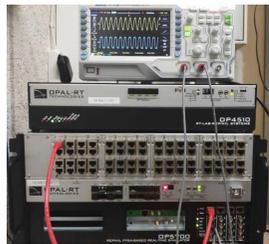
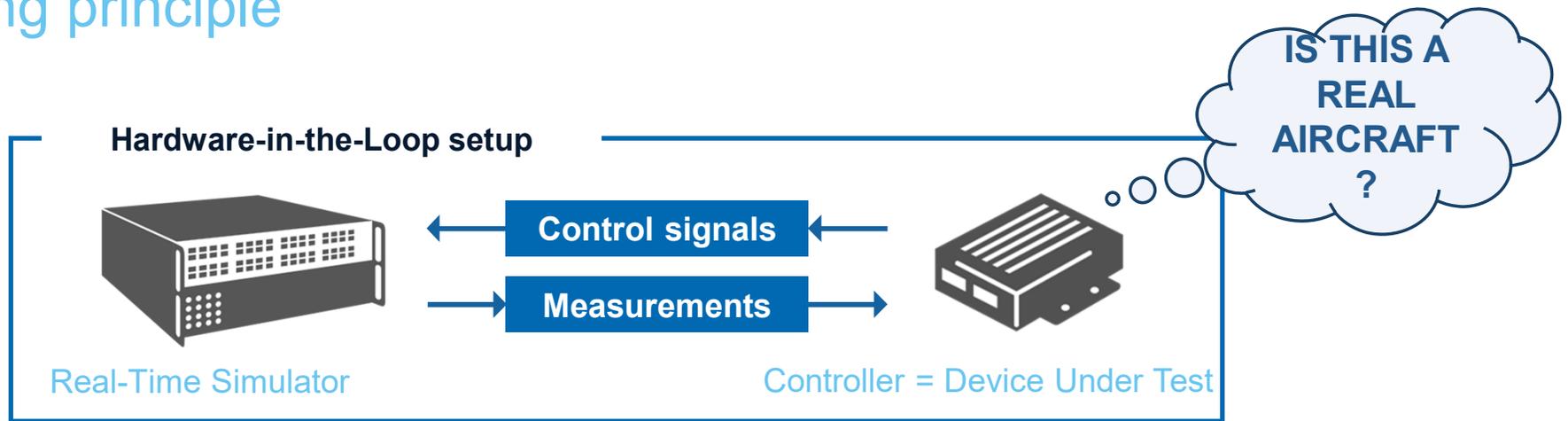


The background is a dark blue, monochromatic image. It features a large airplane in flight in the upper center, a city skyline in the background, and a map of Europe in the foreground. The map is overlaid with various transportation icons: a truck, a car, and a ship. A network of white lines and dots connects these elements, suggesting a global or interconnected system. The overall aesthetic is high-tech and futuristic.

From HIL to Power-HIL: Accelerating Motor Controller Development for Next-Generation Propulsion Systems

