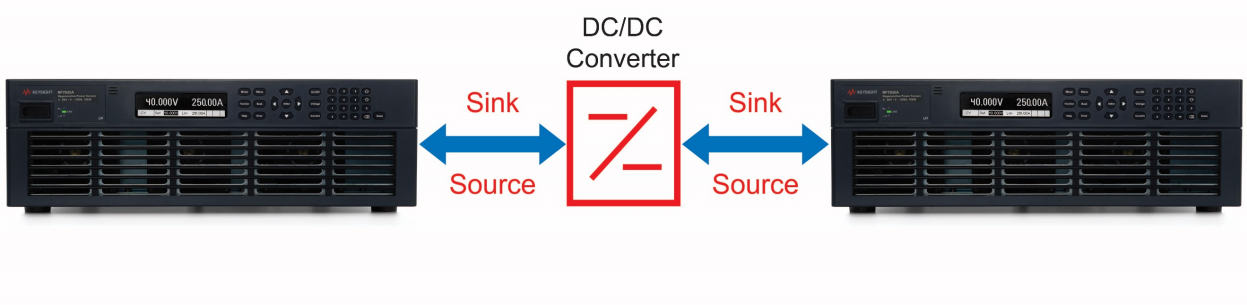
DATA SHEET

Automotive Power Converter Testing with the Keysight EV2000 Platform

Resources for productive design validation test system integration



- For 3 kW – 30 kW converters
- Fast test system integration and deployment
- Portfolio of resources: system components, subsystems, custom fully integrated systems
- Based on Keysight RP7900 Regenerative DC Power System
- Seamless DC source/sink with power units rated at up to 950V/800A/10 kW
- Higher-power operation via paralleled power units.
- Productive and accurate simulation of operating conditions

New Challenges in Automotive Power Converter Design Validation

We are witnessing a global transition to widespread adoption of electric vehicles (EVs). Growth rates of EV production are running at more than 20% per year. As more EVs are produced, there is rapid growth in the number of new EV models being introduced and new EV designs getting underway.

EVs, whether they are EVs powered only by a battery (BEVs), or hybrids powered by a combination of battery and internal combustion engine (HEVs), have complex electrical powertrains. There are variations in the design of these powertrains, but they can be simplified to two models for BEVs and HEVs.

KEYSIGHT TECHNOLOGIES

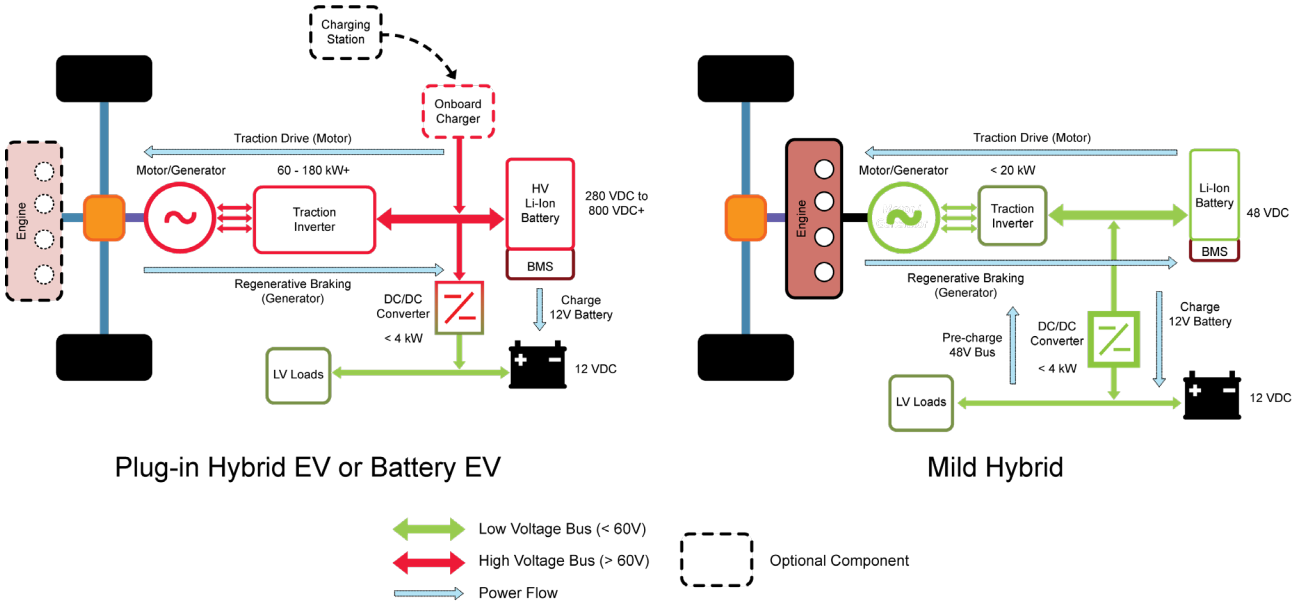


Figure 1 - EV powertrains

As you can see in this illustration, these EV powertrains contain multiple power converters. These include DC-DC, DC-AC, and AC-DC converters, with many of them operating at power levels ranging from 3 kW to 30 kW, and traction inverters operating up to 300 kW. All these converters are key elements of the electrical powertrains that are critical to both performance- and cost-differentiation for EV designers.

The explosion of new EV designs generates a similar explosion of new power converter designs. This leads to rapidly growing demand for design verification (DV) testing of these converters by both those producing the converters and by those consuming them across the automotive food chain.

This DV testing requires large numbers of test specimens and test repetition to accumulate enough data to have confidence in the performance of these new converters. The combination of these things is creating demand for large amounts of DV test capacity for these converters. This demand will escalate as EVs capture more and more market share.

The large amount of DV test capacity needed creates pressure to optimize the utilization of those DV test assets – both financial pressure, and pressure to support the volume of test demand. This sort of DV testing is in the critical path of successfully competing by quickly getting new EV designs to a rapidly growing market.

Because these power converters operate at high power and many of them operate at high voltages, safety during testing is a critical consideration for the DV test systems being used.

Designers and consumers of these power converters are experiencing the need for this increased DV test capacity. In the time-to-market race, they realize they have limited time and/or capability to develop this DV test capacity themselves. They need to quickly make decisions about how much of this DV test capacity and capability they will create themselves and how much they will acquire from a reliable source, all in the pursuit of getting the needed test systems online quickly.

