Precision Voltages

HIL Testing of Battery Management Systems

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The task of a battery management system (BMS) is to ensure that high-voltage batteries always operate in an optimum range. Such systems are classified as safety-critical, and comprehensive testing is indispensable. This article presents hardware and models for testing them.

The Function of a BMS

Batteries for hybrid or electric vehicles usually consist of li-ion cells with a nominal voltage of approx. 3.6 V to 4.2 V. These are connected in series to achieve voltages of more than 600 V. Just one faulty cell in the series affects the behavior of the entire battery.

The main function of a battery management system (BMS) in modern hybrid or electric vehicles is therefore to protect individual cells against overload, deep discharge and overheating. It does this by cell balancing, which ensures that all cells constantly have the same charge state. In addition, a BMS has to estimate the battery's current capacity.

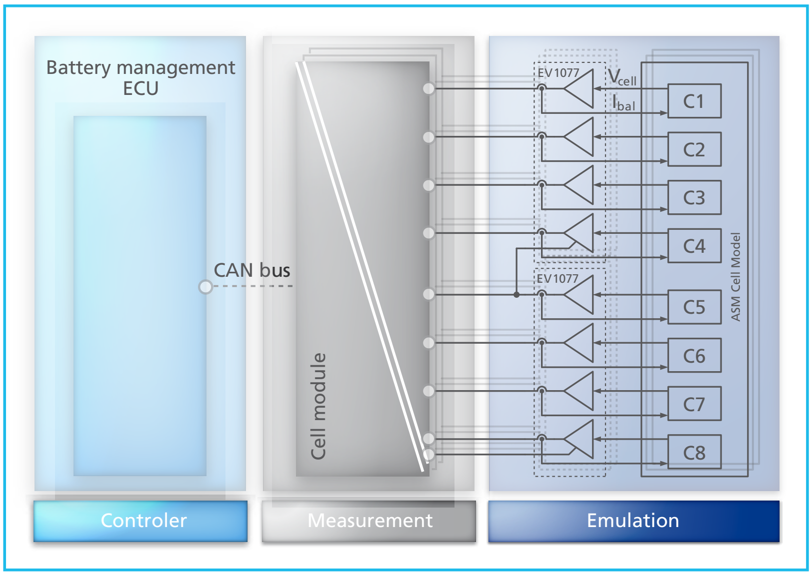

Figure 1:Instead of real battery cells, the cell emulation modules are connected to the cell models. They are controlled by the ASM cell model.

The Structure of a BMS

A BMS is divided into two parts, the BMS ECU itself and the cell modules (CM). These are connected via a galvanically isolated CAN. One CM is assigned to one cell stack.

The CM is responsible for measuring cell voltages and initiating discharge in specific single cells. To do this, it has a transistor for each cell. When the transistor is switched on, it discharges the cell via a resistance. The higher-level BMS ECU causes cells to discharge if they have a higher voltage than the other cells. This mechanism keeps all the battery's cells at the same charge level.

HIL Tests for a BMS

If only the control strategy for the BMS has to be tested, it is sufficient to test the BMS ECU alone. The cell modules are then simulated by restbus simulation via CAN.

To test the entire battery management system, at least one CM has to be integrated into the HIL system. Closed-loop operation requires a real-time-capable battery simulation model and a cell voltage emulator that outputs the analog terminal voltage to the CM. Both of these are available in the form of the cell model in dSPACE's Automotive Simulation Models (ASMs) and the battery voltage emulation module EV1077 (Figure 1).

Real-Time-Capable Battery Models

Unlike conventional battery models for simulating vehicle electrical systems, models for testing battery management systems have to simulate a battery's behavior as a number of connected single cells.

A single cell model represents the cell voltage and charge state of one battery cell. It takes into account technology based differences in charging and discharging, and also dynamic behavior during load variations and leakage currents.

ASM Cell Model

The ASM cell model consists of a cell voltage model and a model for the state of charge. With the cell voltage model, individual physical effects such as internal resistance, diffusion and double-layer capacity can be parameterized. The state of charge model deals with the cell's charge and discharge and also with leakage currents.

A complete cell network of n cells can be formed by connecting n individual models. However, if there are a large number of cells, this type of model becomes difficult to handle and may not be real-time-capable.

Reference and Delta Models

The new ASM multicell model consists of a complex reference cell model that describes the basic behavior of the cell type used, and a delta model that computes the deviation of each individual cell's voltage from the reference voltage. The capacity, initial charge state and deviation from the reference value of the internal resistance can be specified for each cell (Figure 2).

This new modeling technique reduces the computation time on a dSPACE real-time system by a factor of 12 compared with a series connection of 100 individual cell models. Even more time is saved in offline simulation.

