

Motor emulation for PHIL prototyping

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This article presents a Power Hardware-in-the-Loop (PHIL) system where the behavior of a Permanent Magnet Synchronous Machine (PMSM) is emulated for the validation of a physical motor drive. The proposed setup combines an imperix B-Box 4 and power modules with third-party real-time simulators.

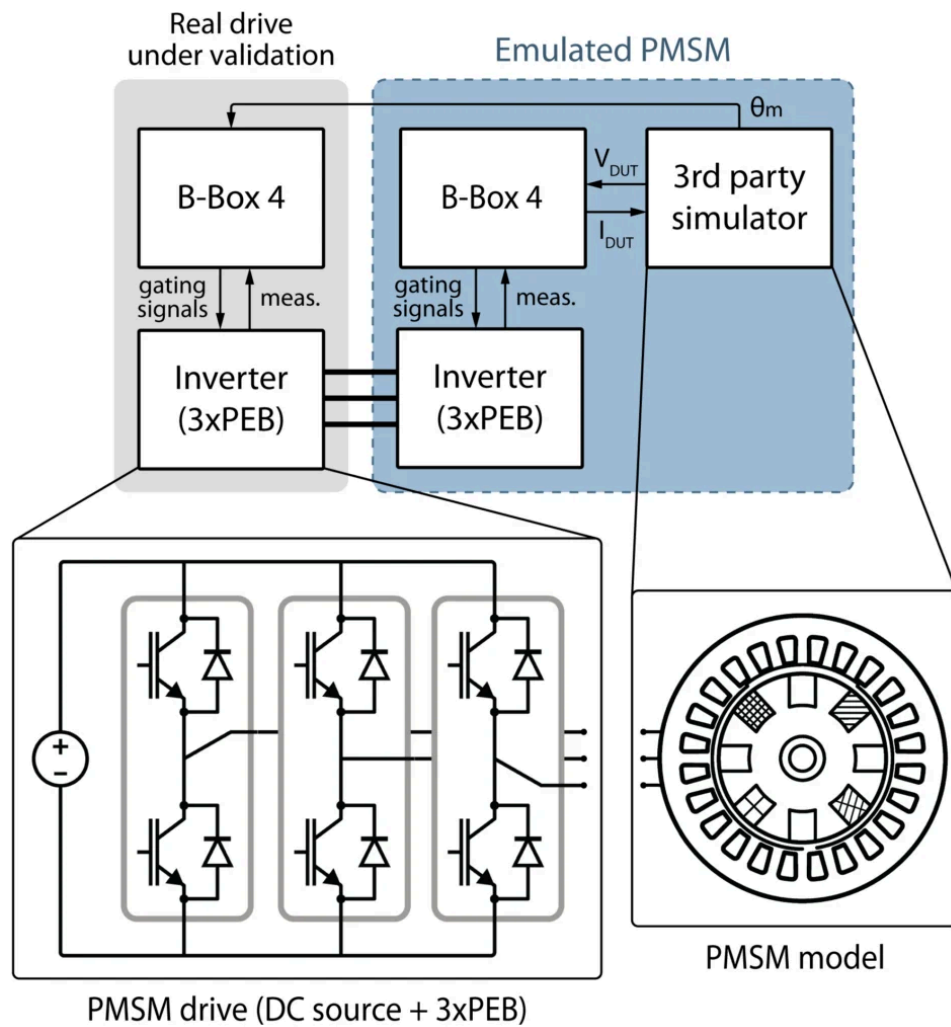
This page provides ready-to-use template projects for OPAL-RT, Plexim and Typhoon simulators, all of which leverage Aurora over the high-speed SFP communication link to exchange data between the imperix device and the simulator. More information about the implementation of the related drivers can be found in [SFP communication drivers](#).

For a more detailed overview of PHIL testing with imperix, please refer to [TN183](#). Another example illustrating the emulation of a microgrid is presented in [TN184](#).

