Challenges and Solutions for High Power Device Testing

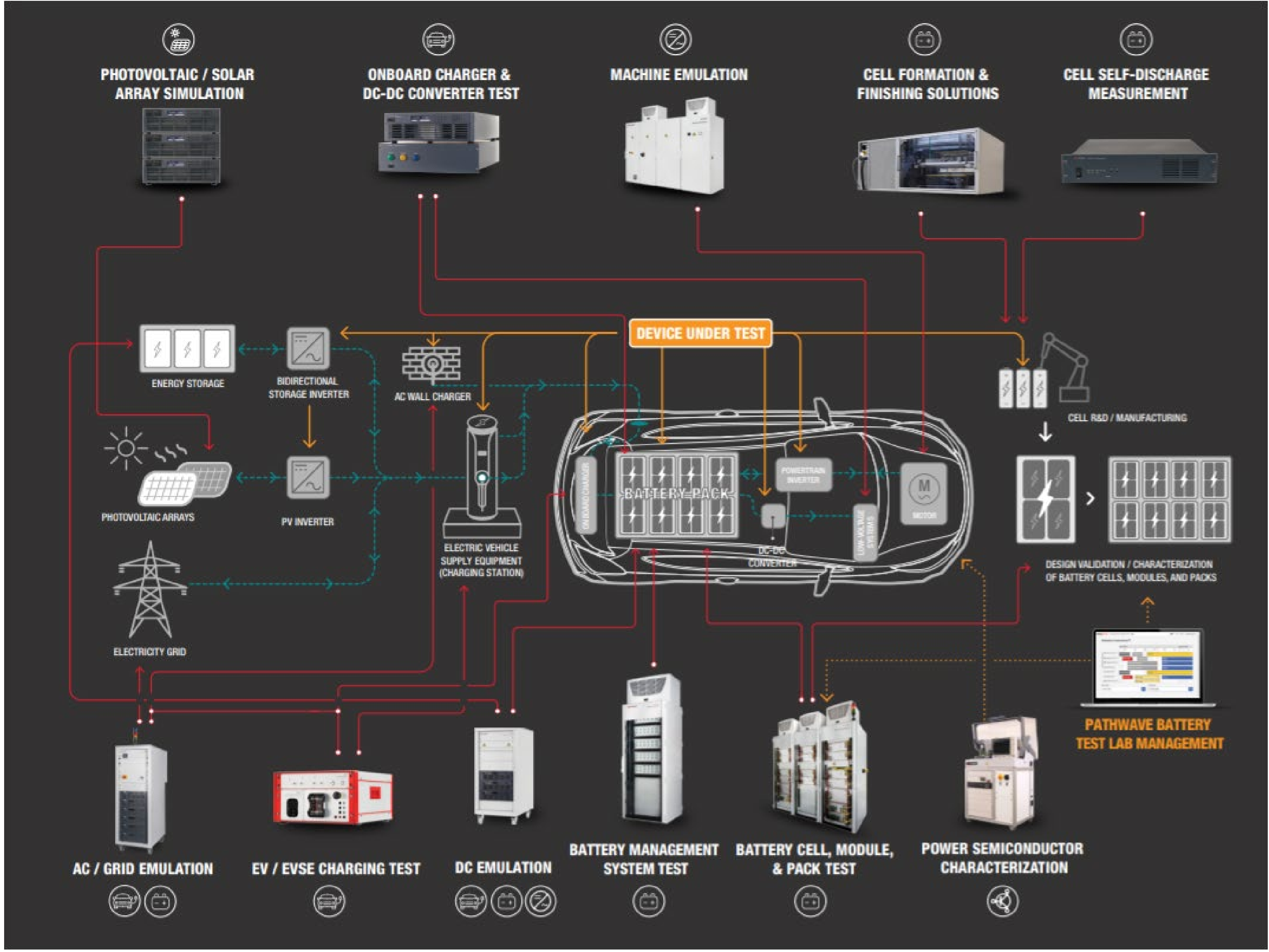
Dr Ervin Mile (PhD),

Power Specialist, Keysight Technologies
June 27th, 2023

Advancing the E-Mobility Ecosystem

Ensuring Safe & Efficient EV Power Systems

Achieving Zero Emissions With Renewable Energy



Power Electronics & Energy Storage event
POWER ELECTRONICS
ENERGY STORAGE
27 juni 2023 | 1931 Congrescentrum 's-Hertogenbosch

acal bfi

Agenda

Onboard Charger Testing

OBC Charger Testing
AC test challenges
AC Motors

Battery Testing

Power Consumption Analysis
Battery Modeling/Emulation
Battery Charging/Discharging/Cycling

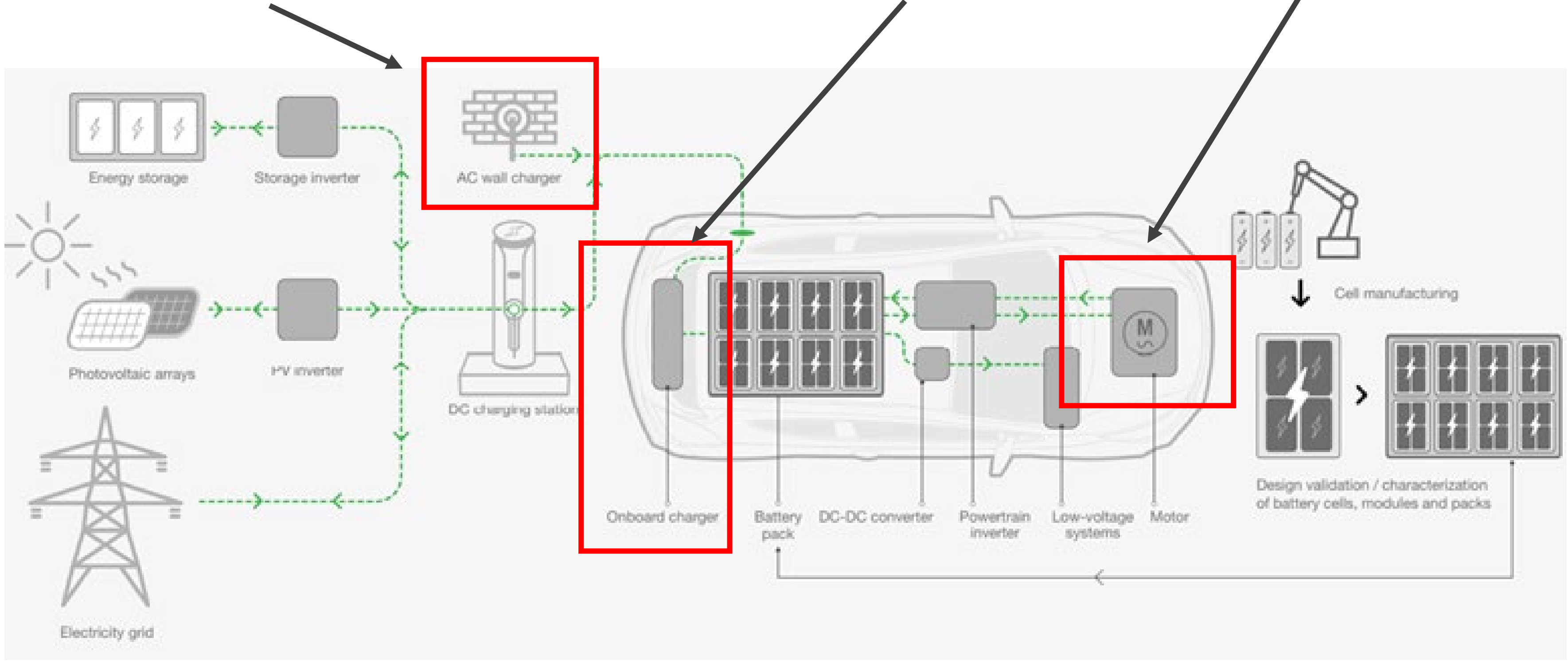
DC-DC Converter Test

Common Tests for DC-DC Converters
Tests for Automotive Power Converters

AC Charger, Onboard Charger and AC Motor

- The main components that run on AC power are:

- **AC Charging Station** or EVSE AC-AC, **Onboard Charger** and **AC Motor**



EV Charging System

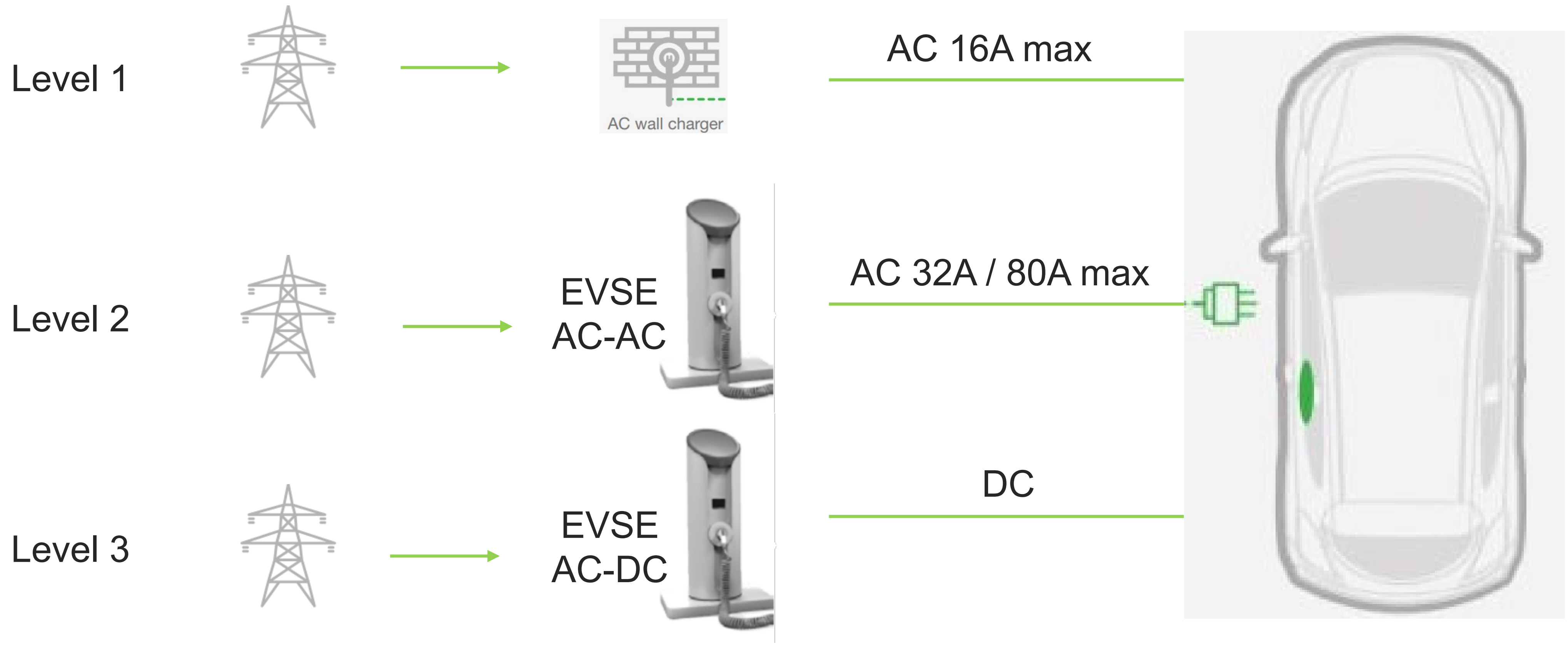
IEC and SAE standards

EV conductive charging are classified in levels or modes depending on the standards

SAE	IEC 61851-1	Description
Level 1	Mode 1	AC slow charge: Standard AC output, 16A Each EV typically comes with a 12A EVSE charger. The slowest and least expensive, mainly for overnight domestic charging.
Level 2	Mode 2	AC moderate charge (7.4kW to 22kW): Domestic or home charging station up to 32A
	Mode 3	AC fast charge (7.4kW to 44kW): Commercial or public charging station up to 80A.
Level 3	Mode 4	DC fast charge (50kW – 300kW): Capable of charging a 24 kWh battery to 80% in roughly 30 minutes.

