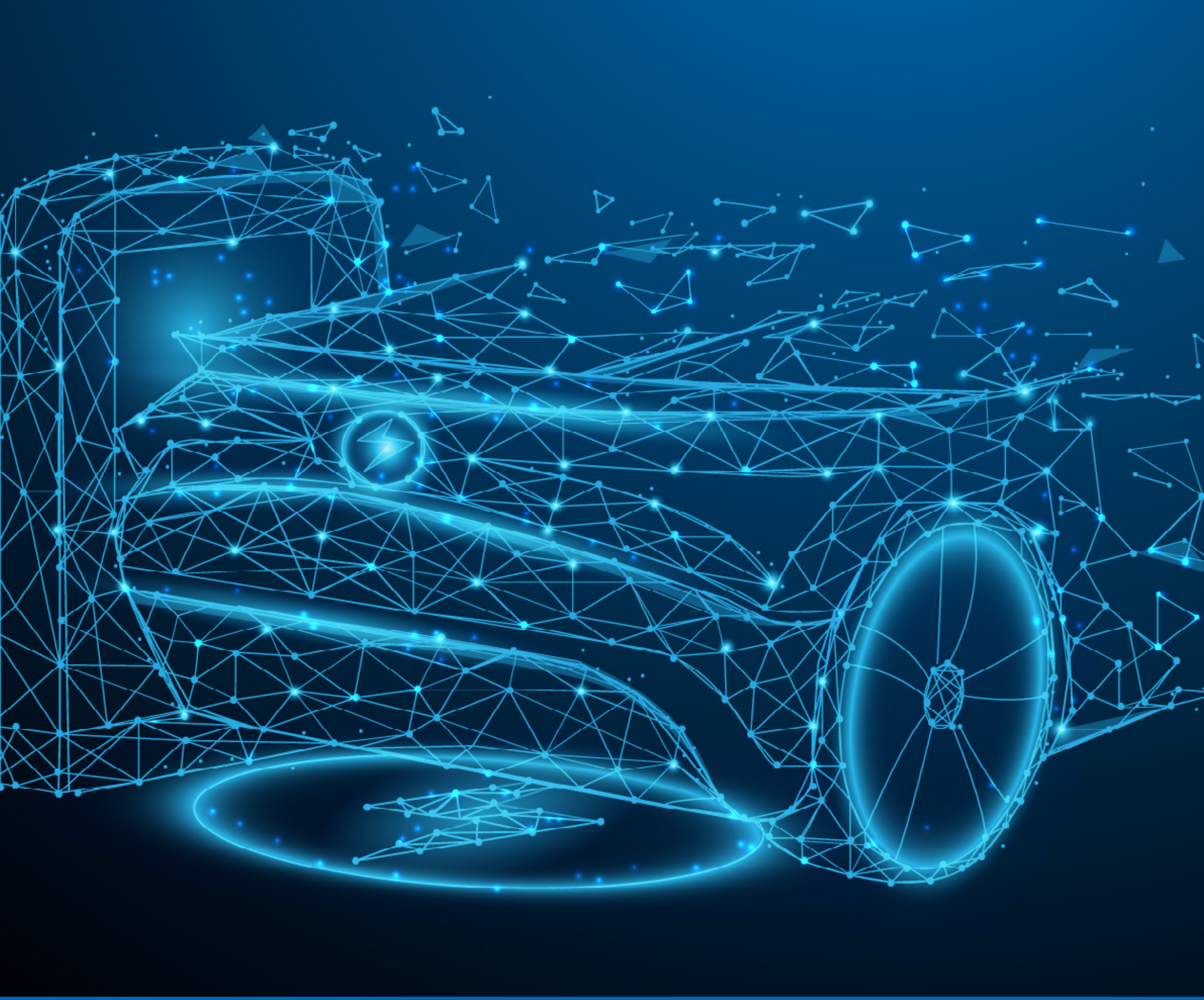

White Paper

BMS Functional Verification:
The Safety-First Approach

pickering

CONTENTS

Introduction

In this white paper, we discuss the goals of battery management system (BMS) verification and explain how simulation with hardware-in-the-loop (HIL) provides a wealth of data, saves time and is safer than working with actual live cells. We also explain how a BMS HIL test system can be created using a range of simulation modules available from Pickering Interfaces.

