68 Nutmeg Road South, South Windsor, CT 06074 | 860-298-9925 | www.bloomy.com

Using the Battery Simulator 1200 in High-Voltage Applications

Summary

The Battery Simulator 1200 is rated for 1000VDC of isolation, enabling the series-connection of hundreds of simulated cell channels across multiple instruments in order to simulate different configurations of battery strings, stacks or packs of up to 1000VDC. However, any time high voltages are present in a system, proper safety precautions must be observed. This guide provides the factory-recommended safety precautions and simulated cell stack connection topologies for using the Battery Simulator 1200 to simulate high-voltage battery packs. For the purposes of this guide, "high voltage" refers to a voltage of greater than ±140V potential from earth ground per IEC61010[1].

Figure 1: A series-connected, 192-cell simulation system using 16 Battery Simulator 1200s

Recommended Safety Precautions

The following safety precautions are recommended in applications where any of the Battery Simulator 1200's simulated cell channels are operating at greater than ±140V potential from earth ground.

Prevent access to all connectors when voltage is applied

Physically prevent access to the Battery Simulator 1200 electronic wiring terminals, including the cell connectors, network connector, and Auxiliary I/O connector, to prevent unintended contact with system voltages. (See Figures 1 and 2.) Specifically, the following is recommended:

1) Minimum: Mount the Battery Simulator 1200s in an enclosed rack to prevent operator access to the network connector, cell connectors and Auxiliary I/O connector, all of which may carry high voltages when many cells and/or other power sources are connected in series. Ensure the rack is closed during normal operation and no unintended access to the cell connectors is possible. Affix labeling to any rack doors or openings to notify operators that high voltage may be present and that the system must be powered off before servicing.

2) Preferred: In addition to enclosing the instruments, install a safety interlock which disconnects the AC power to the Battery Simulator 1200 instruments and disables the outputs of other series-connected power sources in the event that the rack is opened. Install a ground-fault circuit interrupter (GFCI) which disables the system when a fault is sensed.

Figure 2: The rear panel of the Battery Simulator 1200 contains the network connector, cell connectors and the Auxiliary I/O connector. Prevent access to these connectors when high voltages are present.

Note that the Battery Simulator 1200 will withstand abrupt power loss without damage, though any networked computer or controller will lose communication and may require an application reset, restart or reboot depending upon how the software is written to handle communication loss. Typically, CAN communications will restart automatically once the Battery Simulator 1200 powers up.

Current limit series-connected devices

In the event of an internal or external fault, the Battery Simulator 1200's internal ground bond is designed to protect the user and equipment from unintended high-voltage contact. Because the Battery Simulator 1200 cell outputs are rated for a maximum of 500mA of current per cell, any external series-connected power sources should also be limited to 500mA if present. This limit will help to ensure that any current draw from another device will not exceed the Battery Simulator 1200 cell current ratings. The current limit will also help to ensure that the Battery Simulator 1200 ground bond can non-destructively shunt any current caused by a fault to ground.

Isolate ground-referenced signals and communications

When any cell of the Battery Simulator 1200 is expected to be raised to over ±140V potential to ground, the Battery Simulator 1200's ground-referenced signals and communications should be isolated from other devices. Recommended isolation techniques are described below for each type of signal.

1) Ethernet
   a) Use an Ethernet isolator, such as a Phoenix Contact FL ISOLATOR 1000-RJ/RJ2, to connect each Battery Simulator 1200's Ethernet port to any non-isolated Ethernet switches or computers. (See Figure 3.)
   b) When Ethernet is not used, the Battery Simulator 1200's Ethernet ports may be left disconnected and do not require an external isolator.

