Validating the E-mobility Battery、BMS、Converter and Inverters

Gary Hsiao 蕭舜謙

2019/01/15&16

Project Manager, Keysight Technologies

KEYSIGHT TECHNOLOGIES

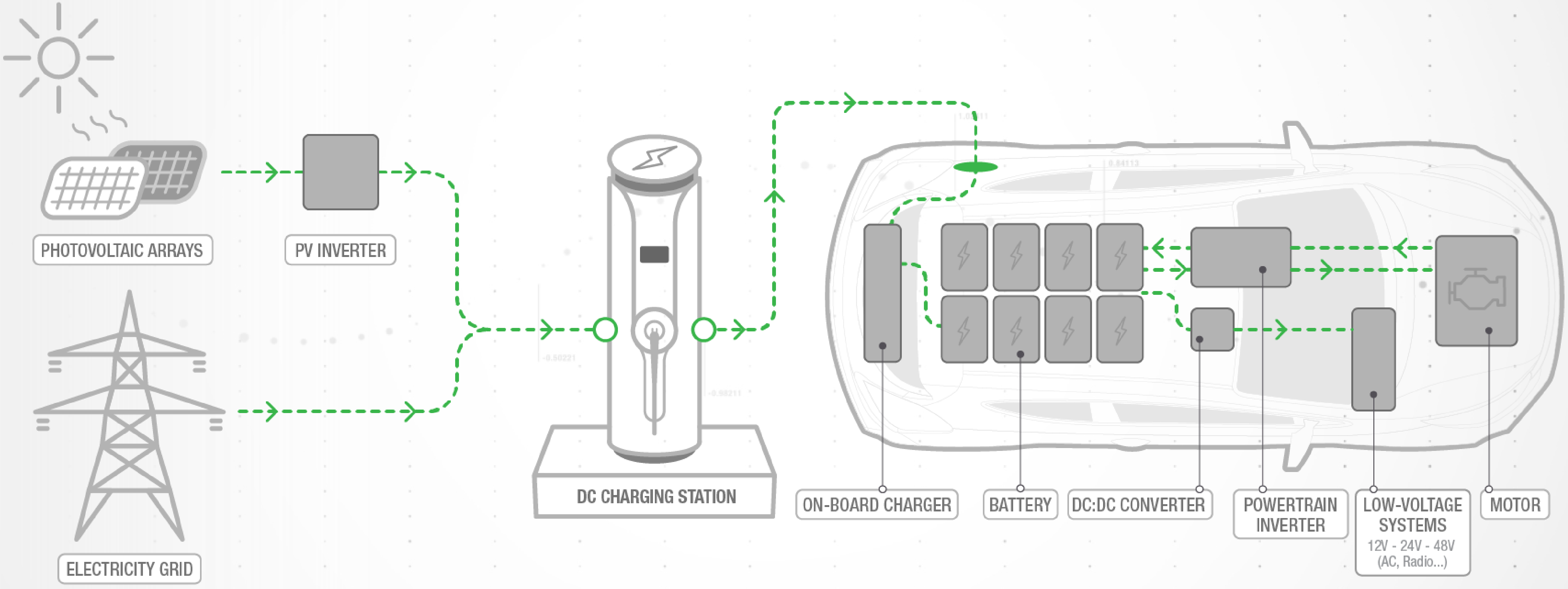
Agenda

eMobility Ecosystem Solutions

- Power Converters in the HEV / EV (“eMobility”) Ecosystem
- HEV / EV Market and Trends
- HEV / EV Design and Test Challenges
- Evolving Trends in Design and Test
- Keysight’s Solution Portfolio
- Battery Measurement - Cell Test Challenges & Solution
- Battery Measurement - Forming Test Challenges & Solution

