E-Mobility: Innovative Design & Test Solutions for the Electric Powertrain and HEV/EV Ecosystem
Keysight’s Global Automotive & Energy Footprint

Keysight’s global footprint ensures we deliver solutions where you need them.

We have established automotive customer centers in Michigan, United States, Böblingen, Germany, Nagoya, Japan, and Shanghai, China.

These centers underscore our commitment to work with and serve customers in local proximity to support innovative technology projects that drive the automotive and energy industries.

We maintain partnerships with international organizations that help set the standards for electromobility (e-mobility).

This translates into future-ready solutions for your automotive design and testing requirements.
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What Is Fueling the E-Mobility Ecosystem?
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The number of pure electric vehicles (EVs) and hybrid electric vehicles (HEVs) on the world’s roads will hit 250 million by 2030, the International Energy Agency forecasts.

That is a big leap from the IEA’s 5.1 million reported for such vehicles in 2018. This growth is matched by advances in technologies for powertrains, power electronics, cells and batteries, and the charging infrastructure (Figure 1).

Manufacturers must ensure their EV fleets comply with CO₂ emission regulations. They also need to improve energy efficiency and range.

It typically takes more than one design cycle before new powertrain technology turns a profit. The cost pressure on EV powertrain components (traction motors, converters, power converters, and batteries) continues to drive new fundamental technologies. These technologies drive demand for design and test solutions that can provide better emulation and test coverage to comply with safety and performance standards.

Growth in the plug-in vehicle market is also fueling new technologies in the adjacent renewable energy ecosystem. These include photovoltaic (PV) inverter and smart grid technologies.
Testing in the High-Power E-Mobility Environment
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Bidirectional test: Testing bidirectional power flow demands equipment that can source and sink power to the converter. Conventional test methods use external circuits and multiple instruments. These methods typically do not allow for smooth signal transitions between sourcing and sinking power, resulting in inaccurate simulations of operating conditions. They also lead to heat build-up in the test environment, requiring costly cooling measures.

New power semiconductor technology: Designers are starting to use wide bandgap (WBG) devices. These offer better power efficiency and the ability to handle higher voltages and temperatures than conventional silicon devices. However, their use complicates the simulation and design of DC-to-DC converters. Traditional simulation tools used in the design of power converters do not accurately capture the behavior of WBG devices and cannot support optimal design of converters using these devices. Designing today’s converters requires new simulation and test technologies.

Safety and reliability concerns: Using new semiconductors requires extra validation and reliability testing to ensure converters will last under harsh operating conditions. Given the power levels used with converters, designers need to be careful when testing them. This requires special safety mechanisms in manufacturing, including redundant systems that do not expose personnel and equipment to high voltages if a failure occurs.

Maximizing efficiency: It is difficult for testers to simulate all of the operational and environmental influences on efficiency to evaluate the real-world, whole-system operation of the converter. Measuring small percentage changes in efficiency demands instruments with high dynamic range.
Test Solutions for Electric Vehicles and Power

To address these emerging design and test issues, Keysight has created and introduced innovative approaches to help developers and manufacturers accelerate their programs. This e-mobility brochure will provide you with an overview of the design and test solutions and services that Keysight offers in this ecosystem:

**Electric powertrain testing:** Ensure energy efficiency at the power semiconductor level, through inverter and DC-to-DC converter testing for onboard systems, as well as cell characterization and power efficiency tests for battery modules and packs, while addressing safety, time, and cost concerns.

**Charging technology and infrastructure testing:** Test the EV and electric vehicle supply equipment (EVSE) charging interfaces in the field or laboratory, from mobile use to comprehensive applications.

**Energy ecosystem testing:** Use leading-edge emulation technology and software, spanning solar cell testing to PV inverter efficiency testing, to help meet stringent industry standards for safety and performance.

Do not hesitate to reach out to us to address specific design and test needs for your products and solutions.

[www.keysight.com/find/e-mobility](http://www.keysight.com/find/e-mobility)
Electric Powertrain Testing
Electric Powertrain Testing

HEVs and EVs have multiple architectural variations

For the strong (or parallel) hybrid and the pure EV (no engine), a high-voltage (HV) bus supplied by a large battery drives the electric powertrain (Figure 2).

Power levels of the inverter and motor/generator range from ~ 60 kW to more than 180 kW. Along with the large lithium-ion (Li-ion) battery, development of these architectures requires a significant investment.

Most of the components are bidirectional, allowing power to go from the battery to the inverter, which turns the motor and moves the vehicle (traction drive). When decelerating, the momentum of the vehicle turns the generator, driving power back through the inverter and charging the battery (regenerative braking). Each step of this powertrain requires thorough testing to maximize energy efficiency for the HEV/EV.

