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North America

SIL for E-Drive Systems for Virtual Calibration and Development

Daniel Berry, General Motors

Srinivas Naveen, General Motors

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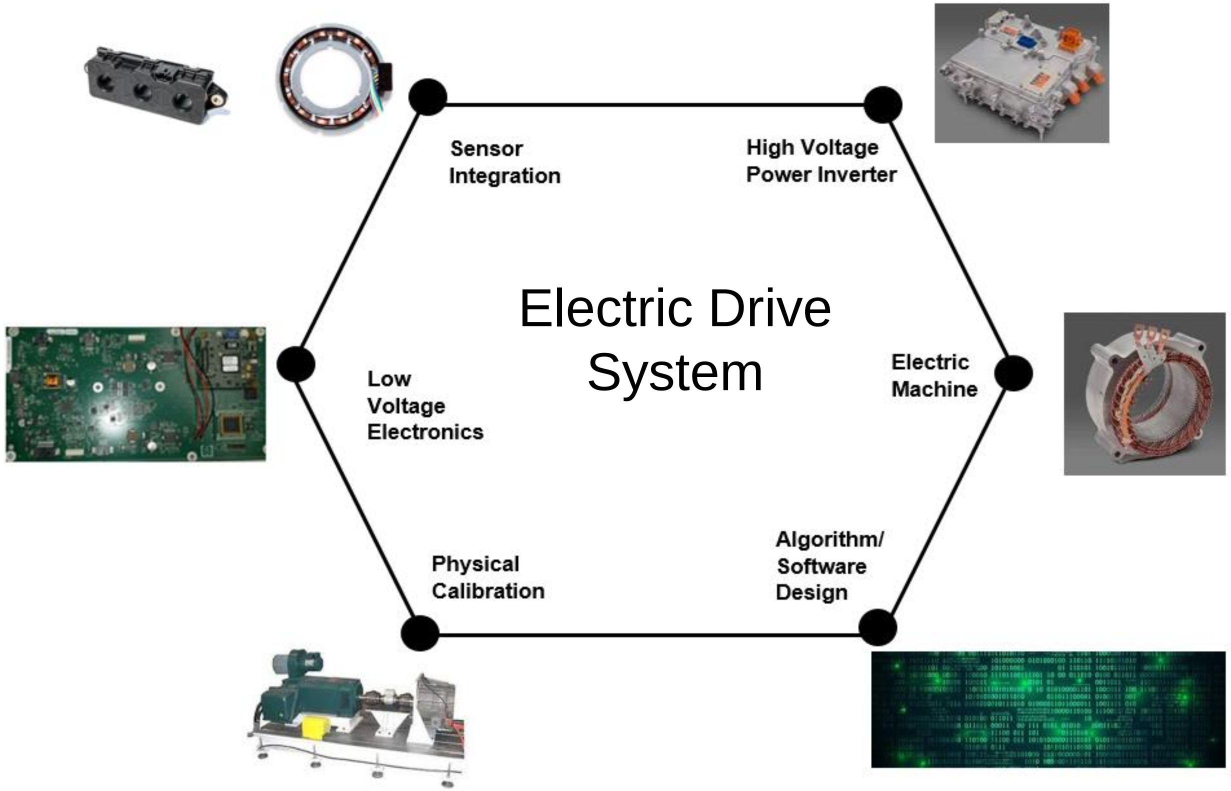
Outline

- Electric Drive Definition
- SIL Model Architecture
- Component Modeling
- Using SIL Models For Virtual Calibration
- Use Cases
- Virtual ECU
- Conclusion