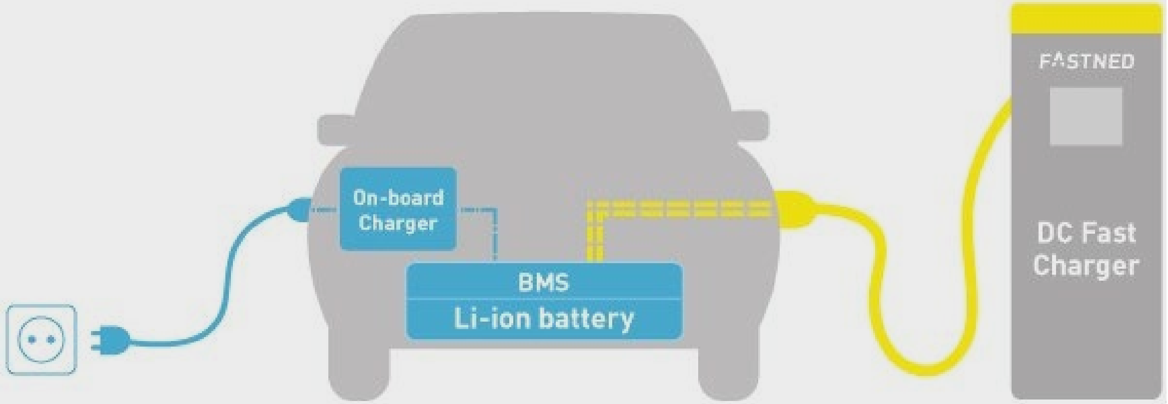
EV Charging System

SAE standard



Onboard Charger

- Onboard charger is the built-in AC-to-DC converters in an EV that convert AC power from the grid to DC for charging the EV battery.
- To reduce charging time, OBC power has increased and evolved from 1-phase to 3-phase, as according to the IEC61851 standard.
- OBC usually has an output in the range of between 3.7 kW and 22 kW.



AC Charging
3.7kW – 22kW

DC Fast Charging
~270kW

EV Charging Time

- EV charging time is determined by:

$$\text{Charging time (h)} = \frac{\text{Battery capacity (kWh)}}{\text{Charging Power (kW)}}$$

- Estimated charging time using different charging station for an EV with **24kWh battery**, and **6.6kW OBC**
  - Home charging station of 3.7kW = **6h30m** (24kWh/3.7kW)
  - AC charging station of 11kW = **3h40m** (24kWh/6.6kW)
  - DC fast charging station of 50kW = **30m** (24kWh/50kWh)

AC Motors In Electric Vehicles

- AC motor in EV:
  - Typically **3-phase**,
  - Running at **240V**,
  - Covering **20kW – 30kW** range.

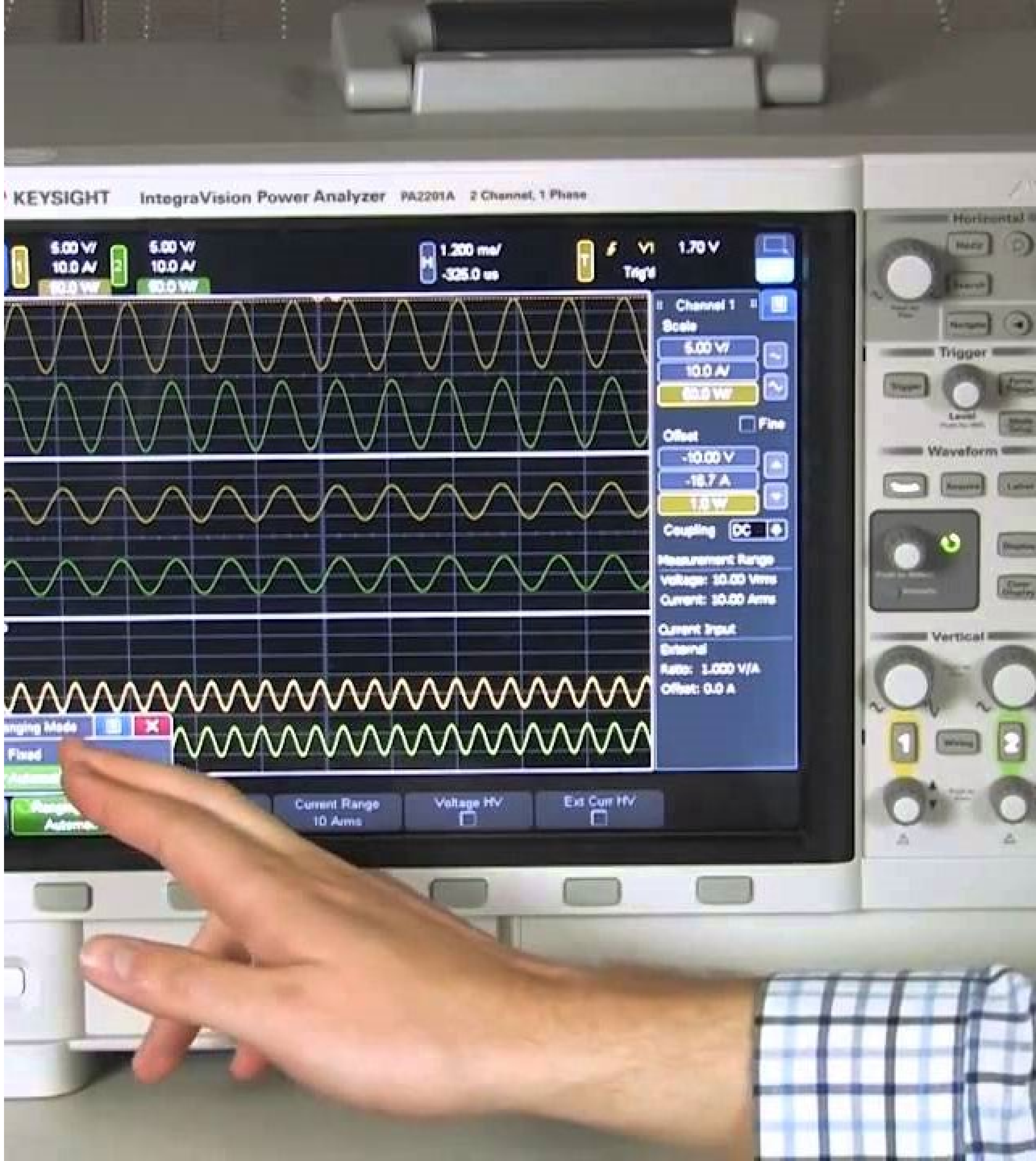
- 3-phase AC motor is commonly used in EV because of:
  - Higher **efficiency**
  - Less **maintenance**
  - Wider **range** and is readily available
  - **Regenerative** capability: can work in reverse and return the braking energy to the battery

Siemens 3-phase AC motors

AC Test Challenges

As EV charging are connected to the grid, power can be noisy, unstable and unpredictable.

- Typical power quality disturbances are:
  - Voltage deviations
  - Frequency deviations
  - Phase imbalance
  - DC superimposed with AC signal



AC Sources in an Automotive Ecosystem

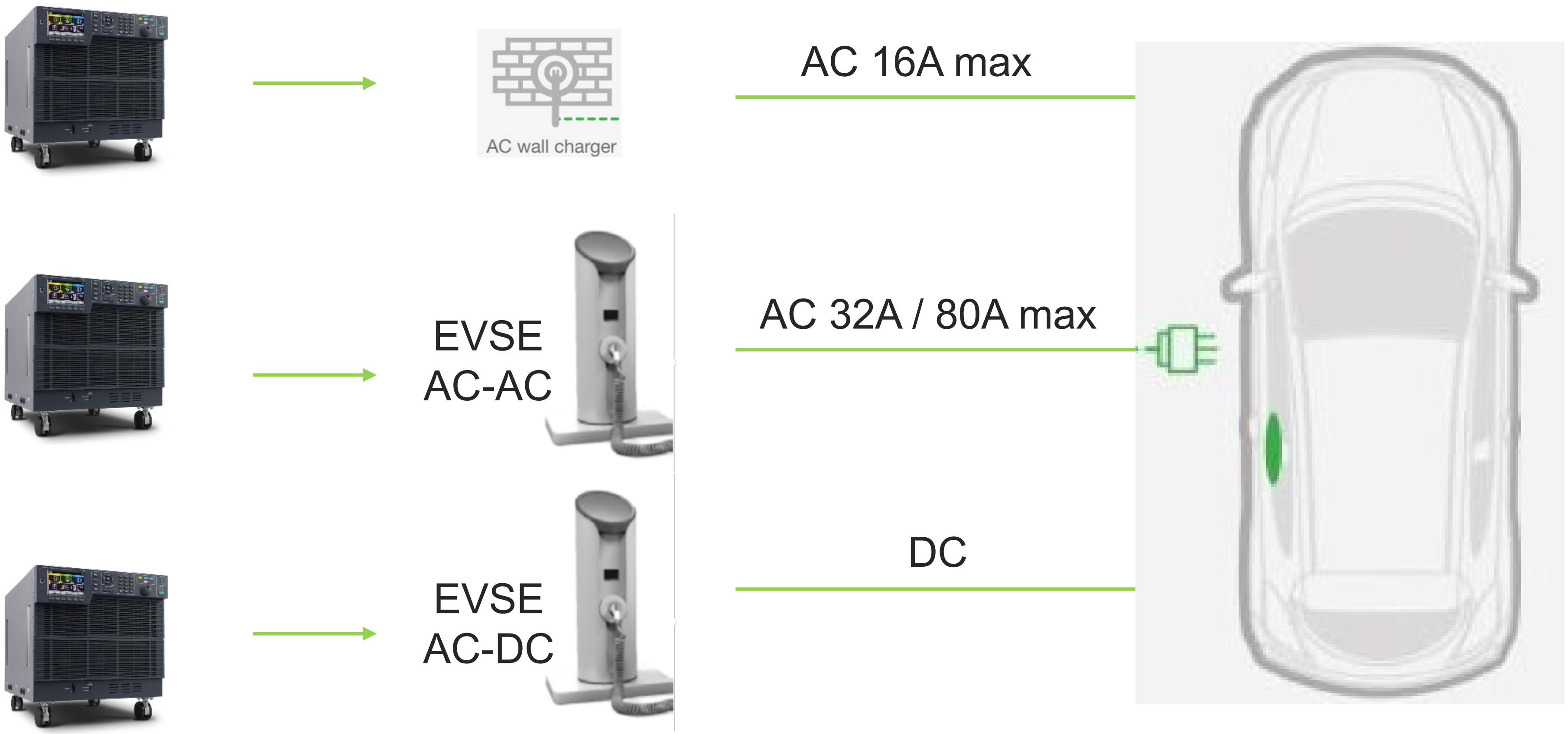
Use an AC source to:

- Simulate voltage and frequency disturbances
- Simulate phase imbalance
- DC superimposed with AC signal

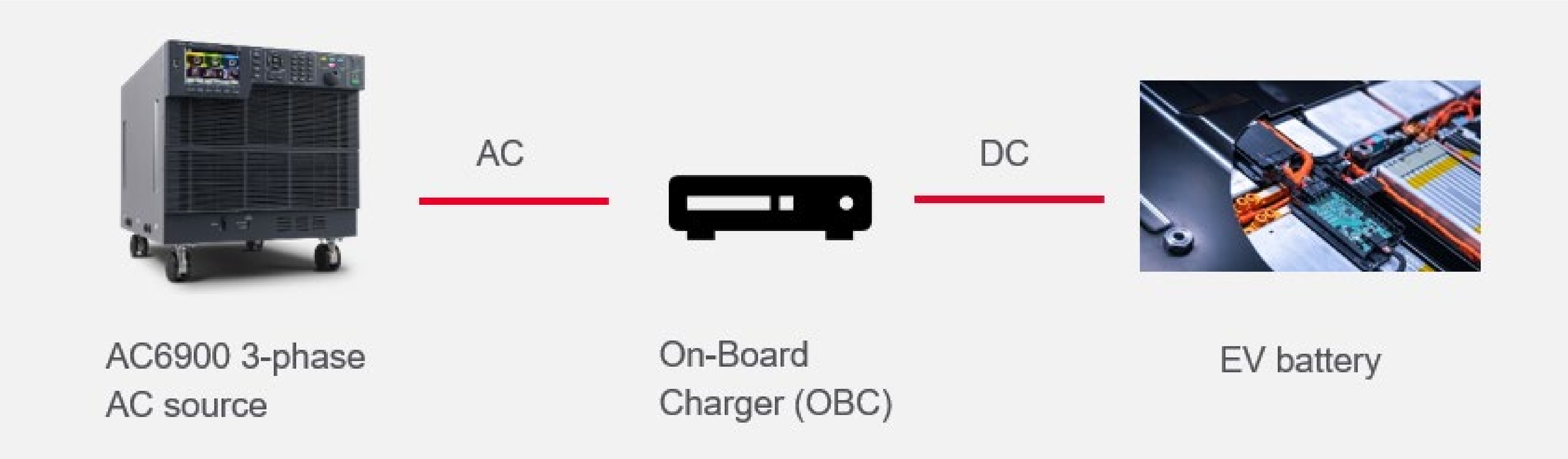
AC source challenges:

- Performance & Accuracy.
- Built-in simulation and sequencer features
- Execute quick power disturbances from the front panel.
- Write code to develop tests.
- Not having 1-phase and 3-phase configurations
- No DC output capabilities.