Figure 2. Simplified block diagram of a strong/full-hybrid EV
In the mild hybrid (MH), the motor/generator, inverter, and battery are also bidirectional. They are not large enough to drive the vehicle by themselves (as in the HEV or EV). Instead, they supplement the engine power during acceleration and recharge the battery during deceleration.

The voltage level for MHs is typically 48 V, keeping the bus structure under the 60 V safety rating for HEVs. That provides four times the potential power of the 12 V bus with the same current rating (Figure 3).

Each component and step of these powertrain systems requires full testing to maximize energy efficiency in the conversion process.

The design and manufacturing phases must account for cohesive functionality of each component and subsystem, as well as safety considerations.

Figure 3. Block diagram of a mild hybrid EV
Inverter test

Inverters are essential components for numerous applications because they convert electrical voltage bidirectionally. Traction inverters convert DC voltage from a battery to AC voltage for an electric machine. This functionality makes inverters an important component in electromobility, as well as numerous industrial applications. Quality, durability, and safety requirements are demanding in the automotive sector. All components are subject to stringent testing throughout development and production. The earlier tests can be performed during the development phase, the more efficient the next steps are. Comprehensive test scenarios and independent component testing can reduce development expenses and speed innovation (Figure 4).

To emulate the inverter environment, replace the battery with a Scienlab Dynamic DC Emulator from Keysight. Replace the electric machine with a Scienlab Machine Emulator.

Figure 4. Real and emulated inverter environment
Scienlab Machine Emulators

For thorough testing of inverters, it is necessary to extensively emulate the electric machine. The Scienlab Machine Emulator from Keysight provides the facility for stressing the inverter using predefined load cycles in conjunction with the Scienlab Dynamic DC Emulator. Refer to “Supporting E-Mobility Test Technologies” for details about the Dynamic DC Emulator.

A variety of machines (e.g., PMSM, ASM, and induction machines) can be realistically emulated. That is possible in both motor and generator mode (four-quadrant mode). The emulation of the electric machine also encompasses all necessary sensors.

In addition, the open interface architecture enables easy connection of the Machine Emulator to an existing automation unit. The Machine Emulator is available for high-voltage, as well as 48 V applications.
Cell and battery test

E-mobility has escalated the need for better cells and batteries with a common goal — improved performance, range, and cost. These devices must be high quality and meet the demands for power, energy density, safety, and durability. Marketplace survival requires cost optimization. For these reasons, comprehensive tests must be carried out to ensure successful design and production (Figure 5).

Figure 5. EV power is determined by how cells, batteries, and packs work together to provide better power and range.
Cell self-discharge analysis

32-channel BT2152B Self-Discharge Analyzer

The Keysight BT2152B Self-Discharge Analyzer directly measures self-discharge current on large numbers of Li-ion cells. Using a potentiostatic measurement technique, it reduces the time required to discern good versus bad cell self-discharge performance from days or weeks to minutes or hours. For cell manufacturers, this provides dramatic reductions in work-in-process inventory, working capital costs, and facility costs. For cell designers and evaluators, this provides faster cell analysis, which drives shorter design cycles and faster time-to-market (Figure 6). The BT2152B, along with the complementary BT2155A software, enables the following key features:

- Up to 32 channels of self-discharge current measurement available in four-channel increments
- Current measurement accuracy: ± (0.33% + 1 μA)
- Voltage measurement accuracy: ± (0.05% + 1 mV)

High levels of Li-ion cell self-discharge are indicative of latent failures. Keysight’s new potentiostatic solution addresses cell self-discharge measurement challenges, allowing users to realize a revolutionary reduction in time, significant cost savings, and accelerated time-to-market.

Figure 6. Keysight’s potentiostatic measurement technique cuts time needed to discern good versus bad cell self-discharge performance
Cell characterization for R&D

Single-Channel BT2191A Self-Discharge Measurement System

Using a new potentiostatic measurement method, Keysight’s BT2191A Self-Discharge Measurement System for R&D (Figure 7) slashes the time needed for measuring self-discharge of Li-ion cells. For cylindrical 18650 or 21700 cells and other smaller cells, you can quickly measure stable self-discharge current in 30 minutes to two hours. For larger-capacity pouch cells (e.g., 10–60 Ah), it can take one to four hours versus days or weeks using the old method of measuring the change in open-circuit voltage of the cell over time. Key benefits enabled by the BT2191A, with the complementary BT2192A software, include:

- Faster measurement of self-discharge current
- Quick analysis of self-discharge current during cell design and evaluation
- Reduced design cycle time and achieving faster time to market

After mechanical production of a Li-ion cell, it must be formed by controlled charging and discharging. Keysight offers modular cell formation systems that allow flexible configurations for forming small numbers of cells in R&D or large numbers in high-volume manufacturing.