Multiple Ways to Quickly Develop and Deploy Converter Test Systems with the Keysight EV2000 Platform

Every project to create design validation test systems for new converters faces a unique set of requirements regarding schedule, capital costs, engineering resources, and test coverage. Each new converter design triggers decisions about how much of the test system to make in-house vs. source from outside. Keysight provides multiple levels of solutions for power converter testing so you can optimize these trade-offs for each new project.

Off-the-Shelf Test System Components - New Resources to Improve Test System Integration

For those who want to want to design and integrate their own converter test systems, Keysight provides standard components that integrate quickly into your test system design. Start with the RP7900 Regenerative Power System as the foundation for power sourcing, loading, and measurements for the converter.

Power Sourcing & Loading

Figure 2 - RP7900 Regenerative Power System

The common core capability needed for many different converter test requirements is bidirectional DC power sourcing/sinking in the 3kW – 30 kW range. This allows you to use a common, off-the-shelf test system resource to apply both sourcing power and electrical loads to bidirectional and unidirectional converters. To meet your system integration schedule, this type of DC power source/sink must:

- Match your converter's operational requirements
- Be fast enough to simulate the charge-discharge of a Li-Ion battery in the EV drivetrain environment.
- Meet test accuracy requirements
- Be easy to integrate and use
- Provide safety features to protect your test operators, your test system, and the converter being tested.

The Keysight RP7900 Regenerative DC Power System provides you with this common core capability in a compact, easy-to-integrate package. The RP7900 performs multiple functions in your converter test system:

- Takes the place of the EV battery (high-voltage BEV battery or 48V HEV battery). Sources DC power (battery discharge) or sinks DC power (battery charge). Easily programmed to emulate your EV battery conditions.
- Provides DC power sinking for the electronic load function on your converters.
- Seamless DC sourcing/sinking for uninterrupted transitions in bidirectional converter operating conditions.

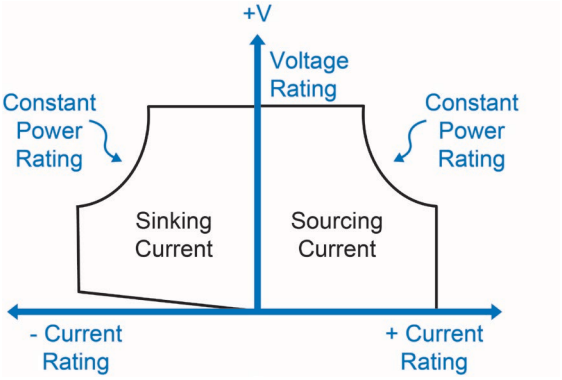


Figure 3 - RP7900 Bidirectional operating profile

- The family of RP7900 models supports up to 950V/800A. Both 5 kW and 10 kW units are available. You can match RP7900 models with different voltage/current/power limits for simulating high-voltage (e.g., 600V), 48V, or 12V bus components.
- Optimized for parallel operation of RP7900 units for higher power with automatic sharing of current between RP7900s.
- Matches operational source/sink conditions with built-in arbitrary waveforms to simulate starting and variable load profiles.
- Regenerates sunk power back onto the AC grid to eliminate waste power and heat in your test facility.
- Fast, integrated safety protection features.

Table 1 - RP7900 DC Ratings (200-208VAC / 400-480VAC)

Model	DC Voltage	DC Current	Power
RP7931A/41A	20 V	± 400 A	5 kW
RP7932A/42A	80 V	± 125 A	5 kW
RP7951A/61A	500 V	± 20 A	5 kW
RP7933A/43A	20 V	± 800 A	10 kW
RP7935A/45A	80 V	± 250 A	10 kW
RP7936A/46A	160 V	± 125 A	10 kW
RP7952A/62A	500 V	± 40 A	10 kW
RP7953A/63A	950 V	± 20 A	10 kW

For a complete description of the RPS7900 Regenerative Power System, please visit www.keysight.com/find/rp7900.

2-Quadrant Power Supply Performance in Power Converter Testing

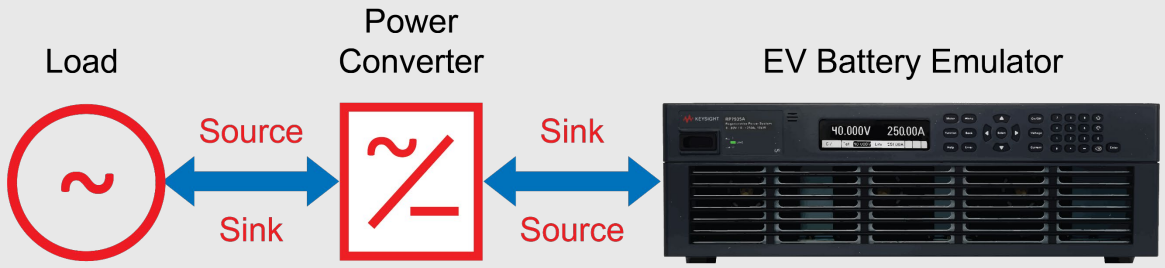


Figure 4 - 2 Quadrant Power Converter Testing

When testing power converters, you need a power source/sink unit to emulate your EV's battery. And it needs to do this while accurately and faithfully emulating the performance characteristics of the EV battery.

The power unit must both source and sink power to cover battery discharge and charge. And the 2-quadrant power unit must quickly react to changes in operating conditions in the power train. If the load on the power converter changes, the 2-quadrant power unit must accurately emulate the behavior of an actual battery in such a situation. For example, if the load on the output of the converter suddenly changes, creating a back EMF, the 2-quadrant power unit needs to regulate its output to constant voltage just as an actual battery does.

In the following screen capture from a Keysight PA2003 Power Analyzer, a change in the converter load current causes the output of a conventional power supply (connected to the input of the converter) to climb from 350 VDC until it reaches an over-voltage protection limit of about 420 VDC.

In contrast, the following screen capture shows the converter load current changing from positive to negative (changing from battery discharge to charge), going from approximately 4A pk-pk on a 8A DC offset to approximately -10A or less. During this transition, the RP7900 Series 2-Quadrant Power Unit holds steady at approximately 350 VDC.

