



The Fundamentals of Battery *Module* and Pack Test

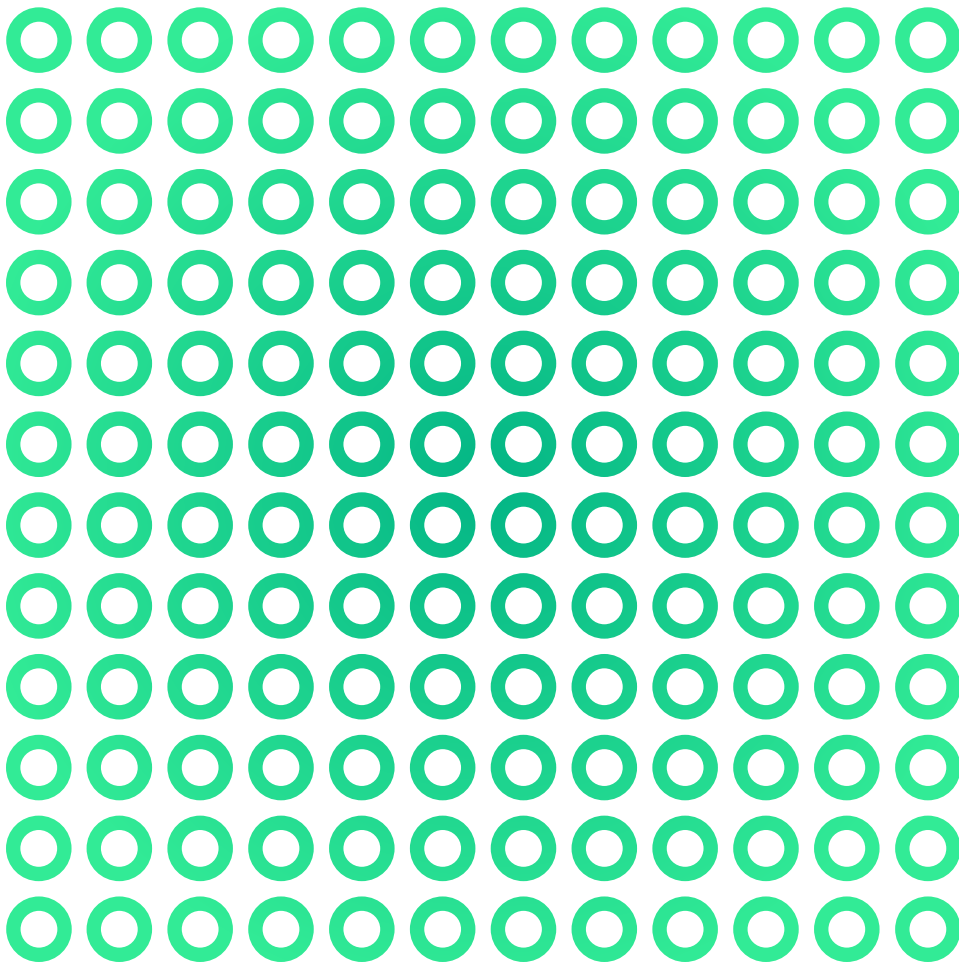




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Introduction

The Importance of Battery Module and Pack Testing

The battery market is growing rapidly due to the acceleration of electrification in the automotive, aerospace and energy industries. In turn, batteries are the pivotal component for electrifying automobiles, planes, trains, and the grid. Therefore, it's imperative that today's engineers, researchers, and managers understand the fundamentals of how to test batteries, as well as, the most productive approaches to ensure product performance, safety, and time to market.

“The battery market is expected to increase exponentially driven primarily by the electric vehicle (EV) industry including electric trucks, buses and commercial vehicles. By 2030, the annual lithium-ion battery demand for EVs is estimated to surpass 1,748 GWh annually.”

BloombergNEF
News Agency

According to BloombergNEF, the battery market is expected to increase exponentially driven primarily by the electric vehicle (EV) industry (Figure 1) including electric trucks, buses and commercial vehicles. By 2030, the annual lithium-ion battery demand for EVs is estimated to surpass 1,748 GWh annually. As a result of decreasing battery costs, global energy storage installations are also expected to multiply exponentially from 9GW/17GWh deployed as of 2018 to 1,095GW/2,850GWh by 2040 (Figure 2).

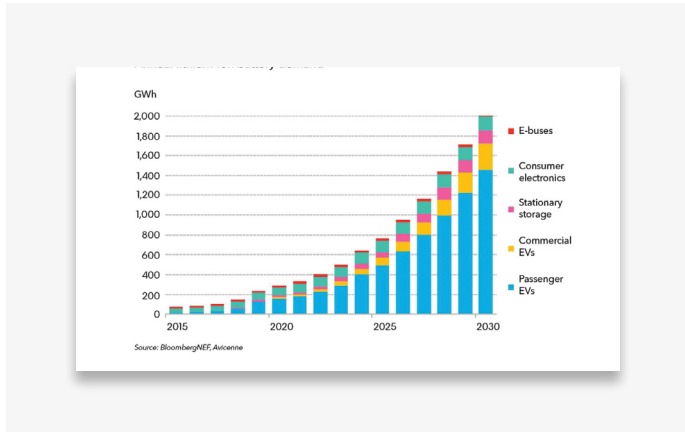


FIGURE 1
Annual lithium-ion battery demand

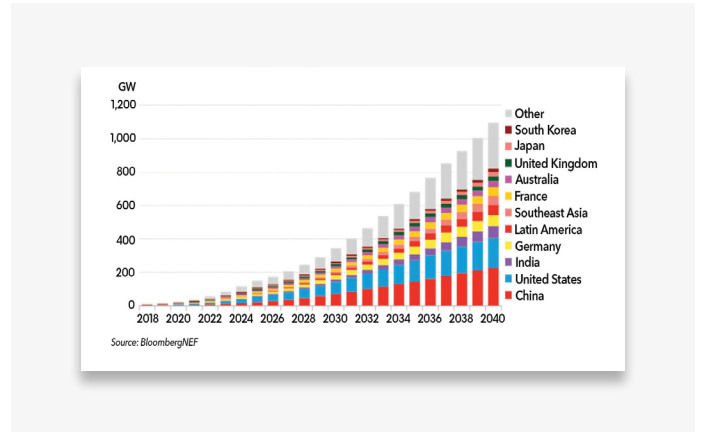


FIGURE 2
Global cumulative energy storage installs

With the growth of electrification, battery manufacturers are competing to develop higher performing batteries with larger capacity, higher energy density and longer life cycles. Meanwhile, engineers are also racing to develop and commercialize the highest performing products using these battery technologies. Not only is battery testing important to battery manufacturers, but system engineers also need to test batteries to evaluate the overall system design and optimize its performance.