Figure 7. Precise measurements by the BT2191A of low-level self-discharge currents to ±(0.025% + 100 nA) with minimal cell disturbance
Cell charge-discharge platform

Keysight BT2200 Charge-Discharge Platform

The Keysight BT2200 Charge-Discharge Platform is cost-effective and easily reconfigurable for Li-ion cell formation. Modular configurations support cells requiring maximum currents ranging from 6 to 200 A, with 8 to 256 cells or user channels per chassis. Benefits of this platform include:

- Modular configurations from 6 to 200 A, 8 to 256 channels; up to eight modules per chassis, 32 channels per module
- ± 6.25 A per physical channel, and up to 32 channels paralleled to increase range up to ± 200 A per user channel, with 1 s sampling intervals

Easily configurable for new or additional capacity ratings, the BT2200 helps manufacturers respond quickly to requirements for different cell types at a low cost.
Cell sample, cell, module, and pack testing

Scienlab test systems from Keysight comprehensively and reliably test battery cells, modules, and packs, including battery management systems (BMS) for e-mobility, mobile, industrial, and stationary use. Keysight’s test systems with the best-in-class Scienlab Energy Storage Discover (ESD) software help you run customized performance, function, aging, and environmental tests, as well as standards compliance and conformance tests (e.g., ISO, DIN EN, and SAE).

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- **Testing Cell Samples**
  - Voltage range: -2 to 8 V
  - Output current: up to ±5 A
  - Measuring ranges: ±150 μA, ±5 mA, ±150 mA, ±5 A, automatic range switchover
  - Manual parallel connection: 2 channels to increase the current to maximum 10 A
  - Control modes: current, voltage, and power
  - Optional electrochemical impedance spectroscopy

- **Testing Battery Cells**
  - Output voltage: 0 to 6 V
  - Output current: ±100 A, ±200 A, ±300 A, ±600 A (parallel connection for increasing current and power possible)
  - Current dynamics: -90% - 90%: 0.8 ms typ.
  - Voltage measuring accuracy: ±1 mV typ. 150 μV
  - Current measuring accuracy: up to 0.05% of the measured value + 6 mA
  - 3 temperature sensors and 1 CAN connection in each channel

- **Testing Battery Modules**
  - Output voltage: 20 to 300 V
  - Output current: ±100 A, ±300 A, ±600 A, ±750 A
  - Current dynamics: -90% - 90%: 0.8 ms typ.
  - Voltage measuring accuracy: ±16 mV ±0.05% of measured value
  - Current measuring accuracy: ±20/40/60/120 mA ±0.05% of measured value

- **Testing Battery Packs**
  - Output power: up to ±360 kW
  - Voltage range: 50 to 1,000 V (optional 0 to 1,000 V for systems up to 180 kW)
  - Current ranges: ±300 A, ±600 A, ±900 A (±2400 A when switched in parallel)
  - Current dynamics: -90% - 90%: typ. 1.6 ms
  - Voltage measuring accuracy: ±200 mV ±0.05% of measured value
  - Current measuring accuracy: up to ±60/120/180 mA ±0.05% of measured value
Supporting software

SL1091A Energy Storage Discover

The Scienlab software Energy Storage Discover (ESD) from Keysight allows time-synchronous control of all Scienlab battery test systems for cells, modules, and packs, as well as all test environment components. It permits validation of all energy storage types. The software enables you to easily create, edit, control, and monitor customized test scenarios (Figure 8). The standardized remote interface allows straightforward integration of test benches into a higher-level control and monitoring system.

Battery management system and testing

The introduction of storage technologies and the interconnection of multiple energy storage cells to form modules or packs requires an intelligent BMS.