EV Charging System Testing Using 3-Phase AC Sources



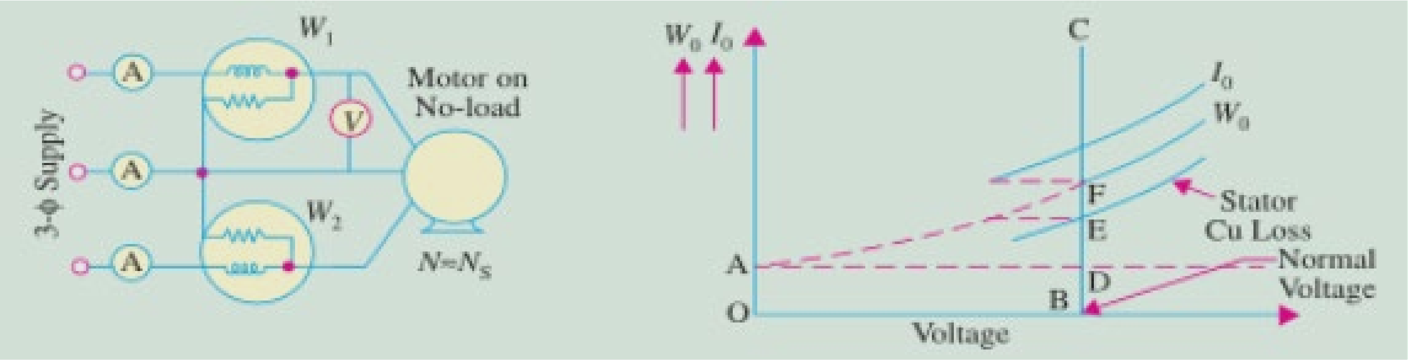
Onboard Charger Testing Using 3-Phase AC Sources



AC Motor No Load Test Using 3-Phase AC Sources

The no load test

- Apply different voltages, below and above the value of normal voltage.
- Measure power input via two wattmeters, W_1 and W_2.
- Use voltmeter and ammeter to measure voltage and current.



SIEMENS

Datasheet for three-phase Squirrel-Cage-Motors

Ordering data: **1LE1001-1AA42-2AA4**

Client order no.:
Order no.:
Offer no.:
Remarks:

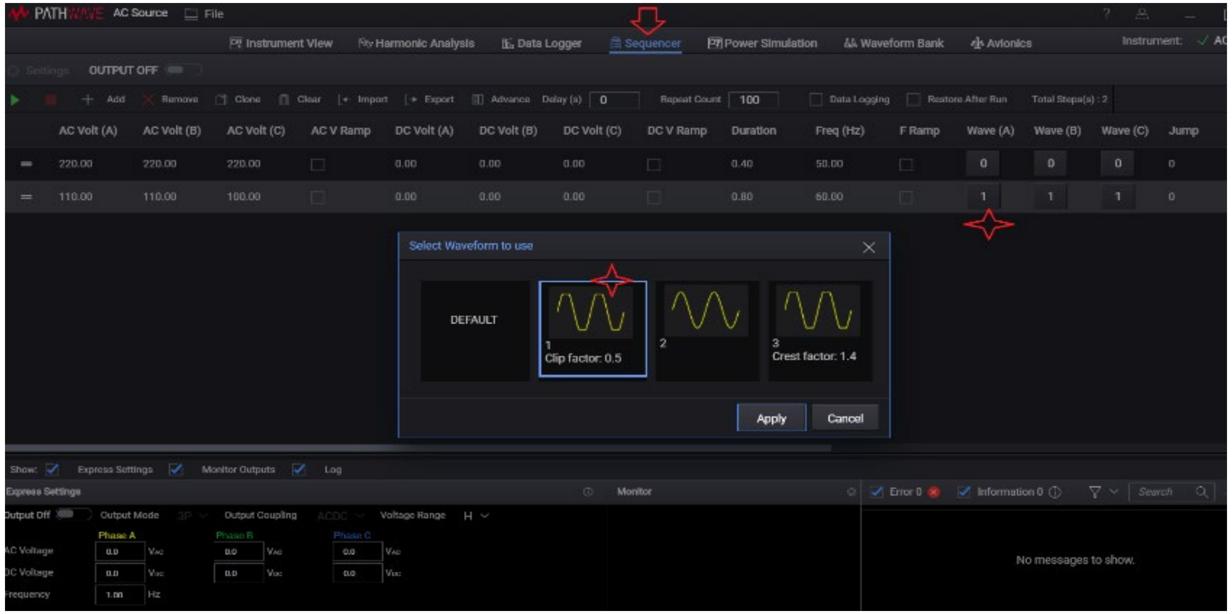
Item no.:
Consignment no.:
Project:

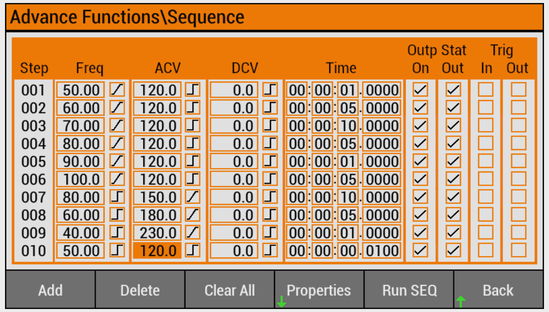
U [V]	Δ / Y	f [Hz]	P [kW]	P [hp]	I [A]	n [1/min]	M [Nm]	NOM. EFF at ... load [%] 4/4	3/4	2/4	Power factor at ... load 4/4	3/4	2/4	I_A/I_N I_l/I_N	M_A/M_N T_l/T_N	M_K/M_N T_B/T_N	IE-CL
230	Δ	50	3,00	-/-	10,61	2905	10	84,6	84,6	83,6	0,84	0,80	0,71	7,0	2,3	3,3	IE2
400	Y	50	3,00	-/-	6,10	2905	10	84,6	84,6	83,6	0,84	0,80	0,71	7,0	2,3	3,3	IE2
460	Y	60	3,45	-/-	5,80	3505	9	87,5	87,5	86,5	0,85	0,81	0,73	7,3	2,2	3,3	IE2
(A) IM 33			FS 100 L			21 kg	IP55		IEC/EN 60034		IEC, DIN, ISO, EN						

Mechanical data		*Terminal box*	
Sound pressure level 50 Hz/60Hz (no load)	67,00 dB (A) | 71,00 dB (A)	Terminal box position	(4) Terminal box - top mounted

Simulate Voltage And Frequency Deviations

- Use built-in sequencer to create voltage or frequency steps, easily generate **voltage** and **frequency transients** to simulate **complex power conditions**.

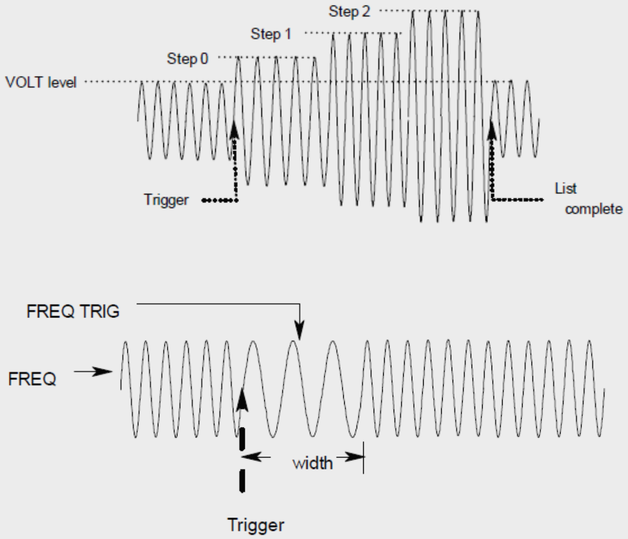




Advance Functions\Sequence

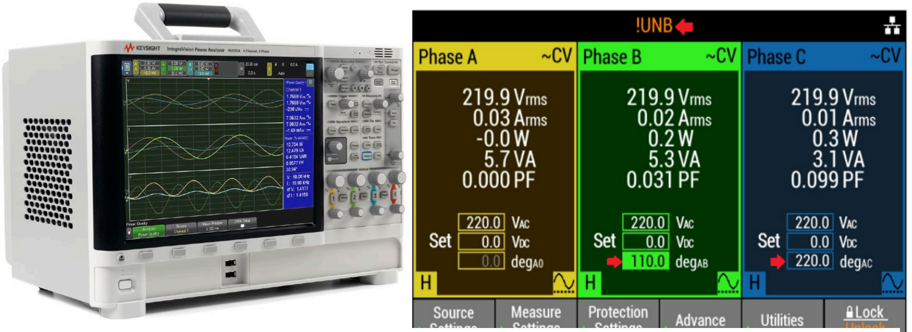
Step	Freq	ACV	DCV	Time	Outp On	Stat Out	Trig In	Trig Out
001	50.00	120.0	0.0	00:00:01.0000	☑	☑	☐	☐
002	60.00	120.0	0.0	00:00:05.0000	☑	☑	☐	☐
003	70.00	120.0	0.0	00:00:10.0000	☑	☑	☐	☐
004	80.00	120.0	0.0	00:00:05.0000	☑	☑	☐	☐
005	90.00	120.0	0.0	00:00:01.0000	☑	☑	☐	☐
006	100.0	120.0	0.0	00:00:05.0000	☑	☑	☐	☐
007	80.00	150.0	0.0	00:00:10.0000	☑	☑	☐	☐
008	60.00	180.0	0.0	00:00:05.0000	☑	☑	☐	☐
009	40.00	230.0	0.0	00:00:01.0000	☑	☑	☐	☐
010	50.00	120.0	0.0	00:00:00.0100	☑	☑	☐	☐

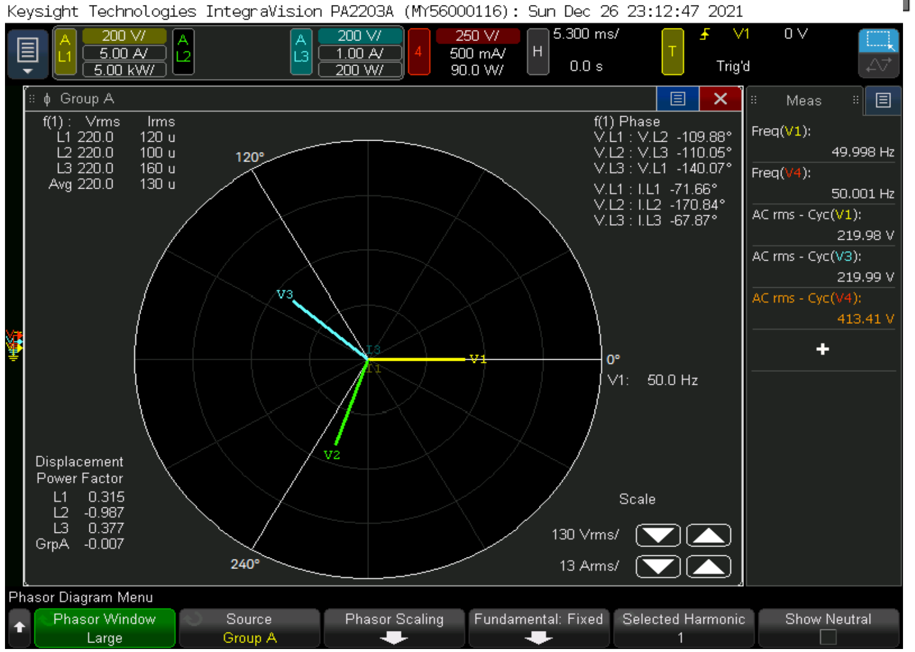
Add | Delete | Clear All | Properties | Run SEQ | Back



Simulate and Measure Phases Imbalances

- The phase angle in a 3-phase system is always 120 degrees for a symmetric balanced system.
- In a real-life power supplied from the grid, an imbalance condition may occur.
- The phase angle of an 3-phase AC source output can be configured to a different degrees to easily simulate this imbalance condition.
- A power analyzer with a phasor graph can be used to capture the phasor window of the imbalance condition.