Battery Management Systems

E-mobility, the electrification of the drivetrains of a wide range of land vehicle types - including electric vehicles (EVs) and all their derivatives, e-bikes, e-trams and construction equipment - requires the use of battery packs. Battery packs are also needed to facilitate the electrification that is taking place within the aerospace sector (with both more-electric and all-electric aircraft, for example) and to support the growing popularity of electric vertical take-off and landing (eVTOL) aircraft and drones. The renewable energy sector also uses battery packs to store power generated by wind turbines and solar panels.

In these applications and others, the battery packs – which can contain from a few dozen to a few thousand cells – must be controlled for optimum performance in terms of releasing and accepting power. The packs must also be monitored to report state-of-charge and -health (SoC and SoH, respectively) to the systems employing them. Also, safety measures/features must be present to isolate the packs (or modules/banks of cells therein) in the event of a fault. These roles are performed by the battery management system (BMS).

Safety

This is an extremely important consideration in all sectors in which battery packs are used. In automotive, for example, the packs and all vehicle/platform components that electrically connect to them are considered hazardous items and must comply with ISO 26262. It applies to safety-related systems that, in the words of the International Organization for Standardization, include "…one or more electrical and/or electronic (E/E) systems and that are installed in series production passenger cars with a maximum gross vehicle mass up to 3,500 kg."

Though ISO 26262 applies to all safety-related systems, including those for anti-lock braking and adaptive cruise control, for instance, the standard makes a point of saying it does not "address hazards related to electric shock, fire, smoke, heat, radiation, toxicity, flammability, reactivity, corrosion, release of energy and similar hazards, unless directly caused by malfunctioning behavior of E/E safety-related systems."

However, a malfunctioning BMS or one which (through a design flaw or a manufacturing defect) is unable to react correctly to the condition of the battery pack's cells could result in many of the above. For example, a battery pack in thermal runaway (triggered by overheating) can produce gases that include hydrogen, hydrogen fluoride, carbon monoxide and dioxide, and volatile hydrocarbons. Accordingly, ISO 26262 very much applies to a BMS used in the automotive sector.

BMS Design & Verification

Most companies adopt a test-driven development (TDD) strategy when designing a BMS. This enables them to not only optimize the battery pack's size (both physical and energy capacity) but also verify the functionality of the BMS throughout the product development lifecycle.

> "Simulation is the safest way to verify that a BMS's features perform as intended because it does not involve creating over-voltage or short-circuit conditions with live cells. It is also easy to replicate open circuits and temperature extremes."

Typical top-level functional requirements for a BMS include:

- Voltages must be monitored at the battery pack's inputs and outputs, and at the individual cell level.
- Current flow into and from the pack must be monitored.
- SoC and SoH should be monitored and made available to systems that draw power from the pack and which charge it.
- Thermal management. For example, lithium-ion cells perform best between 10 and 45 °C, so the BMS must control the heating or cooling of the pack accordingly.
- The BMS must provide protection against in-use conditions such as overcharging and fault conditions (such as an individual cell failing or wires breaking). It must also protect against human errors, such as getting the polarity wrong during a maintenance or repair task.

Verifying through test that the above requirements and others have been met is more than just a development task, though. Every production unit needs to be functionally verified as part of its quality assurance. Moreover, there are instances when a BMS may need to be reverified, in which case it will be essential to repeat the exact same tests.

Simulation with Hardware-in-the-Loop

BMS development with hardware-in-the-loop (HIL) is essential. However, the use of an actual battery pack presents problems. These include:

- Performing over-voltage checks is dangerous – with the risk of fire or explosion.
- It is not easy to change the voltages of individual cells. This means it is difficult to verify that the BMS's cell balancing function works.
- Where the monitoring of individual cell voltages is concerned, it is only possible to check what the BMS *thinks* it is seeing. But what are the real cell voltages?
- How can the BMS's temperature monitoring function be checked without subjecting the pack to temperature extremes?