A BMS assumes important safety, control, and regulation functions. Those functions include monitoring parameters such as voltage, current, temperature, and state of charge. A BMS is also responsible for thermal management, energy management, cell balancing, and performance.
SL101xA Series Scienlab BMS Environment

The Scienlab battery management system (BMS) Environment from Keysight provides all the above-mentioned capabilities and more. The system comes with a hardware-in-the-loop test environment for reproducible testing and BMS optimization. Instead of the cells, Scienlab Cell Emulators connect to emulate various cell types for a range of cell models:

- Voltage: 0 to 8 V
- Current (parallel operation): ±5 A (±10 A)
- Power (parallel operation): ±40 W (±80 W)
- Measuring range: up to ±2 µA ± 0.05% of measured value
- Voltage measuring accuracy: <1 mV

The Scienlab BMS Environment also emulates the following:

- Cell temperature through emulation of typical resistance temperature detector (RTD) sensors such as PT-100, PT-500, PT-1000, Ni, and KTY
- Battery current sensors (up to ±1,000 A at a 100 µOhm shunt)
- Individually defined errors such as insulation faults at the battery voltage, line breaks, short-circuits, and reverse polarity
Charging Technology and Infrastructure Test
Charging Technology and Infrastructure Test

One of the crucial factors for the breakthrough of electromobility is making it possible for all drivers to charge their EVs/HEVs conveniently and safely. This puts high demands on the charging interfaces at both sides of the charging cable — on the EVSE and within the vehicle. Alongside the power itself, fault-free communication between EV and EVSE guarantees reliable charging. This requires electromagnetic compatibility-compliant components, norm-compliant procedures, and compatible technologies. Other factors to consider include local mains supplies, regional climatic conditions, and compatibility with different EVs and EVSEs.

SL1040A Scienlab Charging Discovery System

For comprehensive testing of all EV and EVSE charging interfaces, Keysight offers an all-in-one test solution. The SL1040A Scienlab Charging Discovery System (CDS) series is a breakthrough solution for holistic testing of all AC and DC charging interfaces of EVs and EVSEs. Thanks to its modular and innovative design, the CDS can be configured to customers' needs to ensure an optimal price-performance ratio (Figure 9).

Highlights of CDS include:

- Automated functional, conformance, interoperability, and quality testing for R&D, end of life, and EMC applications
- Time-synchronous measurement and decoding of communication and power signals
- Scalable and future-proof hardware design for all charging protocols and power classes
- Designed according to the CharIN CCS test system specification
- CE and UL conformance certified by CSA
- Broad use by technology-leading EV and EVSE manufacturers, test, and certification bodies
- Conformance test case libraries for immediate testing of CCS, CHAdeMO, and GB/T standards
- Replaces multiple real EV/EVSE with one sophisticated test solution, saving acquisition and running costs
Use case 1: EV test

In this use case, the CDS serves as a universal but configurable charging infrastructure (e.g., DC charging column or AC wall box).

Use it for functional testing of the charging interface of any electric vehicle, as well as for safety, interoperability, conformance, and durability testing.

Use case 2: EVSE test

Here, the CDS is a universal but configurable charging interface emulator replacing a real electric vehicle.

This allows for functional, safety, interoperability, conformance, and durability testing of any EVSE product.

Use case 3: Man-in-the-middle test

In this third use case, the CDS sits between two real devices to capture all electrical signals and digital communication between an EVSE and EV.

This allows the user to identify and trace potential interoperability issues.
Supporting E-Mobility Test Technologies
Supporting E-Mobility Test Technologies

SL104XA Series Scienlab Dynamic DC Emulator

The Scienlab Dynamic DC Emulator from Keysight boasts bidirectionality, integrated DC voltage and current controllers, high dynamics, and regenerative energy feedback capacity. It serves as an all-in-one system for the efficient and effective testing of power electronic components in EVs and EVSEs. The Dynamic DC Emulator is available for high-voltage and 48 V applications.

Some application examples include:

- Testing of power electronic components and systems for maximum failure safety, energy efficiency, and quality (e.g., traction inverters)
- Emulation of batteries using an integrated battery model
- Bidirectional mode testing – enabling EVs to be emulated as a sink or charging infrastructure as a source – to investigate the interoperability of both EVs and EVSEs in combination with the Scienlab Charging Discovery System
- Validation of DC charging processes

SL106xA Series Scienlab Measurement and Control Modules

Scienlab measurement and control modules from Keysight deliver precise results for a wide range of test, measurement, and control tasks in automotive and industrial product development. They are ideal for carrying out challenging measurement tasks, even under difficult environmental conditions (e.g., in a climate chamber).

Capabilities include:

- Provision of a safe working environment with contact protection up to 1,000 V
- Connection via an open Ethernet interface
- Automatic detection of Scienlab ESD software
- Application to challenging test environments (e.g., -40°C to 80°C, IP20)
EV1003A power conversion testing for HEV/EV

HEV and full EV batteries are 300 V and higher, versus the conventional 12 V platform used in many vehicles. EV test equipment suitable to handle this new high-voltage, high-power environment is expensive.