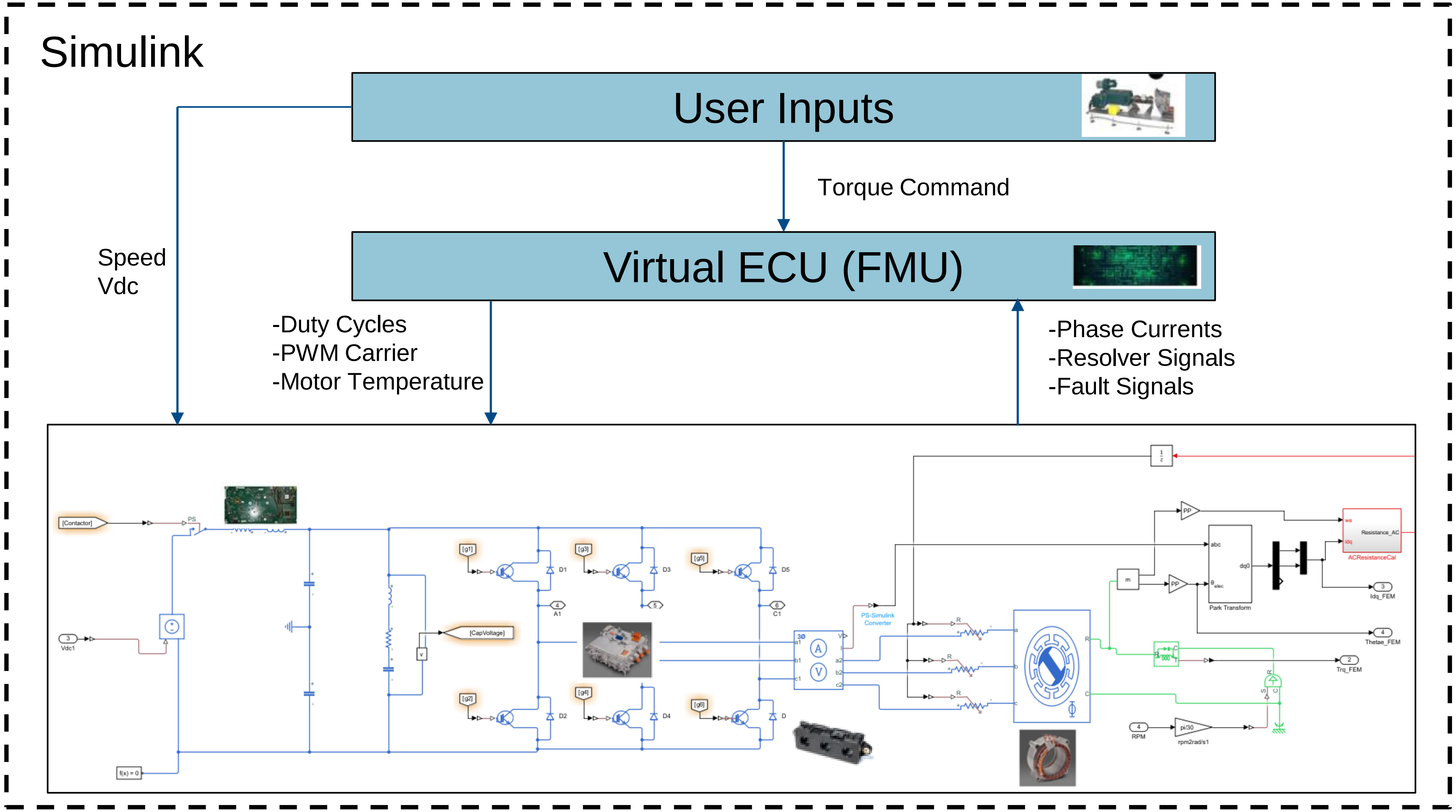
Electric Drive System Definition

- With the push to replace physical testing with simulations, opportunities exist within the electric drive space to virtualize development work
- MathWorks tools, and particularly the Simscape blockset, provide a great platform for modeling both the hardware and software components of electric drive systems.
- These models can then be used for a wide range of both analysis and calibration work.



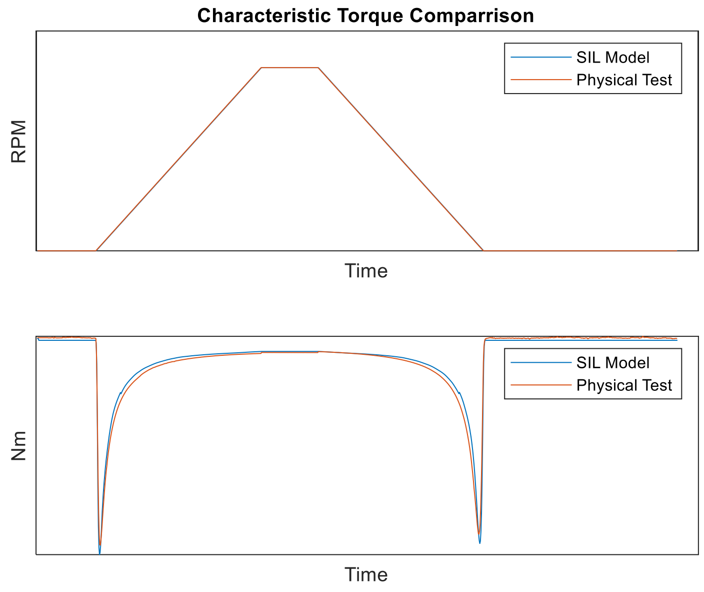
Electric Drive System Virtualization – Virtual Dyno

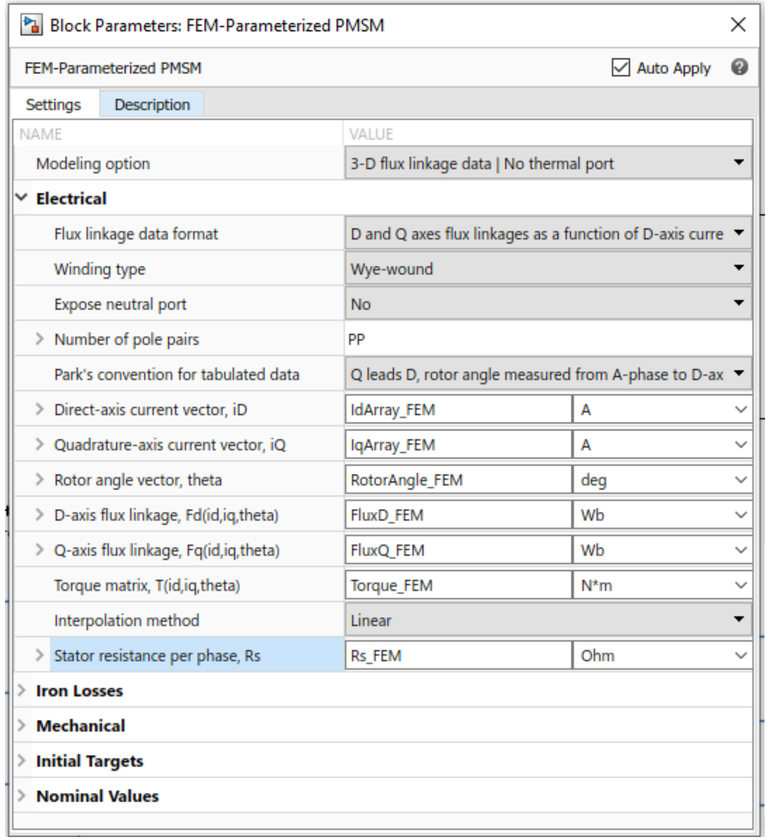
- Shown below is the architecture of a Software In The Loop (SIL) model of an electric drive system.
- Included are both the hardware components modeled using Simscape blocks; as well as software components compiled as FMUs.
- The entire simulation can run natively in Simulink, or compiled as an executable to run in other simulation environments