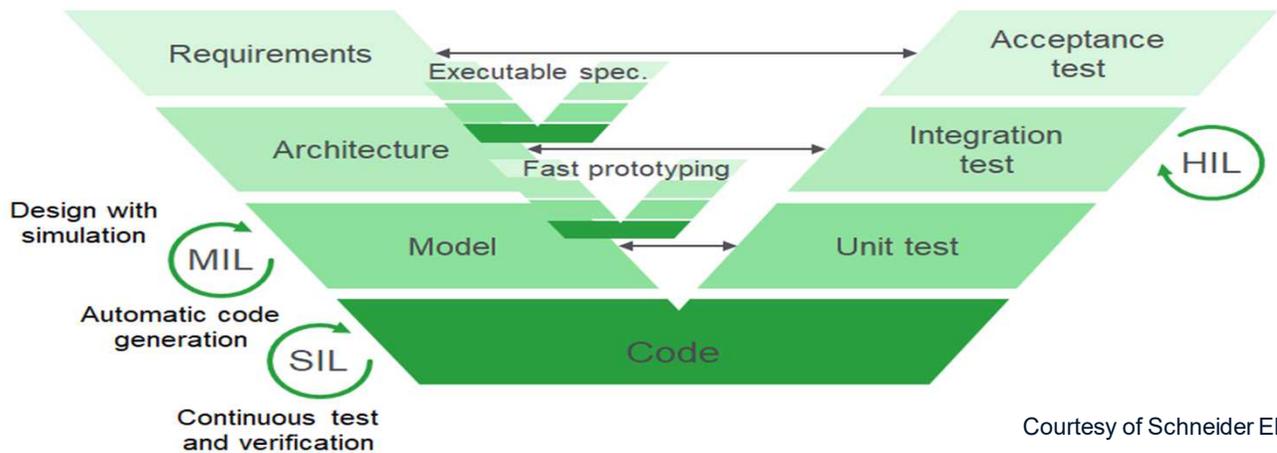
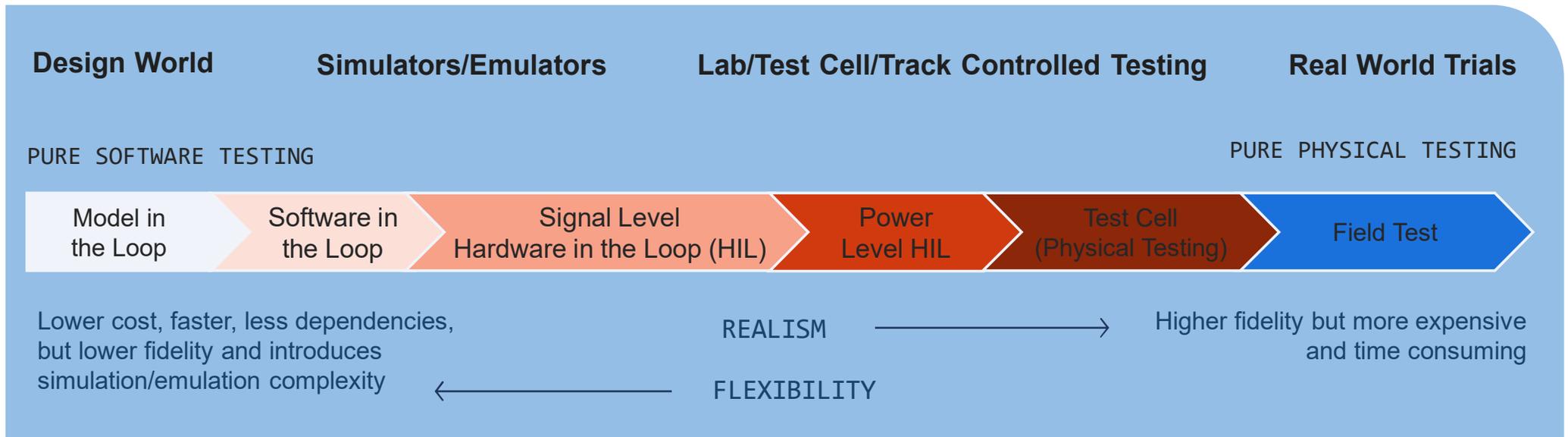
Timo Rösch,
Head of Mobility Business EMEA
FEB 25TH, 2026

Testing while developing to reduce development times: HiL-Testing principle



- Hardware-in-the-Loop (HiL) setup
 - Device under Test (DuT) – control, protection or monitoring system
 - Real-Time Simulator – digital simulation of a system controlled and/or monitored by DuT
 - Information exchange – analog and digital signals, digital communication protocols