Before we discuss how to select the right battery test equipment for a given application, certain key challenges and fundamental concepts of battery testing will be reviewed. This application note is focused on battery module and pack level testing using examples of real-world industry applications. At NI, we understand the complexities and challenges associated with testing batteries. As your partner in test, we simplify the solution path and show you how to overcome these hurdles.

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Battery Testing Challenges

Battery pack and module testing is more critical than ever. Today's engineers face new challenges including increased complexity of the tests and set-ups, long development and test times, addressing safety requirements, and avoiding hazards. Furthermore, testing to the application requires emulating real-world conditions by responding to communication signals from the battery, system or external devices. Although testing batteries may seem like a simple task, there are many challenges due to their complexity and hazardous nature. At NI, we provide solutions to overcome these pain points.

Summary of Pain Points

- **Battery testing takes a very long time**
Battery testing and preparation takes a very long time and chemical reactions can't be rushed. In addition, understanding battery behavior requires re-running tests to address the "what if" scenarios, which takes a significant time. For example, many EV manufacturers are running accelerated life cycle tests that can take as long as 6 months.
- **Errors lead to re-running tests**
Due to the complexity of battery testing there will likely be errors. Yes, Murphy's Law does apply. Tests will need to be re-run and there are no short-cuts to save the time that's been lost.
- **Batteries are hazardous**
Batteries have high voltages, high currents, toxic chemicals, electrolyte leakages and environmental issues that raise huge safety risks and consequences.
- **Battery testing requires large and expensive equipment**
Battery test equipment takes up floor space and requires a capital investment. That's why it is important to select the right test solution that is flexible for a variety of applications and needs.
- **Data collection, analysis and management is time intensive**
The time it takes to collect multiple sets of data, run queries, analyze and process the data, can take up to several months or longer.
- **Testing is different for each application**
Testing requirements differ for each application. Getting solid answers for seemingly simple questions can turn into decades of testing.
- **Integration of multiple instruments and software takes time**
Multiple pieces of hardware and software requires integration beyond the battery tester including DAQs, relays, chambers, digital I/O & CAN communication. The complexity of the entire test system requires automation, significant test development and integration time and effort.

Types of Batteries

A battery is a device that stores chemical energy and converts it into electric power through electrochemical reactions. Battery chemistries vary and have different characteristics, functions and behaviors. There are two basic types of batteries: primary or secondary. Primary batteries are intended for single use and are non-rechargeable, such as alkaline or hearing-aid batteries. Secondary batteries are rechargeable and are intended for multiple-uses such as lead acid, nickel-cadmium and lithium-ion. Lithium-ion batteries are most commonly used by electric vehicle (EV) manufacturers due to their lighter weight and higher energy densities. These batteries are recharged numerous times before the end of its life-cycle. As an exception to these definitions, fuel cells and flow batteries are examples of battery systems where additional chemicals can be added or pumped into the battery and charged or discharged. Fuel cells are becoming increasingly popular to power electric heavy duty commercial vehicles due to their even lighter weight.

What are Battery Cells, Modules and Packs?

Battery Cell, Module, and Pack Definitions

- A **battery cell** is a single device that converts chemical energy into electrical energy.
- A **battery module** contains any number of cells along with connectors, electronics, or additional mechanical packaging.
- A **battery pack** contains any number of battery modules along with additional connectors, electronics, or packaging.

The above distinction is important as battery cells are treated as individual components whereas battery modules and packs are treated as an assembly (reference Figure 3). Similar to power electronics testing, there are very different testing goals used when evaluating components as opposed to a finished assembly.

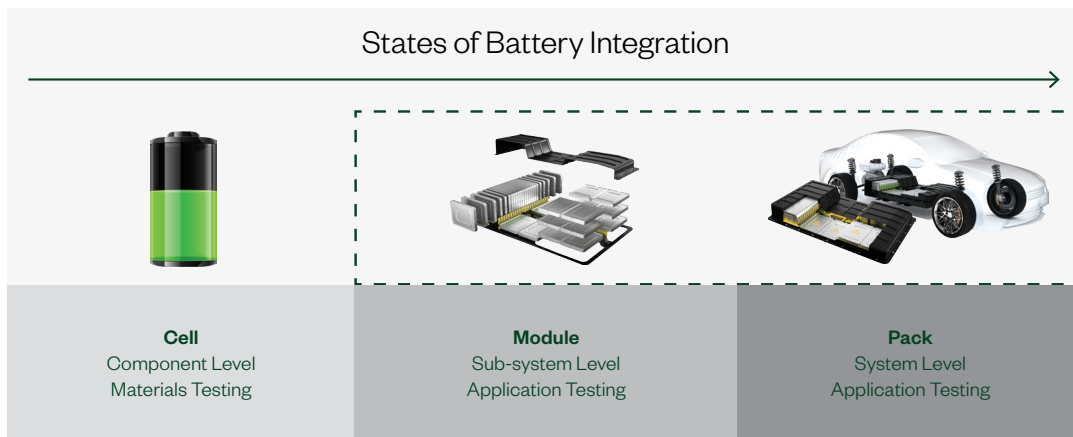


FIGURE 3

Battery cells, modules, and packs involve different types of testing depending on their function. Module and pack testing is application-focused.

Differences in Testing Battery Cells vs. Battery Modules and Packs

Battery Cell Testing Evaluates the Battery Chemistry

Battery cell testing investigates the dynamics of the chemical reactions in order to understand electrochemical performance characteristics and predict the viability for use within a battery module or pack. When testing cells, engineers perform electrochemical techniques to evaluate the internal chemical reactions, and understand the basics of the cell materials (Fig. 4). Cell testing occurs before moving on to module and pack level testing. Once the dynamics and behavior of the cell component is understood, the cells are assembled into individual modules and packs. For example, the 2018 Nissan Leaf Battery Pack is constructed of 24 modules, each containing multiple cells. Types of battery cell tests and techniques may include:

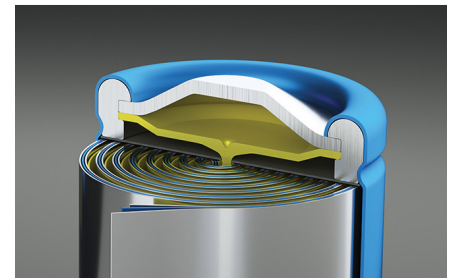


FIGURE 4

The chemical materials in a lithium-ion battery cell.