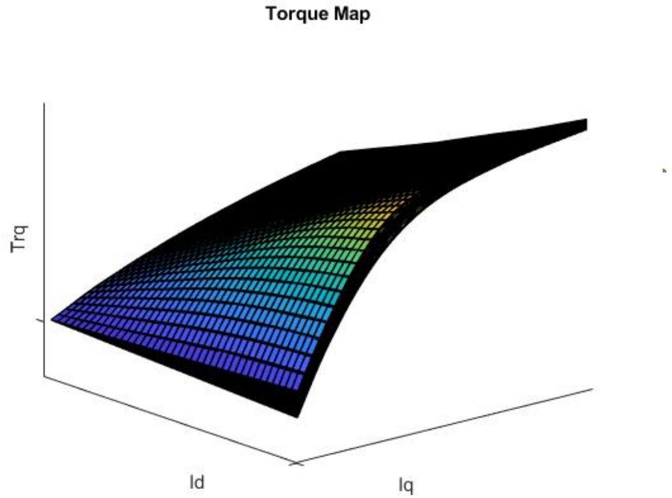


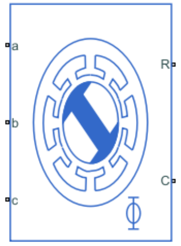
Motor Model Overview

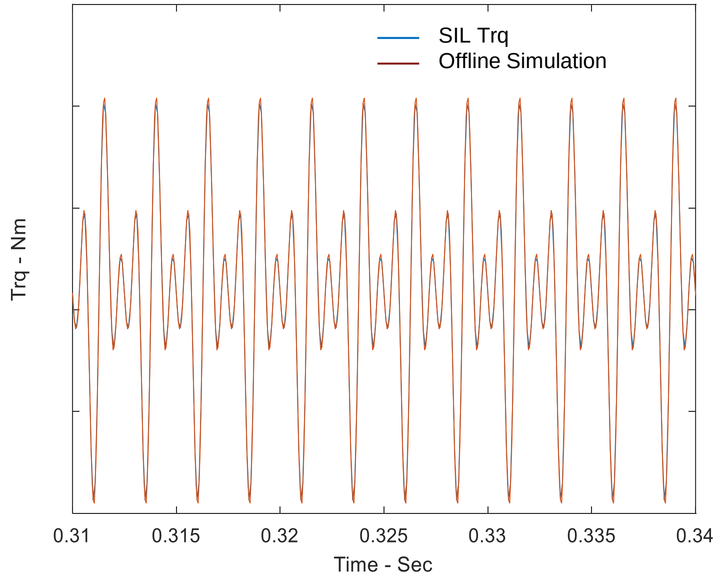
- FEM-Parameterized PMSM block allows for implementation of spatially dependent machine parameters including saturation effects, core losses, and AC effects.
- Parameters can come either from FEA data, or physical testing
- Model matches well physical test data both in terms of average, and harmonic torque.





