Five Technical Challenges for Battery Pack End-of-Line Test Stations

A BATTERY TEST WHITE PAPER

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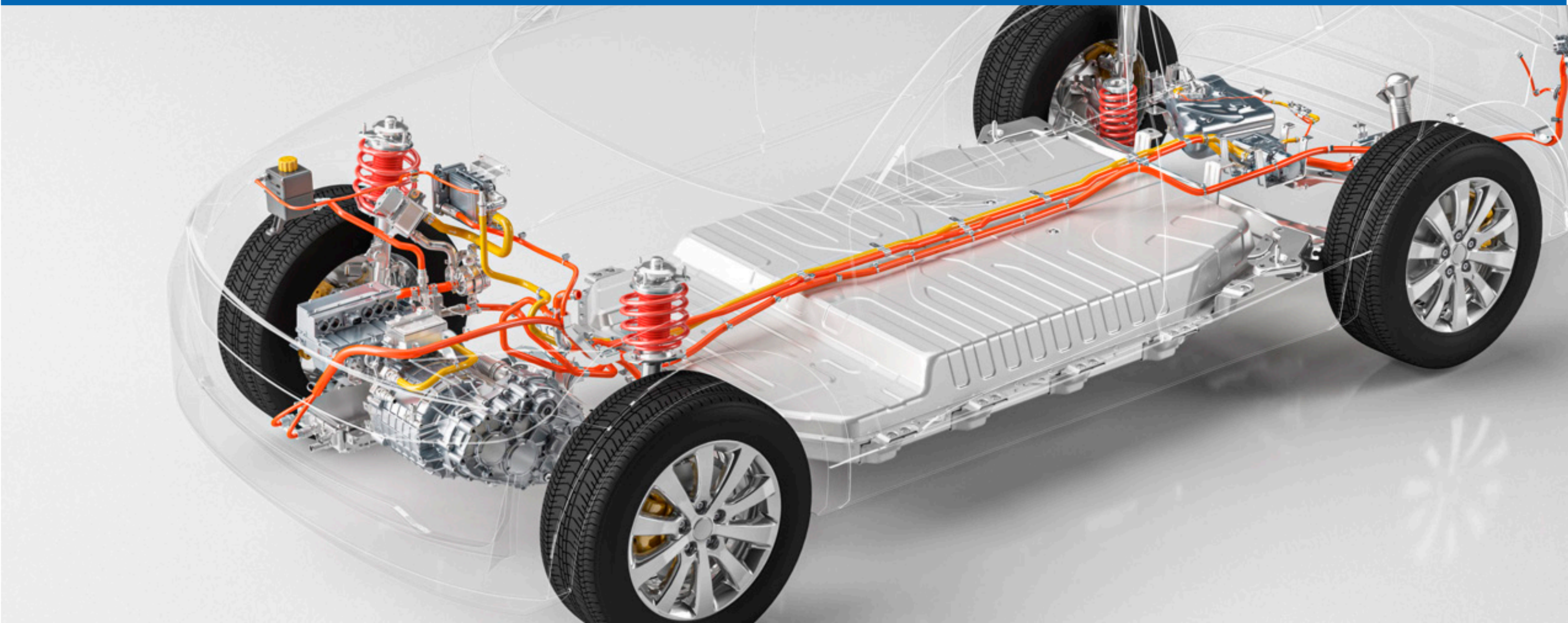
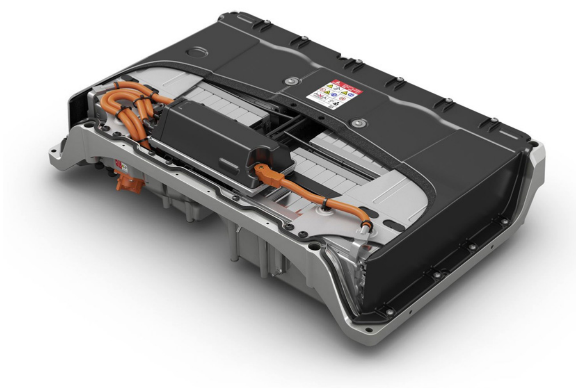
Chroma Systems Solutions