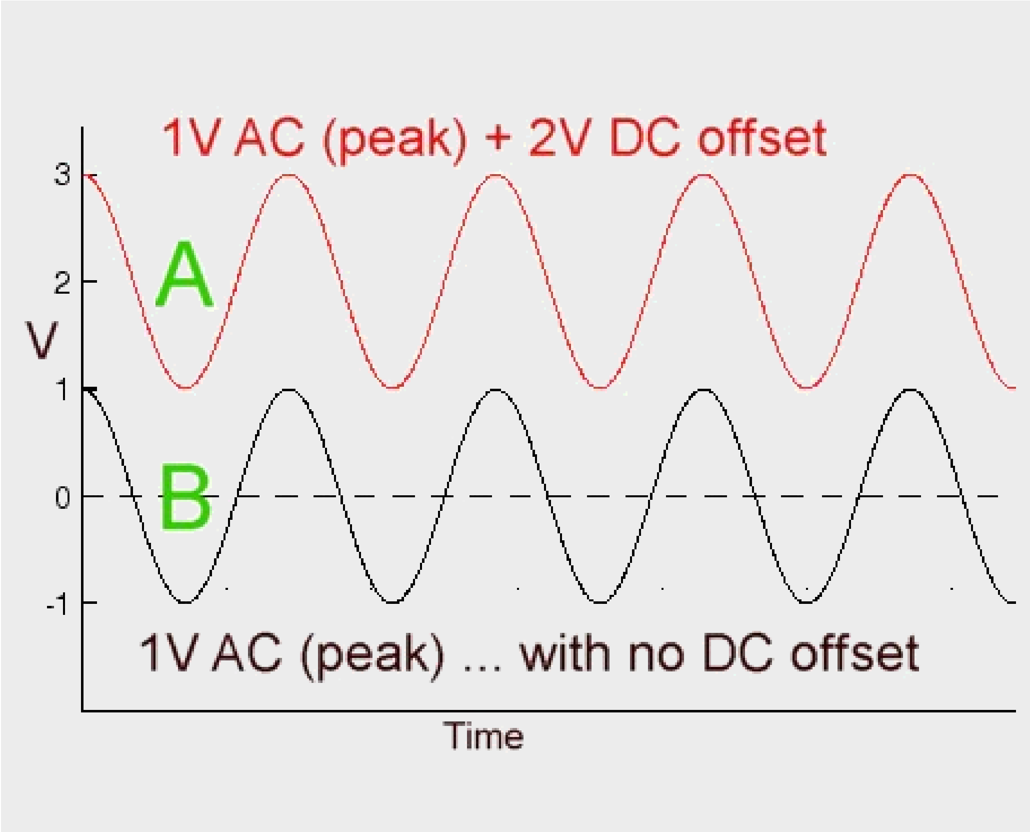


AC Source Capabilities

DC + AC

Produce DC power or DC + AC waveforms

- Some basic AC power supplies do not have **DC capability**.
- AC power supply with built-in DC capability can be used as a DC source.
- High performance AC power supply can produce **DC power at the same maximum power rating**.
- Useful for testing automotive loads that are not pure resistive and also **immunity tests** that involve both AC and DC.



Demo - ISO16750-2:2012, section 4.4

Superimposed alternating voltage

- Test conditions:
  - 1-phase
  - 24Vdc superimposed AC 4Vpp
  - Frequency sweep from 50Hz to 5000Hz
  - Sweep time = 2 minutes

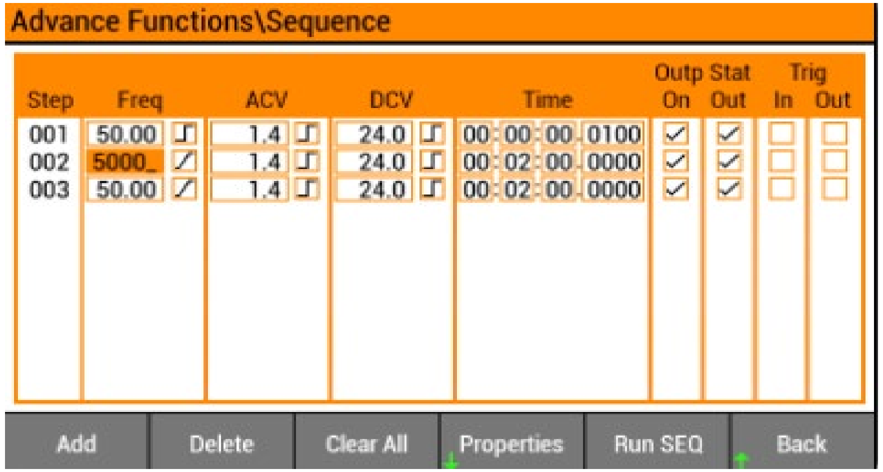
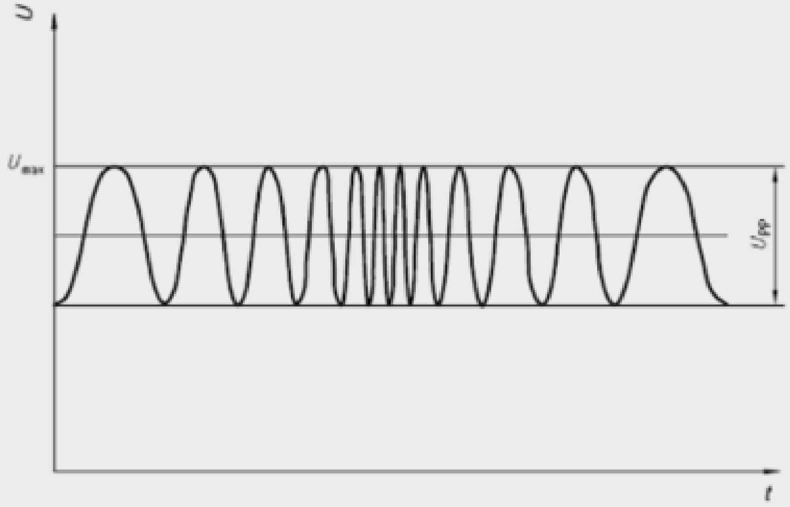


Table 3 — Test values

Test voltage U_{max} (see Figure 2)	16 V for U_N = 12 V systems 32 V for U_N = 24 V systems
a.c. voltage (sinusoidal)	Severity 1: U_{PP} = 1 V Severity 2: U_{PP} = 4 V
Internal resistance of power supply	⩽ 100 mΩ
Frequency range (see Figure 3)	50 Hz to 20 kHz
Type of frequency sweep (see Figure 3)	Triangular, linear
Sweep duration (see Figure 3)	120 s
Number of sweeps	5



Agenda

Onboard Charger Testing

OBC Charger Testing
AC test challenges
3-Phase Motor Testing

Battery Testing

Power Consumption Analysis
Battery Modeling/Emulation
Battery Charging/Discharging/Cycling

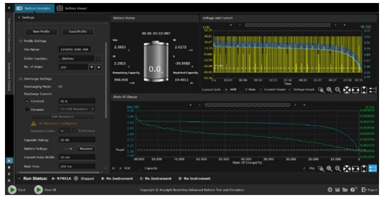
DC-DC Converter Test

Common Tests for DC-DC Converters
Tests for Automotive Power Converters

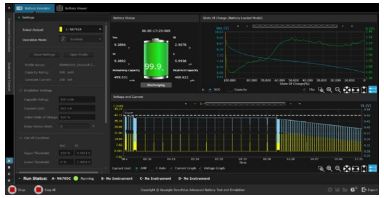
Battery Testing

- How to perform current drain analysis on batteries & EVs

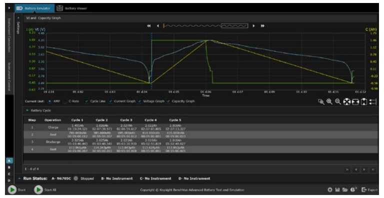
- How to accurately generate a battery model



- How to accurately emulate a battery



- How to validate battery capacity / cycling / capacity loss



Power And Current Drain Measurement Challenges

- Wide dynamic range & current resolution
- DC measurement accuracy
- Measurement sensitivity and noise
- Bandwidth
- Measure AC variations on top of DC rails
- High speed digitizing & datalogging for high voltages and currents

Current Drain Analysis With A DC Power Analyzer With Power & Control Analysis Application

Current Drain analysis System Set Up

Controlling Software

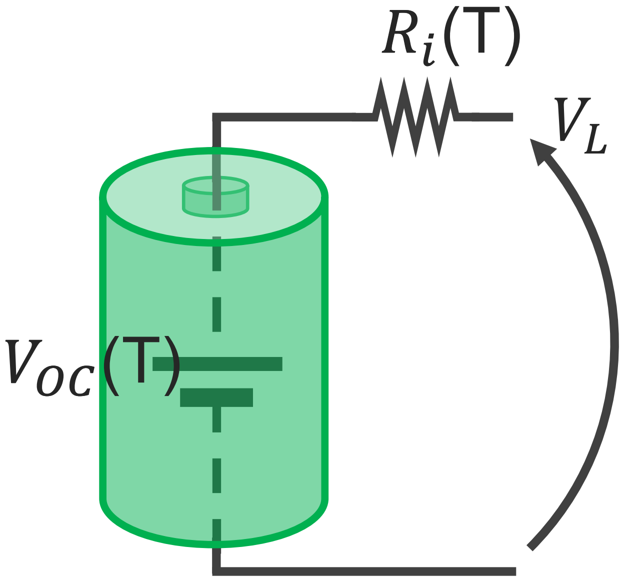
Power Analyzer

E-Vehicle

Battery Model / Profile

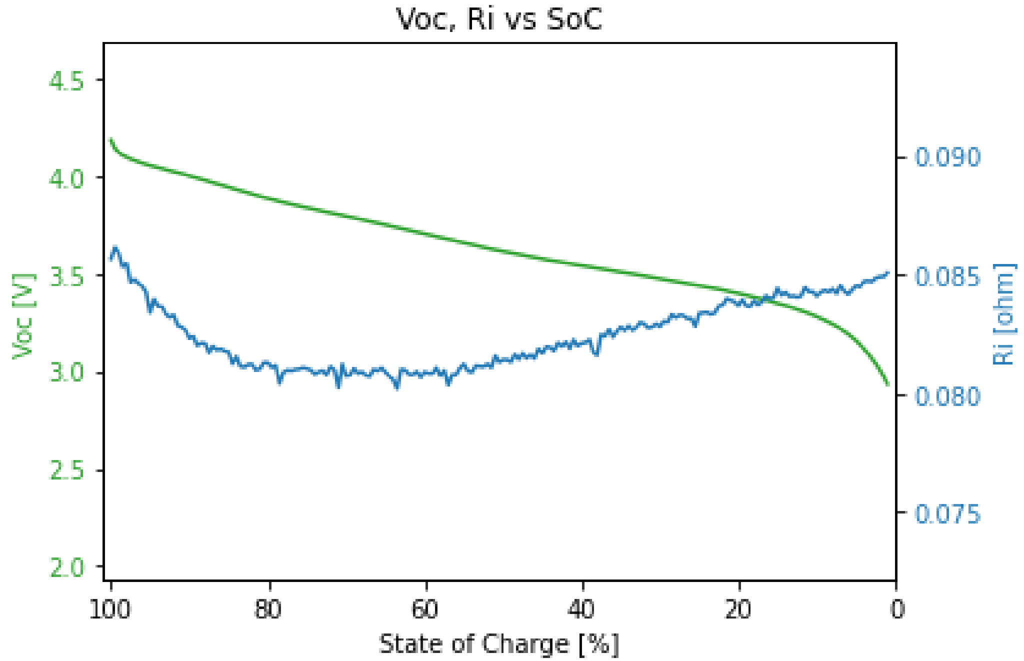
What is a battery Model?

A battery model / profile is the electrical representation of a battery characteristics



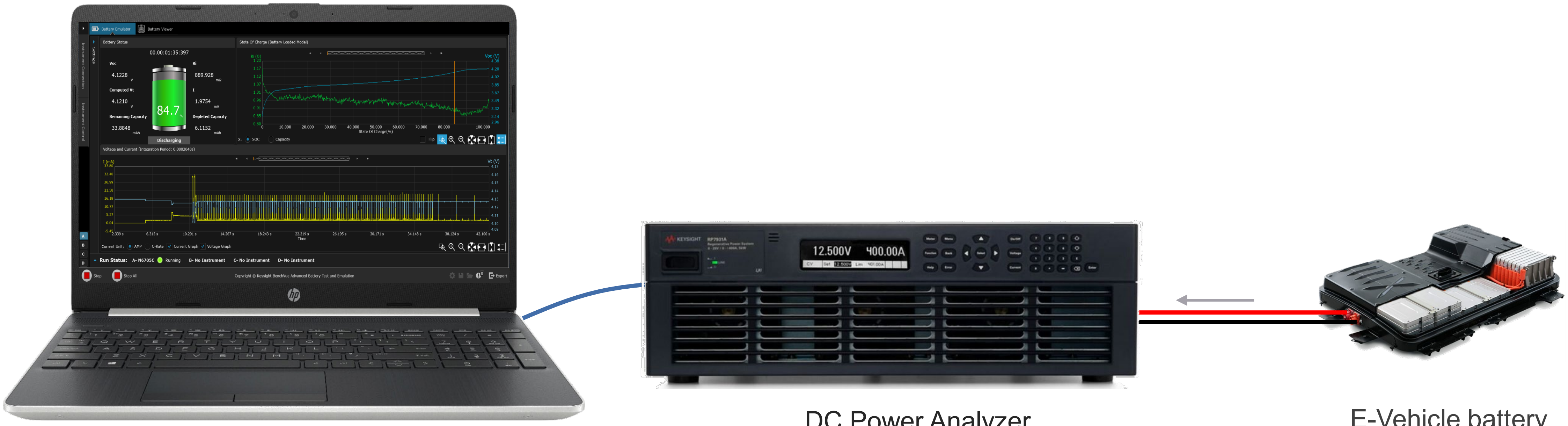
$$V_L = V_{OC} - I \cdot R_i$$

SoC(%)	Voc(V)	Ri(ohm)
100.00	4.18	0.086
99.50	4.14	0.086
99.00	4.12	0.086
98.50	4.11	0.085
98.00	4.10	0.085
97.50	4.09	0.085
97.00	4.08	0.085
....	....	....
....	....	....
....	....	....
2.00	3.07	0.085
1.50	3.04	0.085
1.00	3.01	0.085
0.50	2.97	0.085
0.00	2.93	0.085



Battery Modeling/Profiling – Capacity Validation

Battery Profiling Test Set Up



Controlling Software

DC Power Analyzer

E-Vehicle battery
384V 180Ah 69.12kW

Battery Emulation - Validating Battery Lifetime

Battery emulation Test System Set Up

Battery Test and Emulation
Controlling Software

DC Power Analyzer

E-Vehicle

How Does a Battery Emulator Work?