- **Cyclic Voltammetry (CV)** is a test method used to measure the current and voltage of a electrochemical cell to study its electrochemical behavior.
- **Galvanostatic/Potentiostatic Intermittent Titration Technique (GITT)/ (PITT)** are test methods to evaluate the diffusion of solutes (such as lithium) in electrode materials. The results are used to characterize the rates of chemical reactions and transport properties of electrodes.
- **Differential Capacity (dQ/dV)** is an analysis to measure the alignment of electrodes. This analysis allows the cell degradation mechanisms to be understood.
- **Electrochemical Impedance Spectroscopy (EIS)** is a technique that measures the resistance of current in an electrochemical cell at various frequencies. This complex technique is used to understand the impedance characteristics and chemical reactions of an individual cell.

Battery Module and Pack Level Testing is Application-based

The application drives what type of battery module and pack testing is needed (Fig. 5). Battery module and pack testing involves very little testing of the internal chemical reactions of the individual cells. Module and pack tests typically evaluate the overall battery performance, safety, battery management systems (BMS), cooling systems, and internal heating characteristics. Common performance-based tests include drive-cycles, peak power capability, BMS software validation, and other application-specific characterization



FIGURE 5

Nissan Leaf Battery Pack

tests. Battery testing is important across each phase of the product life-cycle including R&D, manufacturing and depot repair. The goal of testing batteries as an individual component or subsystem is to answer specific questions about the design or build. Another reason why testing is important is that engineers and scientists typically want to create a test that will address a specific “what if” scenario. For example, what happens to my EV battery pack when the temperature is below 30 degrees Celsius? By using real application parameters for testing, you can dramatically reduce testing time, operating costs and mitigate safety risks.

Battery Terminology Fundamentals

Fundamental terms used in battery module and pack testing are described below:

- **Voltage:** The pressure, potential, or electromotive force measured in Volts (V).
- **Current:** The flow of electrons measured in Amps (A).
- **Amp Hour:** An energy-storage rating where one Amp Hour (Ah) is equal to one amp per hour.
- **Watt Hour:** An energy-storage rating where one Watt Hour (Wh) is equal to one Watt per hour.
- **Battery Capacity:** An energy-storage rating expressed in Ah, Wh, or both. Capacity does not imply the acceptable discharge rate and may have additional modifiers included below.
 - **Chemical Capacity:** The full storage capacity of the chemistry when measured from full to empty or the reverse.
 - **Designed Capacity:** The storage capacity allowed to be used in the applications. Generally, the designed capacity is lower than the chemical capacity to ensure safety, performance, or longevity.
 - **Available Capacity:** The accessible storage capacity factoring in age, health, temperature, usage.
- **C or C-Rate:** The C-rate is a measure of the rate at which a battery is discharged or charged relative to its maximum capacity, measured in Ah or Wh. A 1C rate means the level of current (or power) required to discharge or charge a battery in one hour. For example, a 1/2C rate for a 1000Ah battery is 500A and it will provide 2 hours of energy. Conversely, a 2C rate for a 1000Ah battery is 2000A and it will provide 30 minutes of energy.
- **State of Charge (SoC), Depth of Discharge (DoD), State of Health (SOH):** Battery condition terms described on next page.
- **DC Internal Resistance (DCIR):** The electrical resistance of current flowing through the battery, measured in Ohms. The value of DCIR depends on multiple factors such as battery materials, temperature, internal connections, and depth of discharge. The DCIR value influences discharge performance, especially for high voltage batteries.
- **Battery Configuration:** Battery modules and packs are typically constructed of multiple cells in series (S) and parallel (P). Therefore a module containing four (4) cells could be configured as 1S4P, 4S1P, or 2S2P. A 10S4P pack is a total of 40 cells arranged in a 10S and 4P configuration.
 - **Series (S):** The number of cell voltages placed in series. A 10S pack would have 10 times the V per series.
 - **Parallel (P):** The number of cell capacities placed in parallel. A 4P pack has 4 times the Ah per cell.

Battery Rated Capacity (C-Rate)

The C-Rate is used as a way to indicate the theoretical current which could discharge the battery in one hour. This measure is used to normalize testing for charging and discharging a battery regardless of the configuration or types of cells used. The configuration of the battery module and pack is dictated by the desired performance needed for the application. For example, for higher voltages, cells would be placed in series, and for higher current, cells would be placed in parallel. As shown in Figure 6, let us consider various configurations for using a 3.6V Li-Ion cell with a 3.0 amp-hour (Ah) rating. If the battery configurations below were all discharged at 1C (a one hour rate), the 4S1P would require 3A, the 1S4P would require 12A, and the 2S2P would require 6A current levels. Adding a multiplier increases the current level and reduces the time to discharge the battery proportionally. For example, a value of 10C would discharge a battery in 6 minutes at 10 times the current.

Battery Module and Pack Configurations





	BATTERY CELL	1S4P	4S1P	2S2P
				
Voltage (V) V x Series	3.6 V	3.6 V (3.6 V x 1)	14.4 V (3.6 V x 4)	7.2 V (3.6 V x 2)
Amp Hours (Ah) A x Parallel	3.0 Ah	12 Ah (3.0 Ah x 4)	3.0 Ah (3.0 Ah x 1)	6.0 Ah (3.0 Ah x 2)
Watt Hours (Wh) V x Ah	10.8 Wh	43.2 Wh (3.6 V x 3.0 Ah)	43.2 Wh (3.6 V x 3.0 Ah)	43.2 Wh (3.6 V x 3.0 Ah)

FIGURE 6

Battery module containing four battery cells could be configured as 4S1P, 2S2P, or 1S4P

Battery Condition

The State of Charge (SOC), Depth of Discharge (DOD), and State of Health (SOH) are all commonly measured indicators that reflect the overall battery condition, as shown in Figure 7. The SOC indicates the level of charge relative to the maximum capacity of the battery, whereas the DoD indicates the percentage of the battery that has been discharged. The SoH is another important indicator to monitor overall health and battery performance. The SoH takes into consideration the battery’s storage capacity when compared to its initial capacity, the internal resistance, and self-discharge due to stress-related conditions on the battery.

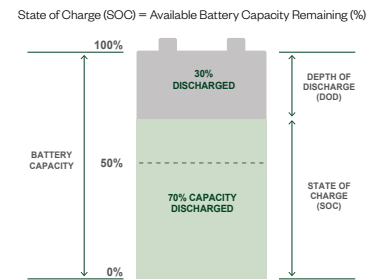


FIGURE 7

Battery capacity diagram. Source: Battery University

Battery Management Systems

What is a Battery Management System (BMS)?

A Battery Management System (BMS) is an electronic system that manages a module and/or pack to ensure that a battery operates within its intended design parameters (Figure 8). These parameters include voltage, current, temperature, state of charge (SOC) and state of health (SOH). The BMS is responsible for measuring, calculating, storing and communicating these battery characteristics when needed.