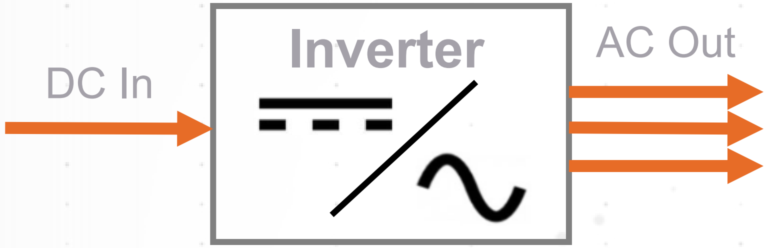
Power Converters in the HEV / EV (“eMobility”) Ecosystem

FOLLOWING THE ENERGY

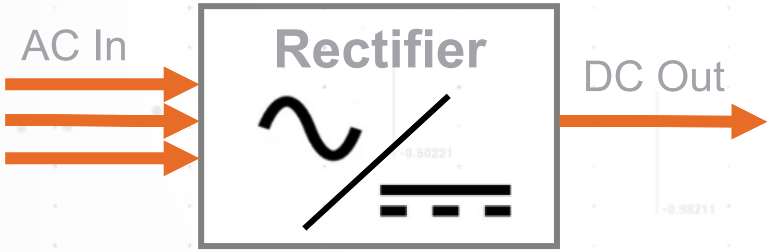


The Different Functions of Power Converters

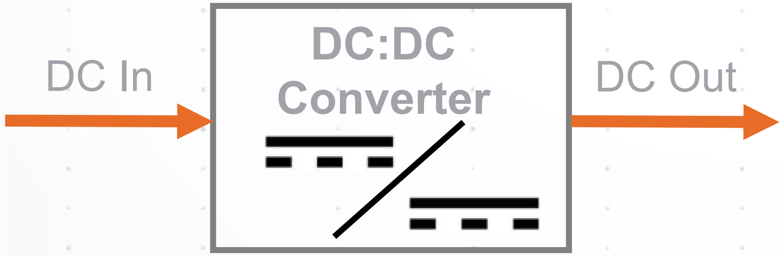
As power is distributed throughout a system, such as in vehicles, the system must:
- match power type for the loads (e.g. DC, 1ϕ AC, 3ϕ AC)
- match appropriate voltage/current levels for the loads (e.g. 380 VDC, 120 Vrms)



Example applications:
- Motor Drive
- PV / Solar
- Power Steering Assist



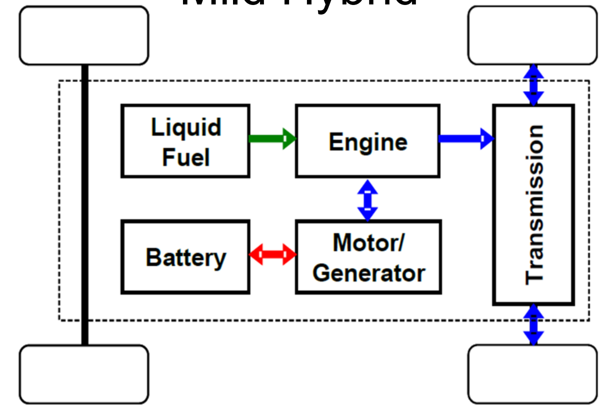
Example applications:
- Charging Stations
- On-board chargers



Example applications:
- Buck converters
- Boost/Buck converters
- Maximum Power Point Tracker (MPPT) / Optimizer

