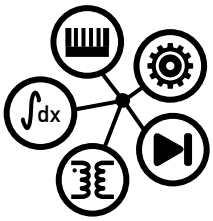

Embedded Code Generation

DEMO MODEL

Simple PIL Model

This model explores the Read and Override Probe blocks of the TI C2000 TSP to perform a PIL simulation

Last updated in C2000 TSP 1.5.1

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- Get the latest TI C2000 and RT Box Target Support Package
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1 Overview

This demo model features a current-controlled H-bridge circuit powering an inductive load. It provides an explanation of the PLECS Processor-in-the-loop (PIL) workflow using the TI C2000 Target Support Package (TSP) and Texas Instruments (TI) C2000 microcontrollers (MCUs).

In order to run this model you will need:

- PLECS Blockset or Standalone 4.5.5 or newer
- PLECS Coder
- TI C2000 TSP 1.3.1 or newer
- PLECS Processor-in-the-loop (PIL)
- A supported TI C2000 MCU

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 the controller subsystem and the plant circuit, as shown in Fig. 1. The Controller subsystem is enabled for code generation from the **Edit + Subsystem + Execution settings...** menu. This step is necessary to generate the model code for a subsystem via the PLECS Coder.

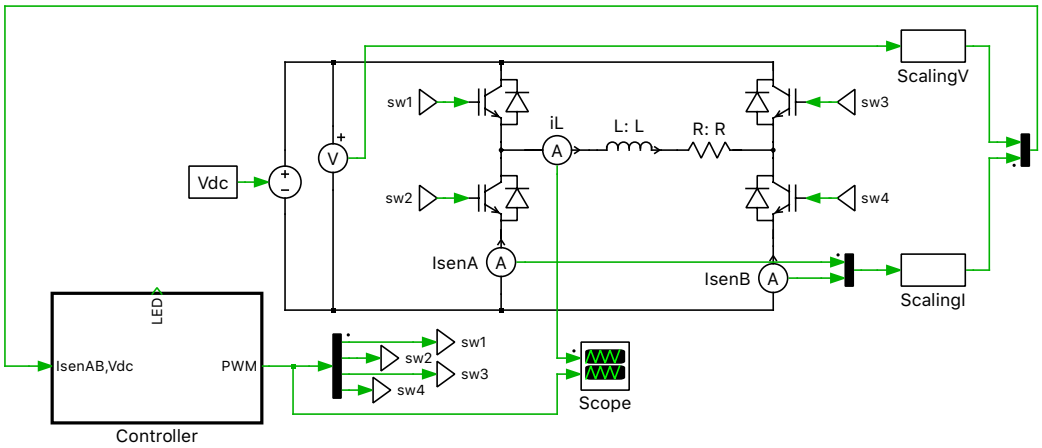

Figure 1: Top level schematic of the model

The H-bridge circuit and the controller are explained in detail in the demo model titled “H-Bridge Converter” in the TI C2000 demo models library. The documentation below solely focuses on the PIL workflow with the TI C2000 TSP.

2.1 Power Circuit

The power circuit, shown in Fig. 1, is supplied by a DC source voltage of $V_{\mathrm{dc}} = 24\,\mathrm{V}$. The H-bridge is composed of two IGBT Half Bridge power module components, powering an inductive load. The pulse-

width modulated (PWM) switching signals are obtained from the controller subsystem. The scaled DC input voltage and output inductor current measurements are sent to the controller subsystem.

2.2 Controls

The controller subsystem is shown in Fig. 2. The control logic is shown in Fig. 3.

The "Right Leg Duty-Cycle" subsystem determines the duty cycle required to maintain an average of $12\,\mathrm{V}$ at the right leg H-bridge output while accounting for variations in the sensed input voltage, V_{dc}. The "Left Leg Duty-Cycle" subsystem determines the modulation index of left leg of the H-bridge based on a proportional-integral (PI) controller. The sensed inductor current is compared to a setpoint that is toggled between $-3\,\mathrm{A}$ and $3\,\mathrm{A}$. This error is used for current compensation by the digital PI controller, which is equipped with anti-windup logic. The switching frequency is set to 10 kHz. The **Discretization step size** of the controller is same as the switching period.

