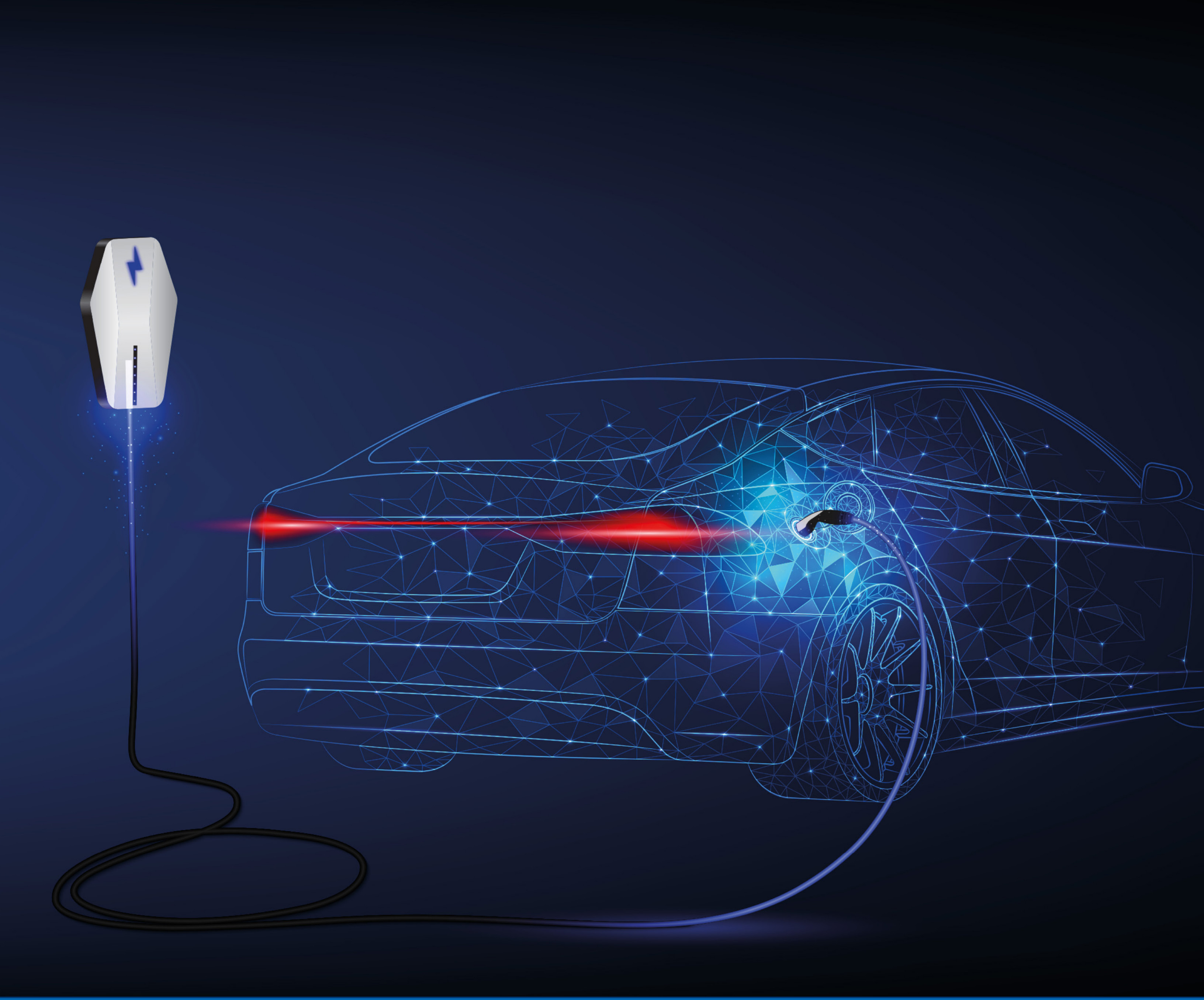

White Paper

The 800 V EV Transition:
HIL Simulation's Crucial Role

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To date, most EVs on the road have 400 V power system architectures. However, 800 V is shaping up to be the next power architecture of choice, and several manufacturers have already launched models. The move is far from as simple as using higher voltage batteries though, as all components handling 800 V must be suitably rated and be more durable than their 400V counterparts. Moreover, to provide improved reliability and safety features the 400 V architecture cannot simply be re-used.