TESTING APPROACHES ACROSS THE DESIGN LIFECYCLE

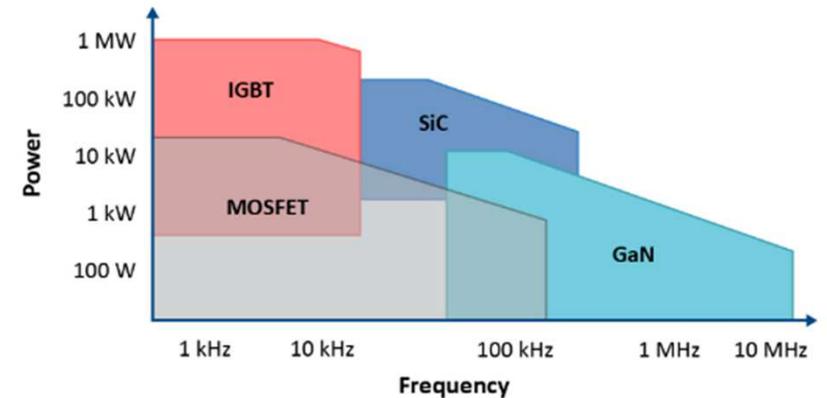


Courtesy of Schneider Electric

- Modern V-Cycle with iterative testing along the design / coding process

Trends in Traction and Propulsion

Component	Automotive Traction	Aerospace Propulsion
E-Motor	3ph to 6ph	3ph to 12ph +
Inverter (DC/AC)	2-level topologies 3-level topologies	2-Level topologies 3-level topologies Multi-Level-topologies
SemiConductor	IGBT SiC GaN	SiC-MOSFET GaN
Switching frequencies	20-50kHz inverter / up to 75-500kHz charger	20-100kHz inverter Up to 1MHz for aux. systems
Design principle	Cost & efficiency optimized	Safety first!

