MATLAB EXPO 2021

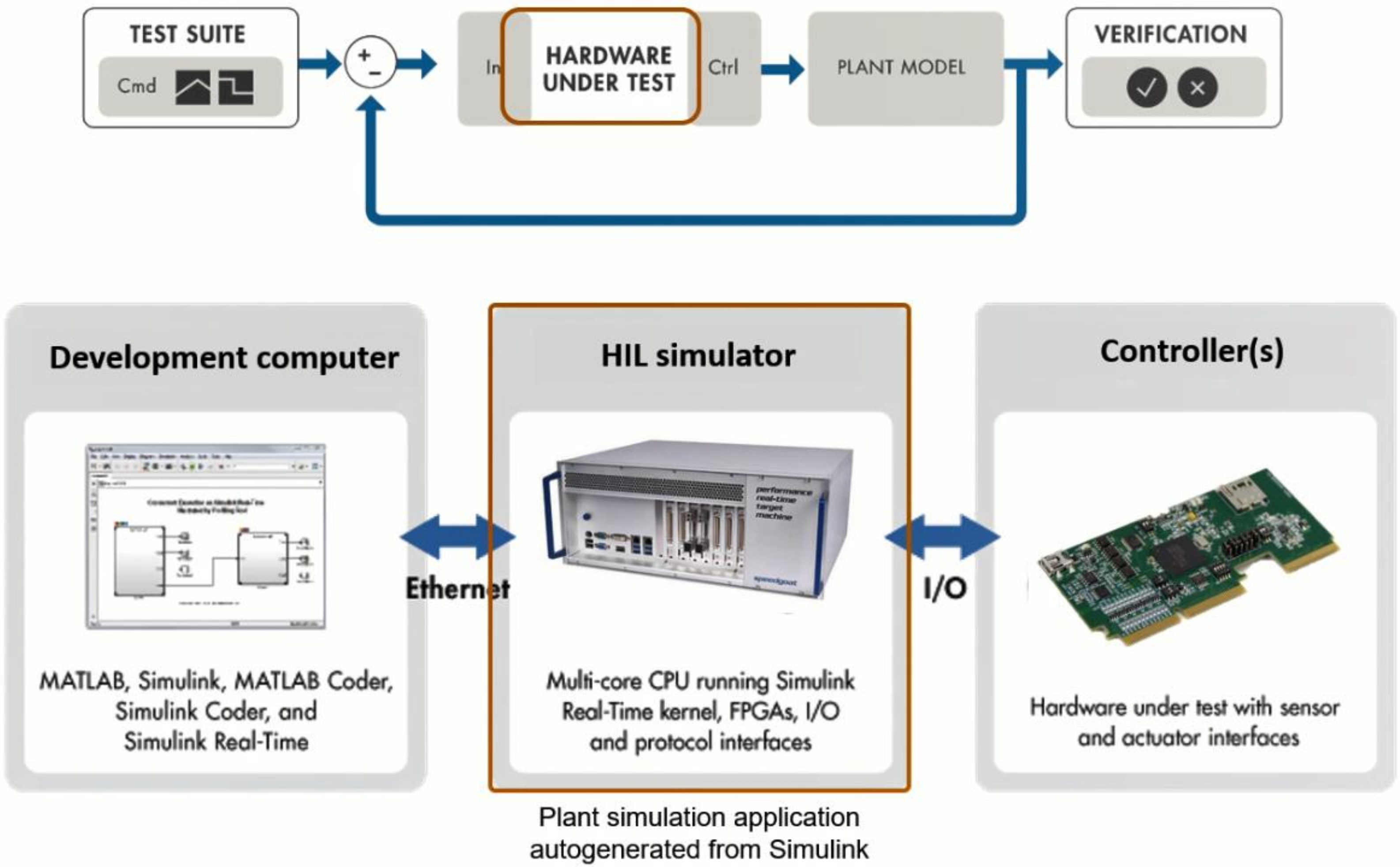
Hardware-in-the-Loop Testing of Control Algorithms for Modular Multi-Level Converters

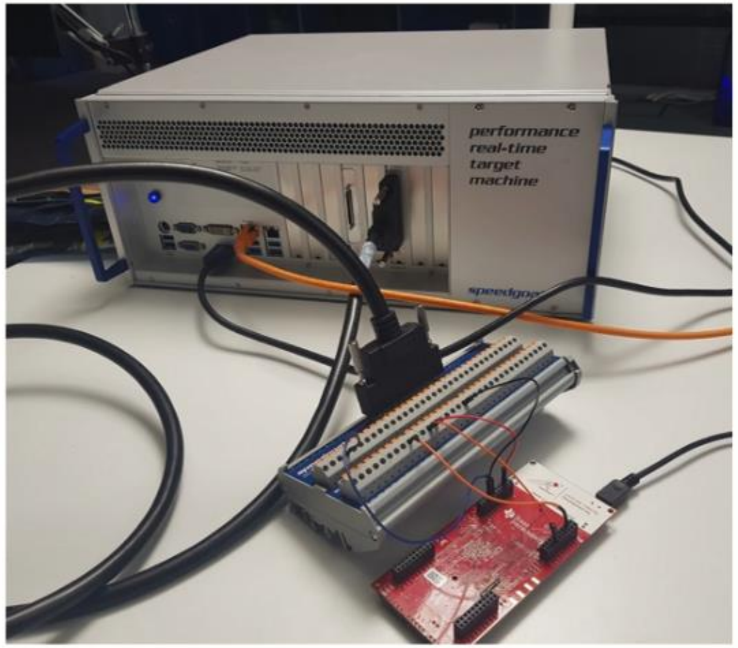
Mohsen Aleenejad and Manuel Fedou

MathWorks

speedgoat
real-time simulation and testing

Where Our Journey Today Will Take Us





Key Takeaways

- MathWorks tools support all stages of technology readiness.
- Complex power converter architectures can be built automatically in Simulink.
- Complex power converter architectures and their control systems can be effectively simulated using both desktop and real-time simulation.
- Variable-step solvers provide accurate PWM timing on desktop and online simulation.
- Functional correctness of control configurations can be rapidly assessed, and hardware implementation can be de-risked using automatic code generation and HIL testing.

About Speedgoat

- A MathWorks associate company, incorporated in 2006 by former MathWorks employees. Headquarters in Switzerland, with subsidiaries in the USA and Germany

- Provider of real-time target computers, expressly designed for use with Simulink

- Real-time core team of around 200 people within MathWorks and Speedgoat. Closely working with the entire MathWorks organization employing around 5,000 people worldwide

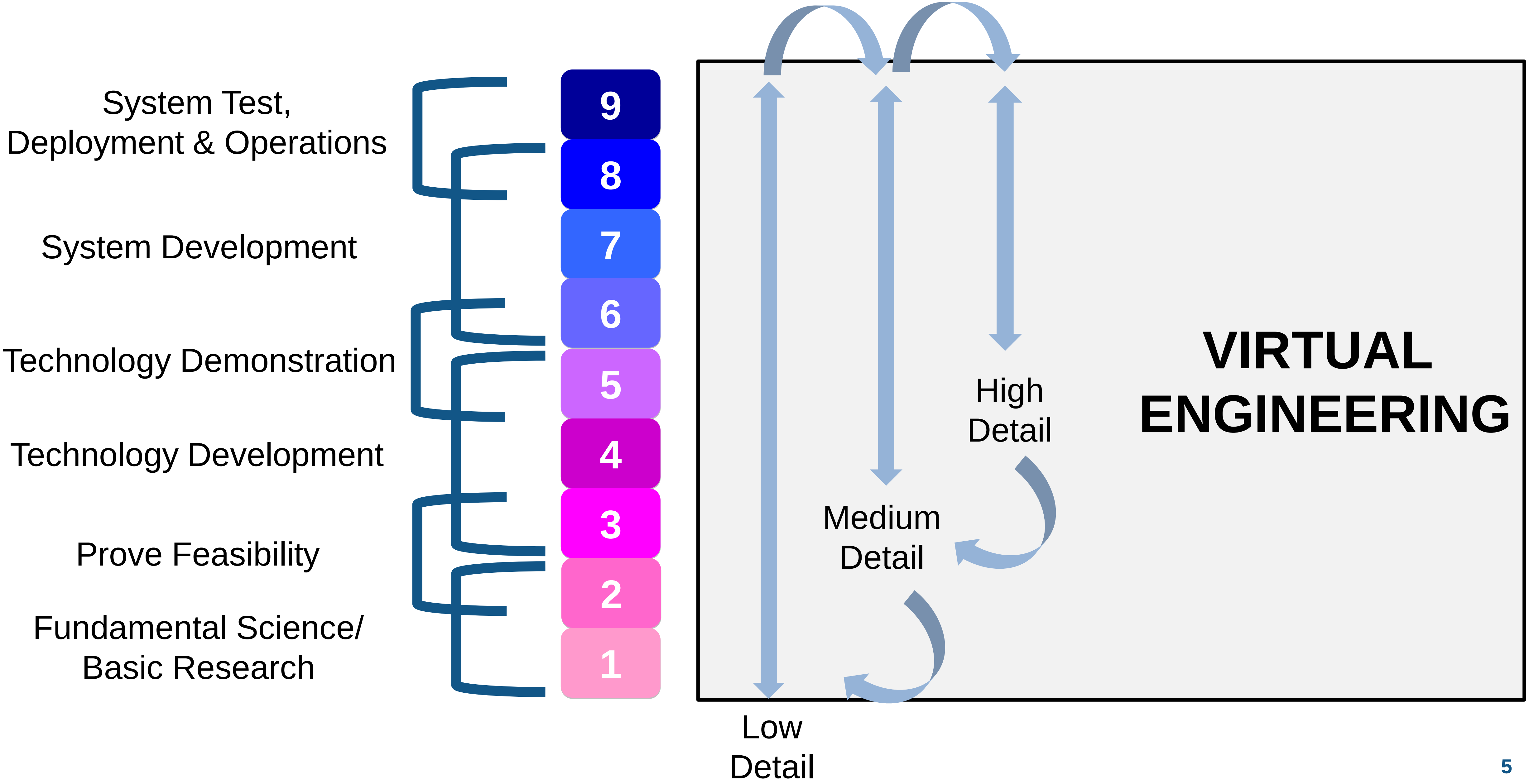
Problem Statement

- There is a persistent need to reduce harmonics and improve fault tolerance of power converters.

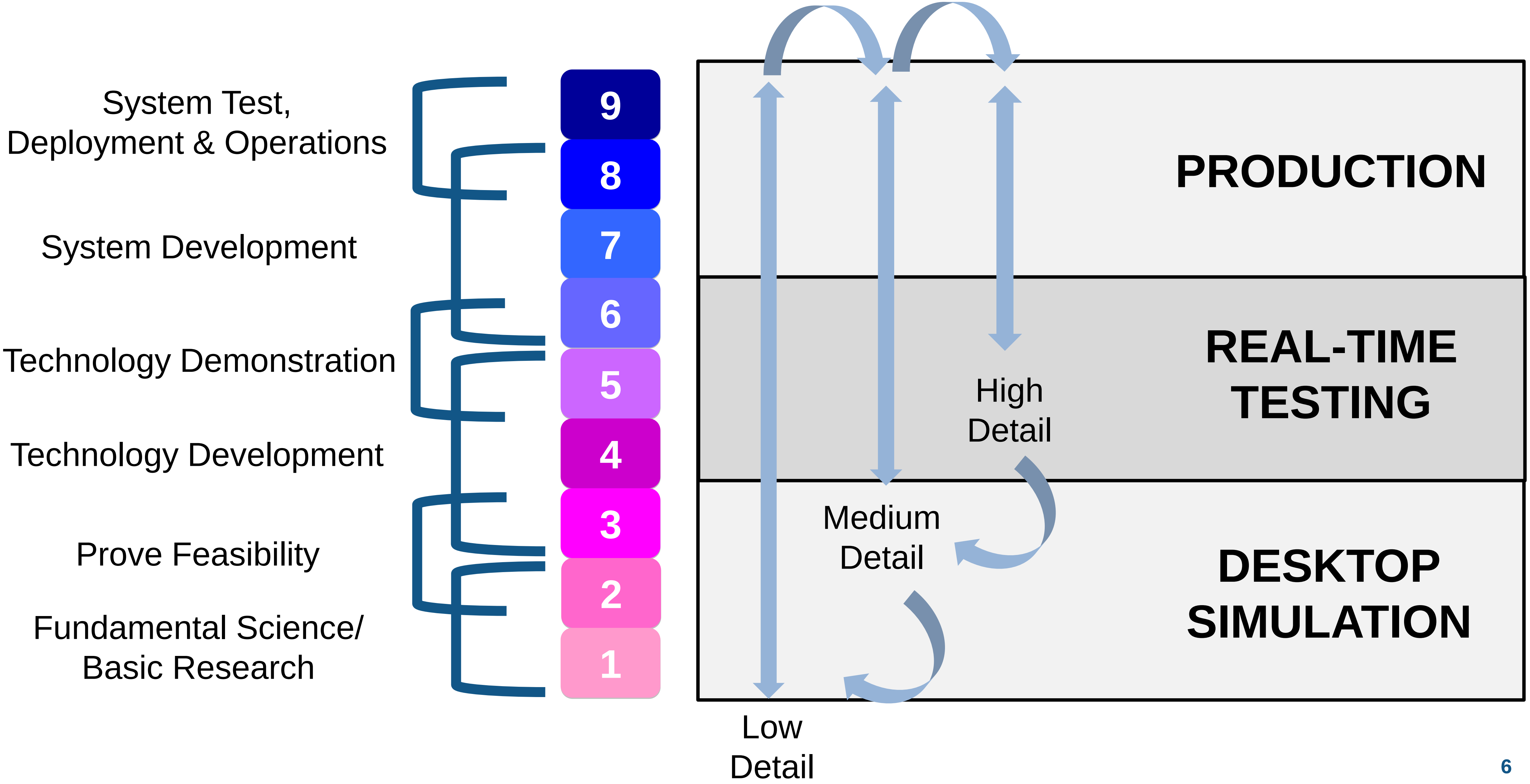
- Harmonics can be reduced by increasing switching frequency and/or increasing the number of power electronic devices. Fault tolerance is improved by increasing the number of devices.

