Electric Vehicle - Powertrain Test

Joergen Etter

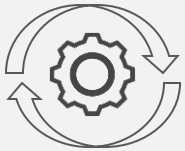
Business Development Manager – Europe

EV Trends Are Challenging Test Organizations

TRENDS

Race To Market

Government Mandates

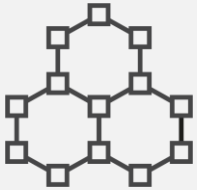


Rapid System Iteration

Multi-Domain Modeling

Emerging Technology

TESTING IMPACTS



Increasing Complexity

Changing Requirements

Unrealistic Schedules

Ultra-High Speed Simulation

NATIONAL INSTRUMENTS

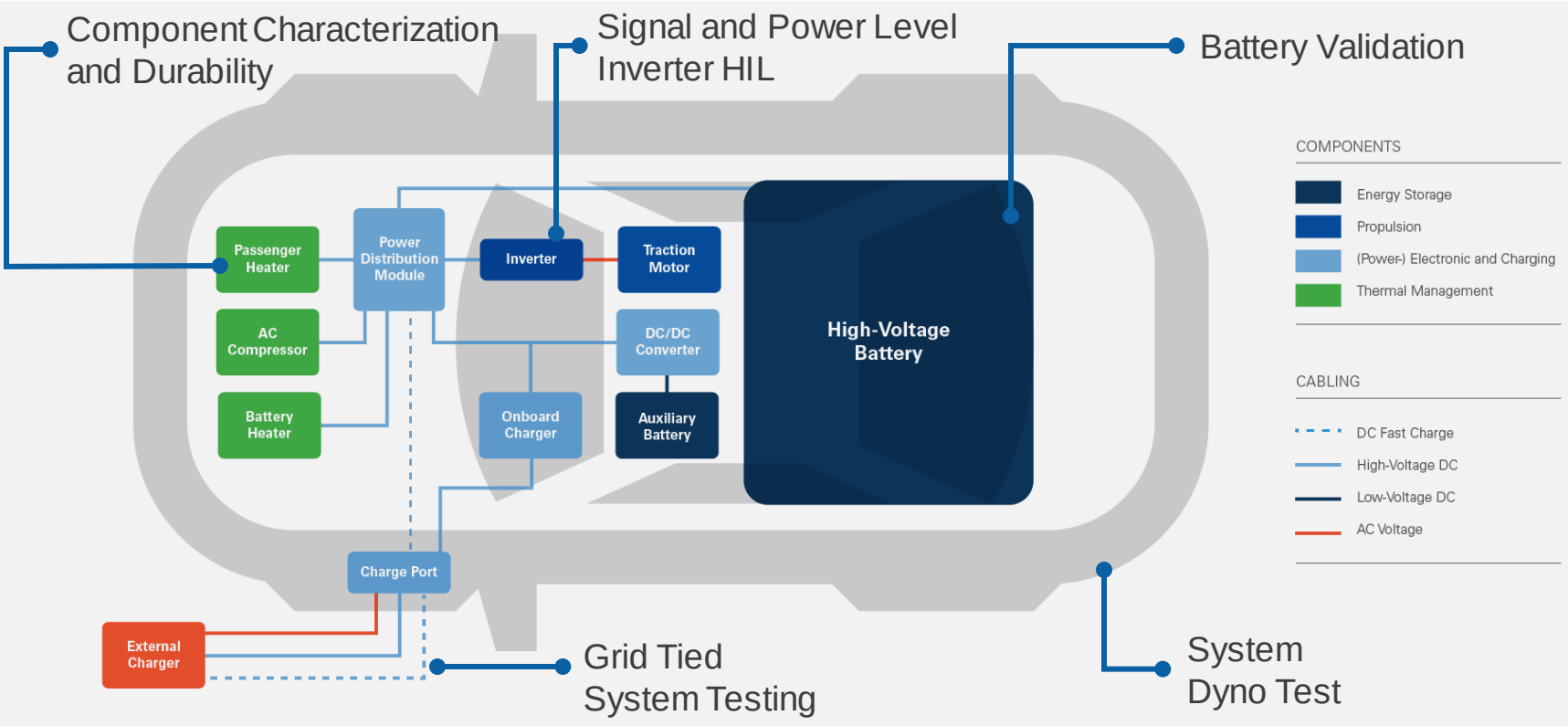
Testing Earlier Requires More Simulation

	xCU Test	Engine testbed	Transmission testbed	E-Motor tesbed	Battery tesbed	Powertrain testbed	Vehicle CD testbed	Road test
VALIDATION								Maneuvers
								Chassis
							Wheels	Wheels
					Battery	Battery	Battery	Battery
				E-Motor		E-Motor	E-Motor	E-Motor
			Transmission			Transmission	Transmission	Transmission
		IC engine				IC engine	IC enginer	IC engine
	xCU	ECU	TCU	xCU	BMS	xCU	xCU	xCU
SIMULATION	IC engine		IC engine	IC engine	IC engine			
	Transmission	Transmission		Transmission	Transmission			
	E-Motor	E-Motor	E-Motor		E-Motor			
	Battery	Battery	Battery	Battery				
	Wheels	Wheels	Wheels	Wheels	Wheels	Wheels		
	Chassis	Chassis	Chassis	Chassis	Chassis	Chassis	Chassis	
	Maneuvers	Maneuvers	Maneuvers	Maneuvers	Maneuvers	Maneuvers	Maneuvers	

Source: *Powertrain Instrumentation and Test Systems,*
Michael Paulweber and Klaus Lebert, Springer Publishing

NATIONAL INSTRUMENTS

What Does NI Help You Test?