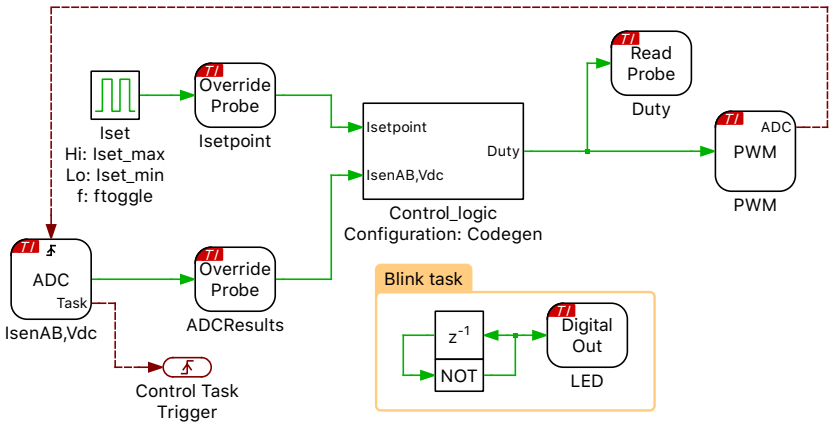

Figure 2: Controller subsystem

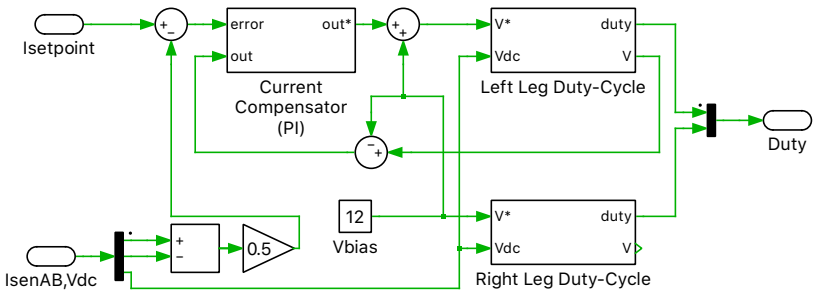

Figure 3: Control logic of the H-Bridge circuit

There is a configurable subsystem labeled "Control_logic" within the controller subsystem. Two configurations are possible. The first configuration is called "Codegen". In this configuration the control logic is implemented using components from the PLECS Control library. It is possible to perform an offline simulation in PLECS using this configuration. The second configuration is called "PIL". In this configuration the control logic is executed on a TI C2000 MCU.

Read and Override Probes

During a PIL simulation, an Override Probe allows PLECS to overwrite variables in the embedded code. In this model, the controller subsystem contains two Override Probes as seen in Fig. 2. The first Override Probe labeled "Isetpoint" allows to modify the current reference set-point, and the second Override Probe labeled "ADCResults" allows to modify the sensed analog measurements. The Read

Probe allows PLECS to read variables in the embedded code. In this model the Read Probe labeled "Duty" reads the duty cycle value calculated by the MCU and feeds it to the PWM generator.

The concept of using Override Probes and Read Probes allows tying actual control code executing on a real MCU into a PLECS simulation without the need to specifically recompile it for PIL. You can think of Override Probes and Read Probes as the equivalent of test points which can be left in the embedded software as long as desired. Software modules with such test points can be tied into a PIL simulation at anytime.

For further details on the PIL simulation, refer to the PIL User Manual [1].

3 PIL Workflow and Simulation

In addition to performing a regular PLECS simulation, this demo model is setup to generated embedded code and perform a PIL simulation. Follow the steps below to perform a PIL simulation.

1 First, set the configurable subsystem labeled "Control_logic" in Fig. 2 to "Codegen".

2 Flash the MCU

Follow the instructions below to upload the Controller subsystem to a TI MCU.

- Connect the desired MCU to the host computer through a USB cable.
- From the **System** tab of the **Coder + Coder options...** window, select "Controller".
- Next, from the **Target** tab, select the appropriate target from the dropdown menu. Then under the **General** sub-tab, select the desired **Build type**.
- Then, to `Build and program` the MCU directly from PLECS, choose either `Run from Flash` or `Run from RAM` as the **Build configuration**, then select `LaunchPad` as the **Board** type, and click **Build**.

Note If programmed correctly, the LED on the LaunchPad board should blink.

For advanced users who are familiar with Code Composer Studio (CCS), there is an option to `Generate code into CCS project`. Included with the TI C2000 Target Support package is a folder titled `projects`. Within the folder there are ZIP archives containing pre-built CCS projects for each MCU. Import the zip archive folder that corresponds to the desired target into CCS. You will notice a new project created in your CCS workspace. Enter the location of the `${workspace_loc}/dev_28xx/cg/` folder from the CCS project into the **CCS project directory** field and click **Build**. Then, proceed to build and debug the project as a normal CCS project. Refer to "Quick Start" section of the TI C2000 Target Support User Manual [2] for detailed step-by-step instructions.

3 Locate the generated `Controller.out` or the `Controller.elf` file. The generated `.elf` file is placed in the folder with a suffix `_codegen` in the same directory as the PLECS model file by default. This is the **Symbol file** that will be used in the next step. Symbol file is the binary file (also called "object file") corresponding to the code executing on the target.

4 Next, set the configurable subsystem labeled "Control_logic" in Fig. 2 to "PIL".

5 Configure the PIL target

Follow the instructions below to configure the PIL target.

- Right click on the "Control_logic" subsystem, then select **Subsystem + Open subsystem**.

- Double click on the PIL block to open the PIL parameters window, and select **Configure**.
- Click on the **+** button to add a new target. Rename the target as desired.
- Click on the **...** button to add the **Symbol file** from above. PLECS will obtain most settings for PIL simulations, as well as the list of Override Probes and Read Probes and their attributes, from the symbol file.
- Then choose the appropriate **Device type** and **Device name**, and click **Accept**.
- Next, click on the **Properties** button to verify that the symbol file is matching the firmware on the target, as shown in Fig. 4.

