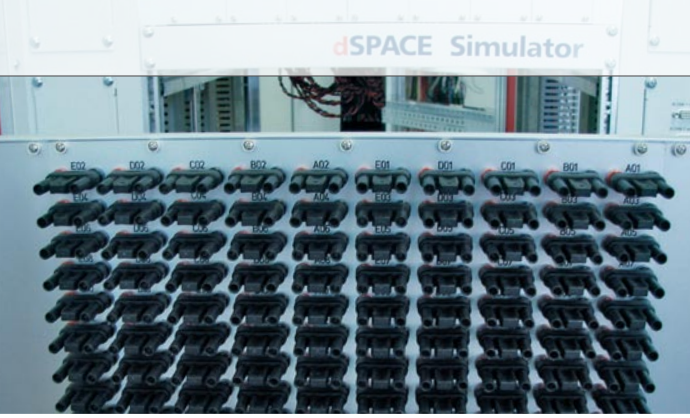
dSPACE HIL simulators at the BMW Group – testing lithium-ion battery management systems

Virtual Energy Cells



No one can say with certainty how long conventional drives will continue to dominate the market. What is definitely certain, though, is that the age of electric drives has arrived. For the vehicles of the future, comprehensive ECU tests are more necessary than ever before, as the complexity and extent of the software increase at a breathtaking speed. The BMW Group is using a dSPACE Simulator to develop functions and test ECUs for a battery management system for lithium-ion energy storage. It simulates battery cells in real time, enabling developers to investigate whether the battery management system meets all requirements.

Electrical System in the Vehicle

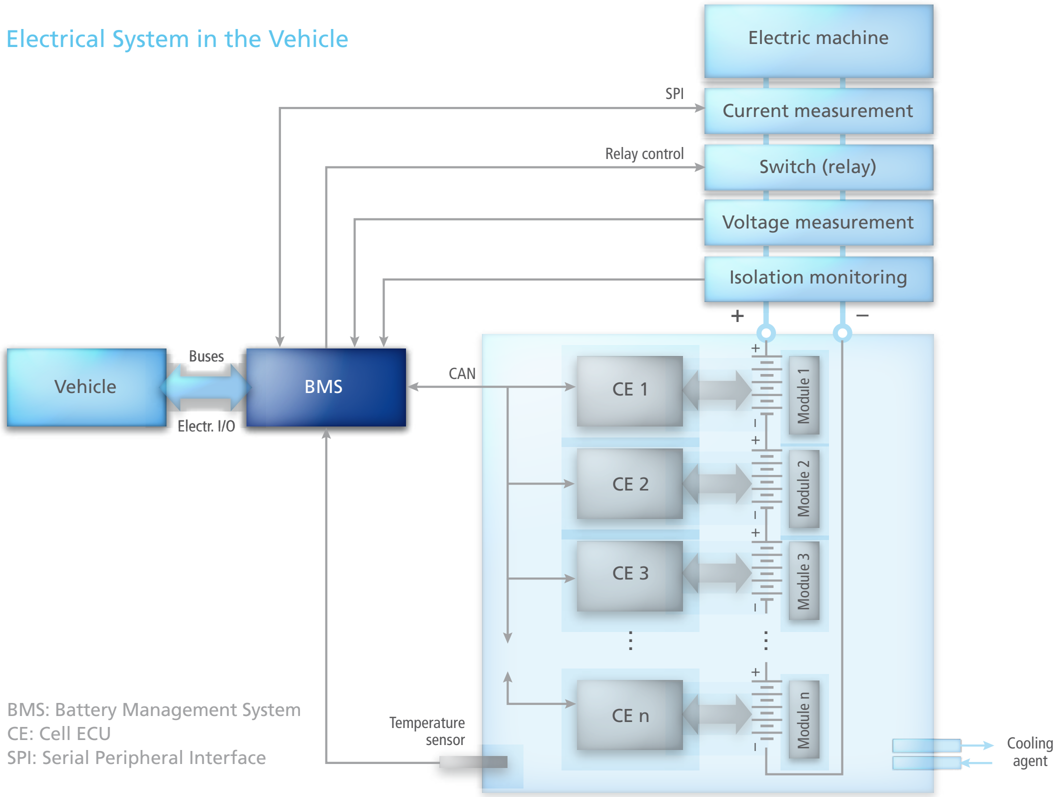


Figure 1: Battery management is performed by the BMS in conjunction with the cell ECUs (CEs), which are directly connected to, and monitor, the battery modules.

