WHITE PAPER

Test Ensures Batteries Meet Performance and Reliability Requirements

Batteries are everywhere—from implantable medical devices to grid-scale energy-storage backup systems and electric scooters to electric vertical takeoff and landing (eVTOL) aircraft. They come in a vast range of sizes and chemistries, as well as voltage and power ratings, but they all share a need for thorough testing to ensure they meet performance, reliability, and safety requirements.

A key test is measuring battery capacity to determine how much energy the battery can store and deliver. Environmental and accelerated-aging tests determine how battery capacity degrades with temperature, humidity, vibration and age, as well as how many charge-discharge cycles the battery can withstand, and they help predict long-term reliability. Testing occurs at various stages of a battery's life—during characterization at the development and prototype stage and in production tests. Batteries can continue to be tested even when in service; AC and DC internal-impedance tests can indicate an aging battery's state of health.

Tests are required at the cell, module, and package levels. For modules and packages, all components must be thoroughly exercised during the test—not just the cells but everything from the busbars that connect cells and modules to the sensors and processing elements that comprise the battery-management system (BMS).

The Growing Battery Industry

Such testing will be increasingly necessary as battery use expands. **The worldwide battery market is expected to grow by a factor of five to ten from 2021 to 2030**, according to the Federal Consortium for Advanced Batteries (FCAB), an organization led by the US Departments of Energy, Defense, Commerce, and State. The FCAB has developed a blueprint for guiding investment in the lithium-based battery manufacturing value chain and conducting research into lithium alternatives.

The FCAB describes the requirements of several application areas. The consortium expects lithium to remain the preferred technology for electric vehicles (EVs) because of its high energy density and long lifetime compared with other currently available technologies. Similarly, lithium will be the top choice for aviation applications, beginning with eVTOL aircraft carrying up to four passengers and extending to the 50- to 70-seat hybrid electric aircraft planned for 2028. For the stationary storage market, which has less stringent energy density and weight constraints, non-lithium chemistries may emerge as cost-effective solutions.[1]

Cell-Level Characterization and Test

Test requirements will vary widely across these diverse application areas. Still, the FCAB has published a battery test manual[2] that defines a series of cell-level characterization and test procedures that enable pre-application technology assessments. The goal of the manual is to encourage commonality in reporting results for manufacturers marketing their battery products to government agencies. The manual also outlines a baseline set of cell tests applicable to non-governmental suppliers.

The tests focus on minimum and maximum voltage limits, temperature control, reproducible fixture-pressure control, and charging procedures. The manual advises that temperature tests performed in an environmental chamber provide the battery under test with sufficient time to reach temperature equilibrium before testing commences. The time will depend on the size of the battery under test, the environmental chamber's loading, and the temperature change level.

A standard charging procedure established by the cell developer should be used uniformly throughout the test process except for high-rate charge tests. For example, a standard charging procedure for lithium-ion cells could be a C/3 constant-current charge (a three-hour charge from zero to full capacity) followed by a fixed-duration constant-voltage hold before discharge.

Specific tests include discharge-rate capability tests across various temperatures and discharge rates to determine when a cell's discharge capacity falls below 50% of its low-discharge-rate room-temperature capacity. A high-rate charge test provides information on a cell's charge-acceptance capabilities. Calendar life tests evaluate cell degradation as a function of time and temperature. Life tests can be interrupted to perform reference performance tests (RPTs), which capture specific data points throughout the life test. One RPT is the hybrid pulse power characterization test, which measures a cell's pulse power and energy capability as a function of aging.

Module and Package Test

Although these RPTs and other tests at the cell level involve low voltages, tests on modules or packages can include hundreds of volts, and your test equipment will require isolation as well as multiple voltage ranges covering the voltage levels of interest.

Module and package tests often involve monitoring the individual cell voltages and module and stack voltages. Critical parameters measured at the module or package level include open-circuit voltage, typically characterized over a range of state-of-charge levels and temperatures. In addition, battery internal resistance can be measured over state-of-charge levels and charge and discharge current levels.