- It can be challenging to evaluate a broad range of configurations and move models seamlessly from desktop to real-time systems at early stages of technology development.

Model Fidelity and Technology Readiness



Model-Based Design and Technology Readiness



Alstom Grid Develops High-Voltage Direct Current Transmission Control System Using Model-Based Design

Challenge

Accelerate control system development for high-voltage direct current voltage source converters

Solution

Use Model-Based Design to model, simulate, verify, and generate code and documentation for the control and protection systems

Results

- Quantifiable process improvements
- Rapid integration with power system simulation software
- Protection systems implemented in one week

Alstom Grid's HVDC demonstrator system with power converter modules. The improved controllability of the VSC in this system makes it well-suited for smart grid applications.

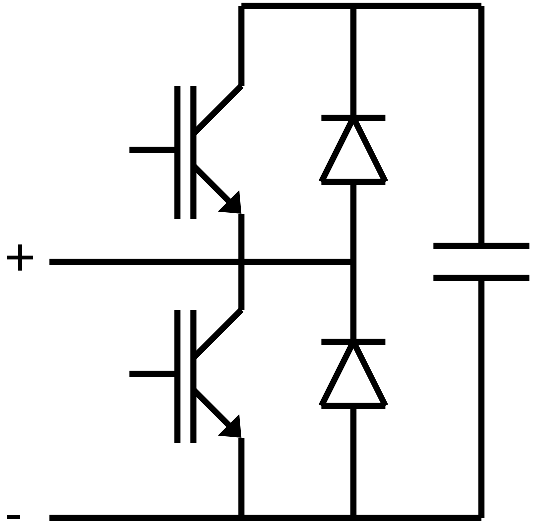
"Using Model-Based Design we developed a complex control system in significantly less time than our traditional process would have required. We eliminated months of hand-coding by generating code from our models, and we used simulations to enable early design verification."

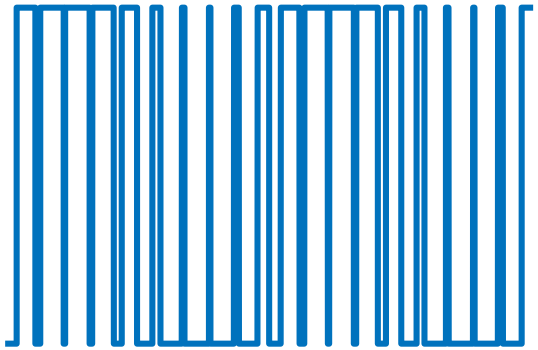
- Anthony Totterdell, Alstom Grid

[Link to user story]

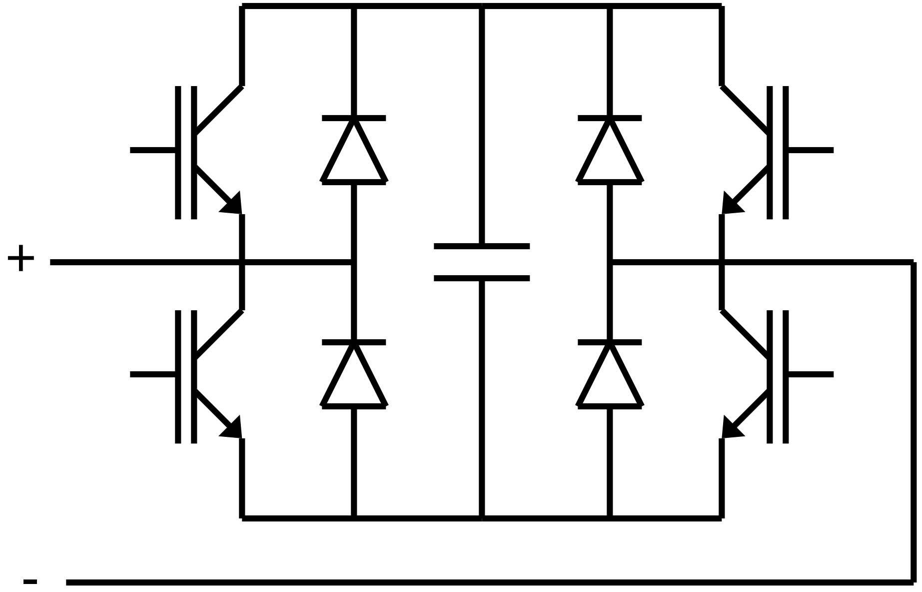
Converter Submodules (SM)

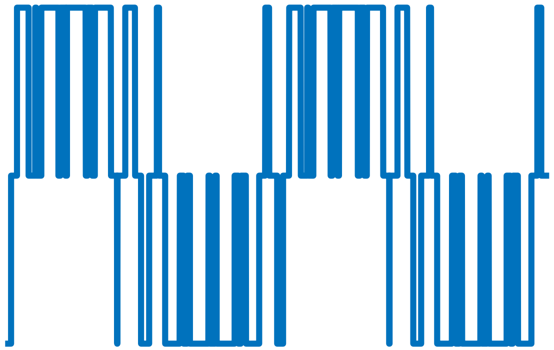
Half-Bridge



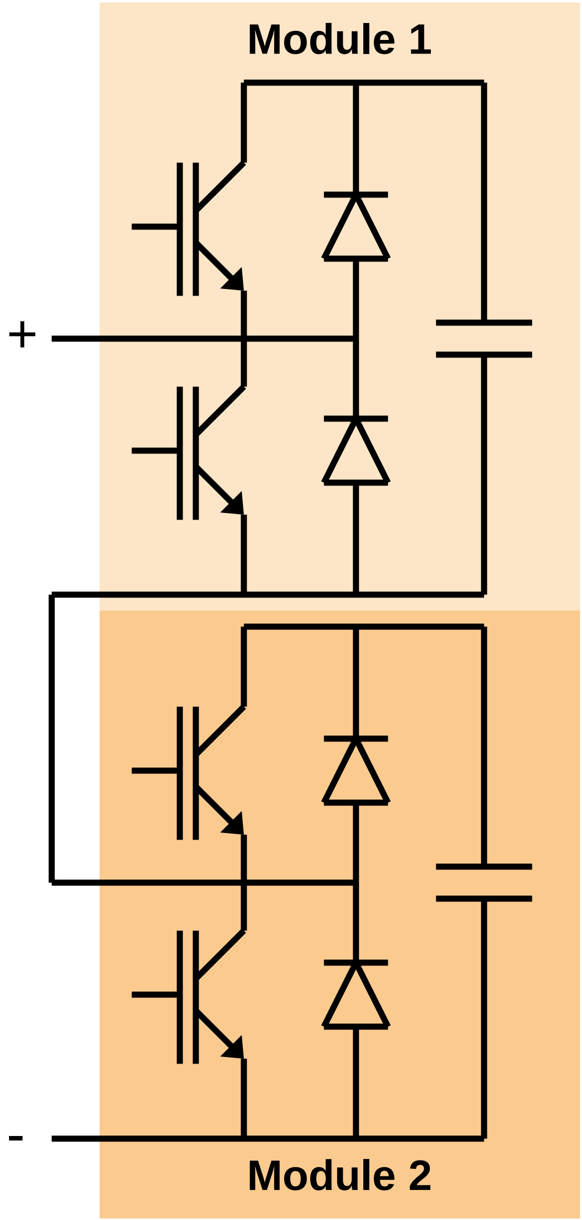


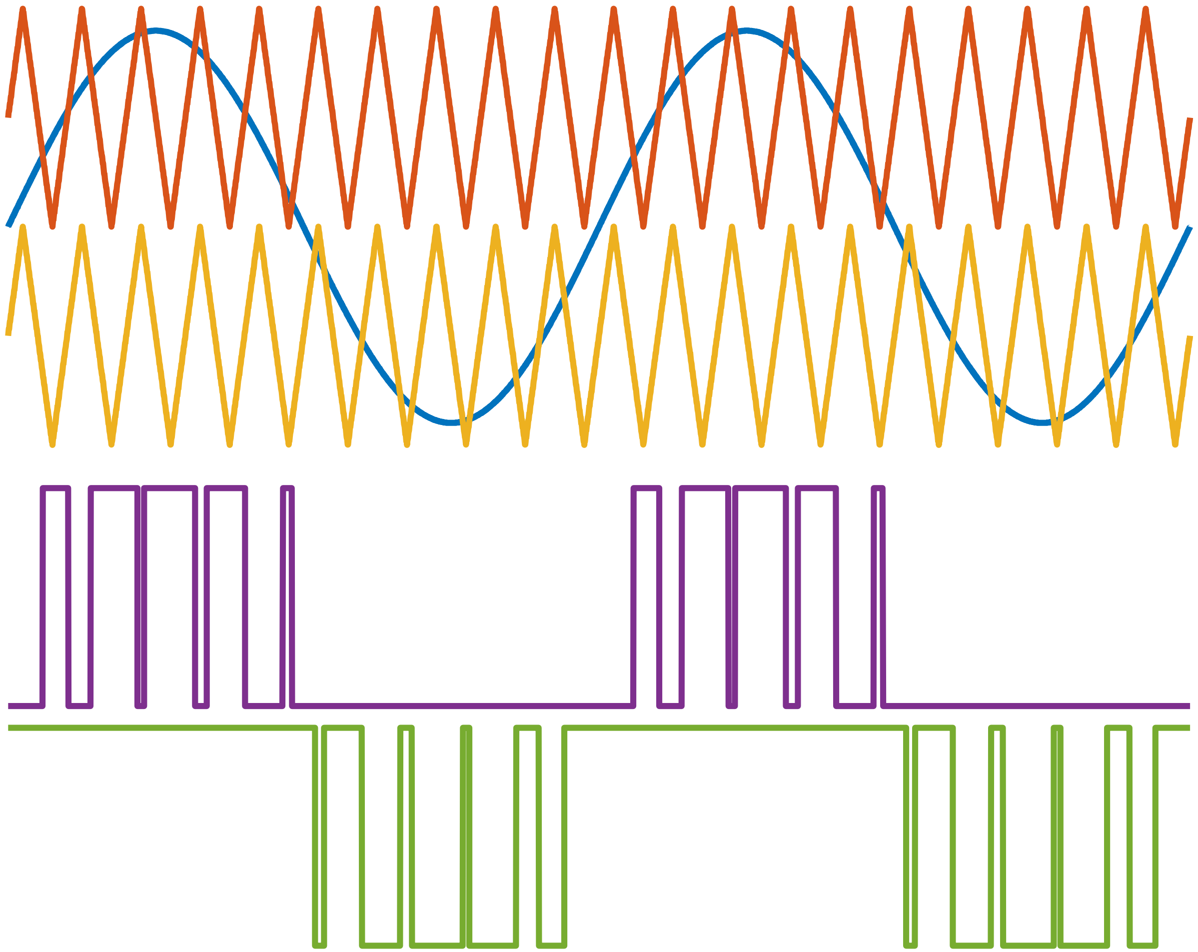
Full-Bridge





Modular Topology

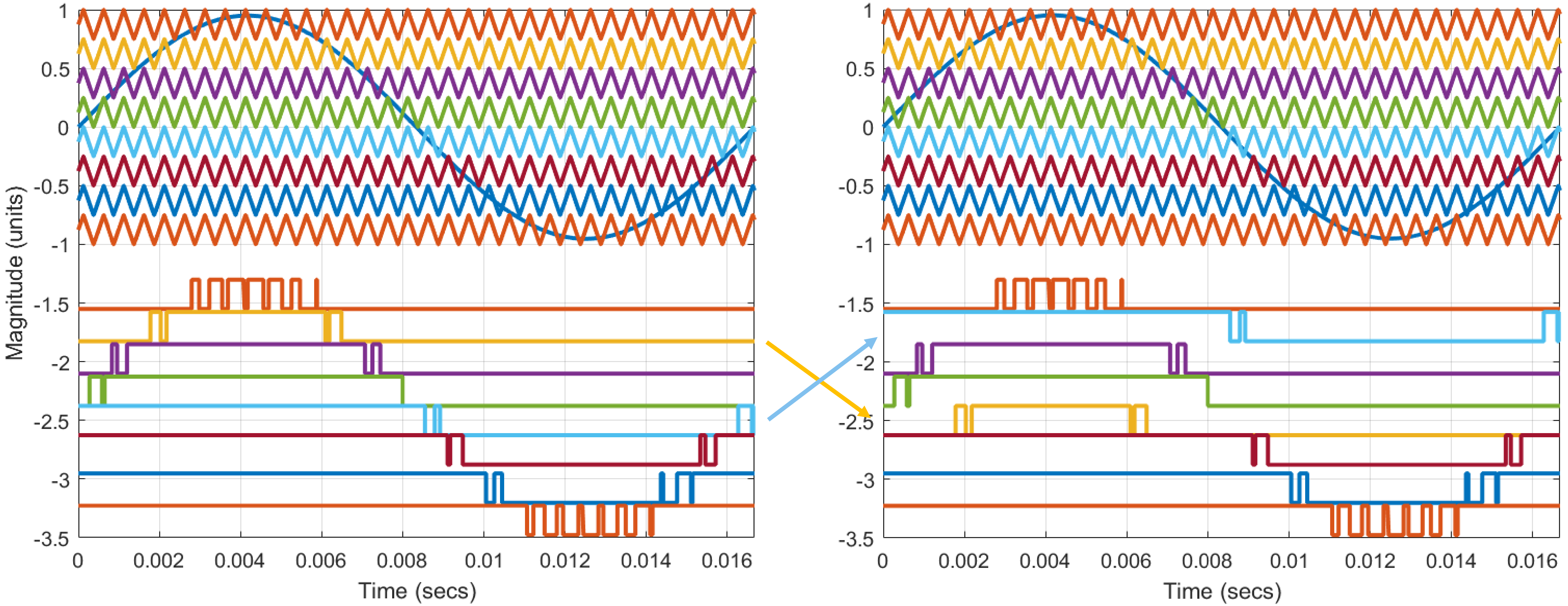




Sorting and Signal Disposition

For the entire fundamental cycle assume:

Vc1 < Vc5 < Vc3 < Vc4 < Vc2 < Vc6 < Vc7 < Vc8



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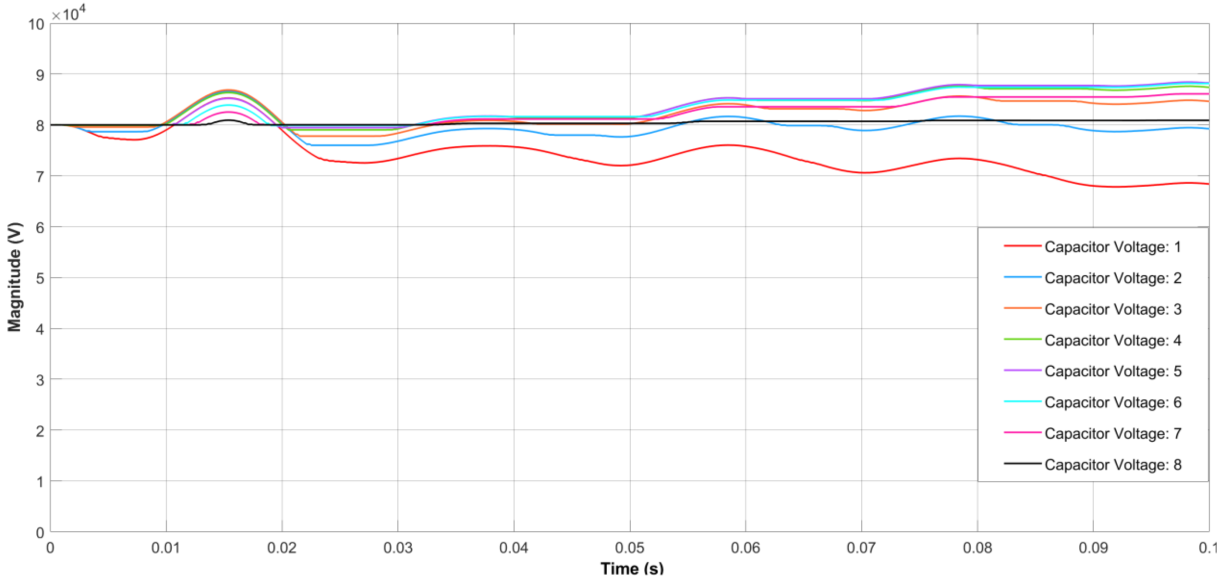
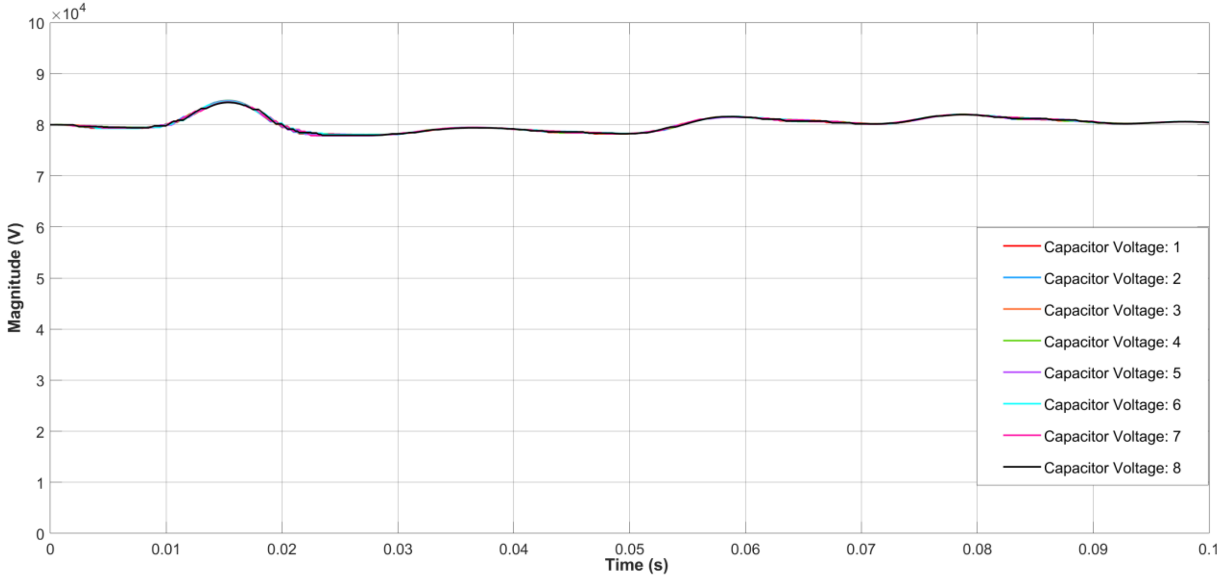
Sorting and Signal Disposition

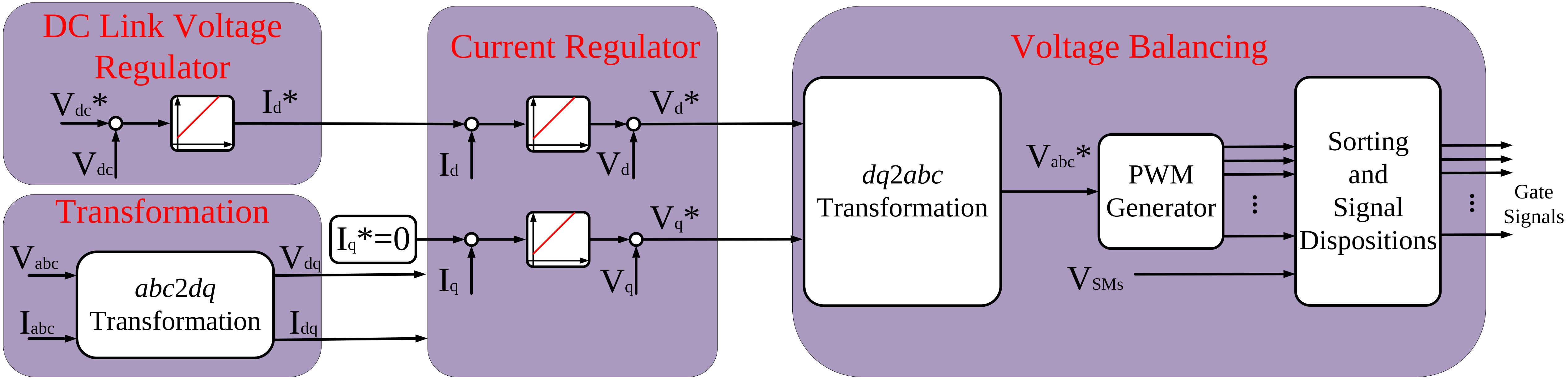
Capacitor Voltages for one arm of the converter before sorting algorithm



Capacitor Voltages for one arm of the converter after sorting algorithm

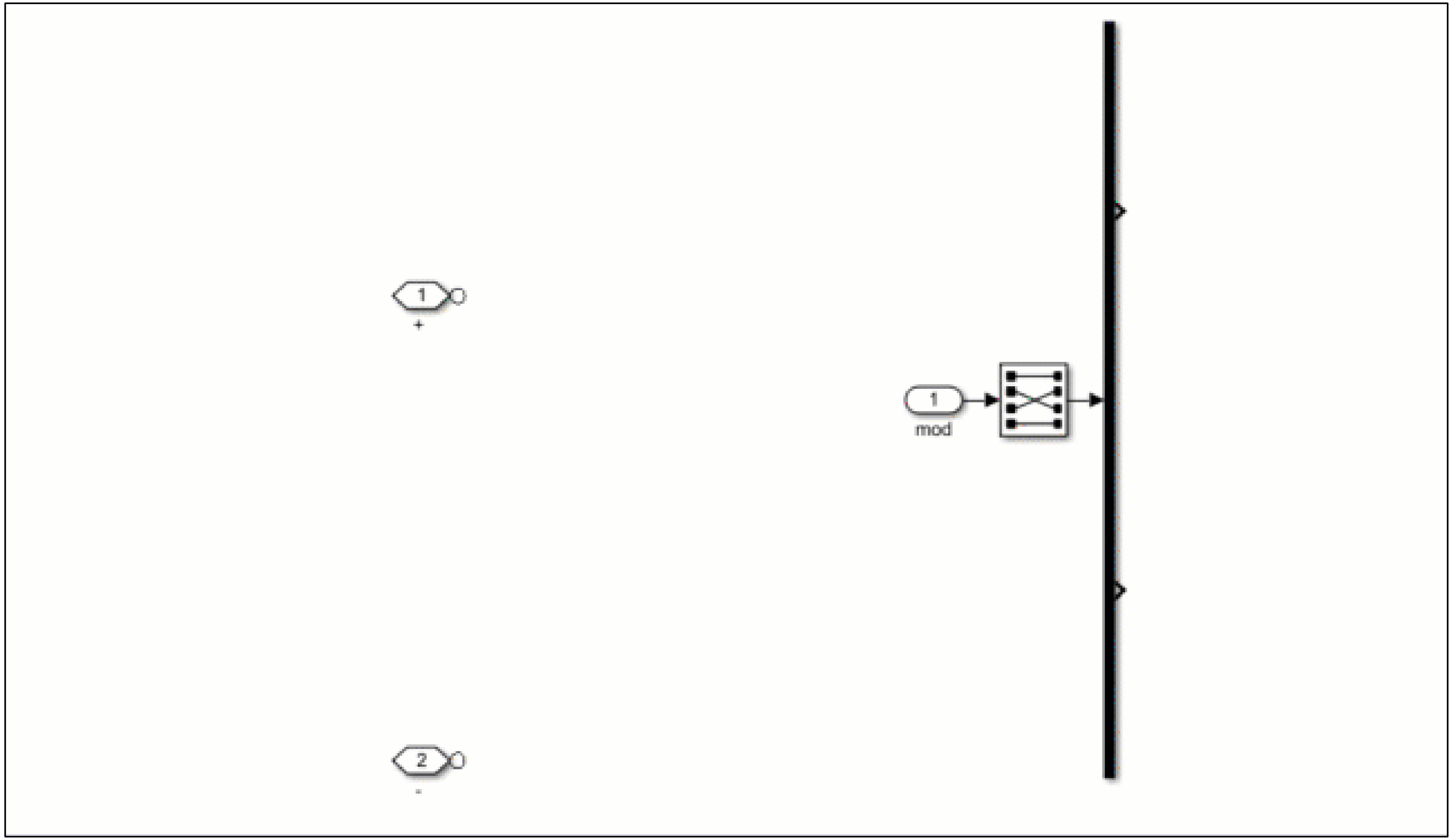


Control Algorithm

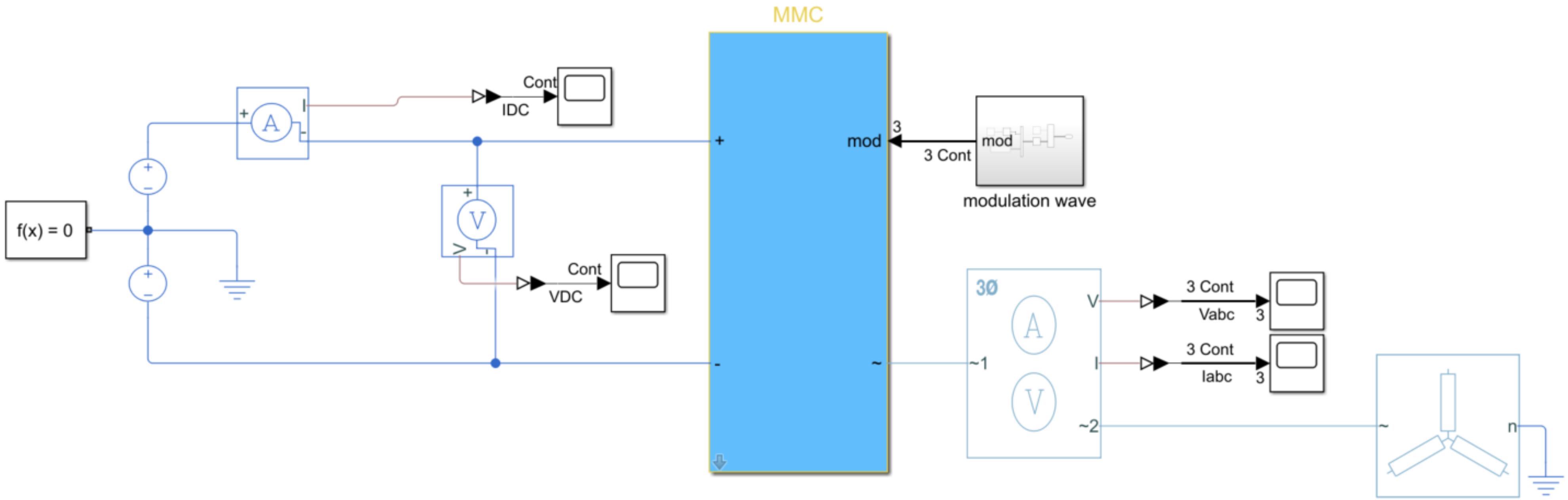


Build MMCs Programmatically

- With MATLAB, we can use the Simulink API to build programmatically more complex power converter architectures.