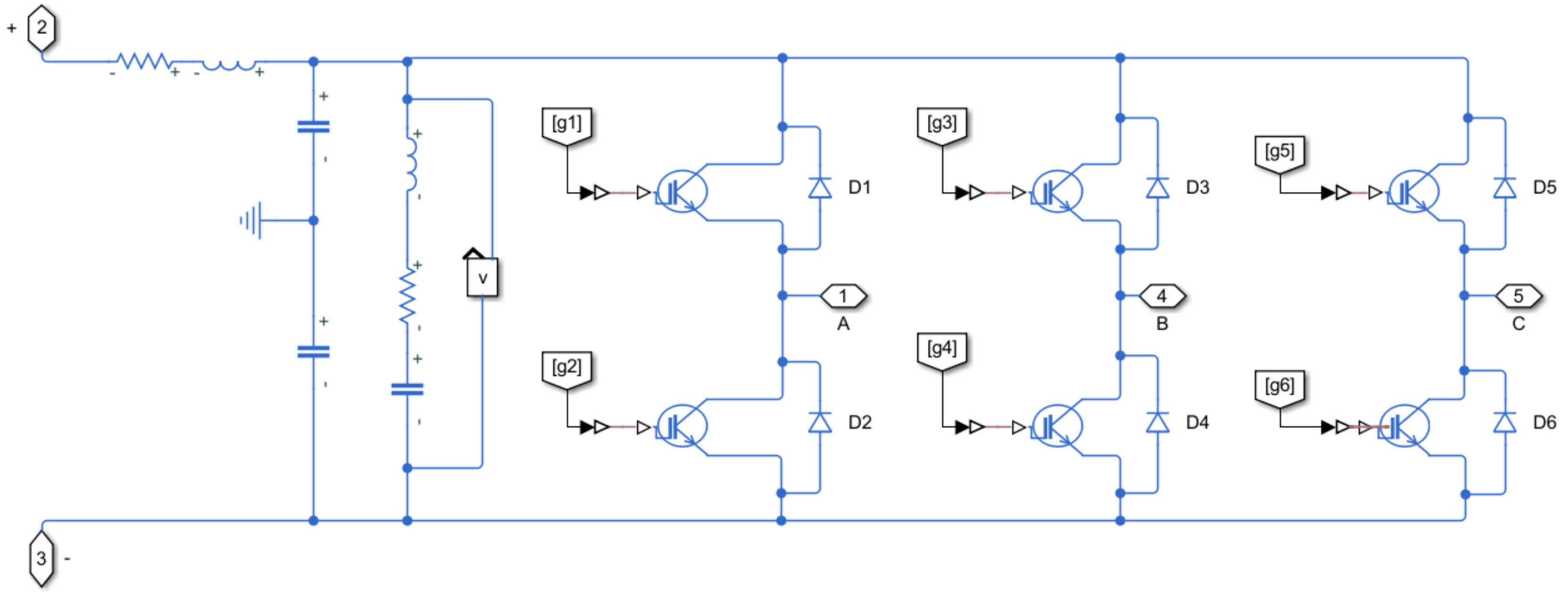


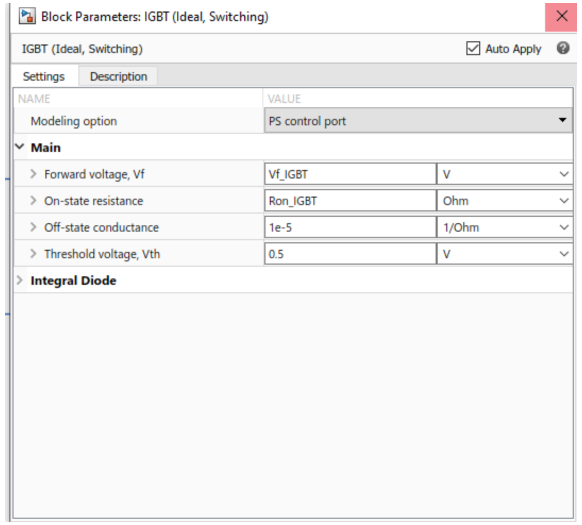


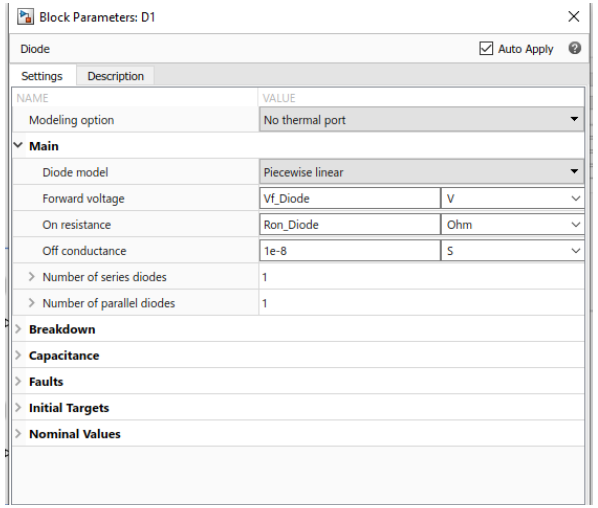


Inverter Model Overview

- Inverter devices and circuits can be modeled with various levels of fidelity depending on simulation needs and balancing required model accuracy with execution time.
- Device parameters can be specified including dependency on current and temperature
- Models can be connected electrically with other circuit components as well as electric machines