Thankfully, provided it can handle the higher voltages, most of the test equipment used for 400 V EV system development and architecture exploration can be re-used for 800 V, and if the equipment is based on a standard like PXI or LXI, an easy migration path exists if it needs to be taken. This means those developing EVs can make the transition from 400 to 800 V without necessarily having to invest in too much (if any) new equipment.

Why 800 V?

Most EVs on the road today have 400 V architectures, within which the battery packs range from 300 to 500 V, as they provide a balance between efficiency, cost, and performance. However, as EVs become ever more popular (global sales are expected to jump from 13.8 million EVs in 2023 to 17.8 million in 2024, according to the International Energy Agency) user expectations are on the rise, most notably there is a desire for more range and reduced charging times.

Both expectations can be met by switching to an 800 V architecture – within which battery pack voltages range from 600 and 900 V – and some manufacturers including Porsche, Hyundai, Kia, and Audi have already launched models.

The advantages of doubling the voltage in an EV architecture are as follows:

- **Increased electrical efficiency.** This is largely due to:
  - Reduced electrical losses. As P = V x I, doubling the voltage means the current can be halved for the same power. However, power loss (which mainly manifests itself as heat) is proportional to the square of current (Ploss = I^2R). Halving the current means power loss reduces to one-quarter of what it was before.
  - Weight reductions. Thanks to improved electrical efficiency, the size and therefore weight of electromechanical components such as motors can be reduced and still achieve the same mechanical power. Wire gauges (the cross-sectional area, CSA) can be reduced too, now that the current (flow) is less.
- **Better range.** This is largely due to the weight savings realized from better electrical efficiency.
- **Faster charging.** As a rule of thumb, the 10 to 80 % charging time can be halved when switching to an 800 V architecture. However, developments in battery cooling are likely to result in even shorter charge times. Note: vehicle acceleration can be improved too as the problem that needs to be avoided during rapid charge or discharge is the buildup of heat; it shortens the life of the battery and if done too quickly can result in fire.

Combining all of the above makes for fast charging vehicles with a long range and, if desired, fast acceleration (at the cost of the range). For example, the recently announced Lotus Emaya – which boasts a 0 to 100 km/h acceleration of less than 2.8 seconds and a WLTP range of 610 km – can charge at 350 kW, which Lotus claims enables a 10 to 80 % charge in less than 18 minutes.

Regarding battery chemistry, lithium-ion (Li-ion) cells, which have liquid electrolytes, are currently used in EV battery packs. An alternative is solid-state batteries. Lithium is still required but, for the same cell energy density, in lower quantities and because the electrolyte is not a liquid, the risk of fire is reduced. Charging is quick too, noting here that many EV manufacturers talk in terms of 'time to 80 % charge', the reason being that the final 20 % of charge can take a long time. Indeed, as cells degrade, they may never accept that final 20 % - and the inability to accept more than 80 % charge is considered end-of-life for a Li-ion cell in the automotive sector. Indeed, solid-state is a serious Li-ion replacement contender and in 2023 Toyota announced its plans to be mass-producing solid-state cells for EVs by 2027. Sodium-ion batteries are another alternative battery technology. Though not as developed at this stage, forecasts are that sodium-ion cells will account for 6 % of the global EV market by 2033.