NATIONAL INSTRUMENTS

EV Test System Functional Building Blocks

Control DUT | Make Measurements | Analyze & Share Data | Manage Systems

VeriStand LabVIEW DIAdem SystemLink

Power Electronics

Application Specific Tester

CompactRIO

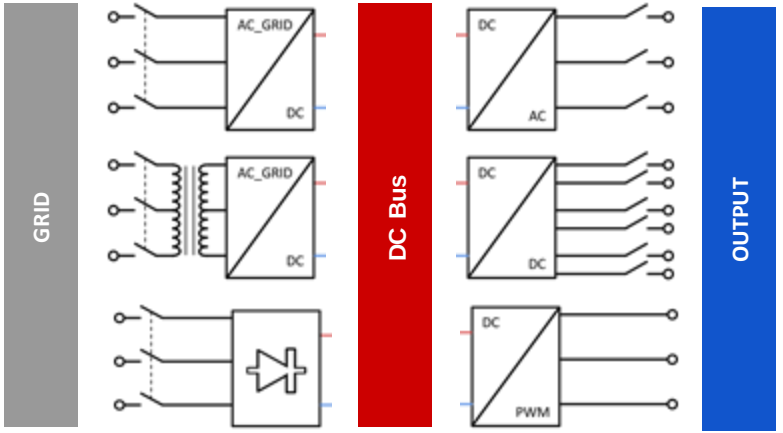
PXI

SLSC

NATIONAL INSTRUMENTS

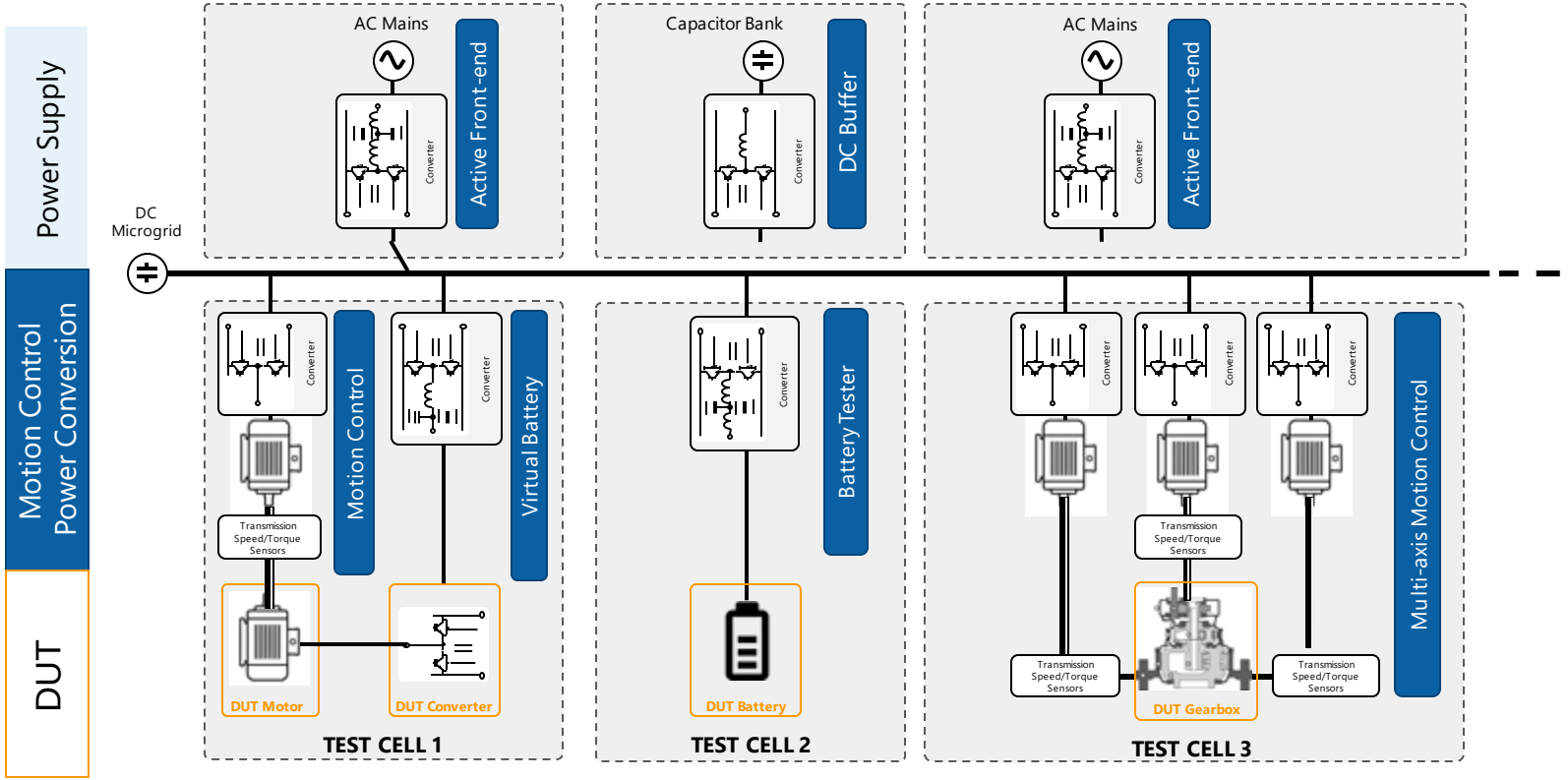
Power Electronics

- Flexible multi-channel power conversion systems for AC and DC
- 15 kW up to 1 MW



NATIONAL INSTRUMENTS

Test Infrastructure Example



NATIONAL INSTRUMENTS

Case Study - High Speed Dyno with Battery Emulator

NI / IPG CarMaker

Battery Emulator
Up to 200 kW
Up to 1200 V
Up to 800 A
< 0.5 ms response

4Q Motor drive
20000 rpm, 550 Nm
9-phase inverter
9x 400A, 330 kW bidirectional power
3.5 kHz torque bandwidth
Up to 1.5 kHz electrical frequency

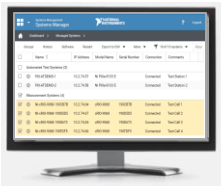
DUT
eMotor + Inverter

NATIONAL INSTRUMENTS

NI/Triphase — **Device Under Test (DUT)** — Partner

Battery Pack/Module Validation Test - Overview

- Systems consists of
  - Measurement & Control HW
  - Battery Cycler
  - Battery Test Application SW
  - System & Data Mgmt. SW



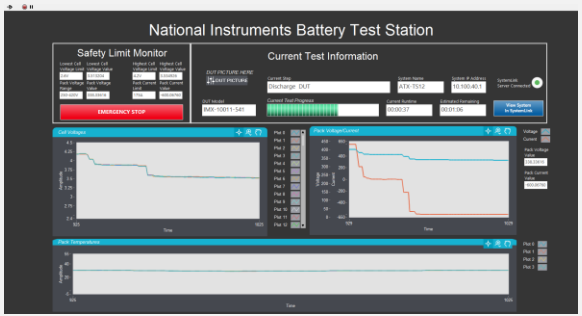
NI SystemLink

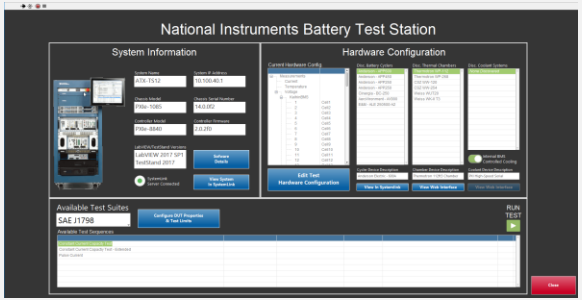
Test Automation Software

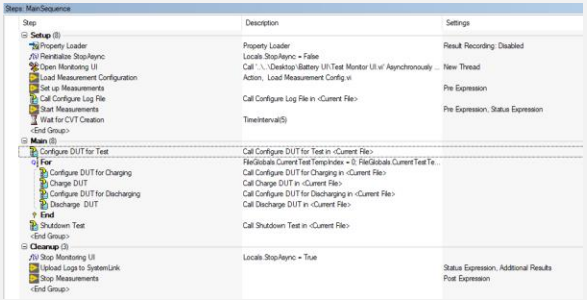
NATIONAL INSTRUMENTS

Battery Test Software

- Real-time engine for headless, reliable execution of test sequences
- Hardware Abstraction Layer with flexible configuration to adapt to changing requirements
- Built-in sequence editor for import/export and configuration of test sequences
- Integration with SystemLink for Test Monitoring and Data Management

