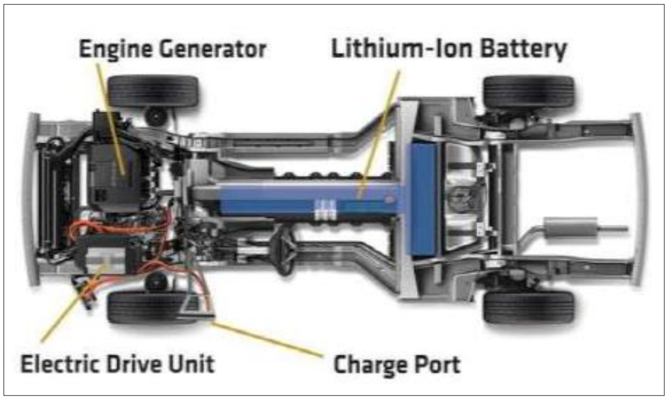
Smart People. Expert Solutions.

WHITE PAPER

DMC BATTERY TESTING PLATFORM

EV Battery Pack Testing in a Manufacturing Environment

OVERVIEW



Electric vehicles are clearly becoming a growing part of the automotive scene. They promise low or no emissions, conceivably low cost of fuel from the power grid, yet they will continue to deliver us safely from here to there. However, electric vehicle design and manufacturing is a clearly a paradigm shift for the Auto Industry – new drive systems, technologies… and test plans.

Electric vehicles are bringing new test and validation challenges to the automotive industry as the electronic and software content of the vehicles grow. In this white paper, we will discuss the basics of electric vehicle battery pack designs and some of the tests that should be performed on them in a manufacturing environment. We'll also show you how the DMC Battery Testing Platform can help solve these complex testing problems.

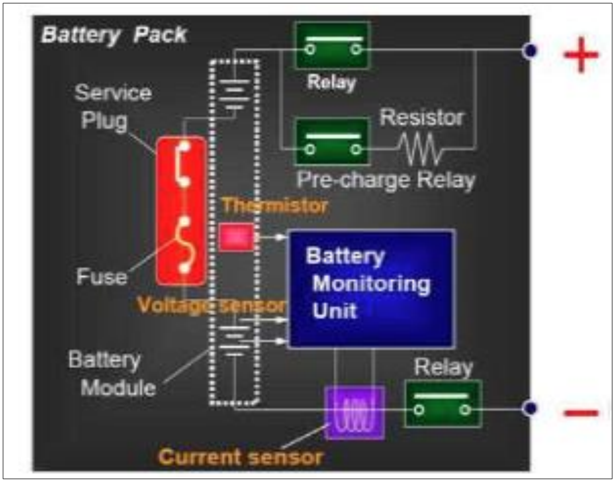
MOTIVATION FOR EV BATTERY TESTING

The battery packs used as the rechargeable electrical storage system (RESS) in electric vehicles (EVs), hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs) are large and complex. Controlled release of the battery's energy provides useful electrical power in the form of current and voltage. Uncontrolled release of this energy can result in dangerous situations such as release of toxic materials (i.e. smoke), fire, high pressure events (i.e. explosions), or any combination thereof.

Uncontrolled energy releases can be caused by severe physical abuse, such as crushing, puncturing or burning, which can be mitigated by mechanical safety systems and proper physical design. However, they can also be caused by shorted cells, abnormally high discharge rate, excessive heat buildup, overcharging, or constant recharging, which can weaken the battery. These causes are best prevented by a properly designed and validated electronic safety and monitoring system, better known as a battery management system (BMS).

One of the major validation and safety challenges to be tackled in modern EVs, HEVs, and PHEVs concerns the effective testing of the Battery Pack itself and the Battery Management Systems (BMS) – the complex electronic system that manages the performance and safety of the battery pack and the high levels of electrical energy stored within. In the sections below we will describe both the battery pack and the BMS in greater detail.