HEV / EV Powertrain Architectures

Mild Hybrid



Full / Parallel / Strong Hybrid

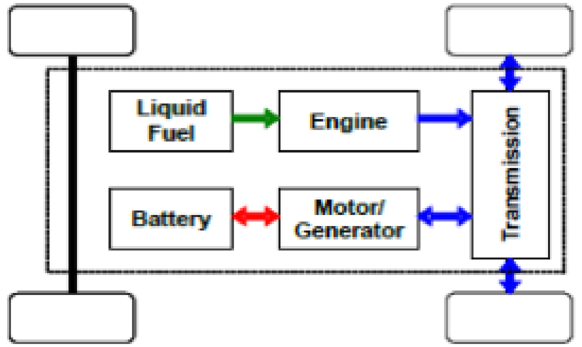
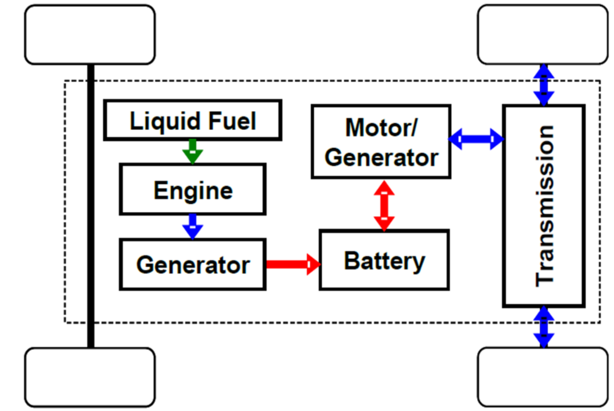
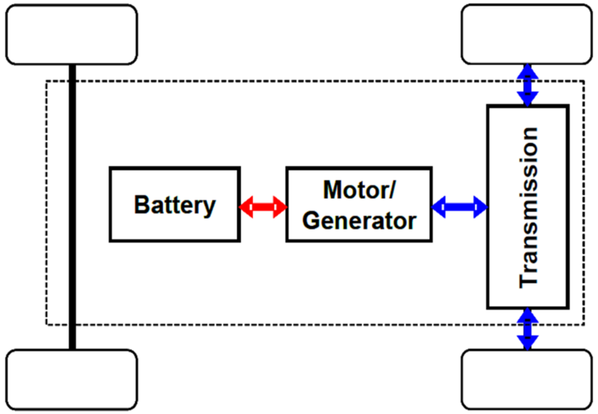


Figure 4: Schematic of a parallel hybrid powertrain

eREV / Series Hybrid



BEV / EV



Credit: MIT Electric Vehicle Team (http://web.mit.edu/evt/)

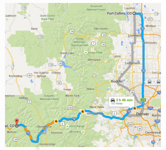
HEV / EV Economic Drivers / Constraints

CO_2 taxation driving sales of low emission cars – Sales in EU-15 countries shows preference towards fuel efficient cars with lower CO_2 emissions. Diesel lost 7% market share in 2009. *Source Frost & Sullivan*

Fuel Economy legislation – NHTSA established a strict regulations for America auto makers to achieve 35.5 mpg by 2016 (39 mpg for passenger cars) *Source the International Council on Clean Transportation*

Government incentives – $2.7B worth of programs are being implemented with $1.5B for batteries, $0.5B for EV mfg components, $0.4B infrastructure and $0.3B for others *Source Global Policy Group*

Energy cost volatility – *Crude oil price fluctuation* (~$45-$140 price fluctuation in the past 24 months) *Source Bloomberg*