Weld-resistance measurements are critical to minimizing losses and preventing failures. Still, other tests might measure insulation and busbar weld resistance parameters. BMSs require tests also. Before installation into a module, they can be tested in conjunction with a battery simulator and electronic load. After assembly, they will need to be tested to ensure they provide proper cell monitoring and balancing as well as other functions, including, for EV applications, safely disconnecting the battery in the event of a collision.

System Test Requirements

The various tests discussed so far require measurement of various parameters—primarily voltage and temperature.

When making voltage measurements, an instrument with numerous measurement input ranges provides more flexibility and can save time and money in testing. Higher input ranges are needed for measuring the entire battery package or module. Lower level input ranges are needed to measure an individual cell or other transducer input, like a current shunt or busbar welds. Another key specification is the sampling rate—a fast sampling rate will enable the instrument to capture fast transients that may accompany battery-system faults and help with AC internal-impedance tests.

Resolution and accuracy are critical in any voltage measurement, especially in battery measurements. Some battery chemistries, for example, have very flat discharge curves. Whereas the voltage for a nickel-manganese-cobalt (NMC) cell drops a few hundred millivolts between the 20% and 60% depth-of-discharge points, the voltage of a lithium-ferro-phosphate (LFP) cell changes very little over the same range. High resolution is an essential requirement for characterizing such batteries and for testing whether the battery's BMS is accurately reporting the remaining charge—which, for an EV, translates to the all-important remaining driving range.[3]

For temperature measurements, look for an instrument with high resolution and accuracy, as well as channel-to-channel isolation. A 16-channel instrument with isolation will allow you to simultaneously capture temperatures at various locations within your battery packs and modules. Measuring these temperatures properly requires a separate signal conditioning and measurement engine, or an analog-to-digital converter (ADC). For thermocouple measurements, look for an instrument that makes it easy to change out individual thermocouples and that implements cold junction compensation (CJC) on a per-channel basis.

For critical data, choose an instrument that can store data locally to a USB nonvolatile storage device while simultaneously streaming it over Ethernet. For both voltage and temperature measurements, the instruments should also have high isolation levels—channel to channel and channel to ground. In addition, look for an instrument that can work in concert with others via LXI-Ethernet connectivity or serve as a standalone data logger.

In addition, support for the IEEE 1588 standard will help ensure that all your voltage and temperature measurements can be synchronized. The instruments should also feature a high signal-to-noise ratio and superior signal integrity.

Software is also a key consideration. You may plan to write your test programs, but you might find it useful to choose instruments that come with an out-of-the-box software package that can get you started quickly making simple measurements. Also, make sure drivers are available for your programming environment—for example, LabVIEW, IVI-COM, IVI-C, Linux, or Windows. Instruments are also available that can operate without a driver. Such instruments support the Representational State Transfer (REST) architecture and can be controlled from any Web browser.

Finally, to maximize your test-system uptime, look for instruments with self-diagnostic features that monitor internal voltage levels and temperatures. And even if you plan to operate the instruments remotely, you might find it helpful to choose an instrument with a high-resolution multifunction display to help with setup and troubleshooting.