INSIDE AN EV BATTERY PACK

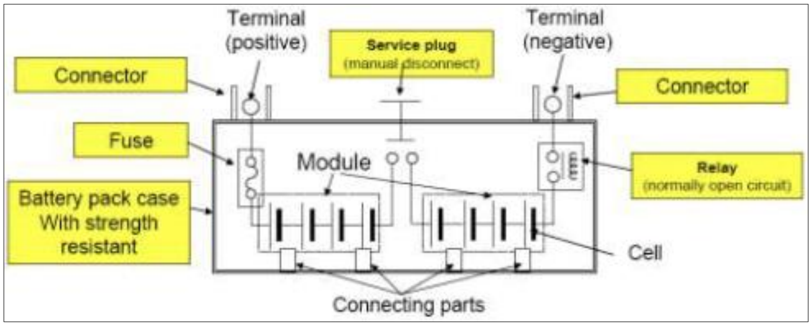


Battery pack designs for EVs are complex and vary widely by manufacturer and specific application. However, they all incorporate combinations of several simple mechanical and electrical component systems which perform the basic required functions of the pack.

We will start with the actual battery cells, which can have different chemistries, physical shapes, and sizes as preferred by various pack manufacturers. However, the battery pack will always incorporate many discrete cells connected in series and parallel to achieve the total voltage and current requirements of the pack. In fact, battery packs for all electric drive EVs can contain several hundred individual cells.

To assist in manufacturing and assembly, the large stack of cells is typically grouped into smaller stacks called modules. Several of these modules will be placed into a single battery pack. Within each module the cells are welded together to complete the electrical path for current flow. Modules can also incorporate cooling mechanisms, temperature monitors, and other devices. In most cases, modules also allow for monitoring the voltage produced by each battery cell in the stack by the BMS.

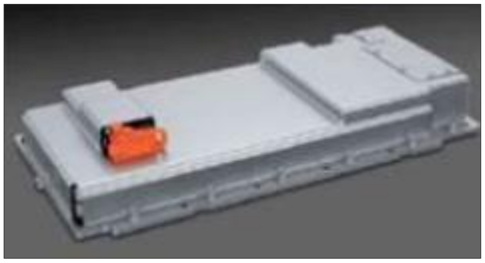
Somewhere in the middle, or at the ends, of the battery cell stack is a main fuse which limits the current of the pack under a short circuit condition. Also located somewhere within the electrical path of the battery stack is a “service plug” or “service disconnect” which can be removed to split the battery stack into two electrically isolated halves. With the service plug removed, the exposed main terminals of the battery present no high potential electrical danger to service technicians.



The battery pack also contains relays, or contactors, which control the distribution of the battery pack’s electrical power to the output terminals. In most cases there will be a minimum of two main relays which connect the battery cell stack to the main positive and negative output terminals of the pack, those supplying high current to the electrical drive motor. Some pack designs will include alternate current paths for pre-charging the drive system through a pre-charge resistor or for powering auxiliary busses which will also have their own associated control relays. For obvious safety reasons these relays are all normally open.

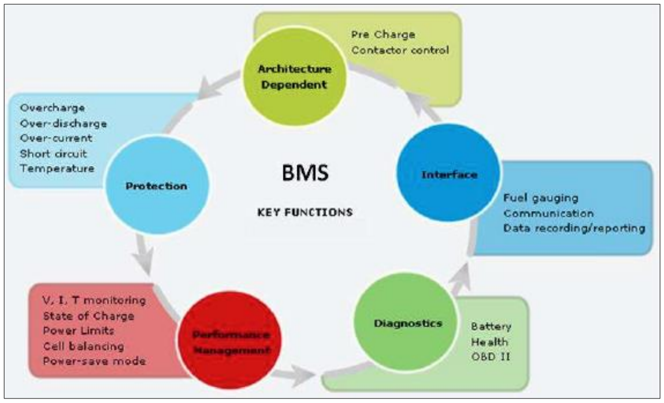
The battery pack also contains a variety of temperature, voltage, and current sensors. There will be at least one main current sensor which measures the current being supplied by, or sourced to, the pack. The current from this sensor can be integrated to track the actual state of charge (SoC) of battery pack. The state of charge is the pack capacity expressed as a percentage, and can be thought of as the pack's fuel gauge indicator. The battery pack will also have a main voltage sensor, for monitoring the voltage of the entire stack and a series of temperature sensors, such as thermistors, located at key measurement points inside the pack.

Collection of data from the pack sensors and activation of the pack relays are accomplished by the pack's Battery Monitoring Unit (BMU) or Battery Management System (BMS). The BMS is also responsible for communications with the world outside the battery pack and performing other key functions, as described in the following section.



