GET TO THE ROOT OF **BATTERY FAILURES**

Modern product applications running on rechargeable batteries typically have built-in sensors and battery management system (BMS) circuitries.

A BMS monitors a rechargeable battery system's voltage, current, and temperature, whether a single cell, a module (a group of cells), or a battery pack (a group of modules). Monitoring the voltage and current flowing from the batteries is usually not enough to determine battery health.

Monitoring battery temperature can warn you of potential defects and quickly isolate fault locations. A BMS monitors battery packs to keep operating temperatures within an optimal range. A battery that is too hot will degrade or malfunction. But a battery that is too cold will perform sluggishly due to slower internal electrochemical reactions, reducing its capabilities.

This white paper highlights common temperature-related battery issues and will show you how test instruments can help you build better battery-operated applications.

COMMON CHALLENGES IN MONITORING BATTERY TEMPERATURE

Thermal imbalance, battery-pack hotspots, low performance, and capacity are areas that you need to keep an eye on when monitoring battery temperature.

WHEN USAGE CAUSES THERMAL IMBALANCE

Large-scale applications typically use battery packs with modules wired in series and parallel connections. Thermal sensors placed strategically across a battery pack detect temperature variations. Large battery-pack thermal imbalance usually starts with the non-uniformities of battery cells affecting their charging and discharging voltages. Over time, the non-uniformity variation accelerates, with some cells overcharging or over-discharging, causing the batteries to overheat disproportionately.

You can minimize thermal imbalance by using a BMS to cell balance, equalize voltages, and state of charge (SOC) among the cells at a full charge. Battery manufacturers can also select batches of battery cells with very close open-circuit voltage to build battery packs and minimize SOC variations.

Product application design can also cause thermal imbalance. For example, the cooling system of battery packs is not effective enough for certain external harsh environments.

BATTERY-PACK HOTSPOTS

Monitoring battery temperatures helps you detect hotspots. Depending on how critical the battery application is, sometimes having just a few sensors strategically located across a battery pack is sufficient. However, in applications that require critical performance such as electric vehicles, you can place a temperature sensor on each battery-pack module.

Hotspots tend to occur on weak battery cells in a battery pack. Weak battery cells are susceptible to overstress and gradually degrade. As a result, they grow hotter during operation versus normal, good cells because they struggle to keep up with the performance of good cells.

Hotspots can also warn you about potential damage to battery cells or modules. A physical impact on the battery pack can puncture or deform the battery cell's internal structure, such as the electrodes or polymer separator. If that happens and no intervention occurs, the battery cell damage can degrade and potentially cause a thermal runaway. Fire and explosion may result, so it is important to detect hotspots, locate the faulty cells, and replace them quickly.

Other causes of hotspots include poor terminal connections, heat dissipation component defects, and external cable shorts.

LOW BATTERY PERFORMANCE AND USAGE CAPACITY

Monitoring battery temperatures represents a proactive, closed-loop process to keep battery packs operating in the optimal charging and discharging temperature ranges.

Frigid temperatures cause sluggish battery performance because of slower electrochemical reactions. As a result, battery usage capacity will drop significantly, and the battery may even stop operating.

A bigger concern is when the battery system operates at temperatures above the manufacturer's specification. Battery life will degrade and weaker batteries may deviate more from the good performing ones. At this point, thermal imbalance and hotspots start to show up.

INDEPENDENT TEST EQUIPMENT MONITORS BATTERY TEMPERATURE

Many commercial battery management systems are available for all kinds of applications, from Internet of Things (IoT) devices to high-voltage automotive applications. Essential features include overcurrent protection, overvoltage protection, overcharge protection, overtemperature protection, undervoltage protection, cell balancing, SOC, and state of health.

However, there are many good reasons to acquire independent test equipment to monitor battery temperature in your applications.

