



How to Accelerate EV Software Release Cycles with AVL E-Motor Emulation Testbeds

Dr. Martin Schmidt, AVL



Dr. Carlos Villegas, Speedgoat



MathWorks
**AUTOMOTIVE
CONFERENCE 2024**

Just imagine you just updated your EV software and:

you cannot use fast charging



your vehicle needs to be towed



or suddenly loses power while driving



Agenda

- ❑ **Powertrain Testing using E-Motor Emulators**
- ❑ Accelerating Inverter Software Release Cycles
- ❑ Simulink® integration with Speedgoat Test Systems
- ❑ Demo using Simscape™ Battery™ and Powertrain Blockset™



About AVL



At AVL, we are one of the world's leading mobility technology companies for development, simulation and testing in the automotive industry, and in other sectors. Drawing on our pioneering spirit, we provide concepts, solutions and methodologies for a greener, safer and better world of mobility.

**1948**

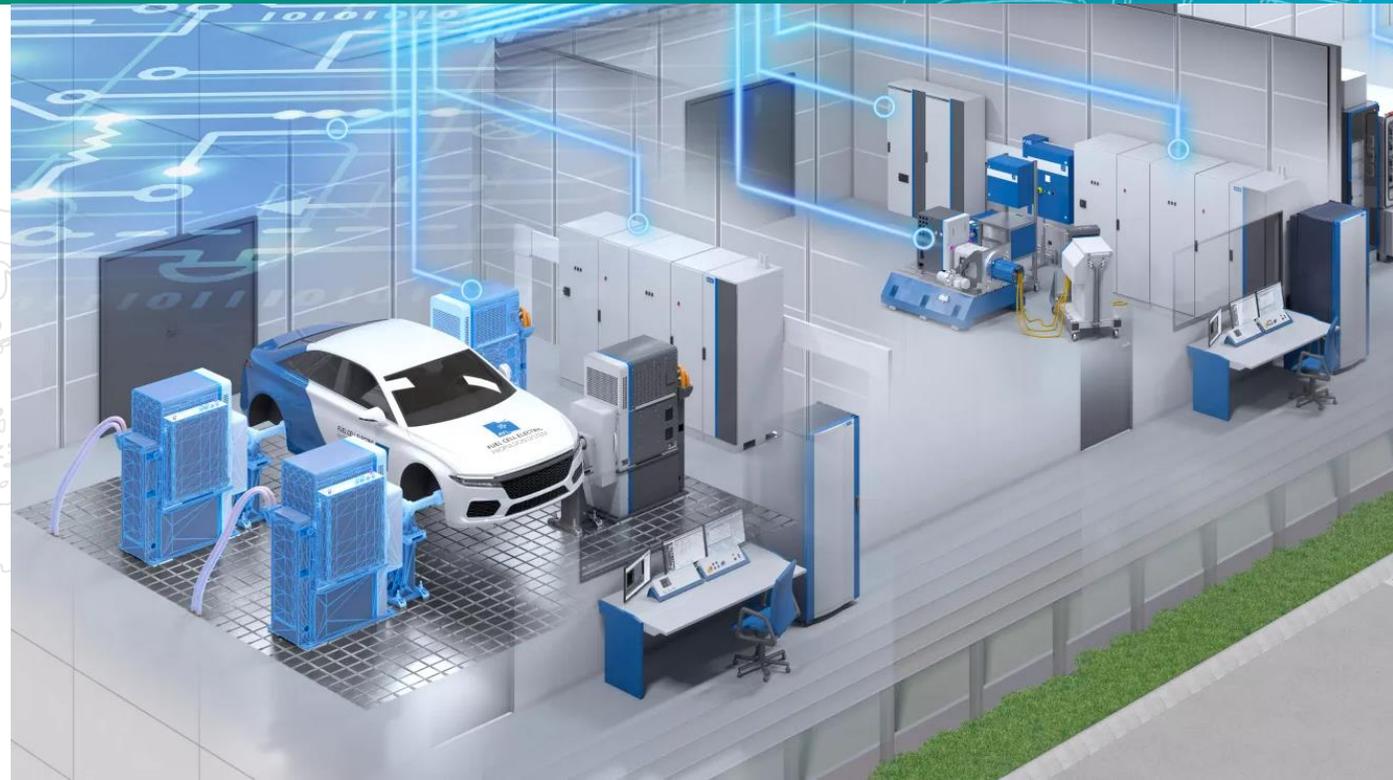
Founded

75

Years of Experience

**26**Countries
Represented**45**Global Tech and
Engineering Centers**11,200**

Employees Worldwide

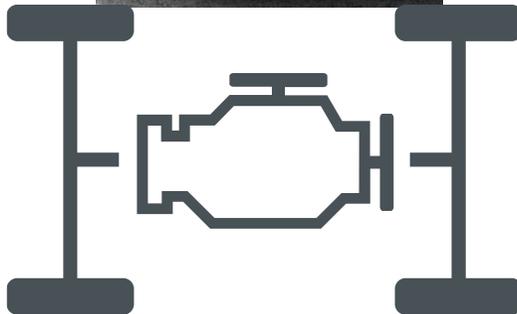
68 %Engineers and
Scientists

Powertrain Testing

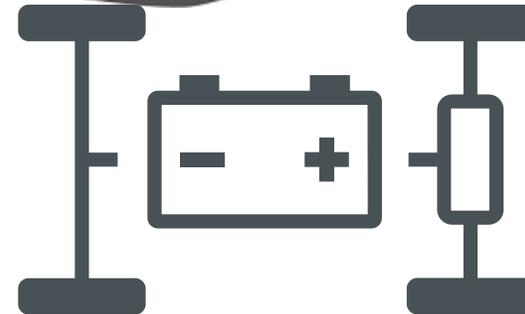
Why should there be a different testing strategy?

“... still four wheels and seats inside – not levitating, essentially the same ...?”

Internal Combustion
Engine ICE

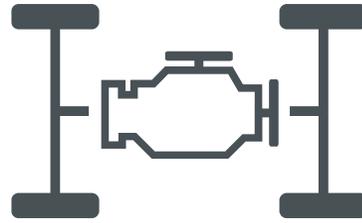


ELECTRIC



ICE Powertrain Testing

Traditional approach



- Well-established validation tests to develop vehicle propulsion systems for:
 - Internal combustion engine-driven vehicles
 - Electric vehicles (EV)
- Typical examples include
 - Durability
 - Performance evaluation
 - Optimization of consumption
 - Driving range
 - Drivability optimization
 - Integration of high-voltage components
 - On-board diagnostics
 - Failure diagnostics
- Test are executed on rotating test beds



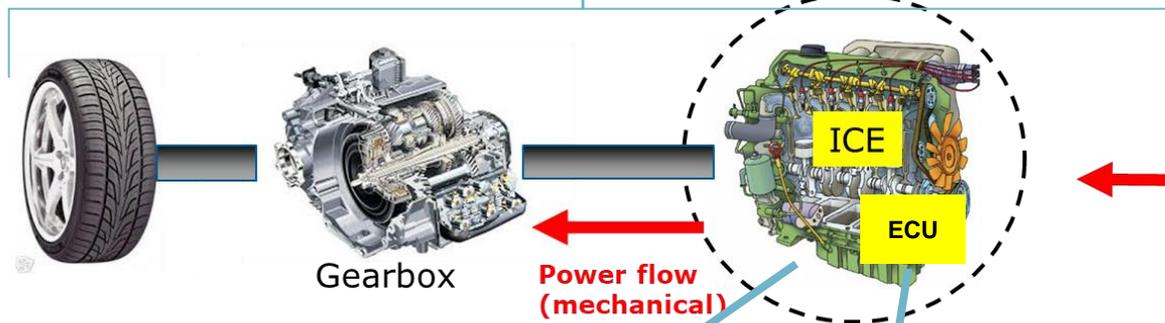
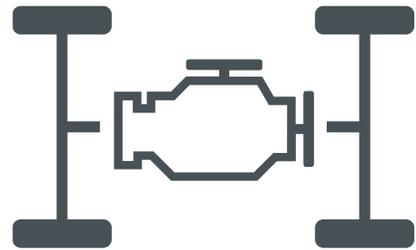
Powertrain Testing

Why should there be a different testing strategy?

... rotating parts are playing a smaller role in electric drive trains – and software a much bigger

Rotating

ICE
Drivetrain



Power flow
(chemical)

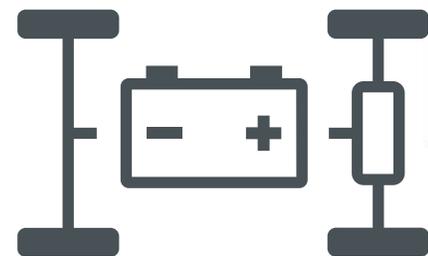


Fuel tank

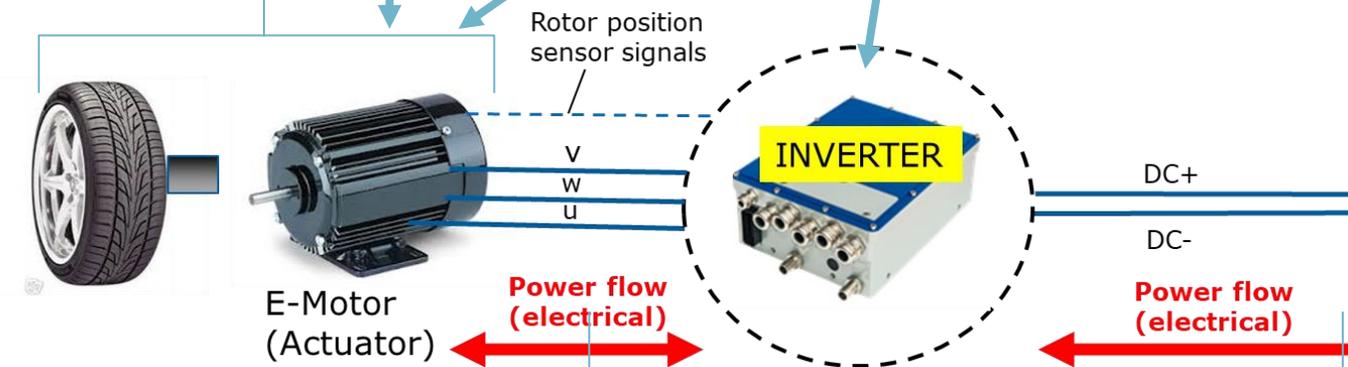
Power flow
(mechanical)

Gearbox

Electrical
Drivetrain



Rotating



DC+

DC-

Power flow
(electrical)

High voltage battery

Power flow
(electrical)

E-Motor
(Actuator)

Rotor position
sensor signals

v
w
u

INVERTER

Purely electric

Powertrain Testing

Inverter Testing Methodology

INVERTER (POWER ELECTRONIC)

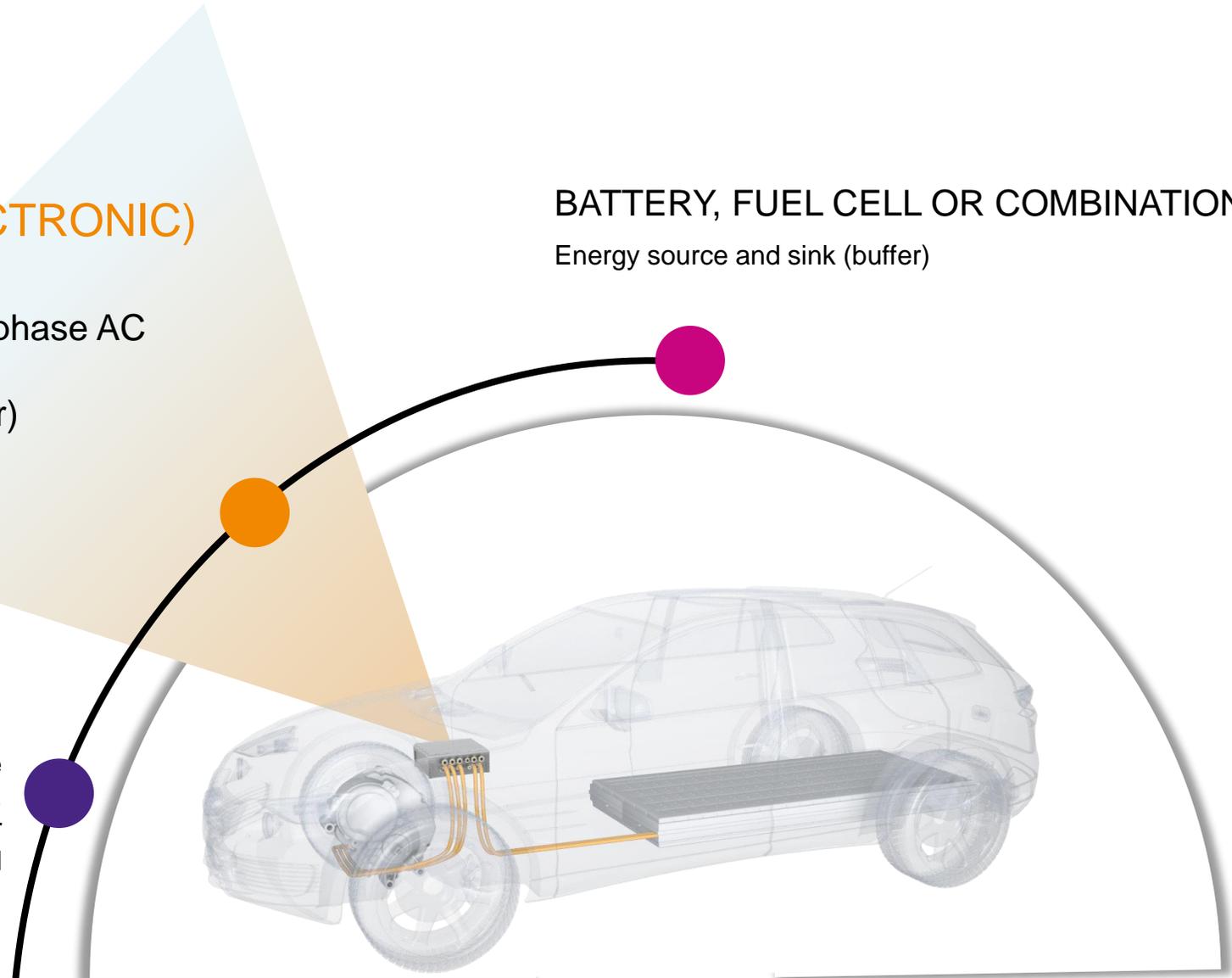
- Intelligent mini-computer
- Converts DC to rotating multiphase AC
- Controls torque
- Protects the actuator (e-motor)
- Heart = power electronics
- Brain = software