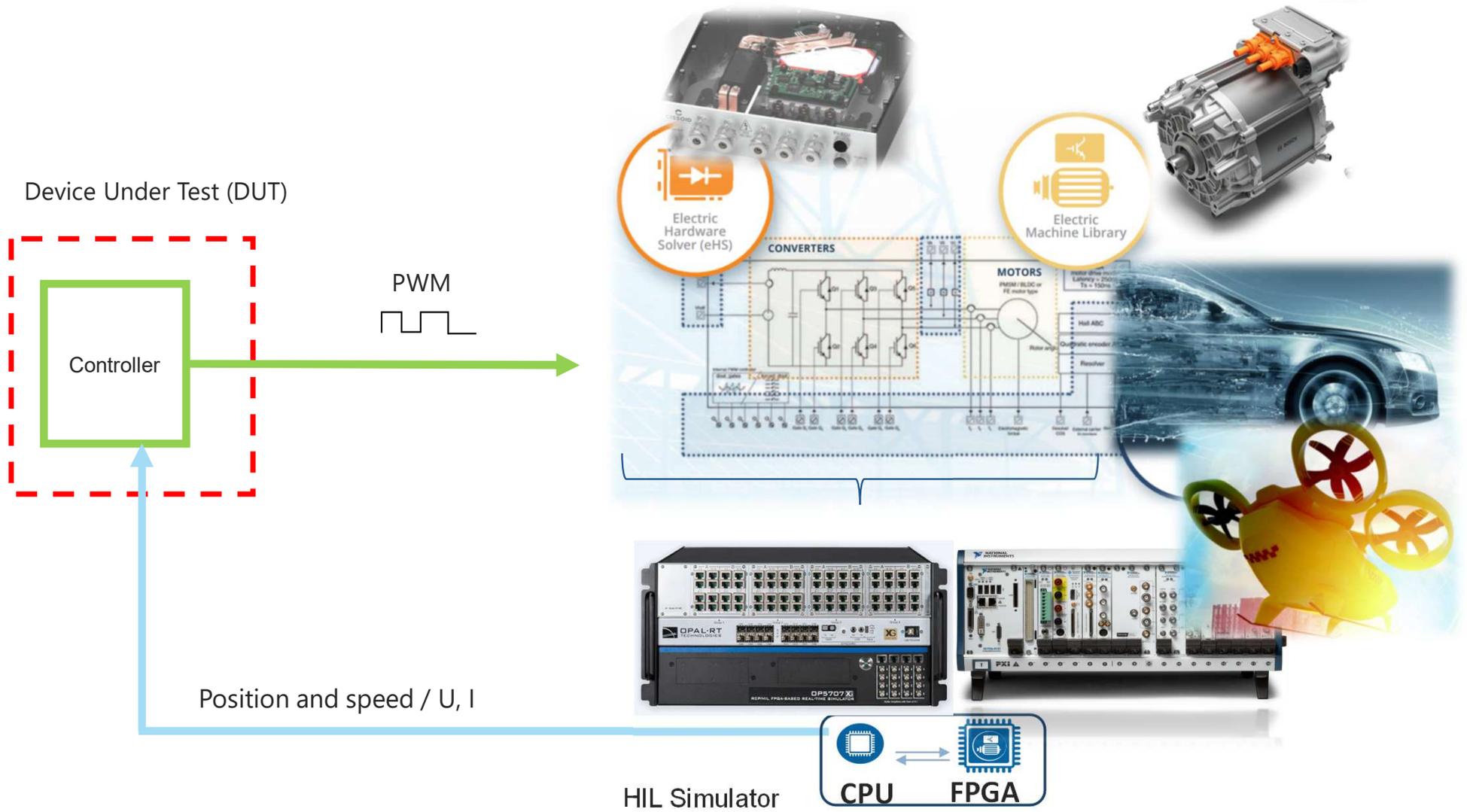


Resulting trends in Motor Controls

- New Modulation trends (different pulse patterns)
- Zero-sequence switching for reduced losses
- Phase-shift modulation
- Model predictive control
- AI optimized controls
- Sensor less controls and more...

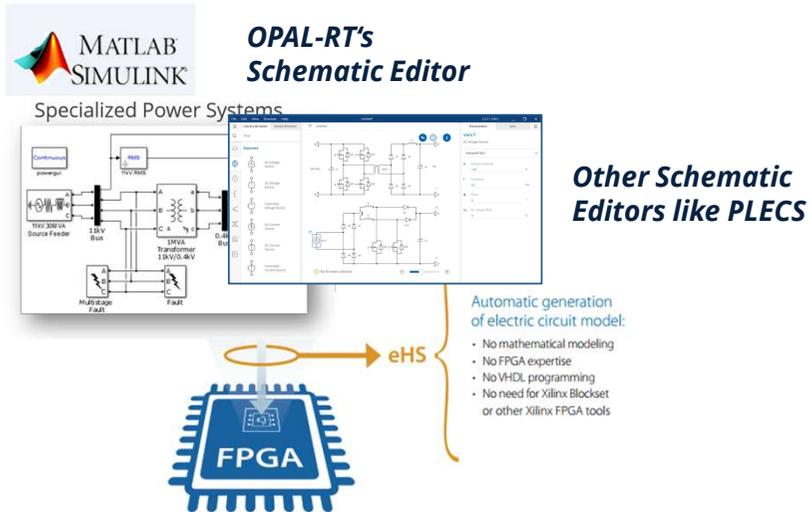
→ More complex controls also increase risks of failures and require more thorough testing

Power Electronics HIL Simulation – Motor Controller use case



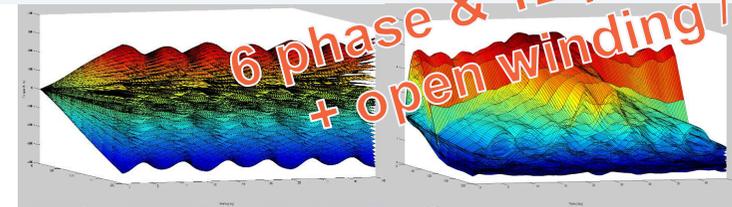
Utilizing FPGA Technology for accurate Motor-HIL