Challenge: Electric Mobility

The history of vehicle drives has reached an interesting evolutionary stage: Engineers are developing the drive concepts of tomorrow – and having to meet numerous new criteria on efficiency and safety. With the right combination of high energy, high power density, and long life, lithium ion batteries are a good economic choice in electrified drivetrains. This form of energy storage typically has a voltage range of several 100 volts and is dangerous when not operated within specified limits. One special challenge is to control the batteries in a vehicle safely and at the same time ensure maximum vehicle availability. Not only high safety requirements have to be complied with, but also optimum operating conditions for good performance and long life.

Battery Management Systems for High-Voltage Energy Storage

The requirements are monitored and implemented by an electronic control system called a battery management system (BMS). The BMS monitors the electric and thermic state of the batteries. It can influence each battery and its individual cells via various integrated control modules and actuators. Typical functions include protection against deep discharge, overcharge, and thermic overload. In a vehicle, the BMS is connected to the vehicle bus so that it can detect driving and operating states. Batteries have extremely high voltages and currents, so the BMS functionality is safety-critical. The development requirements defined in ISO 26262 must be fulfilled in order to ensure the functional safety of the system in a vehicle.

Structure of the Battery Management ECU System

To achieve the high voltages and currents for electrifying the drivetrain, the lithium ion batteries are made out of cascaded cell modules. At BMW, the cells are monitored and controlled by an extensive ECU system (figure 1). It consists of one cell ECU (CE) per battery module and one higher-level BMS, connected via CAN. The main job of each cell ECU is to measure the cell voltage and perform controlled cell discharge, while the BMS takes care of battery management.

Task of the Battery Management System

The BMS is the control center for all the electric, thermal and chemical processes in the battery. The following functions have been implemented:

Cell Balancing: To ensure an even charge state across the cells, the cells are symmetrized according to charge state analyses. This ensures that the cells have optimum performance and avoids cell overload, which in turn has a positive effect on long life.

Temperature Management: Cooling strategies regulate the temperature to prolong battery cell life and ensure optimum performance. Under extreme loads, overheating is avoided by limiting the current or regulating the cooling circuit.

Charge control: The charging efficiency is optimized by controlling the available energy and the energy available during charging.

Safety Functions: To guarantee constant safe operation at high voltages and currents, there are numerous safety functions that ensure that the battery's high-voltage contacts are not live unless the battery is in defined operating states. The battery is then safe to install, transport and store.

Isolation Monitoring: For safety reasons, both the battery poles must be completely isolated galvanically from the car body mass. The isolation monitor checks compliance with this requirement.

On-Board Diagnostics: If a fault or a threshold violation occurs during operation, it is entered in the fault memory and can be read out externally.