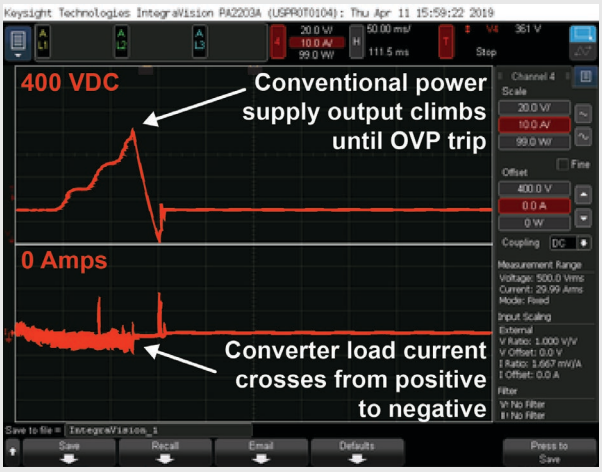


Figure 5 - Conventional power supply struggles to regulate its output voltage and eventually reaches its OVP trip point when the power converter to which it is connected has its load current change from positive to negative.

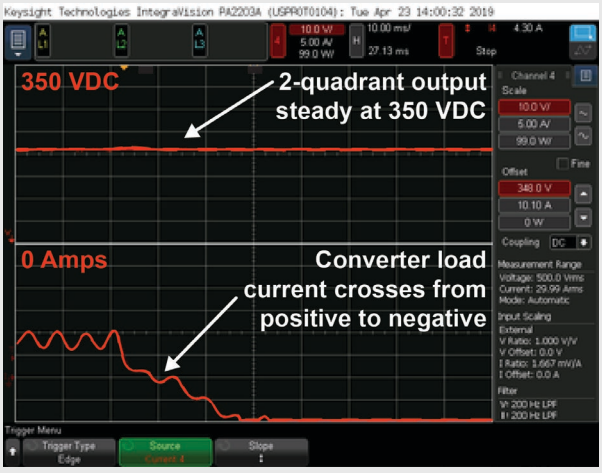


Figure 6 - RP7900 2-quadrant Power Unit holds its output voltage steady while transitioning from current source to current sink as the power converter to which it is connected has its load current change from positive to negative.

Data Acquisition of Environmental Parameters

Adding other instruments like the DAQ970 Data Acquisition System makes it easy to monitor temperature and other environmental conditions during your converter test.

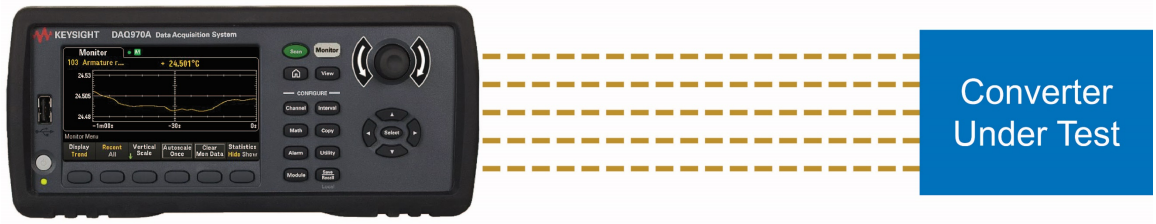


Figure 7 - DAQ970 Data Acquisition System

The DAQ970 measures thermocouples, RTDs and thermistors, AC/DC volts and current; resistance, frequency/period, diode test and capacitance. During design validation, it's critical to monitor converter heating and how it affects performance. With the DAQ970's relay actuators and digital I/O, you can easily control equipment like chillers and coolant pumps.

EV1003A Power Test Subsystem

Since testing automotive power converters typically involves hazardous voltages and high levels of electrical power, protecting the test operators, the test equipment, and the converter-under-test are important considerations in designing a test system.

Figure 8 - EV1003A Power Converter Test with Safety Disconnect

The Keysight EV1003A Power Converter Test Solution incorporates redundant safety disconnect capability with the RP7900 power units. The safety disconnect system will remove the high voltage output in less than 15 ms in response to a fault.

Additional DC and AC power tests can be visualized with the PA2003A 3-phase Power Analyzer. Measure converter input and output power and converter efficiency.