Inverter



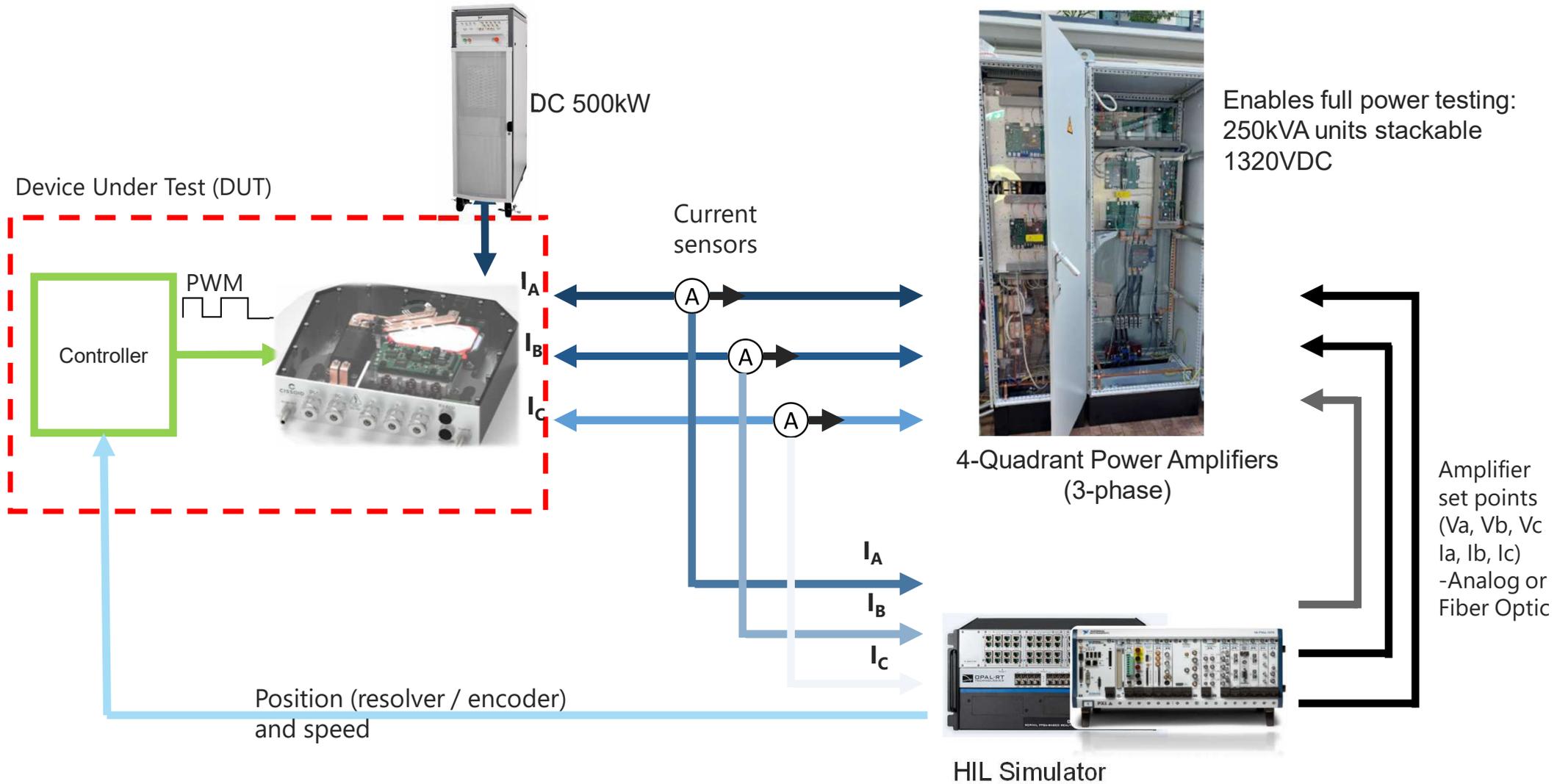
- Enables coupling of more than 144 switches without artificial delays
- Supporting up to **500+ kHz PWM** switching frequencies
- **Sample time** of electrical system solved by eHS ranges from **<100ns to 2.5us**

Motor



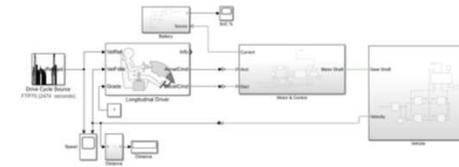
- Fully parameterized motor models
- Torque, flux, inductance tables for import of FEA models

E-Motor Emulator / Motor-PHIL Concept

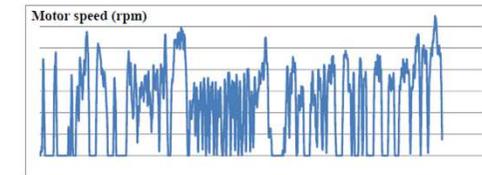


Motor Emulation Testing – the HIL as the brain

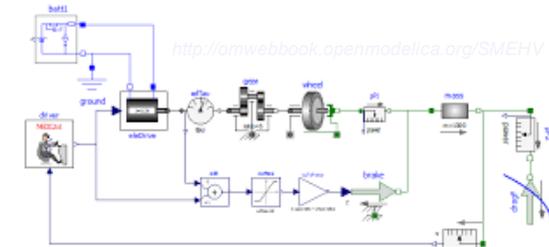
Vehicle Models



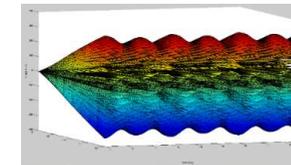
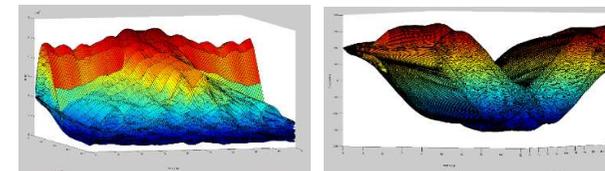
Drive Cycles