INSIDE AN EV BATTERY MANAGEMENT SYSTEM (BMS)

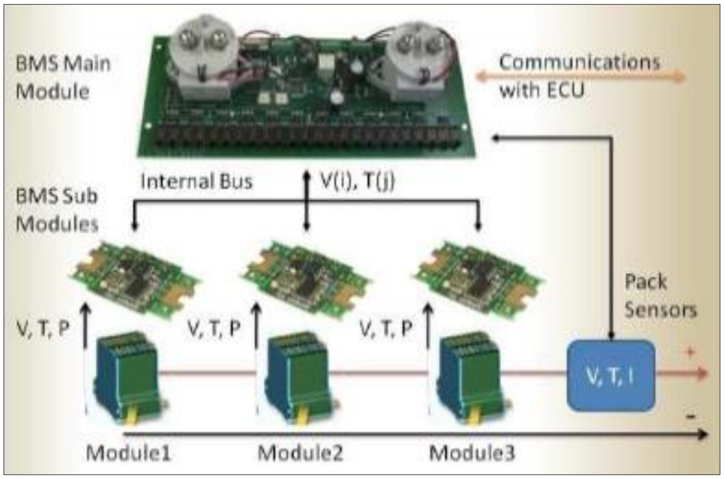
Almost all electronic functions of the EV battery pack are controlled by the BMS, including battery pack voltage and current monitoring, individual cell voltage measurements, cell balancing routines, pack state of charge calculations, cell temperature and health monitoring, ensuring overall pack safety and optimal performance, and communicating with the vehicle engine control unit (ECU).



In a nutshell, the BMS system must read voltages and temperatures from the cell stack and inputs from associated temperature, current and voltage sensors. From there, the BMS must process the inputs, making logical decisions to control pack performance and safely, and reporting input status and operating state through a variety of analog, digital, and communication outputs.

BMS TOPOLOGY

Modern BMS systems for PHEV applications are typically distributed electronic systems. In a standard distributed topology, routing of wires to individual cells is minimized by breaking the BMS functions up into at least 2 categories. The monitoring of the temperature and voltage of individual cells is done by a BMS 'sub-module' or 'slave' circuit board, which is mounted directly on each battery module stack. Higher level functions such as computing state of charge, activating contactors, etc. along with aggregating the data from the sub modules and communicating with the ECU are done by the BMS 'main module' or 'master'.



The sub-modules and main module communicate on an internal data bus such as CAN (controller area network). Power for the BMS can be supplied by the battery stack itself, or from an external primary battery such as a standard 12V lead acid battery. In some cases, the main module is powered externally, while the sub modules are powered parasitically from the battery modules to which they are attached.

BMS STATE OF CHARGE CALCULATION

The BMS is responsible for tracking a battery pack's exact state of charge (SoC). This may simply be for providing the driver with an indication of the capacity left in the battery (fuel gauging), or it could be used for more advanced control features.

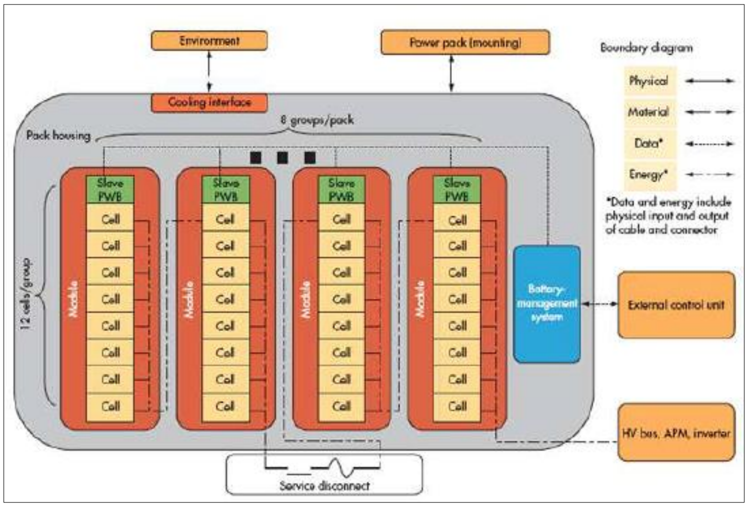
For example, SoC information is critical to estimating and maintaining the pack's usable lifetime. Usable battery life can be dramatically reduced by simply charging the pack too much, or discharging it too deeply. The BMS must maintain the cells within the safe operating limits. The SoC indication is also used to determine the end of the charging and discharging cycles.