BATTERY, FUEL CELL OR COMBINATION

Energy source and sink (buffer)

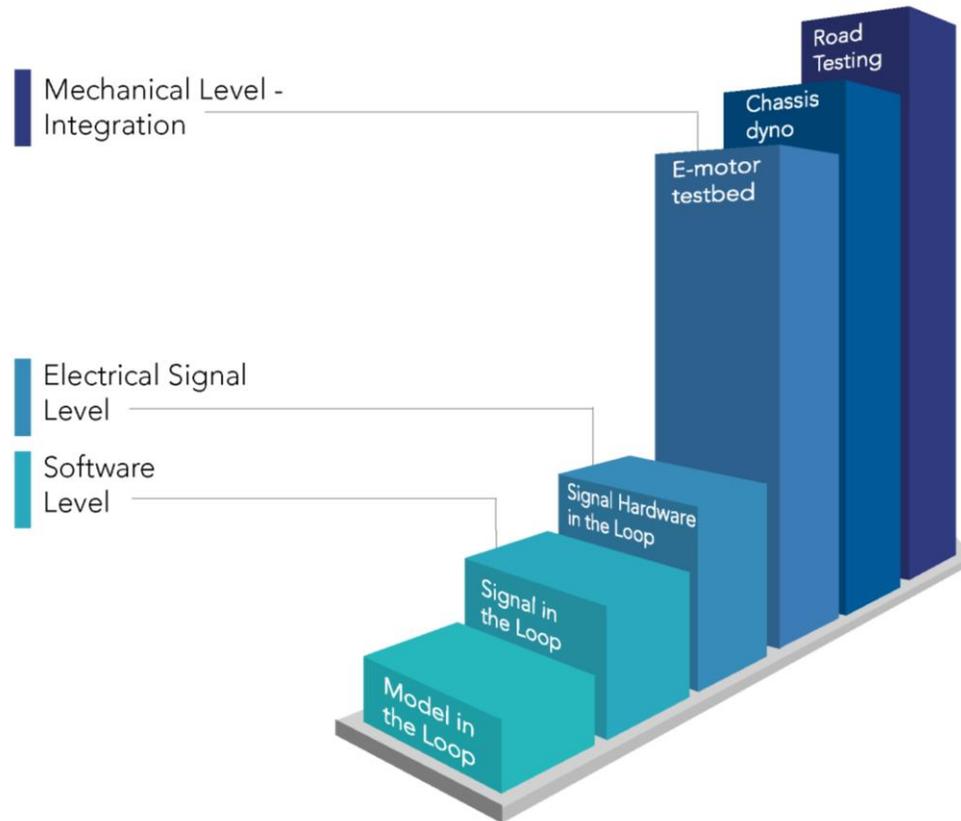
E-MOTOR

Transforms electric current into torque through “copper and iron”.
Is an actuator controlled from the inverter in a closed loop control



Powertrain Testing

Inverter Testing Methodology



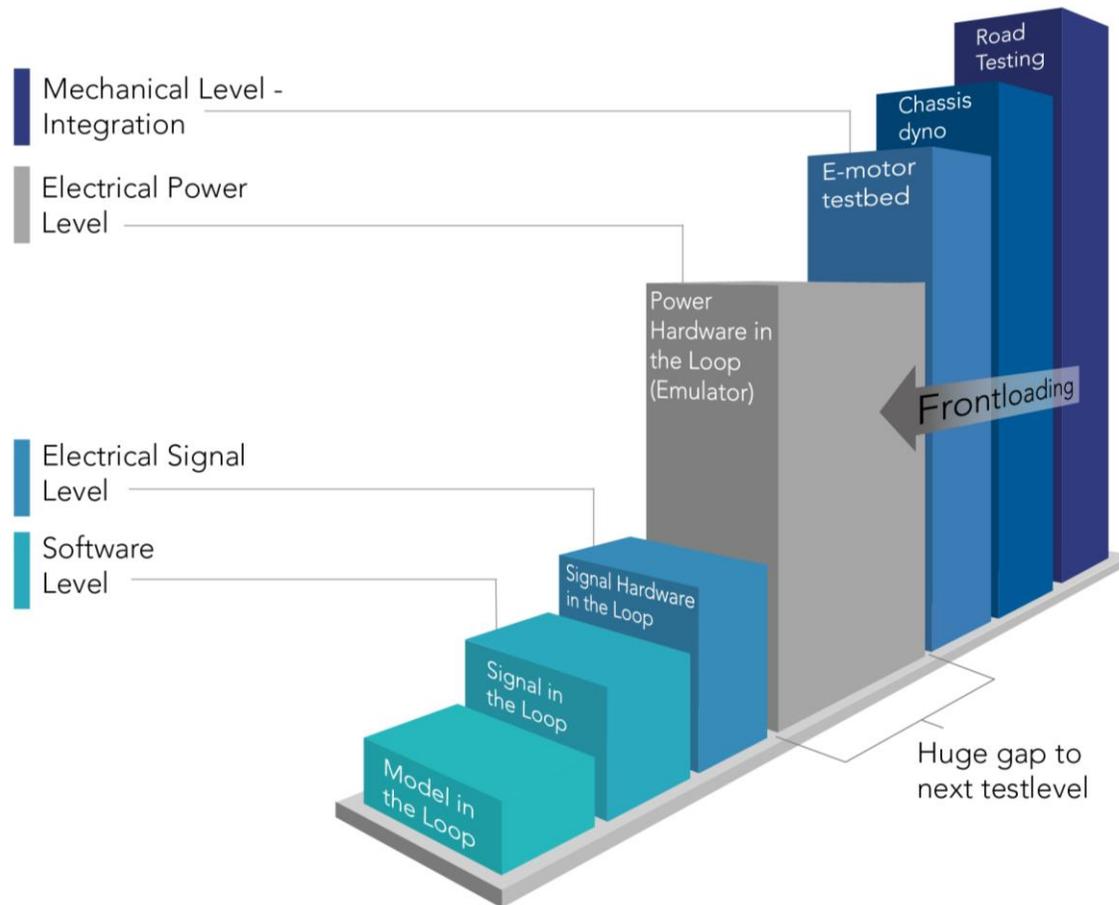
According to the traditional process...

On an E-motor testbed, the combination of inverter and electric motor is tested.
The electrical power level of the inverter is not tested before **integration** with the e-motor takes place



Powertrain Testing

Inverter Testing Methodology

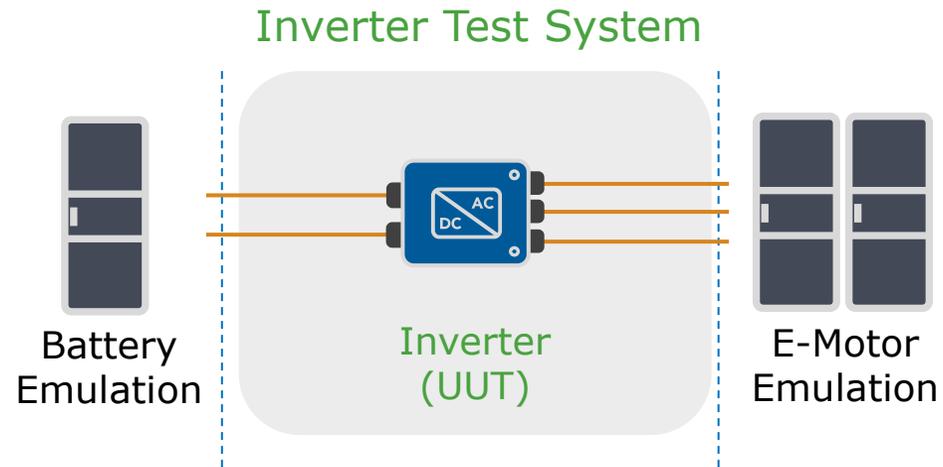


Frontloading of tests at full power...

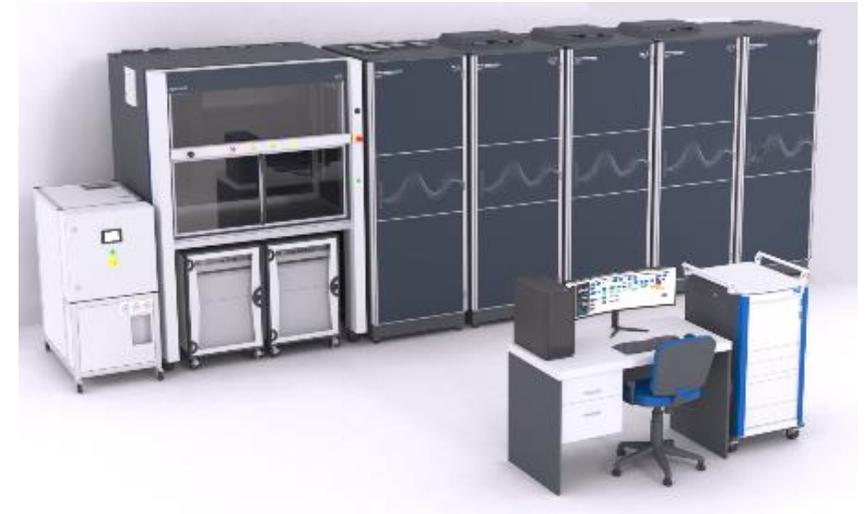
- No real e-motor needed
- Testing at full voltage and power
- Protection of the inverter
- No mechanical testbed
- Failure emulation
- Emulated "driving"

Powertrain Testing

Inverter Testing Methodology



- E-motor/gearbox not needed
- Easy evaluation of inverter issues
- Inverter can be tested to the performance limits
- No influence of dynamometer characteristics
- Fault injection is simple, safe and reproducible
- Test setups and test runs are extremely fast