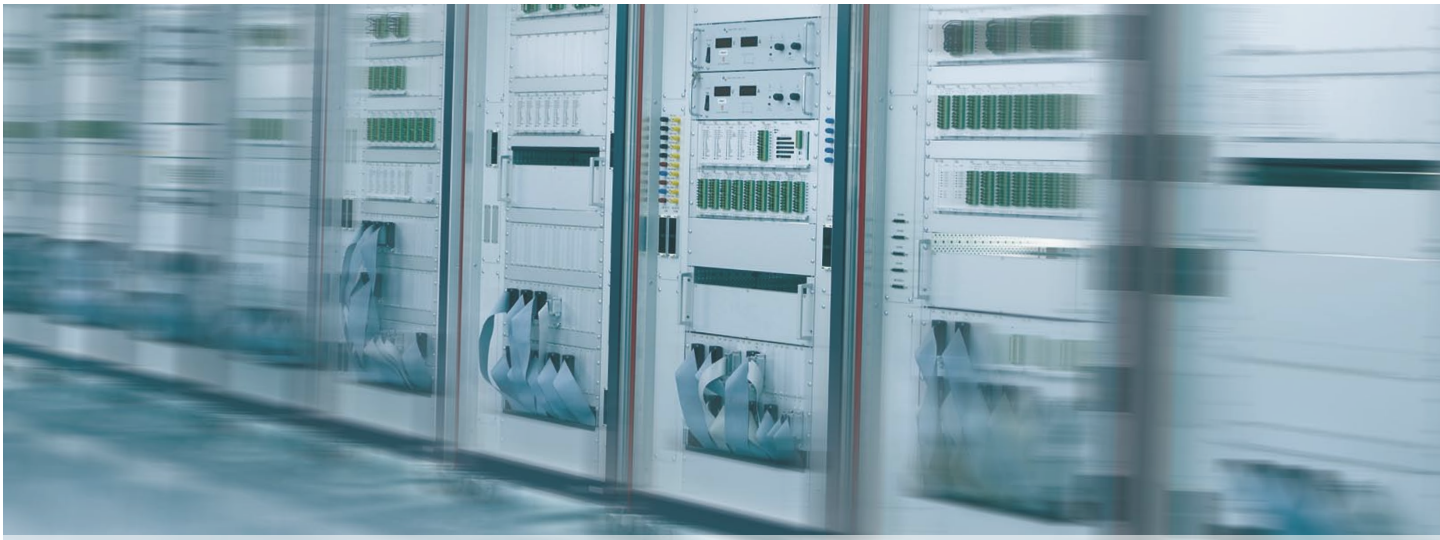
There are also further functions, such as those that indicate and check vital battery states:

- Measuring and displaying the charge state
- Monitoring the general state
- Determining the aging state
- Computing the available performance and energy
- Complying with current, voltage, and power limits

Conception of the HIL Simulator

To completely test the BMS and cell ECUs, the battery's different charge and operating states need to be present in a reproducible form. The solution is to run multi-stage simulations in accordance with the test requirements, both for individual battery cells and for the entire cell module. To ensure safety, the overall voltage is scaled down to under 60 V by adjustments inside the ECU. dSPACE has developed a very precise, very fast 60-V voltage source for this, which unlike normal power units can lower the voltage just as quickly as it can raise it. The overall voltage simulation must follow the single cell simulation dynamically in order to generate consistent values for the ECU.

The simulator structure for single cell emulation is as follows: An emulated cell voltage is provided to the ECU with high precision. The cells of CE1 are emulated with a highly precise voltage source from Scienlab electronic systems GmbH. The source supplies a galvanically isolated terminal voltage that can be regulated between 0 and 5 volts and take a load of up to 150 mA. These emulators are cascaded to form a cell module that supplies a voltage of 60 V. The currents and voltages of the individual cells can be measured directly on the emulator to test the cell balancing function.
The emulation of selected cells has lower precision, but also allows the insertion of electrical faults. Emulation of the necessary temperature sensors is also available for these cell modules. Further cell modules are integrated into the system by restbus simulation (figure 2).



Communication between the dSPACE hardware and the Scienlab Cell Emulator runs via a dSPACE low voltage differential signaling (LVDS) interface. A plug-on device (POD) from dSPACE converts the serial LVDS interface into a parallel microcontroller interface on the cell emulator side. This provides very fast data transmission (400 ns per measurement value) at a cable distance of up to 5 meters. The voltages of the complete cell stack can be adjusted in less than a millisecond.

HIL as Battery Simulation Environment

This configuration of the dSPACE hardware-in-the-loop (HIL) simulator makes it possible to simulate the entire energy storage. The simulation model is a battery model developed by the BMW Group. The necessary test cases are created and executed with test automation software. The simulator uses the test cases to represent the battery states at which the battery management system has to be tested. At the same time, the simulator can capture the ECUs' control currents and signals and evaluate how well they function. ECU testing provides information on whether the system detects faults, reacts to them correctly, and carries out the appropriate control strategy. Specific test sequences require highly dynamic processes such as sudden voltage drops and other transient events, as well as short circuits, to be simulated very precisely at the battery poles.