Mechanical Components



Motor Models



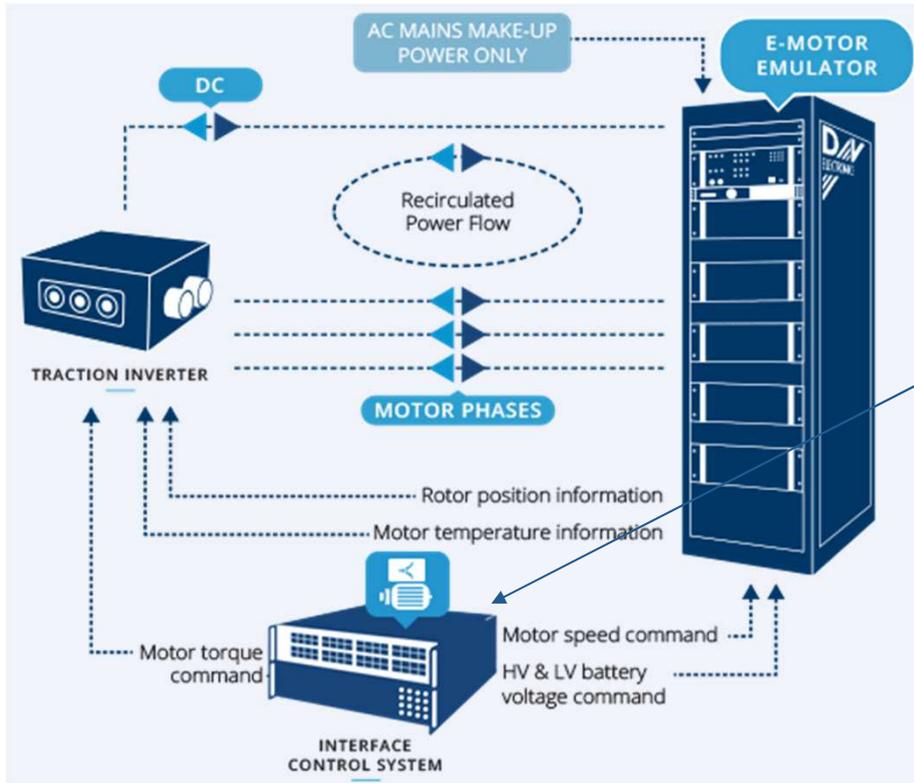
Permanent Magnet Synchronous Machine (PMSM – IPM – BLDC- SPM)



Induction Machine (DFIG – DFIM – Squirrel Cage Induction Machine)



Switch Reluctance Machine (SRM)



How Full Power Battery & Motor emulation provides a robust platform for control algorithm and inverter validation

1. Reduced time to market

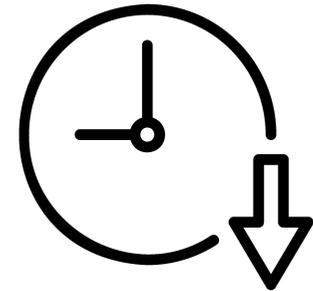
- A significant portion of inverter software (SW) and hardware (HW) can be developed and validated before motor hardware is available, reducing the time required in traditional test cells.
- Real-world issues can be predicted, reproduced, and resolved before or concurrently with dyno or test cell work

2. Reduced development cost

- Allows for the development and validation of control software (SW) and inverter hardware (HW), including fault detection and response, without risking damage to the inverter hardware

3. Higher quality product

- Real-world issues can be predicted or reproduced and solved prior to or in parallel with dyno or test cell work