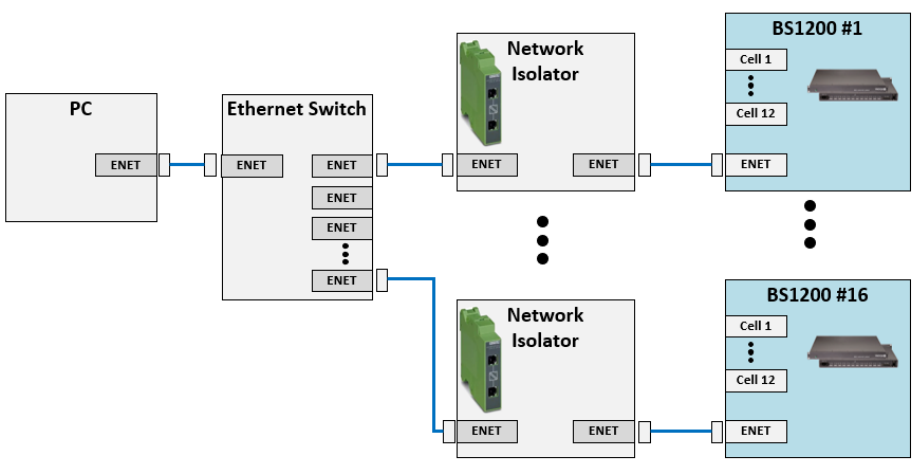

Figure 3: Install one network isolator per Battery Simulator 1200 when the Ethernet port is used or connected.

2) CAN
   a) Use a CAN isolator/repeater, such as a PEAK PCAN-Repeater3, to connect a network of Battery Simulator 1200 instruments to the CAN ports of a computer and other CAN devices. For optimum performance, we recommend one CAN isolator/repeater per 2-4 Battery Simulator 1200 instruments, each connected to a separate CAN interface port on the computer or CAN controller. (See Figure 4.)

b) When CAN is not used, the Battery Simulator 1200 CAN terminals on the auxiliary I/O connector may be left disconnected and do not require an external isolator.

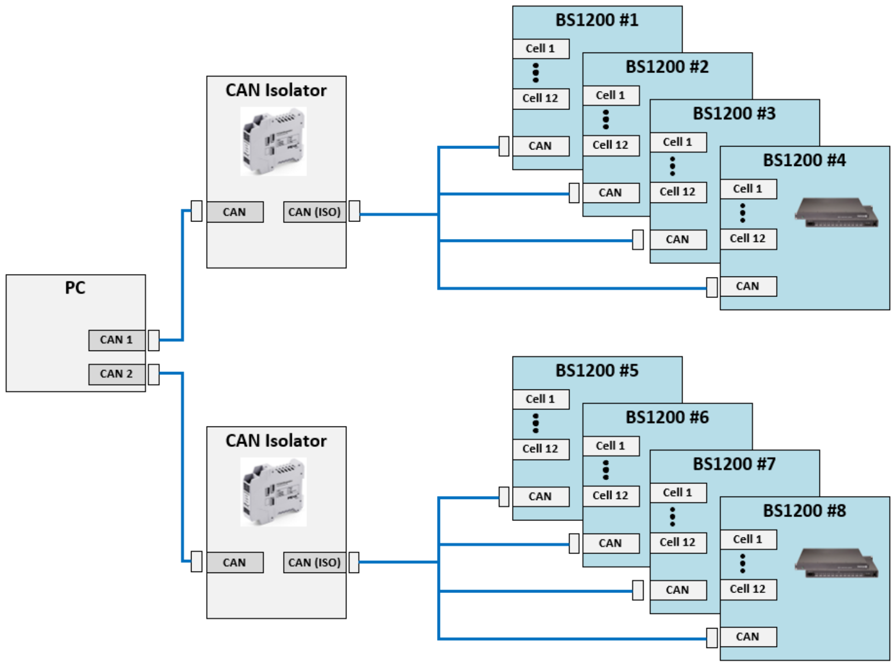

Figure 4: Install one CAN isolator per 2-4 Battery Simulator 1200s when CAN communications are used.

