing the 'Trigger point' on a coordinate system with the x-axis ranging from 0.00 to 0.04 and the y-axis from 0 to 10. The green line is at y=0 until x ≈ 0.02, where it jumps to y=10. A legend indicates 'Trigger point' with a green square. The right plot shows the evolution of the system on a coordinate system with the x-axis ranging from 0.00 to 0.04 and the y-axis from -10 to 10. Three lines (blue, red, and green) represent different components of the system. All lines are at y=0 until x ≈ 0.02, where they diverge and oscillate between approximately -10 and 10.

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At this stage, your model should be identical to *from_offline_to_realtime_4.plecs*.

3.4 Prevention of Overflow

As the simulation time is not limited in real-time, some state variables may accumulate towards infinity in certain circumstances. In this motor drive model, the concerning sources of potential numerical overflow are the integrators of the PI regulators. It is therefore highly recommended to create a reset port for such blocks.

Activate the trigger port of the two integrators inside the “Controller” subsystem by setting the “External reset” parameter to “level”. Add a Manual Signal Switch and connect a Constant block with a value of 1 to one of its input ports, as shown in Fig. 7. Drag the Manual Signal Switch into the “Parameter Inlining” tab before uploading the model back onto the RT Box. After uploading the model, the Integrator can be activated by toggling the Manual Signal Switch with External Mode activated.

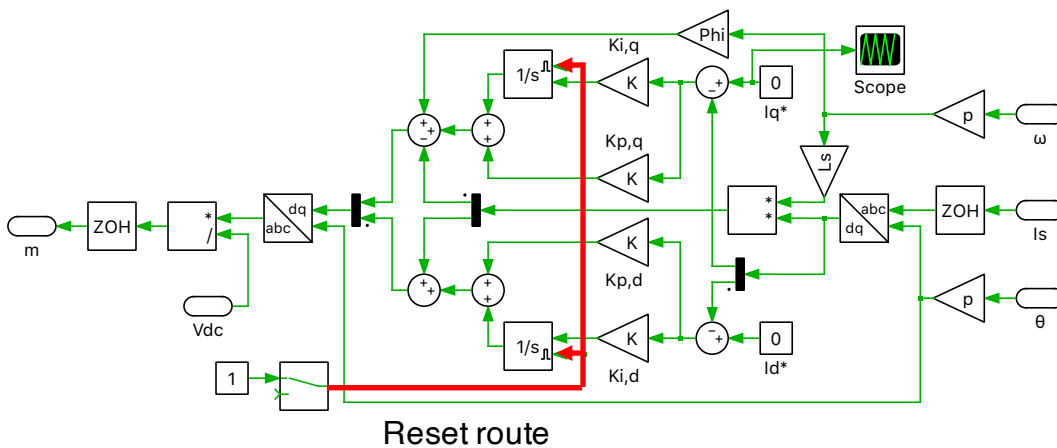


Figure 7: Activate the reset port for the integrators



At this stage, your model should be identical to *from_offline_to_realtime_5.plecs*.

3.5 Conclusion

This tutorial summarizes some of the necessary modifications required to make an offline simulation model real-time capable. One should always keep in mind the timing issues that are present in real-time simulations.

Revision History:

Tutorial Version 1.0 First release

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