There is also the issue of test repeatability and documenting test conditions and results. Test set-up and the reporting of results are both open to human error. This means the accuracy (and by extension validity) of the BMS verification data could be called into question.

The single solution to all the above issues is simulation. It removes the need to work with live cells, so it is safer. The voltages supplied to the BMS in lieu of individual cells can be monitored, so there are values against which the BMS's observations can be compared.

Simulation is also highly repeatable as fault conditions, such as broken wires and overheating cells, are far easier to simulate than they are to replicate with live cells.

In addition, the use of an industry-standard platform such as PXI – a modular and scalable PC-based platform supported by more than 60 T&M vendors - enables the creation of a comprehensive test environment. Accordingly, most BMS verification tasks can be controlled by a single environment and results easily recorded.

The next four sections of this white paper outline specific simulations that can be performed using Pickering Interfaces products.

High Voltage Switching

This can be achieved using a number of solutions from Pickering Interfaces; over 60 PXI/PXIe modules and 28 LXI modules. For example, the 40-323-701 (PXI) and 42-323-701 (PXIe) are 14xSPST relay modules suitable for applications requiring high voltage power switching. They have current handling up to 0.25 A for cold switching up to 7 kVDC (7 kVAC peak) and for hot switching up to 5 kVDC (5 kVAC peak).

Battery Cell Simulation

Pickering Interfaces' multi-channel battery simulator module (41-752A PXI version and 43-752A PXIe version) was created with BMS design and verification in mind.

The module (see figure 1 for a block diagram) comprises a number of power supply channels (two, four or six per slot), capable of supplying up to 7 V and 300 mA, that are isolated from one another and from ground. The power supplies on the module can therefore be used to emulate a stack of battery cells which, as mentioned, the BMS must be proven to monitor on an individual cell basis. Also, each channel can sink up to 300 mA to emulate a battery under charge.

Each channel provides independent power and sense connections, allowing the simulator to sense a remote load and correct for wiring losses.

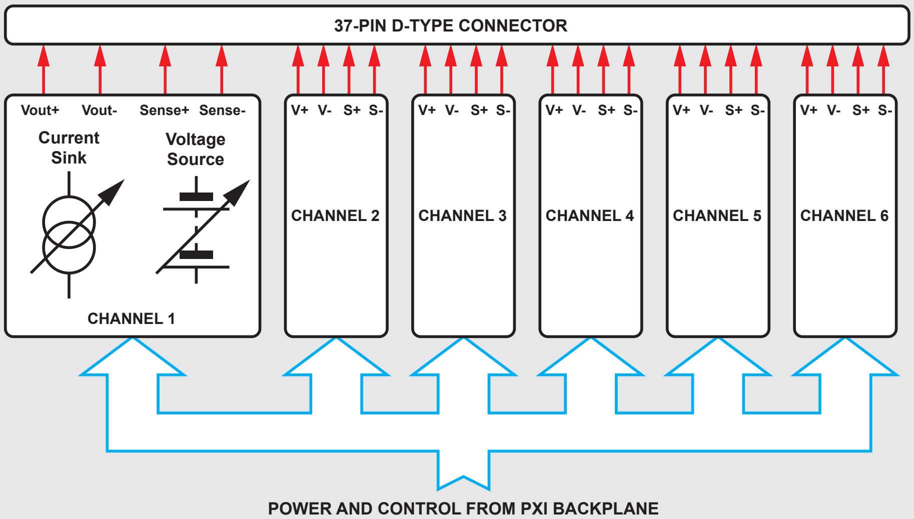

Figure 1: Block diagram of the 41/43-752A 6-channel battery simulator module

RTD & Thermocouple Simulation

Resistance temperature detector (RTD) simulators can emulate the behavior of positive or negative temperature coefficient thermistors. For example, the PT100 resistance temperature sensor is commonly employed in battery packs - noting that 'PT' reflects that it is made from platinum and the '100' that it has a resistance of 100 Ω at 0 °C.