BENEFITS OF AN INDEPENDENT TEST VALIDATION SYSTEM

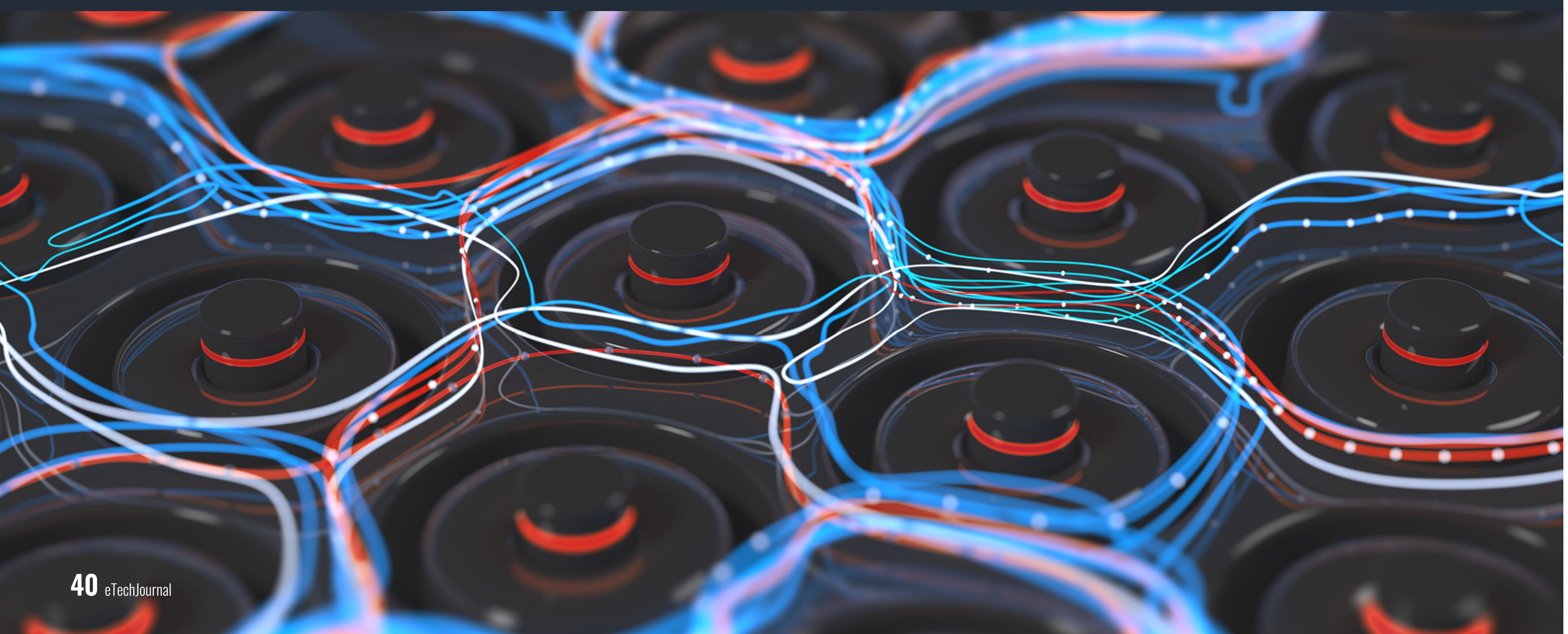
Having an independent test validation system, such as a modular data acquisition (DAQ) system, helps validate that your BMS is performing properly. It also helps validate the overall integrated system of your application. An independent DAQ system can do the following:

Measure more accurately with many types of temperature sensors, such as thermocouples, thermistors, and resistance temperature detectors (RTDs). Using thermistors or RTDs, you can achieve temperature accuracies of ≤ 0.1 °C.

Measure temperature ranges from -150 °C to 1,820 °C. This allows you to monitor both the internal battery system and external environmental temperatures at the same time.

Measure more points than the BMS implementation in your application to validate that your BMS is not missing out on any key locations.

Measure in much shorter intervals without taxing your BMS and the application's hardware resources. Shorter intervals help you find the best interval setting for your BMS monitoring system.



GAIN EXTERNAL REDUNDANCY FOR MISSION-CRITICAL APPLICATIONS

A key reason for having an independent test system is to provide redundancy for mission-critical applications.
For example, medical devices that monitor and control vital organ functions cannot afford unscheduled power interruptions during operations. Another example is large energy storage systems that power essential building functions such as IT, telecommunications, and medical equipment.

An independent DAQ system can do the following:

- Provide an independent alarm and emergency secondary switch-off to prevent a battery system meltdown or fire.
- Provide a backup monitoring and control system if the primary system malfunctions or loses communication.