To measure SoC the BMS must include a very accurate charge estimator. Since you can't directly measure a battery's charge, the SoC has to be calculated from measured characteristics like voltage, temperature, current and other proprietary (depending on the manufacturer) parameters. The BMS is the system responsible for these measurements and calculations.

BMS CELL BALANCING FUNCTIONS

The BMS must compensate for any underperforming cells in a module, or "stack", by actively monitoring and balancing each cell's SoC. In multi-cell battery chains, small differences between cells (as a result of production tolerances, uneven temperature distribution, intrinsic impedance, and/or aging characteristics) tend to be magnified with each charge and discharge cycle. In PHEV applications the number of cycles can be very high due to the use of regenerative braking mechanisms.

Assume degraded cells with a diminished capacity existed within the battery stack. During the charging cycle, there is a danger that once it has reached its full charge it will be subject to overcharging until the rest of the cells in the chain reach their full charge. As a result, temperature and pressure may build up and possibly damage that cell. During discharging, the weakest cell will have the greatest depth of discharge and will tend to fail before the others. The voltage on the weaker cells could even become reversed as they become fully discharged before the rest of the cells resulting in early failure of the cell.



Cell balancing is an active way of compensating for weaker cells by equalizing the charge on all the cells in the chain and thus extending the battery pack’s usable life. During cell balancing circuits are enabled which can transfer charge selectively from neighboring cells, or the entire pack, to any undercharged cells detected in the stack.

In order to determine when active cell balancing should be triggered, and on which target cells, the BMS must be able to measure the voltage of each individual cell. Moreover, each cell must be equipped with an active balancing circuit.

STATE OF HEALTH AND DIAGNOSTICS

The State of Health (SoH) is a measure of a battery's capability to safely deliver its specified output. This metric is vital for assessing the readiness of the automobile and as an indicator of required maintenance.
SoH metrics can be as simple as monitoring and storing the battery's history using parameters such as number of cycles, maximum and minimum voltages and temperatures, and maximum charging and discharging currents, which can be used for subsequent evaluation. This recorded history can be used to determine whether it has been subject to abuse, which can be an important tool in assessing warranty claims.

More advanced measures of battery SoH can include features such as automated measurement of the pack’s isolation resistance. In this case, specialized circuits inside the battery pack can measure the electrical isolation of the high current path from the battery pack ground planes. Such a safety system could preemptively alert the operator or maintenance technicians to potential exposure to high voltage.

BMS COMMUNICATIONS

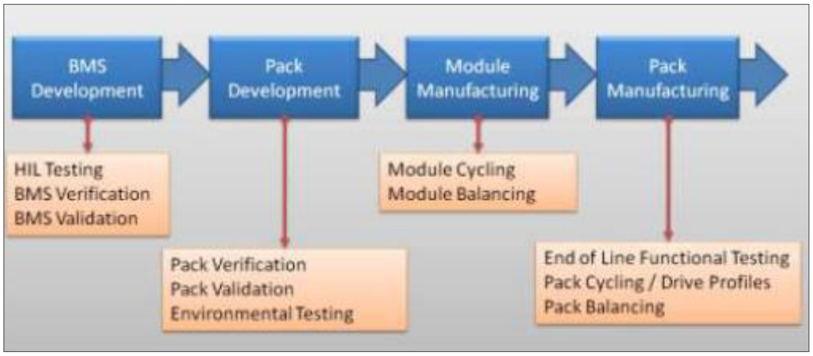
Most BMS systems incorporate some form of communication with the world outside the battery pack, including the ECU, the charger controller, and/or your test equipment. Communications interfaces are also used to modify the BMS control parameters and for diagnostic information retrieval.

In automotive applications, CAN (controller area network) is the most common communications bus, although RS232 / RS485 serial, TCPIP or other networks could be used. CAN networks come in a variety of implementations and can include a range of higher level protocols.

Aside from a digital bus, separate analog and/or digital inputs and outputs could be considered as BMS communication. Discrete inputs and outputs can be used for redundancy of for operations requiring a separate interface such as activating an external contactor, fan, or dashboard lamp.

