"High-performance modular instruments allow us to do test-bench-based development of future vehicular fail-operational low-voltage power systems. Through communication with selected measurement and control components, the system under test can be stressed electrically with an automated validation test process. Highly dynamic and accurate measurements are immediately evaluated. Results from these physical tests help us to significantly improve our models deployed in our digital twin."

Martin Baumann
Simulation Electrical Power Supply, BMW

Challenge

Vehicle electrification and automation greatly impact safety-relevant and functional power system requirements because interferences to those can cause fatalities. Critical situations should be discovered in the early concept phase through simulation. Countermeasures such as harness redesign, component modifications, and anti-interference solutions can be derived. Virtual designs reduce development time and preserve financial resources, but they also require a close measurement feedback loop to validate the models against the real physical systems and system-inherent retroactive effects.

Solution

The BMW Group designed and developed a digital twin for low-voltage vehicular power systems. With a newly defined validation approach and the development of a system-level physical and digital twin, highly dynamic processes can be simulated and emulated to fully stress the low-voltage power system and therefore identify weaknesses quickly, which reduces development time and costs.

Designing and Developing a Digital Twin for Low-Voltage Vehicular Power Systems

Digital Twin Methodology

A digital twin is a virtual replica of the physical twin, which represents a physical asset (object, system, device, process, product, service, and so on). This includes modeling and simulating its functionality and behaviors. A tight connection between the digital and physical twins is required to make sure that the virtual replica can mimic the physical effects as closely as possible. Real-time data and sensor measurements play a critical role in establishing and evolving the digital twin because data and measurements are key to compare and fine-tune the modeling and simulation aspects of the digital twin.

Solution Requirements

BMW's ultimate goal is to shift the development of the low-voltage power system toward a virtual approach, thus making it a digital twin. Therefore, accurate models are needed for those components connected to the power system influencing its behavior. Safety-relevant components ranging across multiple Automotive Safety Integrity Levels (ASILs) include brakes, steering, windshield wipers, headlights, central electronic control units (ECUs), and sensors for object recognition purposes (advanced driver assistance systems, or ADAS). High-power components such as power electronic driven machines, audio boosters, fans, and amplifiers impact the power system's voltage stability. Hence, precise models are needed for the power supply and wiring harness. As a first step, BMW improved these models by characterizing the physical components on a component-level test bench. Then they recorded electrical behaviors through road testing and replaying those phenomena back in the lab. Finally, BMW developed a system-level test bench as a physical twin within the lab (see `FIGURE 01`) to validate the results of the digital twin against reality. By injecting the recorded electrical waveforms from road testing into the power system of the physical and digital twins, BMW can further optimize the simulation. The physical twin also includes simulation and emulation technology to mimic real driving, startup, and malfunction behavior by injecting interferences.

Before BMW implemented this multistage model characterization and validation process including the previously mentioned system-level validation test bench, virtual development had successfully provided valid results for long-term processes such as driving cycles. Initial improvement steps were taken by implementing a first test bench for a low-voltage vehicular power system using adequate loads[1] but no highly dynamic effects and interferences.

With further developments on functional safety, particularly focusing on highly automated vehicles (HAVs) ranging up to fully automated vehicles (FAVs), fail-safe functionalities and fail-operational functionalities have become more crucial. At the same time, these safety features and the already existing non-safety-critical devices and subsystems (for example, HVAC) are all connected to the same energy (voltage) source. This can lead to a severe impact on safety-relevant components as well as comfort systems. With the newly defined validation approach and the development of a system-level physical and digital twin, these highly dynamic processes can be simulated and emulated to fully stress the low-voltage power system and therefore identify weaknesses quickly, which prompts designing and implementing appropriate countermeasures.

Approach

The previously mentioned requirements can be met with a high-performance modular instrument that is capable of high-accuracy measurements and process elaboration at high speeds. A modular design supports customizable test applications. NI's real-time PXI system meets these requirements. The instrument acts as the central test system and main connection to guarantee a seamless integration of all necessary measurement and control capabilities needed to fully orchestrate (time, trigger, sync) the whole system-level validation test bench.