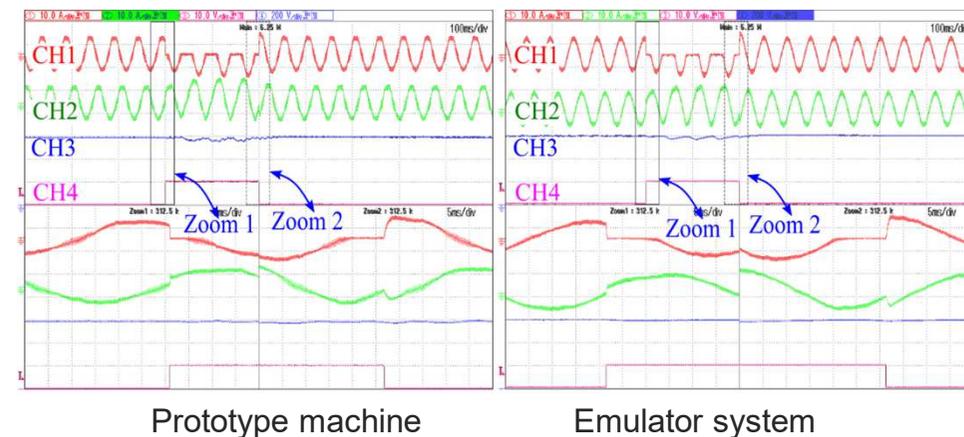
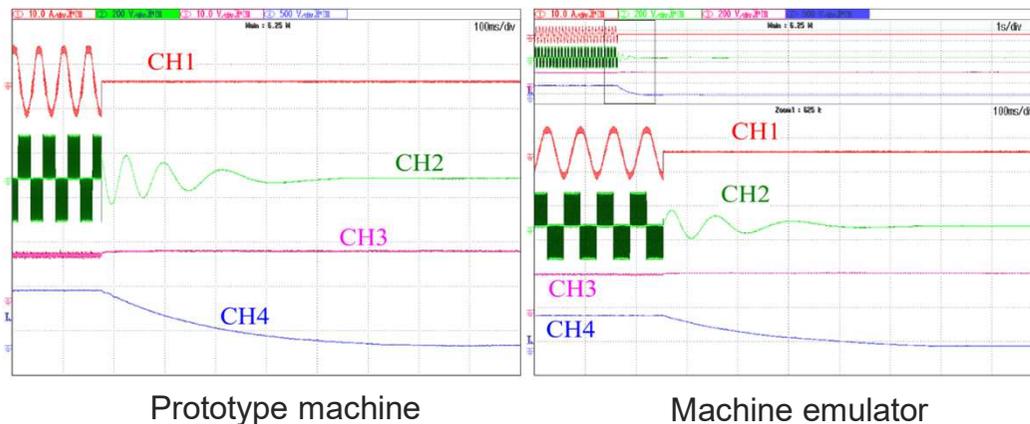
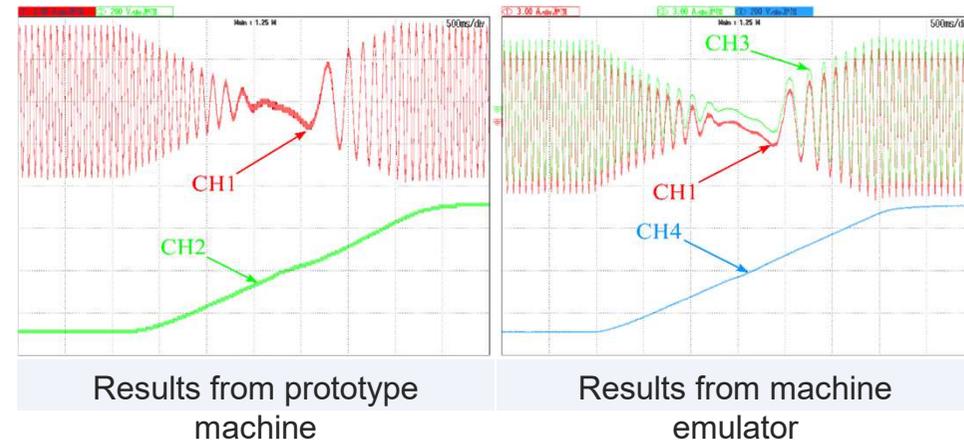
How Full Power Battery & Motor emulation provides a robust platform for control Prototyping and inverter validation