TESTING AN EV BATTERY PACK

Developing a test strategy for an assembly as large, complex, and powerful as an EV battery pack can be a daunting task. Like most complex problems, breaking the process down into manageable pieces is the key to finding a solution. Accordingly, testing only at critical points in the development and manufacturing process will reduce the size of the problem. Key points for most pack manufacturers are BMS development, pack development, module assembly, and pack assembly. What tests are performed at each step is a different matter altogether, and depends on the specifics of the process and the device.



BMS DEVELOPMENT TESTING

During BMS Development, engineers need a way to reliably test the BMS under real-world conditions to complete their verification and validation plans. Testing such as Hardware-in-the-Loop (HIL) is often performed at this stage. HIL testing involves simulating physical inputs and external digital connections to the pack while monitoring its outputs and behavior relative to design requirements.

It is not easy to accurately simulate all of the real-world conditions a BMS will be subjected to. But what does it cost you to skip testing over every condition? In the end, simulating nearly every combination of cell voltages, temperatures, and currents you expect your BMS to encounter is really the only way to verify that your BMS reacts as you intended in order to keep your pack safe and reliable.

PACK DEVELOPMENT TESTING

At the Pack Development stage, engineers are typically concerned about testing the entire assembly through various types of environmental stress testing as part of design validation or product validation plans. Environmental stress could include exposure to temperature extremes, thermal shock cycling, vibration, humidity, on-off cycling, charge discharge cycling, or any combination of these. The testing requirements here typically include performing a full batch of performance tests on a pack both before and after application of the stress. Live monitoring of the pack throughout the environmental stress period may also be required.

MODULE ASSEMBLY TESTING

Requirements for Module Level testing vary widely depending on the actual design of the system. The main testing to be done at this point involves simple charge / discharge testing to ensure that connections between cells are robust and can handle the intended current loads without failing or shedding excessive heat. Further testing could involve ensuring the cell voltages are reported correctly, that the cells are balanced, and/or that the cooling and temperature monitoring sensors are working properly.

PACK ASSEMBLY TESTING

Pack Level testing is done after the pack has completed, or is at least very close to, the point of final assembly, or “End of Line” (EOL). At this stage, the pack must complete a full batch of tests to ensure proper functioning of every major pack subsystem (functional testing). These tests include simple pinout and continuity checks, confirming proper relay operation, testing functionality of safety devices such as the service disconnect, carefully measuring the isolation resistance under high potential (hi-pot testing), and testing proper communications and operation of the BMS.

After EOL functional testing is completed, packs may also be subjected to charge / discharge cycling and drive profile cycling, which will simulate the typical conditions the pack will see when integrated into the EV drivetrain. Packs can also be run through active cell balancing routines in order to set the initial charge state of each cell to a nominal condition, or to set the Pack SoC to a level appropriate for shipping and storage.

EV BATTERY PACK TESTING SOLUTIONS

Once you have decided where you are testing, and what you are testing, you need to determine how you will be testing. Since every battery pack design is unique and testing requirements are primarily left up to the end user and manufacturer to agree upon, in reality there is no one-size-fits-all solution for everyone’s battery pack testing needs.

OFF-THE-SHELF TESTING SOLUTIONS

That being said, some portions of the testing, such as charge / discharge / drive cycle evaluation in specific, are standardized. As such, pre-packaged, off-the-shelf hardware and software solutions exist for these particular test steps. These systems make use of the only elements common to every battery pack: the positive and negative output terminals. These turn-key systems may even allow you to add in options required to test components and functions specific to your battery pack, such as CAN communications, external relay activation, etc.

When considering off-the-shelf systems for use in your test plan, make sure to ask yourself these three basic questions:

(1) Are you getting everything you need just the way you want it… or are you settling for what the other guy needed?

(2) Are you using everything you are going to pay for… or are you paying for things you won't use?

(3) Is it flexible enough to accommodate my future needs… but not so flexible that it becomes cumbersome to use?

ARGUMENTS FOR A CUSTOMIZED, MODULAR TEST SYSTEM APPROACH

Building a functional test system customized to your battery pack and your specific testing needs often sounds like a more costly and time consuming approach… and it can be. However, the route you take to achieve that end goal makes a world of difference in the outcome.

Choosing a modular hardware and software testing platform which can be customized to meet your requirements, can be used to jump start this approach, making it a very viable option. This is especially true if the platform you choose leverages proven commercial technologies and open industry standards.

In the end, this modular platform based testing approach can have several benefits:

(1) It can dramatically lower cost of the test system, both in initial capital expenditure, and in overall cost of ownership, through the use of commercial technologies and standards.