The PXI hardware is controlled with engineering software products including LabVIEW and VeriStand. Besides that, the measurement system architecture allows for preserving existing investments in third-party tools and equipment through full integration into the whole setup (for example, Vector CANoe for Restbus Simulation). This software-connected PXI-based test system has become an all-in-one solution to address communication bus simulation, measurements, and control of third-party devices, such as electronic loads, sources, and in-house-developed prototypes, as well as logical interfaces to the safety environment including safety switches, relays, circuit breakers, and so on (see FIGURE 02). The established measurement setup enables the development of highly automated test sequences, which leads to never-before-achieved repeatability within the whole validation workflow.

The predecessor of the current system was developed as a joint project between the Technical University of Munich and BMW,[1] so BMW has had a lot of positive experiences with high-performance modular instruments, which can be reused. Modular instruments also address demanding requirements such as high-frequency measurements (>3 MS/s), communication with third-party products, test automation capabilities, and automatic report generation of results. Additionally, the software toolchain is comprehensive, allowing for straightforward test solutions for both experts and students.

Furthermore, the modular and scalable design of the PXI system enables expansion and adjustments of measurement and control capabilities at any point in time, so the setup is optimized to meet future challenges and requirements easily and cost-effectively. Simple yet powerful details like standardized connection concepts such as the SCB-68 Terminal Block and SH96 connectors and cables allow for straightforward system upgrades to enhance the performance when necessary.

The models used are either acquired directly from the component suppliers or developed by BMW itself. Simulation tools and programming languages used include the MathWorks MATLAB® and Simulink® software, Plexim PLECS, Python, Modelica Dymola, and others. Homegrown models are typically generated through system identification methods and/or designed by acquiring current and power profiles from each component to perform a proper device characterization.[2] This, again, includes measuring back high-dynamic current pulses and fault-injection behavior.[3]

Signals used to stress test the system range from 0 kHz to 150 kHz. The acquired profiles are then imported into the simulation as lookup tables to further fine-tune and improve the existing models.

Results and Benefits

This new approach to validate the low-voltage power system, including both physical and virtual testing techniques, has enabled BMW to design completely new models by leveraging a new model development methodology. It is now possible to find new defects earlier in the overall design and development process, which reduces development time and cost because engineers can fast track to an initial higher quality prototype. The data and insights generated can be shared with suppliers and internal stakeholders at BMW to further improve their models. Some of the models used are running 95% faster now,[4] while interferences to the power system in the range of 10 kHz to 100 kHz have been reduced by 75% due to stability countermeasures made to the previously mentioned physical-to-digital design flow.[5] Moreover, the new and improved models already achieve a less than 5% deviation compared with the real-world component in the up to 150 kHz frequency range. Because of this, BMW feels confident it is on track to achieve 20% faster development cycles, leading to shorter times to market through digital design, as predicted by research initiatives such as the PANDA project.[6]

Outlook

A complete system simulation model still needs to be validated because only parts of the system have been fully validated. System optimization concepts will be physically implemented and compared with the simulation results. Furthermore, time-overlapping pulse injections will be implemented in the future to fully understand and diagnose cross interference. Last but not least, a Network Analyzer will be integrated to acquire online transfer functions and execute impedance measurements.