For more information on the EV1003A, please visit www.keysight.com/find/EV1003A

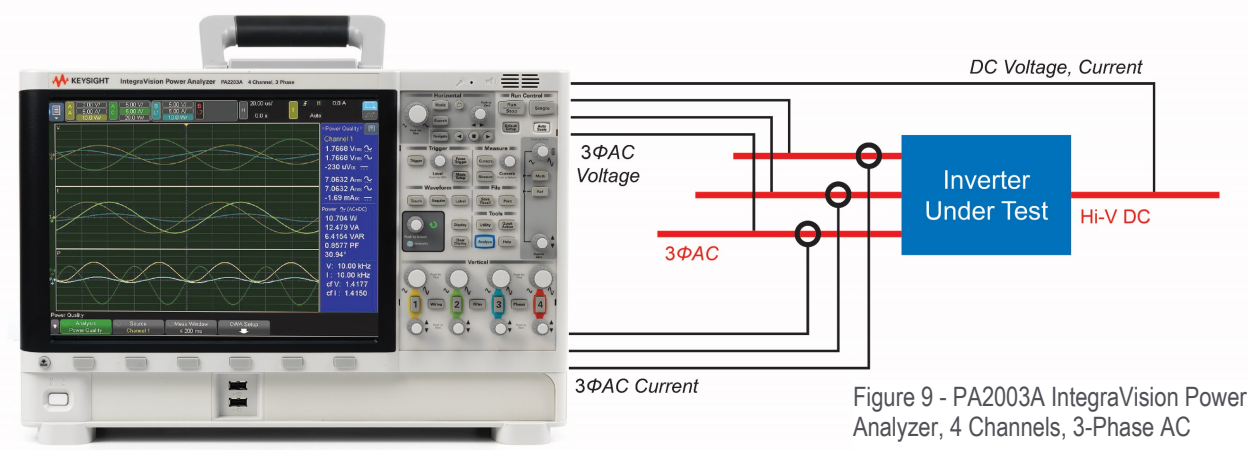


Figure 9 - PA2003A IntegraVision Power Analyzer, 4 Channels, 3-Phase AC

EV2000 Custom Test Systems

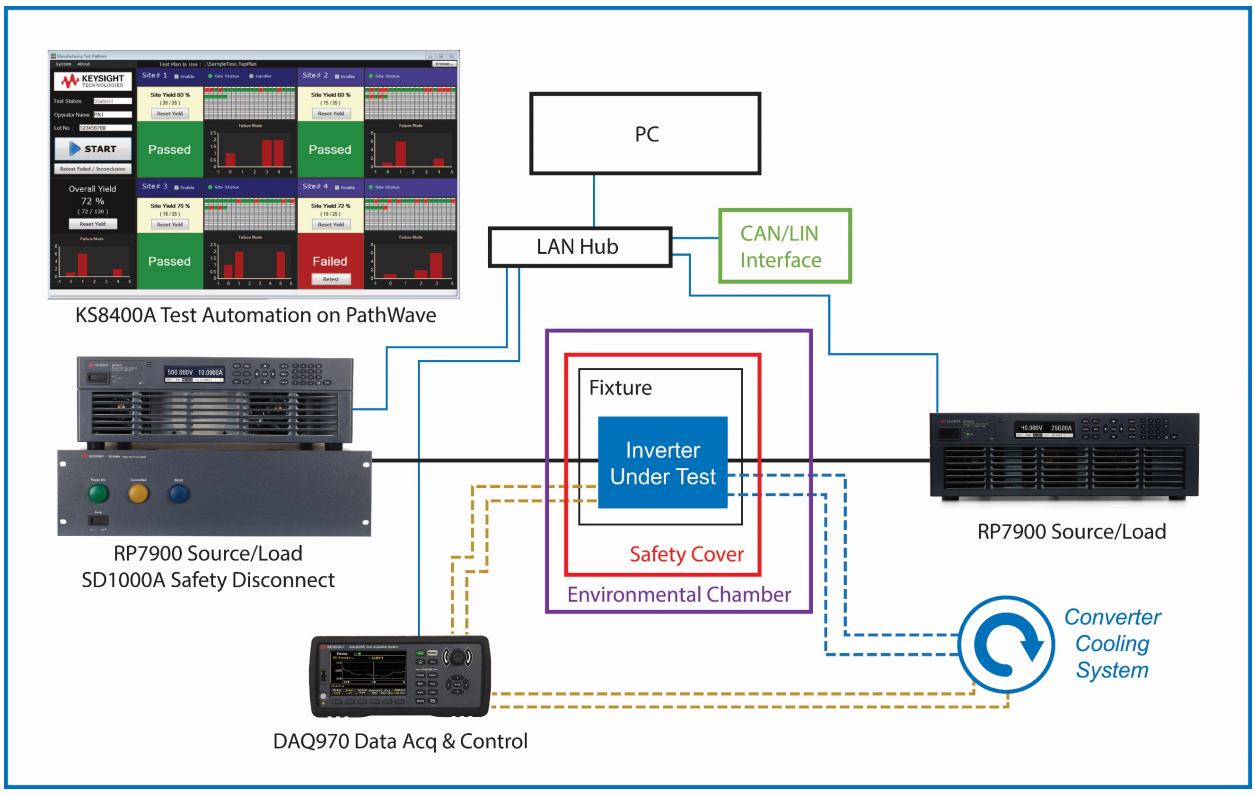


Figure 10 - Example Custom Converter Test System Controlled with Test Automation Platform

For converter design projects requiring the acquisition of a more complete test system, Keysight can work with you to specify and develop a variety of custom solutions. These custom systems can address constraints on internal engineering resources, schedule, and worldwide support of deployed test systems.

Keysight can provide systems that start with the foundation of power sourcing, loading, and measurements and incorporate additional capabilities including:

- Temperature and other environmental measurements
- Redundant safety disconnect systems
- Power converter control via CAN or LIN bus
- Customized test software based on Keysight's Test Automation on Pathwave, including test plan creation and sequencing and test results storage, analysis, and display.
- Control and temperature regulation of power converter chillers and cooling systems
- Environmental chambers
- Fixturing and safety covers and interlock mechanisms
- Racking and enclosures
- Networking and interfacing to all test resources

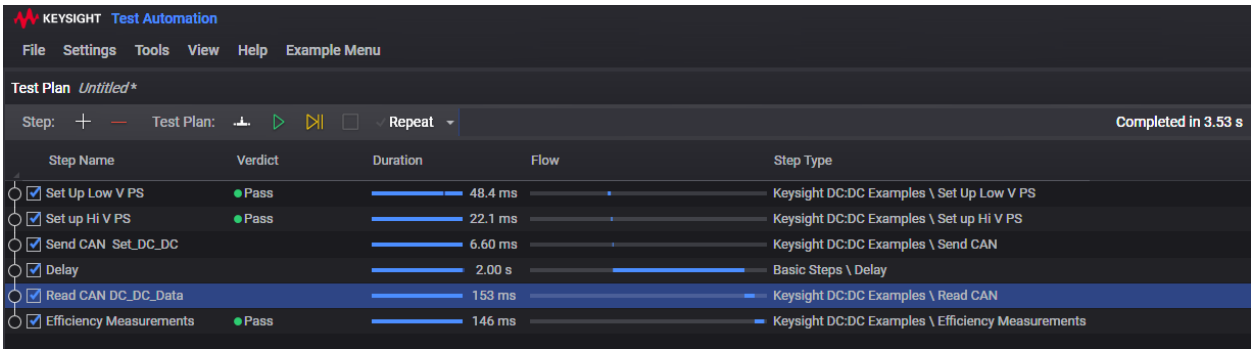


Figure 11 - Example test plan using Keysight's Test Automation on Pathwave platform. Test steps control power supplies, data acquisition, and CAN bus analyzer.

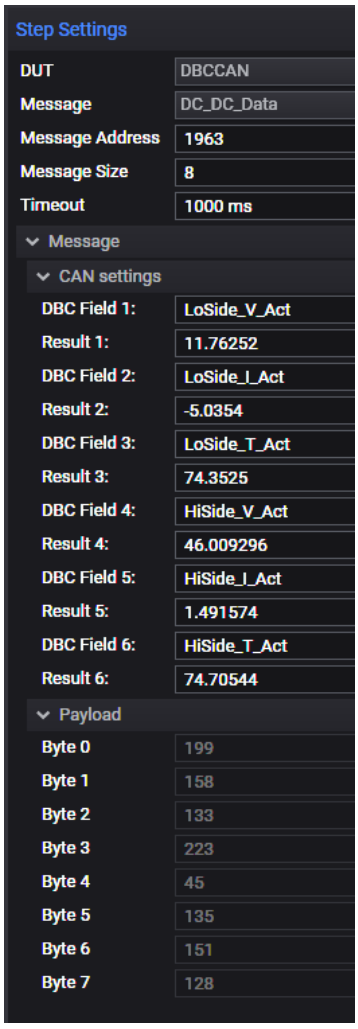


Figure 12 - Example test step details using Keysight's Test Automation on Pathwave platform, showing CAN bus analyzer reading results.