Precise emulation

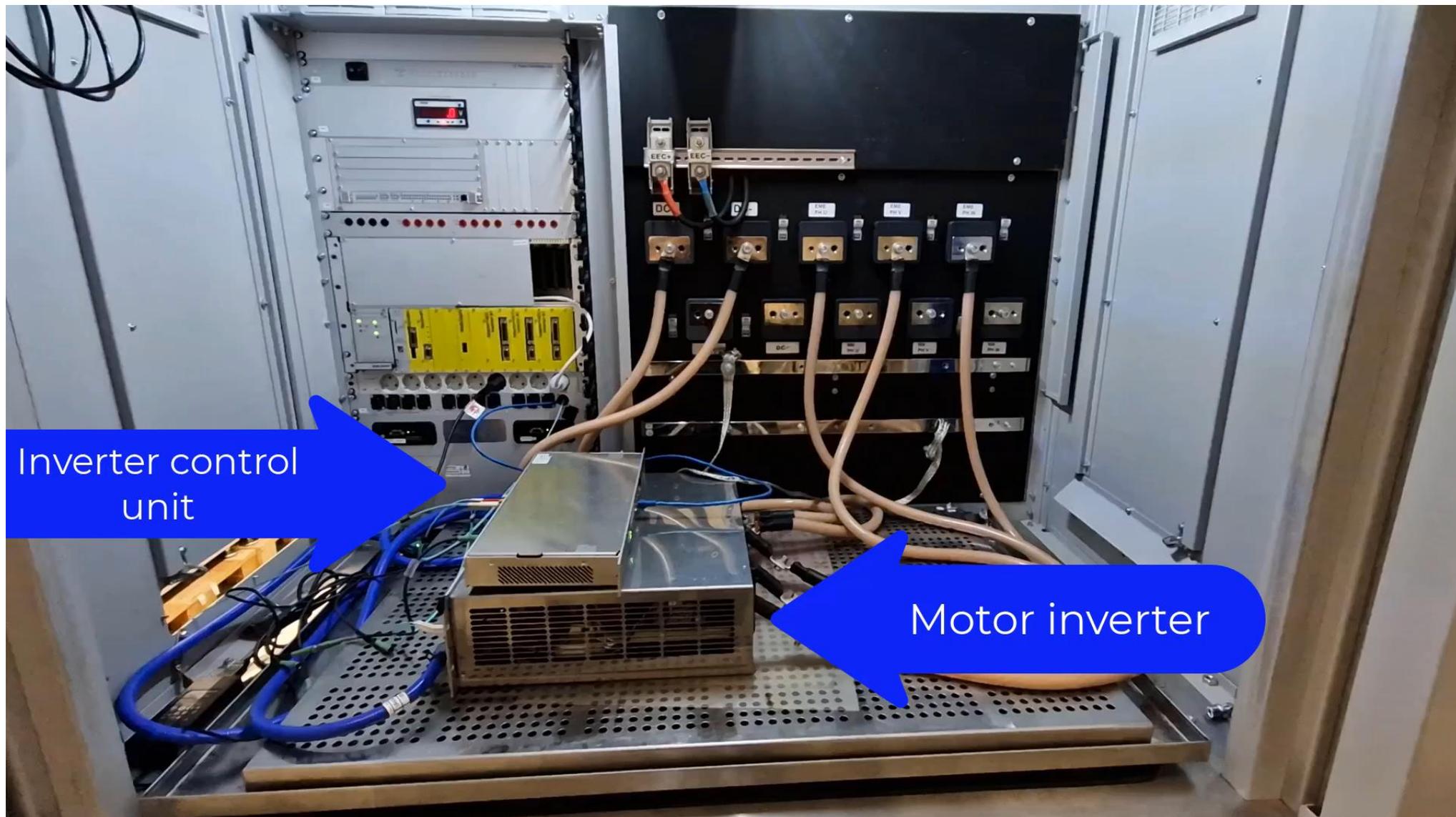
Powertrain Testing

Inverter Testing Methodology



Powertrain Testing

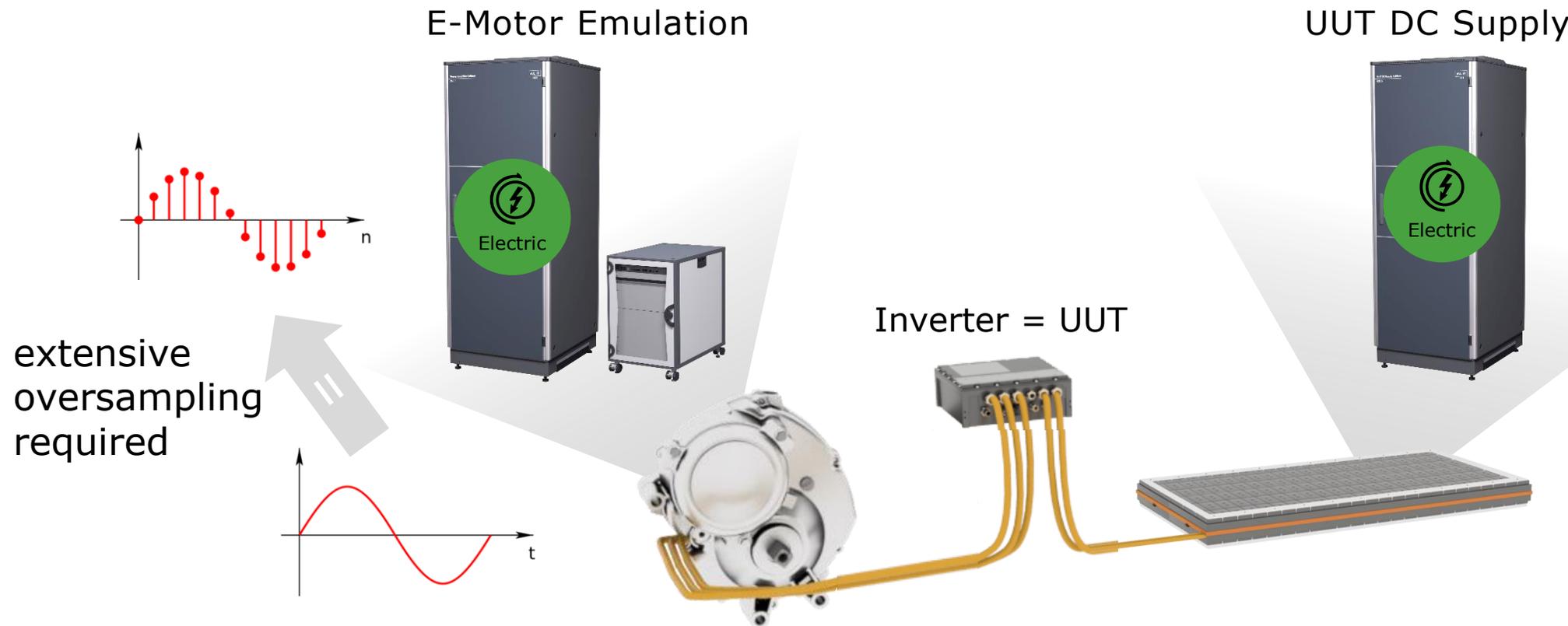
Inverter Testing Methodology



Software Testing

Inverter Testing Philosophy

Real systems operate in continuous time. As a result, emulators require real-time systems.



Agenda

- Powertrain Testing using E-Motor Emulators
- Accelerating Inverter Software Release Cycles
- Simulink® integration with Speedgoat Test Systems
- Demo using Simscape™ Battery™ and Powertrain Blockset™



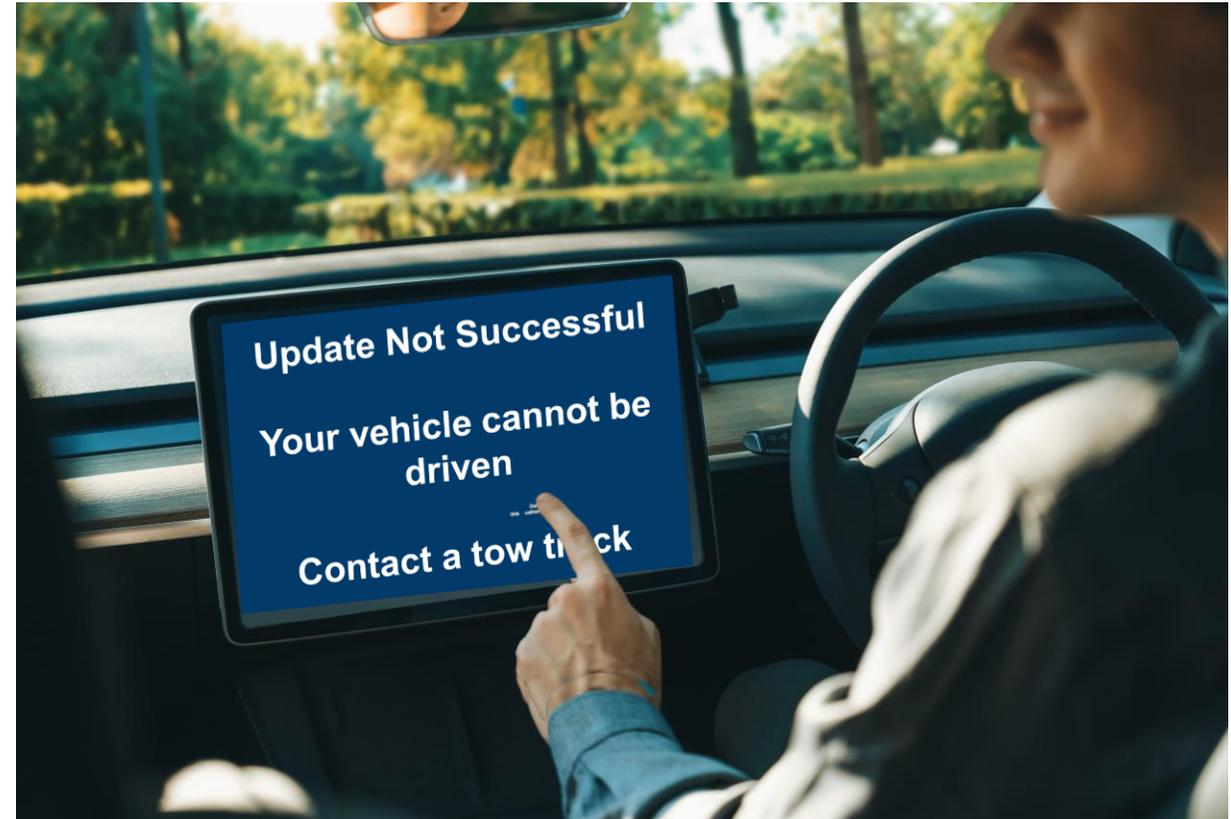
Why test Inverter Software Releases?

New software updates every few weeks

- Over-the-air updates
- Normally installed during idle conditions
- Different control units get updated
- Interactions with multiple charger types
- Includes safety and critical functionality
- Minor changes in software can have massive effects

Issues reported after an update:

- Unable to use fast charging
- The vehicle cannot be driven
- ADAS issues (Recall)
- Sudden power loss while driving (Recall)



EV Software Release Cycles

Test types for software testing

- Typical tests for software release testing
- They have to be performed for each software release (regression tests)
- Example from German OEM.

A. C. Kulzer et al. (Hrsg.): ISSYM 2023, Proceedings, S. 448–459, 2023.

https://doi.org/10.1007/978-3-658-42048-2_32

Inverter Test Systems for Remote and Unattended Function Testing

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² AVL SET GmbH, Wangen im Allgäu, Germany

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1 project

1000 tests

100 hours

1 typical project consists of 1000 tests and we need to perform these tests in 100h → these tests need to be completed for every software release (regression tests) and need a high level of automation.

Diagnostics and flashing

Network and interface

Inhouse developed functions

System limitations

Sensors and actuators

L1 safety functions

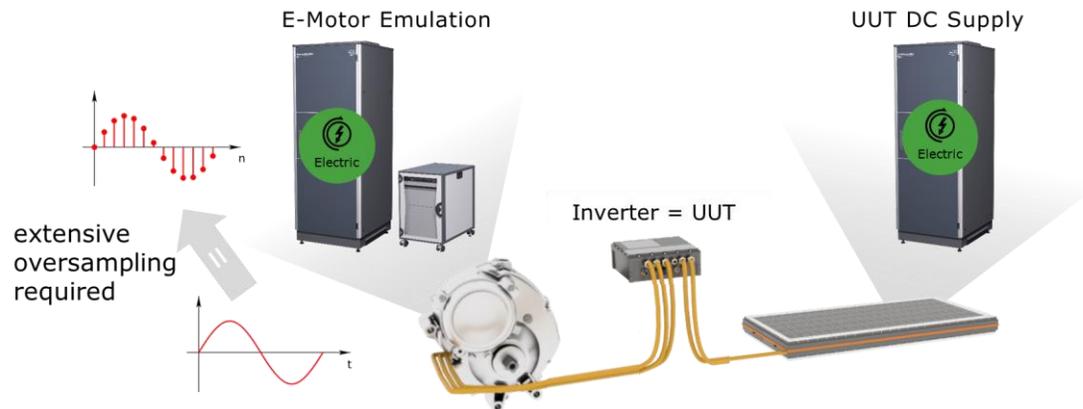
L2 safety functions

Other system functions

EV Software Release Cycles

Test types for software testing

- Even if they just test software, some tests require real power flow to be representative.
- So they are mainly performed on an inverter test system (= **E-Motor Emulator**)



Diagnostics and flashing

Network and interface

Inhouse developed functions

System limitations

Sensors and actuators

L1 safety functions

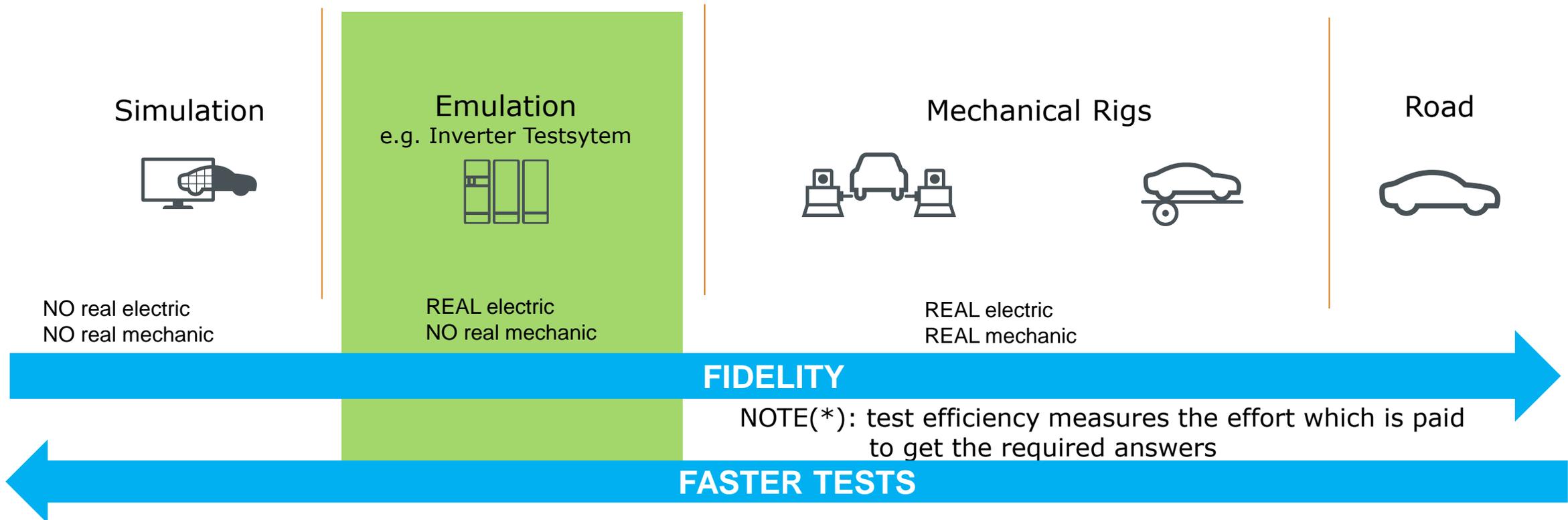
L2 safety functions

Other system functions

Powertrain Testing

Inverter Testing Methodology

... test efficiency^(*) will be a main differentiator:
(test efficiency measures the effort which is paid to get the required answers...)
Test Efficiency = Test Coverage / (Costs * Time)



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About Speedgoat

- MathWorks associate company, incorporated in 2006 by MathWorks employees in Switzerland, with subsidiaries in the USA, Germany and worldwide Distributors
- Provider of real-time test systems, expressly designed for use with Simulink
- MathWorks and Speedgoat people involved developing real-time simulation and testing solutions has continuously grown (currently 200+)
- MathWorks and Speedgoat are collaborating at all levels