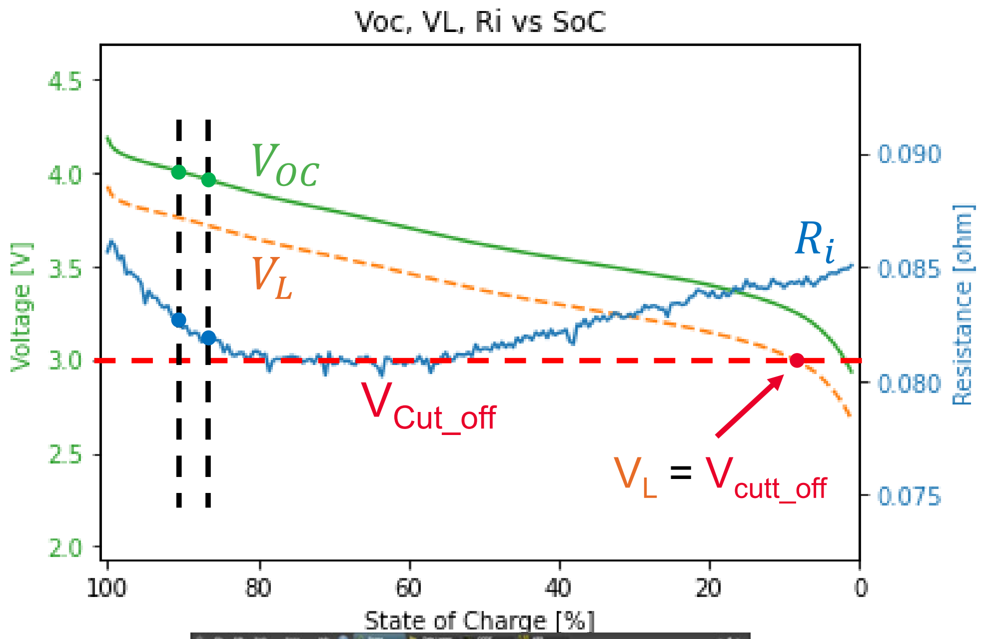
1. Load a battery profile into the battery emulator
   Voc, ***Ri*** *vs* ***State of Charge***

2. User specifies **Initial State of Charge** (SoC = 90%)
   Cut_off Voltage (*example 3V*)

3. Battery Emulator measures device charge consumption

4. Based on measured discharge the Battery Emulator modifies its output (Voltage and Resistance) to follow the loaded battery profile

5. Battery Emulator stops when $V_L = V_{cutt\_off}$

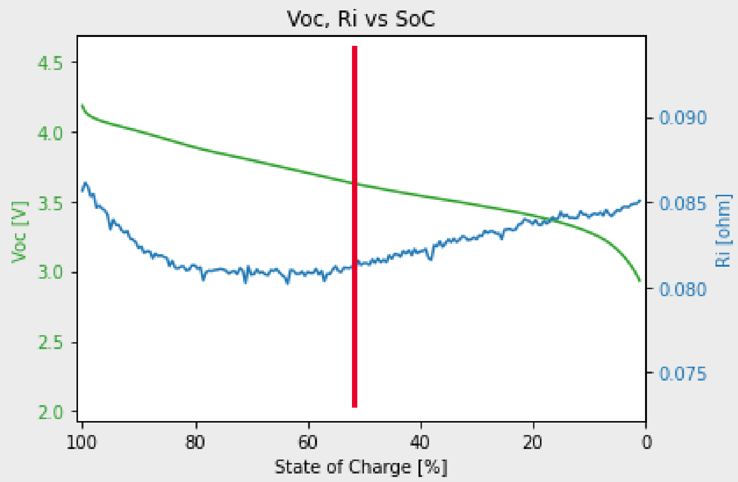


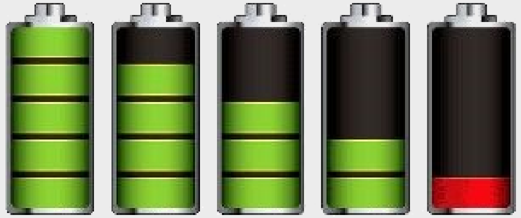
Current profile consumption measurements

Why Use A Battery Emulator vs A Battery?

Benefits:

- Creates a safer test environment
- Provides more repeatable results
- State-of-charge programmed instantaneously
- Reduces test setup time





Emulator

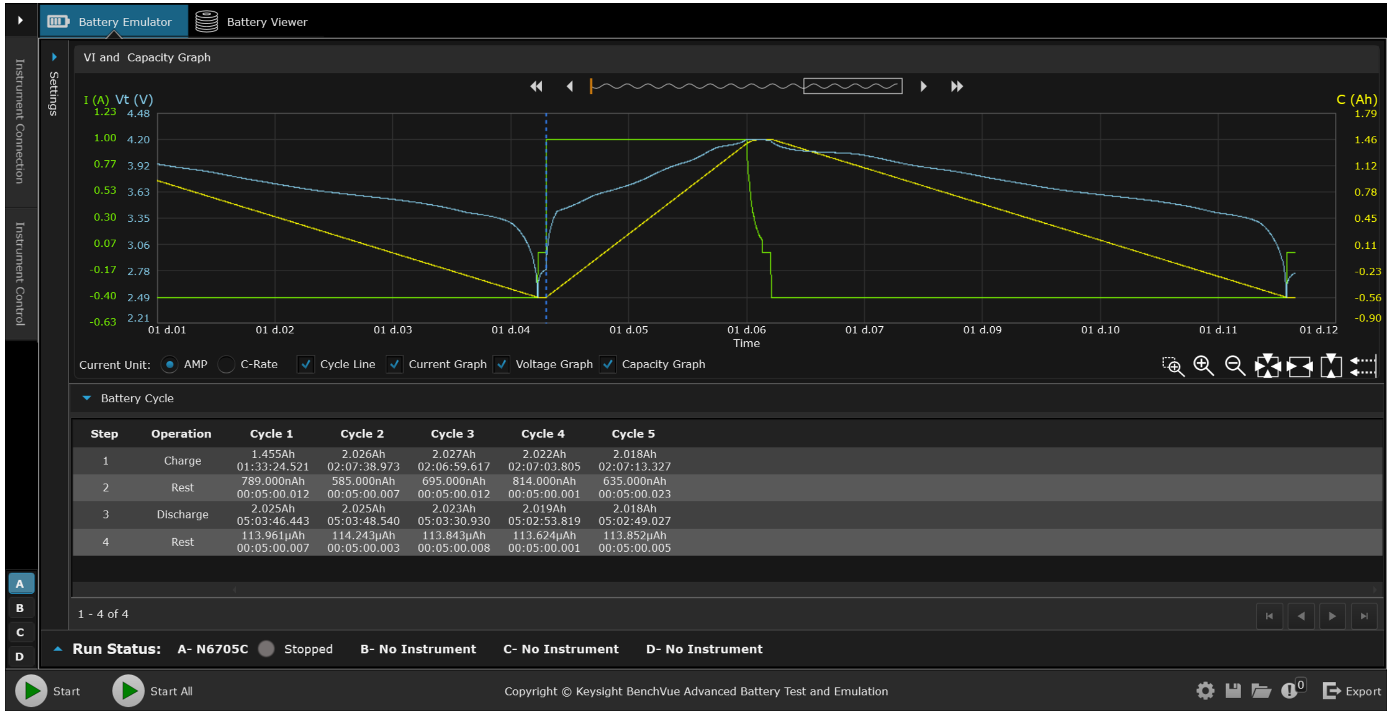
VS

Battery

Power Electronics & Energy Storage event
POWER ELECTRONICS
ENERGY STORAGE
27 juni 2023 | 1931 Congrescentrum 's-Hertogenbosch

acal bfi

Battery Cycling



Step	Operation	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
1	Charge	1.455Ah 01:33:24.521	2.026Ah 02:07:38.973	2.027Ah 02:06:59.617	2.022Ah 02:07:03.805	2.018Ah 02:07:13.327
2	Rest	789.000nAh 00:05:00.012	585.000nAh 00:05:00.007	695.000nAh 00:05:00.012	814.000nAh 00:05:00.001	635.000nAh 00:05:00.023
3	Discharge	2.025Ah 05:03:46.443	2.025Ah 05:03:48.540	2.023Ah 05:03:30.930	2.019Ah 05:02:53.819	2.018Ah 05:02:49.027
4	Rest	113.961µAh 00:05:00.007	114.243µAh 00:05:00.003	113.843µAh 00:05:00.008	113.624µAh 00:05:00.001	113.852µAh 00:05:00.005

- Combines power supply, e-load, datalogger and arbitrary waveform generator in a single instrument
- Combine several charging discharging steps to create complex charging discharging cycling profiles
- Create complex cycling steps and validate your battery aging without writing a single line of code

Agenda

Onboard Charger Testing

OBC Charger Testing
AC test challenges
3-Phase Motor Testing

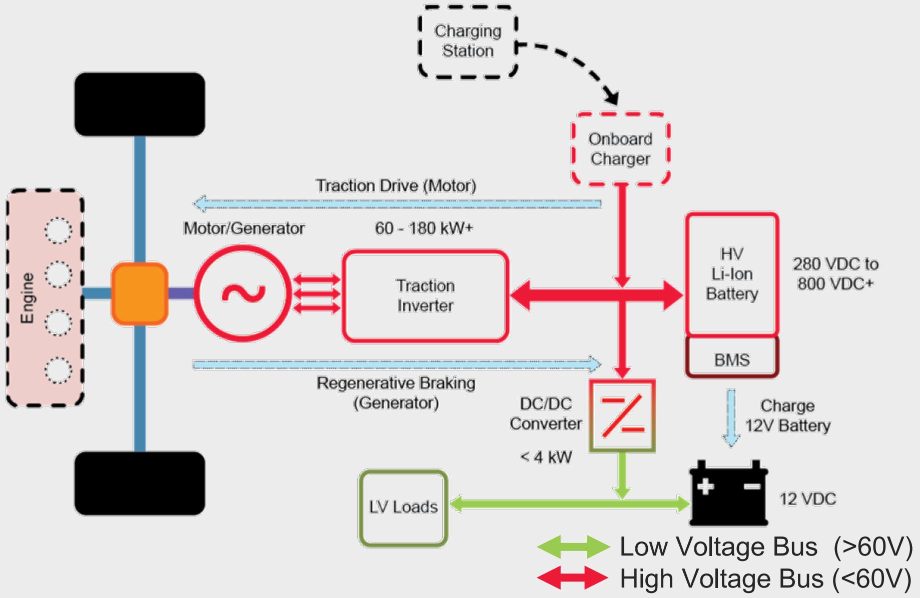
Battery Testing

Power Consumption Analysis
Battery Modeling/Emulation
Battery Charging/Discharging/Cycling