Five Technical Challenges for Battery Pack End-of-Line Test Stations

The emerging growth of the EV market has created significant challenges to battery manufacturers on how they test and validate the functionality of battery modules and packs effectively and efficiently, especially during high voltage tests. It is also critical while manufacturing to adhere to associated test standards and regulations during the test phases.



The four primary test phases with associated test functionalities and systems:

1. Sub-Module Welding Test: Quality verification on welding for the battery sub-modules
2. Module-level End-of-Line (EOL) Test: Functional verification for the individual battery modules under a systematic test
3. Automatic Test System (ATS) for module-level In-Line (IL) Test: Functional verification for the all battery modules under a systematic test before installing the external enclosure
4. Automatic Test System (ATS) for pack-level End-of-Line (EOL) Test: Functional verification for production battery pack prior to the release to the vehicle assemble

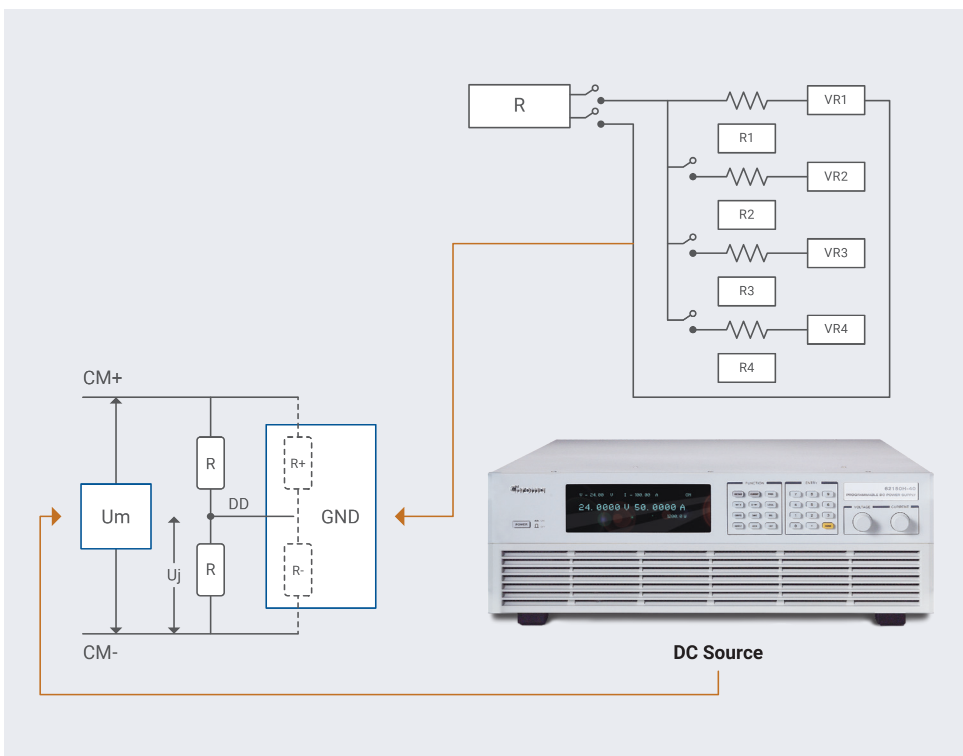
These test phases and systems shown above have created several technical and logistic challenges. Based on the years of experience in assisting the OEM customers around the world in testing battery modules and packs, Chroma ATE discusses in detail the top five challenges of automated pack level end-of-line battery testing.