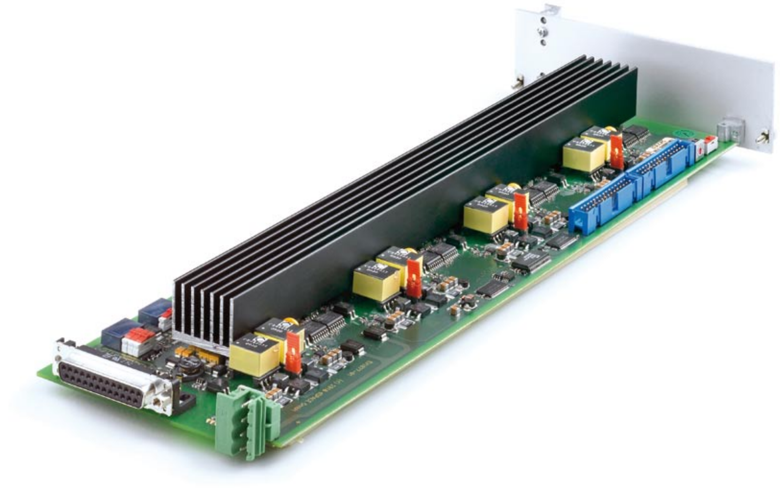

Figure 2: EV1077 cell voltage module for 4 channels.

Hardware Requirements for Cell Voltage Emulation

In emulation, cell voltages must be connected in series in the same way as in a real battery, because cell voltage measurement in the CM runs via one line only. The emulation therefore has to consist of galvanically isolated voltage sources.

Li-ion cells have a very flat discharge characteristic. The ECU therefore performs voltage measurement with high precision, and the cell voltages must also be emulated with a precision of at least 1 mV. This precision must also be maintained in the event of balancing currents of several hundred mA. The cell emulation hardware measures the balancing currents and passes them to the battery model for correct simulation of the state of charge.

Failure Simulation

A complete HIL simulation also covers faulty battery states. This can involve simulating a defective cell with a changed internal resistance or capacity, or simulating a broken wire or a short circuit.

High Dynamics Requirements

When the load on the battery changes quickly, the voltages change almost simultaneously on all the cells. Thus, each individual cell has to be able to change its voltage within one model cycle. This requires fast transmission of reference values and also fast control of the output voltage.

Other typical requirements are short-circuit protection, overload protection, and high insulation strength, because series connection can cause high voltages.

Emulation Electronics Setup

The cell voltage modules provide an adjustable voltage in the range 0 to 6 V. This relatively wide range allows damaged cells to be emulated. For example, a short-circuited cell can be emulated by outputting 0 V, and a voltage higher than the nominal voltage simulates a cell's increased internal resistance during charging.

The voltage is output with a precision of +/-1 mV across the entire working temperature range. Galvanic isolation allows the modules to be connected in series up to a voltage of 800 V. A reference value step is corrected completely in less than 500 µs. All the cell modules are given their new reference value in less than 1 ms.

Each channel can supply and sink a maximum of 1 A, so it is sufficiently sized for the usual balancing currents. For special requirements, up to four channels of one module can be connected in parallel to achieve ±4 A.

With the compact design, up to 32 channels can be accommodated in a standard 3-HU 19" subrack. Only four such subracks are needed for the maximum cell number of 128.

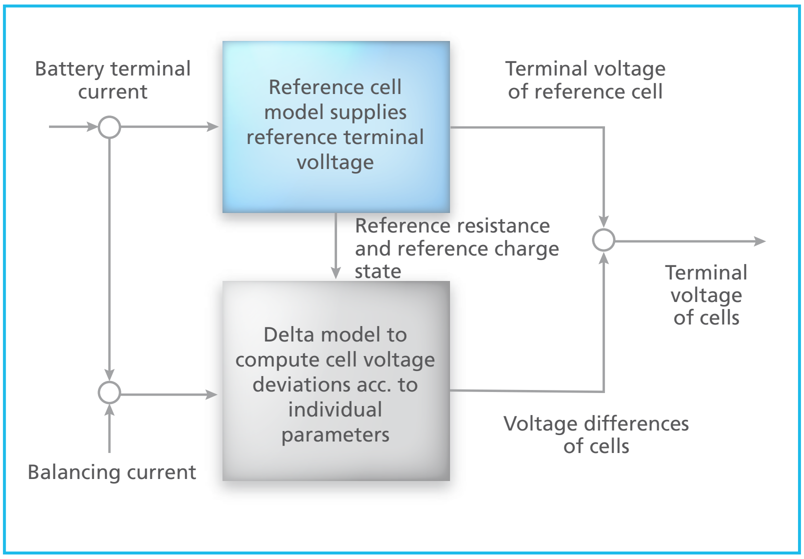

Figure 3: The input values to the cell network are the input current to the reference cell. The delta model calculates the i-th cell's deviation from the terminal voltage. The terminal voltage of the i-th cell can then be computed from the reference cell's terminal voltage and the calculated deviation.

HIL Integration of the Emulation Unit

The real-time processor and the cell voltage emulation hardware exchange data via an LVDS interface. This ensures high precision and galvanic isolation. A control board receives the reference values for the individual cells from the real-time processor and transmits galvanically isolated data to the individual modules for cell voltage emulation (Figure. 4). It receives not only the reference values, but also the control commands that switch the relays. The measured cell currents and the temperature of each module are transmitted in the opposite direction. The relays on a module set up the connection to the ECU and also disconnect it for the purposes of failure simulation.

Conclusion

For HIL tests on a battery management system (BMS), high-voltage batteries have to be simulated at cell level. To make this possible, dSPACE provides a scalable, real-time-capable cell model and a high-precision emulation unit to output the cell terminal voltage. The two are combined to set up an HIL simulator that runs tests reproducibly under automatic control.

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