Figure 2: The 40-263 is a 3U PXI RTD module for simulating how the resistance of a PT100 changes over the temperature range -150 to 850 °C

Pickering Interfaces has six simulator modules (with 4, 8, 12, 16, 20 and 24 channels, respectively), that can simulate the resistance range 40 to 900 Ω, which equates to a temperature of -150 to 850 °C, to a resolution of less than 10 mΩ. Figure 2 shows an example module.

Thermocouples are also employed in battery packs, particularly during product development because of their high accuracy. These too can be simulated during the development and verification of the BMS ahead of its connection to (or integration within) an actual battery pack.

Pickering Interfaces has a range of PXI millivolt thermocouple simulator modules that provide 8, 16, 24 or 32 channels of highly accurate low-voltage sources. Each channel can be operated over three voltage ranges to simulate the three most common thermocouple types in use.

Fault Insertion

Pickering Interfaces' range of PXI fault insertion units - also known as fault injection switch products - is designed specifically for safety critical applications where the behavior of a control system, such as a BMS, needs to be fully evaluated.

For example, the 40-592 fault insertion break-out (FIBO) is a large-scale, high-density switching matrix. It is one of a range of modules designed for applications requiring the simulation of a variety of faults in complex designs that feature a high number of signals/connections, a battery pack being a prime example.

Typical faults that can be simulated are open circuits and short-circuits (to either another signal/component or to ground, as shown in figure 3).

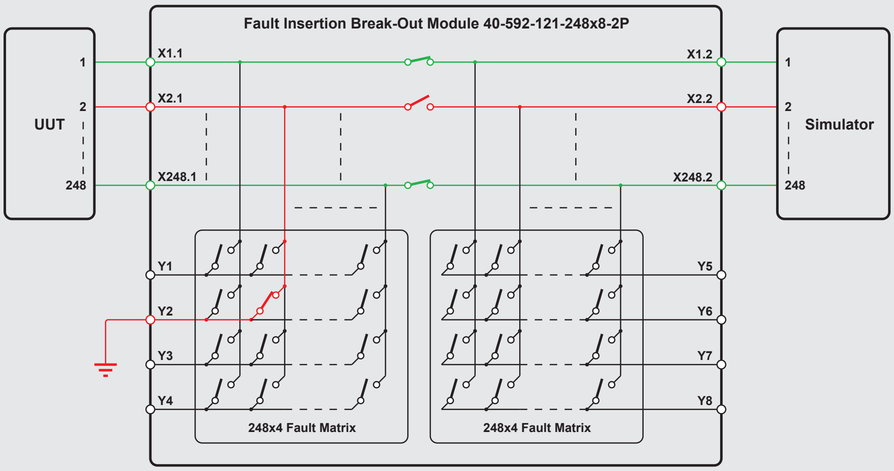

Figure 3: The UUT (Unit-Under-Test) would be the BMS. Signal X2.1 would normally connect to X2.2. Instead, the link has been broken and, on the BMS side, has been shorted to ground at Y2. Equally well, the 284x4 fault matrix could have been used to short-circuit any of the 248 lines to one or more of the remaining 247

BMS HIL Test System

Because the above example modules are all PXI- or PXIe-based, creating a comprehensive HIL test system for BMS verification is possible. See figure 4.