Challenge #1

Applying the low voltage signals and validating the battery management system (BMS) functionality

It is essential to follow the procedure as the battery pack is connected to the power sources, either through the power source such as a charging station, or the electric vehicle used for the test. These test procedures are required to adopt the International Unified Diagnosis Service (UDS) protocol according to ISO 14229-1 to unlock the battery pack from the ECU. They can present an anti-counterfeiting mechanism, enabling users to secure control over rights in ECU obtained through the UDS Service Identifier. In order to gain access, the test system may require certain anti-counterfeiting or wakeup signals such as Checksum and Live Counter. The Checksum signal can verify the software version and check the correctness of the file in ECU. And Live Counter can send the heartbeat signal to wake up the system.

Additionally, the test solutions must check each relay switch to validate the presented High-Voltage Interlock Loop (HVIL) signal; thus, the HVIL circuit design is required in the EV to use low-voltage signals to detect and verify the integrity or connectivity of high-voltage components, wires, and connectors to confirm if there is an abnormal situation occurred in time. In case the HVIL circuit fails to present, a Diagnostic Trouble Code (DTC) will be triggered immediately to prevent the high-voltage system from being powered to protect the operators.



The circuit of unbalanced bridge detection for BMS

When the EOL ATS has completed the above inspection procedures, it will then proceed to the BMS test. The Battery Management System (BMS) is a significant part of the battery pack. The BMS has the functions of voltage management, system communications, battery state of charge (SOC) estimation, warning of abnormalities, cell balancing and thermal management, etc. In general, testing a BMS requires these four segments: communication, connection, safety signals simulation, and V/I/temperature verifications. The EOL ATS would need to perform the initial software version checking, flash process, and the read/write functions for the communication function. The connection function of the test system would perform relays ON/OFF checking and DI/DO response checking. For safety signals simulation, test instrumentation equipped with an unbalanced bridge test circuit can provide various resistances to simulate the faulty situation to trigger the BMS protection. For the current/temperature verification, the testing system would need to check the charge and discharge current capacity in positive and negative, read the temperature, and write the data into the BMS.

Also, there is always a chance that the BMS board's firmware is an older version. Therefore, it is necessary to establish the methodology to update the BMS firmware at the EOL ATS station. The test system must read the Seed & Key from the ODX file and obtain flash control permissions.

The BMS detects abnormalities and implements a safety strategy. This diagram shows the unbalanced bridge method detection principle through voltage detection of Uj and Um and applying the resistance R to calculate R+ and R-, whether positive and negative voltage insulation is abnormal. Implementing the relevant safety systems and insulation resistance simulation will be necessary to inspect this on the production line quickly.