EV Manufacturer's Test System

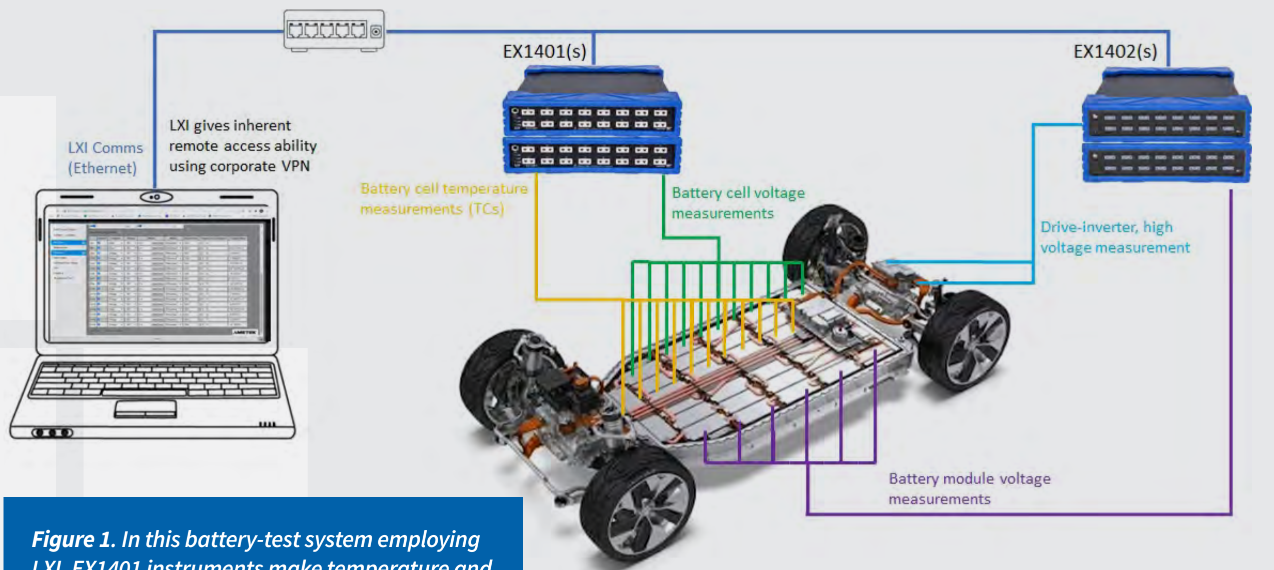

***Figure 1**. In this battery-test system employing LXI, EX1401 instruments make temperature and low-voltage cell measurements, while EX1402 instruments make high-voltage measurements.*

A case study involving an EV manufacturer provides an overview of how such voltage- and temperature-measurement instruments can work together in a battery-test application. The manufacturer needs to characterize the performance of its custom battery system on a component and system level, monitoring the voltage output while measuring the temperature of the battery and drivetrain components.

Specifically, the company's test strategy is to acquire the output voltage of each 4-V cell and 24-V module as well as the full 400-V battery-stack voltage delivered to the traction inverter. In addition, the company needs to measure battery, module, and cell temperatures to ensure they remain within a safe operating range. Raw data must be saved for subsequent post-processing, and the system requires remote configuration support for engineers working offsite. The company chose the EX1401 16-channel isolated thermocouple and voltage measurement instrument and the EX1402 16-channel isolated high-voltage instrument from AMETEK Programmable Power's VTI Instruments brand. As shown in Figure 1, the company uses the EX1401 instruments to make thermocouple and low-voltage cell measurements. In contrast, it uses the EX1402 instruments to make battery-module voltage measurements and battery-stack and traction-inverter voltage measurements. The instruments communicate with a host computer using LXI-Ethernet, which provides inherent remote access over the company's corporate VPN. A web-browser soft front panel supports out-of-the-box configuration and data logging without additional software.

Conclusion

As batteries proliferate, the need to test them will increase. Choose instruments that exhibit superior signal integrity, easy-to-use input connections, flexible measurement ranges, and high resolution and sampling rates. Looking to the future, make sure you choose scalable instruments as your volumes increase and adaptable as your test requirements evolve. For example, the PXIe DSA digitizers from AMETEK Programmable Power's VTI Instruments brand can work in tandem with the EX1401 and EX1402 to add high-speed vibration and acoustics measurements to your voltage and temperature measurements. AMETEK Programmable Power can work with you to get the battery-test system up and running today while providing a path to future system upgrades as your business expands and evolves.

References

1. *National Blueprint for Lithium Batteries 2021-2030*, *Federal Consortium for Advanced Batteries*, June 2021.
2. *Pre-application Battery Test Manual*, *Federal Consortium for Advanced Batteries*, August 2021.
3. Ng, Mark, et al., *How Innovation in Battery Management Systems is Increasing EV Adoption*, *Texas Instruments*, 2022.