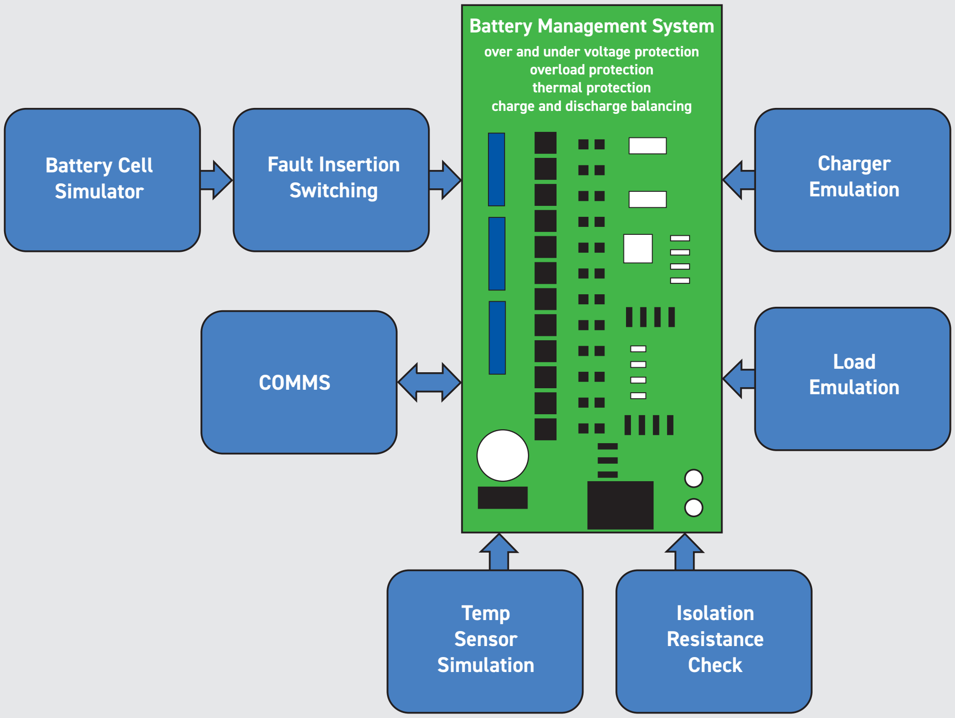

Figure 4: A BMS can be thoroughly exercised by connecting it to a suit of emulators and simulators

Considering each of the blocks in figure 4:

- **Battery Cell Simulator**. It simulates each cell's voltage and current output and has individual current sinks to emulate cell charging.
- **Fault Insertion Switching.** This simulates short- and open-circuits on each battery cell output as well as wiring faults between cells and the BMS. Polarity reversal can also be tested (i.e., to verify that the BMS would recognize a manufacturing defect such as an inverted cell in the pack).
- **Charge Emulation**. A programmable current source.
- **COMMS**. The ability to send commands to and receive data from the BMS. In the automotive sector, the comms protocol would typically be CAN bus.
- **Load Emulation**. A programmable resistive load to emulate battery stack loading.
- **Temp Sensor Simulation**. This provides the BMS with inputs from RTDs or thermocouples.
- **Isolation Resistance Simulator**. To verify the BMS's electrical isolation monitoring function (if applicable).

Together, the above can be used in a variety of permutations to replicate all the standard operating conditions the BMS and battery combination are designed to cope with and to verify that the BMS performs all its functions, including cell balancing, voltage and current monitoring and temperature monitoring, reporting faults and taking appropriate measures.

A demo of a test system similar to the one described above was recently built by Pickering Interfaces in conjunction with Austin Consultants and used to exercise [expose to harsh fault conditions] an off-the-shelf BMS. A video of the demo can be accessed here.

Summary

Simulation is the safest way to verify that a BMS's features perform as intended because it does not involve creating over-voltage or short-circuit conditions with live cells. It is also easy to replicate open-circuits and temperature extremes.

A comprehensive HIL test environment can be created using commercially available PXI- / PXIe-based simulators (some of which were designed with BMS in mind), emulators and fault insertion switches, where the popular and industry-standard PXI/PXIe format provides modularity, flexibility, and scalability.

Importantly, for traceability and certification purposes, simulation provides more meaningful data that is easy to capture and record.

About Pickering Interfaces

Headquartered in the United Kingdom with global operations locations throughout North America, Europe and Asia, the Pickering Group has been in switching technology since 1968 when the Reed Relay Division, Pickering Electronics, introduced its first reed relays. Since their introduction, these relays are used by most major test and measurement companies. In 1988, Pickering Interfaces was formed and introduced its first modular switching systems and instrumentation for use in electronic test and simulation.

Today, Pickering Interfaces offers modular signal switching, simulation, software and services to streamline the development and deployment of high-performance electronic test and verification systems. The company provides the most extensive range of switching and simulation solutions in the industry for PXI, PCI, LXI and USB applications. To support its switching and simulation solutions, the company also offers application software and software drivers along with a full range of supporting connectivity and cabling solutions.

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