2

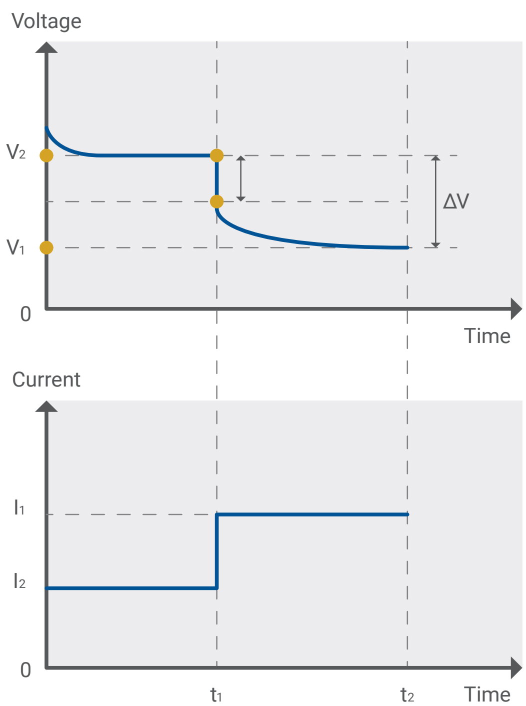
Challenge #2

Implementing effective DC internal resistance (DCIR) testing

The direct current internal resistance (DCIR) test is a test method to quickly verify the status of the battery pack in the production line, which requires high current charge and discharge test equipment. DCIR test data can correlate to the quality of the soldering and assembly inside the battery pack. Comparing its data to a golden sample can quickly detect if the battery pack is abnormal. DCIR tests typically use the current and voltage difference between two charge or discharge currents, often calculated according to the standards set by IEC 61960. As seen in the battery cell model diagram in the attached figure for the DCIR test, the DCIR is derived from the voltage change produced by the current. It is important to note that the current profile will affect the battery cell chemistry and voltage transient profile. When using multi-point sampling to test its voltage transient changes, if the current transition shape of charging or discharging does not change smoothly and linearly, or the current changing time is too long (>1000ms), it will be wrong DCIR data results.

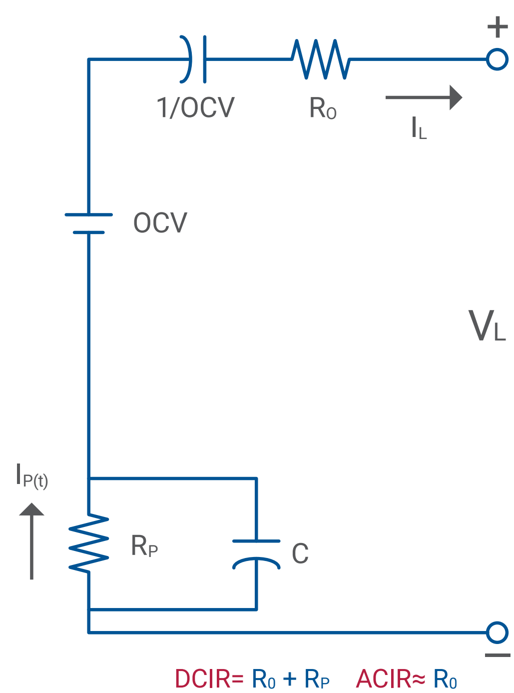
The BMS may be disturbed by electromagnetic effects due to the high current flowing through the battery pack. Therefore, it is recommended that an additional charge-discharge test for about 10 seconds with dynamic high current changes to check for EMI. The test system needs to perform BMS communication during this dynamic test and check that the BMS communication content is correct. It can diagnose battery internal parts or wiring without any assembly defects. It can help reduce the risk of future battery data errors due to electromagnetic interference, resulting in unbalanced cells, overcharging, or thermal runaway.

DCIR Test



$$DCIR = R_0 + R_P = \frac{\Delta V}{\Delta I} = \frac{V_2 - V_1}{I_1 - I_2}$$

Li-ion Battery Equivalent Circuit Model



DCIR is to measure the DC resistance characteristic of the battery

Challenge #3

Integration capabilities for electrical safety testing

Designing a battery pack to comply with safety requirements and regulations is critical. In addition to the standards outlined by ISO 6469, JIS D 5305, GB/T 18384, GB/T 18284.1, the SAE J1766 Electric Vehicle Crash Test Specification contains specific "electrical safety" requirements. On the production line, battery packs must also pass safety tests such as insulation strength test, insulation resistance test, ground connection test, leakage current test, etc.

The majority of the battery pack production lines use electrical safety testers to perform these tests within a single test station. Ultimately Chroma has the products to combine the battery testers and electrical safety analyzers into a single EOL ATS. One of the benefits is that these tests can configure the built-in test sequences and set up the tests to execute in a batch. The battery pack is subjected to multi-point insulation testing. Despite the positive and negative poles of the high-voltage connector to the shell, it is also required to verify the potential equalization connectors, chassis/EMC-shielded connectors, low-voltage, and communication connectors, etc. An automatic test system with high efficiency ensures all connectors are free of safety hazards. In addition, another important benefit of integrating functional and safety testing into one station is the reduction of battery pack loading and unloading time and the space in the test station to save manufacturing costs.