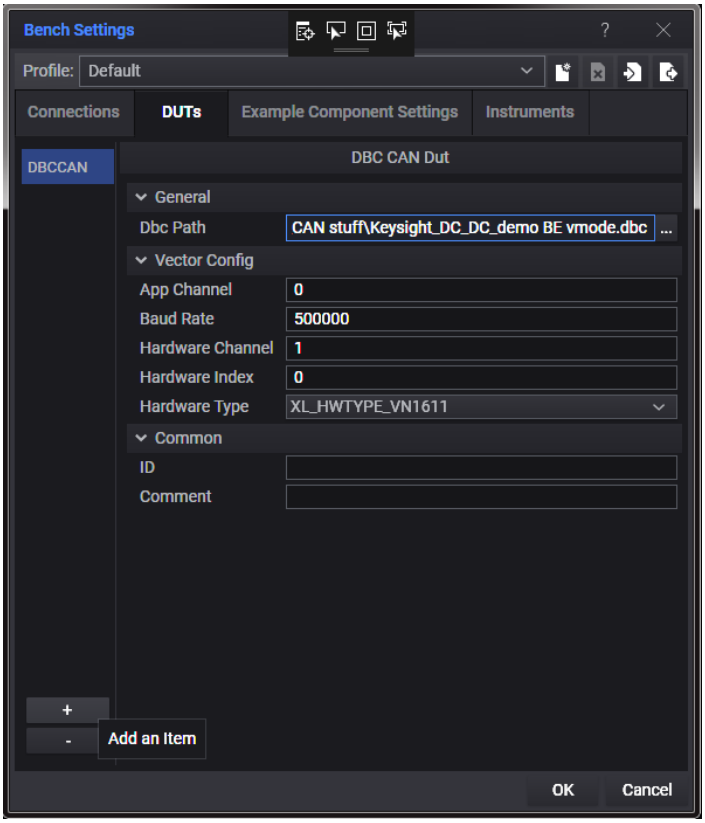


Figure 13 - Example settings window in Keysight's Test Automation on Pathwave platform, showing CAN bus configuration and DBC file information.

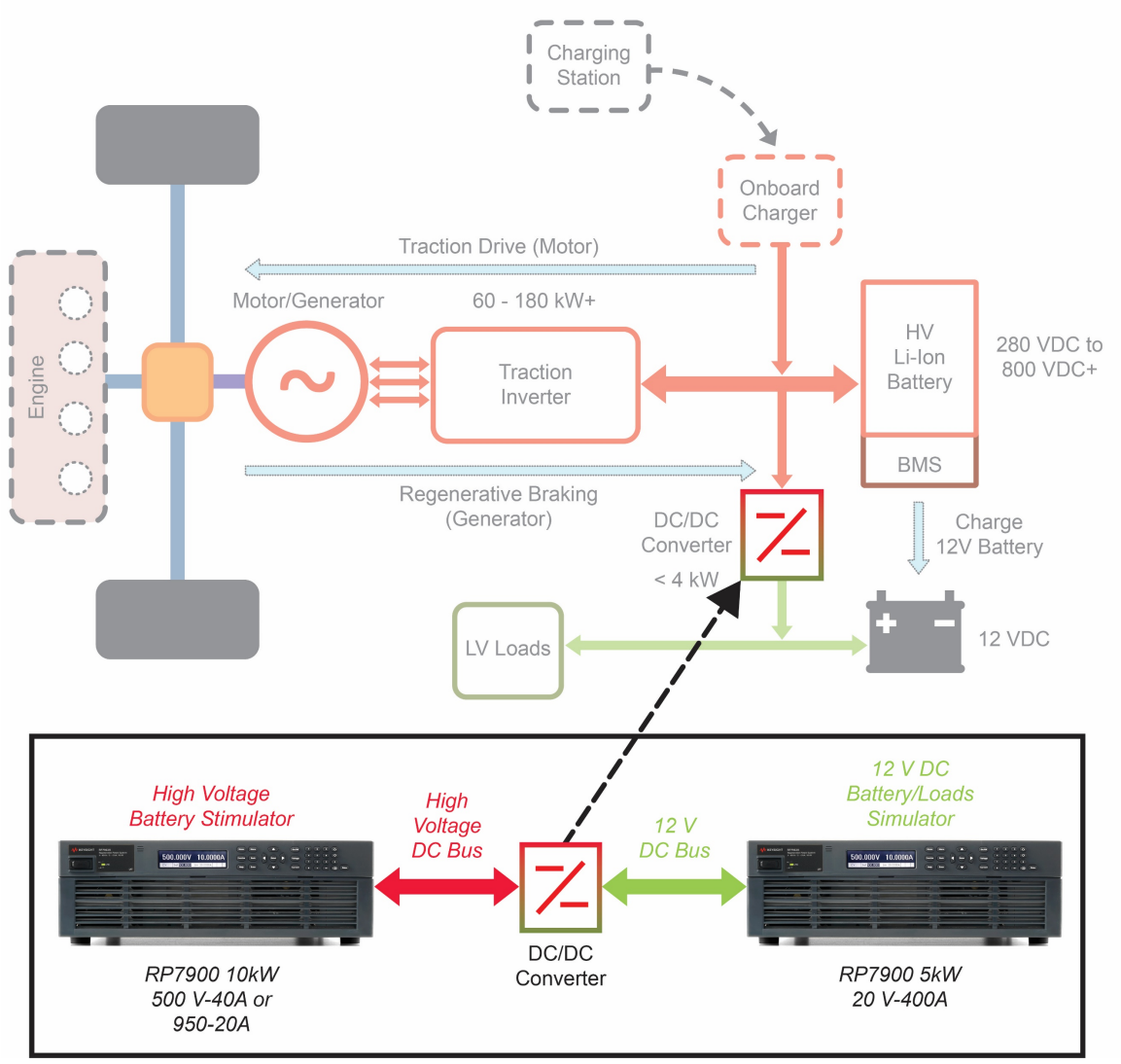
A custom converter test system allows you to buy the portions of a test system what you want, and make the portions that you need. You can optimize the mix of obtaining off-the-shelf standard hardware and software components and custom engineering, while using your own engineering in the focused areas where they can provide the greatest impact on project schedule and test coverage. Custom test systems can be designed for various combinations of Keysight-provided equipment and equipment that you provide.

Please contact your local Keysight representative to begin exploring how a custom test system can get your next converter design project to market more quickly and productively.