DC-DC Converter Test

Common Tests for DC-DC Converters
Tests for Automotive Power Converters

Challenges In Automotive Power Converter Design Validation



Plug-in Hybrid EV or Battery EV

- Large number of tests
- Hight test capacity / throughput
- Safety During Test

Power Source & Loading

Regenerative Power System

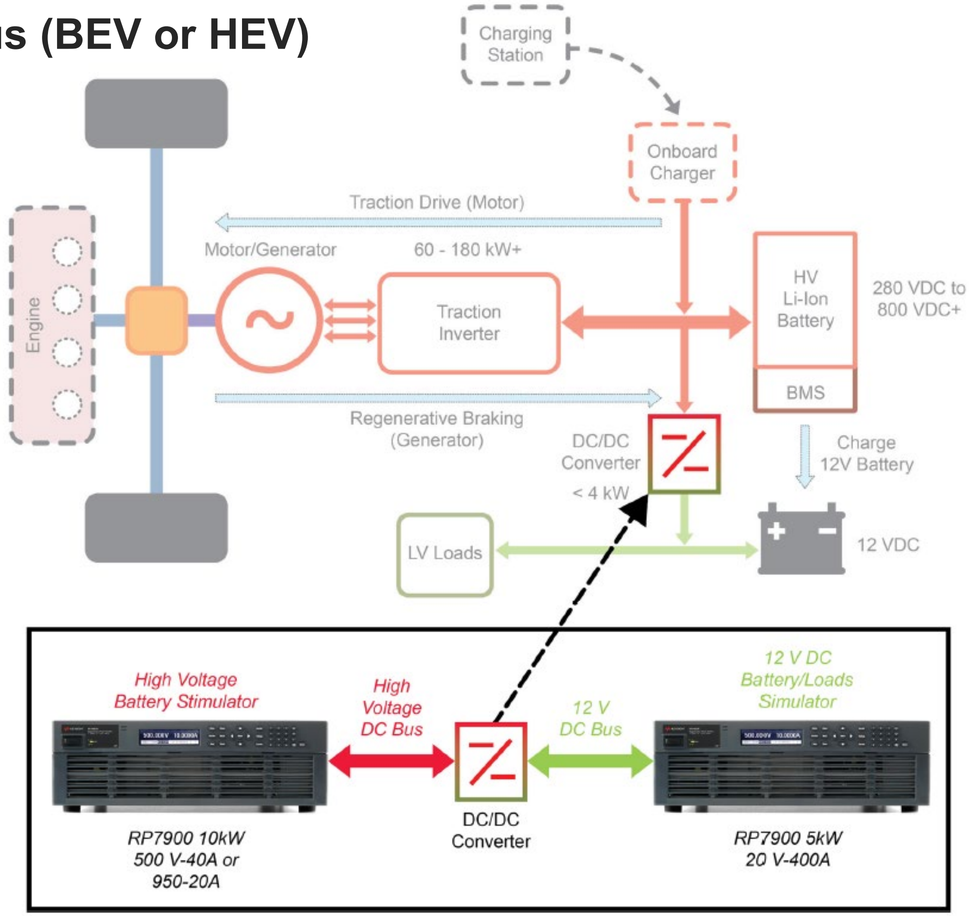
- Match converter requirements
- Bandwidth and programming speed
- Meet test accuracy needs
- Easy to integrate & generate waveforms
- Provide safety / protecting features

Power Converter Design Validation Test Applications Using Bidirectional Regenerative Power Analyzers

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

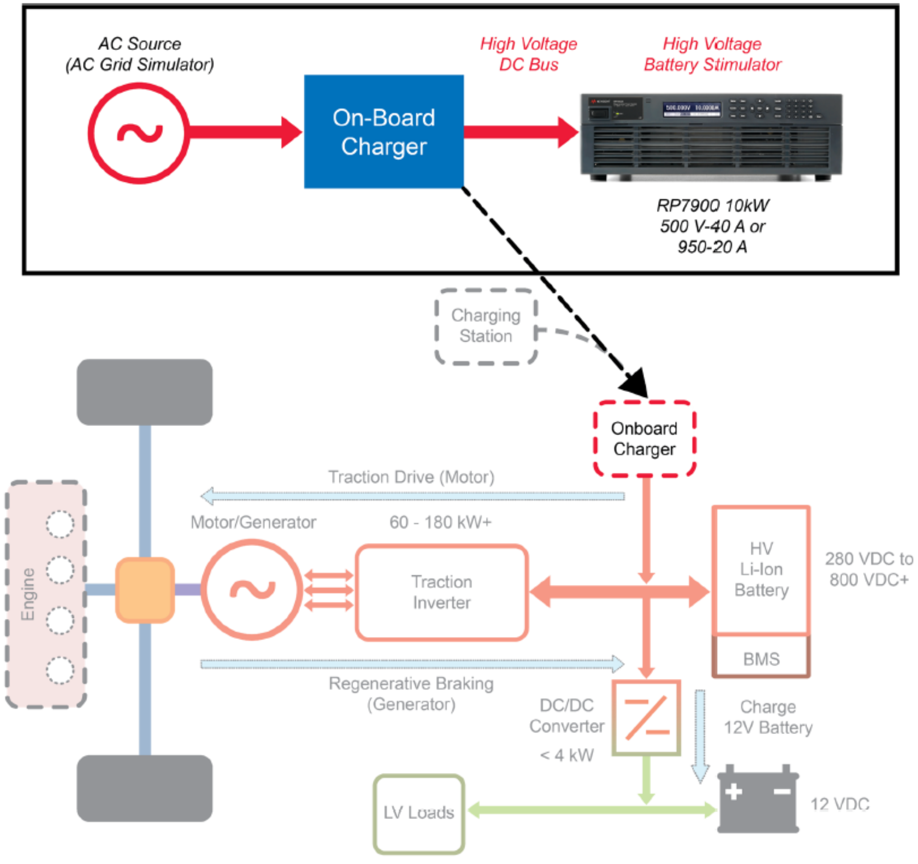
- Use a 500V or a 950V Power System to perform the source/sink function of the EV battery.

- Use a 20 V Power System to simulate the source/sink of the 12 V bus.



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

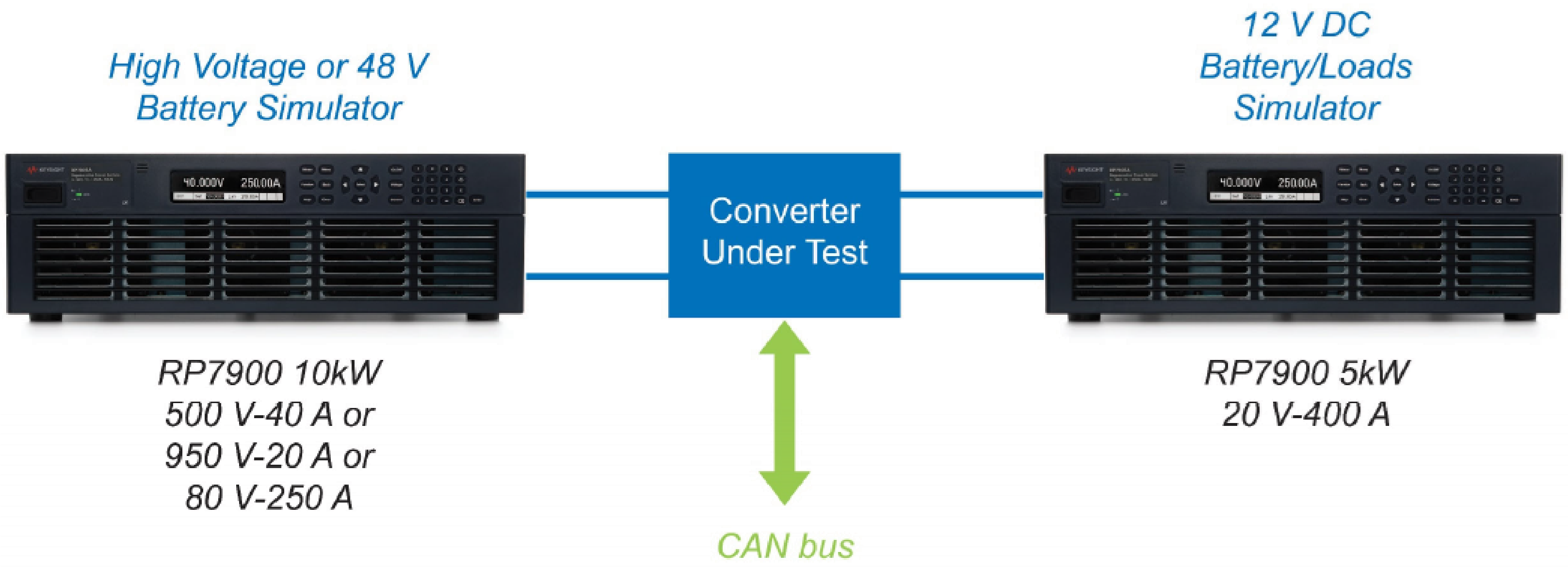
- Use a 500V or a 950V Power System to perform the source/sink function of the EV battery.



BEV or HEV

Example Tests for Automotive Power Converters Using Power Systems

- Simulate the battery with a high-voltage (500 V or 950 V) Power Supply / Analyzer.
- Load the converter output with a 20 V Power Analyzer acting as a programmable electronic load with built-in voltage and current measurements.

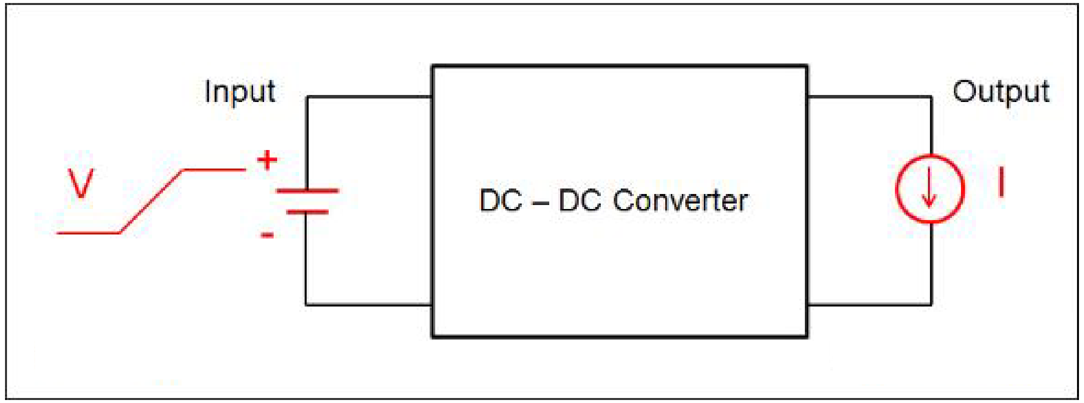


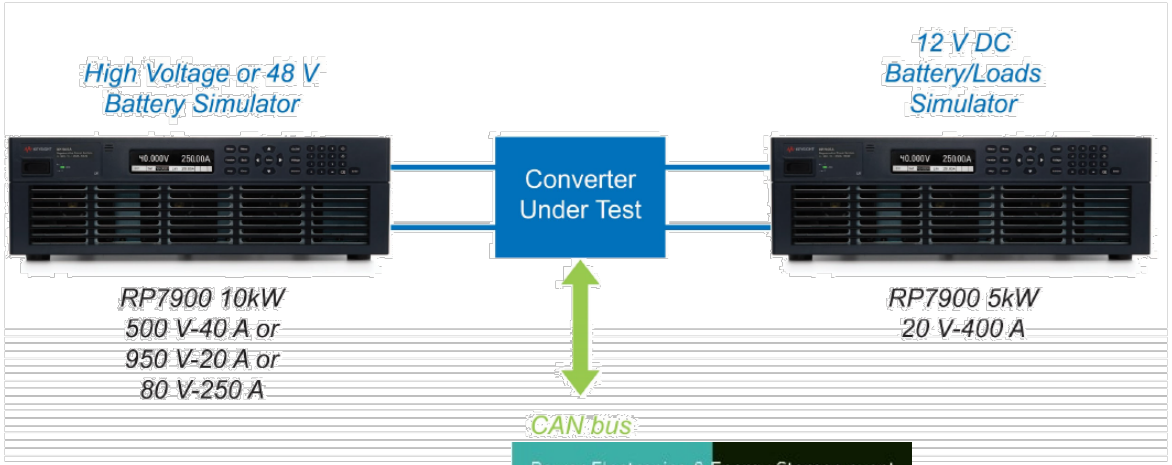
Common tests for DC/DC converters

- Validate that DC/DC converters operate within their **specified limits**
  - DC/DC converters have a specified **input/output voltage operating range**
- Confirm the DC/DC converter **works properly over the entire range** of input voltages, they are tested using an adjustable or programmable dc source to provide the input voltage.
- **A DC electronic load** is used on the output of the DC/DC converter to set the output load current and **simulate the device** that the DC/DC converter would power.
- Measure **Input turn-on, input turn-off voltage levels** and **timing tests**

Converter Input/Line Regulation – Output Stability Test

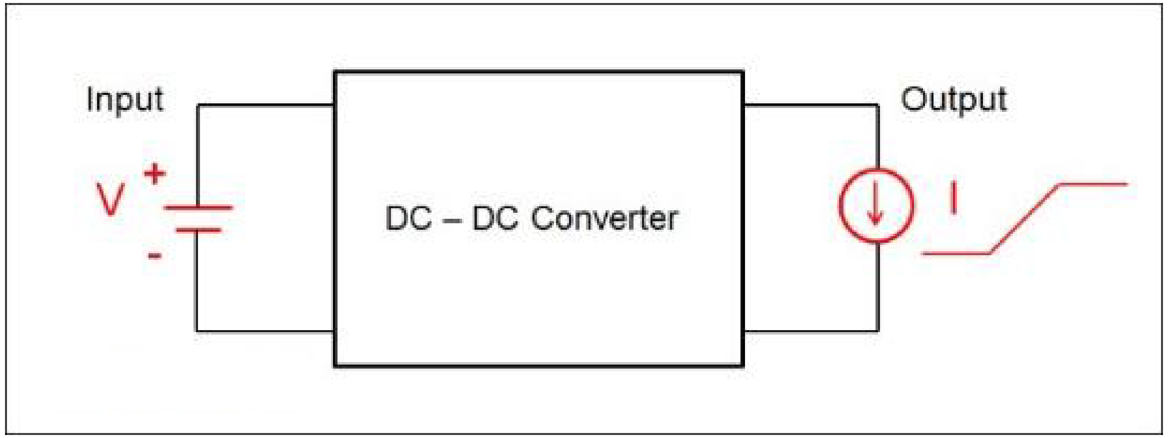
- Measure converter output voltage and current as the input voltage is varied.
- Test output static limits and recovery time after change of input.