Important BMS functions include battery safety and protection, identifying state-of-charge and state-of-health (capacity), and indicating risks or end-of-life. Batteries have communication standards that enable communication with interconnected systems. For example, the BMS of a 2018 Nissan Leaf battery pack will prevent the battery from overcharging and exceeding its safety operating limits as well as communicate SoC levels to the vehicle. All BMS systems vary in level of function and capability.

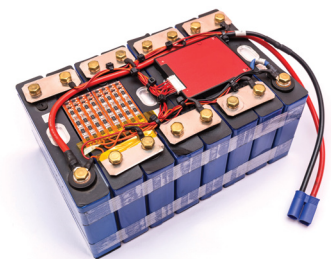


FIGURE 8

Battery with BMS components attached

What is a BMS?

- **Safety and Protection:** The BMS regulates the battery from operating outside of its safe operating conditions such as over or under current, voltage, temperature, etc. When charging or discharging, the battery is disconnected if limits are exceeded or if a failure occurs.
- **Monitoring of State-of-Charge (SoC) & State-of-Health (SoH):** The BMS monitors and controls the charge and discharging of batteries for optimum battery longevity.
- **Indication of hazards, service or end-of-life:** The BMS provides critical information and notifications on the status of the battery modules and packs over time.
- **Communication:** The BMS captures battery data communicated to the overall system (Fig. 9).

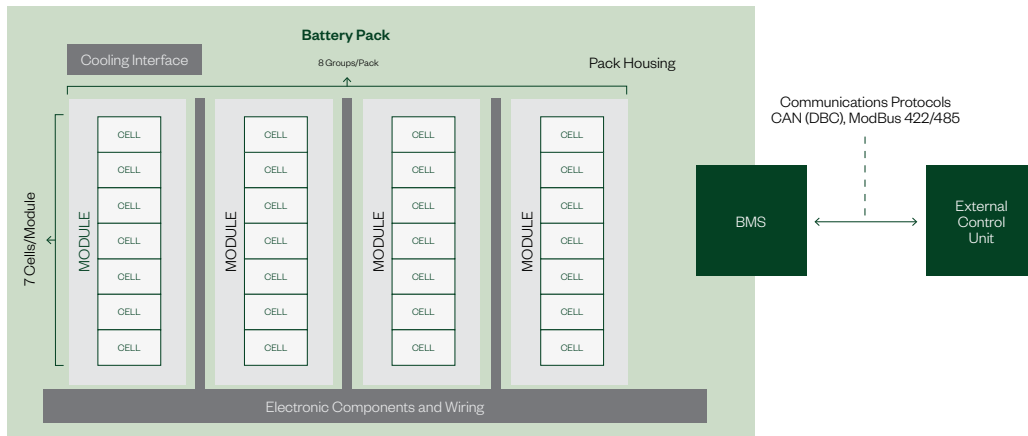


FIGURE 9 Battery Systems Architecture, example of EV Battery. The BMS communicates with the external control unit.

BMS Communication

BMS communications standards such as the Controller Area Network (CAN) bus allow for data from the BMS to be used at the system-level as shown in Figure 10. Signal information from the module level is collected at the pack level and reported to the BMS. In many cases, the BMS is a subsystem that must communicate with other subsystems. For example, an electric vehicle battery is a subsystem to the overall vehicle and connects to the EV charger, the electric powertrain and other in-vehicle electronics. Therefore, the ability to extract data from the BMS is critical to optimize the overall electric vehicle design and system performance.

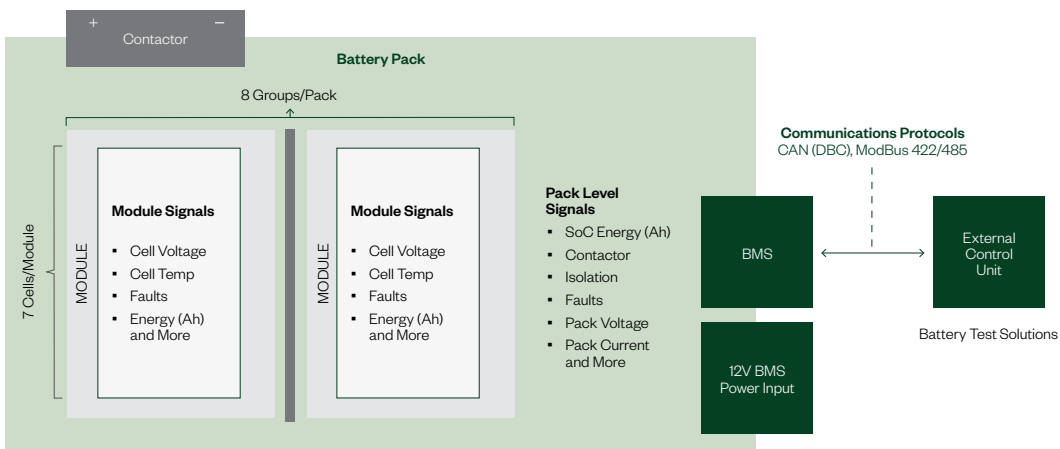


FIGURE 10 The Importance of Data Send/Receive to/from BMS. The BMS communicates important data up to the system hierarchy.

Battery Module and Pack Testing

Battery module and pack testing is critical for evaluating the battery's condition and performance. This includes measuring the state of charge (SoC), depth of discharge (DoD), direct current internal resistance (DCIR), and state of health (SoH). Tests are also conducted to evaluate the performance of the electronic components and systems that are attached to the battery such as the BMS, connected wires, sensors and battery fuses. Battery tests are also vital for answering "what if" scenarios for the end-application, as shown in the list below.

Module Level

Module level battery testing typically involves charge and discharge tests to ensure that the cell connections are secure and strong enough to manage the anticipated current loads without weakening, failing or overheating. Additional tests could involve ensuring cells are balanced, voltages are reported accurately and that the temperature sensors function as needed.

Pack Level

Pack level testing takes place after the pack has been assembled or is close to the final assembly (end of line testing). A full collection of tests needs to be completed to ensure that each pack subsystem performs properly including the safety mechanisms, the external hardware and BMS communications. After testing is complete, packs may undergo additional testing to simulate the typical conditions the pack will be subjected to once integrated into the end-product or system. For example, an EV battery will be subjected to drive profile cycling to anticipate the number of drive cycles before the vehicle performance is impacted for a particular design.