The highly versatile DAQ system is the best option for independent test equipment to monitor temperatures. Plus, it is flexible enough to accommodate large-scale projects.

Many modern DAQ systems have built-in high-resolution, 6.5-digit multimeter instruments. They also come with various solid-state, armature, and reed-switching multiplexer modules to monitor more than 100 channels of temperature points. In addition, since the DAQ has a built-in digital multimeter (DMM), it can measure other signals besides temperature, such as AC / DC voltage and current, resistance, and capacitance.

The DAQ system that appears in Figure 1 is modular and allows for the expansion of channels for temperature monitoring. The system allows you to add modules to scale up accordingly when your project expands. This means you do not have to invest in new systems and can save precious development time.

Figure 1. Keysight 34980A data acquisition switch / measure unit (SMU)

TEST EQUIPMENT TO HELP BUILD BETTER BATTERY-OPERATED APPLICATIONS

Once you understand the sources of battery failures, you can use battery emulation software to predict drops in battery capacity.

BATTERY FAILURE MECHANISMS AND CONCERNS

You can analyze the root cause of battery failures by physically cross-sectioning them. However, electrical measurements offer signs that can help predict failures before they happen.

One source of failure comes from lithium plating or dendrite growth on the anode electrode.1 This growth is typically due to overcharging batteries through many cycles, causing lithium deposits on the anode. Over time, this may cause an electrical short across the two battery electrodes. It is difficult to monitor such an electrical short because it happens quickly — within milliseconds of a voltage drop.

Another source of failure is degradation of the electrode. In this case, the electrode shows oxide buildup or microcracks from charge and discharge cycle fatigue and repetitive chemical reactions of the electrolyte.

Internal battery separator failure can also occur causing an electrical short. 3 A separator failure can come from a physical impact or puncture of a battery or exposure to very high temperatures. In addition, a material defect during manufacturing can also cause failure.

Aging and a drop in battery capacity are not serious failures requiring immediate intervention. However, these factors are concerning to battery application users. Open-circuit voltage measurement itself is not a good indicator of battery capacity. The internal resistance of aging batteries increases over time, but you cannot take a snapshot of resistance measurement and make an immediate capacity degradation conclusion. Temperature, SOC, and discharge rate affect internal battery resistance. Figure 2 shows a few key battery failure mechanisms that can occur in a battery cell over time.

Battery failures are complex because of electrochemical reactions and batteries' exposure to physical variables such as temperature and mechanical stress. The battery charging method is another factor. For example, if a battery is subjected to fast charging very often, it gets heated up much higher temperature than normal charging and degrades faster over time.

There is no single battery test instrument that can provide a definitive diagnostic solution for battery failures. However, there are test equipment solutions available to meet your needs depending on your application, power usage requirements, capacity, and production cycle (R&D, compliance testing, or production). See the "Learn More" section for links to test equipment to meet your diagnostic needs.

Now we will explore test equipment tools to help you better substantiate battery life and the effects of temperature on it.

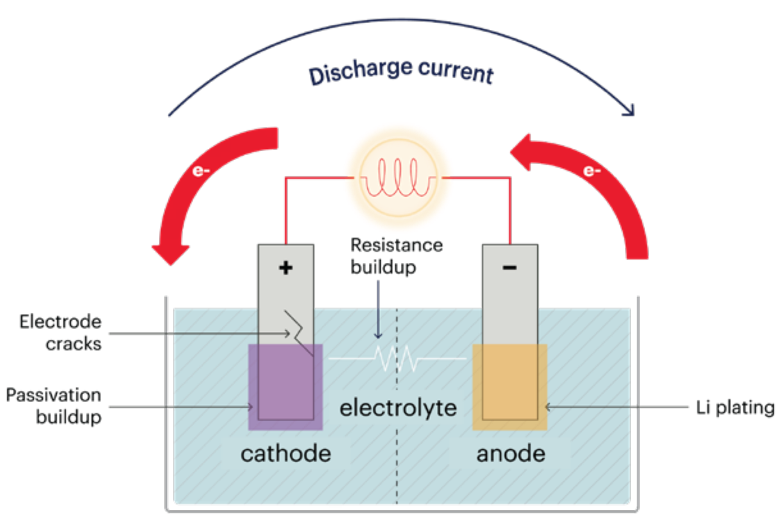


Figure 2. Internal battery failure mechanisms over time.