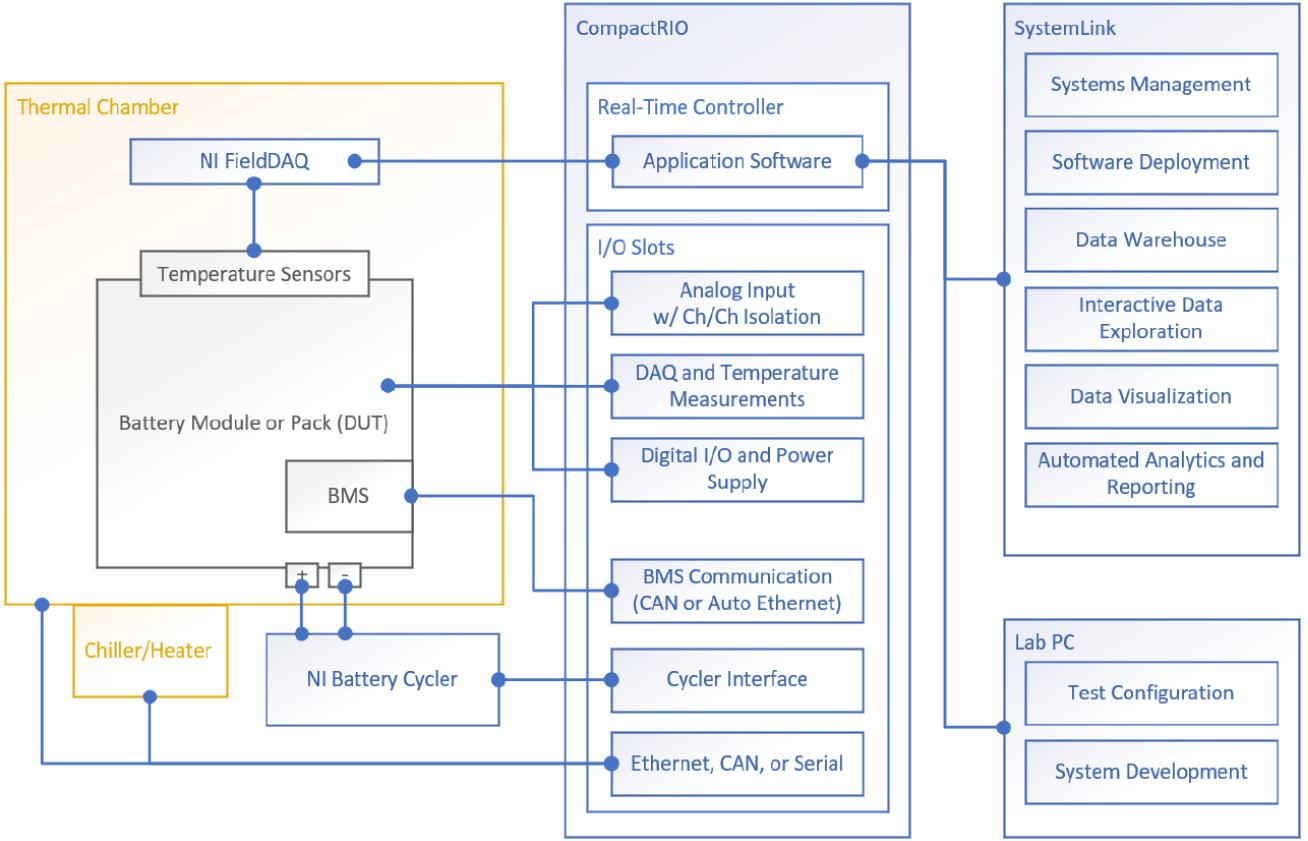






NATIONAL INSTRUMENTS

NI Battery Test System - Block Diagram



NATIONAL INSTRUMENTS

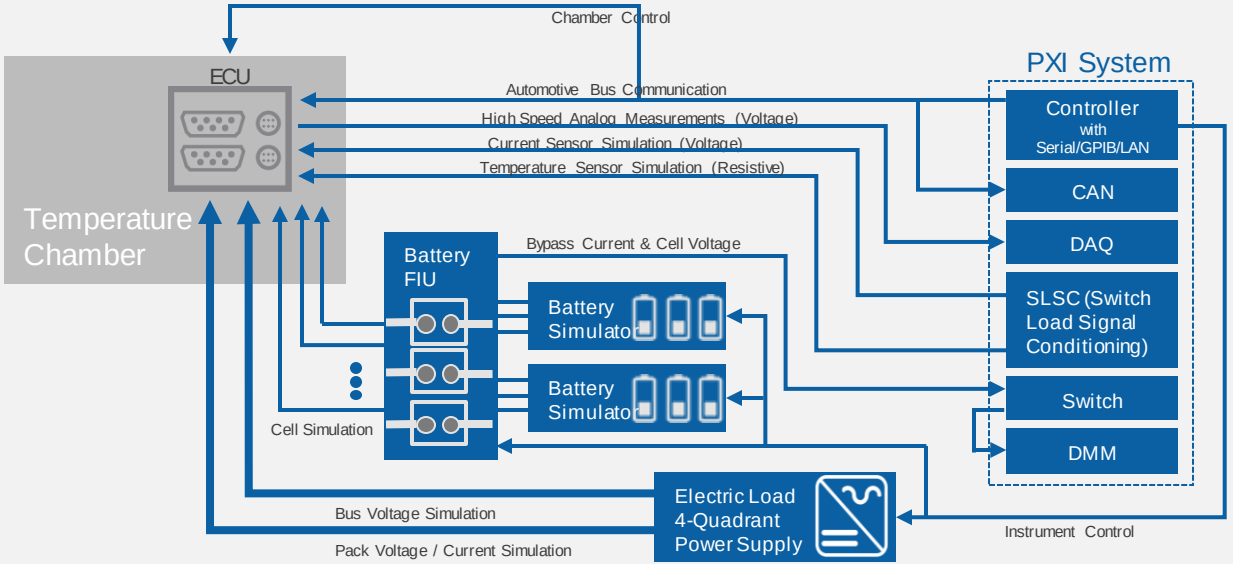
Key Specifications

Equipment Integration	Integrate any 3rd party environmental chambers or control/measurement devices and easily manage a heterogeneous fleet of equipment
Flexible Control	Sequencing, alarms, fully definable profiles, and variable/PID/custom thermal setpoints and profiles
Data and Systems Management	Scalable enterprise ready tools for data organization and storage, interactive data exploration/visualization, custom automated reporting and analytics, SW versioning and remote deployment, etc.
Charge/Discharge Mode	CC/CV/CP/Waveform
Voltage Range (Cycler)	*0-1200V*
Current Range (Cycler)	*±1600A*
Power Range	*Up to 1.2MW*
Power Regeneration	*Recycle energy back to the DC bus or to the grid (utility)*
High Precision Measurements	Easily add any of NI's extensive I/O library to scale the test system to meet test requirements now and in the future (temperature, thermal cameras, DIO, stress/strain, vibration, etc.) for few to hundreds of I/O channels
Cell Voltage	*±10 V, 24 Bit, 1 kS/s/ch Simultaneous, 250 Vrms, CAT II, channel-to-channel isolation*
Cell Temperature	*J, K, T, E, N, B, R, and S thermocouple Types (24-bit, simultaneous sampling)*
Digital Input/Output	*30 VDC, 7 µs Sinking DI, 500 µs Sourcing DO, 60 VDC, CAT I, channel-to-earth isolation, with PWM support*

NATIONAL INSTRUMENTS

BMS (Battery Management System) Validation Test

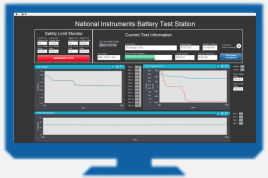
- Test Battery Control Algorithm and Management Functionalities (Cell Balancing, Safety, …)
- Sensor Simulation (Cell/Pack Voltage and Current, Temperature Sensor, Current Sensor, …)
- Measurements: Bypass Current and Cell Voltage
- Fault Insertion: Open and Short circuits



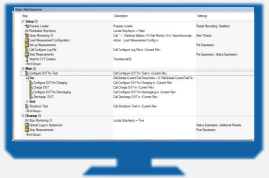
Test Software Architecture for NI TestStand

Pre-existing components & architectures for

- File Management
- Hardware Abstraction
- Operator Interfaces
- Result Processing