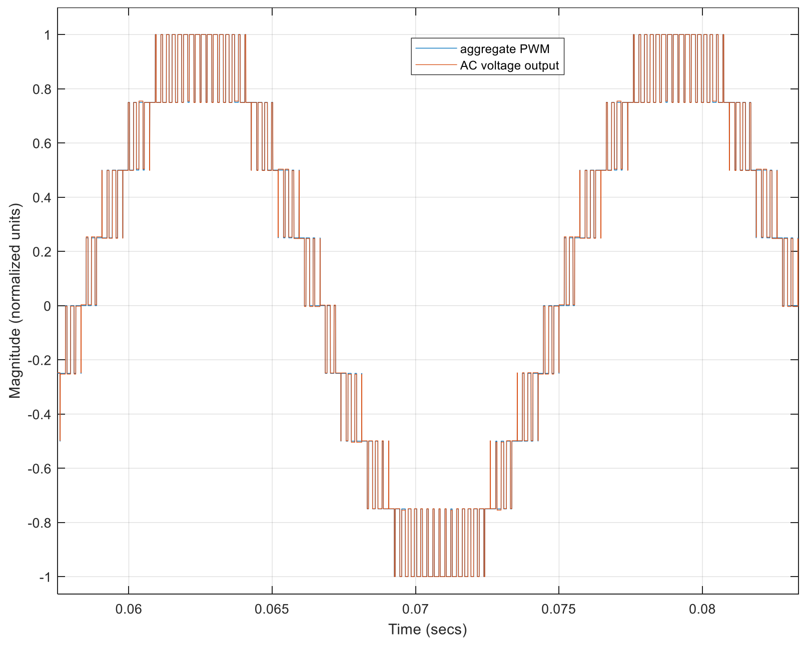


Desktop Simulation and Simulink Online

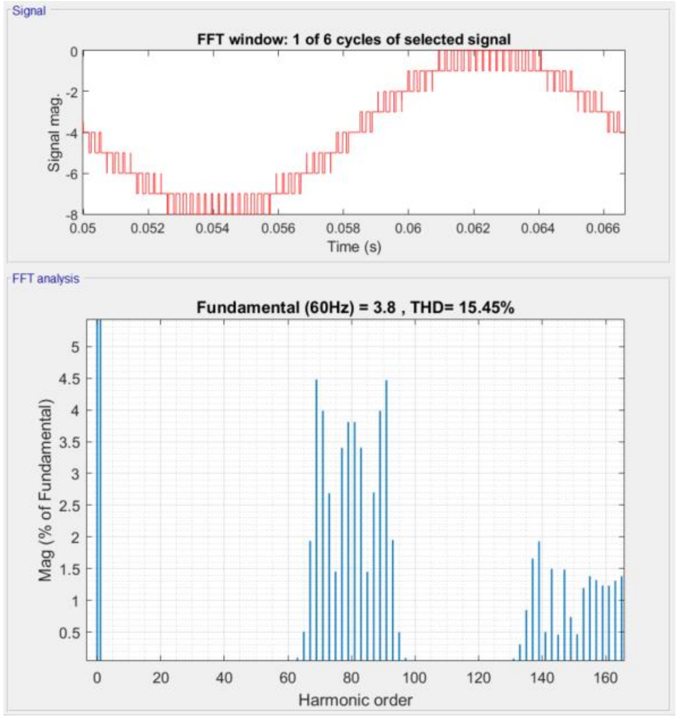


Desktop Simulation and Simulink Online

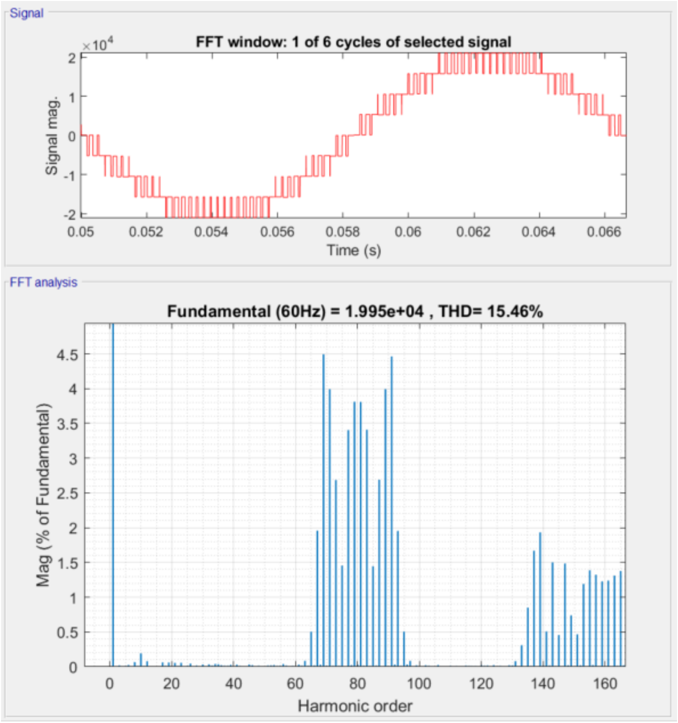
- After running a simulation, we compare the ‘aggregate’ PWM signal and the AC voltage output. A visual comparison is a good step, but a more rigorous evaluation is to compare the harmonics of the signals. With a stylized test-harness, we expect to see ‘clean’ waveforms and ‘clean’ harmonic profiles.



(a) Aggregate PWM and AC voltage output overlaid



(b) Harmonic analysis of aggregate PWM



(c) Harmonic analysis of AC voltage output

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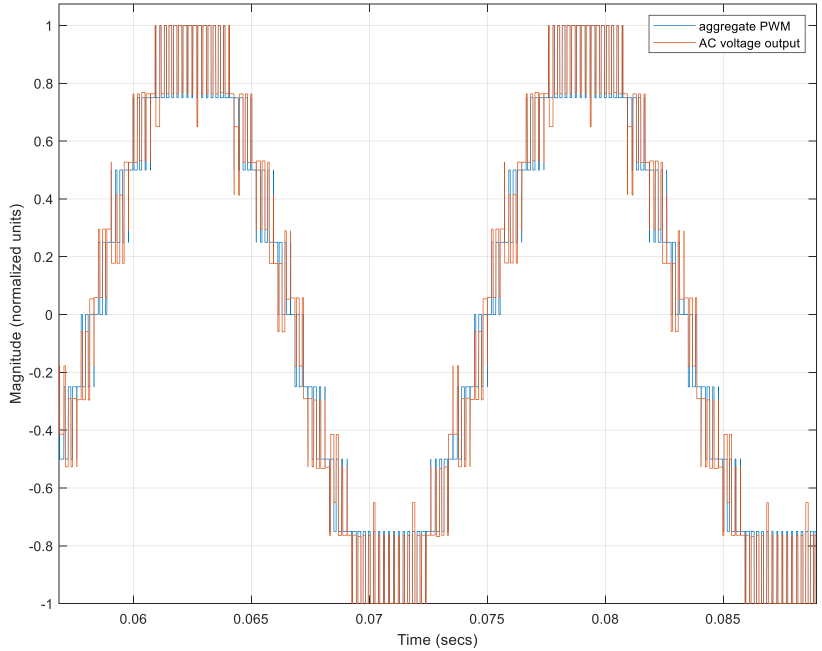

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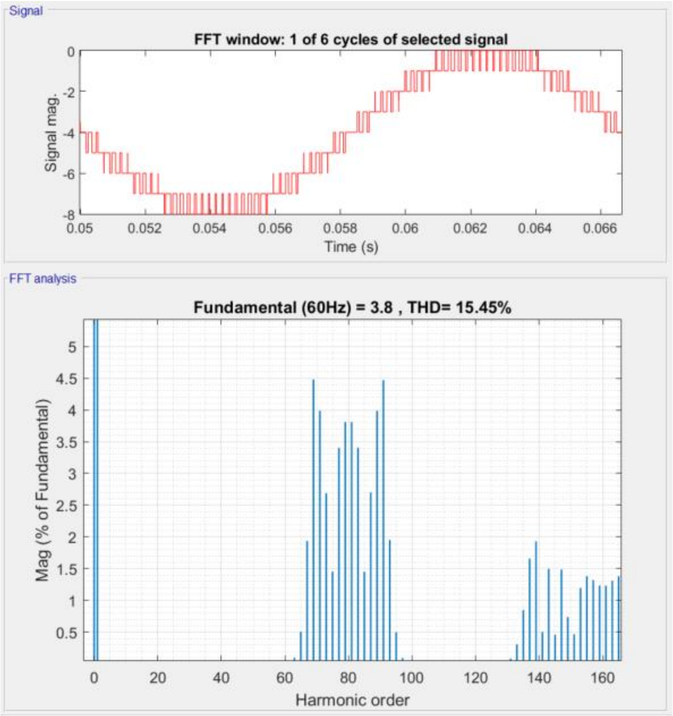

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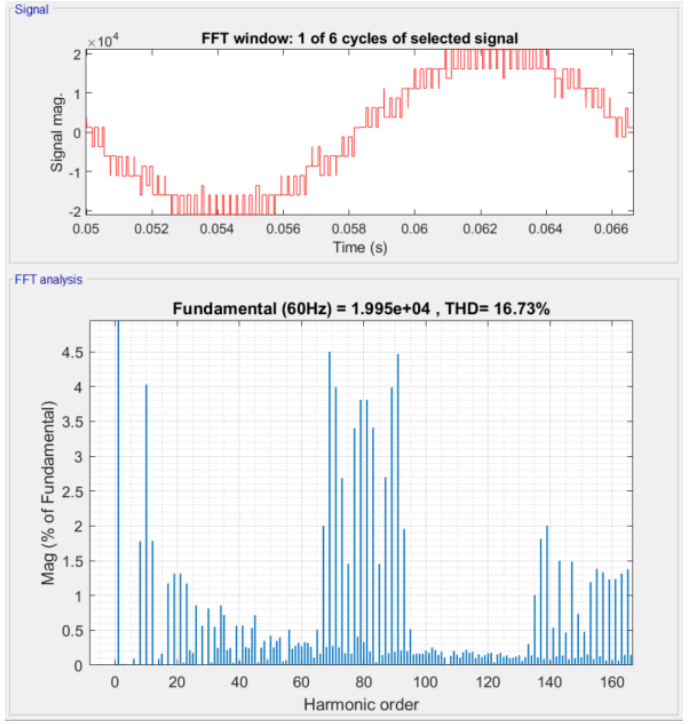

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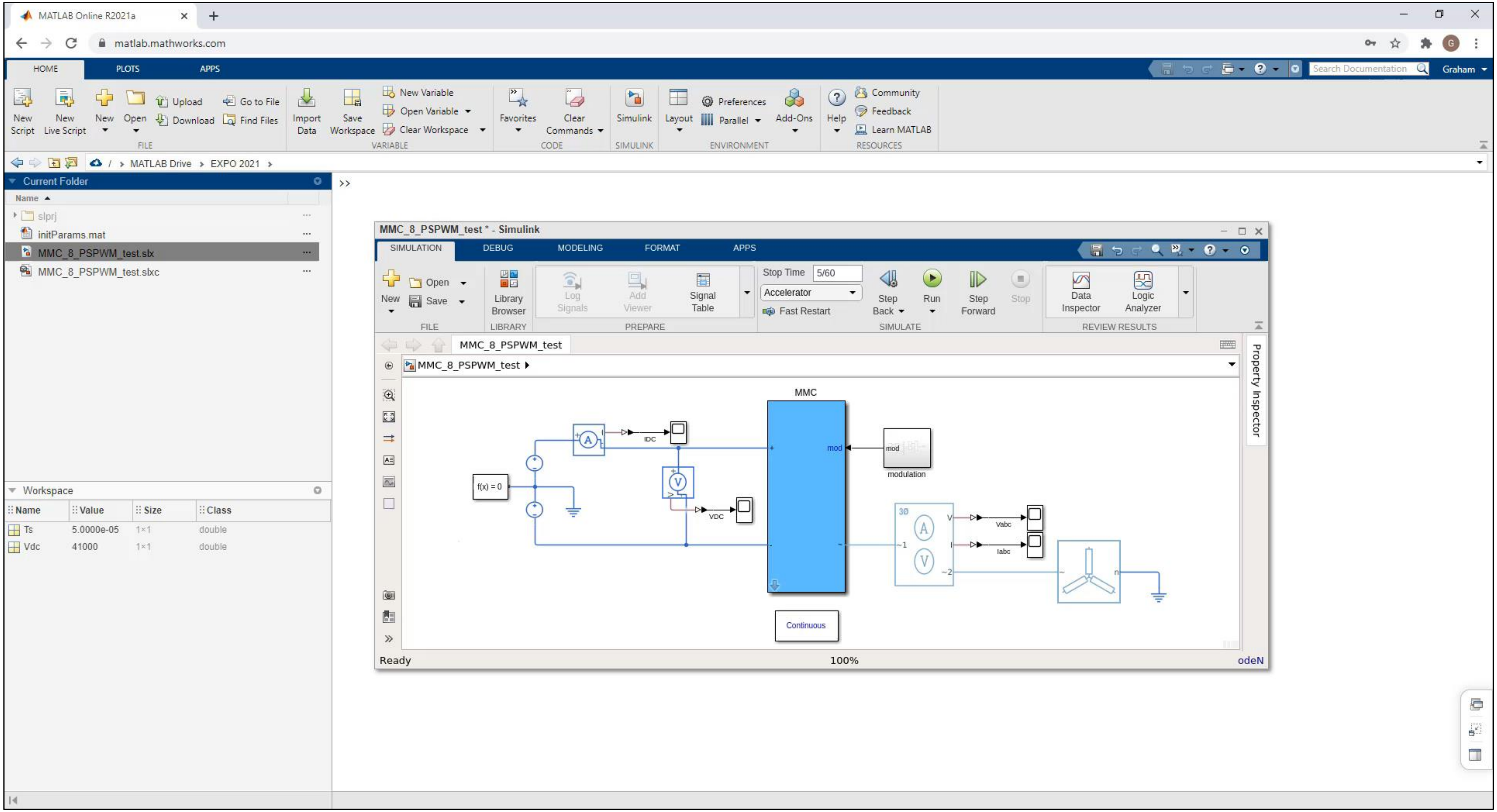
Desktop Simulation and Simulink Online