Electrical Failure Simulation

When faults occur in the battery or the cable harness, the BMS must always function correctly and react appropriately in all circumstances. Electrical failure simulation is therefore a vital part of HIL simulation. A failure insertion unit (FIU) can be used to feed in various types of faults to all I/O and communication channels, for example:

- Broken wire
- Short circuits to ground or to other ECU signals
- Loose contacts

This failure simulation is performed at the BMS's electrical I/O lines and CAN lines, and also at the cell ECUs.

Summary and Outlook

BMW currently has several dSPACE Simulators for developing and testing battery management ECUs. The systems are used in function development as well as in release tests for ECUs. HIL simulation has proven to be a reliable instrument for developing and testing battery management ECUs. HIL simulation will play a major role in future battery management development projects.

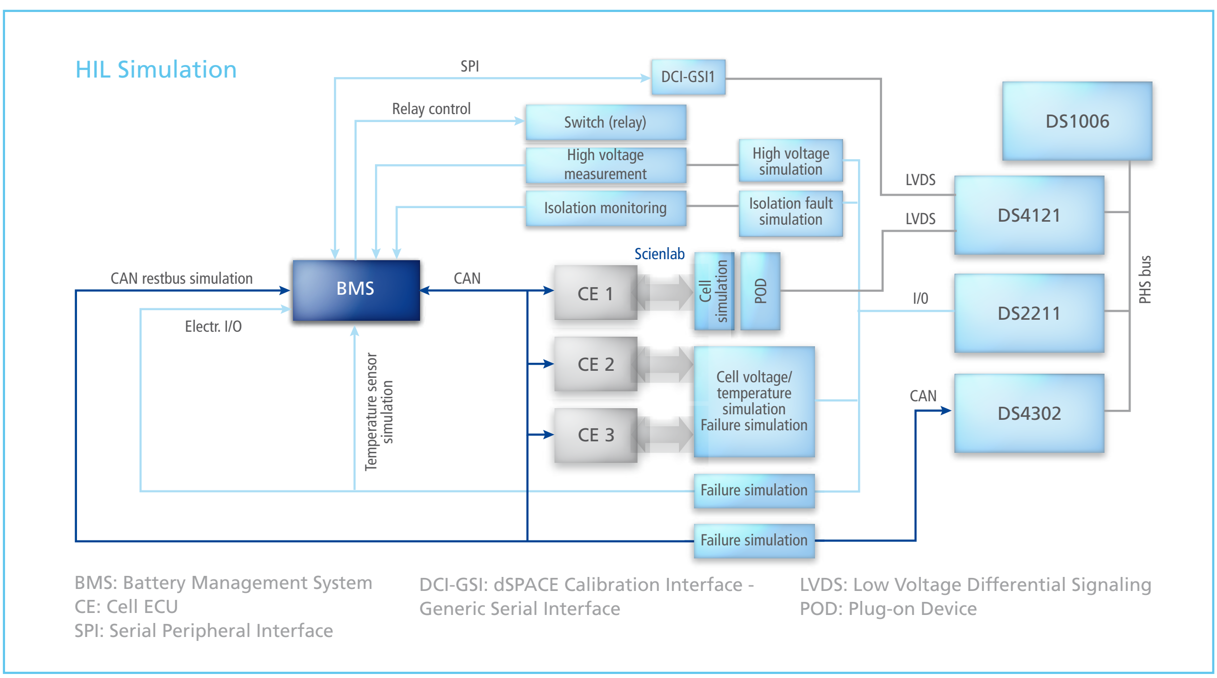


Figure 2: The BMS, some cell module emulators, and further real parts are integrated into the HIL simulator. dSPACE components round off the test environment.

Tests on Isolation Monitoring

For safety reasons, the battery poles must be separated from the vehicle chassis potential (IT network). The ECU is able to test whether the resistance of one of the battery's two poles to the chassis is too low. For HIL testing, defined resistances can be specified on the plus and minus sides in compliance with the BMW specification for each test to represent specific ranges of isolation values. The ECU must then detect these fault cases and react to them (e.g., by switching off the system).