NI LabVIEW
Instrument Control
Test Code



NI TestStand
Test Sequence Development

NATIONAL INSTRUMENTS

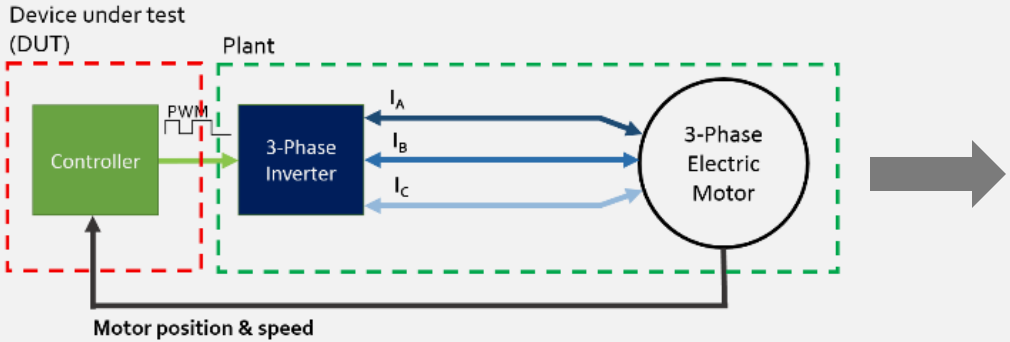
Inverter Software Testing (signal level)

Plant including inverter and motor are modeled FPGA:

- Varying converter topologies and motor designs
- Fault and non-ideal behavior simulation
- Hall-effect and resolver simulation

Controller is connected to simulator via:

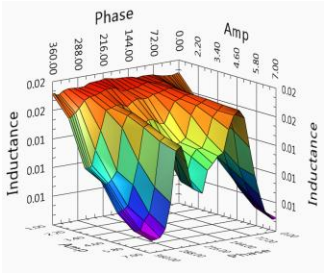
- Analog/Digital I/Os
- CAN-bus
- TCP/IP-based protocols

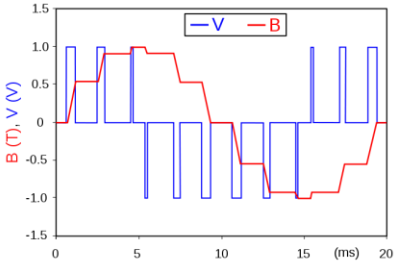


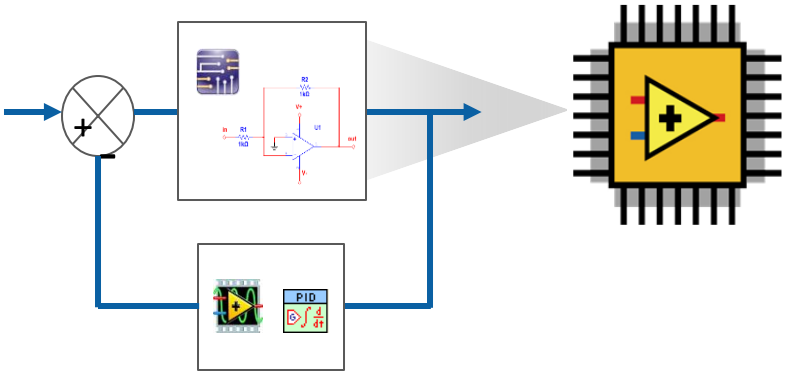
NATIONAL INSTRUMENTS

What Makes Power Electronics HIL Different?

- Very fast PWM inputs to models
- Special electrical modeling tools
  - Simscape Electrical™ (formerly SimPowerSystems)
  - PLEXIM
  - PSIM
  - Multisim
- Non-linear motor models
- Power-level testing – from 500W to 25MW