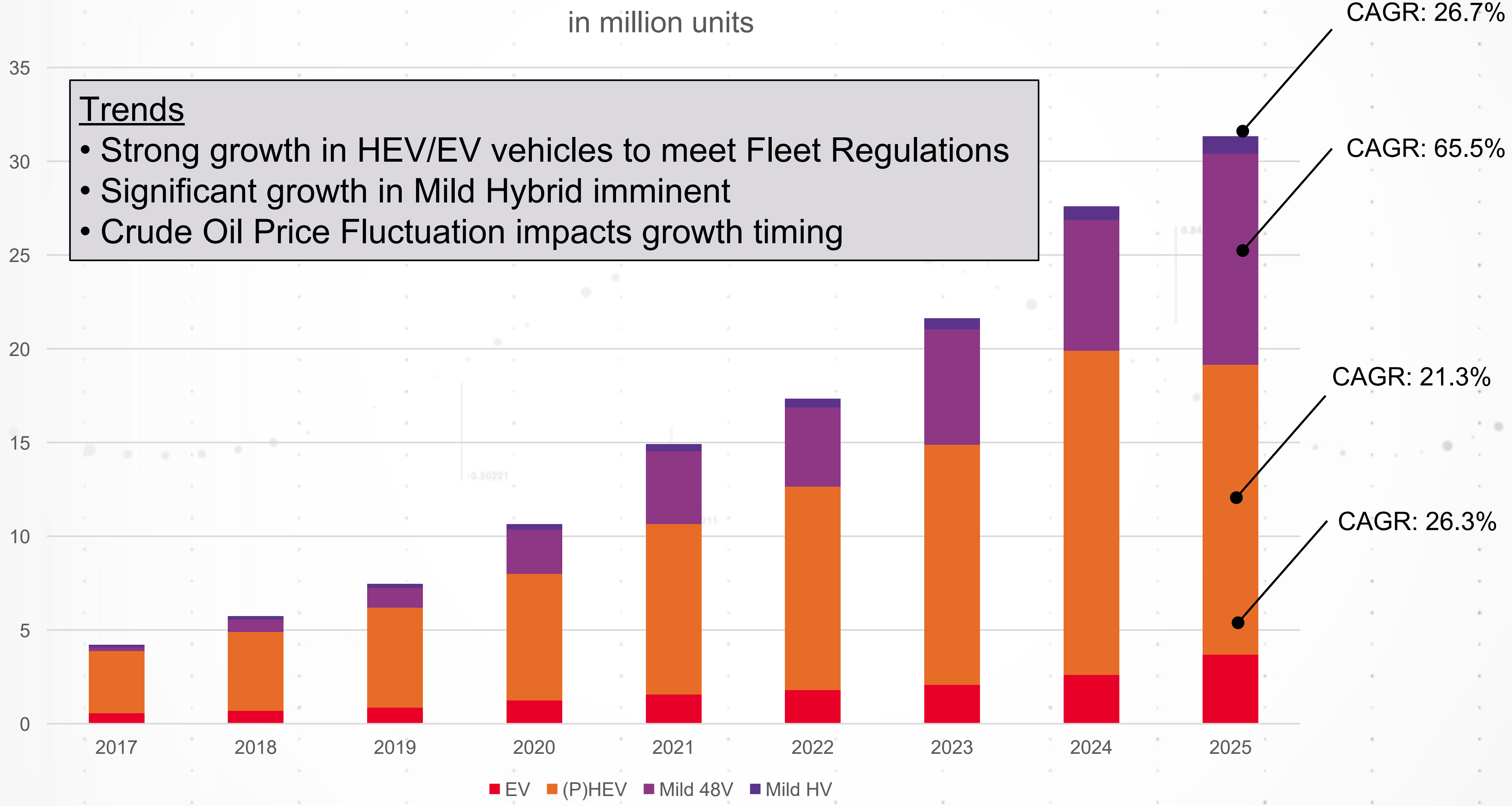


Range Anxiety - Even people who never drive beyond 80 miles in a day want the option to do so. *Source Quora*

Charge Time – The length of time to fully charge your EV is not similar to filling your gas tank. Even Fast charging takes 15+ minutes.

Charging Infrastructure –
Less than 10,000 public charging stations as of April 2014.
Source: US Department of Energy