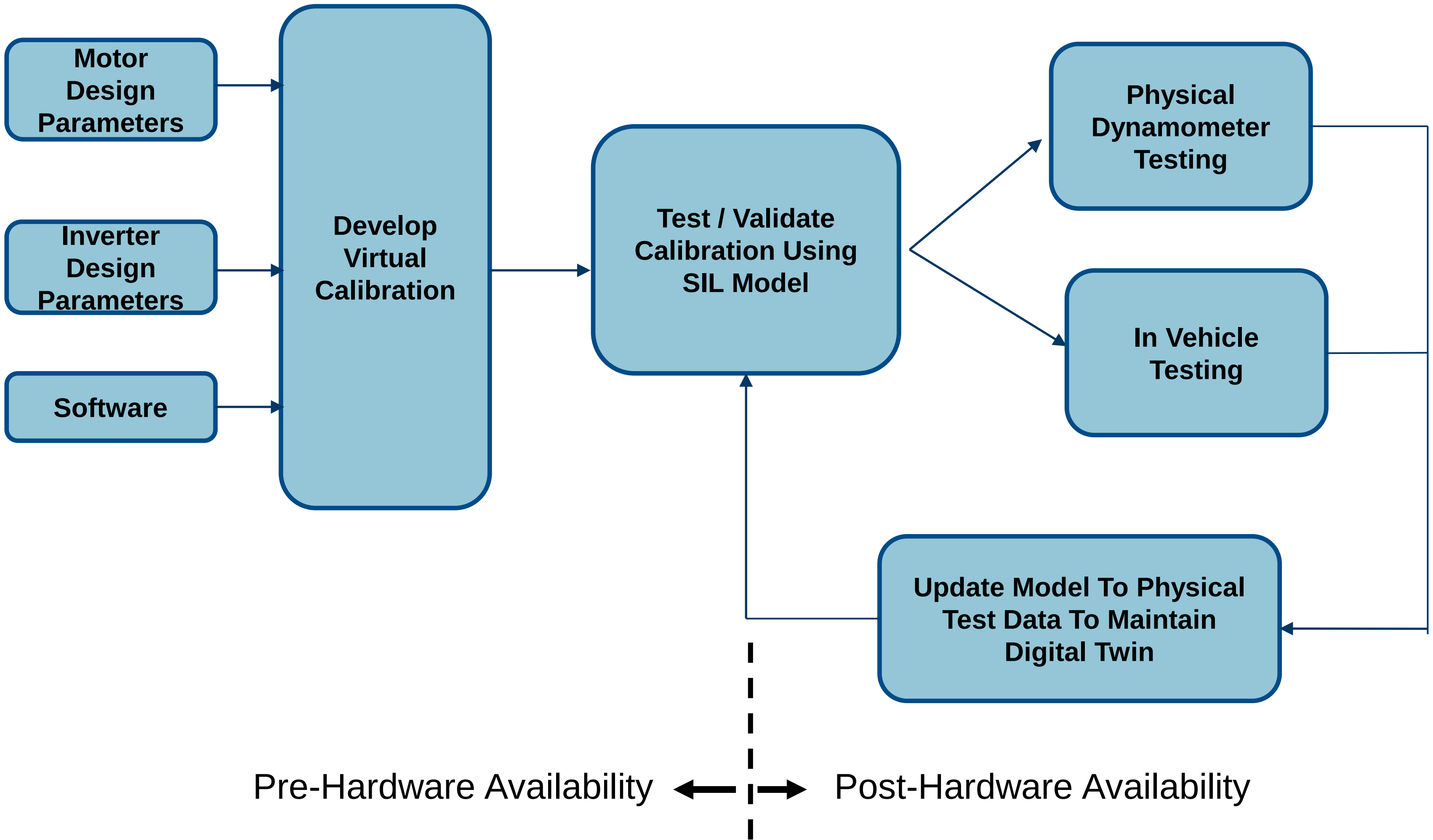






Utilizing Simscape Models in a Virtual Calibration Process Flow

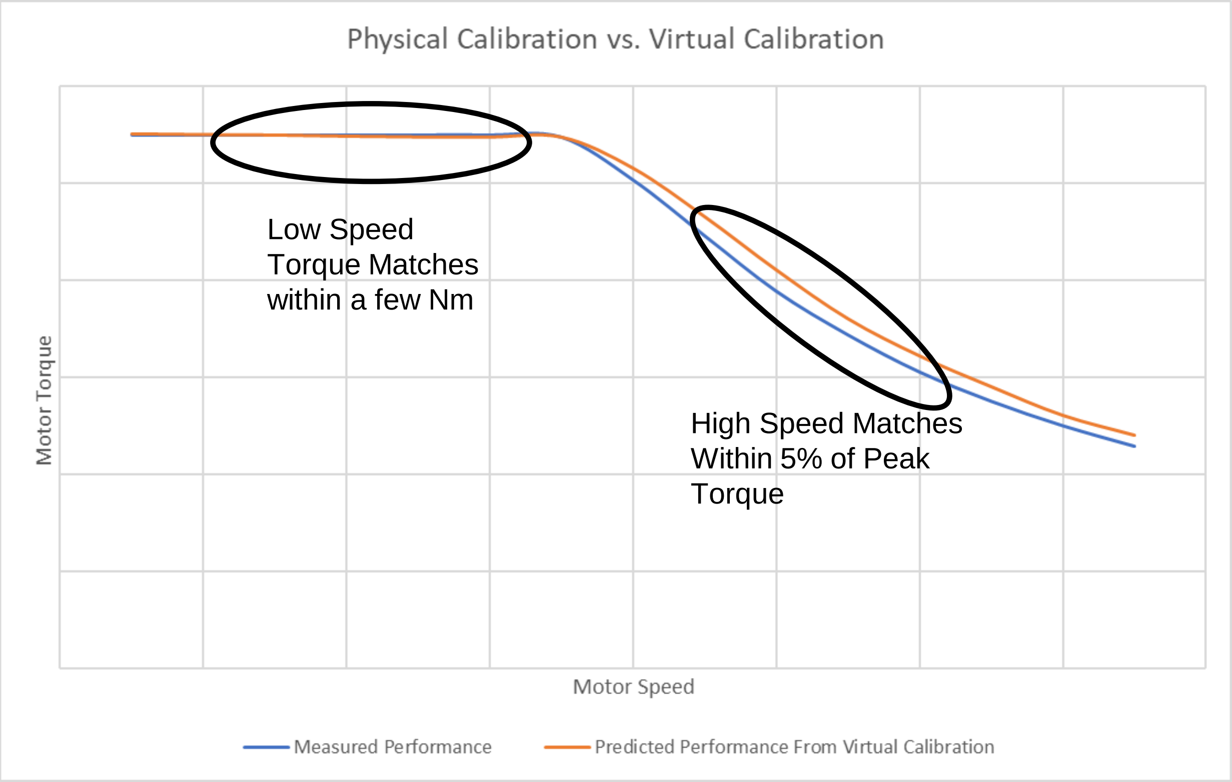
- Given these high fidelity electric drive system models along with the appropriate software to run them, calibrations can be developed and verified in a virtual environment enabling a significant amount calibration work to be done prior to hardware availability.
- Additionally, by creating a digital twin to align with physical hardware, evaluation of calibration or system changes can be performed without the need for physical testing.



Using SIL Models To Enable Virtual Calibration

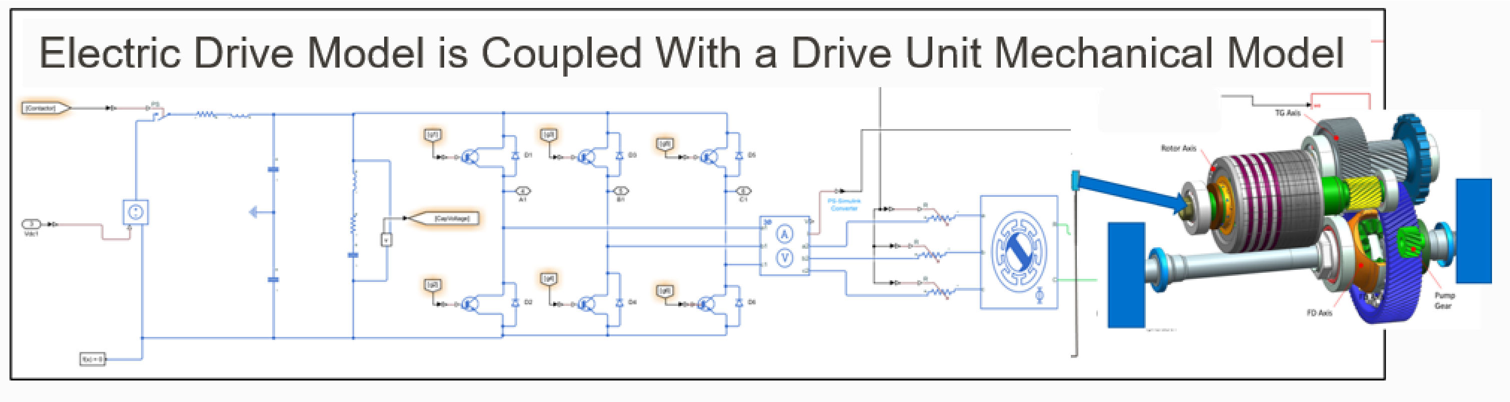
- Prior to any physical testing and utilizing only FEA generated machine parameters and the SIL model for calibration development, a virtual calibration can achieve ~95% performance targets both in terms of peak performance and calibration accuracy