A Scalable and Unified Solution for Testing Electric Drive Controls

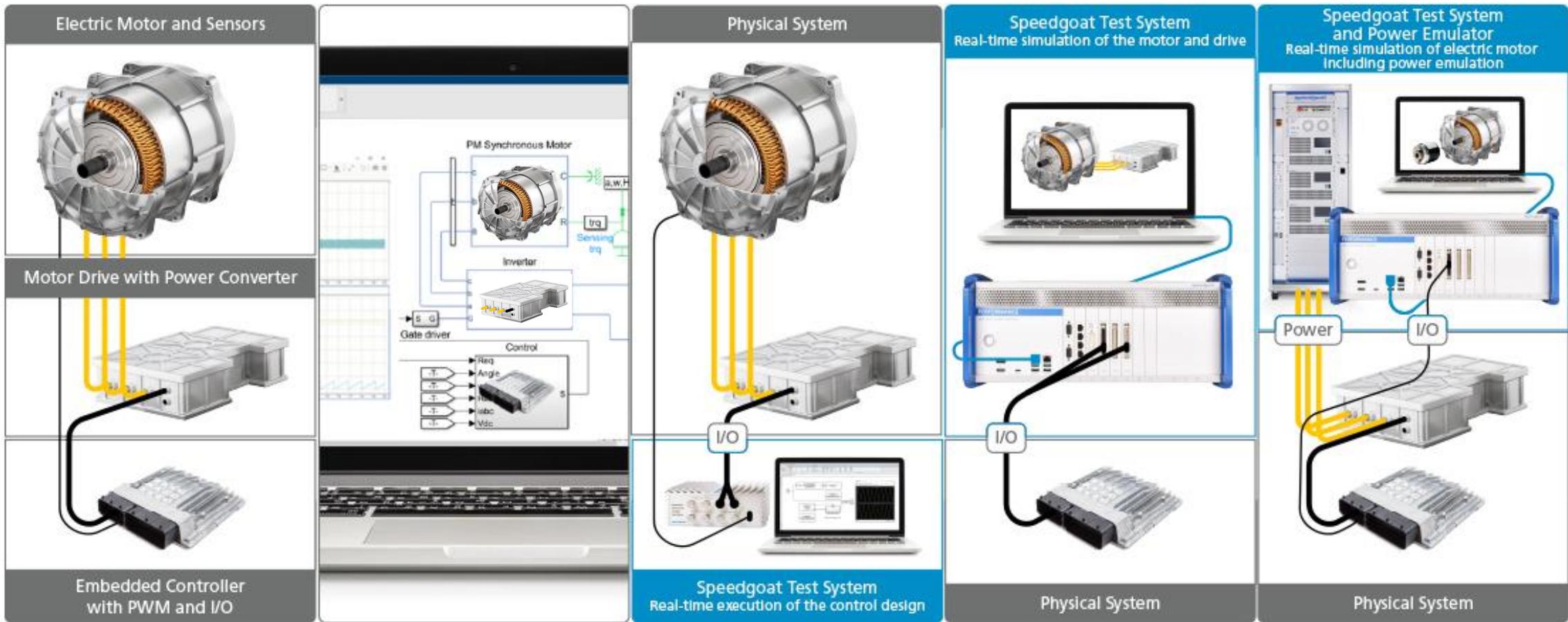
Systems to be Developed

Desktop Simulation
Including model and software-in-the-loop (MIL and SIL)

Control Design Prototyping
with real-time execution of the control design

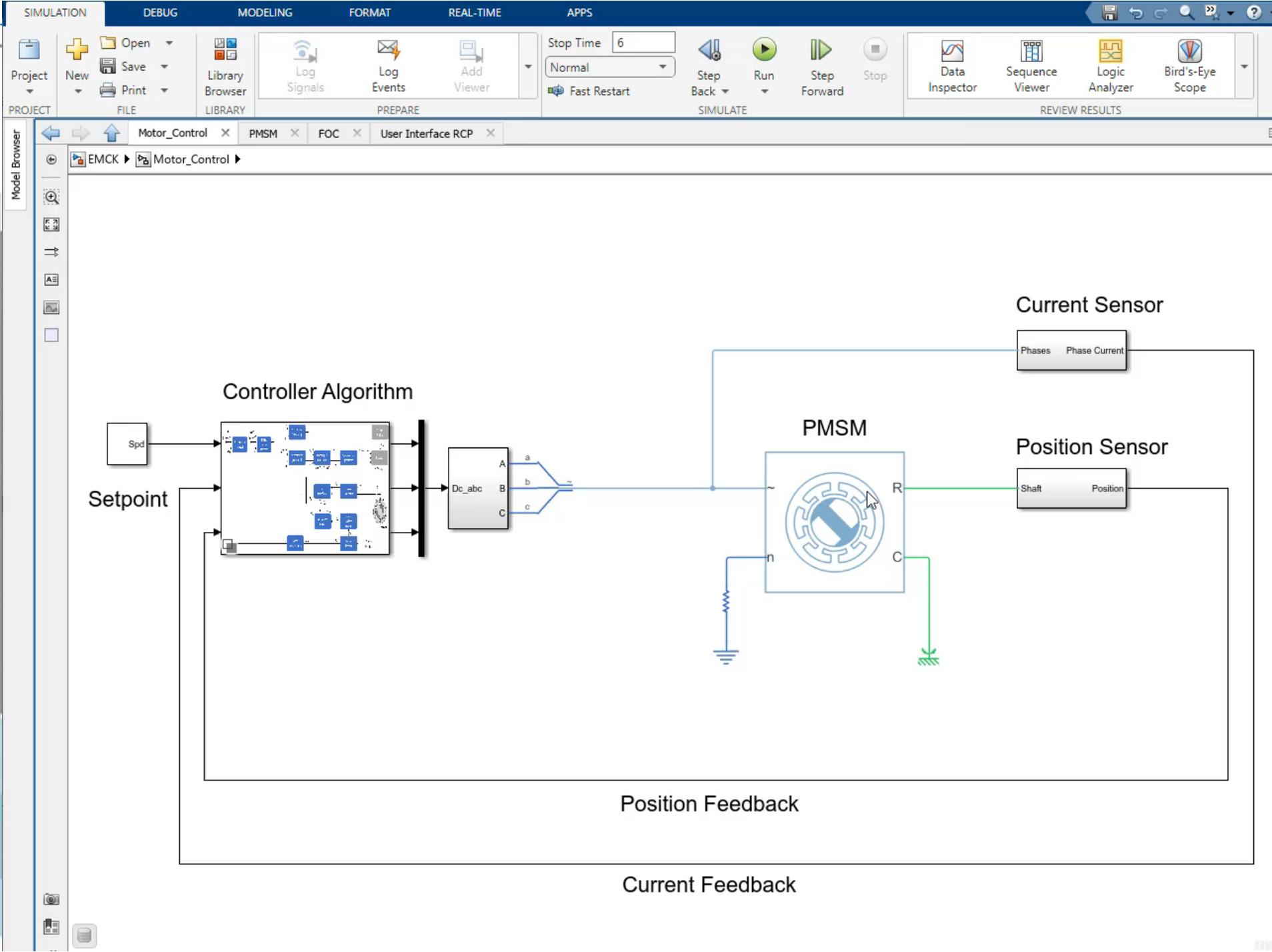
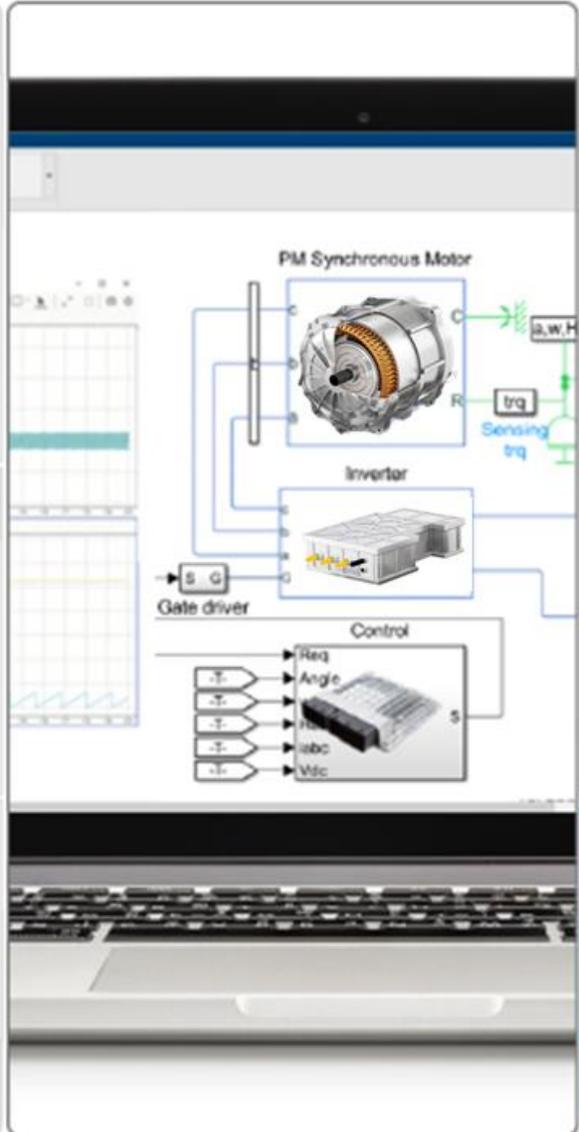
Embedded Controller Testing
HIL simulation of the electric motor and drive

Motor Drive Testing
Power HIL of electric motor with electric power emulation

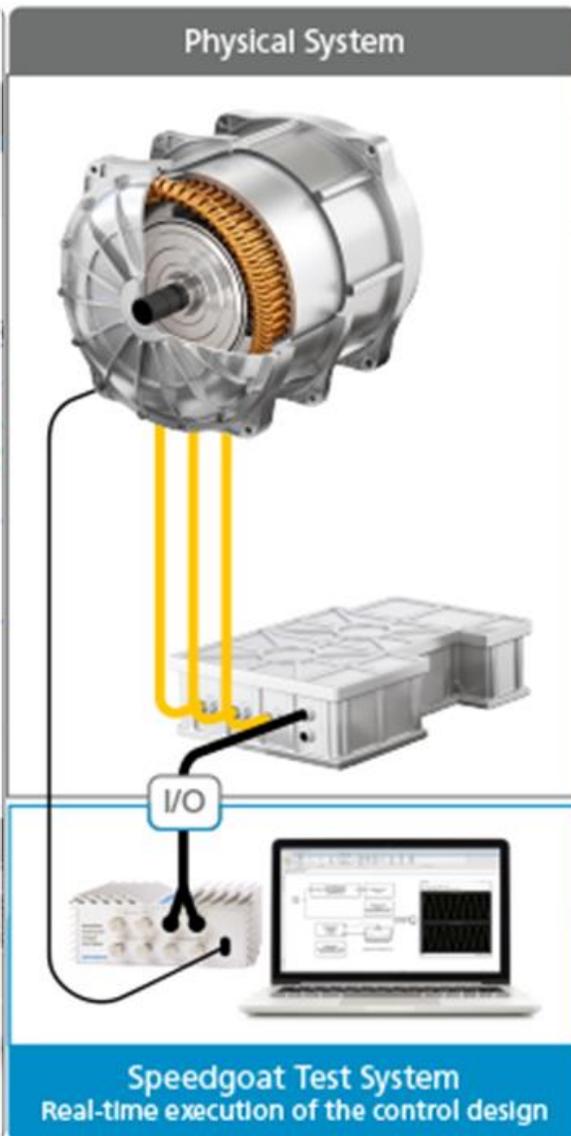


Desktop Simulation

Including model and software-in-the-loop (MIL and SIL)



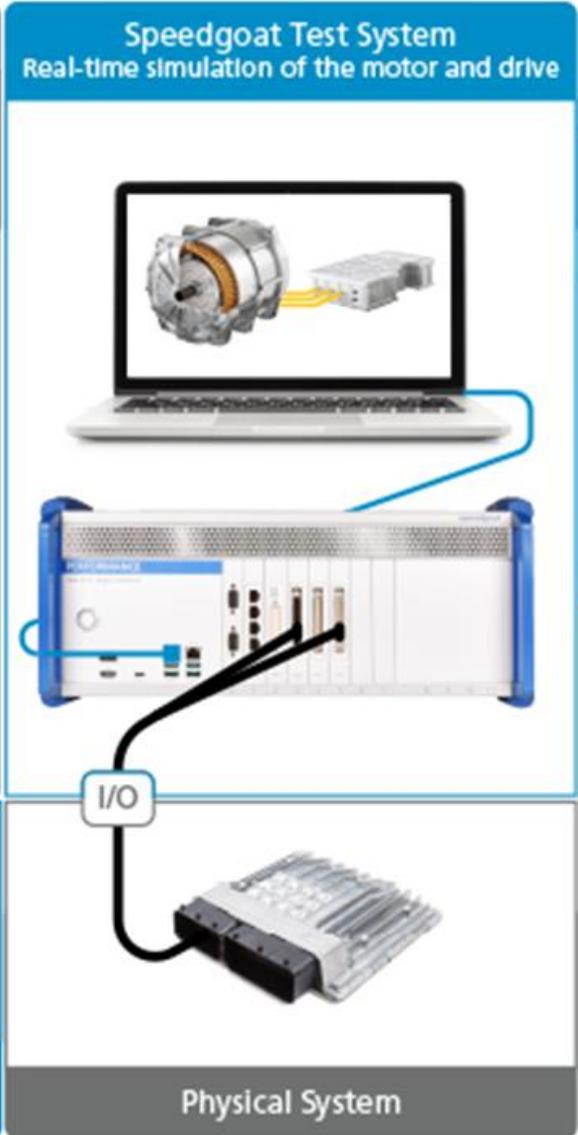
Control Design Prototyping
with real-time execution of
the control design



Embedded Controller Testing

HIL simulation of the electric motor and drive

Speedgoat Test System
Real-time simulation of the motor and drive



The Speedgoat Test System is shown as a laptop displaying a 3D model of an electric motor and drive, connected via a blue cable to a rack-mounted hardware unit. Below the hardware unit, an I/O interface is shown connected to a physical system.