Integrating electrical safety testers into an EOL ATS presents some technical challenges. EOL ATS includes DC power supplies, battery chargers and dischargers, other instruments, and low-voltage CAN communication equipment. According to IEC 60950, the test voltage is twice the battery voltage plus 1000 volts. If an abnormality occurs, it is easy to damage other components. So when doing high voltage testing, the system needs to be able to disconnect all other equipment from outside the test path of the electrical safety test. Only those with relevant design experience and high integration capabilities can make EOL ATS work safely.

Challenge #4

The significance of in-line self-inspection ATS

Most EV OEMs (Original Equipment Manufacturers) require routine EOL testing for battery pack production. Therefore, it is essential to conduct the scheduled calibration for the test equipment to ensure the proper operations with accuracy. Implementing the specific MSA (Measurement System Analysis) for the EOL ATS equipment is often required. The equipment must guarantee the traceability of output and measurement data and be sure not to cause errors in test results. Statistical data must regularly validate MSA to comply with the required accuracy after long-term use.

The OEMs usually schedule an annual calibration for the test systems. Production lines need to be stopped until all the calibrations are completed and productions return to normal operations. However, a yearly calibration sometimes does not reach specific test equipment with inaccurate specifications. To avoid such conditions and effectively verify the equipment and check the accuracy of the entire system, Chroma ATE recommends that the production lines are equipped with a self-checking system. Such a system would be able to integrate many instruments to simulate a battery pack. It maps customized test items to the battery pack test procedure. It can verify the test instrument and the path to the end of the battery pack, eliminating possible incorrect wiring.

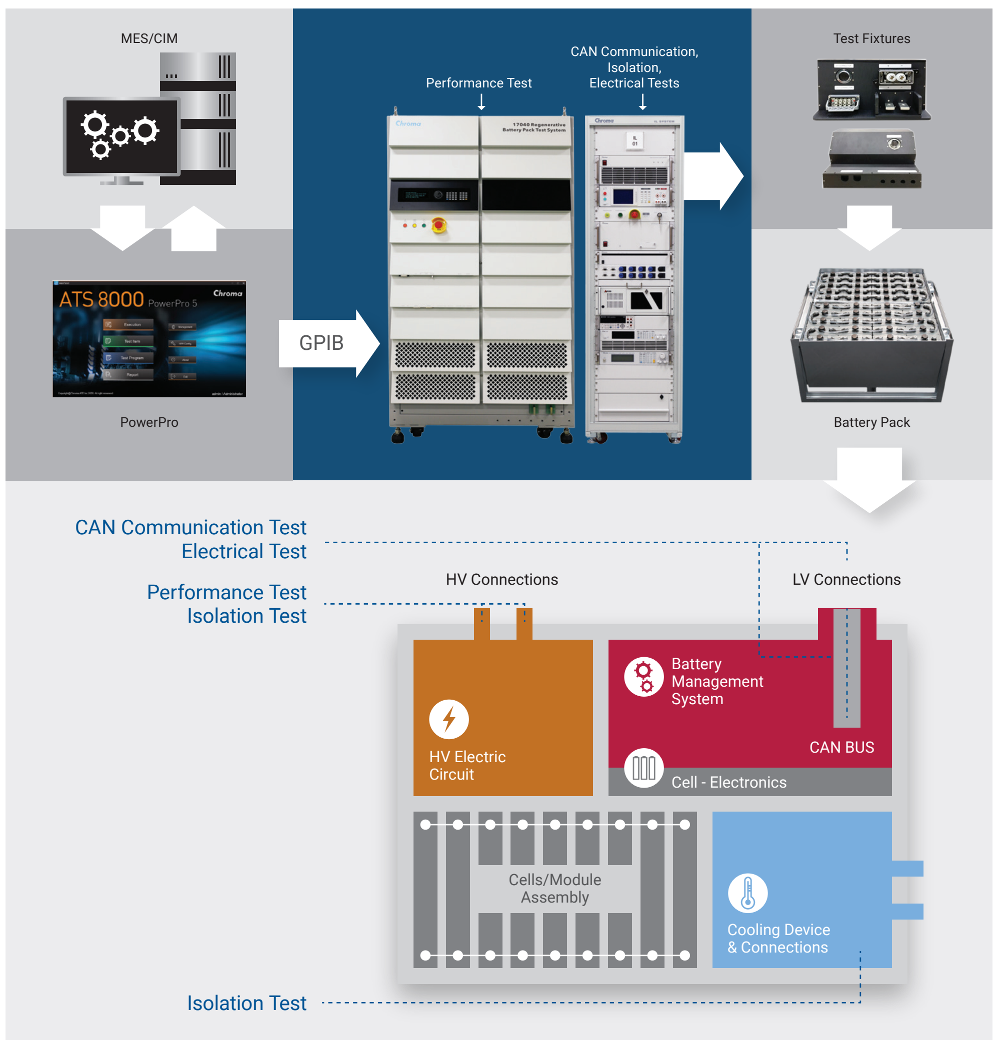
Potential equipment problems can be reduced without affecting production line operations. Manufacturers are advised to perform self-checks before daily production and upload the results to the Manufacturing Execution System (MES). Uploading the results to the MES will also help manufacturers quickly check when faced with quality issues. Also, it meets the data retention requirements of ISO 16949 7.5.3.2.1 for traceability.