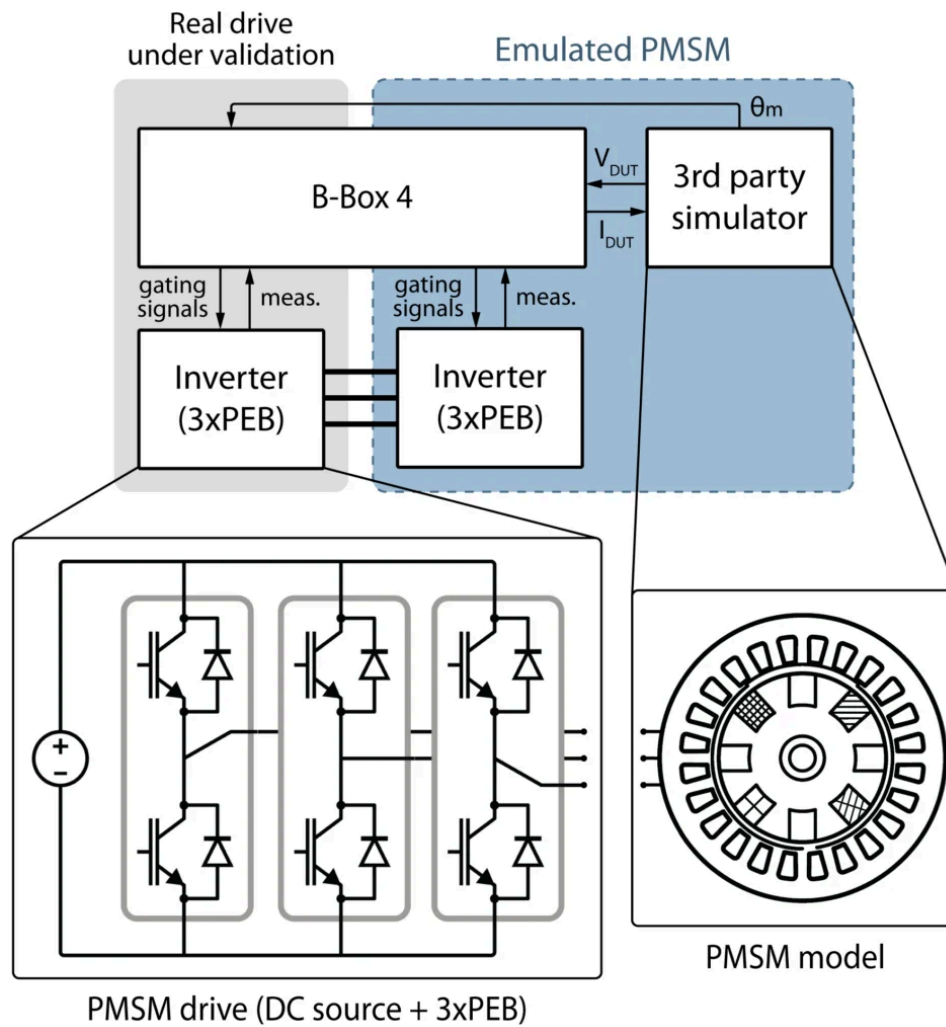
1. System description

The system architecture is illustrated below. The third-party **simulator** runs a model of a Permanent Magnet Synchronous Machine (PMSM) and its load. Conceptually, the **power amplifier** and **drive** are separate entities, each consisting of a dedicated [B-Box 4](#) and three [PEB-800-40](#) modules.

In practice, thanks to its high processing capacity and I/O count, **a single B-Box 4 is used** to execute both the power amplification and drive FOC control algorithms simultaneously, thereby minimizing required hardware.



- Conceptual system architecture, where the emulated system's power amplifier and DUT have dedicated controllers.



- Simplified system architecture, where a single B-Box 4 controls both the emulated system's power amplifier and the DUT power hardware.

2. Downloads

This example relies on three software components:

- The **power amplifier and drive control model** to be loaded onto the **B-Box 4's CPU**.
- The **vendor-specific bitstream with Aurora drivers** to be loaded onto the **B-Box 4's FPGA**.
- The **vendor-specific PMSM simulation model** to be loaded onto the **third-party simulator**.