Examples of Applications for Module and Pack Testing:

- Performance under simulated environment
- Degradation over time, number of cycles, etc.
- Aging characteristics of battery
- Capacity measurement
- Second Life
- Qualification manufacturing
- Mechanical stress effects
- Cooling system efficiency test
- Fast charging performance/SoH effects
- Cell to module/pack correlation
- Manufacturing production
- Delivery preparation
- Warranty validation
- Balancing tests for R&D

Stages of Battery Testing in Design and Manufacturing

Batteries are tested during the engineering characterization and manufacturing production stage of a product life-cycle as shown in Figure 11. The primary goal of engineering characterization testing is to validate if the battery meets the design specification requirements. For example, if an engineer is designing a battery for an electric truck, the battery may need to have different characteristics than a battery designed for a small, urban commuter vehicle. Essentially, engineering characterization testing is used to define a "good battery". A "good battery" is defined as meeting all design specification requirements. Design validation takes an extensive amount of time to test all corner case scenarios to ensure that the design meets all application requirements.

Manufacturing production testing occurs after engineering characterization is complete, and the design specifications have been validated and finalized. The primary goal of manufacturing production testing is to verify that the battery is manufactured to meet the design specifications. In other words, the manufacturing production verifies that the battery is a "good battery".

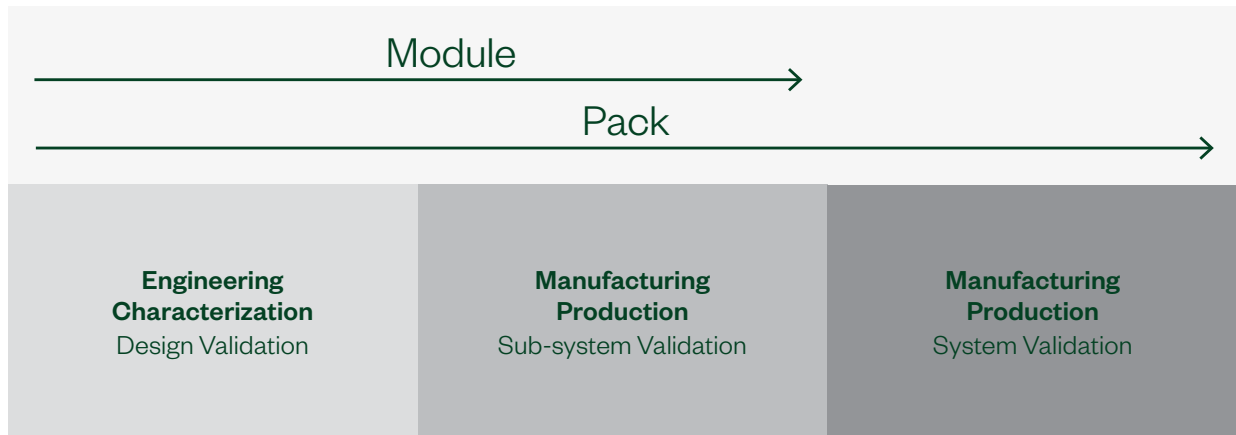


FIGURE 11

Diagram of battery module and pack testing in design and manufacturing.

There is significantly less time available to test during production due to high throughput. Typically the system validation done on the pack level can easily take upwards of 6 minutes per unit. For example, an EV battery manufacturer may plan to manufacture up to 40,000 or more battery packs a year. If it takes 6 minutes to test every battery, it would take 4,000 man- hours or over one man-year to achieve this goal. This calculation assumes that there are no errors and that tests do not need to be repeated, which is generally unlikely. Reducing the test time by even a small amount can result in a very large time and cost savings as well as higher throughput in production.

Battery Cycling is Fundamental in All Testing

A core element of battery module and pack testing is battery cycling. Battery cycling is the process of charging and discharging a battery and plays a role in all types of tests. How a battery is cycled depends on the chemistry, application, and the objectives of the test.

Let's explain in more detail. A battery is an energy source used in devices that require energy. Depending on the application, these devices range in performance, and demand more or less energy at faster or slower rates (Fig. 12). Due to this varying demand of energy, a battery needs to be tested accordingly to ensure it meets the end-requirements of the application. This requires a method to change the amount and rate of energy demanded from the battery. Therefore, battery cycling is fundamental for determining if the battery can meet the application energy requirements.

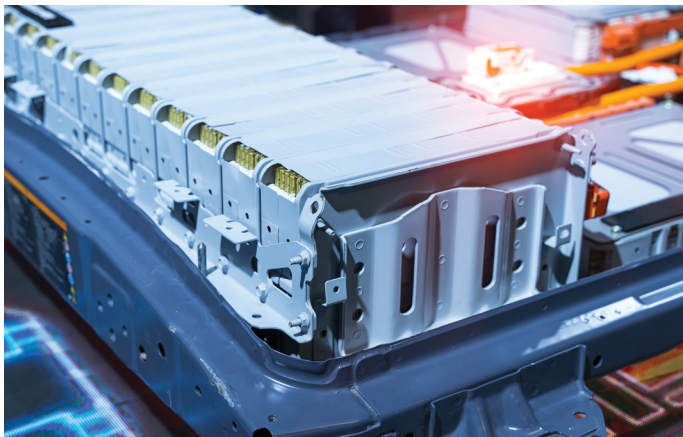


FIGURE 12

An EV battery (left image) demands energy at a different rate and speed than a UPS battery (right image). The batteries are charged and discharged according to the expected energy requirements of the application.

Charge/Discharge Tests

An inherent part of battery testing includes charge and discharge tests to measure the battery capacity and the DC internal resistance at different state of charges (SoC). A battery is charged by using a source to put energy into the battery or discharged by using a load to draw energy out. Let's consider a one-time-use battery as an example. A test engineer may wish to verify the manufacturer's capacity rating or may need to understand how hot the battery gets when discharged at a specific rate. In both cases, the battery is discharged and the desired characteristic is measured.

To discharge, a load is connected between the anode and cathode of the battery. Once connected, the electrons and corresponding cations (positively charged ions) move from the anode to the cathode as shown in Figure 13. The battery chemical storage (and voltage) decreases as energy is consumed.

For rechargeable batteries, charging the battery reverses this process. Current is forced into the battery causing the electron to move in the reverse direction as shown in Figure 14. The chemicals in the battery store this energy and increase the stored potential (and voltage).

When testing batteries, it is useful to control, measure, and report voltage, current, power and energy measurements. A battery cycler that has a GUI display can simplify battery preparation and charge/discharge tests.