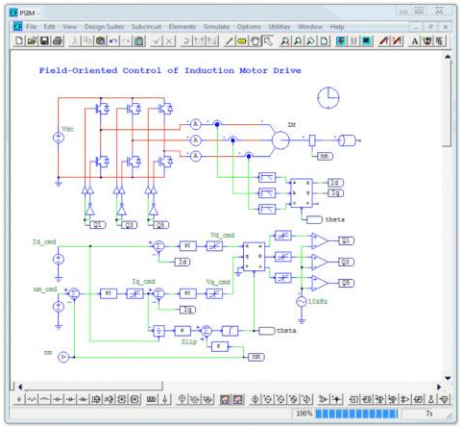


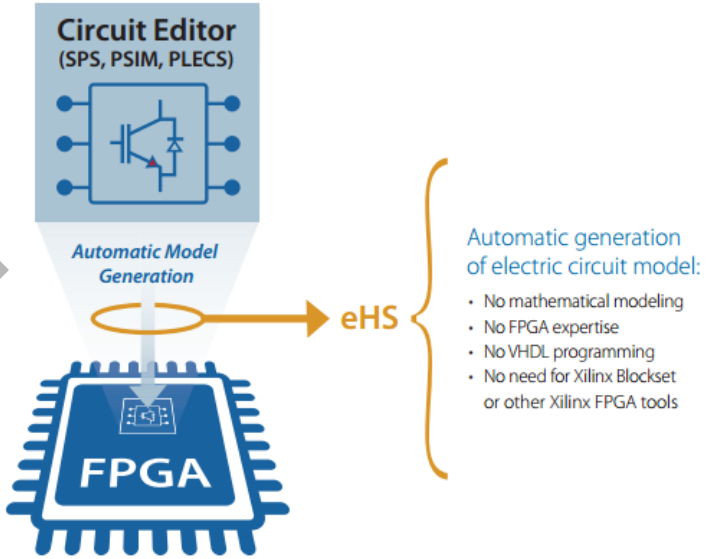




NATIONAL INSTRUMENTS

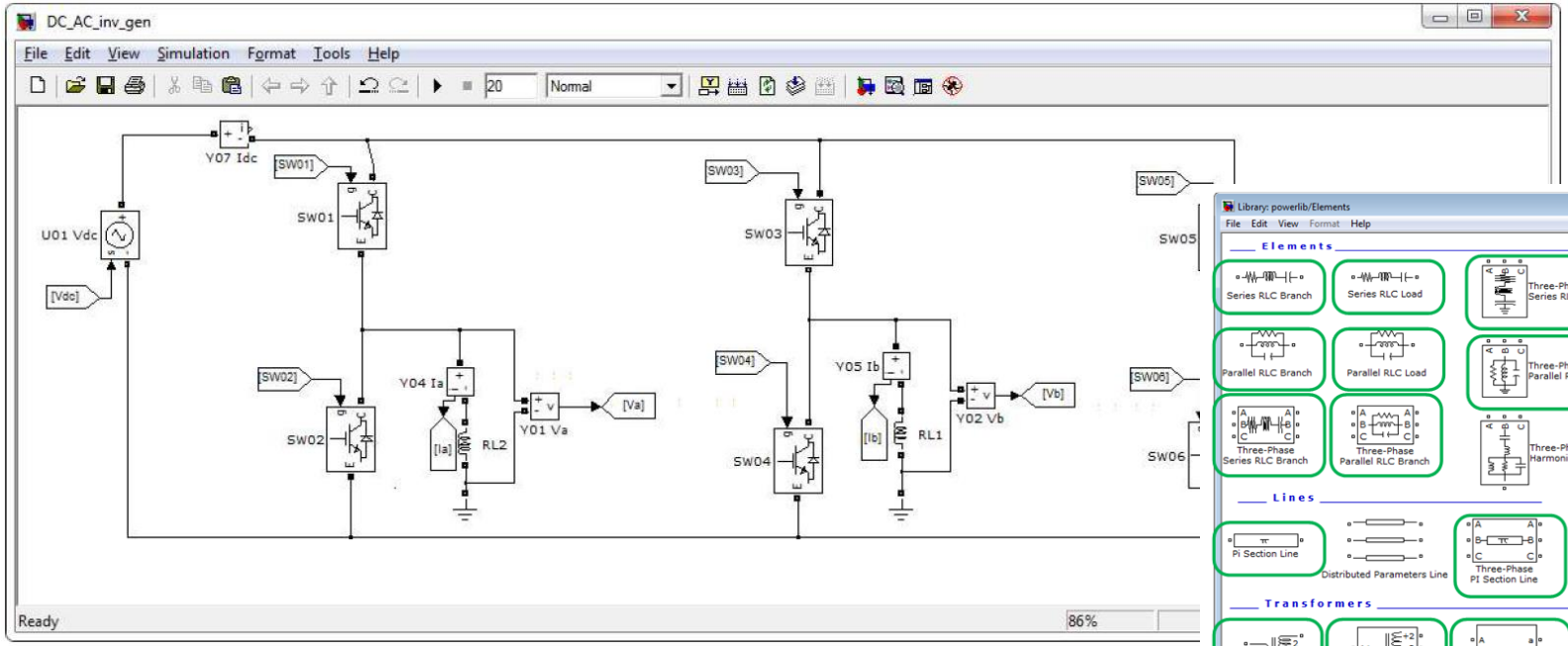
OPAL-RT – Circuit Simulation in FPGA

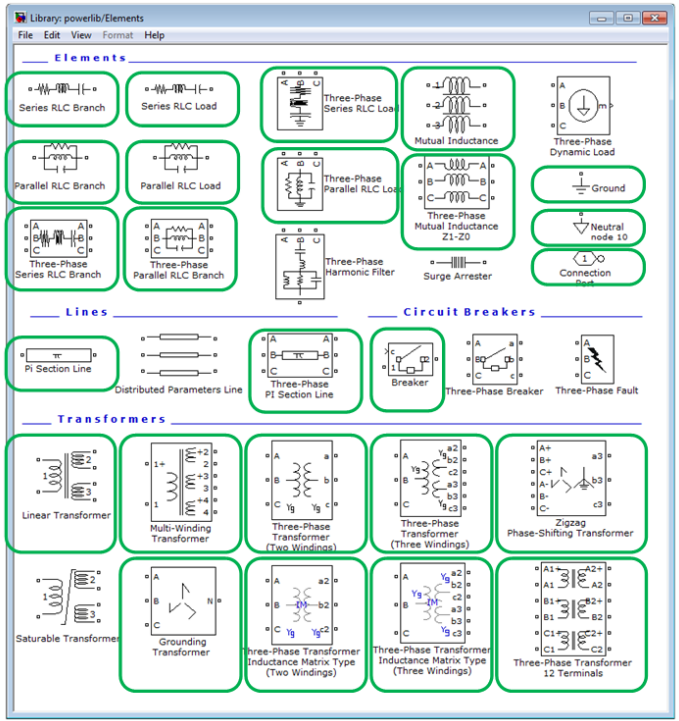




NATIONAL INSTRUMENTS

Example: Three-Phase Inverter in Simulink / Simscape Electrical





NATIONAL INSTRUMENTS

MathWorks®

Electric Machine Simulation

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

The automotive and transportation industries comprise the core markets for PMSMs. This machine type is known for its power density (power per unit of size/weight), and its higher speed capacity. OPAL-RT's solutions provide resolver and encoder I/O interfaces and communications protocols to exchange time-accurate information and position sensor responses. The following PMSM models have been developed:

- Constant parameter model
- Variable parameter model
- Finite element analysis (FEA) model

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

Induction motors are widely used as industrial drives because they are self-starting, reliable and economical. They're also increasingly used with variable-frequency drives (VFDs) in variable-speed service, as well as in wind turbines, for example. OPAL-RT's solutions support various machine configurations, machine parameters that can be modified at runtime, enabling flexible test possibilities--making our simulation tools indispensable for induction machine control testing. The following IM models have been developed:

- Constant parameter mode

Switch Reluctance Machine (SRM)

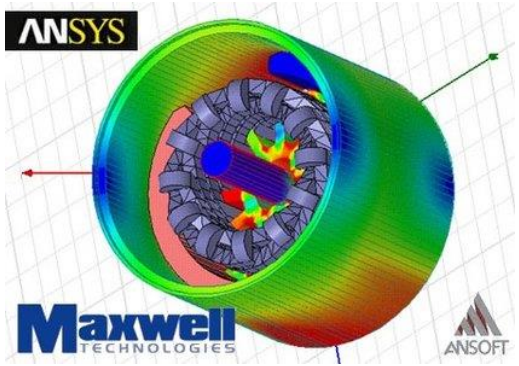
The switch reluctance machine runs with reluctance torque and delivers power to windings in the stator. SRMs are used in appliances and vehicles, are considered uncoupled, and have a complex relationship between excitation current, rotor position, and flux linkages. OPAL-RT's solutions interface easily with modeling packages for finished components, like JSOL's JMAG-Studio or Maxwell from Ansys. This improves high-precision testing and logging of the complex informational exchanges between the flux and other variables mentioned above.

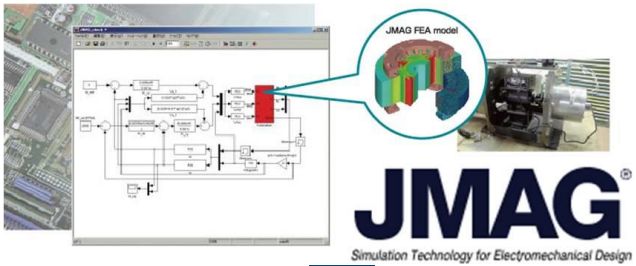
- Linear model
- FEA model

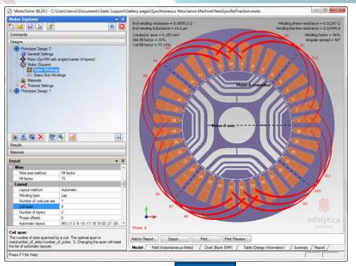
NATIONAL INSTRUMENTS

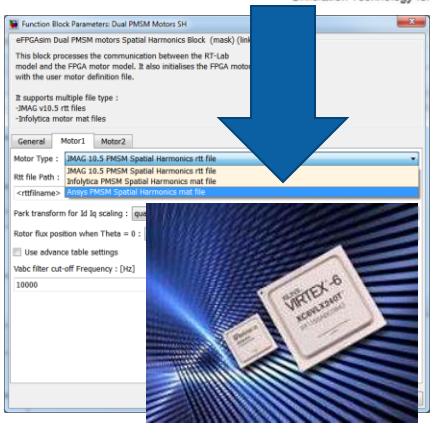
OPAL-RT TECHNOLOGIES

IMPORT OF SPATIAL HARMONICS MODELS (FEA)