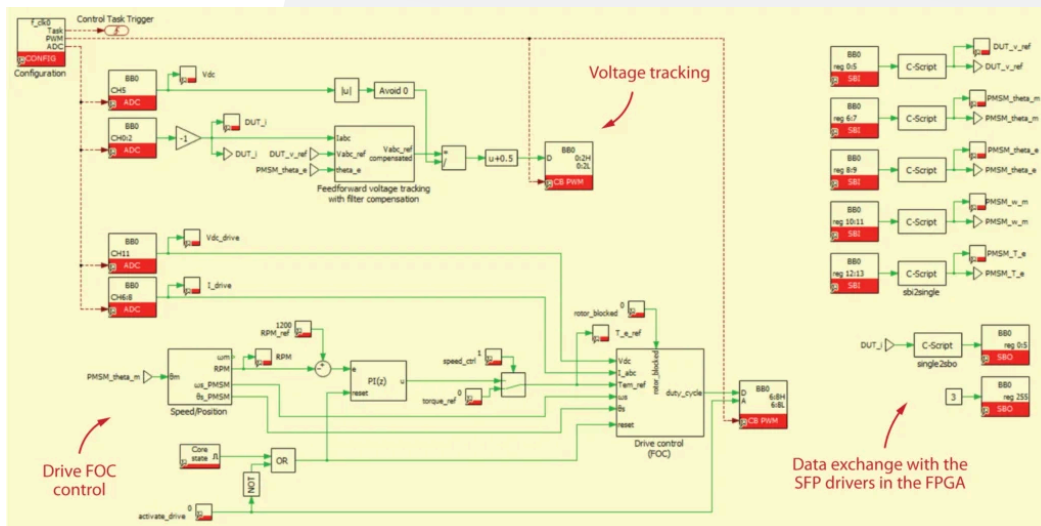
The list of supported devices is available [here](#).

2.1 Power amplifier and drive model

The B-Box 4 simultaneously runs the power amplifier control – essentially a voltage controller – and a motor drive control – here, a FOC method – for the drive under validation. The voltage tracking is a basic feedforward control with a compensation of the voltage drop on the inductors, while the FOC control is directly inspired by [TN111](#).

Both algorithms are gathered within one single PLECS model. Once built, this model must be loaded onto the B-Box 4's CPU via Cockpit.

[Download phil_pmsm_ix.zip](#)



2.2 Bitstream with Aurora drivers

In this example, the B-Box 4 and the simulator communicate over SFP, which requires Aurora drivers specifically designed for the targeted third-party simulator. A template Vivado project with appropriate drivers is provided for each vendor in the table below.

To generate the bitstream, download the bitstream generation scripts from the table below and follow the [step-by-step bitstream generation procedure](#). Once generated, load the bitstream onto the B-Box 4's FPGA via Cockpit.

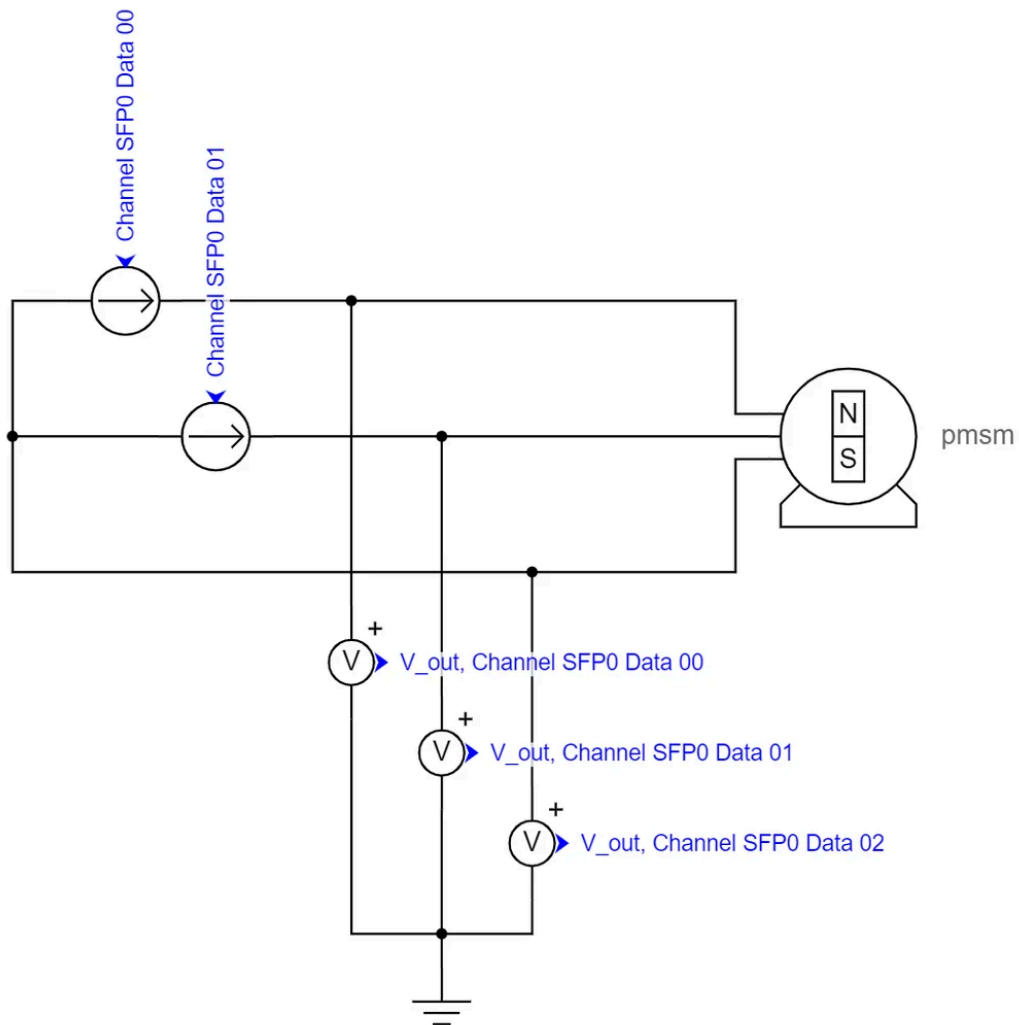
For interested readers, the related pages provide explanations about the provided drivers.