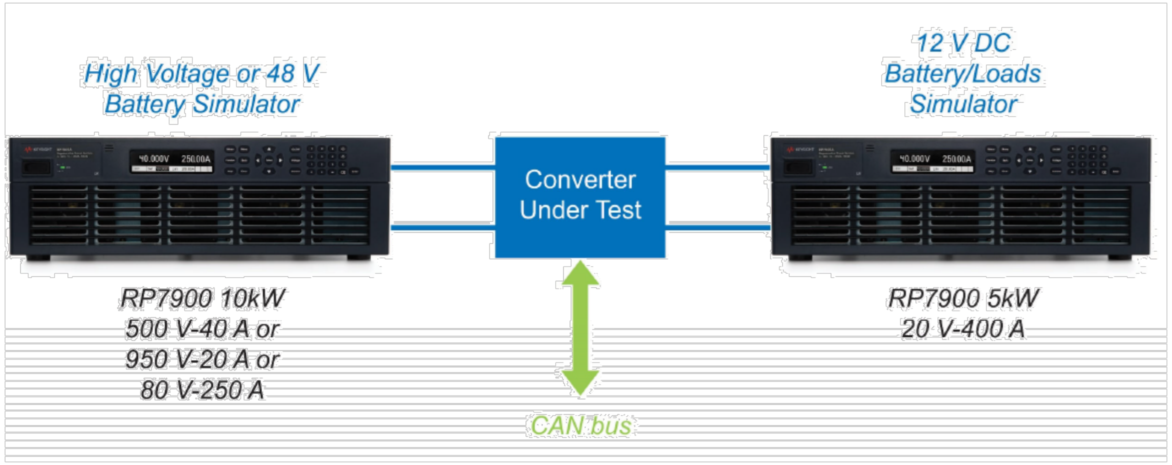




Converter Load Regulation

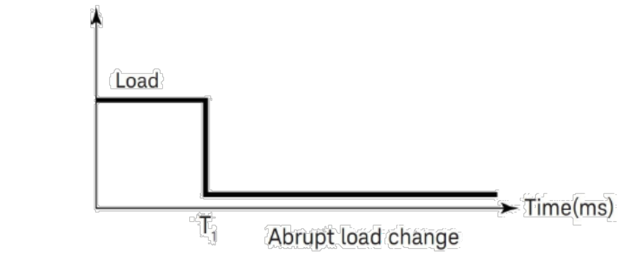
Measure the converter's output voltage as the converter's output load current is changed.

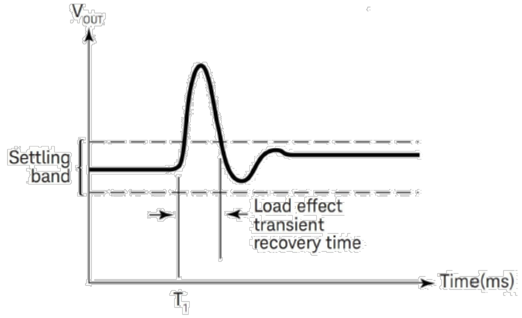


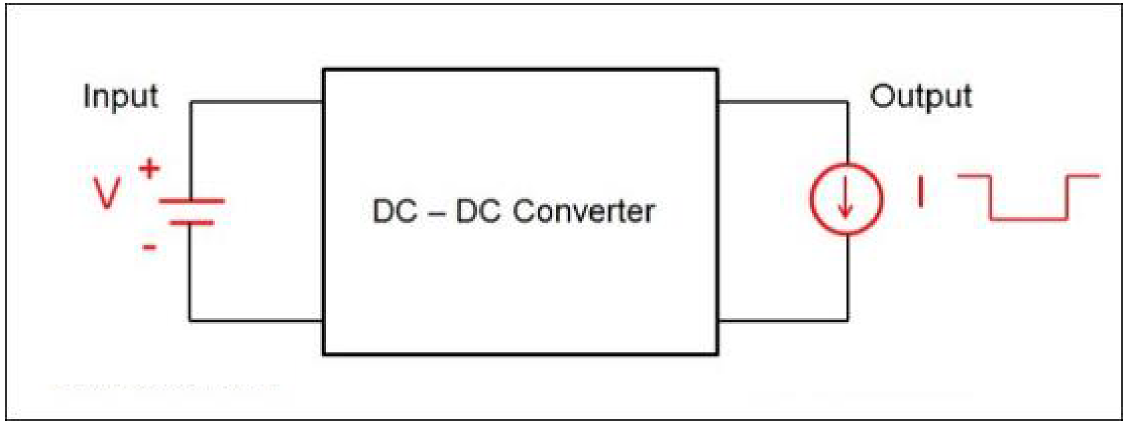


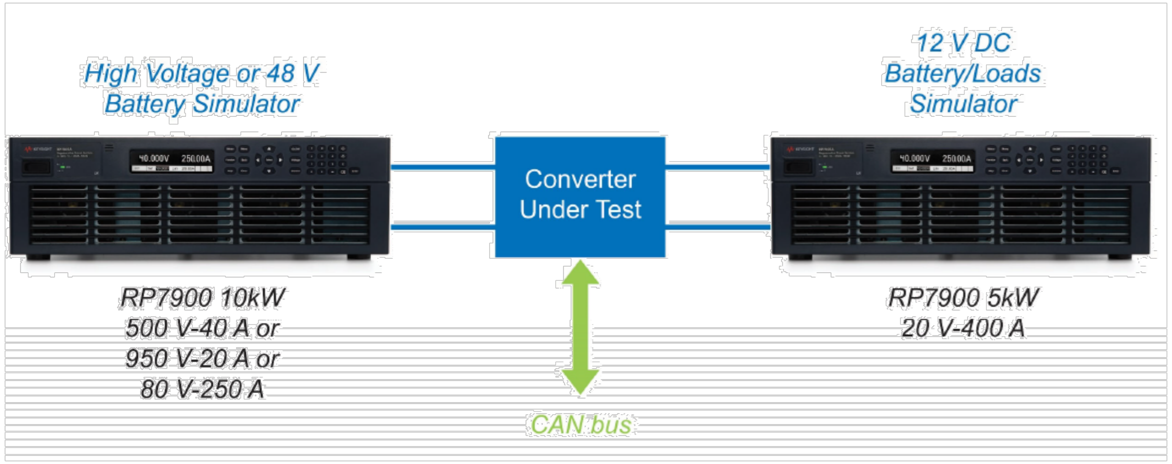
Converter Load Regulation – Stability for Transient Load Changes

Measure converter output voltage recovery time with step change on output load current.





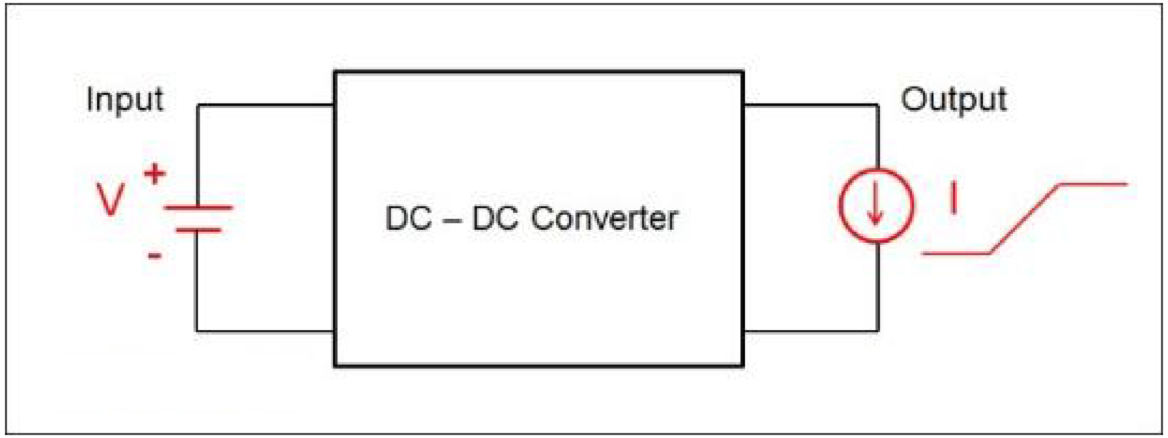


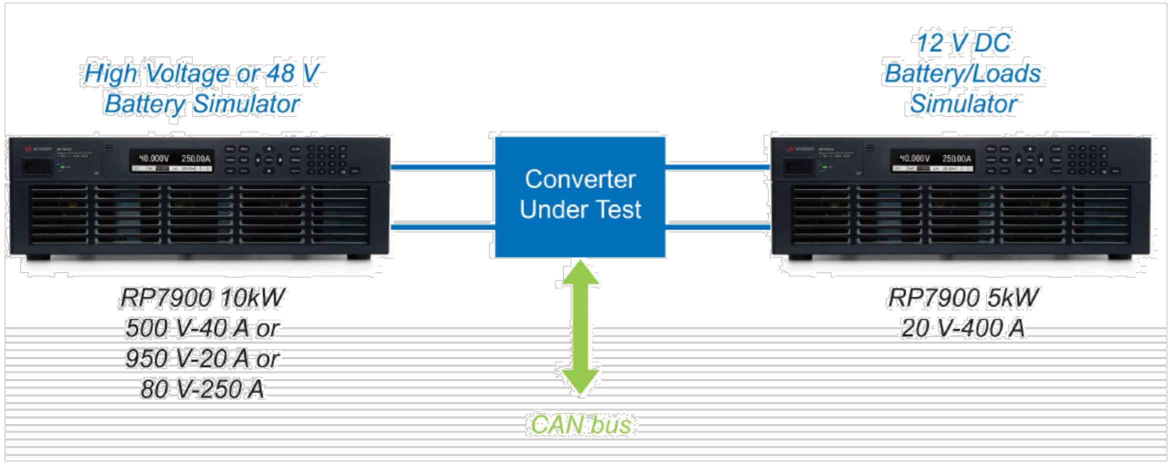


Converter Power Efficiency and Output Voltage Accuracy

- 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.

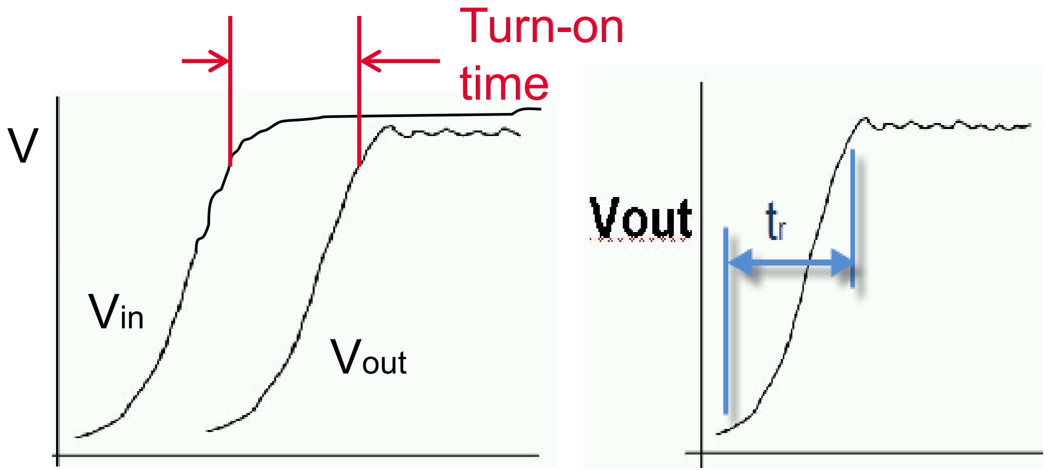
- Measure output voltage vs specified accuracy limits for various load and environmental conditions.