Power Converter Design Validation Test Applications Using RP7900 Power Systems

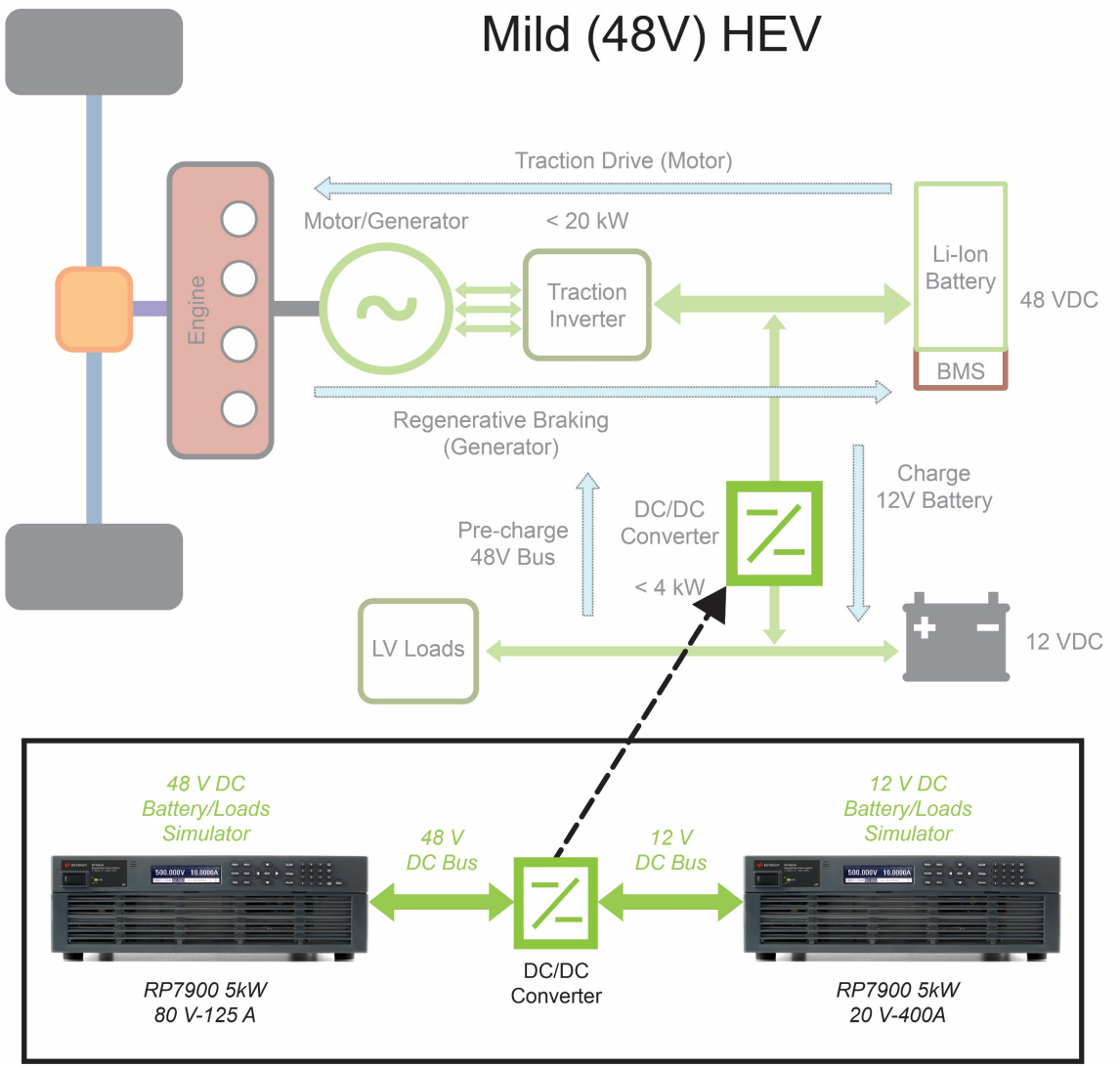
Bidirectional DC-DC Converter, High-Voltage DC to 12V DC bus (BEV or HEV)

- Use a 500V or a 950V Power System to perform the source/sink function of the EV battery.
- Use a 20 V Power System to simulate the source/sink of the 12 V bus.



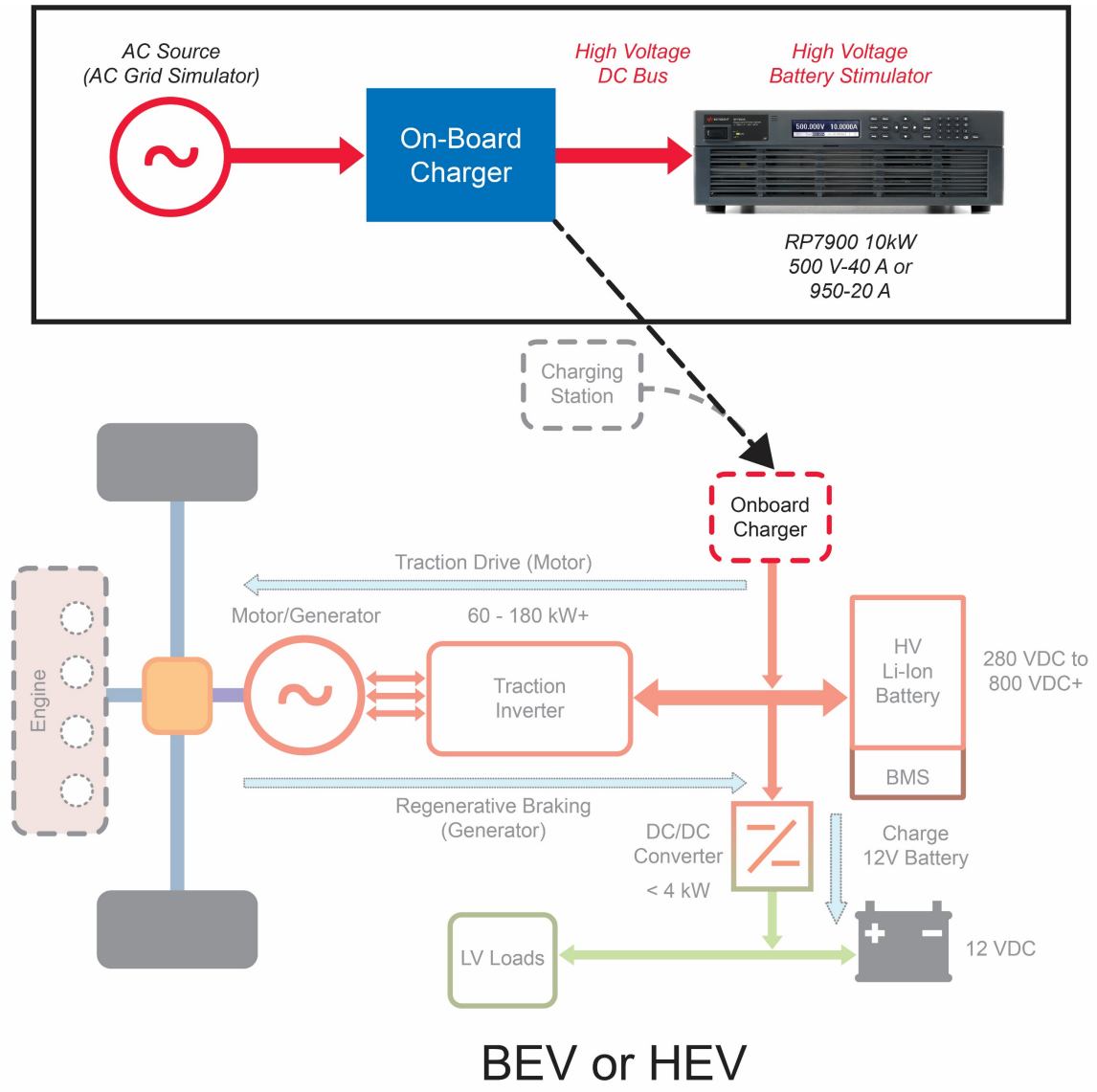
Bidirectional DC-DC Converter, 48V DC bus to 12V DC bus (Mild Hybrid)