I/O

Physical System

Embedded controller
Unit under Test



High-fidelity power electronics models in FPGA



Protocol communication

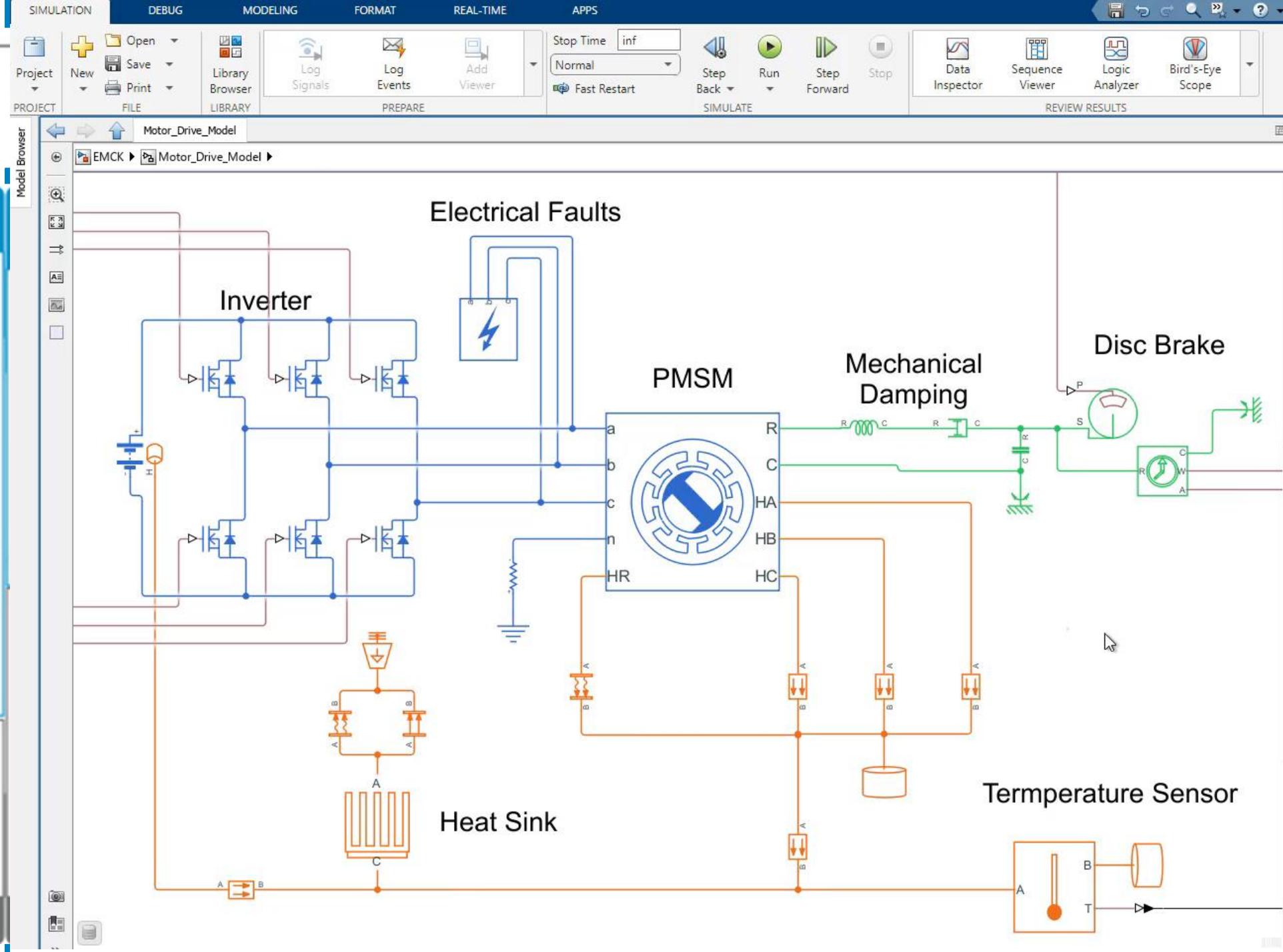
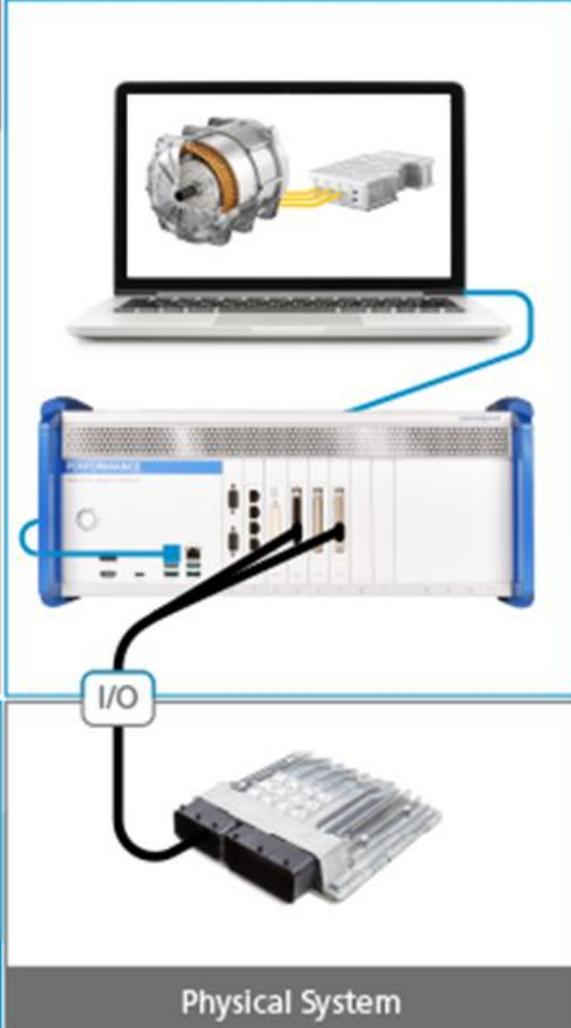
I/O, PWM, and sensor emulation

Embedded Controller Testing

HIL simulation of the electric motor and drive

Speedgoat Test System

Real-time simulation of the motor and drive

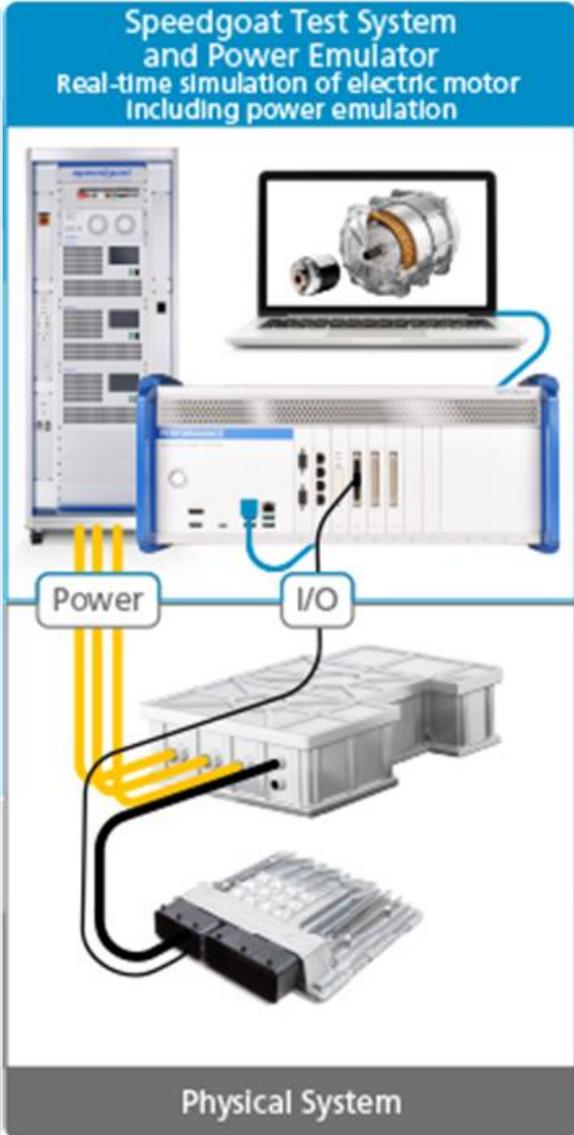


Motor Drive Testing

Power HIL of electric motor with electric power emulation

From 1 kilowatt...

to hundreds of kilowatts



Speedgoat Power HIL Testbed



AVL E-Motor Emulator

Motor Inverter Testing using Motor Emulation

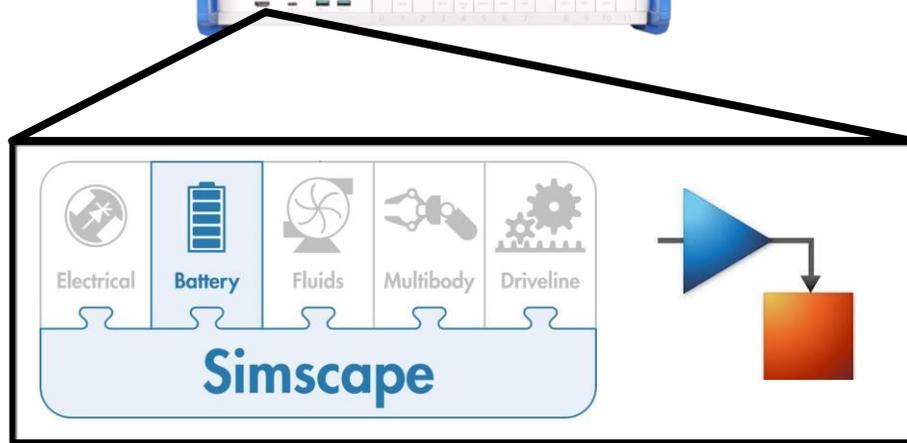
Speedgoat interface to AVL E-Motor Emulator

AVL E-ME uses the Aurora communication protocol as a **low latency interface** in the 1-2 μs range

- You can use your own toolchain / workflow
- Simulink® Real-Time™ and Speedgoat Test Systems provide a proven Aurora interface to AVL E-ME



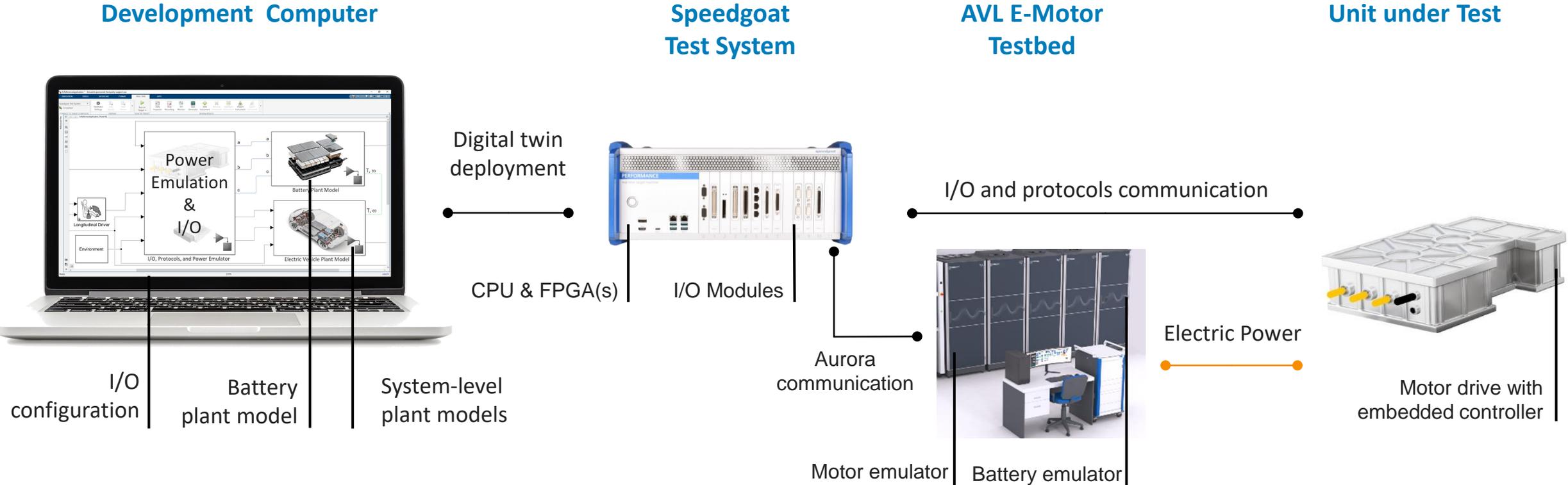
Aurora communication



- Fiber optic: not affected by EMI
- Aurora interface: 1-2 microsecond latency
- Bi-directional communication: sensors and controls
- Multi-gigabit transceiver: high-data throughput

Motor Inverter Testing using Motor Emulation

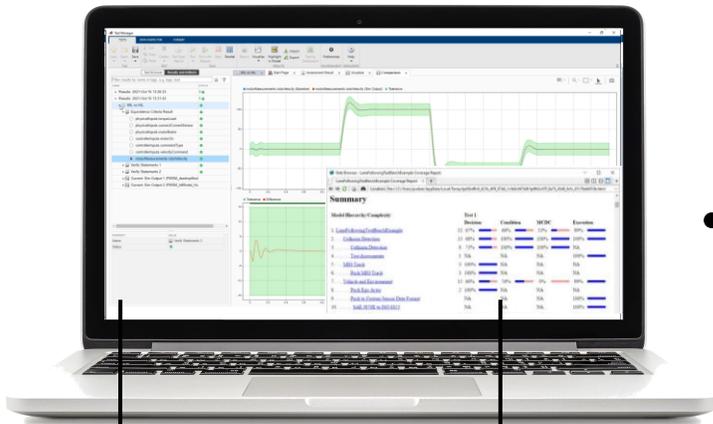
Speedgoat Test System and AVL E-Motor Testbed