Vendor	Bitstream generation scripts	Related page
OPAL-RT	aurora_ix_opalrt_gen_scripts.zip	Aurora link with OPAL-RT via SFP
Plexim	aurora_ix_plexim_gen_scripts.zip	Aurora link with Plexim via SFP
Typhoon	aurora_ix_typhoon_gen_scripts.zip	Aurora link with Typhoon via SFP

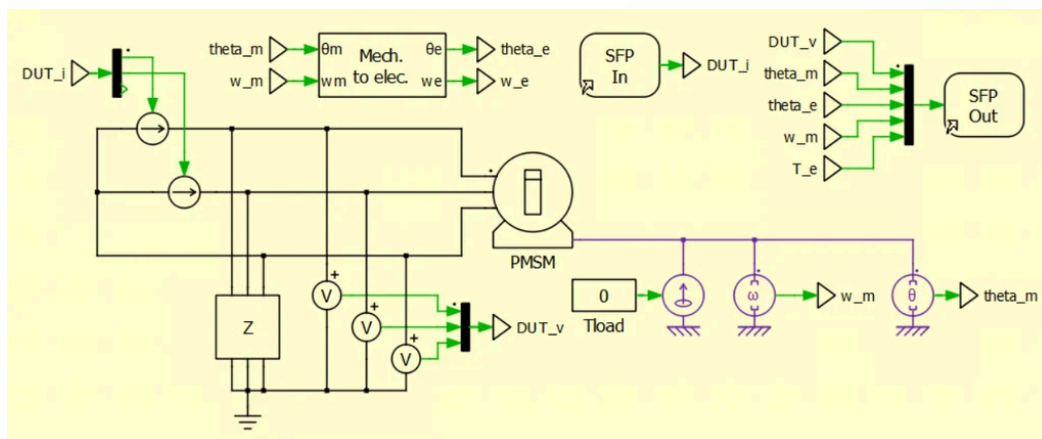
2.3 PMSM simulation files

The PMSM model has been implemented for each considered vendor. The files are available in the table below.