- Use a 80V Power System to perform the source/sink function of the 48 V battery.
- Use a 20 V Power System to simulate the source/sink of the 12 V bus.



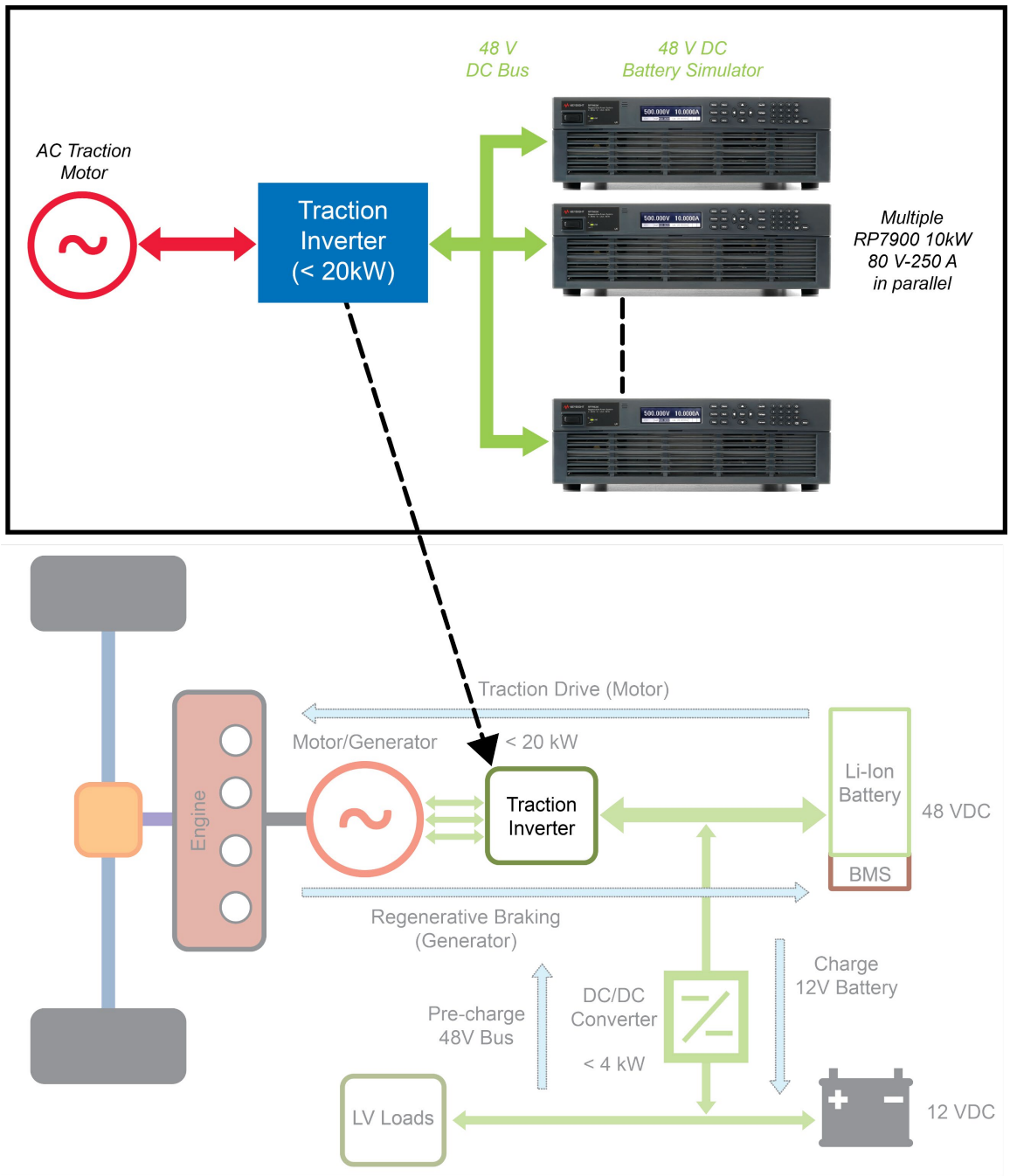
Unidirectional AC-DC Converter, AC Grid to High Voltage Bus through On-Board Charger (BEV or HEV)

- Use a 500V or a 950V Power System to perform the source/sink function of the EV battery.



Bidirectional Low Power Traction Inverter, Mild Hybrid 48V bus

- Use multiple 80V Power Systems in parallel to perform the source/sink function of the Mild Hybrid 48 V battery.



Mild (48V) HEV

Example Tests for Automotive Power Converters Using RP7900 Power Systems

- Simulate the battery with a high-voltage (500 V or 950 V) RP7900 or 80 V RP7900 for either high-voltage or 48 V systems.
- Load the converter output with a 20 V RP7900 acting as a programmable electronic load with built-in voltage and current measurements.