Motor Inverter Testing using Motor Emulation

Speedgoat Test System and AVL E-Motor Testbed

Test Automation System



Configuration and management of tests

Results validation and report generation

Speedgoat Test System



Test automation

AVL E-Motor Testbed



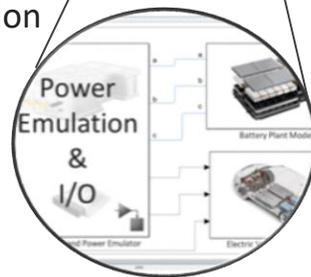
I/O and protocols communication

Electric Power

Unit under Test



Motor drive with embedded controller



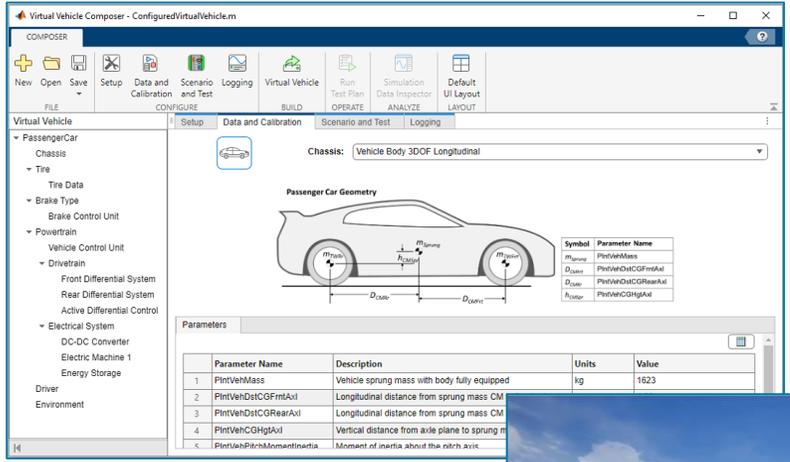
Real-time execution of battery and system-level plant models

Lowering the Barrier for Virtual-Vehicle Simulation

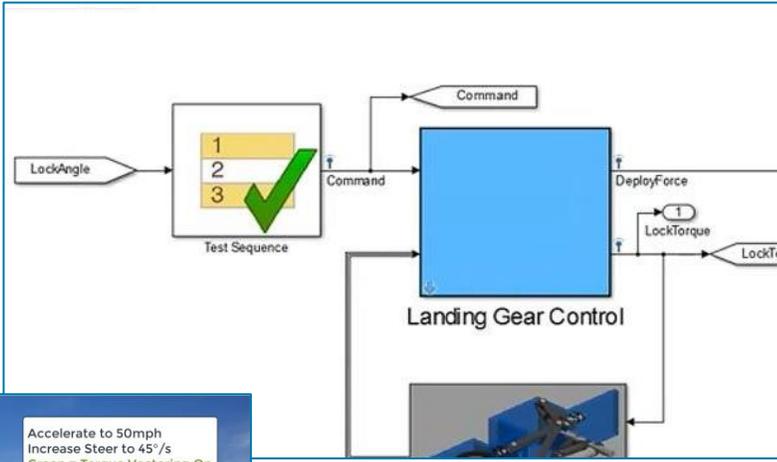
- (Power) HIL-ready and examples
- Component and system-level simulation
- Configuration tools



Virtual Vehicle Composer



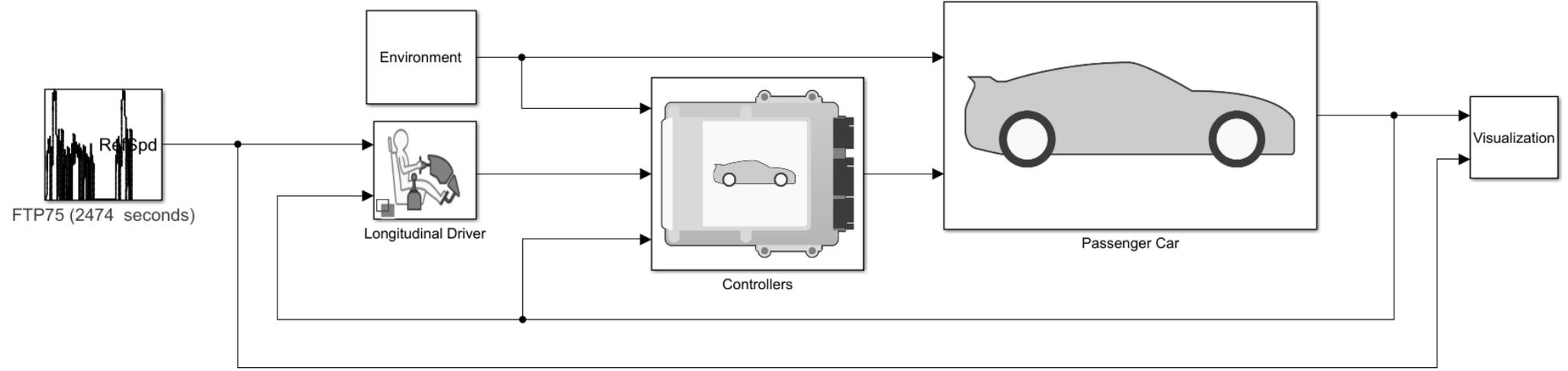
Test Automation



3D simulation

Bring your Simulink Models and Test Cases

- Stay in Simulink
- Use your own models
- Use your own workflow



Analyze Power and Energy

Variant Selected: Powertrain Blockset
Toggle To
Simscape Electric Plant

Help

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Bring your Simulink Models and Test Cases

- Stay in Simulink
- Use your own models
- Use your own workflow

Simulink®
Real-Time™

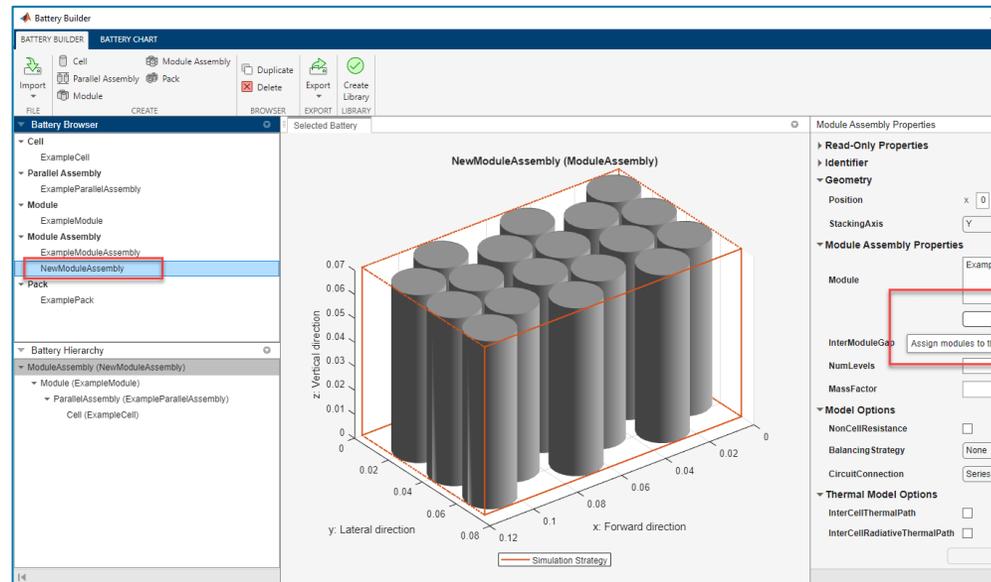
HDL Coder™

Powertrain
Blockset™

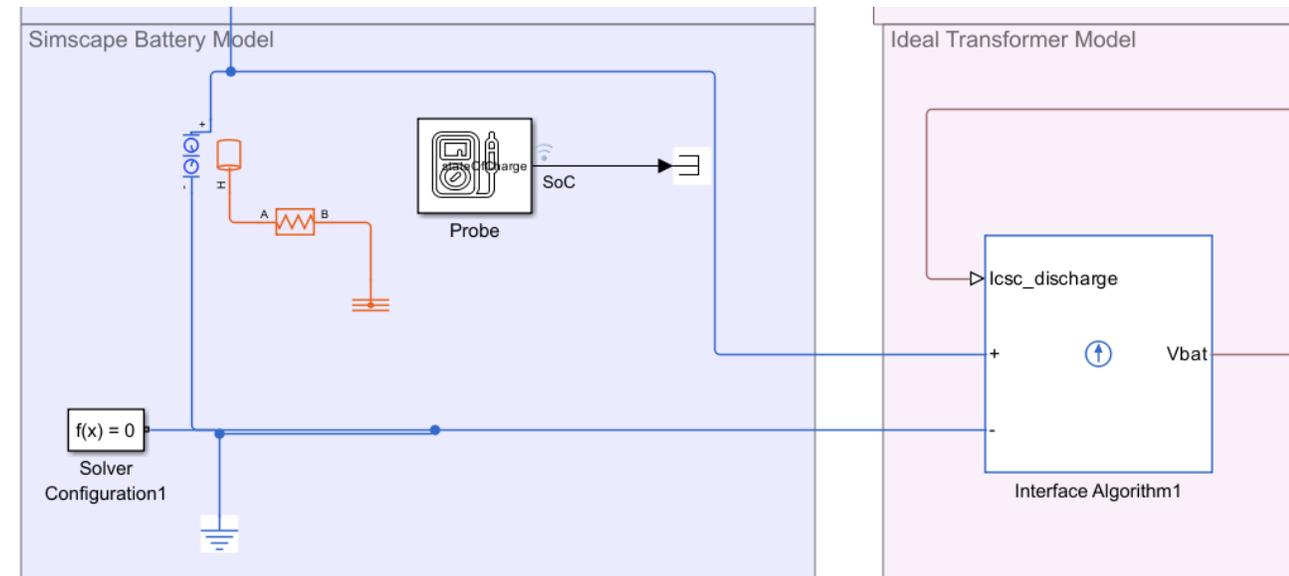
Simscape™
Electrical™

Simscape™ Battery™

Simulink®
Test™



Battery Builder



Single Particle Battery Model

Bring your Simulink Models and Test Cases

Simulink®
Real-Time™

HDL Coder™

Powertrain
Blockset™Simscape™
Electrical™

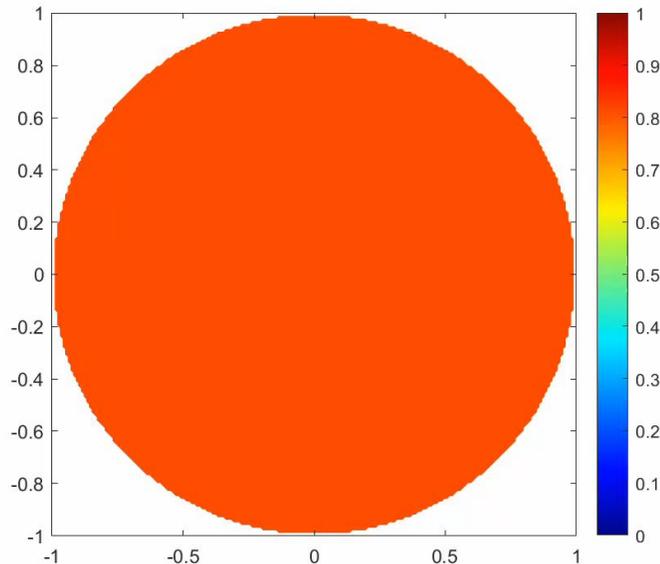
Simscape™ Battery™

Simulink®
Test™

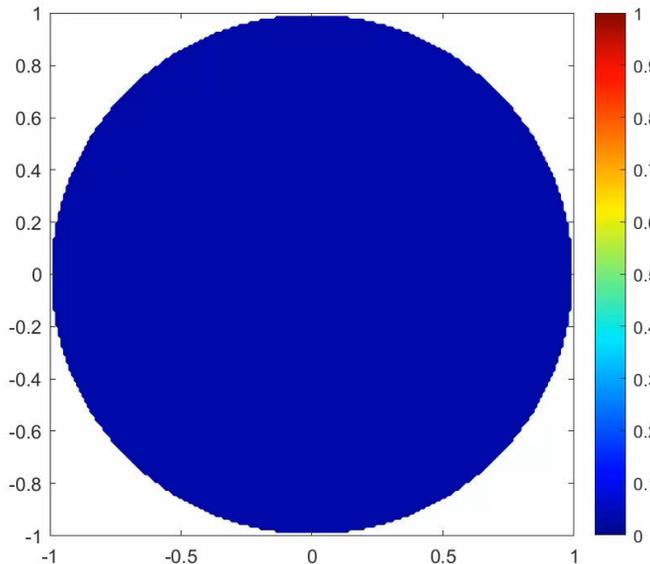
Real-time execution of Single Particle Model with Electrolyte (SPMe)

Li-ion Concentration (Normalized)