(2) It can increase your test throughput with fast measurement hardware and software capable of managing multiple test routines in parallel.

(3) The time required to redesign test systems for new products will decrease through the use of flexible, modular software and hardware.

(4) You can get exactly what you need, the way you want it. You can get everything you paid for and your test station will be flexible, without being cumbersome to use.

THE DMC BATTERY TESTING PLATFORM

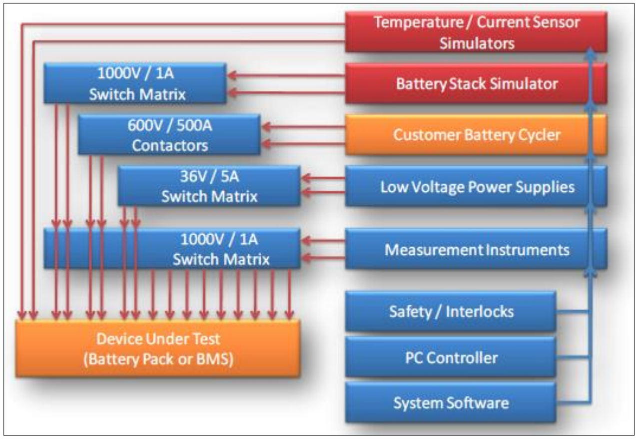
The DMC Battery Testing Platform is specifically designed for testing entire battery packs, battery modules, and BMS components for EV, HEV, and PHEV manufacturers, suppliers, and third party testing facilities. The Battery Testing Platform is quickly leveraged to produce completely automated test systems specifically designed for EOL manufacturing tests, BMS validation and verification, and environmental monitoring.

DMC's modular Battery Testing Platform incorporates proven software and hardware architectures, along with flexible and reliable subsystem components, which can be completely customized to end user specifications.

The Battery Testing Platform is built around high quality off-the-shelf hardware assembled from a variety of vendors, including National Instruments (NI), Pickering Interfaces, Lambda, and Agilent, among others. Selection of individual instruments in the DMC system is based completely on required performance, not allegiance to a single hardware vendor. This strict attention to specifications and performance provides DMC battery test system users with best in class performance.

HARDWARE SYSTEM DESCRIPTION

The DMC Battery Testing Platform leverages a modular hardware architecture, flexible subsystem components, and reliable instrumentation, to create completely customized test systems tailored to meet end users specifications. Use of the modular platform allows the production of a completely customized battery test system with the performance and cost of a turn-key, off the shelf solution.



The basic block diagram of a test system is shown at right. Each test system produced will include only the modules required to meet end user specifications. Modules can be easily customized, or new ones added, as needed for your implementation.

Core system instrumentation and hardware includes:
o NI PXI Chassis with NI embedded system controller
o Lambda low voltage, programmable DC power supplies
o Dual, NI 7 . digit PXI DMMs: +/-10 nV to 1kV voltage readings and current to 1 pA.
o Pickering Interfaces 1000VDC PXI relay modules.
o NI Dual port, software selectable CAN transceiver (HS, LS, 1-wire), PXI cards.
o NI High speed simultaneous sampling Analog and Digital I/O PXI DAQ cards.
o Agilent high voltage, programmable power supplies.