Test costs are also escalating. For example, a 10 kW power source consumes 10 times the energy of a 1 kW power source when sourcing full power. This creates a lot of heat, which incurs further cooling costs. You must also comply with high-voltage safety regulations, such as NFPA 79, and provide safety disconnect contingencies. Keysight created the EV1003A Power Converter Test Solution to help you overcome these challenges. The solution comprises three key components:

PA2203 Series IntegraVision Power Analyzer

The IntegraVision Power Analyzer makes EV testing for AC and DC power measurements simple. Easily measure power on any vehicle power converter, such as AC-to-DC power conversion efficiency of the onboard charger:

- Achieve power analyzer accuracies and scope-like waveform visualization with reduced setup time
- Address multiple test scenarios with the flexibility of wide-ranging, isolated inputs
- Visualize transients, in-rush currents, and state changes with a high-speed digitizer that captures voltage, current, and power in real time

RP7900 Series Regenerative Power System

The RP7900 Series Regenerative Power System is the core of the solution. It provides battery emulation capabilities for vehicle electrification tests, such as two-quadrant (source/sink) operation and programmable output resistance. It also regenerates greater than 85% of power back to the grid.

Safety Disconnect System

The SD1000A Safety Disconnect Solution works exclusively with the RP7900 Series. In less than 15 ms, the safety disconnect will remove the output voltage to safeguard your device under test and your people in response to a fault. For testing purposes, the RP7900 can generate faults, or the user can generate them manually. The system complies with key global EMC and safety regulations.
Energy Ecosystem
Energy Ecosystem

PV and smart grid technologies

Supporting the electrification of the modern vehicle is an entire energy ecosystem, from PV inverters that harness and convert solar energy to storage and distribution. Energy efficiency is an integral factor across this ecosystem.

New criteria are emerging to regulate the industry for safety, performance, and business viability. The challenge for engineers is how to verify and test each design, from development to high-volume production, to ensure a smooth and safe transition into this brave new world of e-mobility.

Keysight provides a comprehensive range of solutions to help address your design and test challenges, so you can drive your e-mobility innovations to reality faster. For more information, visit www.keysight.com/find/e-mobility
Agile Design and Test Software

Engineering leaders know that every step in the path to new electronic product development is crucial—from design and simulation to verification and manufacturing. Unfortunately, measurement results from one step don’t seamlessly transition to the next. Test engineers spend hours correlating measurements from their design teams. Software engineers write workarounds because their hardware and software don’t natively talk to each other. Most organizations use standalone products for design, test, measurement, and monitoring. This siloed structure creates disconnected and inefficient workflows and is a major cause of frustration.

Connected, agile design and test is a ground-breaking way to approach the development of electronic systems. It combines new software, new workflows, and powerful automation tools, in a way that transforms legacy processes and yields substantial productivity and equipment utilization improvements. Integrating design and automation software throughout a product development workflow increases efficiency by accelerating routine tasks. Keysight PathWave software is a systems engineering platform that connects design and test, providing common data models and open standards to accelerate product development lifecycles.

Bring Your Design Ideas to Life
PathWave Design is a collection of electronic design automation software tools that connect circuit design, EM analysis, and system simulation. PathWave Design accelerates product development by reducing the time engineers spend in the design and simulation phase.

Automate, Accelerate, and Scale Your Tests
PathWave Test is a collection of test software that connects teams and test stations. Scalable from a single user to a global enterprise, PathWave Test accelerates your test workflow, giving you the power to collaborate and manage test projects from your web browser.

Perform Analytics for Improved Decision-Making
PathWave offers powerful analytics to help you find, visualize, and understand big data to improve business knowledge. It includes visualization tools, real-time asset monitoring, and advanced algorithms that predict and anticipate anomalies to drive process improvements and increase productivity.

To learn more, go to: www.keysight.com/find/pathwave
Your Partner in Automotive Design and Test Solutions
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Calibration and repair services

Having the right measurement solution is only the beginning. Design engineers count on repeatable results across work groups to avoid discrepancies that can impact development cycle time, time to market, and budgets.

Manufacturing strives to meet production goals, but inaccurate measurements can affect yield and product quality. Keysight calibration and repair services keep instruments operating to warranted specifications over their lifetime, ensuring accurate, repeatable measurements across R&D and manufacturing.

Our partnership with you

Keysight offers a broad portfolio of services and support to address all your test equipment needs:

- Startup assistance and training help you quickly and effectively use your new equipment
- Calibration and warranty assurance plans provide coverage for five, seven, or 10 years
- Flexible service delivery includes on-site mobile labs that reduce your calibration turnaround time from days to hours
- Premium used equipment includes the same high performance and three-year standard warranty as new units
- Trade-in programs (available on both Keysight and non-Keysight models) offer you significant credits to upgrade to the latest Keysight technology