Speeding up production time will help meet the rising demand for EV batteries

Challenge #5
Collaboration across different industrial entities

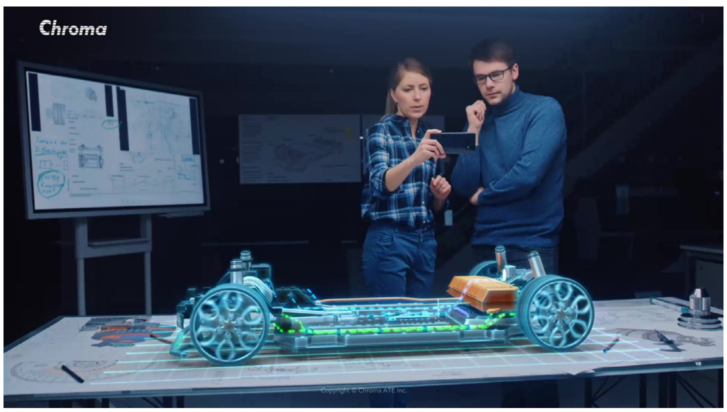
Building a battery pack production line requires a whole team effort. For the integrator of the EOL test station, he has to work very closely with the car manufacturer, including his plant management department, product development department, test function planning, quality assurance department, etc. It also acts as a coordinator, cooperating with the automation flow line provider for system operation and scheduling. It also needs to ensure the various production steps and communication. For example, when the battery pack is transported by the automatic guided vehicle (AGV) into the test station or the battery pack is delivered by the conveyor belt, the programmable logic controller (PLC) will notify the EOL ATS. The EOL ATS needs to immediately ask the MES for the status of the battery pack, and then it can decide whether to test.

Each entity associated with the EOL ATS usually has specific functions with expertise. Therefore, the test system's prior planning, communication, and coordination require the participation of people from these different areas of knowledge. The success of EOL ATS often requires the high involvement of the various industrial entities with the precise definitions and responsibilities.



EOL ATS would require high involvement with automation flow line provider and MES

The complete test station for the battery pack production line is somehow different from validating the battery performance in a laboratory. It requires more system integration capabilities under a limited test time. It also needs the fast and routine upload of new BMS firmware to be compatible with to ensure good production throughput. Hopefully, this information on the five technical challenges provides a valuable reference for the managers and planning personnel of the battery pack production lines.



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