Note: reducing power losses is also behind another change taking place in the world of automotive power - the switch from 12 to 48 V. 12 V has been the de facto DC voltage in cars since the 1960s, used for headlights, indicators, cabin lights, infotainment systems, etc., and subsystems such as power steering, active suspension, power windows, and heated screens and seats are particularly power-hungry. Again, greater efficiency can be achieved with a higher voltage. This time quadrupling the voltage means the current can be quartered, and losses reduced to just one sixteenth. A few mild-hybrid vehicles are already using 48 VDC and Tesla's CyberTruck is the first BEV to use it.

Challenges of Moving to 800 V

Though the move to 800 V is seen as an evolutionary step, it is not without its challenges. For example, battery packs will require more subcomponents (cells, for example) to be placed in series. This could have an impact on manufacturing techniques as, for example, it is easier to connect cells in parallel.

The battery management system (BMS) in an 800 V EV will need to be more complex than in a 400 V one as it will need to perform voltage, current and power measurements at higher voltages, and the sensitivity (accuracy and resolution) of those measurements will need to be high if defects/faults are to be detected at the earliest opportunity. Indeed, fault detection is more important than ever before and the BMS and other systems handling high power must be able to initiate a safe and rapid shutdown if required.

Further mitigation against failure is redundancy, and something else the BMS may have to manage. Redundancy is a common practice in the aerospace and other safety-critical industries and sees the duplication of some components and, in some cases, alternate routes for power. To a degree some of the weight savings discussed earlier may need to be offset against redundancy measures.

At 800 V there is a greater risk of arcing and insulation breakdown, potentially compromising vehicle reliability and safety. Accordingly, more durable components with higher standoff voltages will be needed. Better insulation materials will be needed too and any modules or subsystems that connect with both high voltage sources/loads and lower circuitry will need excellent and fail-safe isolation.

Also, operating at higher voltages can increase the potential for electromagnetic interference (EMI) within the inverters. This EMI might result in failures if low-level signals are corrupted. Accordingly, enhanced EMC design considerations are needed to prevent interference and to comply with regulatory standards.

There is also the bigger picture to consider, namely EV charging infrastructure and ensuring 400 V and 800 V fast-charging compatibility. The rollout of 400 V charging stations has not been as rapid as EV drivers would have liked so to start upgrading some to 800 V is not practical. New charging stations can of course be 800 V, but what if a 400 V EV wants to use it? One solution is to use DC-DC power converters within the EVs (see figure 1).

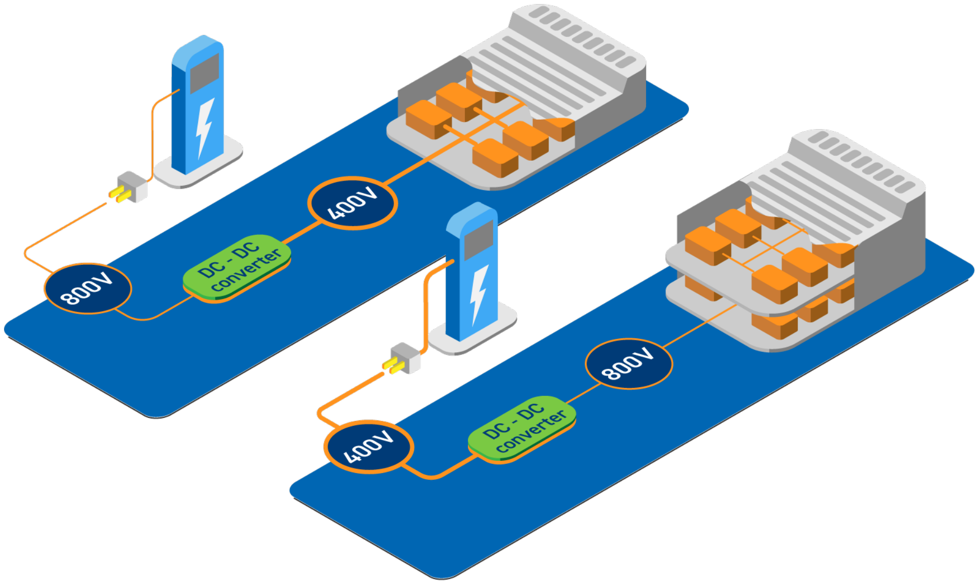

Figure 1 – Compatibility between 400 V/800 V EVs and 400/800 V charging stations will be best addressed through on-board DC-DC converters.