- Enables significant reduction in product development time by being able to deliver a working calibration immediately at hardware delivery

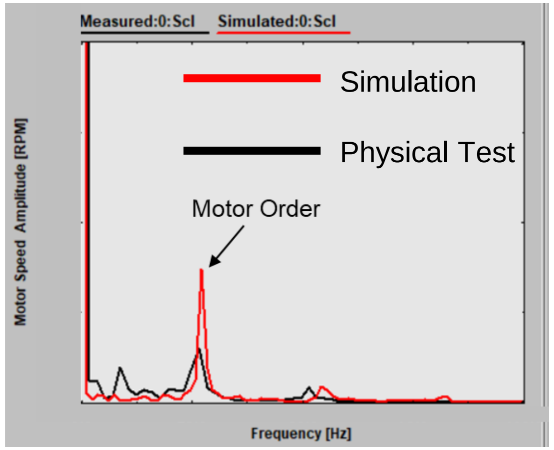


Coupling Electric Drive SIL Models With Driveline Models

- Electric drive models can be further coupled with mechanical driveline models to enable a full driveline simulation including the effects of motor torque ripple, gear lash, and driveline resonance.
- Critical mechanical frequency orders are accurately modeled
- Control mitigation and calibrations can be modeled and tested using these complete system models well before hardware availability to identify and mitigate any potential issues

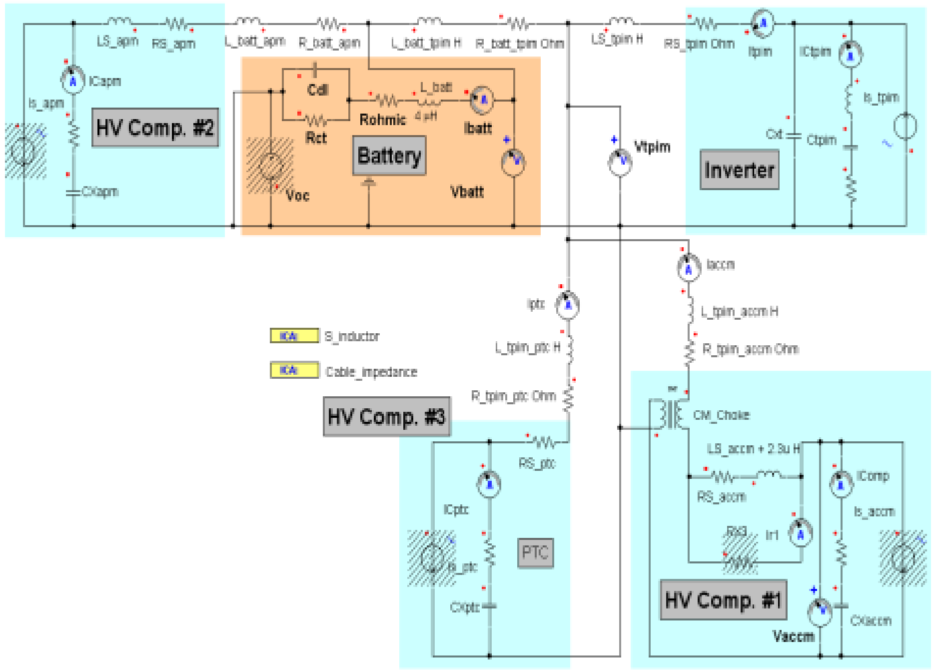


Frequency Response

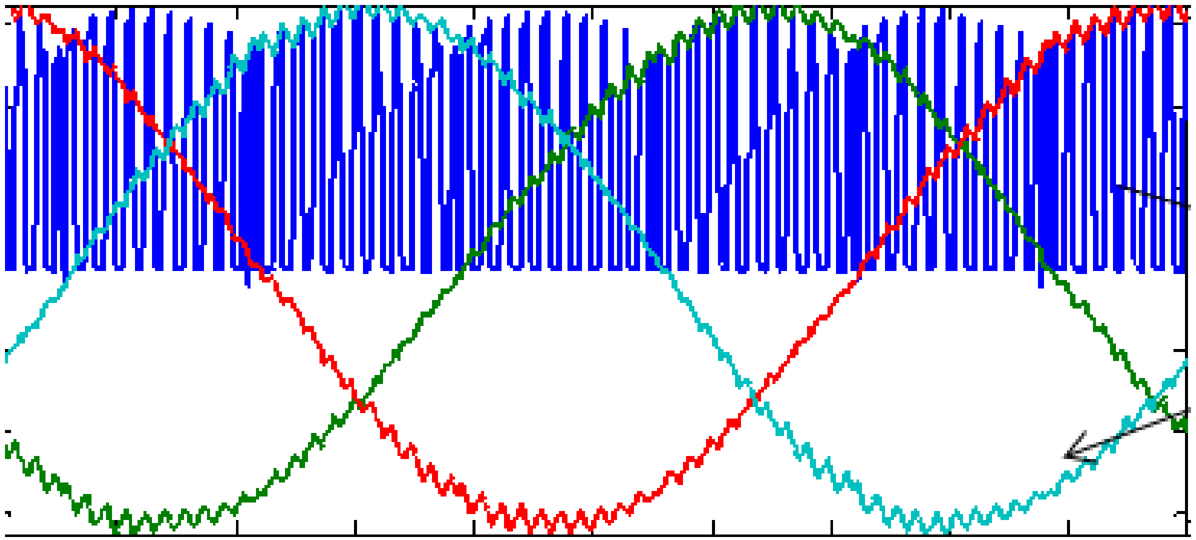


Coupling Electric Drive SIL Models With Other Electrical Models

- The electric drive system (including multiple systems) can be connected electrically to circuit models of other components on the high voltage bus (battery, charging module, etc…)
- This allows for modeling of electrical interactions between the different components.
- Calibration strategies can be modeled and simulated to optimize desired bus behavior; while avoiding critical resonance points any minimizing current/voltage ripple.