Evaluation of the Test System

HIL simulation makes it possible to simulate a battery realistically, generate all the states needed for further function development, and test the states systematically. This is done with electrical interfaces and with the communication interfaces (SPI, CAN incl. software gateway function). Powerful functions for simulating electric cable faults and isolation faults are also available; these are vital components in test sequences that verify ECUs. The dSPACE system has proved its stability and reliability in operation. The emulated cell and terminal voltages are precise enough to test elementary battery management functions such as cell balancing. The simulator fulfills the requirements for testing the BMS, both in function tests and in communication tests in the ECU network. ■

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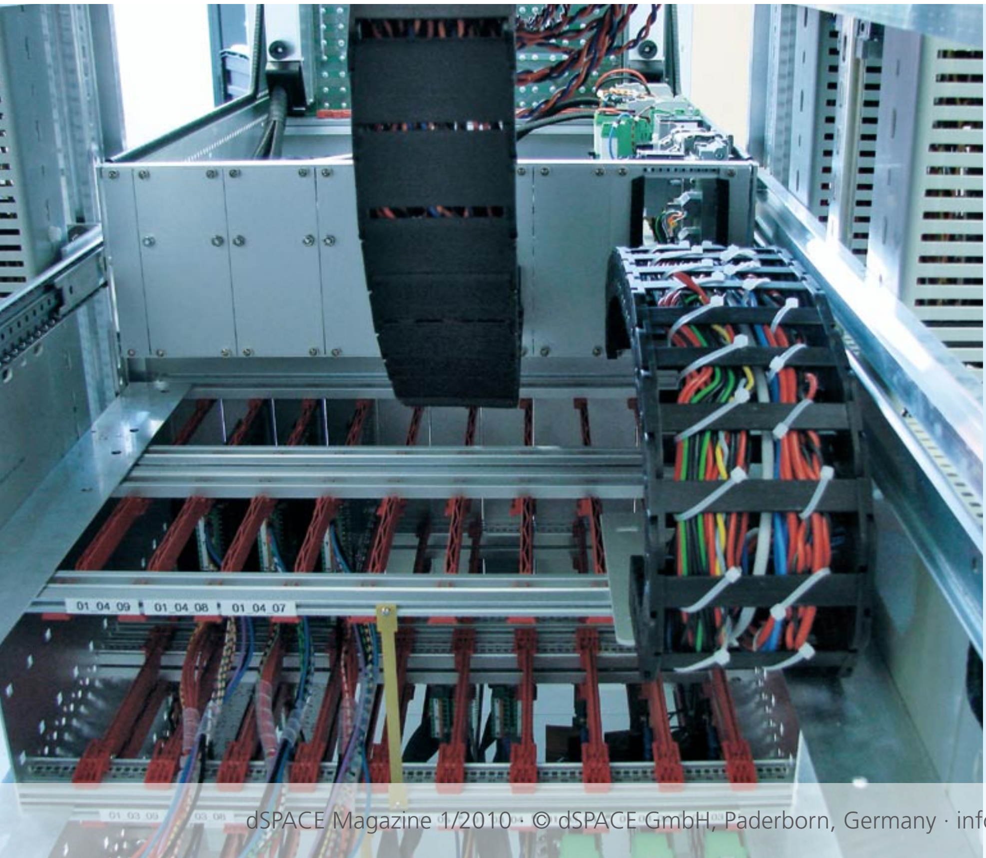
Communication via SPI Interface

Communication between the ECUs and the sensors in the BMS runs via a serial peripheral interface (SPI). SPI is a very generic standard for synchronous, serial master-slave communication between integrated circuits. SPI is therefore designed for very short cable lengths. This poses challenges to simulator use, which usually requires cables that are longer than those in a vehicle. An LVDS SPI converter developed by dSPACE is therefore used to enable integration into an HIL system. The converter is located directly on the ECU and converts the SPI data into an LVDS protocol to achieve cable lengths of 5 meters. In the other direction, data arriving via the LVDS interface is converted into SPI and passed to the ECU.



Conclusion

- Electrified drivetrain poses new challenges in developing and testing battery management ECUs
- Test system to virtually represent the electrical and thermic properties of a lithium-ion battery down to cell level
- Comprehensive function tests with electric failure simulation for a battery management system