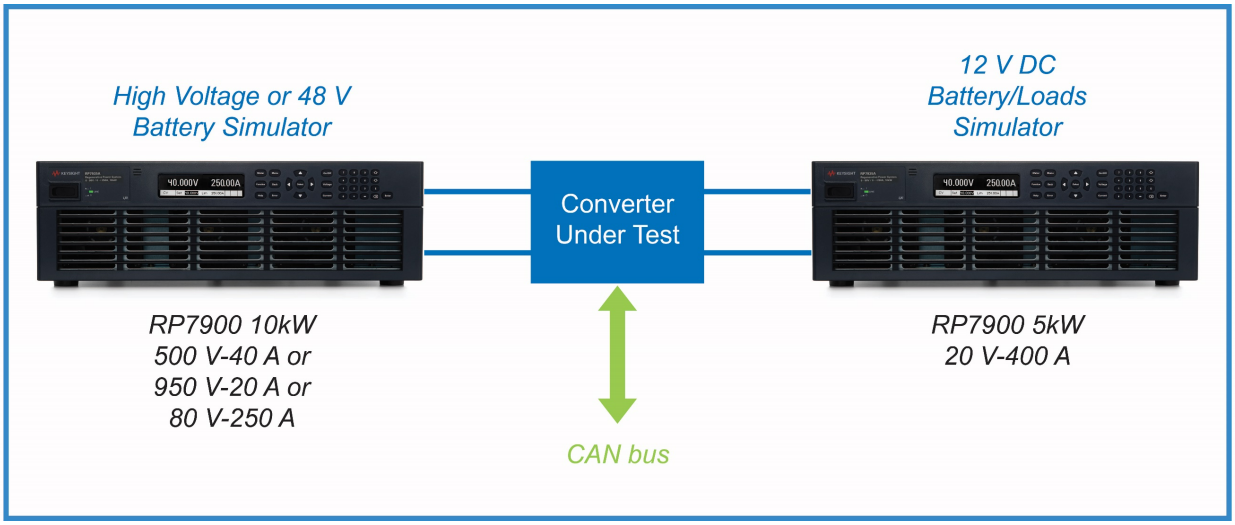


Figure 14 – Basic Automotive Converter Test Configuration

Converter Input Regulation

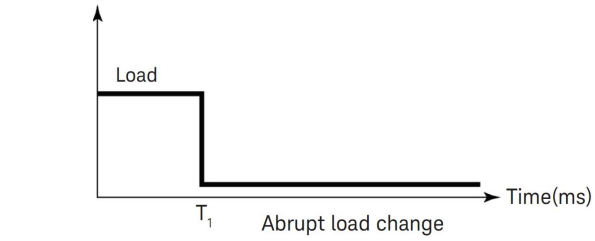
Measure converter output voltage and current as the input voltage is varied. Test output static limits and recovery time after change of input.

Converter Load Regulation

Measure the converter's output voltage as the converter's output load current is changed. Measure converter output voltage recovery time with step change on output load current.

Converter Output Voltage Accuracy, Power Efficiency

Measure converter output voltage and current vs. input voltage and current for a variety of load and environmental conditions across the operating range of the converter. Measure output voltage vs. specified accuracy limits for various load and environmental conditions.



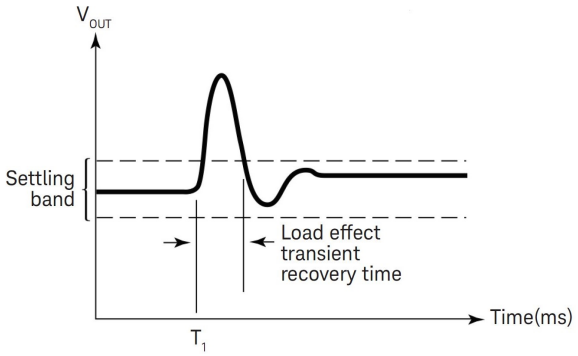


Figure 15 - Coverter Load Regulation

Converter Transient Response

Measure converter output voltage and/or current with the RP7900 digitizer to verify turn-on times, turn-off times, and output rise/fall times for a variety of load and environmental conditions across the operating range of the converter.

Converter Protection Limit Verification

Program the converter to specific output current limits, then program the RP7900 acting as the converter load to sink currents beyond the over-current protection limits.

Program the converter to specific output voltage limits, then program the RP7900 acting as the source to the converter to input values to produce converter output voltages beyond the over-voltage limits.

Additional Keysight Solutions for the e-Mobility Revolution

Increased battery performance, innovative electric drivetrains, availability of efficient charging stations, and better power conversion across the e-Mobility ecosystem are improving the performance, cost, and range of hybrid and electric vehicles.

Keysight helps you design, test, and manufacture innovative electronics for renewable energy integration, advancement in battery technology, the rapid development of new electric and hybrid electric vehicles, and charging systems compatibility.

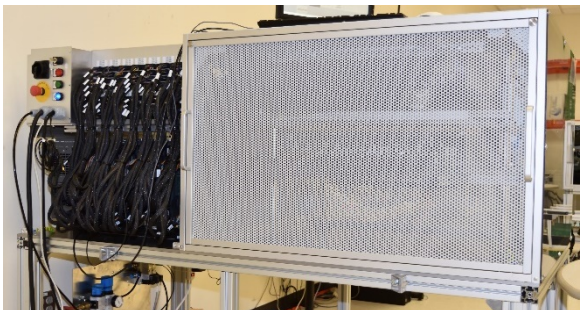
Keysight offers solutions in the following areas in the e-Mobility Ecosystem:

Charging Systems Test	**Cell & Battery Solutions**
• DC-DC Converters	• Cell & Battery Characterization and Test
• DC-AC Converters	• Cell formation and Finishing Systems
• EVSE Equipment	• Cell Self-Discharge Measurement
• Vehicle Charging System	• Battery Management System Test

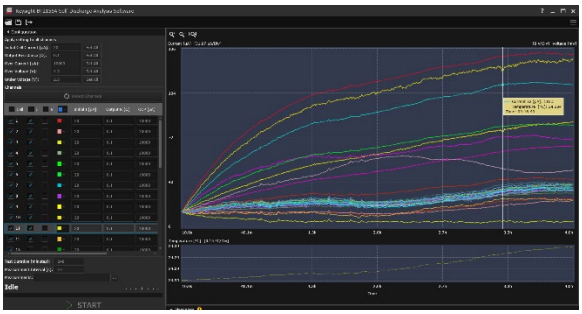
Charging Systems

Battery Test

Cell Formation and Finishing



Cell Self-Discharge Measurement



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