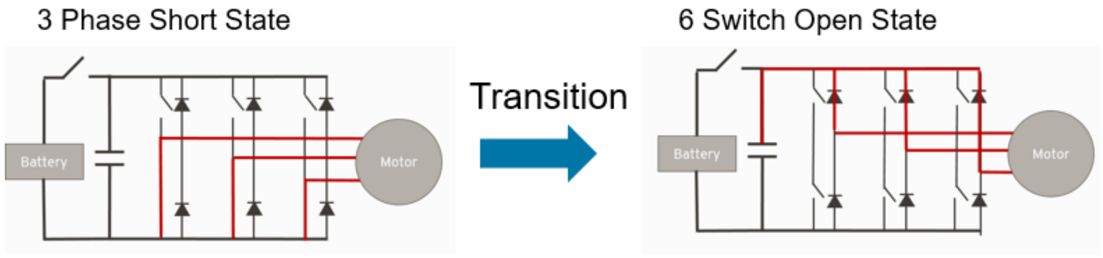


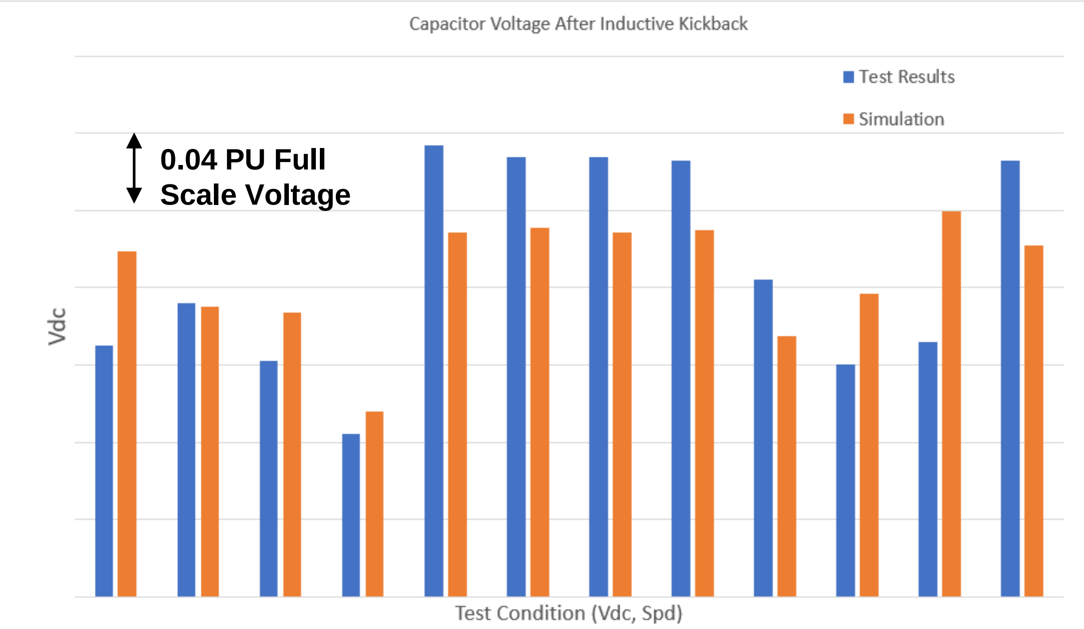
Inverter Phase and DC Link Currents



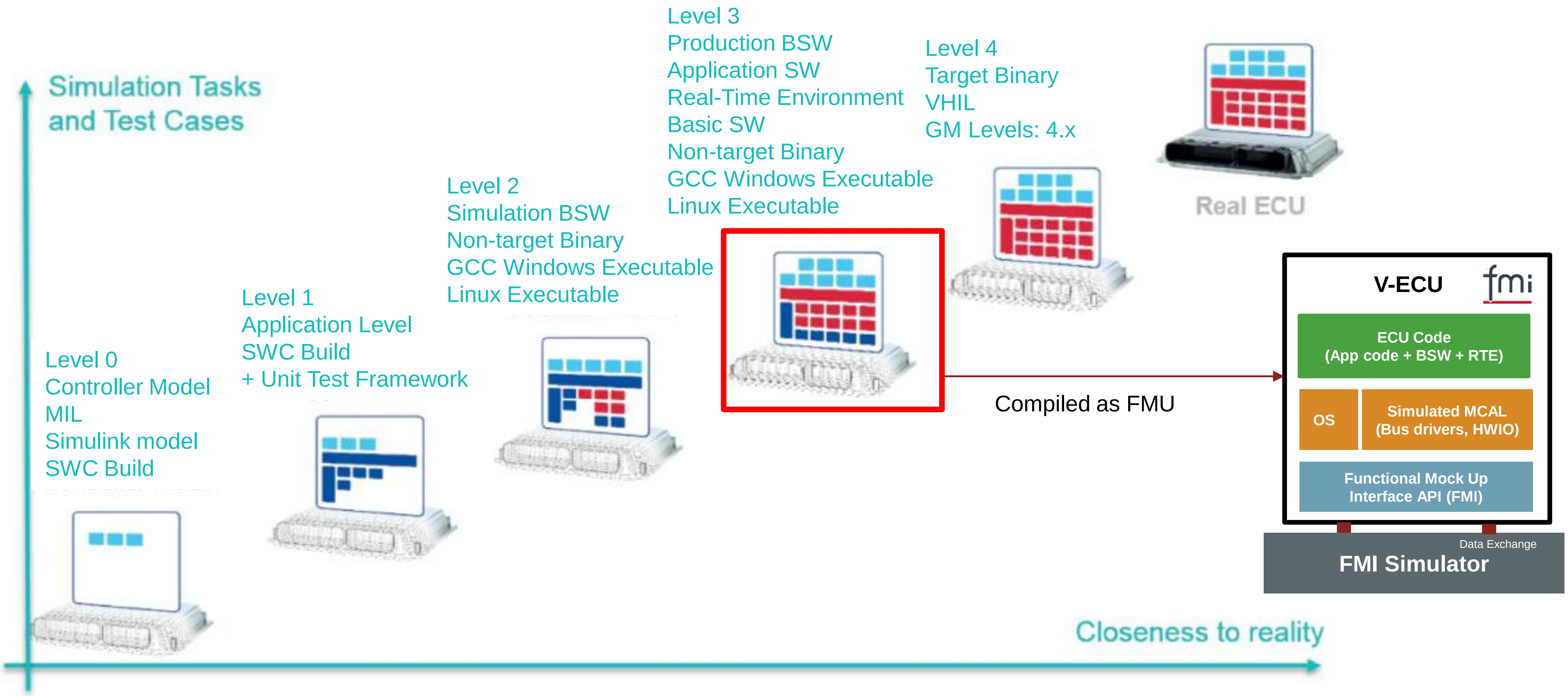
Using SIL Models to Model Fault Response Behavior