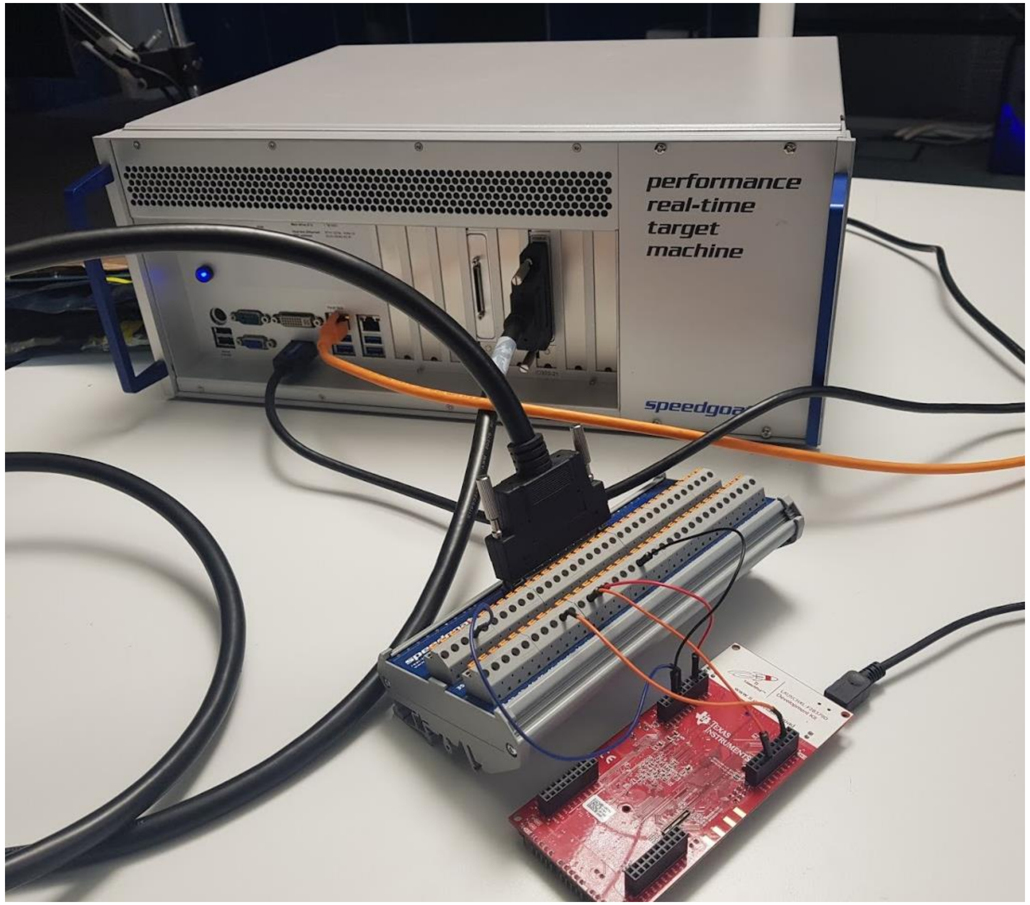


Real-Time Testing with Simulink Real-Time and Speedgoat

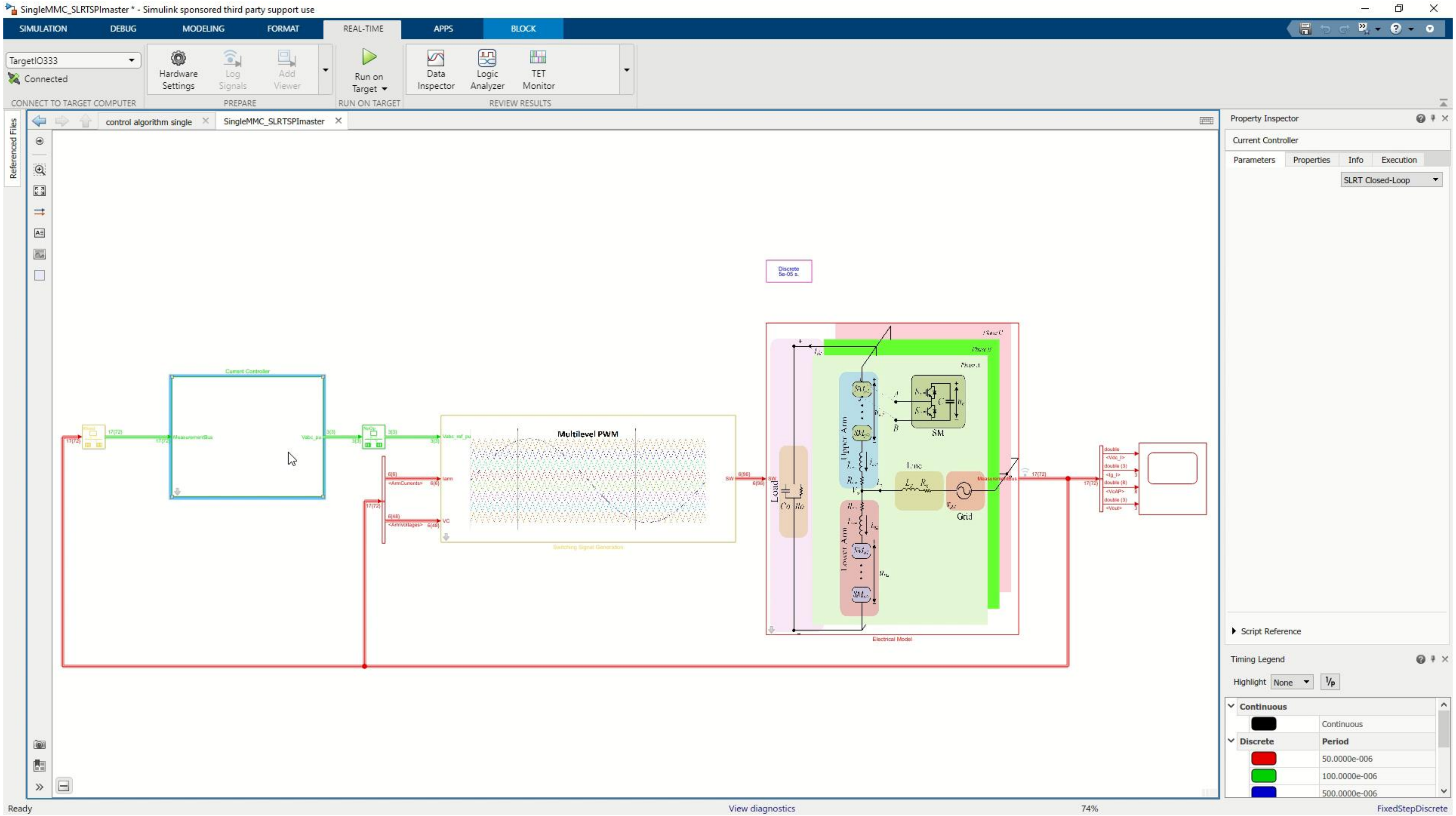
- Prepare the model to run on Speedgoat hardware and run model in real-time at 50us sample rate

- Deploy the controls to a microcontroller and perform PIL testing

- Prepare the Simulink model for HIL, run HIL and compare results



Configure and run model in real-time on Speedgoat



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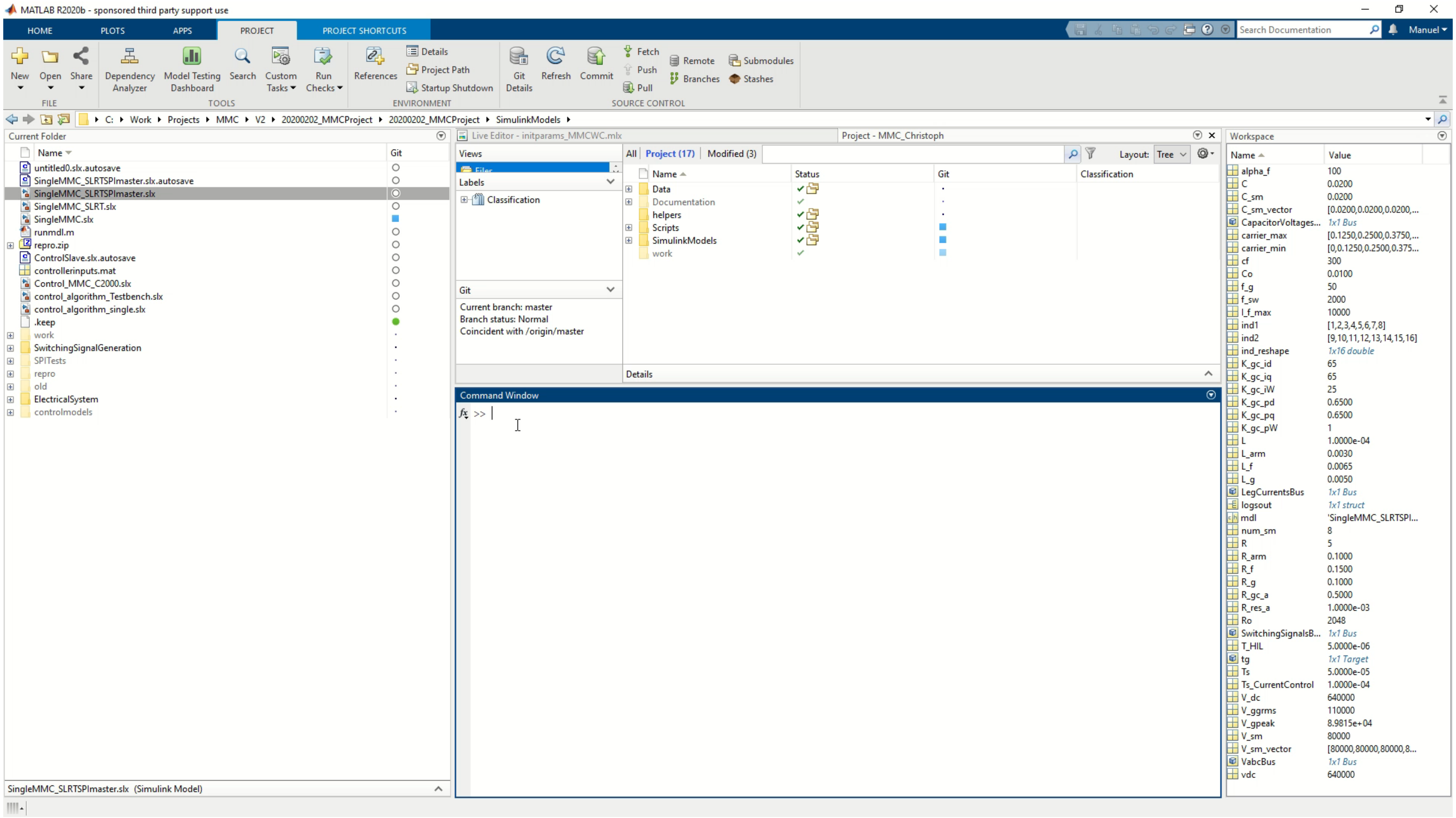

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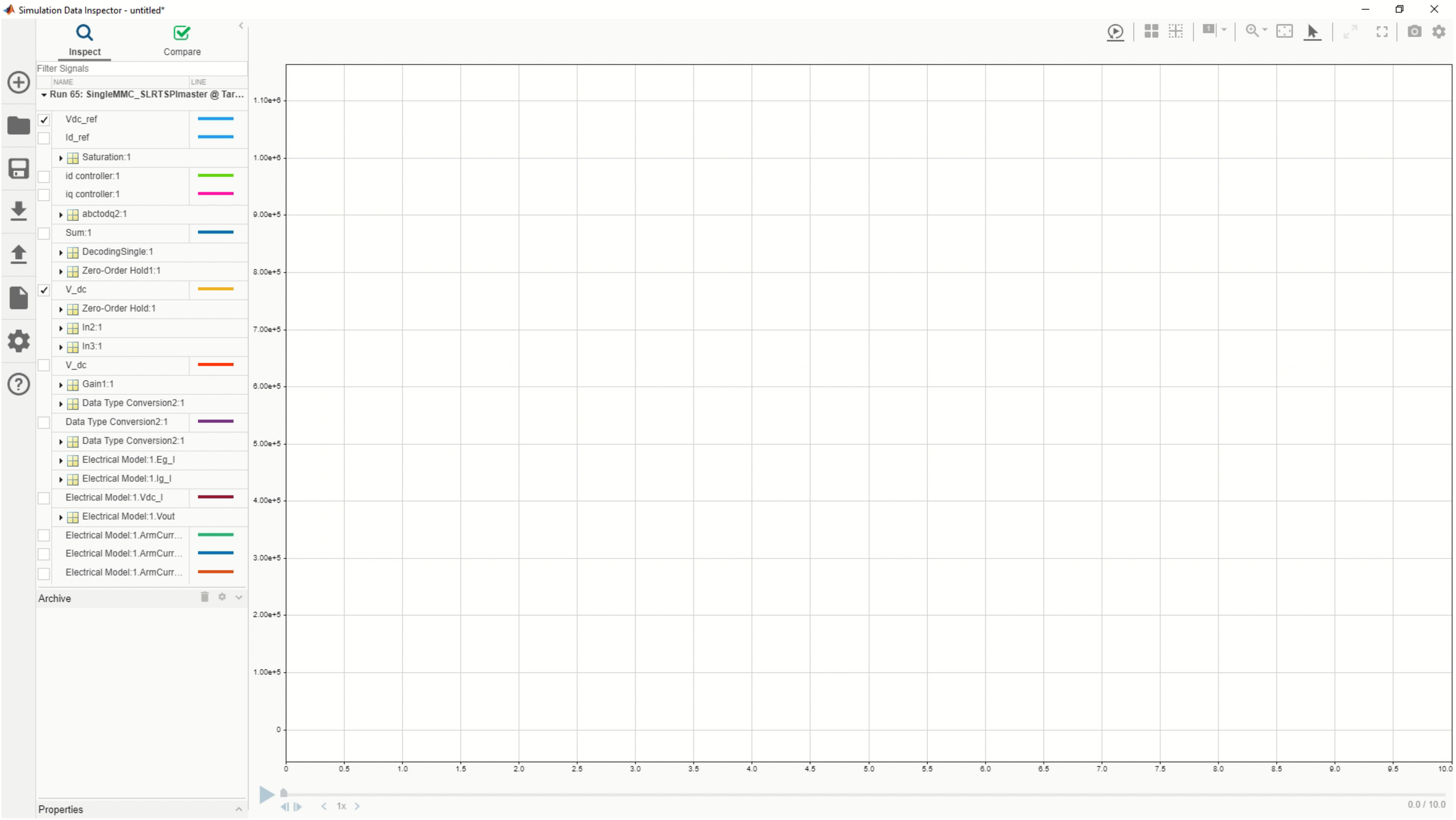
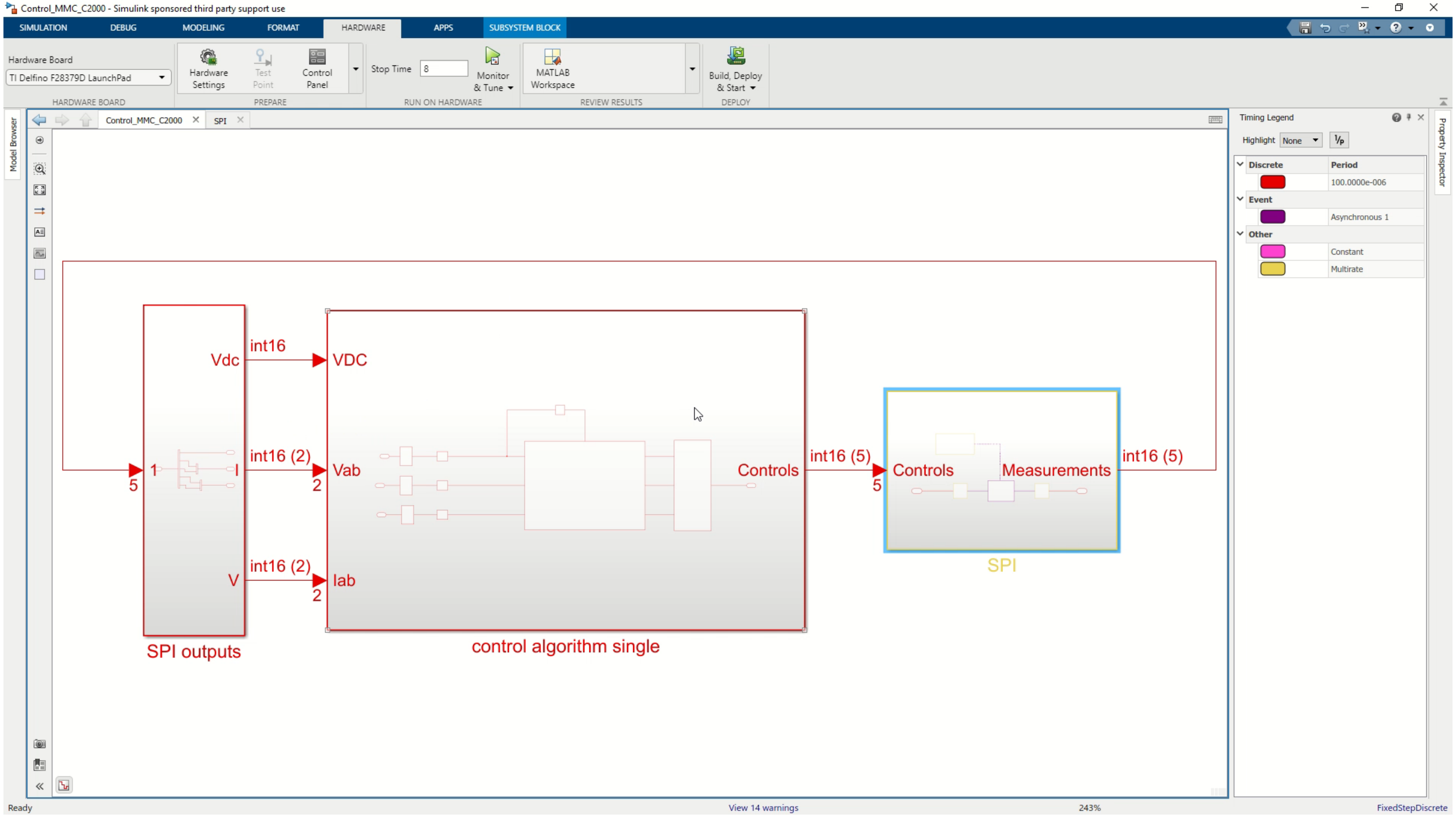