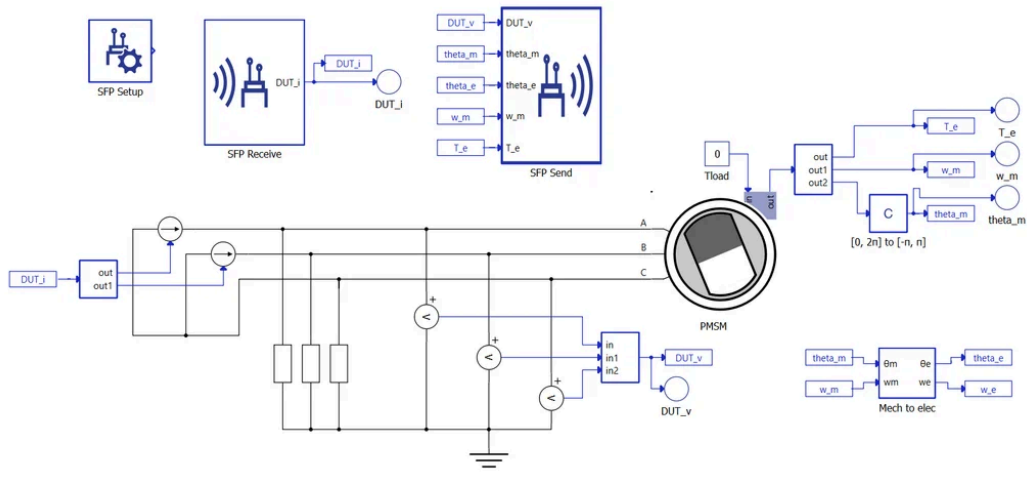
Vendor	Microgrid model
OPAL-RT	phil_pmsm_ix_opalrt_rtlab.zip
Plexim	phil_pmsm_ix_plexim_rtbox.plecs
Typhoon	phil_pmsm_ix_typhoon_files.zip



PMSM model in the
OPAL-RT Schematic Editor



PMSM model in the
Plexim PLECS environment



PMSM model in the
Typhoon Schematic Editor

3. Experimental validation

The lab setup is depicted below. As detailed in the [system description](#), it consists of an imperix B-Box 4 controlling six PEB-800-40 modules forming two three-phase inverters. The B-Box 4 is directly connected to a third-party simulator via SFP. Coupling inductors are placed between both inverters.



To avoid a common-mode loop between the power amplifier and driver inverters, both inverters are powered by separate, galvanically isolated DC power supplies.

4. Results

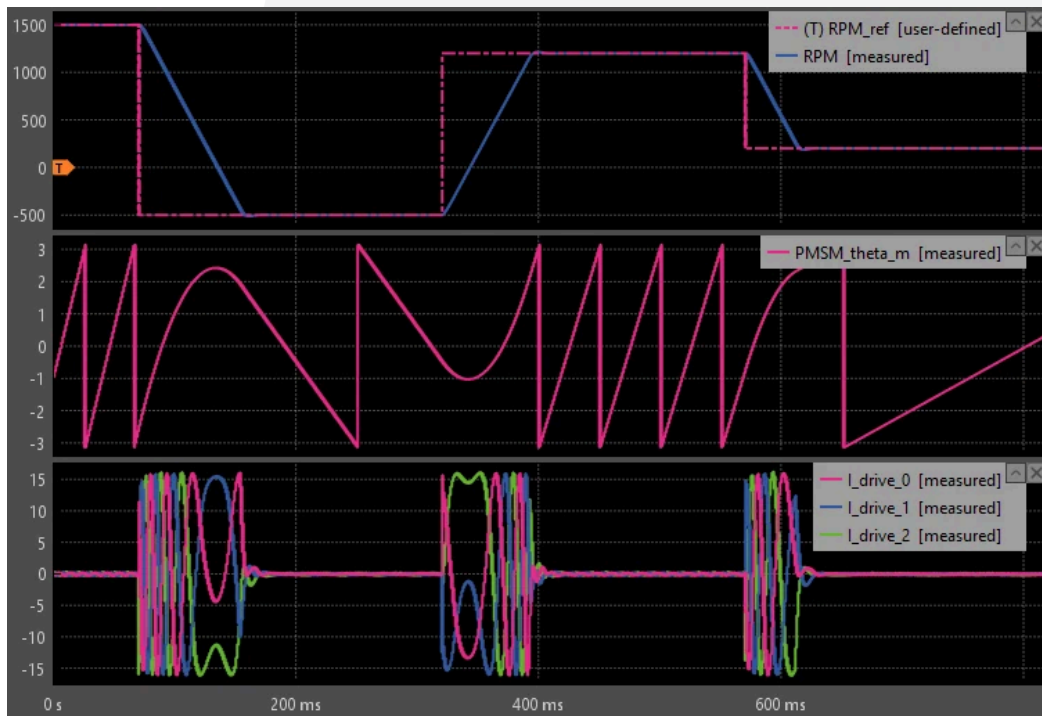
This section exposes the experimental results collected during laboratory validation. While these measurements were acquired using an RT-Box 1, equivalent results were obtained with an OPAL-RT OP4510 and a Typhoon HIL506. The presented figures highlight the drive control perspective.