SOFTWARE SYSTEM DESCRIPTION

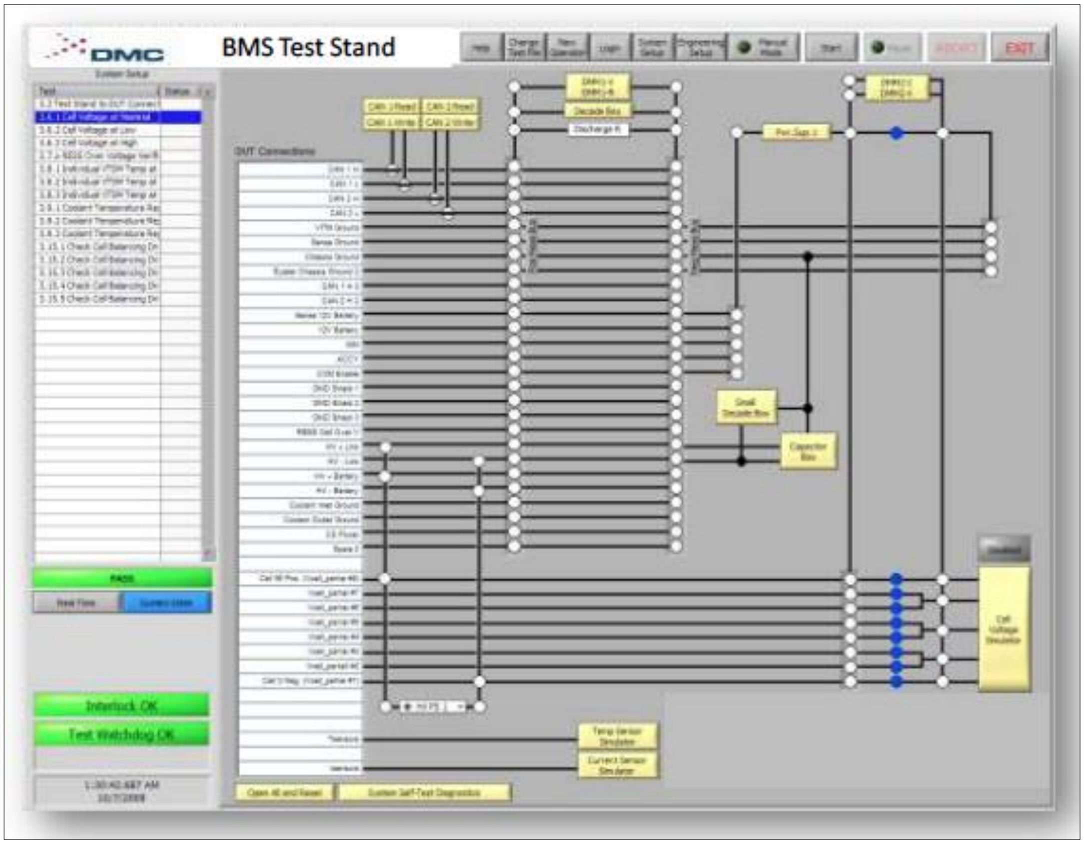
DMC's modular Battery Testing Platform solutions run proven and flexible software architectures built using National Instruments' LabVIEW Development System platform. Test software is built with several audiences in mind.

- Engineers are provided with password protected access to: test settings, system parameters, a fully interactive "manual mode" which provides low-level access to all instruments and subsystems, and to all system self-test and diagnostic routines.

- Maintenance-staff have full access to an embedded calibration tool set.

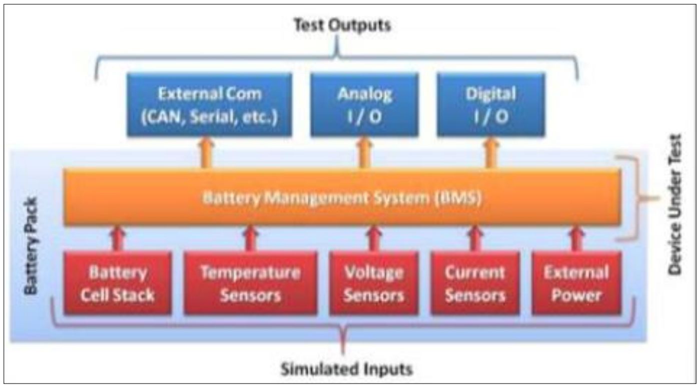
- Operators and technicians have the ability to load test sequences and recipes, enter extended DUT information, start tests with a single button press, monitor ongoing tests on the live data screen, and view final data reports.

- Managers have access to usability statistics, error reports and logs, and can be emailed on test completion failures, and/or system trouble.



EXAMPLE SYSTEM - BMS VALIDATION TESTING

Effectively testing a BMS system involves two primary functions, (1) accurately simulating the required sensors and battery cell stack inputs to the BMS, and (2) measuring, collecting, and processing the digital and analog outputs produced by the BMS system as a result of those inputs.



DMC's modular Battery Testing Platform solution can be configured specifically for testing your entire BMS, or individual components of the system. Of course your specific requirements will be different, but an example BMS testing solution might have the following physical requirements:

BMS SIMULATED INPUTS

- Simulate a fully adjustable, 100-cell battery stack.
- Simulate 26 pack temperature sensors.
- Simulate various analog current and voltage sensors.
- Simulate several pack contactors/relays.
- Simulate drive motor’s impedance model.
- Simulate BMS external, low voltage power supply / backup battery.