Generate Embedded Application on TI C2000 Microcontroller



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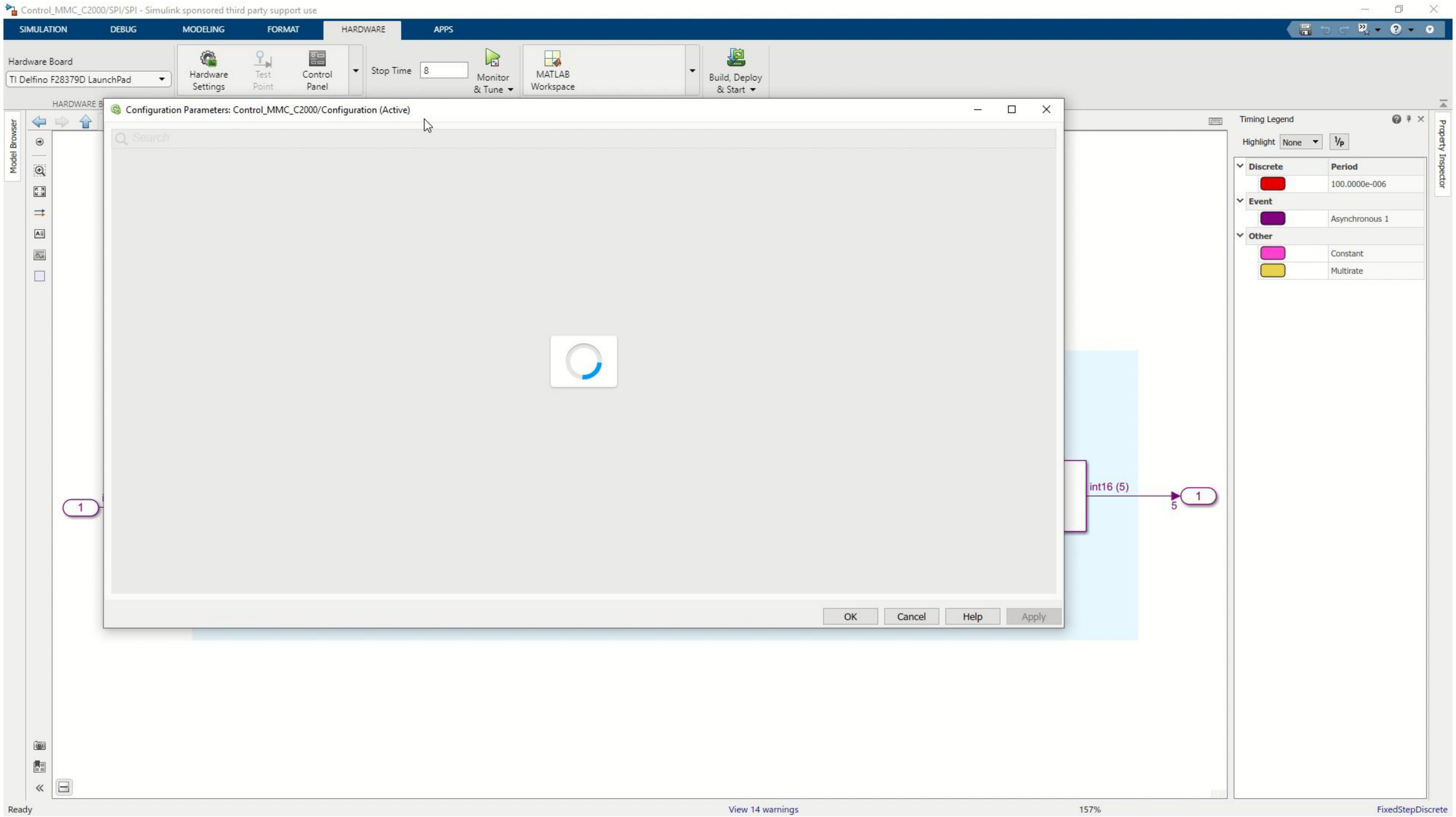

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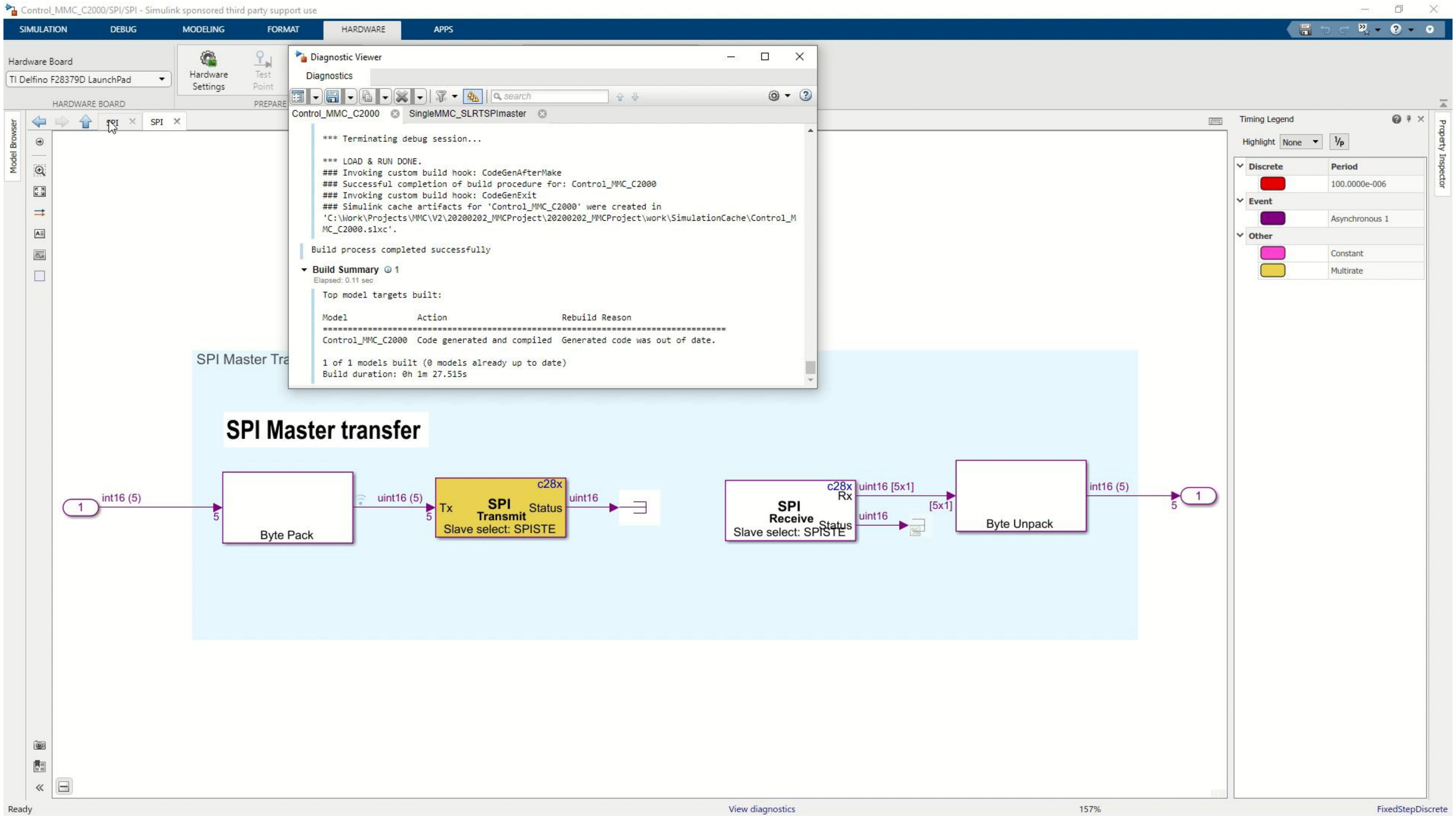
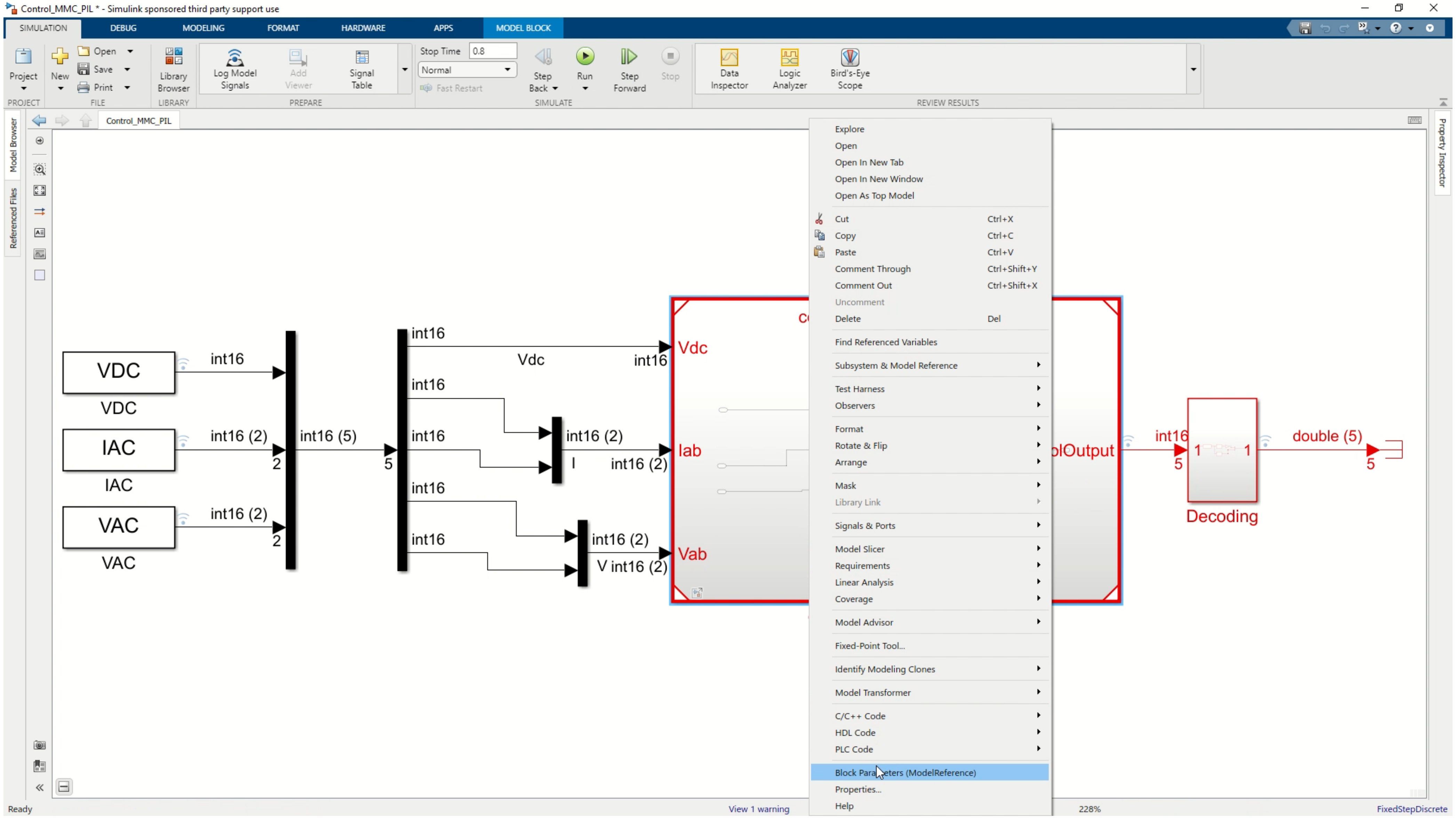