Anode Particle

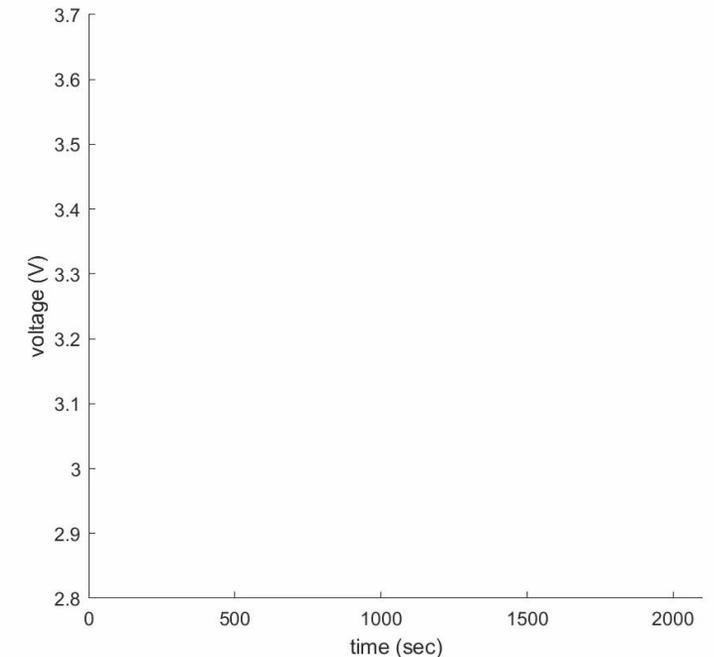


Cathode Particle



Terminal Voltage

During Discharge



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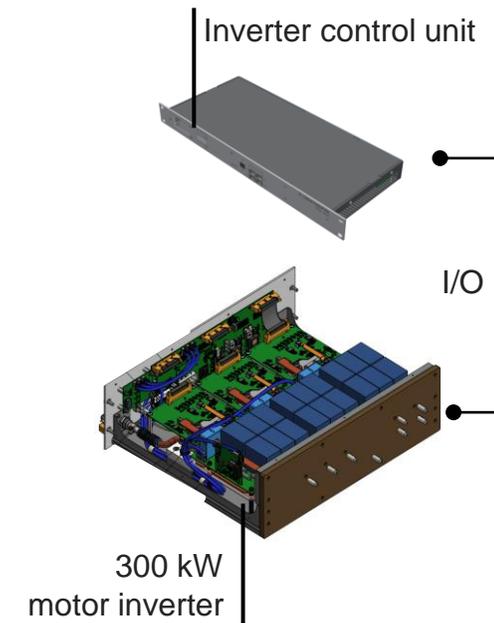
Development Computer

Demo using Simscape Battery and Powertrain Blockset

Unit Under Test

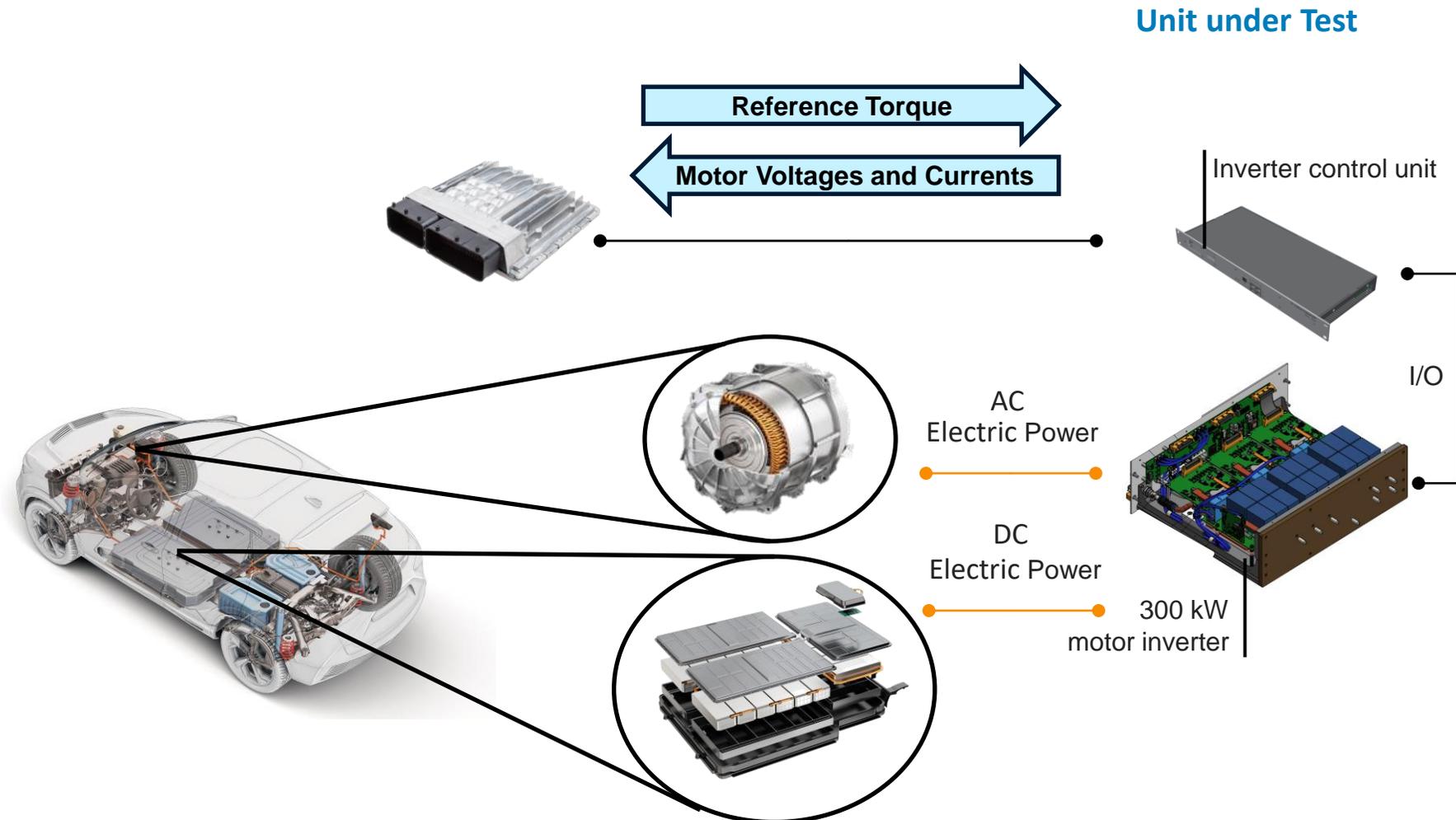


Unit under Test



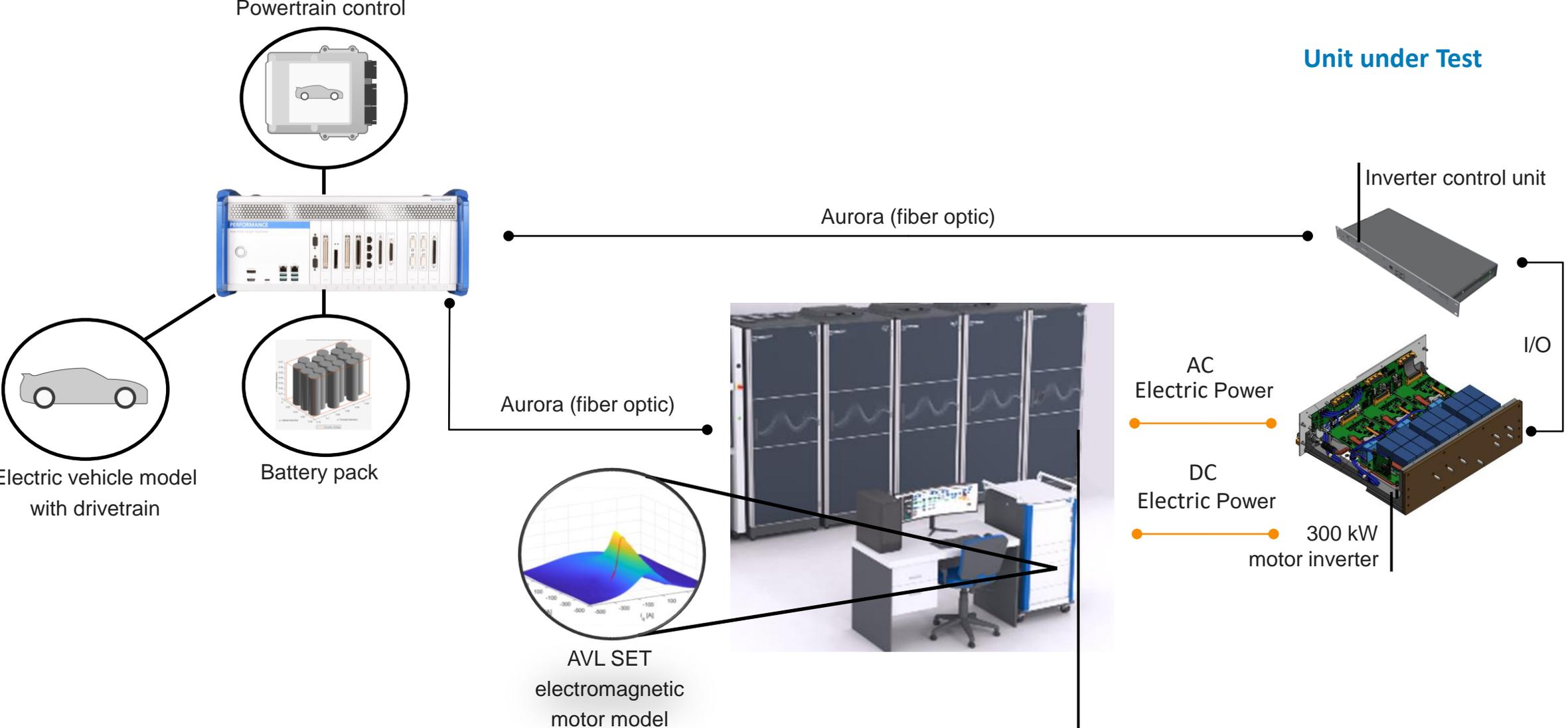
Demo using Simscape Battery and Powertrain Blockset