As mentioned, the move from 400 to 800 V architectures is an evolutionary step, one that is being taken by the OEMs of EVs and those developing major components, who have already invested in (or are still in the throes of investing in) equipment to rise to the above challenges.

The Benefits of Hardware-in-the-Loop and Simulation

When developing systems for EVs most companies adopt a test-driven development strategy that uses Hardware-in-the-Loop Simulation (HILS), where hardware simulates components being considered for use (or under development) and real-world conditions. In other words, the hardware under test (a BMS for example) interacts with a simulated environment that mimics the real-world operating conditions that the hardware will encounter. This can include simulating physical conditions, such as temperature, pressure, and environmental factors, as well as dynamic conditions like motion and vibration, thus enabling engineers to see how a system behaves under conditions that closely resemble those it will encounter in the field.

By subjecting the hardware (and software) under development to simulated real-world conditions, engineers can identify potential issues and weaknesses in the design, components, or control algorithms early in the development process. This is crucial for making design improvements and avoiding costly problems later in the product development lifecycle.

A distinct advantage of simulation where EV development is concerned is that harsh and extreme fault conditions – such as rapid discharging and short circuits – can be safely created to evaluate the behavior of the BMS, for example, without having to use (and potentially damage) a real battery pack.

Creating a HIL Test Platform

Whilst a HIL test platform could be created from scratch, the cost (both monetary and time) of doing so tends to be prohibitive in the automotive industry. The use of an industry-standard platform is therefore highly recommended. There are two standards to consider, namely PXI and LXI, which are based on the PCI and Ethernet industry standards respectively.

Both are supported by a large number of global vendors with many commercial off-the-shelf products available, and both provide seamless vendor-independent plug and play. Of great benefit is that product longevity is assured, and the vendors have obsolescence management processes in place.

A few words on each of the standards:

- PXI (PCI eXtensions for Instrumentation) defines a rugged modular platform which is both flexible and scalable when building up a test system. The standard also defines triggering and timing at the chassis level to aid in synchronization between different modules within the system. Because it is PCI-based it is also ideal for real-time systems, due to its deterministic behavior.
- LXI (LAN eXtensions for Instrumentation) has no defined mechanical footprint, making it ideal for both integrated test systems and bench top equipment alike. Accordingly, physically large, cumbersome, or problematic components can be separated from other parts of the test system. In addition, power and cooling requirements are designed around the intended application of the LXI unit, leading to efficiency and enabling more specialized products. Lastly, because it is LAN-based, large test systems can be networked (up to 100 m) over Ethernet with no need for repeaters, and an LXI unit can be controlled from anywhere in the world.

Note: Pickering has developed a hybrid solution based on both standards, namely LXI chassis that will accept any of the company's PXI modules. The result: the modularity of PXI (and access to thousands of modules) in a form factor that can be controlled over Ethernet.

400 to 800 V Testing Migration Path

As mentioned, many OEMs and systems houses serving the automotive sector have already invested in equipment – including HILS systems – for the development and verification of EVs. If they are using PXI or LXI platforms the good news is that, when moving from a 400 to an 800 V architecture, many of the modules they have already invested in will still be fit for purpose, i.e. a large proportion of the test system can simply be reused.

For those parts that cannot (and this tends to be due to the higher voltage ratings), due to the modularity and scalability of PXI and LXI, they be easily swapped out for upgraded ones.

In the next few sections of this white paper, we discuss a few of Pickering Interfaces' products that are suitable for use on 800 V architectures.