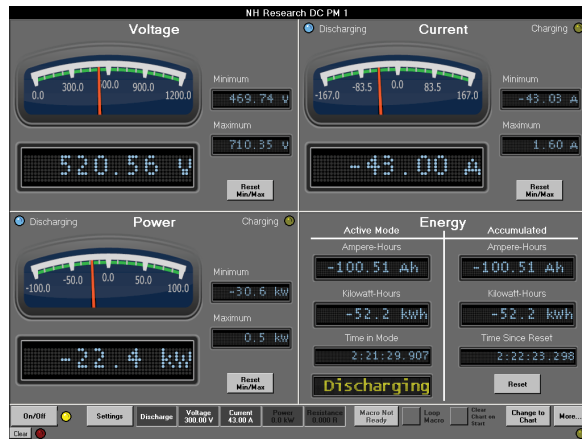
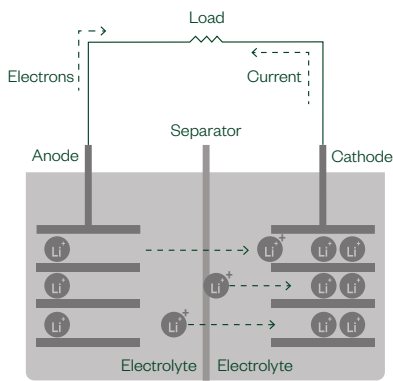


FIGURE 13

Example of a 720 V battery discharging. Diagram of battery chemistry during discharge (left) and NI's NHR 9300 GUI panel display of live battery data (right).

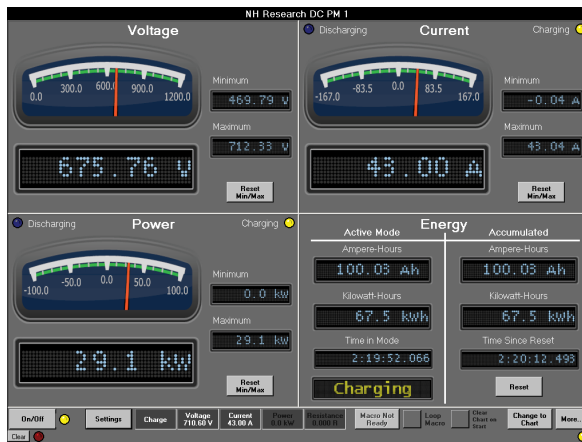
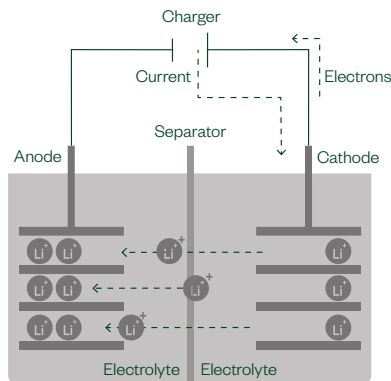


FIGURE 14

Example of a 720 V battery charging. Diagram of battery chemistry during charge (left) and NI's NHR 9300 GUI panel display of live battery data (right)

Common Types of Battery Tests

Today's applications require more intricate tests that use combinations of charge and discharge patterns to uncover specific battery characteristics. In most cases, automation software (a sequencer or controller) is required to capture and manage this data, as well as integrate with additional instrumentation such as the BMS, temperature chambers, and chillers.

Examples of common tests that have complex test patterns are described below.

Performance Cycling and Stress Tests

Performance cycling tests simulate real-world conditions in which the battery is used. Examples include drive cycles, grid-cycles and flight profiles. Life-cycle testing involves a culmination of performance tests over a shortened period of time to project failure rates. Similarly, stress tests are performed to test the limits of the battery under harsh conditions ranging from extreme temperatures to repetitive vibration shocks.

It is common to perform several tests on the same battery. For example, EV batteries are tested using multiple test profiles (Fig. 15) to ensure they meet performance expectations for differing use patterns and international standards. Some EV test profiles include FUDS (US), US06 (USA), WLDC (EU), NEDC (EU), CLTC (CN), JC08 (JP).

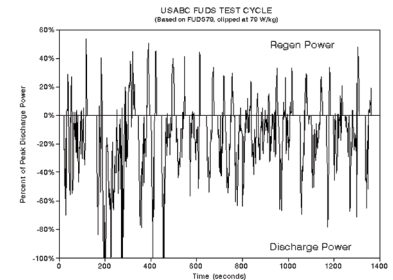


FIGURE 15
Idaho National Laboratory. Example of an EV test profile using the FUDS Test Cycle standards pattern

Reference Performance Tests

Reference performance tests (RPTs) are conducted at periodic intervals to characterize the performance of the battery over time. RPTs generally involve multiple types of tests to look at a combination of variables. For example, an EV battery may be subjected to a RPT in order to evaluate the storage capacity after the car has been driven for 100, 200, or 1,000 miles. In this case, a capacity test would be inserted periodically in between performance tests. The combination of hybrid pulse power characterization (HPPC) (Fig. 16), peak power, and capacity validation tests can also provide an initial baseline of how the EV battery changes over time.

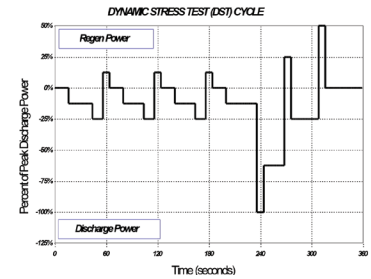


FIGURE 16
Idaho National Laboratory. Results of Hybrid Pulse Power Characterization (HPPC) test run on EV battery

BMS Data Validation and Hardware Testing

The Battery Management System (BMS) communicates to the rest of the system or product using communication protocols such as CAN, Modbus, Serial (422, 485), etc (Fig. 17). Testing the BMS software and hardware is typically done at the pack level to ensure that all parts of the battery work together and that the BMS performs safely and accurately. Engineers need to test the BMS to meet industry standards such as ISO 26262 and IEC 62304.

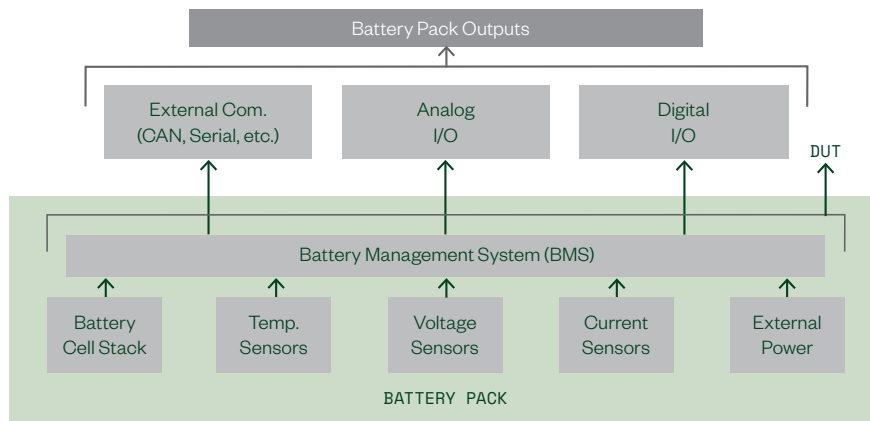


FIGURE 17
BMS interfaces include pack inputs and outputs.