3) Auxiliary I/O

a) Damage to the Battery Simulator 1200 may occur if the Auxiliary I/O signals are raised beyond the limits of the I/O (3.3V digital, +5V analog) referenced to chassis ground. Because these signals are referenced to chassis ground, care must be taken in any application to protect the inputs and outputs from voltages beyond these ranges, regardless of whether the signals are used in a high-voltage application or not.

b) In high-voltage applications, the Battery Simulator 1200 chassis ground may unintentionally be raised to a high voltage thus causing the signals and signal returns also to be raised to the high voltage. Either ensure that the devices connected to the Auxiliary I/O signals are tolerant of this voltage or that appropriate isolation is installed between the Battery Simulator 1200 Auxiliary I/O and the connected devices.

c) Where isolation is necessary, the following guidelines apply:

i) Use a galvanic isolator tailored to the application for each of the analog and digital I/O signals in use. Galvanic isolation separates the inputs of the isolator from the outputs of the isolator to prevent current flow, passing the signals through an optical, capacitive, or inductive field rather than through a direct connection. Note that the CAN bus is also present on the Auxiliary I/O connector and must be isolated as described above.

ii) When the Auxiliary I/O is not used, the Battery Simulator 1200 auxiliary I/O ports may be left disconnected and do not require an external isolator.

Programmatic safety precautions

The Battery Simulator 1200 powers on in a safe state with all cells at 0V and 0mA until the cell voltages and current limits are programmed from the host computer or other control device. The Battery Simulator 1200 has a programmable cell current limit parameter that is individually controllable per cell. Because power dissipation in connected circuits is proportional to both voltage and current, it is a good practice to set the individual cell current limits to the lowest current necessary for the application (e.g., activating and testing the cell-balancing functionality of the battery management system). Limiting the cell power by limiting the current reduces the risk and severity of component damage as well as of electric shock.

Cell Stack Simulation Connectivity

High-voltage battery packs may be simulated using one of a number of topologies. Several of these are shown on the following pages along with their advantages and disadvantages. For illustrative purposes, a common high-voltage BMS architecture consisting of one BMS master and multiple slave cell monitoring units (CMUs) will be connected to a 192-cell stack with sixteen 12-cell CMUs. These connection topologies can be extended to other simulated battery configurations and distributed BMS topologies as well.

Note that all simulated cells in these examples are connected in series and not in parallel. Connecting the Battery Simulator 1200 cells in parallel is not recommended because it may increase the combined current flowing through the simulated cells above the limits of the individual cells. In particular, do not exceed more than 500mA current per cell under any circumstances. Exceeding the 500mA current limit may damage the instrument and possibly cause other hazards. Moreover, parallel cell connections are not a supported control mode of the Battery Simulator 1200.

Full stack simulation

In this configuration, all 192 cell voltages of the stack are simulated by 16 Battery Simulator 1200 instruments, each containing 12 individually-programmable cells connected to the 16 CMUs. (See Figure 5.) All simulated battery cells from all 16 Battery Simulator 1200s are connected in series to create the full pack voltage which is then routed to the high-voltage measurement on the pack controller board. If contactors/disconnects are required, they can be simulated using real components.

