RT Box

Tutorial

Virtual Prototyping

Running a system with controls and plant on two RT Boxes to create a virtual test setup

Tutorial Version 1.0

www.plexim.com

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

1 Introduction

This tutorial is an extension of the second tutorial on building a simple voltage source inverter (VSI) on the PLECS RT Box. You will apply the optimization techniques learned in the previous tutorial exercises to implement closed-loop control of a three-phase VSI system. You will use a virtual prototyping setup where the controller and plant will run on separate RT Boxes connected by loopback cables.

The learning goal for this tutorial is to apply concepts from the previous tutorial exercises so that you're equipped to use these tools in your real-time simulation applications.

Before you begin This tutorial requires an RT Box and a PLECS Coder license and requires knowledge about the basic RT Box operation and usage.

The tutorial is designed so that it can be completed with two (2) RT Boxes and two (2) loopback cables. The loopback cables drive the RT Box analog and digital inputs from the RT Box outputs. A D-SUB 37-pin male-to-female cable can be used for this purpose.

2 The Virtual Prototyping Concept

When developing HIL and RCP models it is often helpful to evaluate the performance of the real-time platform before connecting to any control or power hardware. Virtual prototyping can be used as an intermediate stage when developing real-time simulations for the RT Box. The virtual prototyping concept is shown in Figure 1.

In a virtual prototyping setup one RT Box will model the converter and a second RT Box will model the controller. The I/Os of the RT Boxes are then connected so there is a complete closed loop system with measurement and control signals exchanged between the two units.

There are a few key advantages to using virtual prototyping:

- Quickly build and deploy models to determine the exact plant and/or controller execution time
- Confirm RT Box pinouts
- Check the ADC and DAC offset, scaling factors, and check for signal saturation
- Non-synchronous execution of different parts of a system

Once testing in a virtual prototyping setup is complete, you will have increased confidence moving forward with HIL or RCP testing.

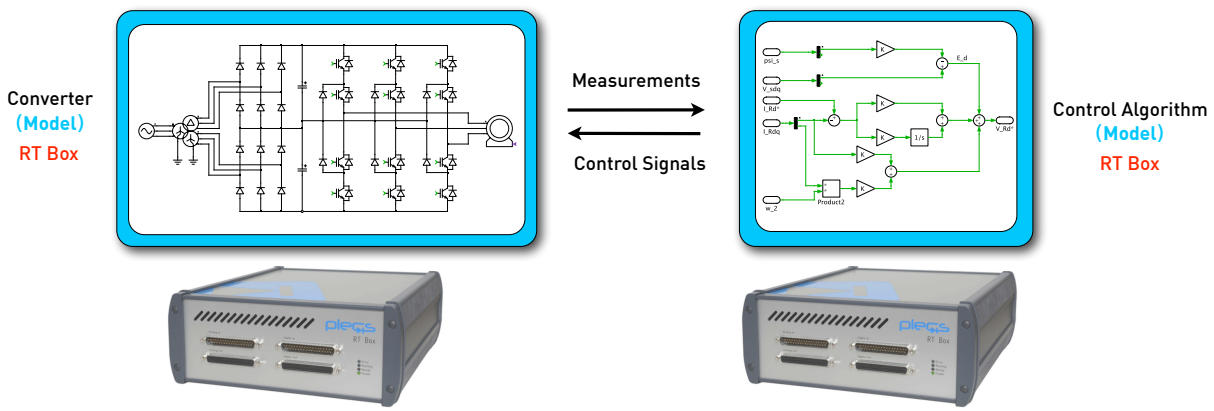

Figure 1: Conceptual diagram of a virtual prototyping test setup

3 Model Preparation

In this exercise you will transform the open loop VSI model you previously developed into a model suited for real-time simulation. You will segment the model into plant and controller systems that can be run offline or deployed in real-time to your virtual prototyping environment.

Your Task:

1. Start from the open loop VSI model you developed in "RT Box Tutorial 2: Building a Simple VSI on the PLECS RT Box". It should look like the reference model `vsi_loopback_1.plecs`.
2. Create two separate subsystems for the plant and controller. Label the subsystems accordingly.
3. Use the "Target Inport" feature of the RT Box library blocks to create an online and offline version of the systems within the same PLECS model. That is, place the existing RT Box library components into the corresponding "Plant" or "Controller" subsystem and then connect the control signals between the subsystems in the top-level schematic. Refer to Figure 2 for the arrangement of the top-level schematic (see also the tutorial "Introduction to the RT Box using PLECS").
4. Add an Analog In component to the "Controller" subsystem to measure the VSI output currents and connect the Analog In results to a Scope inside the subsystem.
5. Keep the controller in open loop and check the results of the offline simulation.

   What results do you expect to observe? Do the simulation results agree with your expectations?