The battery itself plays a secondary role when validating the BMS. Verifying the measurements reported by the BMS typically requires the battery to be cycled to evaluate the software and hardware used in these systems. Examples of measurements include voltage, current, power, temperature, energy (Ah or kWh), available power, and state of charge (SoC). An example of BMS validation is to ensure that the BMS accurately calculates the capacity. In this use case, the battery is discharged and charged to a known point, and the amp hours (Ah) are measured. The capacity estimated by the BMS is compared to the actual measured capacity on the hardware.

Subcomponent and Environmental Tests

Batteries typically have external subcomponents that protect and support the battery for its intended use. These auxiliary systems such as battery fuses, connectors and attached cabling (Fig. 18), must be tested to ensure safety and high performance. During these tests, the battery plays a secondary role and is cycled (charged and discharged) to evaluate the mechanical, structural and thermal behavior and characteristics of these systems. Additionally, some of these auxiliary systems may be tested individually or as a complete system.



FIGURE 18
EV Battery with orange fuses, connectors and cabling attached.

The Evolution of Battery Test Approaches

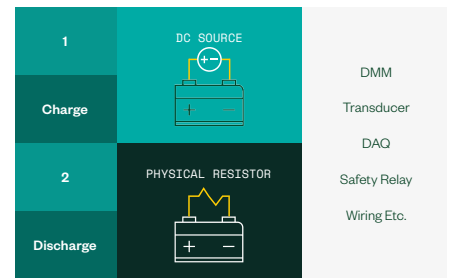
The test and measurements industry is moving towards increased automation to reduce complexities for the user and speed up workflow. As the demand for better designs increase, engineers need to have automated solutions for testing R&D, production and post-manufacturing objectives (Fig. 19). Software is becoming more critical to manage data seamlessly, to align with market requirements and to ensure customer success. Battery test solutions have evolved from manual testing to automated and next generation battery test systems. This section describes the evolution of these methodologies over time to align with the evolving test requirements..



FIGURE 19
Battery test approaches are becoming more automated and sophisticated.

Manual Testing

Although manual battery testing is a legacy method, it is still used today. Testing a battery manually involves two independent test set-ups to cycle the same battery. Charging requires connecting the battery to a DC source and discharging requires connecting the battery to a physical resistor. Furthermore, a number of external pieces of equipment, such as DMMs, relays and transducers, are required to take measurements and need to be switched between sourcing and loading. All these instruments must be manually set-up, controlled (start/ stop), managed independently, and manually recorded by the user.



Pros

- Hardware customization
- User familiarity with equipment
- Minimal investment

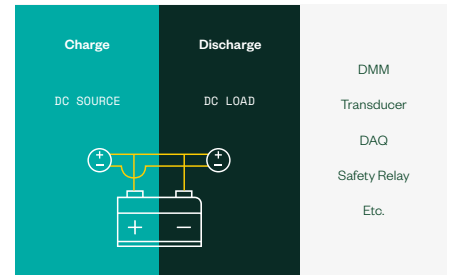
Challenges

- Manual process (no automation)
- Complex set up; extra equipment and wiring
- Difficult to control; requires two test set ups
- Very high risk of human error
- Poor test repeatability and difficult to adjust
- Reduced productivity; manual start/stop
- High power testing is challenging
- Increased safety hazards
- Difficult to make changes
- Very slow to collect and process data manually
- Not a scalable solution



Electronic DC Source and DC Load

An approach engineers often take is to build their own battery test set-up using an electronic DC Source and DC load. These general purpose test equipment are found in most power electronics labs. This approach provides an opportunity to automate testing by programming the test parameters within the source and load. However, these instruments still need to be controlled separately and external equipment is also required to collect measured data.



Pros

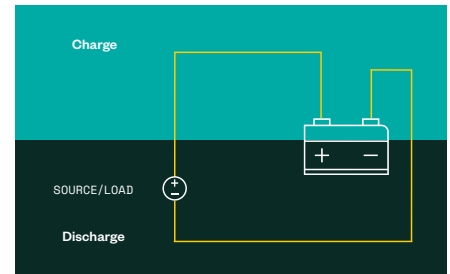
- Single test set up for charge/discharge
- Improved automation
- Some built-in measurement capability
- Less time consuming than manual test

Challenges

- Requires external equipment
- Complex set up; extra equipment and wiring
- Complicated to control; two instruments
- High risk of human error
- Fixed voltages and module size
- Reduced worker productivity
- Data management and integration
- Not a scalable solution

Automated Battery Test Systems

Automated battery test systems integrate an electronic DC source and load within a single product along with advanced built-in automation tools and improved measurement capability. These test systems range from custom-engineered to commercial off the shelf options. These systems vary in technological approaches, capabilities and limitations.



Pros

- Advanced automation improves productivity
- Simplified set up; single product
- Simplified control; programmable
- Smaller footprint; eliminates extra equipment
- Improved built-in measurement capability
- Simplified data collection mechanism
- Eliminate need for extra equipment

Challenges

- Many of today's battery test systems are custom-engineered for a specific solution.
- Fixed voltages and module size
- Speed and accuracy varies by vendor
- Safety is often an add-on feature
- Limited integration with third party tools
- Limited hardware and software control options
- Not scalable solution, limited flexibility

Next Generation Battery Test Systems

Modern battery test systems continue to evolve providing new capabilities to address the changing technology and business needs. Key battery test technology trends include: higher voltages for faster charging, wider power ranges, faster response times to emulate real world conditions of e-mobility, and more environmental testing with broader adoption. On the business side, key trends include declining battery costs, increased use of lithium and alternative materials, shorter design cycles to address increased competition and market growth, and increased outsourcing of testing due to limited talent availability.

To address these trends, battery test systems now require: wider operating envelopes (esp. voltage and power), modular configurations with scalable and expandable power, multiple layers of integrated safety features, fast transient response-times, built-in measurements, and easy third party integration. In order to select the right test solution, it's important to develop a test plan that addresses the technical, user, and business needs of today and in the future. Important elements of a test plan include automation software, battery cycler hardware and other external equipment including chambers, data acquisition, relays, I/O and auxiliary loads or sources.