Unit under Test



Demo using Simscape Battery and Powertrain Blockset

Speedgoat Test System and AVL E-Motor Testbed

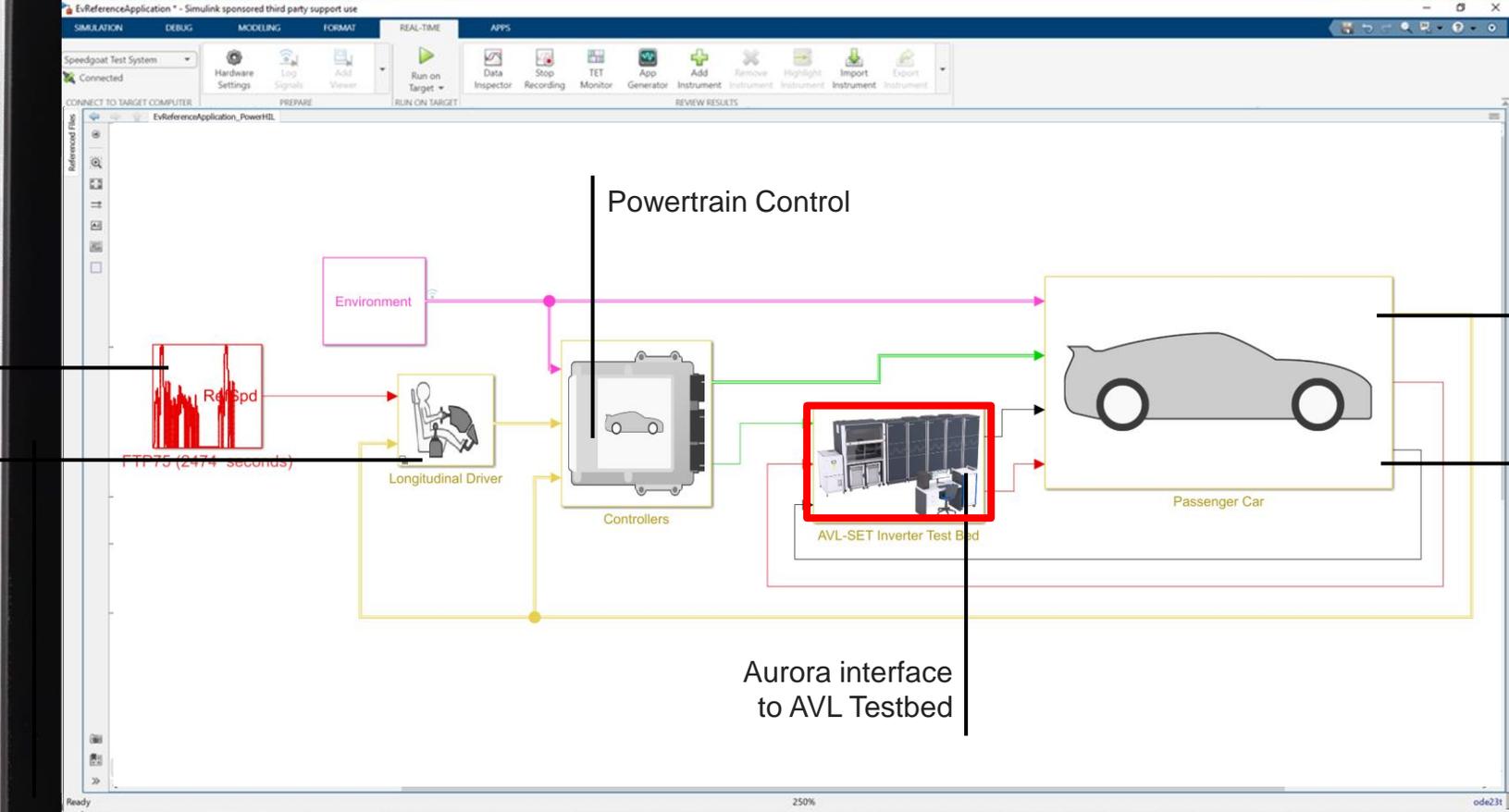


Powertrain
Blockset™

Simscape™
Battery™

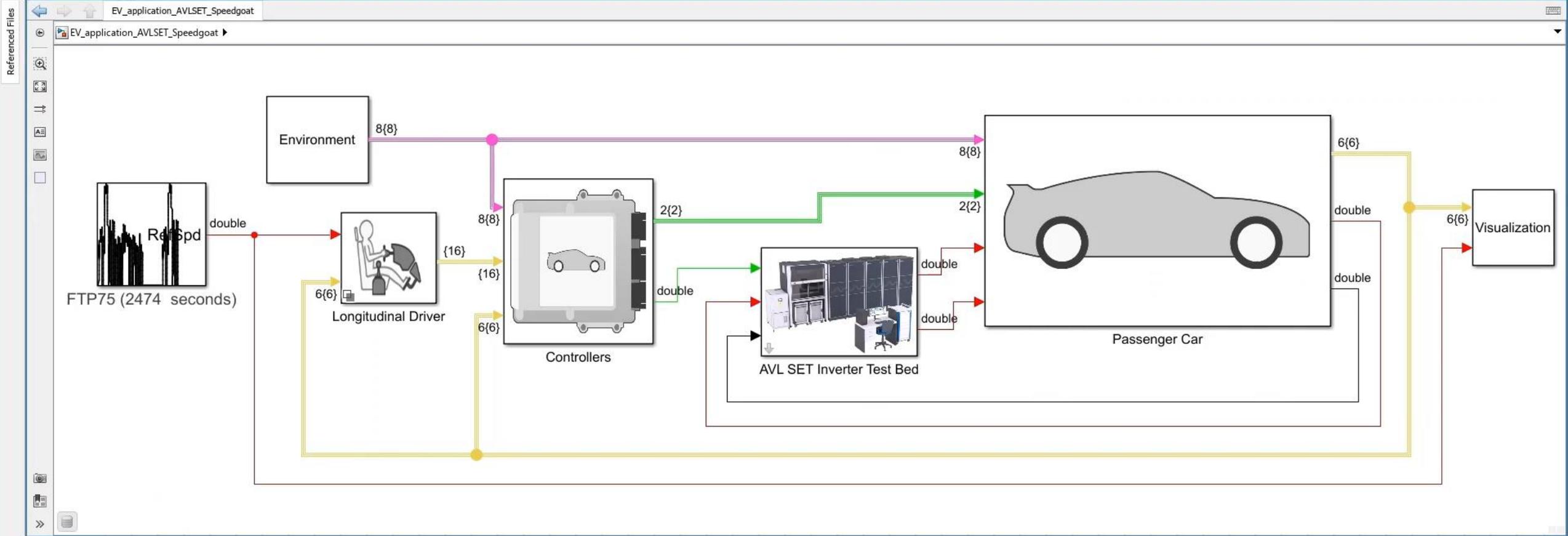
City Driving Cycle
EPA FTP-75

Driver model



Single Particle
Battery Pack Model

Vehicle Dynamics
and Transmission
Model



Diagnostic Viewer

0:01 PM: Model Save (| 0 1 0 |

▼ Model Save (EV_application_AVLSET_Speedgoat)

Using find_system without the 'Variants' argument skips inactive Variant Subsystem blocks in the search. This behavior will change in a future release to look at all choices of the Variant Subsystem. To find blocks that are active in simulation or code generation, compile the model and use the built-in variant filters with the 'MatchFilter' option. To find all blocks use filter '@Simulink.match.allVariants' with the 'MatchFilter' option.

► Show stack trace

Component: Simulink | Category: Model warning

Electric Drive Power HIL

Motor torque command (Nm): -3

Motor speed (rpm): 2660

Motor electric power (kW): -1

Battery voltage (V): 333

Direct/Quadrature voltage (V): Plot showing voltage signals over time (534.3 to 539.3).

Direct/Quadrature current (A): Plot showing current signals over time (534.3 to 539.3).

Motor Emulator outputs motor currents to the inverter

Electric Drive with Control Unit

Simulated Electric Drive & Motor

View diagnostics 40% T=537.803 21%

Key Takeaways

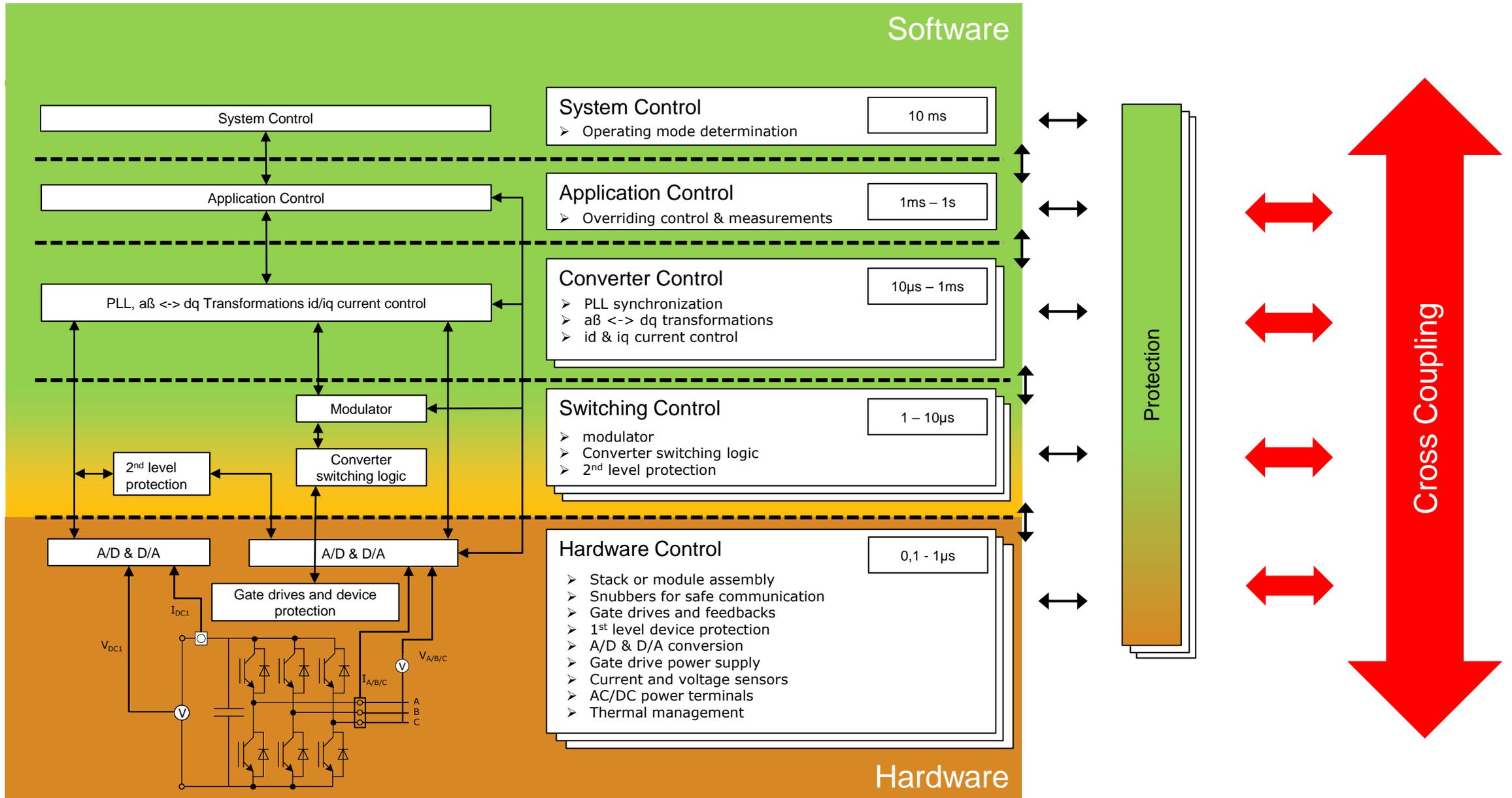
- Accelerate testing of inverter software release cycles using the AVL E-Motor Emulator (E-ME)
- Develop EV software from desktop simulation to (power) HIL testing with Speedgoat Test Systems
- Connect MATLAB® & Simulink® to AVL test rigs with Speedgoat Test Systems



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Thank you

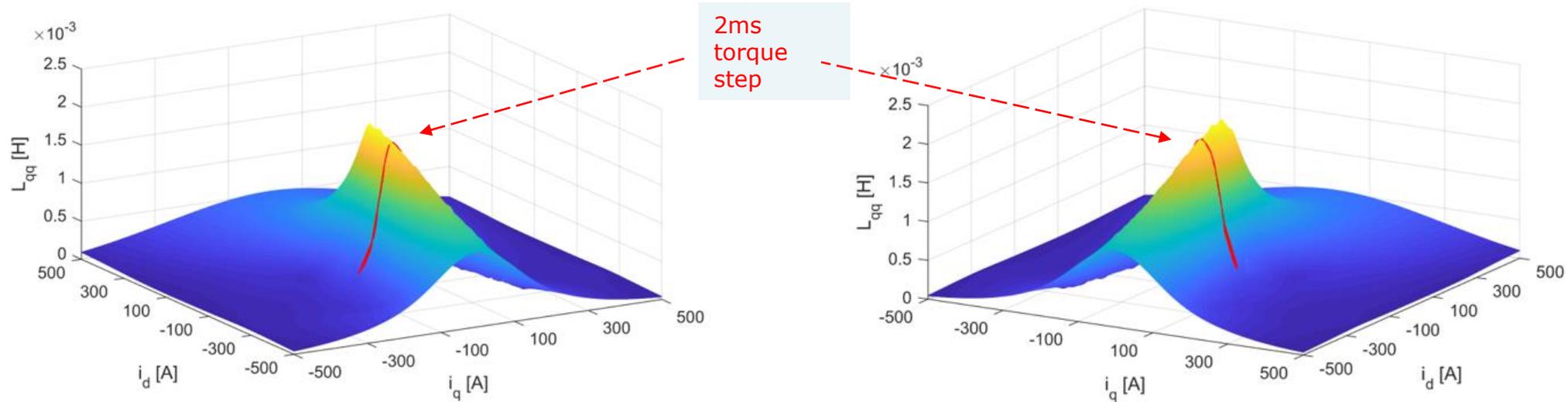




Software Testing

Use Cases

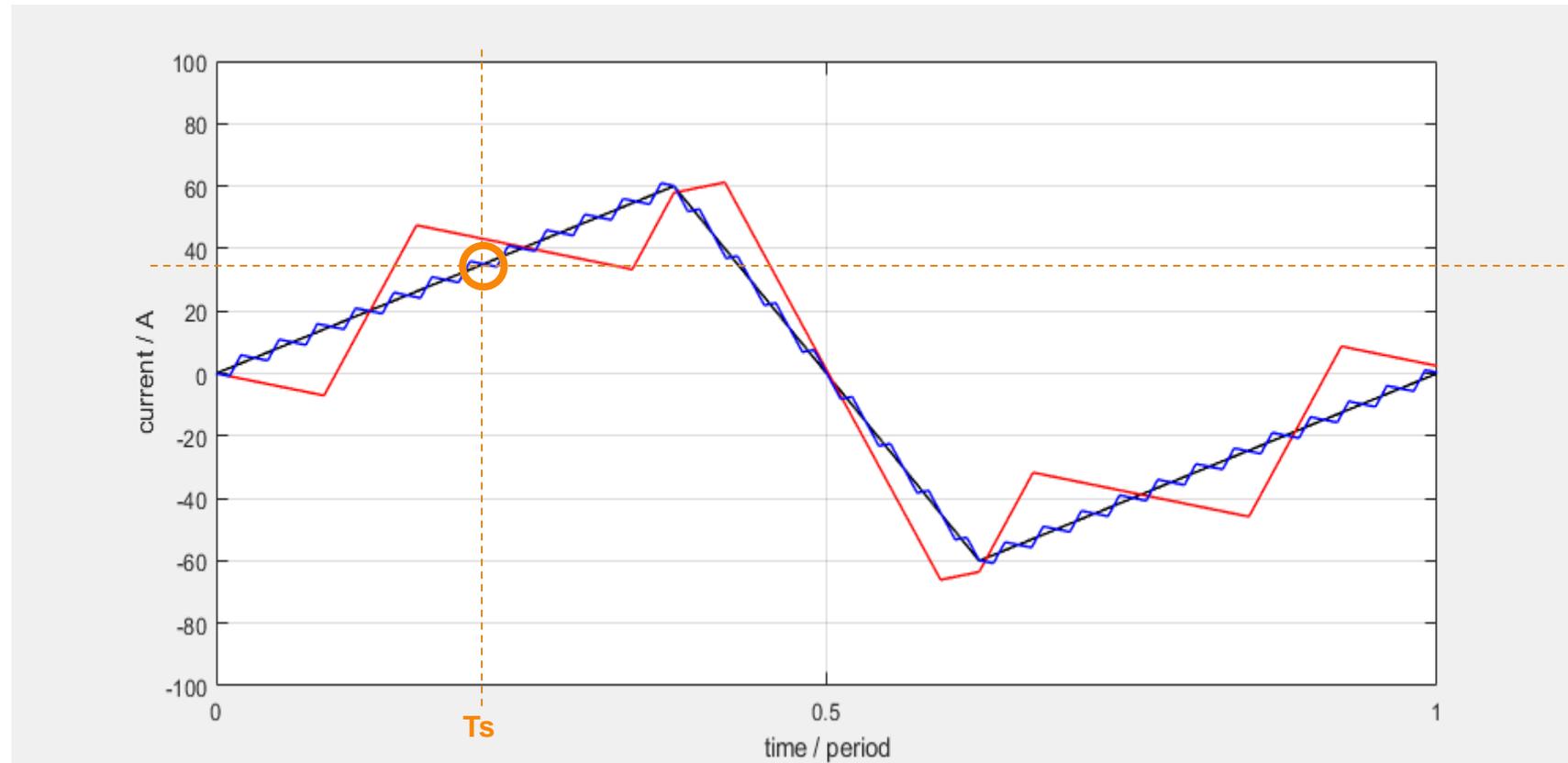
correct e-motor replication including e.g. saturation, cross-coupling, ...



The red line shows, how the emulated inductance (measured at the EME phases) exactly follows the programmed flux-linkage tables, - thereby emulating extensive saturation during a 2ms torque step from i_q -300A to +300A.

OTHERWISE...

emulators influence the test results and are not suitable for system tests



- Black: real e-motor
- Red: slow emulator
- Blue: fast emulator

Inverters (UUT) current sampling point T_s



- Torque offset must be “tuned”
- Emulator induced torque modulation (torque oscillates)

Powertrain Testing

Inverter Testing Methodology