   The "Current" Scope should show a balanced three-phase sinusoidal inductor current. These results are expected based on the sinusoidal input signals to the PWM Out blocks. The current and PWM waveforms should be similar to those you observed in the initial "RT Box Tutorial 2: Building a Simple VSI on the PLECS RT Box" exercise. Changing the structure of the model should not impact the results.

Your model should now look like the reference model `virtual_prototyping_1.plecs`.

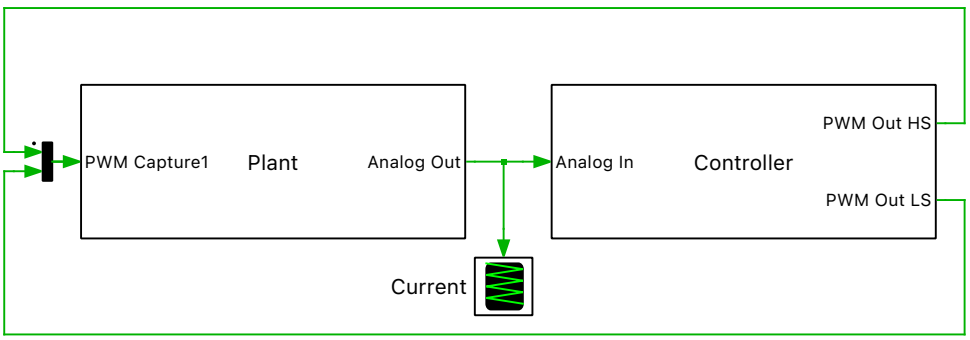

Figure 2: Overview of top-level schematic after step 4

4 Controller Implementation

Now that there is a suitable open-loop model ready to be deployed to the RT Box, you will implement a closed-loop controller for your VSI system.

Your Task:

1. Copy the ready-made controller block in the provided `dq_control.plecs` model and paste the component into the "Control" subsystem. Connect the phase current measurements for the Analog In block to the current input of the controller.
2. Connect Constant blocks to the "iq*" and "id*" inputs to the DQ controller to the q-axis current to 300 A and the d-axis current to 0 A.
3. Double-click the DQ controller component to see the subsystem parameters. Choose parameters based on the known characteristics of your plant. Then estimate reasonable values for the Kp and Ki gains.
4. Perform offline simulations to check the system response for different parameter values.

What modifications and changes are still needed to run this model online?

The "Plant" and "Controller" subsystems must be enabled for code generation. Simulation step sizes must be selected and entered into the **Coder Options + General** menu.

The RT Box channel assignments and analog input and output voltage ranges should be aligned. Another critical step is determining the scaling and offset factors for the analog signals, as the peak inductor current must be adjusted to be within the RT Box analog output voltage range. Similarly, the current measured by the Analog In component in the "Controller" subsystem must be scaled and offset to represent the actual current in the circuit.

Your model should look like the reference model `virtual_prototyping_2.plecs`.

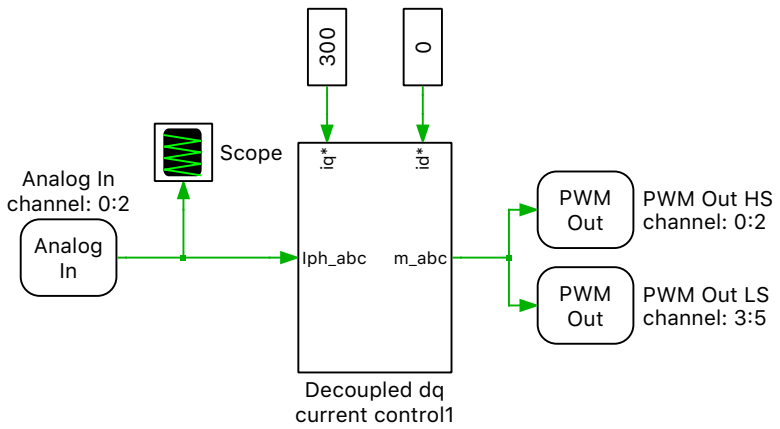

Figure 3: Configuration of the decoupled DQ current controller

5 Virtual Prototype Deployment

After designing a complete closed-loop system in offline simulation the model is almost ready for real-time deployment. However, a discretization step size must still be chosen and analog signal scaling must be taken into account before generating code for the RT Boxes. At the end of this exercise you will have implemented a complete real-time virtual prototyping setup evaluating the closed-loop control of the three-phase VSI system.

1 Enable code generation for the "Plant" and "Controller" subsystems.

2 Make the I/O port configuration of the ADC and DAC consistent.

(?) What are reasonable scaling factors inside the Analog In and Analog Out library blocks? Apply these settings in your model.