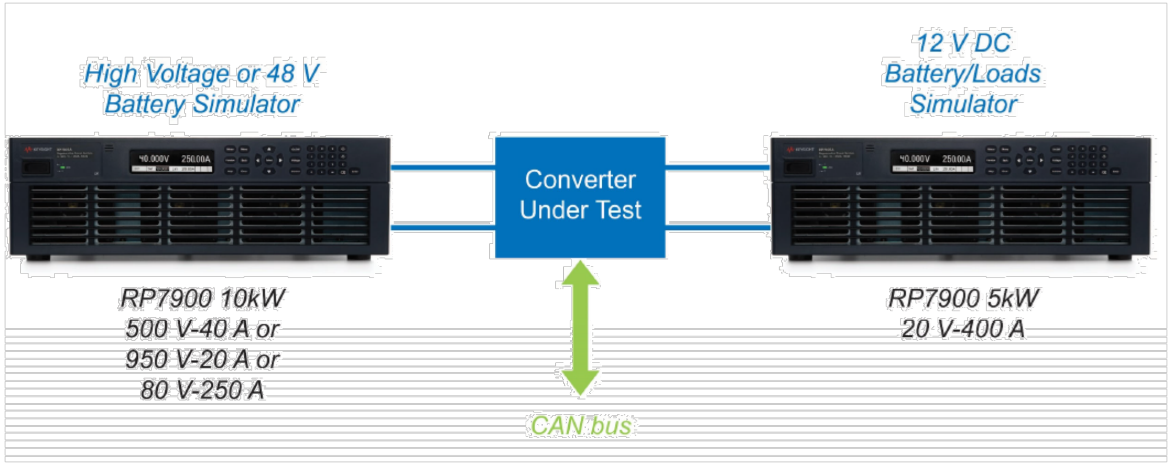




Converter Transient Response

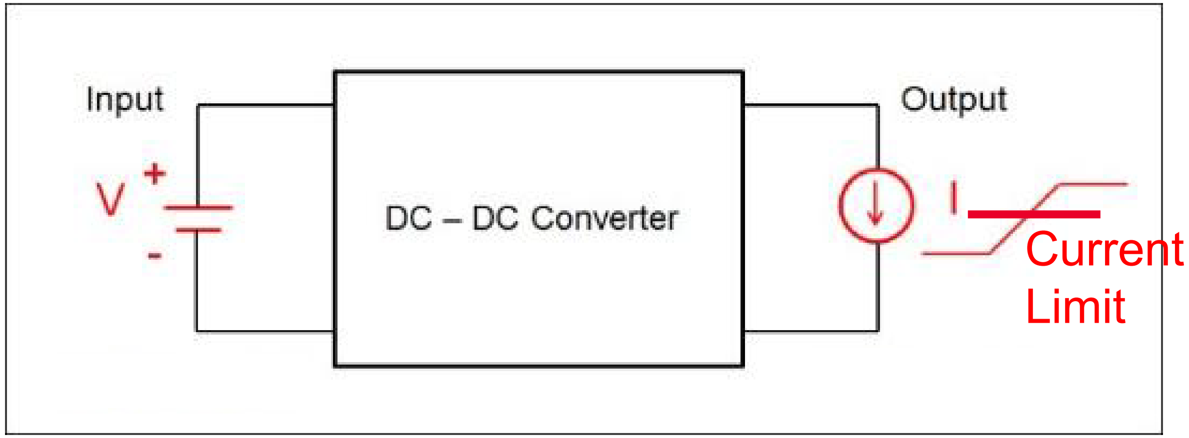
- Measure converter output voltage and/or current with the power analyzer built-in fast digitizer to verify turn-on times, turn-off times, and output rise/fall times for a variety of load and environmental conditions across the operating range of the converter.

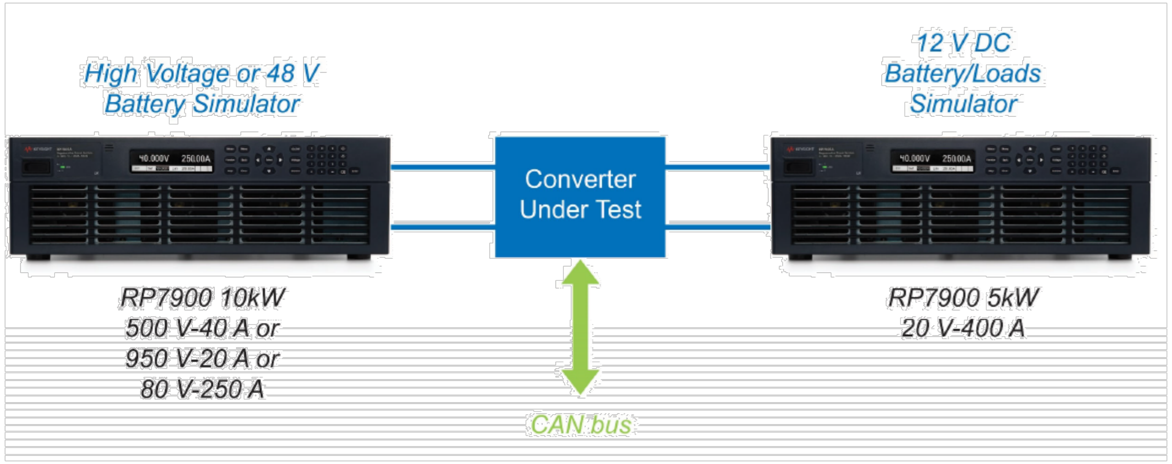




Converter Protection Current Limit Verification

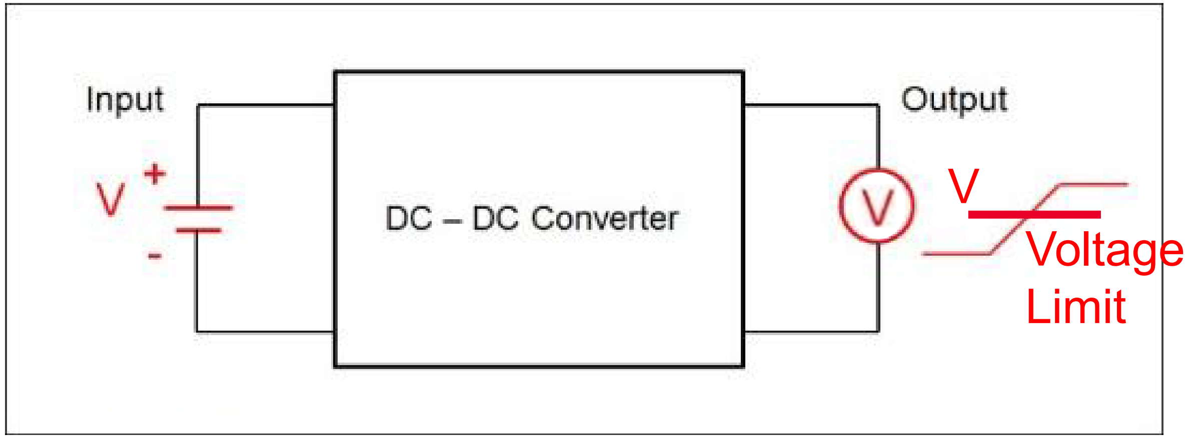
- Program the converter to specific output current limits, then program the bidirectional power source acting as an e-load to sink currents beyond the over-current protection limits.

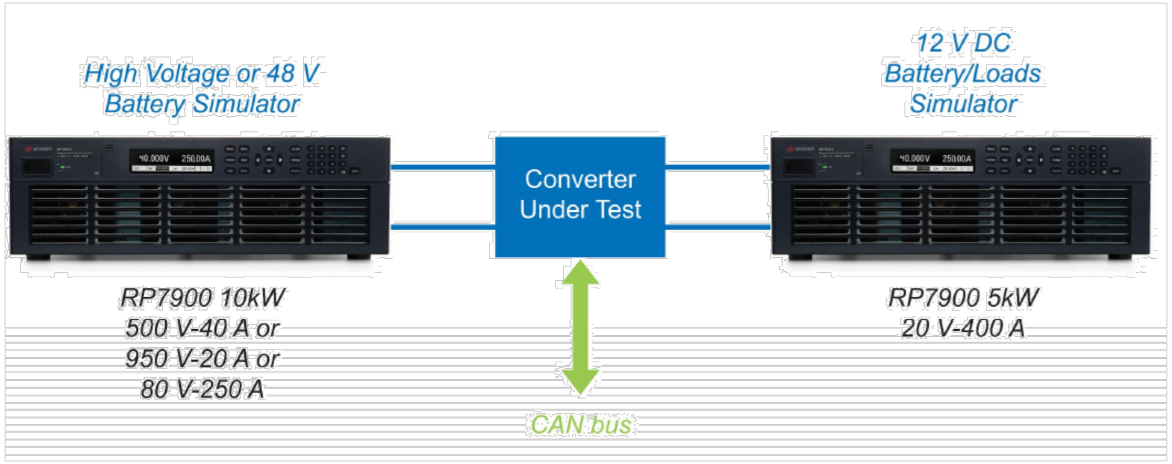




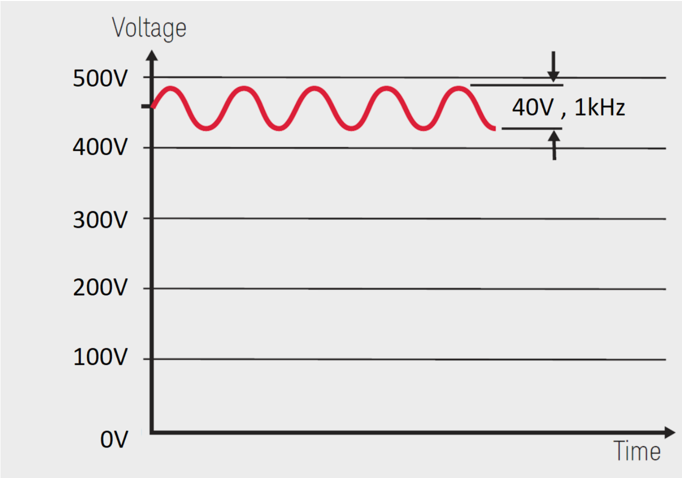
Converter Protection Voltage Limit Verification

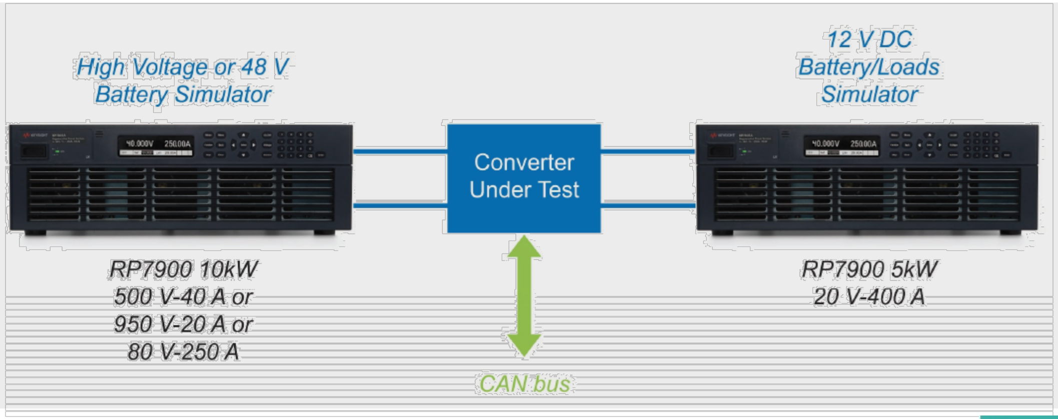
- Program the converter to specific output voltage limits, then program the power analyzer acting as a voltage source to the converter output to produce converter output voltages beyond the over-voltage limits.





DC-to-DC Converter Ripple Rejection Measurements





DEMO

Power Analysis made easy with the Keysight IntegraVision PA2200 Series Power Analyzer

Designed specifically for R&D engineers, this powerful tool revolutionizes the way you measure, analyze, and validate AC and DC power consumption. With an impressive 0.05% basic accuracy and 16-bit resolution, you can now confidently evaluate power conversion efficiency, operational response to stimuli, and essential AC power parameters like frequency, phase, and harmonics.

Join us for an exclusive demo session and see firsthand how the IntegraVision PA2200 Series Power Analyzer empowers you to see it, measure it, and prove it

Thank you

acal bfi

KEYSIGHT TECHNOLOGIES
Authorized Premium Distributor

Email: sales-nl@acalbfi.nl

Phonenumber: +31 (0)40-2507451

Address: Luchthavenweg 53, 5657 EA Eindhoven (NL)

Website: acalbfi.com/nl