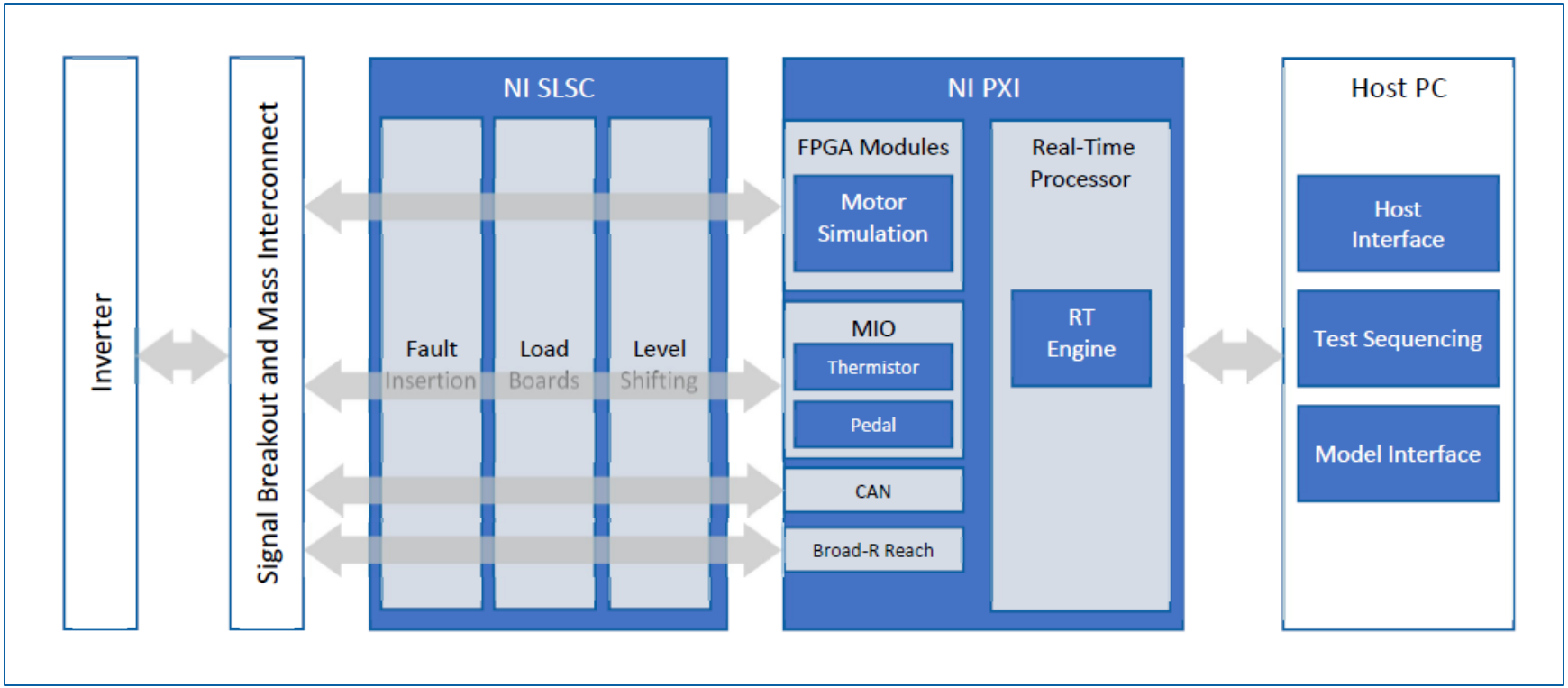






NATIONAL INSTRUMENTS

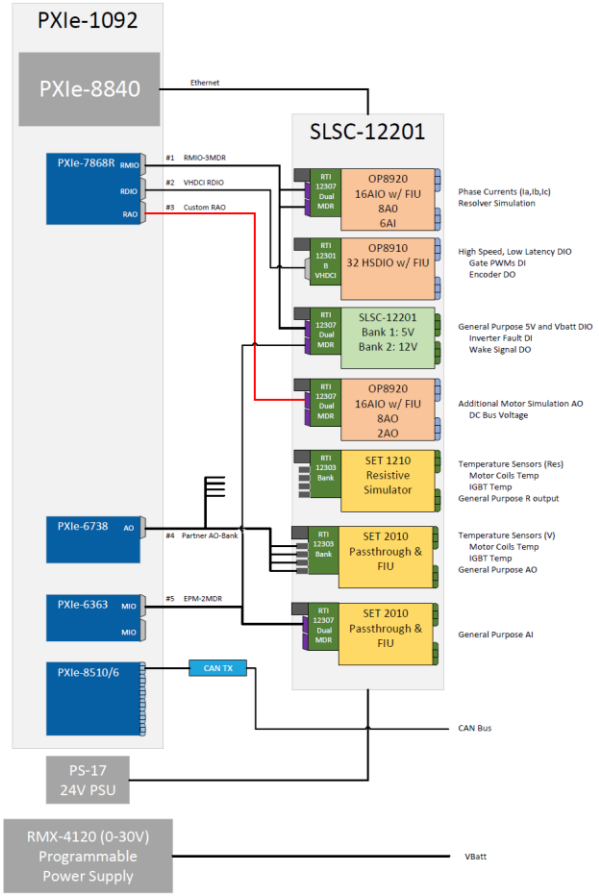
Signal Level Inverter Validation



Inverter HIL – Application Specific System

Key Features and Advantages:

- Unique Accuracy and Fidelity with Analog I/O at 1MS and 16 Bit
- True closed-loop model rate inlcuding I/O as low as 1µsec
- Accredited Calibration Options
- Large FPGA (Xilinx Kintex-7 325T)
- Extensive Fault Insertion Features
- No FPGA-compile time due to eHS precompiled model engine with direct connect to Matlab Simscape Electrical and other modelling environments



NATIONAL INSTRUMENTS

PXIe-786x FPGA based I/O Board for EV HiL Applications

- Analog Input
  - 6 Analog Input Channels, 16 Bit, Differntial or Sigle Ended Input
  - 1 MS/sec Simultan
  - Input Ranges: +/- 1V, 2V, 5V, 10V
  - Overvoltage Protection 42 Volt
  - Internal (to onboard references) and External Calibration
- Analog Output
  - 18 Analog Output Channels, 16 Bit
  - 1 MS/sec +/- 10V
  - Internal (to onboard references) and External Calibration
- Digital I/O
  - 16Ch at 10MHz max, 32 Ch at 80 Mhz max
- FPGA: Xilinx Kintex-7 325T

Fast Model Loop Rates of up to 1µsec – FPGA Architecture and Peer to Peer Streaming

By performing the simulation calculations on the FPGA in parallel to the I/O node, there is no communication latency. Additionally, if you have to split the simulation across multiple modules, you can use peer to peer streaming transfer data directly without having to go through host memory, which further minimizes latency.

Specialized Modeling Tools – Power Electronics Simulation Tools by OPAL-RT

OPAL RT tools let you use existing design models from industry-standard power electronics modeling toolchains and deploy the models directly to FPGA for very high-speed power electronics simulation.

NATIONAL INSTRUMENTS

NI SLSC

An open architecture for extending NI hardware with switches, loads, and signal conditioning targeted at HIL applications.