Processor-In-the-Loop (PIL) Testing



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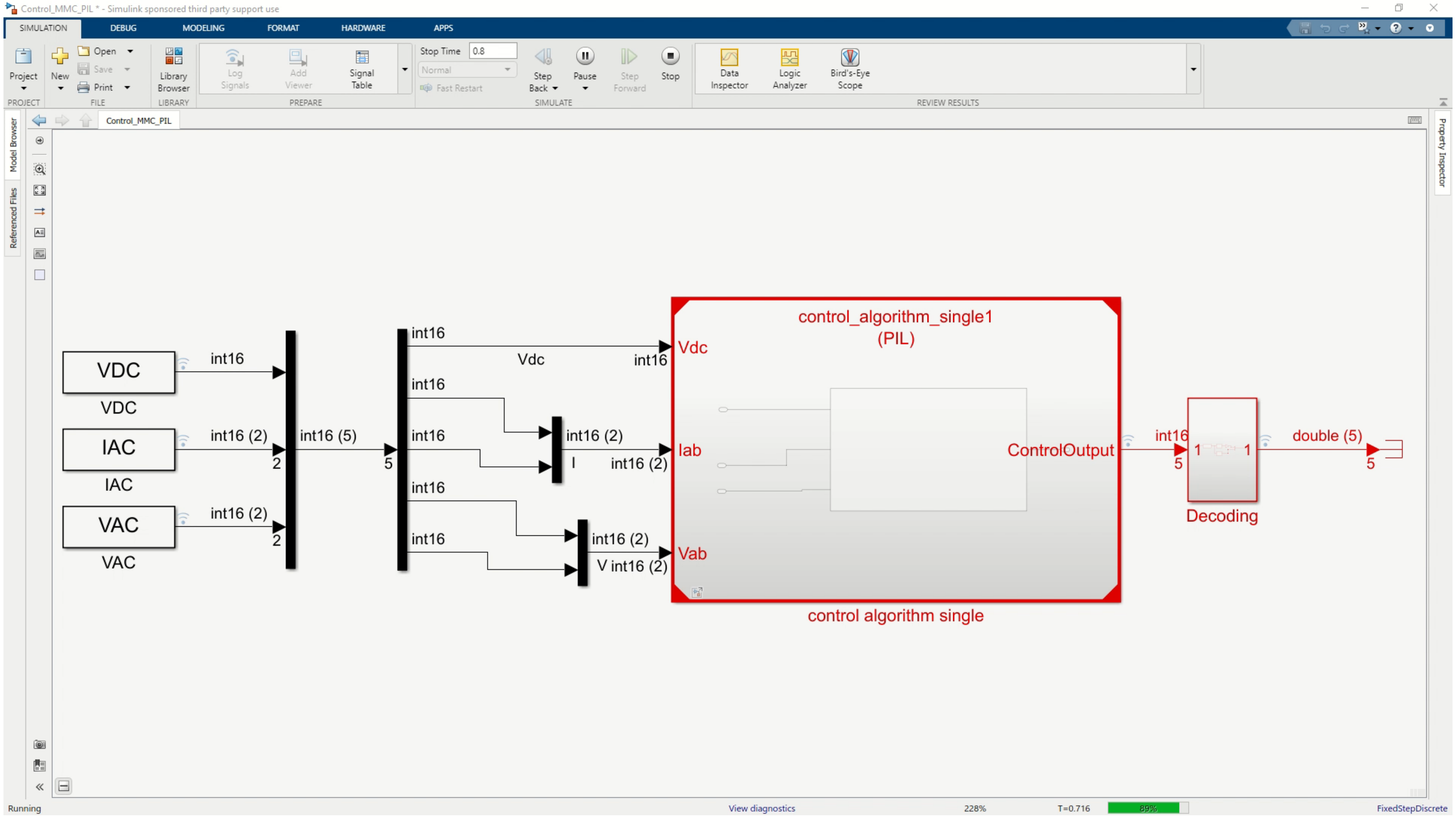
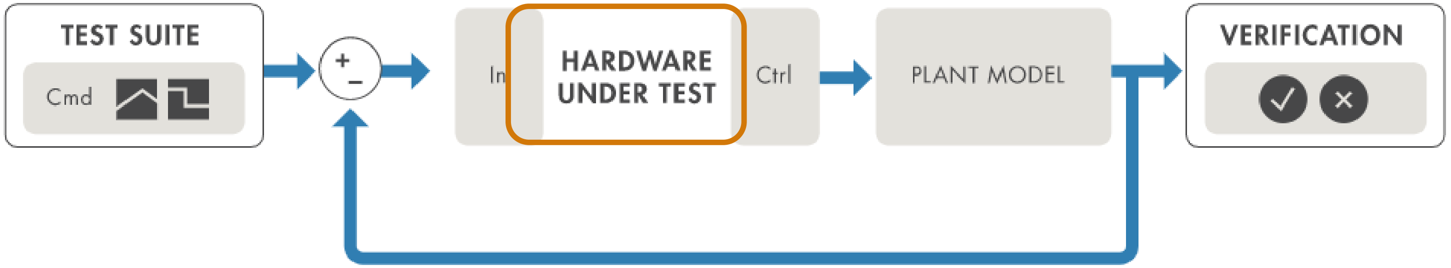
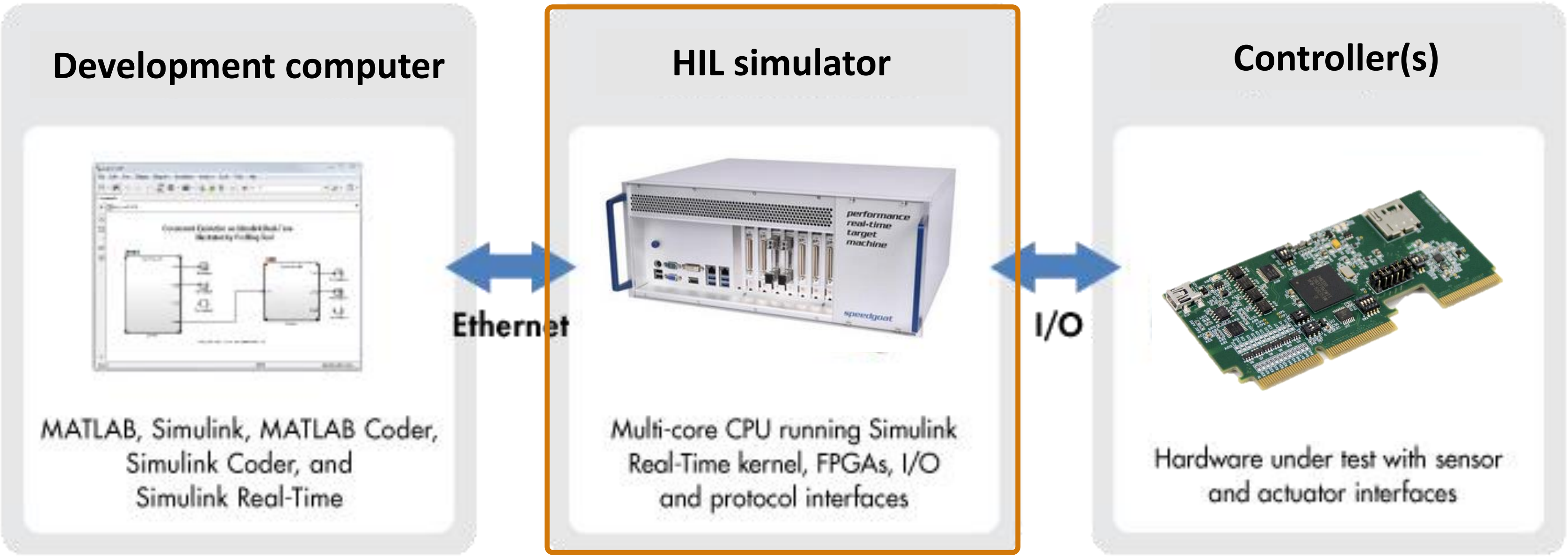
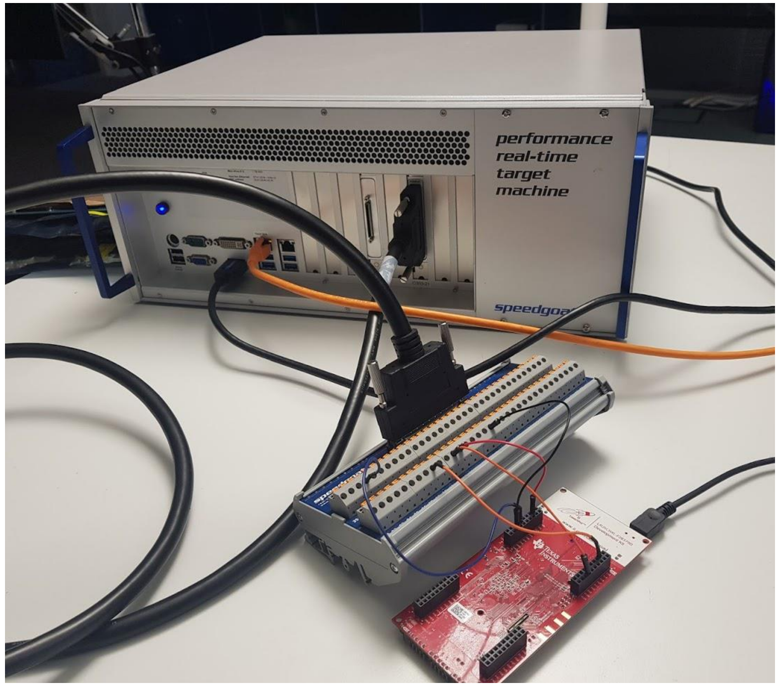


Hardware-in-the-Loop Simulation



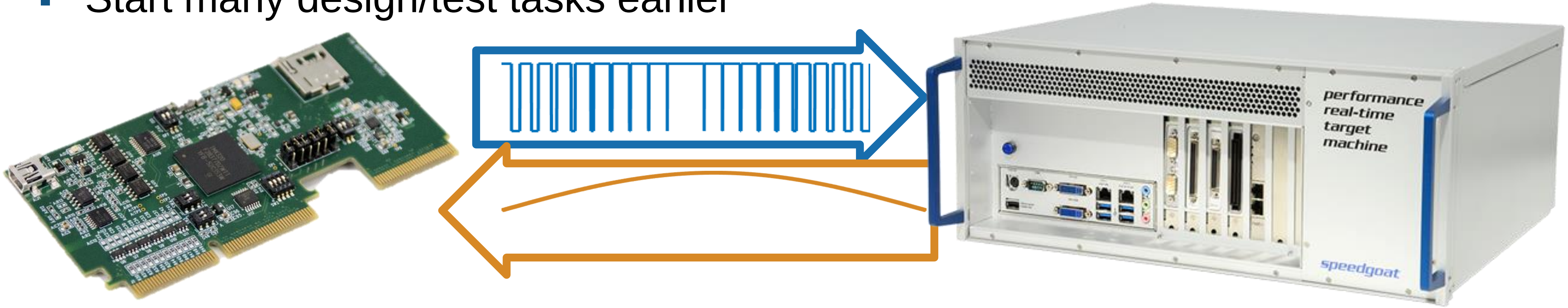


Plant simulation application autogenerated from Simulink



Advantages of Hardware in the Loop (HIL) Testing

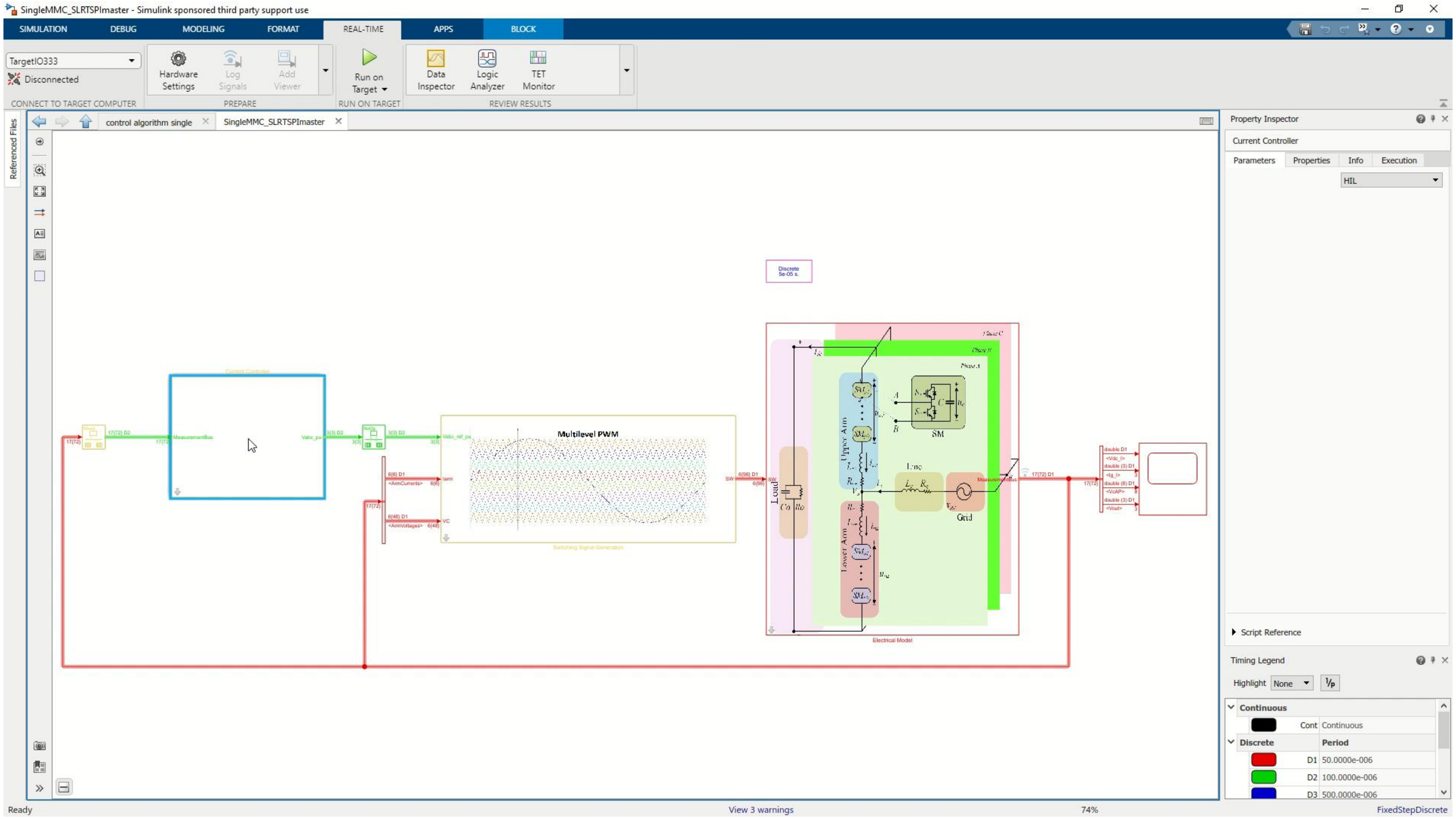
- Can replace prototypes or production hardware with a real-time system
- Easier to automate testing
- Safer than most power electronics hardware
- Start many design/test tasks earlier