BATTERY EMULATION TO VALIDATE BATTERY PERFORMANCE, INCLUDING EFFECTS OF TEMPERATURE

You can use battery emulation software to better understand and predict drops in battery capacity over time. In addition, battery emulation software can predict the impact of temperature on battery life.

Before you emulate a battery, you must first profile it. You need to understand the amount of energy the battery can store and supply as a battery discharges over time. The open-circuit voltage and internal resistance vary as the battery discharges.

Therefore, it is crucial to map these out so that battery profiles accurately reflect the real-world performance of the battery. Figure 3 is an example of a typical plot. An engineer can obtain a battery profile by using battery modeling software or receiving a profile from a battery supplier. Modeling software creates a profile that reflects the current consumption for a specific device; it is more accurate than a battery supplier's generic profile. The battery profile is the basis for the software to emulate the battery.

It is critical to consider the effect of temperature on battery life. Figure 4 shows how temperature can affect the capacity curves of a battery. Generating profiles at different temperature values enables you to better predict the impact of temperature on battery life.

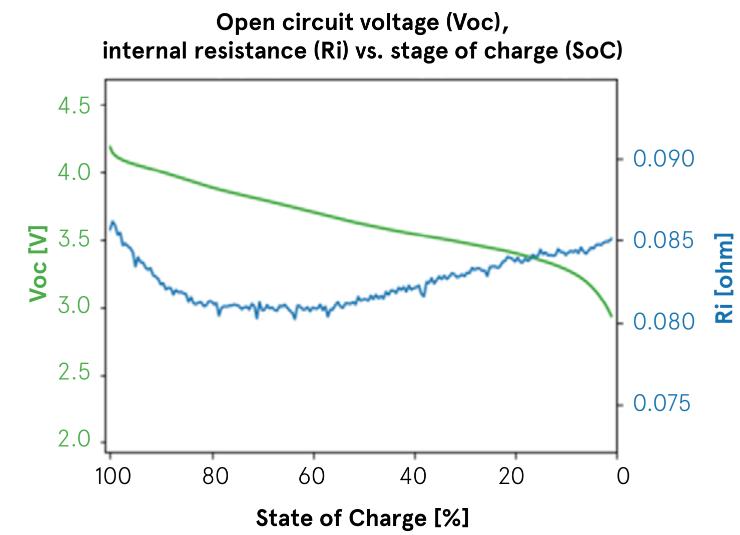


Figure 3. Battery profile created with Keysight BV9210B / 11B PathWave BenchVue advanced battery test and emulation software.