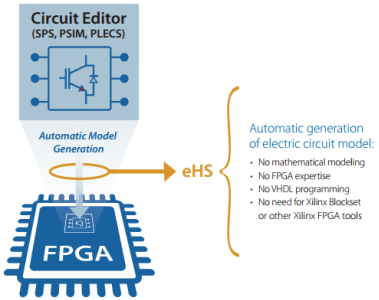
- Enables larger switches for fault insertion
- Handles small to medium loads on a simple circuit card
- Adds custom signal conditioning
- Reduces signal routing complexity

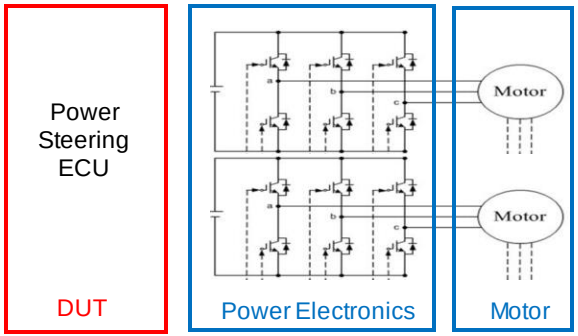
Design Validation of Future EPS Systems

Design for Fail Operational Redundant Systems

Requirements

- Steering of future autonomous cars need to evolve from fail safe to fail operational mode and require new ways of advanced dual model based motor emulation techniques

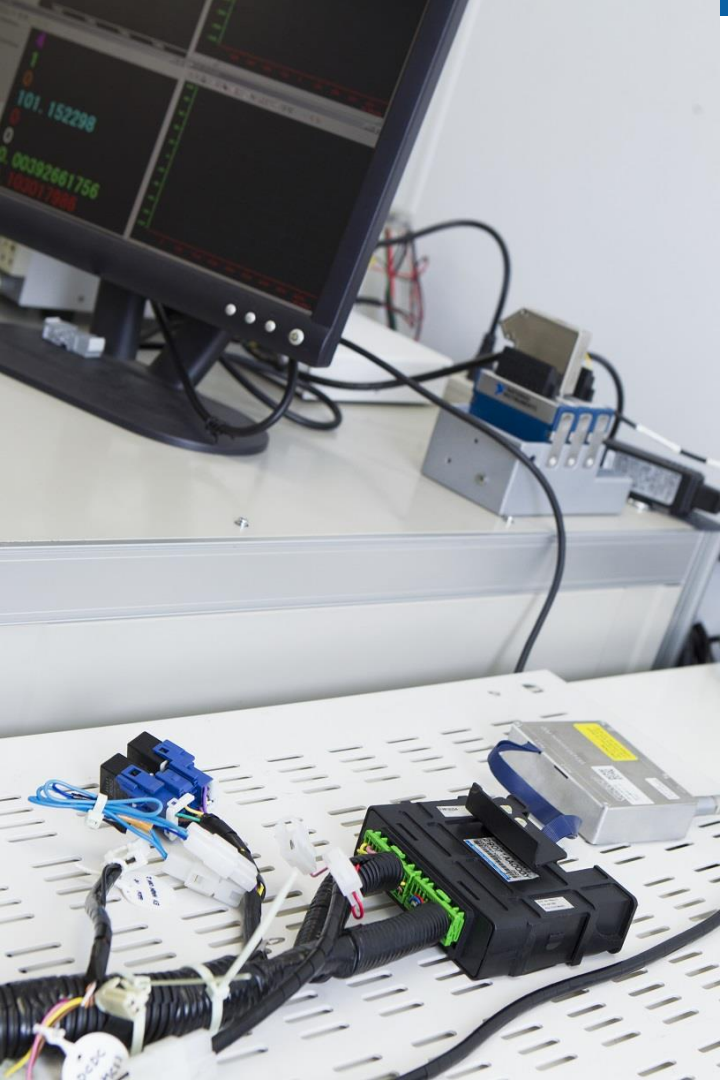




Solution

- Use Simulink Models to simulate Power Electronics (Inverter) stage and motor
- Fault insertion
- Early validation software enables test before power stage and motor are present

NATIONAL INSTRUMENTS



Subaru HIL System

Custom integration with existing test tools
- Flexible test software
- Automated testing and analysis

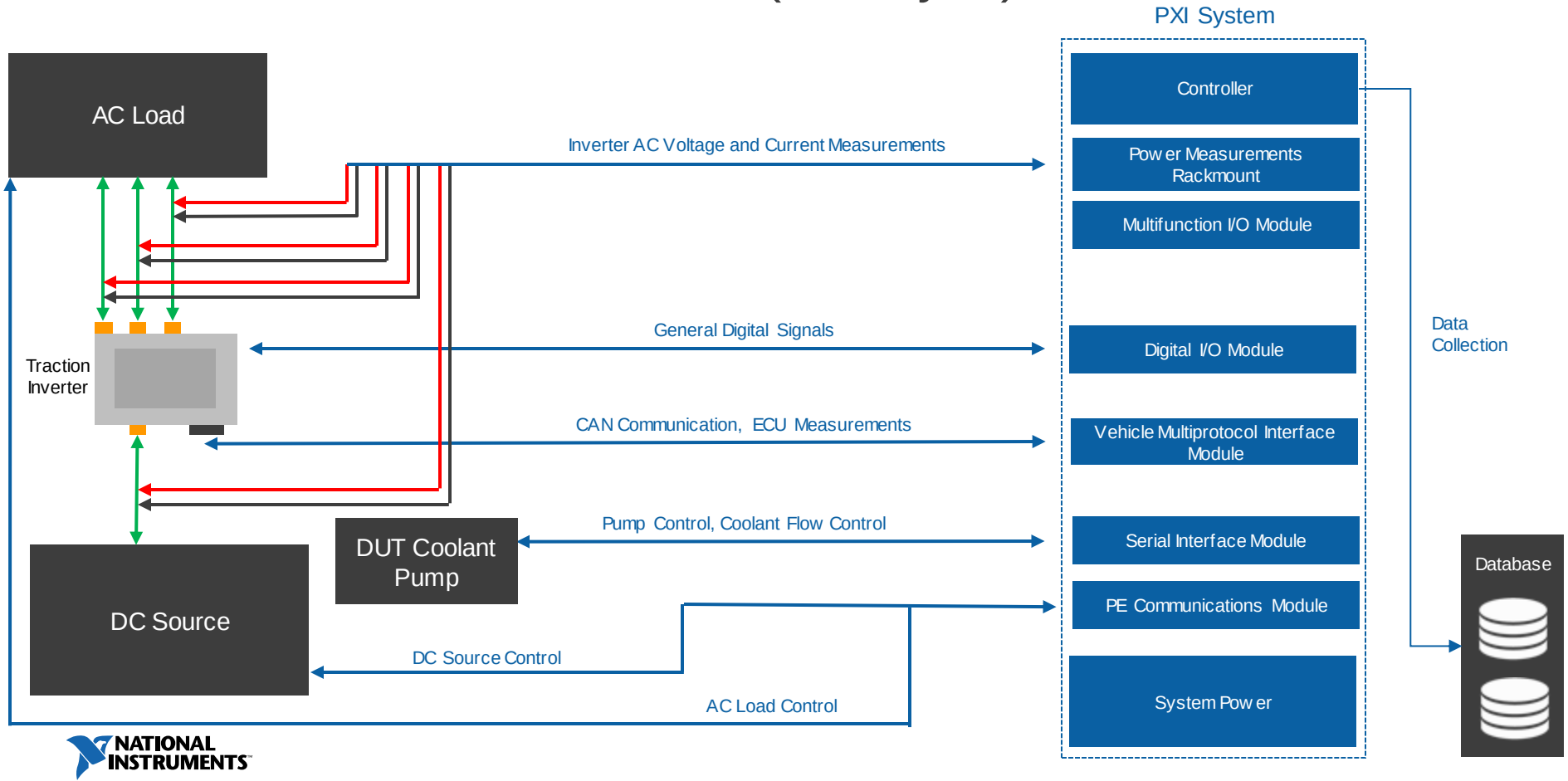
Motor models imported from finite element analysis software

FPGA-based simulation – high speed computation
- Low IO latency
- Loop rates near 1 micro-sec