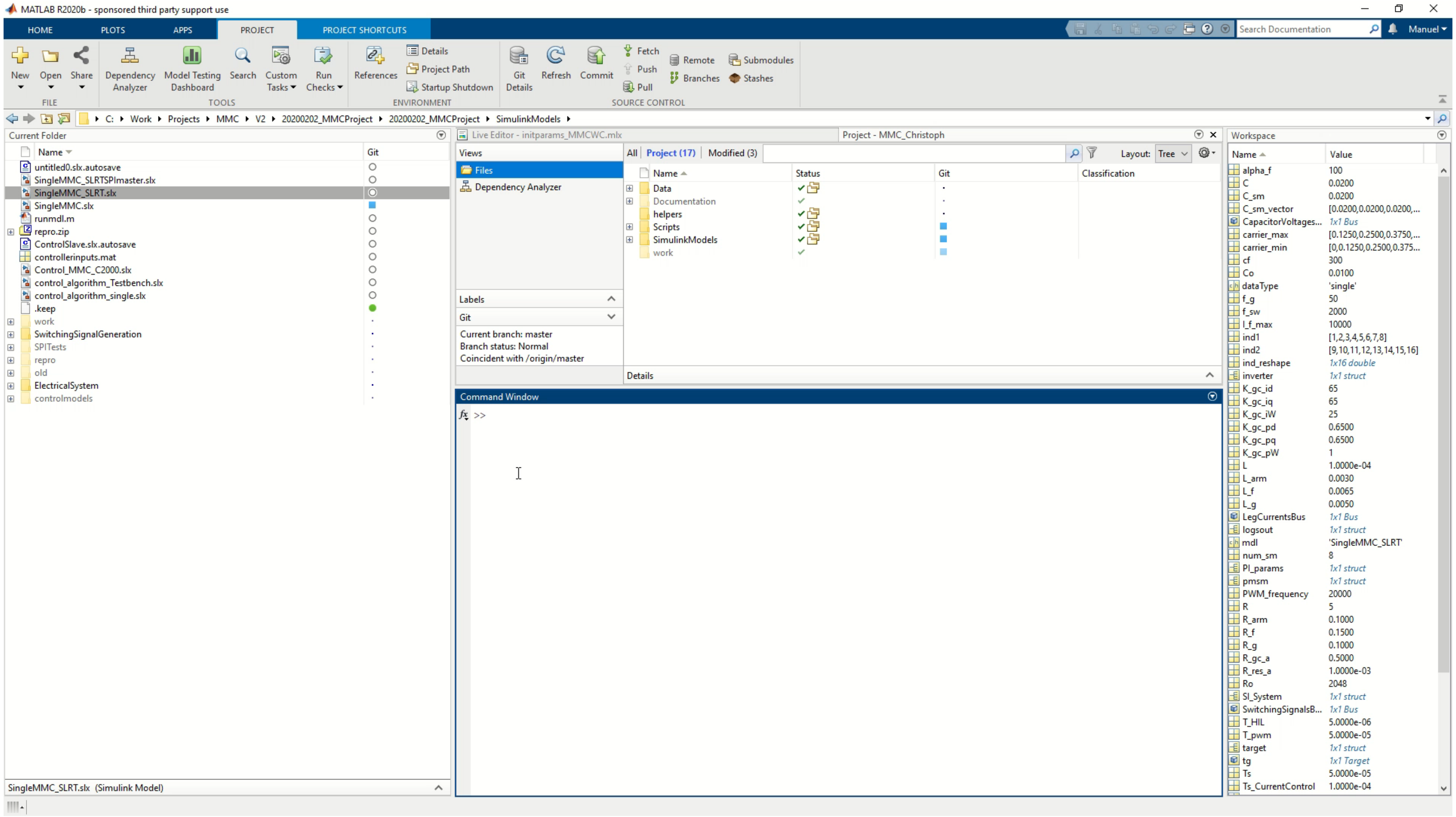
Controller

Virtual Simulation (Plant)

Hardware-in-the-Loop Simulation



Hardware-in-the-Loop Simulation



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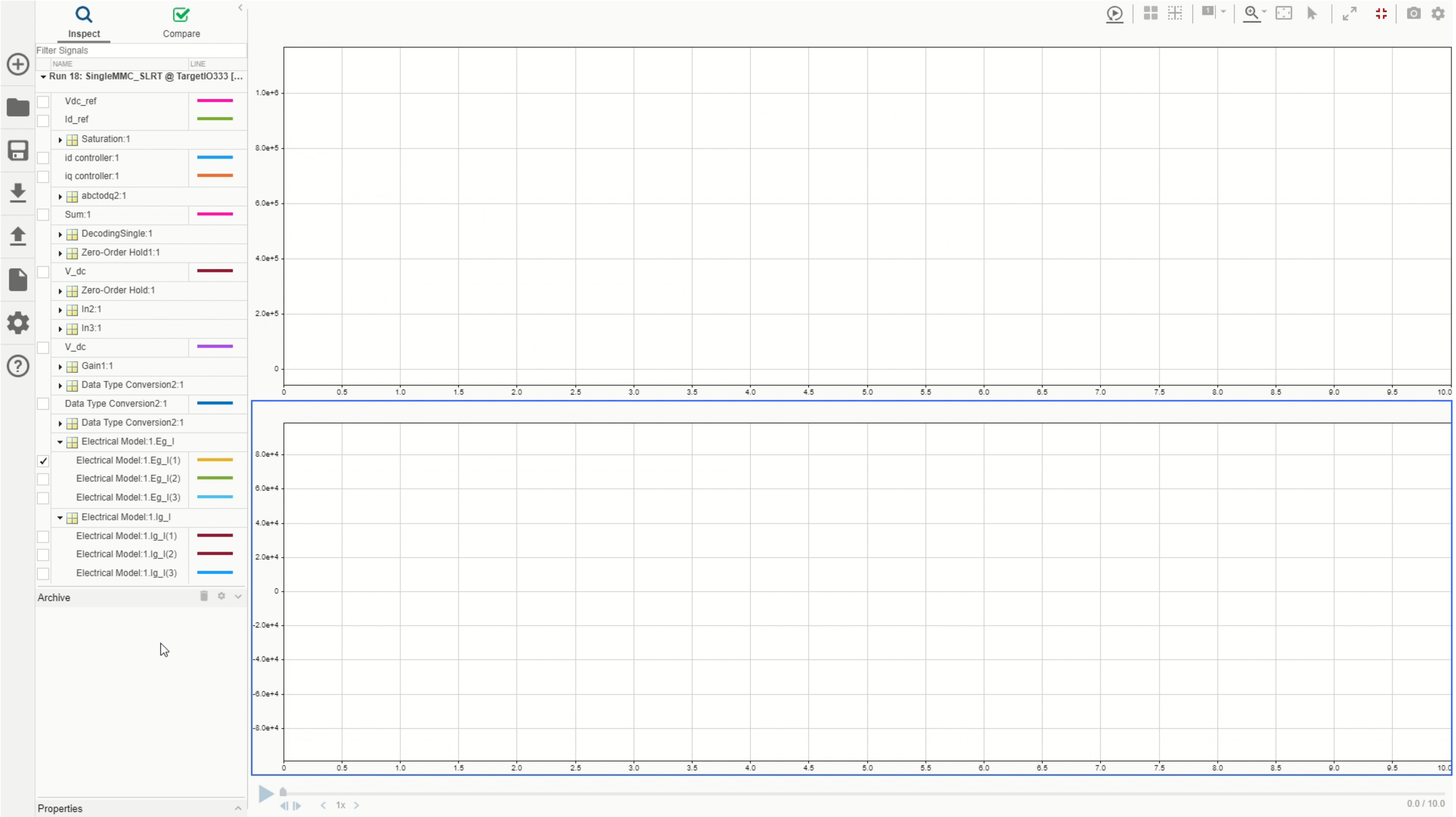

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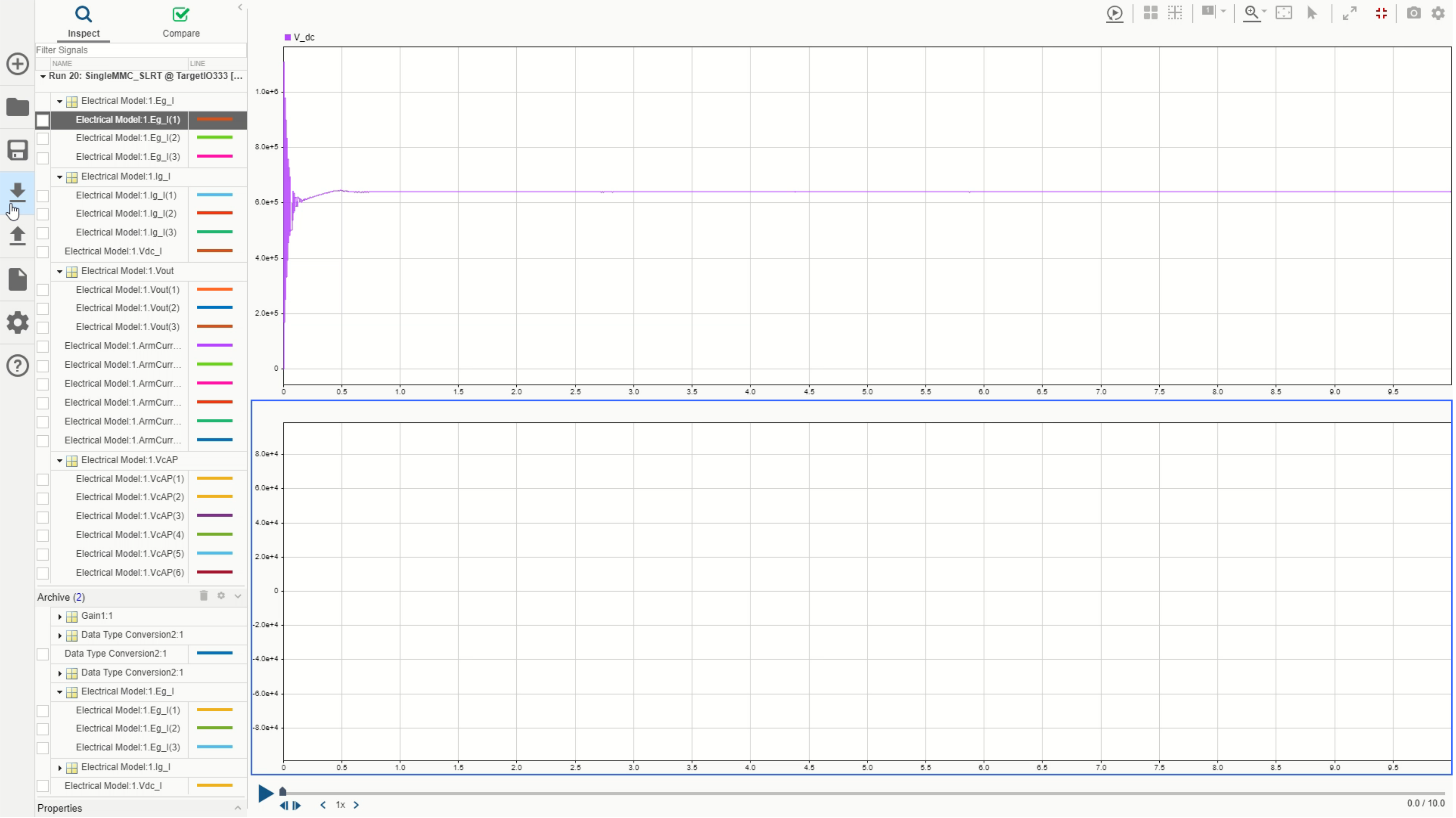

Conclusion

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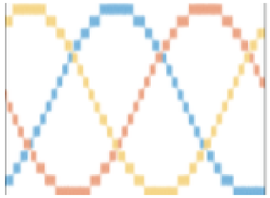
Trial software



Modeling Systems with Multilevel Converters in Simscape

version 1.0.0.3 (15.1 MB) by Graham Dudgeon STAFF

Files to accompany the webinar: 'Modeling Systems with Multilevel Converters in MATLAB and Simulink'

★★★★★ 2 Ratings

31 Downloads

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Overview | Functions | Models

We demonstrate how MathWorks tools may be used to model and simulate systems containing multilevel converter technology. A modular multilevel converter example will be used to explore the following topics,

- Build models of multilevel converters programatically from base components
- Use configurable subsystems to switch between different converter architectures
- Analyze pulse-width modulation (PWM) harmonic signatures to verify the correctness of the models
- Simulate different operational scenarios to test control system operation
- HVDC power transfer
- PMSM generation control
- Automate report generation to record the output of simulation studies

For more information on MathWorks solutions for Power Electronics Control Design, please visit this link
https://www.mathworks.com/solutions/power-electronics-control.html

Requires

MATLAB
Simulink
Simscape
Simscape Electrical

MATLAB Release Compatibility

Created with R2015a
Compatible with any release

Platform Compatibility

☑ Windows ☑ macOS ☑ Linux

https://www.mathworks.com/matlabcentral/fileexchange/51198-modeling-systems-with-multilevel-converters-in-simscape

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Thank you

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