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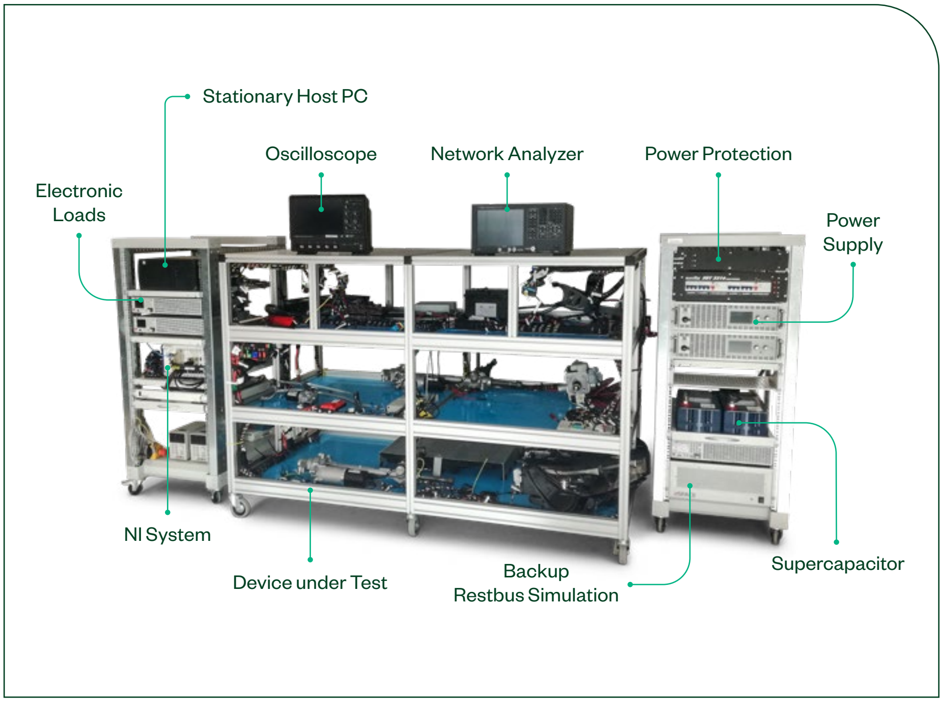

FIGURE 01

System-Level Validation Test Bench

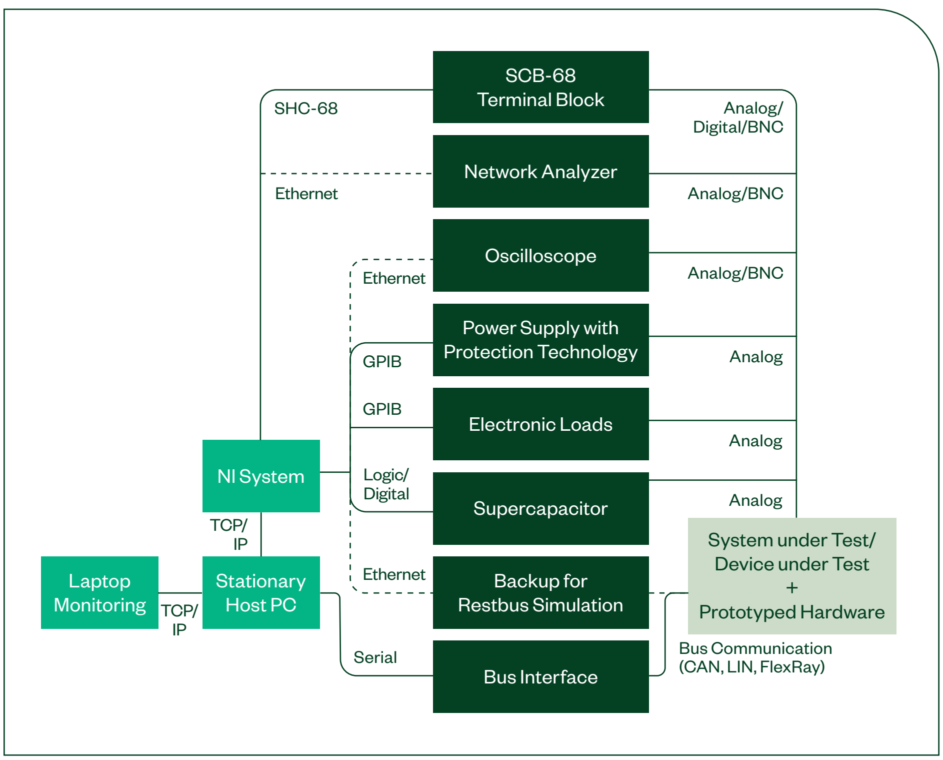

FIGURE 02

System-Level Validation Test Bench: Measurement and Control Architecture

Company:

BMW AG

MUNICH, GERMANY

Industry:

AUTOMOTIVE, RESEARCH

Application Area:

MULTIDOMAIN VALIDATION

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NI PRODUCTS USED:

- PXI System
- FPGA-based Multifunction I/O
- VeriStand
- LabVIEW