- Control system fault response testing is one area in which the Simscape blockset offers great benefits over other modeling approaches. Highly transient events; such as modeling of inductive kickback during a 3 switch short to 6 switch open transitions is well captured due to the electrical coupling between the motor and inverter models.
- Coupled with the software modeling, various fault case scenarios can be modeled without the need of physical hardware tests





Virtual ECU Overview

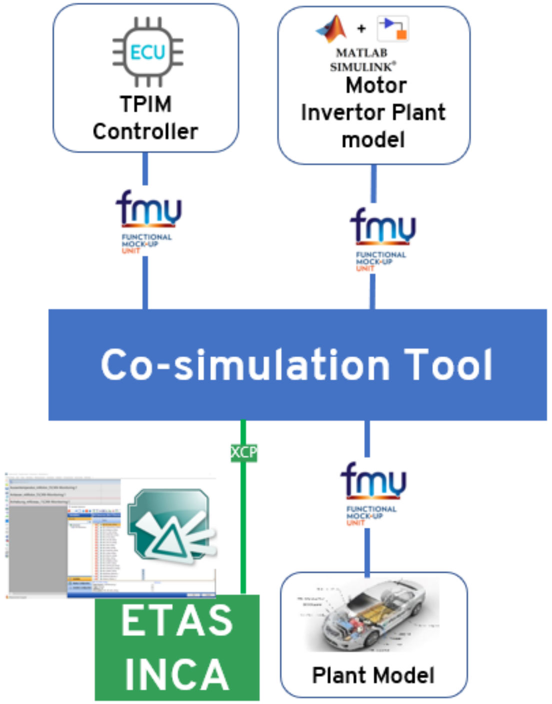


Simulation Setup

- Two possible implementations available to achieve Level 3 vECU.

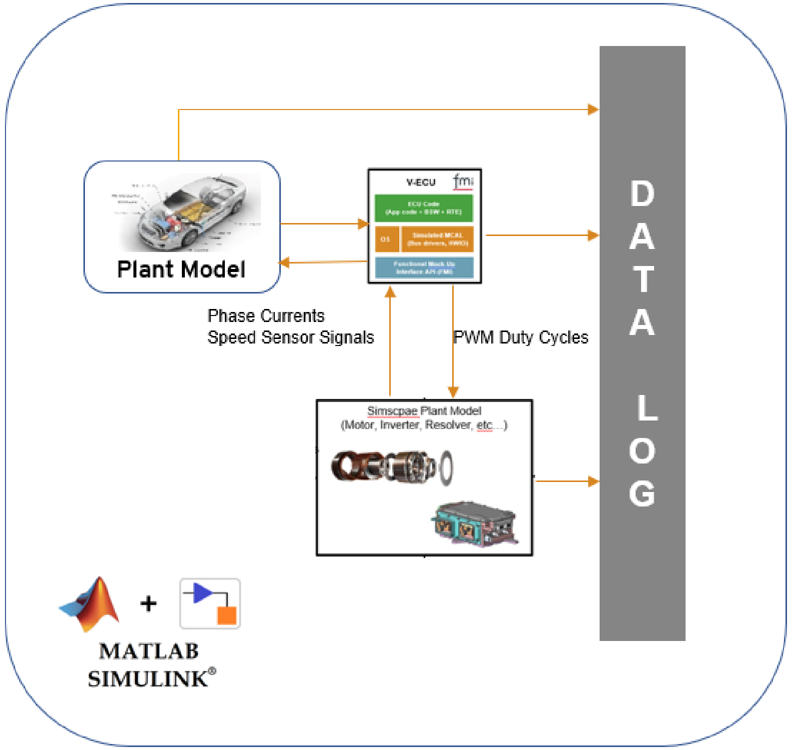
Co-Simulation

- Software and plant models compiled as FMUs and run in Co-Simulation engine.
- Allows for interfacing with external models/tools but can be slower depending on required synchronizations speeds.
- Generally better for mature models being distributed to a large amount of users



Native Simulink

- Controller FMU can run directly in Simulink with native Simulink components.
- Generally better for development purposes when frequent software/model changes are planned



Summary /Conclusion

- Using Simscape components inside of Simulink; combined with a virtual ECU enables virtualization of many critical electric drive development tasks including:
  - Calibration
  - Algorithm Development
  - Simulation
  - Software Development / Regression Testing

- Simscape electric drive components offer the right mix of options to balance high fidelity system modeling with easy to integrate components to enable a complete simulation package.

- Using high fidelity electric drive plant models, combined with SIL packages has been able to cut in half the amount of time needed on a dynamometer

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Thank you

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