HEV / EV Worldwide Forecast

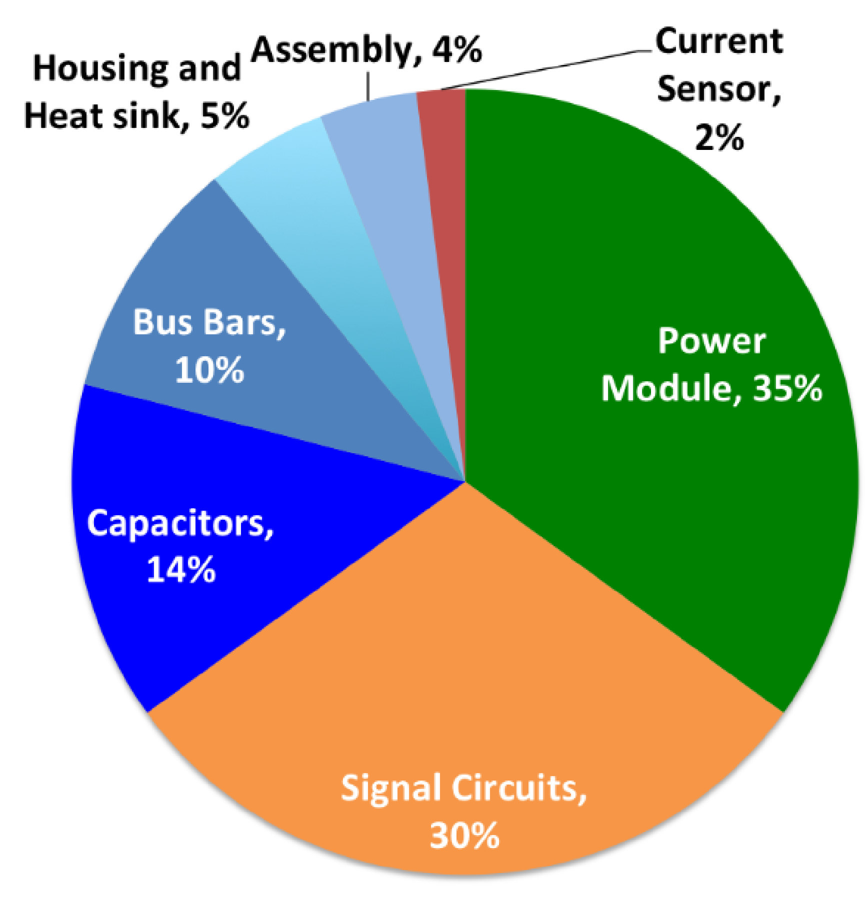


Trends
- Strong growth in HEV/EV vehicles to meet Fleet Regulations
- Significant growth in Mild Hybrid imminent
- Crude Oil Price Fluctuation impacts growth timing

Source: Average of multiple reports (Navigant, Yole, ,etc.)

Market Challenge: Cost Pressure

4X COST REDUCTION TO COMPETE WITH INTERNAL COMBUSTION ENGINE (ICE)



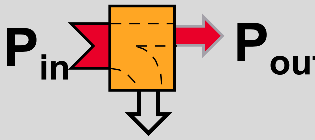
- Current specific cost: $13.70 USD / kW
- 2020 R&D target: $3.30 USD / kW
- On-road Inverter Cost $1092.00

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Source: https://www.energy.gov/sites/prod/files/2014/09/f18/fy_2014_vto_amr_apeem_overview-final_version.pdf

Cost Pressure → Design / Test Challenges

HOW ARE MANUFACTURERS AND SUPPLIERS LOWERING COSTS?