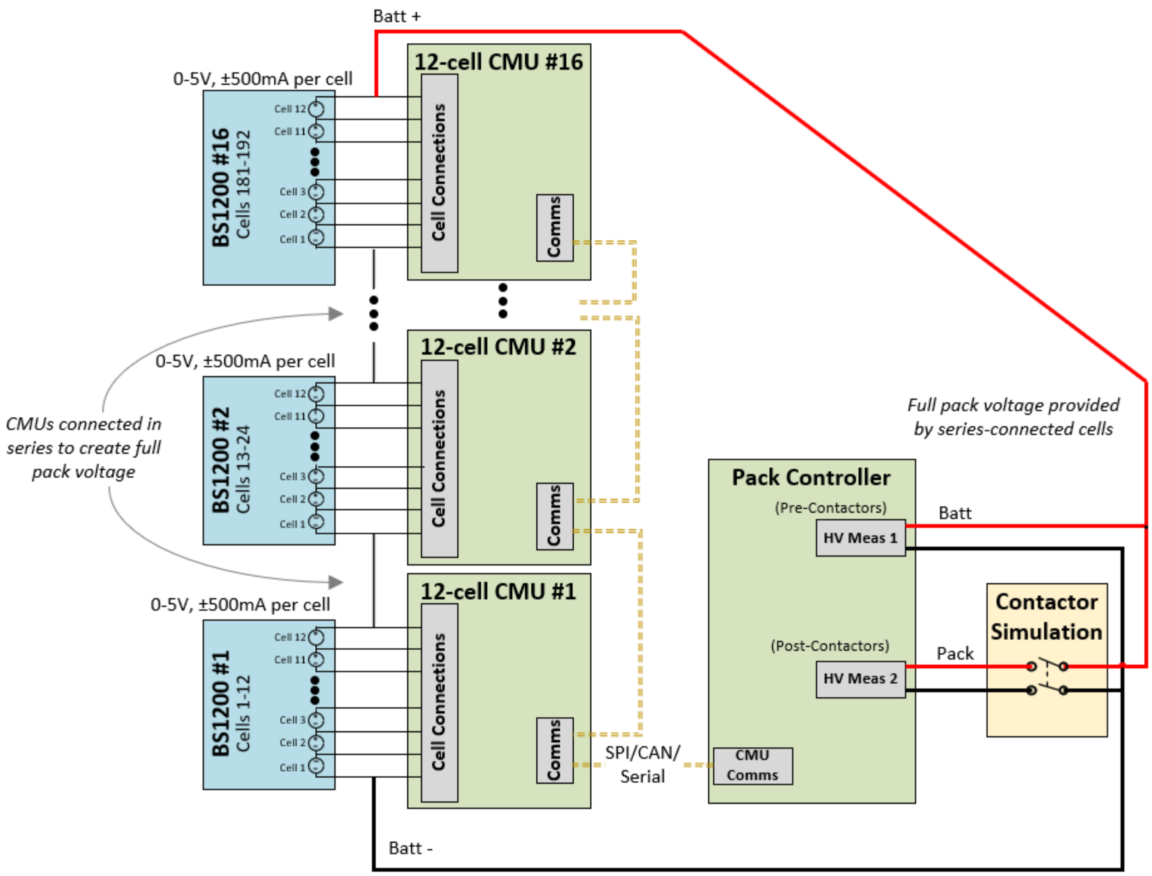

Figure 5: Full stack simulation: all cells are individually simulated, controlled and connected in series, most similar to an actual battery stack.

Advantages	Disadvantages
Allows individual cell voltage and balancing current control and monitoring	Doesn't simulate error cases associated with pack voltage measurements, for example:
Most closely resembles the actual battery pack configuration	ΔV between sum of cell voltages and stack voltage measurement
Maximizes real-world application testing	Contactor resistance buildup
Allows CMUs to set their own addresses based on positions in stack voltage if necessary	Uses large number of high-voltage connections exceeding 140V
	Delivers substantial power at high voltage (up to 960V@500mA, or 480W, in configuration shown above)

Low-voltage, full-cell simulation

In this configuration, all 192 cell voltages of the stack are simulated by 16 Battery Simulator 1200 instruments, each containing 12 simulated cells connected to the 16 CMUs similar to the full stack simulation above. However, instead of connecting all cells in series, each CMU's Cell 0 (lowest voltage) is referenced to ground. In this configuration, the simulated cell voltages will never exceed [5V/cell × *n* cells] per CMU. For a 12-cell CMU, the maximum possible cell voltage will be 60VDC. The high-voltage battery taps may be simulated for the pack controller measurements using external 1000V programmable sources. Since the pack controller is not using the sources' current for balancing, the 1000V sources can be current limited to a lower level than the simulated cells, such as < 5mA.