Battery Cell Simulation

This is essential in EV development. Moreover, it is crucial to simulate at the cell level and not just the pack as a whole. For example, the EV's BMS needs to be able to see a fully charged pack. Accordingly, to verify that function, it is necessary to simulate individual 3.2 to 3.7 V cells, while having the ability to stack them to create the full stack voltage - which means going from a series stack of 96 cells for 400 V to 192 cells for 800 V.

Also, the BMS is responsible for cell balancing. This means the test hardware needs to simulate each cell's charge level at rest and during charging and discharging, and to introduce imbalance.

Due to simulating the cells independently, as long as the cell emulator can handle higher voltages, the same equipment can be used when moving from a 400 to an 800 V architecture by just adding additional modules (i.e. simulated cells to the stack).

Figure 2 shows the block diagram of a multi-channel battery simulator module available in PXI (41-752A) and PXIe (43-752A). It comprises several 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 system ground. The power supplies on the module can therefore be used to emulate a stack of battery cells. 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.

Note: although we cite BMS development as the main use for battery cell simulation modules, as they are essentially voltage sources with the ability to sink current, they can be used for many other purposes.

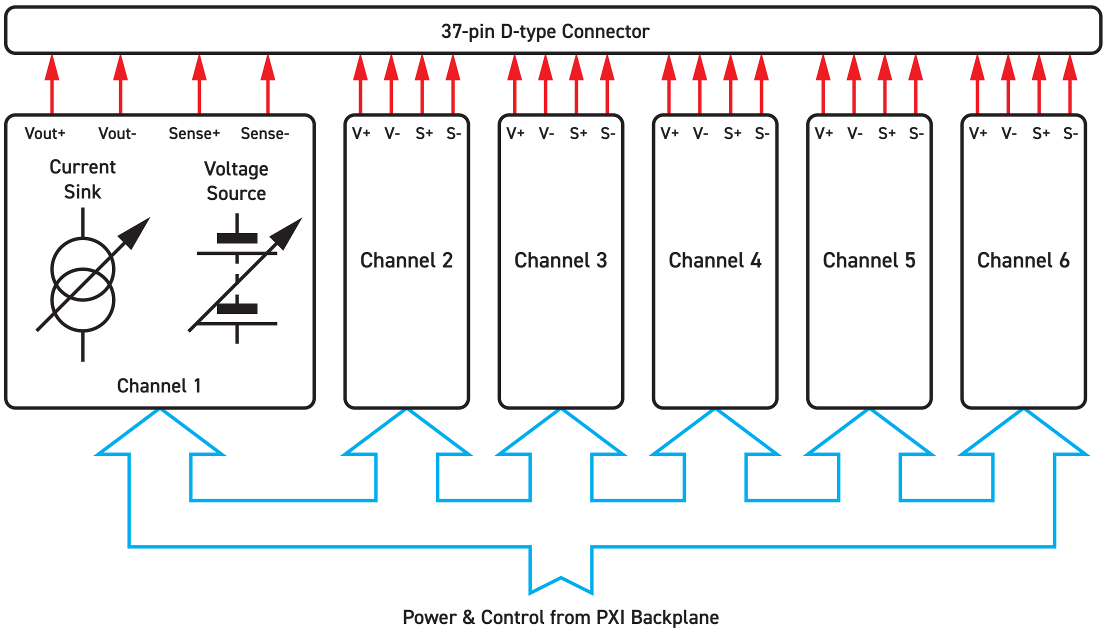

Figure 2 – Above, a block diagram of the 41/43-752A 6-channel battery simulator module.

High Voltage Switching

High voltage switching can be used in any application within a test system that needs to connect or disconnect signals - as well as moving signals between different points – and can be achieved using one of three switch configurations:

- Uncommitted - for example single-pole single-throw switches (either normally open or normally closed).
- Matrices, which allow for the connection of any input to any output.
- Multiplexers (MUXs), which allow for the connection of a single input to multiple outputs.

Each configuration is available with varying numbers of relays and connections, and switching modules are available that are capable of switching up to several kV. Such modules are ideal for any application requiring switching, including use as isolation switching and breaker simulation.