Capability	What it enables	Advantage
Real-time Real Power testing	Faster testing/tuning/calibration	Full flexibility on operating test points
Running SW on real HW	Signal-level integration, testing hardware integration at the same time	Early debugging of HW functions
Simulated Motor model	Variance of motors (IPM, IM, EESM, etc) Validating Inverter compatibility for potential motor design	Early development and calibration
Fault insertion capabilities	Support DFMEA and DVP&R	Less risky validation
Allows spatial harmonics modelling	Complex function development	Early development, saves rig time
Test automation	Faster validation	Reduce labour costs

How realistic is our Motor Emulator? Transient cases - measurements

Results for machine speed reversal

- Results obtained from a prototype machine compared with that obtained from a developed machine emulator
- A good match proves emulation accuracy and utility



Results for driving inverter faults

How Full Power Battery & Motor emulation provides a robust platform for control algorithm and inverter validation

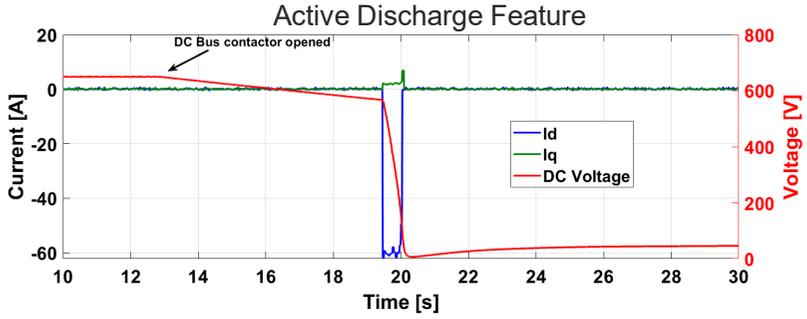
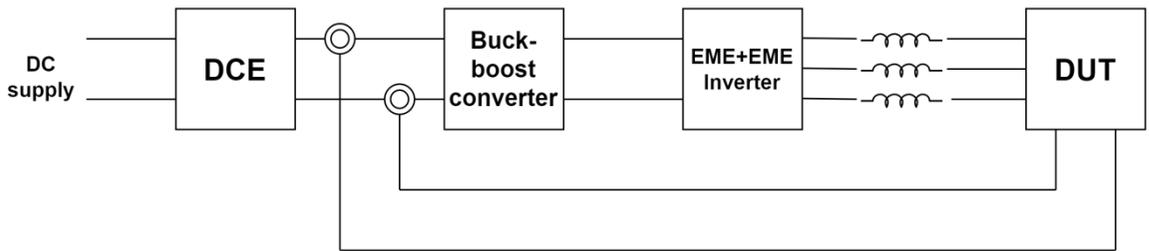
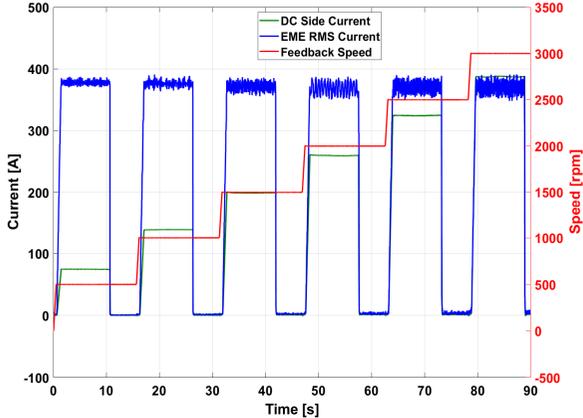


PHIL Test : Case Study-1

- The focus of this work was to validate an Inverter's (Sample A and B) HW and SW functionalities based on system and component level requirements
- There was fixed number of tests conducted with the help of a P-HiL to evaluate and assigned a pass, fail status

User experience

S/N	PHIL Test
1	Peak and Continuous Current
2	Stall Capability
3	DC current/voltage accuracy
4	Active Short Circuit
5	High Acceleration/Deceleration
6	Passive Rectification
7	Active Discharge
8	Inverter Current sensor accuracy through reported and commanded torque
9	Power Module temp/ primary control board temp
10	Active Fault Mode
11	Temperature Fault Detection



Thank You!

Visit us at our booths #6
to learn more about HIL!



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