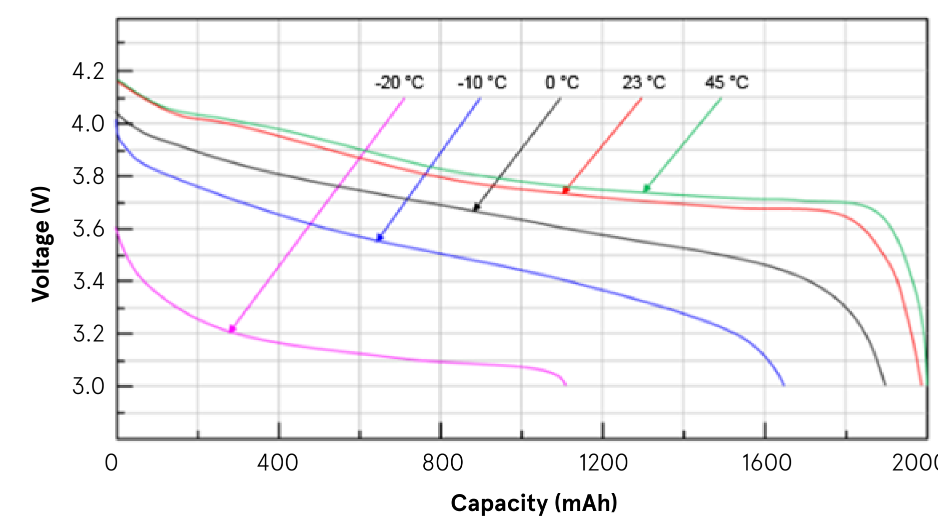


Figure 4. 1,000 mAh Li-ion cell, 3 V cutoff voltage — temperature variation

Once you develop battery profiles, you can use battery emulation software to cycle batteries to determine loss of capacity and battery life reduction. Battery performance can decline significantly over a lifetime of charging and discharging which is why it is vital to simulate battery cycling. Battery test and emulation software offers an easy solution to accomplish this. It is important that the software support arbitrary waveform generation (AWG) and data logging. In addition, it is valuable to have the ability to create various charging and discharging waveforms for a battery.

Engineers can combine multiple disparate charging and discharging sequences to simulate complex cycling profiles. They can then confirm how a battery's performance degrades over time. Emulation software solutions enable engineers to make, for example, up to 1,000 cycle operations to determine the battery's age effect and reliability under sequence test conditions (see Figure 5).

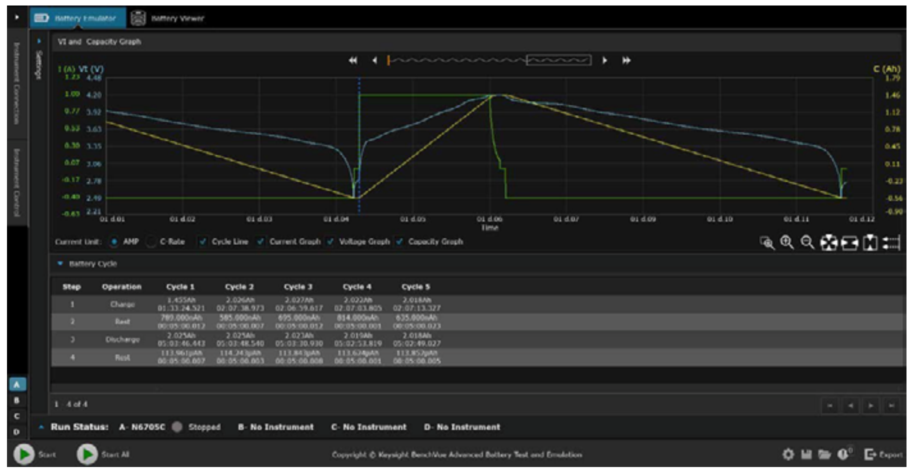
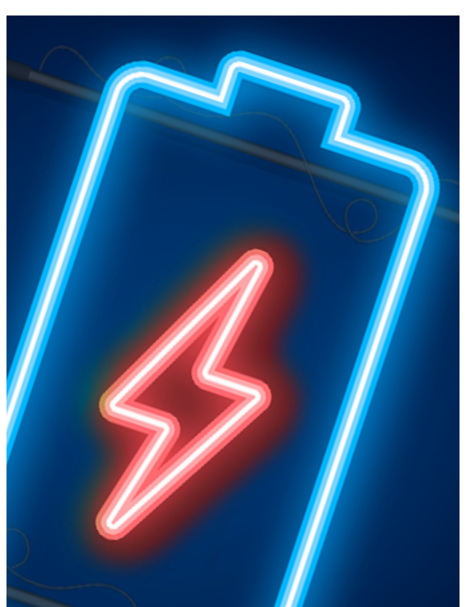


Figure 5. Battery cycling testing results using Keysight's BV9210B / 11B software

Keysight's BV9210B / 11B PathWave BenchVue advanced battery test and emulation software, along with the N6705C DC power analyzer and the N6781A or N6785A source measure unit (SMU) modules, can perform battery profiling, battery emulation, current drain analysis, and battery cycle testing.



SUMMARY AND RESOURCES

Having an independent test system to monitor battery health and temperature is indispensable. An independent test system enables you to detect potential issues such as thermal imbalance, hotspots, and changes in ambient temperatures that can affect the overall performance of your battery system even if you already have a BMS.

An independent battery test system can serve as a test validation system and an external redundancy safety system; it expands to meet all your battery test system needs. Further, the system helps in troubleshooting battery failures. And with a few additional setups and battery software applications, you can use the system as a battery emulator to help build better battery-operated applications.

CLICK HERE