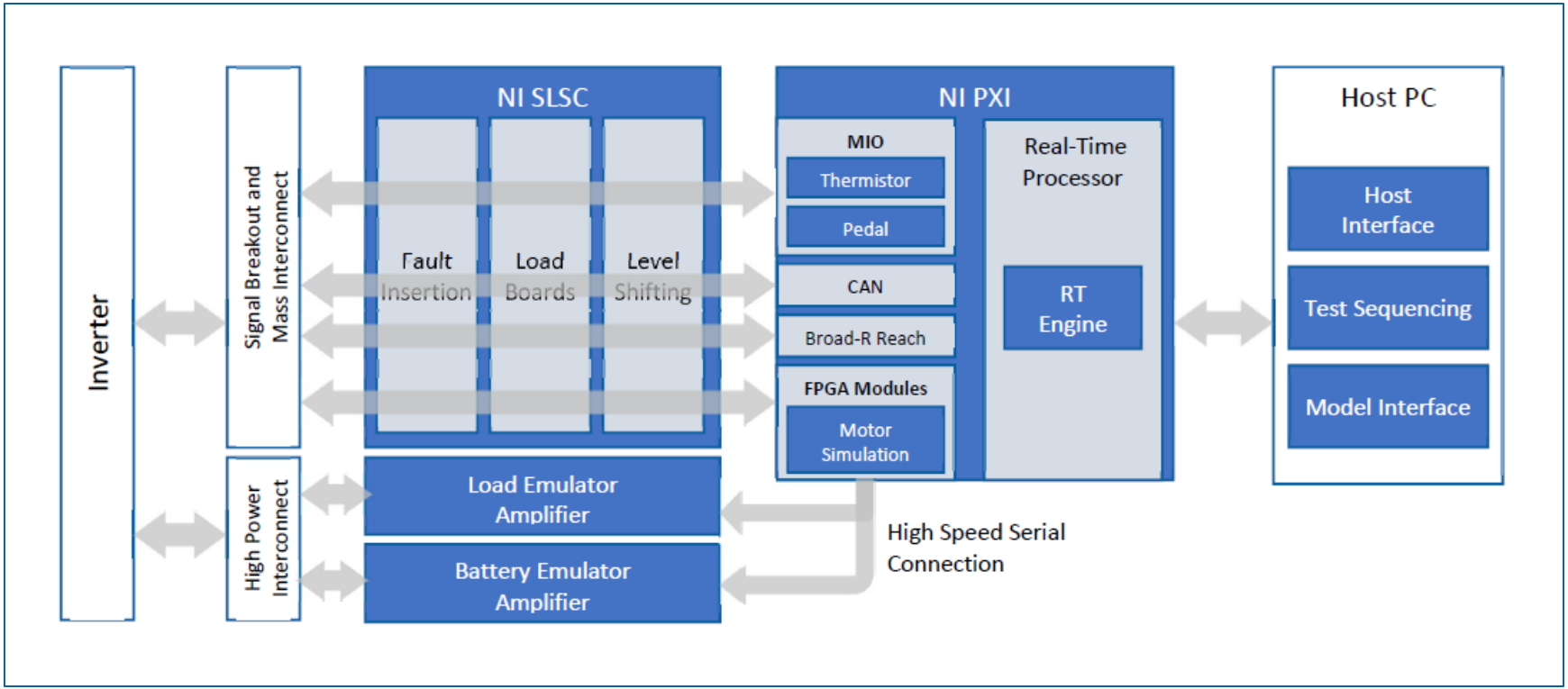
Improved test coverage
- Testing torque ripple of the electric motor
- DRAM

By adopting FPGA-based simulation using the NI hardware and software platforms, we achieved the simulation speed and model fidelity required for verification of an electric motor ECU. We reduced test time to 1/20 of the estimated time for equivalent testing on a dynamometer."

Power Level Inverter V&V Test (non-dyno)

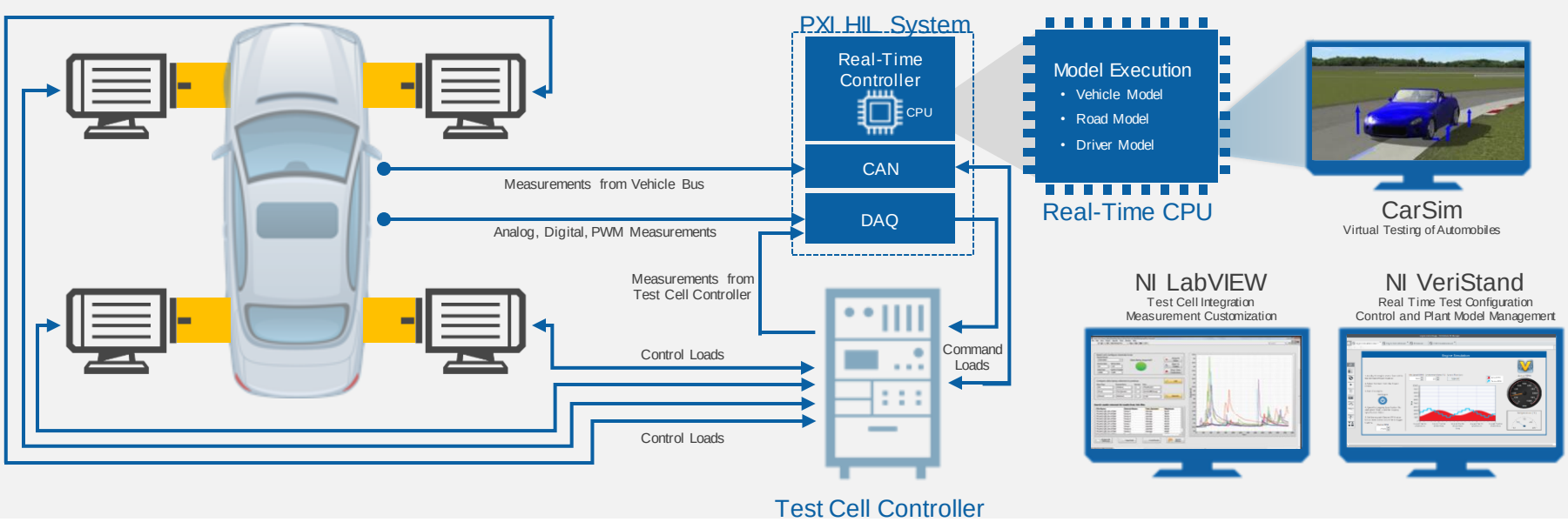


Power Level Inverter Validation



System Performance Test (Model-based Test Cell)

- Real-time model execution (Vehicle, Road, and Driver)
- Dedicated motors for each wheel apply loads to wheels in real time
- Malicious Tests – conditions cannot be realized in field tests
- Easy to change conditions (ex. Icy road surface with a 30% gradient → change it to 40% instantly)



Note: Other vehicle simulation tools could be used for model execution

Source: National Instruments Case Study – Subaru and Horiba

"By adopting NI HIL Platform for CarSim vehicle and road simulation on a Horiba dynamometer, we were able to replace over 70% of on-road testing with the simulated environment and reduced 30% of test time. We achieved 1/6 of the automated test software development time and cut 1/3 of test system capital cost using LabVIEW and PXI."

—Mr. Daisuke Umiguchi
Electrified Power Unit Research and Experiment Dept

NATIONAL INSTRUMENTS

SUBARU

Power Measurements Conditioner

RM-26999

Features

- High power measurement capabilities
- Four power measurement channels
- 2 kV voltage input
  - Four input ranges: ±200V, ±400V, ±1000V, ±2000V
- Current sensor support with options up to 2,000 A
- Single cable sensor connectivity
- Integrated sensor communication and power supply
- Up to 3.5 MS/s/ch simultaneous measurements
  - Compatible with PXIe-6356, PXIe-6366, PXIe-6376

Software

- Getting started examples for common configurations
- RM-26999 API with NI-DAQmx

NATIONAL INSTRUMENTS

Thank you for your Attention

Joergen Etter

Business Development Manager – Europe