BMS OUTPUT / FUNCTIONAL MONITORING

- Over voltage and under voltage protection analog output signals
- Cell balancing RMS current draw and I/V waveform capture.
- In-rush, parasitic, sleep, and wake current monitoring.
- Cell voltage and stack voltage accuracy measurements.
- Temperature sensor accuracy measurements.
- System communications performance (CAN, Serial, etc.)
- Safety system and fault condition recognition

The example BMS testing system can be configured to run the following test sequences:

- *BMS Connection Check*
- *Terminal Resistance Checks*
- *Terminal Capacitance Checks*
- *Interlock System Validation*

CAN Communications Checks

- Sleep/Wake Mode Current Measurement
- Activate / Deactivate Timing and Voltage
- CAN Communications Check
- Low / High Voltage Performance
- Power Dropout Sensitivity

BMS Validation Tests

- Active Isolation Capability
- Nominal
- Simulated Fault Conditions

Cell and Pack Voltages

- Nominal Cell Voltage
- High Cell Voltage

- Low Cell Voltage
- Cell position reporting verification

BMS Validation Tests (Continued)

- Pack Current / SOC
  - Nominal Current
  - High Current
  - Low Current

Cell and Pack Temperatures

- Nominal Temperatures
- High Temperatures
- Low Temperatures
- Cell position reporting verification

Cell Balancing Capability

- Nominal Cell Voltage
- High Cell Voltage
- Low Cell Voltage

Diagnostic Trouble and Fault Codes

- Validate all Trouble / Fault Code Operation
- BMS Software Version Validation

In addition to the core platform hardware components listed previously, configuration of the BMS test stand requires integration of a major hardware assembly which can simulate the series stack of approximately 100 Li-ion cells comprising the actual battery to be connected to the BMS. Adding this functionality allows users to simulate nominal, out of norm, and worst-case battery stack conditions, which could not be produced repeatedly, reliably, or safely with a normal chemical battery cell. As a result, the system can be used to measure live waveform captures of the currents and voltages produced by the stack under varying BMS conditions. With this information end users can gain unique and valuable insights into the real world operation of their BMS system.

The modular, flexible, and open nature of the DMC Battery Testing Platform solution made selection, integration, and use of the battery stack simulator component simple and straightforward.

For more information on this system configuration, see this DMC Case Study:

http://www.dmcinfo.com/Case-Studies/View/ProjectID/200/Battery-Management-System-BMS-Validation-Test-Stand.aspx

EXAMPLE SYSTEM - END OF LINE FUNCTIONAL TESTING
DMC's modular Battery Testing Platform solution can also be configured specifically for automated end-of-line testing of your entire battery pack, including battery cycler control for charge / discharge / drive-cycle testing. Your specific requirements will be different, but the example EOL battery pack test system can be configured to run the following test sequences:

• Pack Connection Check

• Chassis Ground Isolation Resistance
– Direct DC V method (to 1kV)
– USA DOT Federal Motor Vehicle Safety Standard (FMVSS) 305
– UN ECE 324 Regulation 100
– Proprietary / Other Methods

• Battery Terminal Isolation Resistance
• Other Terminal Isolation Resistance
• Terminal Resistance Checks
• Terminal Capacitance Checks

• Contactor Characterizations
– Turn On Timing / Voltage / Current
– Turn Off Timing / Voltage

• Fuse Path Validation
• Interlock System Validation

• BMS Validation Tests
– Sleep/Wake Mode Current Measurement
– Activate / Deactivate Timing and Voltage
– CAN Communications Check
– Low / High Voltage Performance
– Voltage Accuracy Testing
– Power Dropout Sensitivity
– Active Isolation Capability
– Cell Balancing Capability

- Service Disconnect Performance

- CAN Communications Checks
  - Cell and Pack Voltages
  - Pack Current / SOC
  - Cell and Pack Temperatures
  - Diagnostic Trouble and Fault Codes
  - BMS Software Version Validation

- Battery Pack Cycling Tests
  - Max / Min Current Validation
  - Drive Cycle Performance
  - Fuse Performance

For more information on this system configuration, see this DMC Case Study:
http://www.dmcinfo.com/Case-Studies/View/ProjectID/121/Hybrid-Electric-Vehicle-Battery-Test-System.aspx