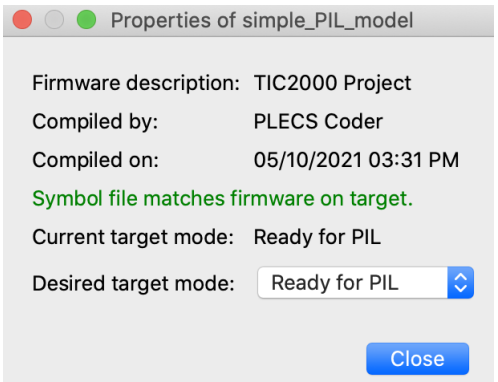

Figure 4: PIL target properties

- Change the desired target mode to `Ready for PIL`. This means that the target is ready for a PIL simulation, which corresponds to a safe state with the power-stage disabled.
- Then go back to the PIL parameters window, and select this configured **Target**.

6 Finally, start the PIL simulation from **Simulation + Start**.

The inductor current and PWM waveforms can be viewed in the Scope. The inductor current reference is toggled between $-3\,\mathrm{A}$ and $3\,\mathrm{A}$ using the "Iset" (Pulse Generator) component of the "Controller" subsystem. The step response of the inductor current is shown in Fig. 5.

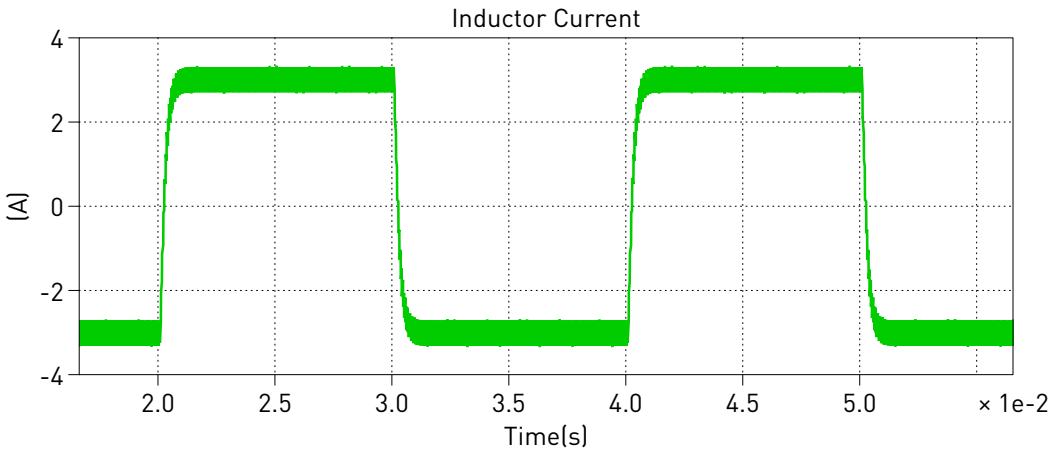

Figure 5: Inductor current measurements with a PIL simulation using a TI 28069 LaunchPad

In addition to the TI 28069 LaunchPad, this demo model also supports code generation for other TI C2000 MCUs, such as the TI 28377S [4], TI 28379D [5] and TI 280049C [6] LaunchPads; as well as the TI 28379D [7] and TI 28388D [8] controlCARDs. From the **Model initialization commands** window of **Simulation Parameters... + Initializations** tab from the **Simulation** menu, change the

value of `type_evm`, to choose the desired target. You must also configure the corresponding **Target** in the **Coder Options** window accordingly.

4 Conclusion

This model explored the Read and Override Probe blocks of the TI C2000 TSP to perform a PIL simulation. It also provided a PIL simulation workflow with step-by-step instructions using the TI C2000 TSP and a TI C2000 MCU.

References

[1] PIL User Manual,
URL: https://plexim.com/sites/default/files/pilmanual.pdf.

[2] PLECS TI C2000 Target Support User Manual,
URL: https://www.plexim.com/sites/default/files/c2000manual.pdf.

[3] TI C2000 Piccolo MCU F28069M LaunchPad development kit,
URL: http://www.ti.com/tool/LAUNCHXL-F28069M.

[4] TI C2000 Delfino MCU F28377S LaunchPad development kit,
URL: https://www.ti.com/lit/pdf/sprui25.

[5] TI C2000 Delfino MCU F28379D LaunchPad development kit,
URL: http://www.ti.com/tool/LAUNCHXL-F28379D.

[6] TI C2000 Piccolo MCU F280049C LaunchPad development kit,
URL: http://www.ti.com/tool/LAUNCHXL-F280049C.

[7] TI C2000 F28379D controlCARD development kit,
URL: https://www.ti.com/tool/TMDSCNCD28379D.

[8] TI C2000 F28388D controlCARD evaluation module,
URL: https://www.ti.com/tool/TMDSCNCD28388D.

Revision History:

C2000 TSP 1.3.1	First release
C2000 TSP 1.4.5	Updated the web links
C2000 TSP 1.5.1	Added support for 28388D and 28379D controlCARD targets; Minimized the usage of double-precision math in the controller

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