This configuration maximizes safety by reducing the number of high-voltage connections to two. None of the Battery Simulator 1200 and CMU connections are high voltage, yet all of the cells are present and individually controlled.

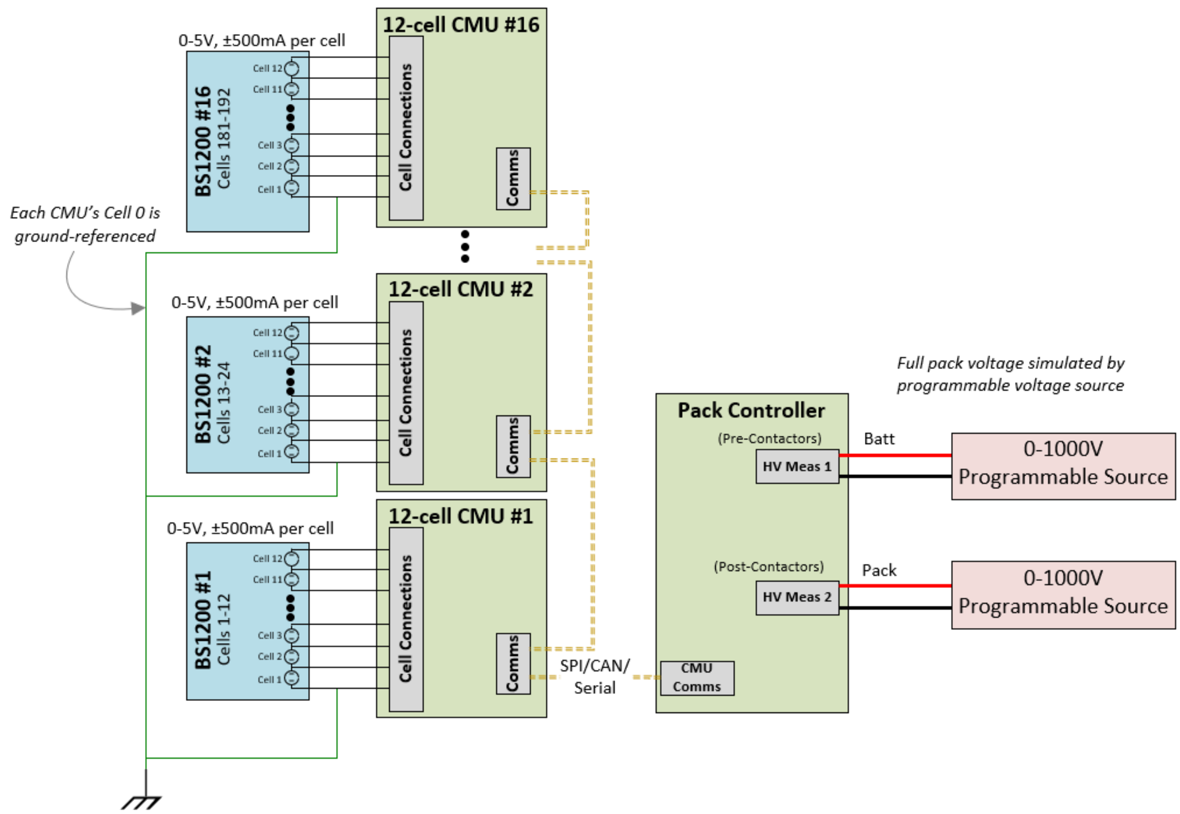

Figure 6: Low voltage, full cell simulation: all cells are individually simulated and controlled, though each CMU is ground-referenced. High voltage is simulated by external programmable sources.