THE FUNDAMENTALS OF BATTERY MODULE AND PACK TEST

Next generation battery test solutions provide different options to automate that include multiple programming languages or a powerful test executive that can simplify and reduce software development time and complexity. With respect to hardware, battery test systems need advanced hardware performance to ensure accurate, scalable and repeatable test results. Voltage and current transitions, or slew rates, of the test system must be faster than the battery under test to emulate real-world settings. Flexible and scalable power enables users to address future power requirements with no or minimal investment in new infrastructure. And, having multi-layered built-in safety measures dramatically reduces safety hazards. In addition, users often need the flexibility to have easy integration with third party tools such as software communication interfaces, temperature chambers or DAQ systems. Many automated test systems do not easily integrate with third-party tools and as a result, limits testing capability and takes a long time. The ability for a battery test system to interface with and control an entire test environment is critical. Today's users need an easy way to collect, manage and analyze the data from the battery tests in order to achieve their testing objectives.

Next Gen Battery Test Systems:

- Reduce time to market and improve engineering productivity
- Decrease capital expenses (CAPEX) and operating expenses (OPEX)
- Eliminate use error and ensure repeatable testing
- Reduce safety hazard
- Provide future-proofing to address future power levels

Summary

Battery testing is more important than ever with electrification and there are many challenges because it is complex, time-consuming, data intensive and hazardous. Key fundamentals of battery testing include understanding key terms such as state of charge (SOC); the battery management system (BMS) which has important functions including communication, safety and protection; and battery cycling (charge and discharge) which is the core of most tests. Unlike cell testing, module and pack testing is application based. This application note showed that battery testing is primarily used in design (engineering characterization) and manufacturing and that each has a different objective. In reviewing the evolution of battery testing we showed that many testing challenges can be overcome by selecting the right solution. Testing without the right equipment and software tools can delay projects, increase safety risks and hinder productivity. Today's battery applications demand higher performance, capacity, efficiency, speed, accuracy, and safety. Next generation battery test systems provide a comprehensive test solution with the flexibility to address today's applications and tomorrow's innovations

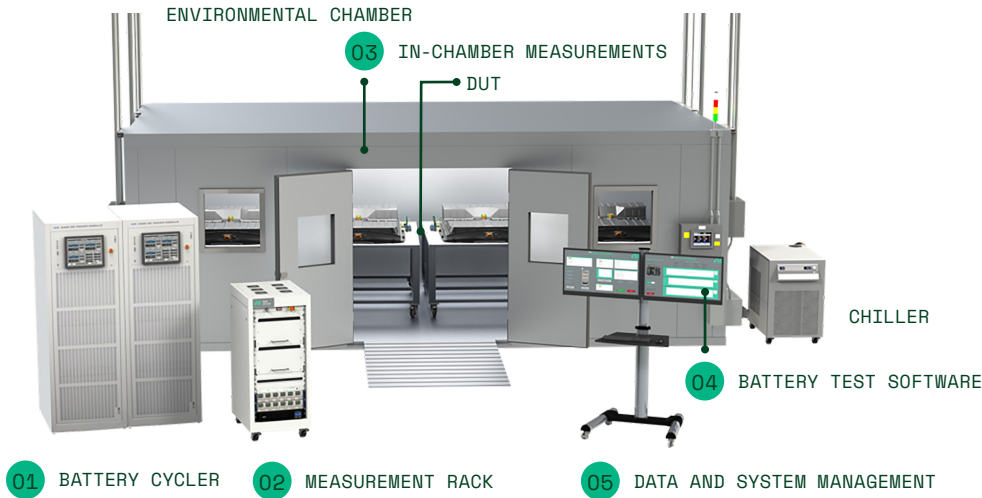
For more information or application consultation, please visit ni.com/evbatterytest.

The Evolution of Battery Test Approaches

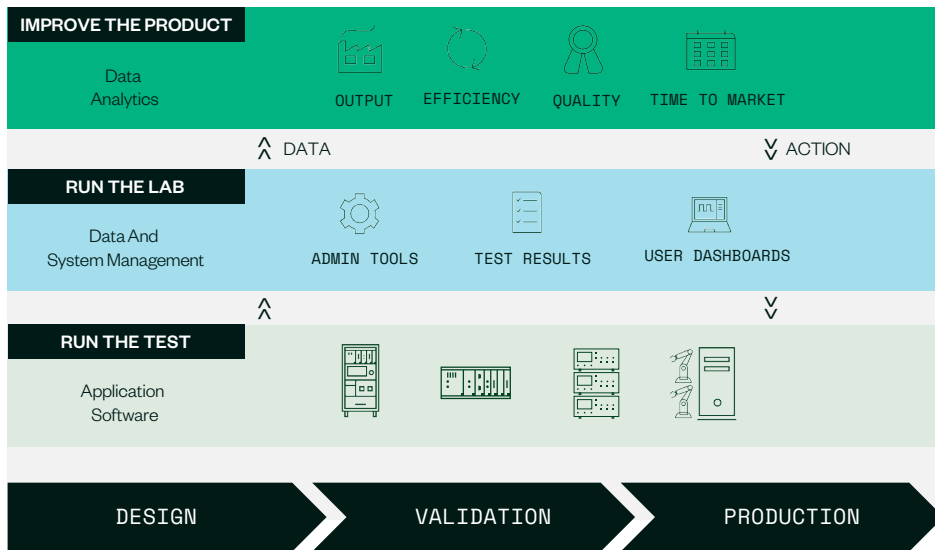
	MANUAL	AUTOMATED SOURCE/LOAD	NI'S NEXT-GENERATION
Wide Operating Range	-	-	●
Modular, Scalable Power	-	-	●
Fast Slew Rate & Accuracy (CV, CC, CR, CP)	-	-	●
Layers of Built-in Safety	-	◐	●
Choice of Software Options	-	◐	●
Easy and Powerful Software	-	◐	●
Easy Third Party Integration	-	◐	●
Multiple Control Options (S/W, GUI, Remote)	-	◐	●
Built-in Measurements	-	◐	●
Regenerative Energy Savings	-	◐	●
Reduced Testing Time	◐	◐	●



THE FUNDAMENTALS OF BATTERY MODULE AND PACK TEST



- 01 Connection to power electronics, less rework
- 02 Scalable measurements at low cost per channel
- 03 Rugged in-chamber measurements
- 04 Open, out-of-the-box or custom battery test software
- 05 Customized data dashboards for facility management



- Automate and Streamline Workflows
- Connect and Increase Utilization of Test Systems
- Enhance Data Management and Analysis

The Software-Defined Lab

A Comprehensive Approach to Battery Test

We're revolutionizing how enterprises use battery test and data insights to drive product and business performance. Scale your battery lab through NI's optimized workflows, enterprise lab management software, and integration partners.

With NI's **Software-Defined Battery Lab Solution**, you can future-proof your battery testing processes by leveraging a software-connected approach that combines advanced software capabilities with modular hardware. Benefit from seamless integration, automated test sequences, real-time data analysis, and customizable algorithms, enabling you to optimize battery performance, accelerate time-to-market, ensure compliance with industry standards, and reduce costs.

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