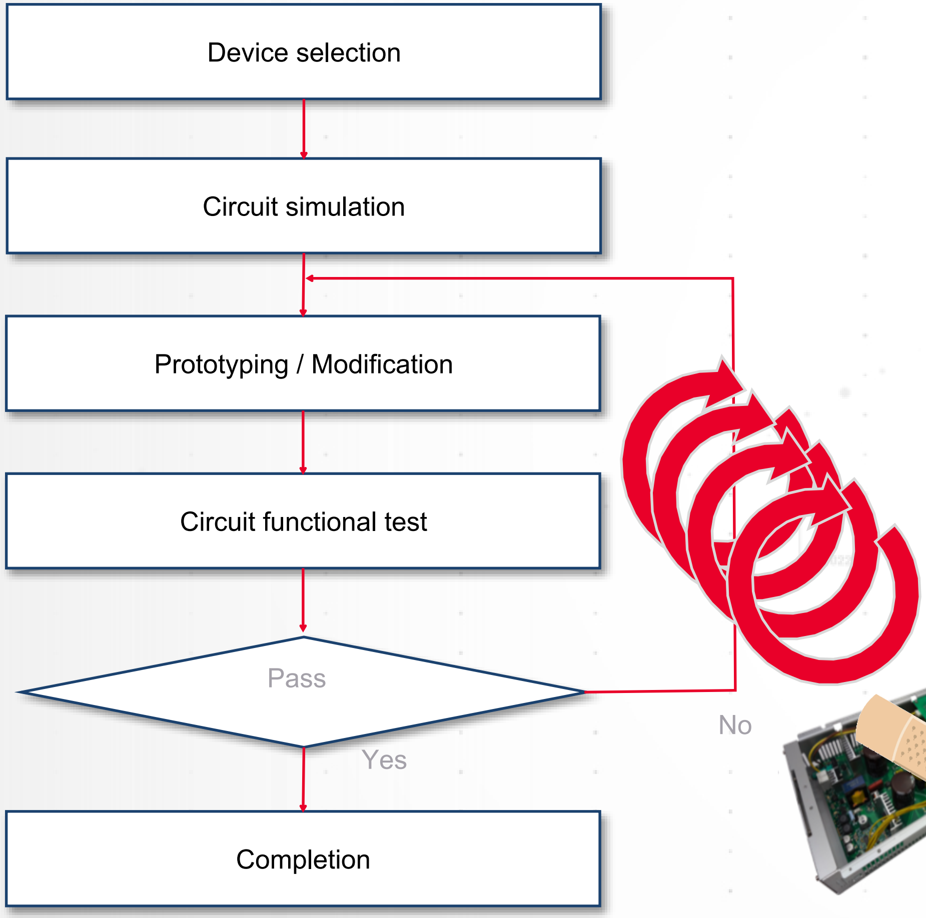


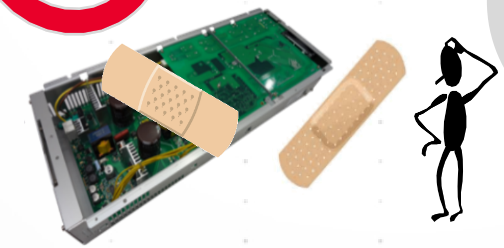
- **Design power converts to maximize efficiency while keeping cost and size down**
  - Test Challenge: Accurately measure as little as 0.1% incremental changes in power conversion efficiency
    - Power converters are at or above 95% efficiency; incremental changes require precision measurement
  - Design Challenge: Operate at high voltage to reduce size, cost of components (see below)
  - Design Challenge: Find components that work at high voltages (see below)
- **Operate at higher voltages; reduces power converter system size, weight, and cost**
  - Test Challenge: Design power converters to efficiently operate at high voltages
    - New wide-bandgap semiconductor technology helps achieve this, but comes with it’s own design challenges
  - Test Challenge: Finding test equipment that operates at high voltages
    - Cost of this equipment is higher (CAPEX)
    - Cost to operate (electricity) is higher (OPEX)
    - Produce more heat, cost to cool system increases (OPEX)
  - Test Challenge: Operating over 60 V means safety regulations (NFPA 79 in USA)
    - Adds complexity and cost to test system

Safety Disconnect

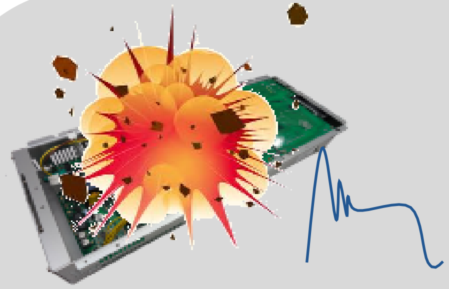
Design Challenge: New Wide-Bandgap (WBG) Technology