High voltage switching can be achieved using a number of solutions from Pickering Interfaces; over 60 PXI/PXIe modules and 28 LXI modules. For example, the 40-323-901 (PXI) and 42-323-901 (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 9 kVDC (9 kVAC peak) and for hot switching up to 7.5 kVDC (7.5 kVAC peak).

RTD Simulation

Temperature must be monitored at many locations in an EV including within the battery pack (at several points), motors, the power inverter, the charger port and within the cabin. A popular and relatively low-cost transducer type well-suited to the task is the resistance temperature detector (RTD). Its resistance is proportional to temperature and a common device is the PT100, so called because it is made from platinum and has a resistance of 100 Ω at 0 °C. There are many other types of RTD though and RTDs will have either a positive or a negative temperature coefficient (PTC or NTC respectively).

The simulation of RTDs makes very good sense, as the alternative is to subject the design under test to a potentially wide range of temperatures (and probably requiring the use of expensive environmental test chambers).

PXI-based RTD simulator modules are available from a number of companies. For example, Pickering Interfaces has many modules suitable for RTD simulation including the 40-263 (with 4, 8, 12, 16, 20 and 24 channels) that can simulate the resistance range 40 to 900 Ω, which equates to a temperature range of -150 to 850 °C, to a resolution of less than 10 mΩ. Figure 3 shows an example module.

Figure 3 – The 40-263-001 is a 3U PXI RTD module for simulating how the resistance of a PT100 changes over the temperature range -150 to 850 °C.

To a lesser degree, thermocouples are also employed in EVs, mainly during product development because of their high accuracy. But these too can be simulated as the output of a thermocouple is essentially a small voltage (a few millivolts). 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 any standard thermocouple types in use within the industry.

Fault Insertion/Injection

The ability to insert faults during system development and verification is essential. As mentioned above, systems might need to instigate a safe shutdown or, if redundancy is built in, power re-routed if a fault is detected, and this functionality needs to be fully validated.

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 under all potential real-world fault conditions.

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 4.

Note: In the diagram below, 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 238.

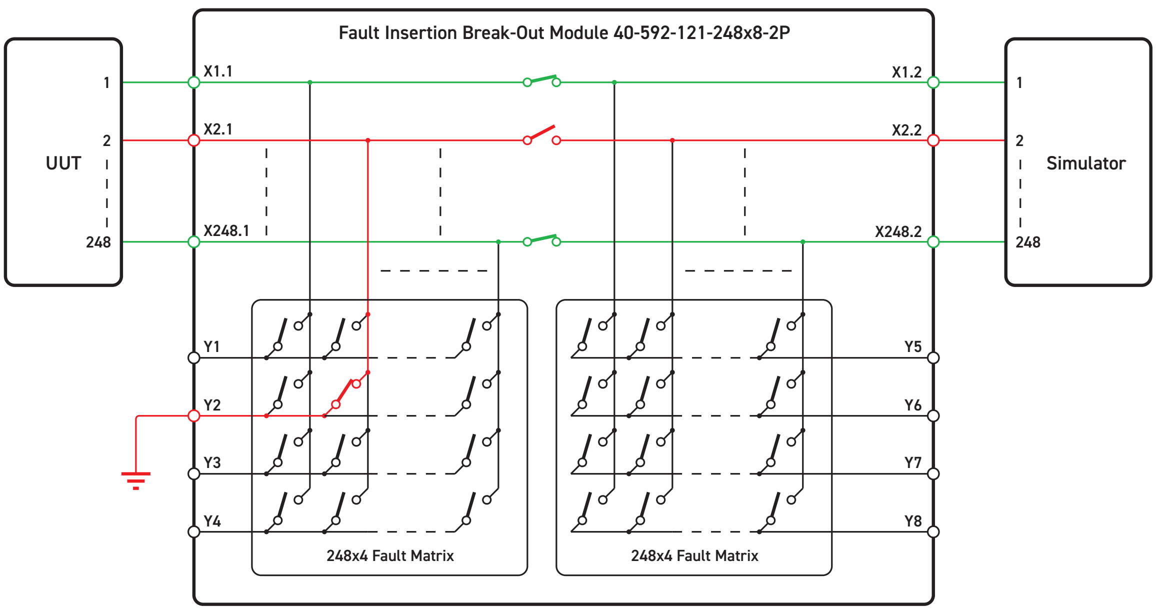

Figure 4 – Fault simulation with a Fault Insertion Break-Out module 40-592-121-248x8-2P.