(A) From the open loop exercise, a peak current of $\pm 376\,\mathrm{A}$ was observed with a modulation index of 1.0. The default analog output voltage range is $\pm 10\,\mathrm{V}$. Rounding the peak current up to 400 A and allowing for a factor of two margin before the output voltages are clamped, we can determine a scaling factor of $10\,\mathrm{V}/(2 \cdot 400\,\mathrm{A})$ or 0.0125 for the analog outputs. In order to simplify the offset settings, change the RT Box target's analog input range to $\pm 10\,\mathrm{V}$. With a zero offset value and a $\pm 10\,\mathrm{V}$ analog input range, the Analog In scaling value is simply the inverse of the analog output scaling factor.

3 Specify a step size and generate code for each subsystem. Add scopes at the appropriate places in the top-level schematic to compare the results from Normal and CodeGen mode.

(?) What is an appropriate discretization step size?

(A) An appropriate discretization step size for the "Plant" was determined in "RT Box Tutorial 2: Building a Simple VSI on the PLECS RT Box". A value of $5\,\mu\mathrm{s}$ is acceptable. This corresponds to 20 simulation time steps per switching period.

The discretization step size requirements for the "Controller" subsystem are more flexible. Generally, any value that does not degrade the performance of the controller is acceptable. Start with a $5\,\mu\mathrm{s}$ step size.

4 Set the **Averaging interval** of the PWM Capture component to the chosen discretization step size.

5 Add additional scopes within the "Plant" and "Controller" subsystems to observe important quantities during the real-time simulation (e.g. currents, PWM signals, etc.). You may want to run the model and hold the offline traces for comparison with the real-time results.

6 Run each subsystem on a separate RT Box and check the execution time. Do not yet connect the loopback cables.

(?) What is the execution time for each RT Box?

(A) The execution time is approximately $1.5\,\mu\mathrm{s}$ for the "Plant" and $1.2\,\mu\mathrm{s}$ for the "Controller". The discretization time step could be further reduced since the processor loading is low.

7 Connect the corresponding digital and analog I/O ports with a DSub cable as shown in Figure 4.

8 Start the External Mode for both RT Boxes and check the results in the scope.

(?) What is the execution time for each RT Box?

The execution time is approximately $1.6\,\mu s$ for the “Plant” and $1.3\,\mu s$ for the “Controller”. The execution time is increased due to the changing system states and External Mode communication overhead.

Your model should look like the reference model `virtual_prototyping_3.plecs`.

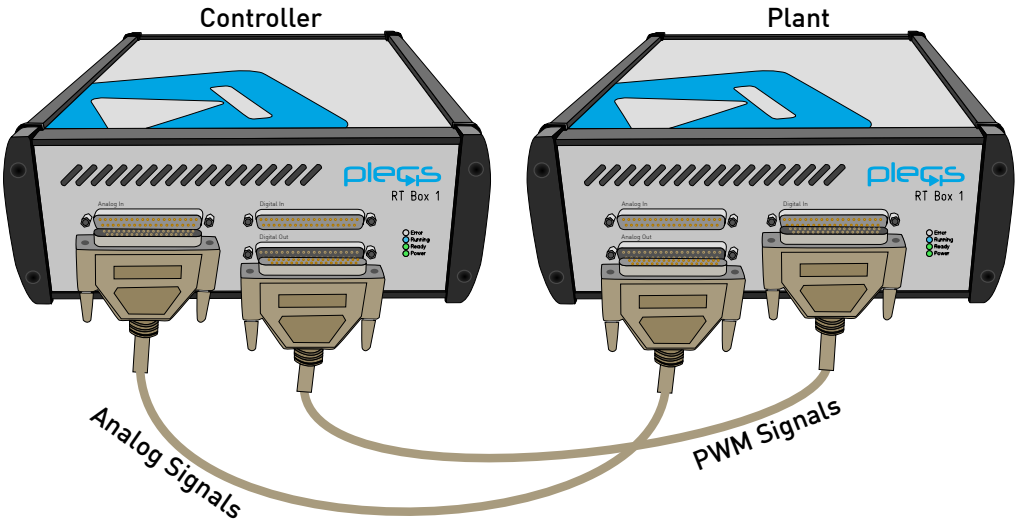

Figure 4: Loopback cable connection for the virtual prototyping setup

6 Conclusion

You have now completed a complete closed-loop control of a three phase VSI in a virtual prototyping environment. In the exercise you have applied key concepts on how to optimize PLECS models for real-time simulation including sub-cycle averaging, hybrid power modules, CodeGen simulations, and step size selection. You should now be well prepared to apply these tools to future real-time simulation applications.

Revision History:

Tutorial Version 1.0	First release

How to Contact Plexim:

☎	+41 44 533 51 00	Phone
	+41 44 533 51 01	Fax
✉	Plexim GmbH Technoparkstrasse 1 8005 Zurich Switzerland	Mail
@	`info@plexim.com`	Email
	`http://www.plexim.com`	Web

RT Box Tutorial