Thanks to the high-speed SFP communication between the TPI and the simulator, additional simulation variables – such as the PMSM electromechanical torque (PMSM_Tem) – can be transmitted and monitored directly from Cockpit.

4.1 Speed profile

In the following figure, a reference speed profile is fed to the drive controller. As shown, the speed profile is well followed. The angle variation is consistent with the speed profile, particularly during speed reversals.

The maximum acceleration of the PMSM is bounded by the maximum torque specified in the drive FOC control to limit the current flowing in the inverter branches.

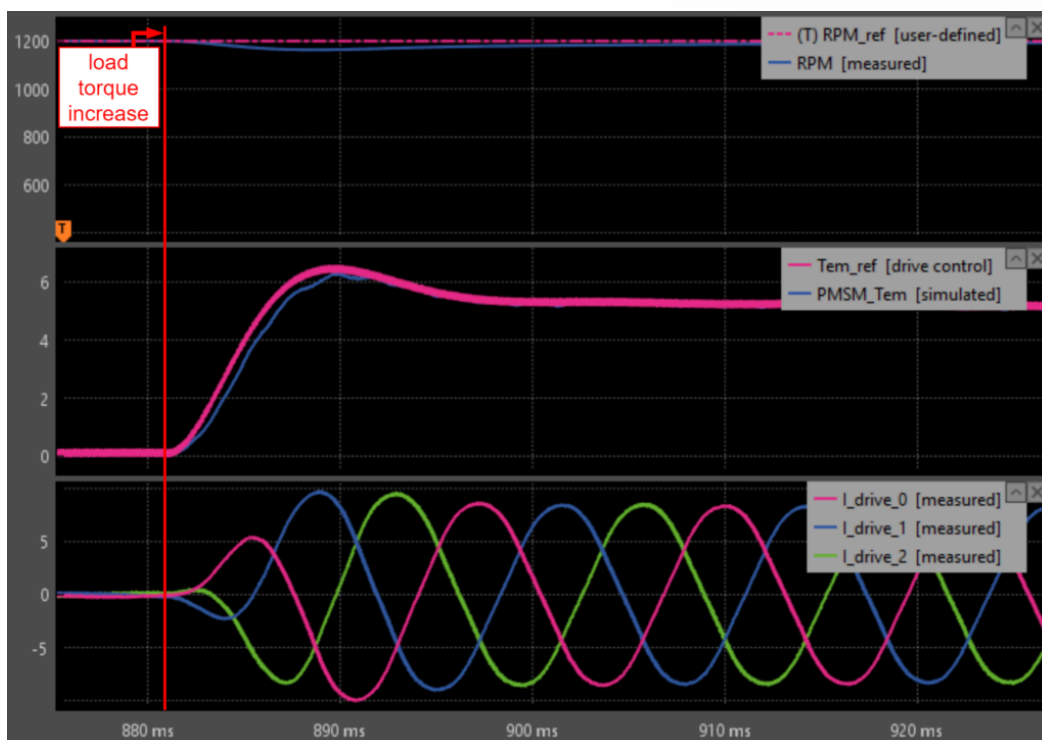


Experimental results obtained when feeding a speed profile to the drive controller ([Cockpit](#) software)

4.2 Load torque step

In the figure below, a load torque step from 0 to 5 Nm is applied in the simulation model during runtime.

As expected, this change leads to a slight decrease of the motor's speed, pushing the drive control to increase its internal electromagnetic torque reference (T_{em_ref}) and output currents (I_{drive}). This increase of currents amplitude is captured by the simulation, as verified by the PMSM_ T_{em} variable – extracted from the simulation model – that closely follows the T_{em_ref} variable from the drive control.



Experimental results obtained when applying a load torque step in the simulation during runtime ([Cockpit](#) software)

The presented results confirm that, from the drive's perspective, the emulated system behaves in the same way as a real motor.