Advantages	Disadvantages
Allows individual cell voltage and balancing current control and monitoring. Does not limit the maximum number of simulated cells. Closely resembles a full pack, but without any voltages exceeding [5V/cell × *n* cells] per CMU. Requires only two high-voltage connections (*HV Meas 1* and *HV Meas 2* in Figure 5) which maximizes safety. Limits power and current (<5mA) for high-voltage connections. Simulates difference between sum of cells and pack measurement error condition. Simulates contactor faults (e.g., welded contactor) and degradation (e.g., high-resistance contacts, increased wear and delay) by directly controlling high-voltage signals.	Does not provide necessary input for CMUs which "address" themselves based on stack voltage. Requires coordinated closed-loop control of high-voltage simulations for pack and contactor voltage measurements. Requires separate high-voltage sources for pack controller's battery measurement taps if required.

Low voltage, shared cell simulation

This final topology minimizes the number of Battery Simulator 1200s required to simulate a pack. All CMUs are ground-referenced, similar to the low-voltage/full-cell configuration. CMU voltages cannot exceed [5V/cell × n cells] per CMU. In this configuration, however, the simulated cells are shared among multiple CMUs connected in parallel. The primary limitation of this configuration is that the shared cell currents must not exceed the 500mA per cell current capacity of the Battery Simulator 1200. For example, if one CMU balances with a 200mA maximum current per cell, then three CMUs connected in parallel may require as much as 600mA of combined cell current, violating the maximum current limit of the cell simulator. As with the previous configuration, the high-voltage battery taps may be simulated for the pack controller measurements using external 1,000V programmable sources.