Summary

There are many benefits, such as higher performance and faster charging, to be derived from moving from 400 to 800 V architectures. However, while the use of a higher voltage allows for more compact components and smaller gauge cables/wires – both producing weight savings – there is a need for greater durability and safety. There is also an increasing requirement for EV architectures to include redundancy to mitigate against single point failures and to improve safety and reliability, both of which contribute significantly to the manufacturer's reputation.

Simulation is the safest way to develop, explore and thoroughly verify an EV's architecture, systems, and core components. For example, the functionality of a BMS can be verified without using a physical battery pack. Fault injection, such as introducing short circuits, is much safer. Moreover, test conditions and results are easily recorded, which is important for traceability purposes.

The use of PXI and LXI based test equipment is a logical choice for manufacturers currently developing products for a 400 V architecture and contemplating the move to an 800 V one because there is an easy migration path. For example, chassis and controller (in the case of PXI) and modules rated at 1 kV can simply be re-used, thus protecting the initial investment.

Doing so enables the optimization of key system components such as the battery pack, motors, power inverters and the BMS. Overall system performance can be determined without having to wait for a prototype vehicle to take out on the road. Also, because HIL can be automated, tests can be performed unsupervised, and system development is greatly accelerated. HIL testing is also highly repeatable.

About Pickering Interfaces

Pickering Interfaces designs and manufactures modular signal switching and simulation for use in electronic test and verification. We offer the largest range of switching and simulation products in the industry for PXI, LXI, and PCI applications. To support these products, we also provide cable and connector solutions, diagnostic test tools, along with our application software and software drivers created by our in-house software team.

Pickering's products are specified in test systems installed throughout the world and have a reputation for providing excellent reliability and value. Pickering Interfaces operates globally with direct operations in the US, UK, Germany, Sweden, France, Czech Republic and China, together with additional representation in countries throughout the Americas, Europe and Asia. We currently serve all electronics industries including, automotive, aerospace & defense, energy, industrial, communications, medical and semiconductor. For more information on signal switching and simulation products or sales contacts please visit: pickeringtest.com

Direct Sales & Support Offices

Pickering Interfaces Inc., USA
Tel: +1 781-897-1710 | e-mail: ussales@pickeringtest.com

Pickering Interfaces Ltd., UK
Tel: +44 (0)1255-687900 | e-mail: sales@pickeringtest.com

Pickering Interfaces Sarl, France
Tel: +33 9 72 58 77 00 | e-mail: frsales@pickeringtest.com

Pickering Interfaces GmbH, Germany
Tel: +49 89 125 953 160 | e-mail: desales@pickeringtest.com

Pickering Interfaces AB, Sweden
Tel: +46 340-69 06 69 | e-mail: ndsales@pickeringtest.com

Pickering Interfaces s.r.o., Czech Republic
Tel: +420 558 987 613 | e-mail: desales@pickeringtest.com

Pickering Interfaces, China
Tel: +86 4008-799-765 | e-mail: chinasales@pickeringtest.com

Pickering Interfaces, Malaysia
e-mail: aseansales@pickeringtest.com

Local Sales Representative/Agents in Australia, Belgium, Canada, China, India, Indonesia, Israel, Italy, Japan, Malaysia, Netherlands, New Zealand, Philippines, Singapore, South Africa, South Korea, Spain, Taiwan, Thailand, Turkey, Vietnam and throughout North America.

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