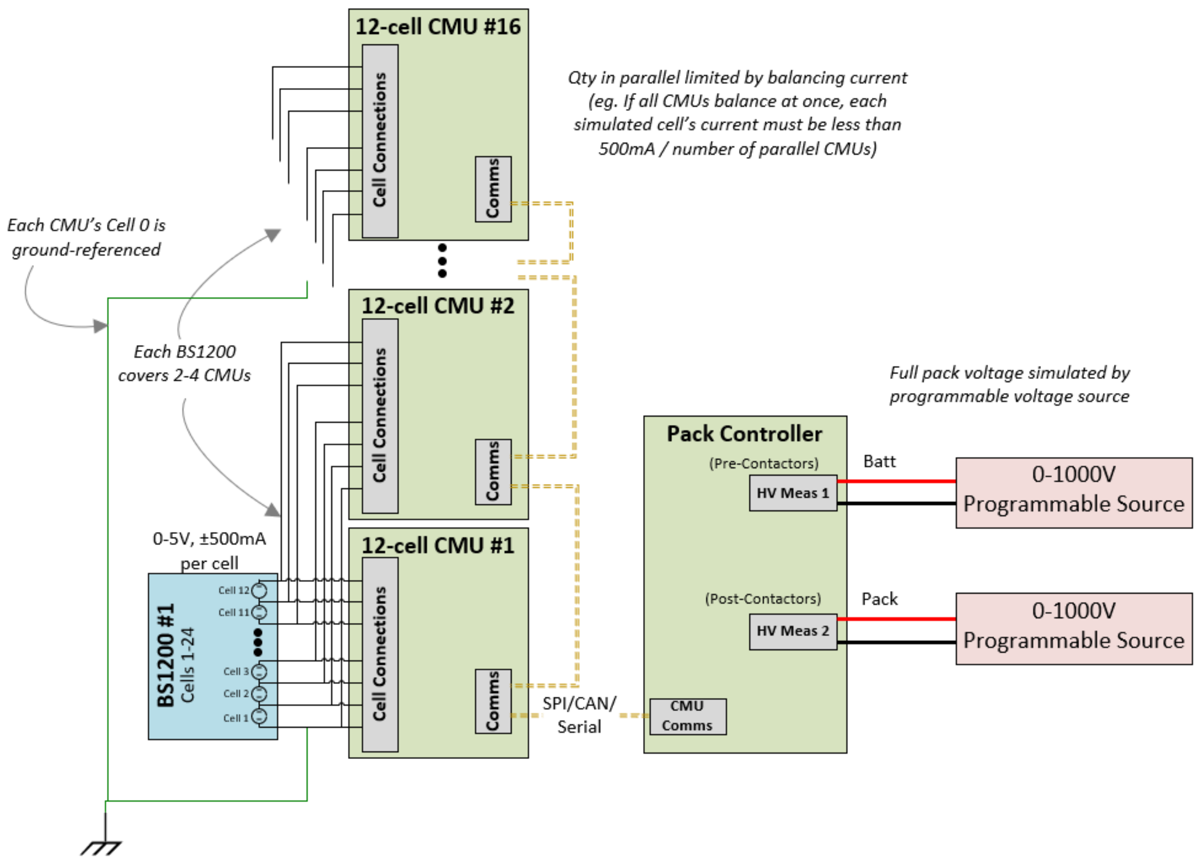

Figure 7: Low-voltage, shared cell simulation: simulated cell channels are shared among multiple CMUs, each CMU is ground-referenced, and high voltages are simulated by programmable sources.

Advantages	Disadvantages
Reduces system cost by minimizing number of Battery Simulator 1200s. Does not limit the maximum number of simulated cells. Closely resembles a full pack without any cell voltages exceeding [5V/cell × *n* cells] per CMU. Requires only two high-voltage connections (*HV Meas 1* and *HV Meas 2* in the figure above) which maximizes safety. Limits power and current (<5mA) for high-voltage connections. Simulates difference between sum of cells and pack measurement error condition. Simulates contactor faults (e.g., welded contactor) and degradation (e.g., high-resistance contacts, increased wear and delay) by directly controlling high-voltage signals.	Shares cell voltages and balancing currents among multiple CMUs making determination of which CMU is drawing balancing current using Battery Simulator 1200 feedback impossible. Does not provide necessary input for CMUs which "address" themselves based on stack voltage. Requires coordinated closed-loop control of high-voltage simulations for pack and contactor voltage measurements. Requires separate high-voltage sources for pack controller's battery measurement taps if required.

Summary and Recommendations

Simulating the cell stack of high-voltage battery packs is a critical requirement for BMS validation testing. By exercising proper safety precautions and matching the test topology to the requirements of the BMS, the test system's safety and effectiveness can be maximized. Of the topologies shown here, the optimum tradeoff between safety and performance is provided by the low voltage full cell Simulation configuration which provides the ability to simulate and monitor all cells individually, while simultaneously simulating the pack and contactor voltages through external programmable sources. The minimized number of high-voltage connections and lower current limit of the external sources provides a maximally safe and effective test environment. It also provides the most flexibility to test the BMS responses to edge cases such as when the measured pack voltage differs from the CMU's reported sum of cell voltages.

If using a fully-stacked, high-voltage pack cannot be avoided through one of the alternate methodologies, mount the Battery Simulator 1200 instruments in an enclosure which shuts down all AC and DC power when the door is opened or when a ground fault occurs. Additionally, always use external galvanic isolators for controlling the Battery Simulator 1200 via CAN or Ethernet, and remove the auxiliary I/O and any unused communication interface connections. These steps ensure proper system isolation from high voltages. Finally, program the Battery Simulator 1200 cell current limits to exactly what the BMS requires for exercising the functions to be tested.

For more information, contact Bloomy at www/bloomy.com/contact-us.

Notes

1) IEC 61010 specifies safety requirements for electrical equipment for measurement, control and laboratory use. See https://www.iec.ch/homepage
2) For more information, see https://www.phoenixcontact.com/en-us/products/network-isolator-fl-isolator-1000-rjrj-2313915.
3) For more information, see https://www.peak-system.com/PCAN-Repeater-DR.216.0.html?&L=1