SIMULATION CAN REDUCE COSTS, BUT NO WBG MODELS

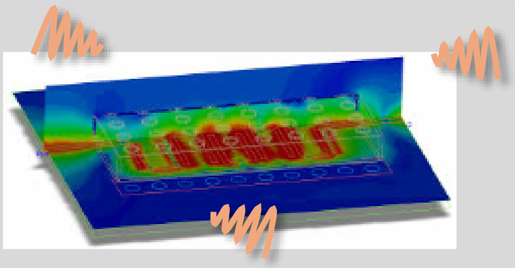




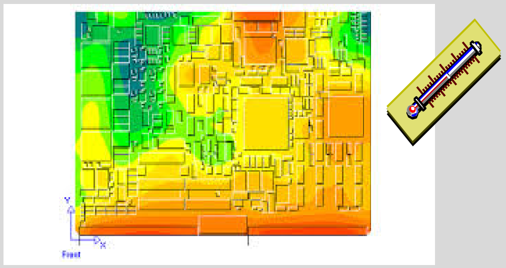
Trial and error approach won't work for WBG due to its high frequency



Prototype circuit explosion due to unexpected surge



EMI becomes the issue due to its high frequency operation



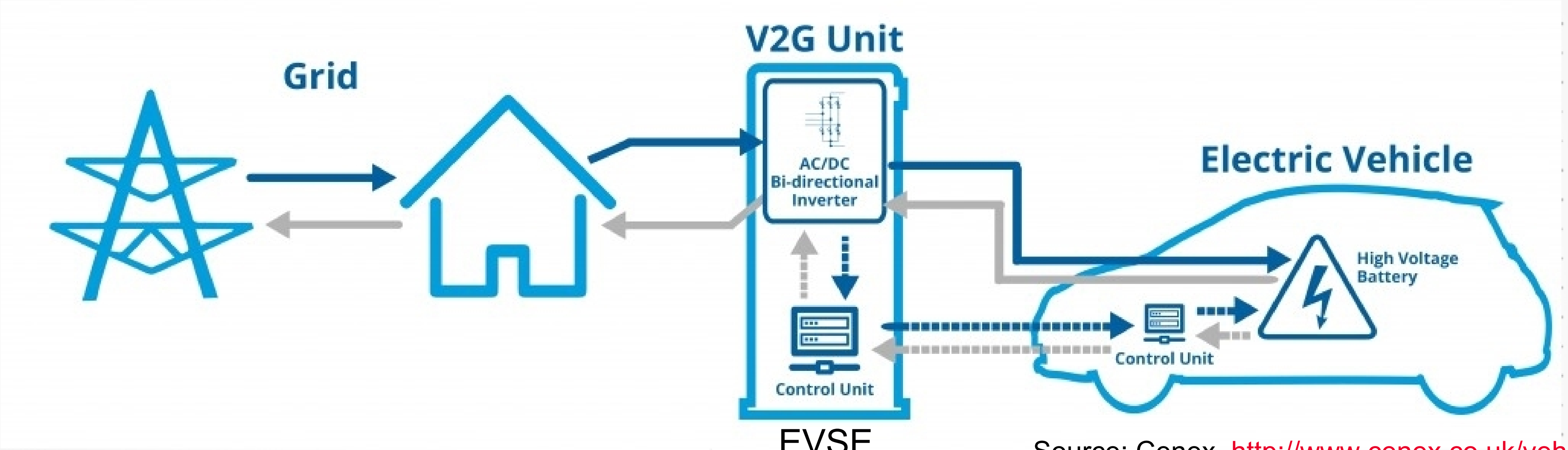
Thermal analysis is important because of high energy nature of power electronics

Poor Design Implications

– Development Costs Overrun ($100ks)
– Delayed Product Introduction (months)
– Reliability Concerns (Automotive recall - $2B)

Market Challenge: Evolving / Competing Test Standards

ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE) CHARGING STATIONS



EVSE

Source: Cenex, http://www.cenex.co.uk/vehicle-to-grid/

Evolving and competing EVSE standards

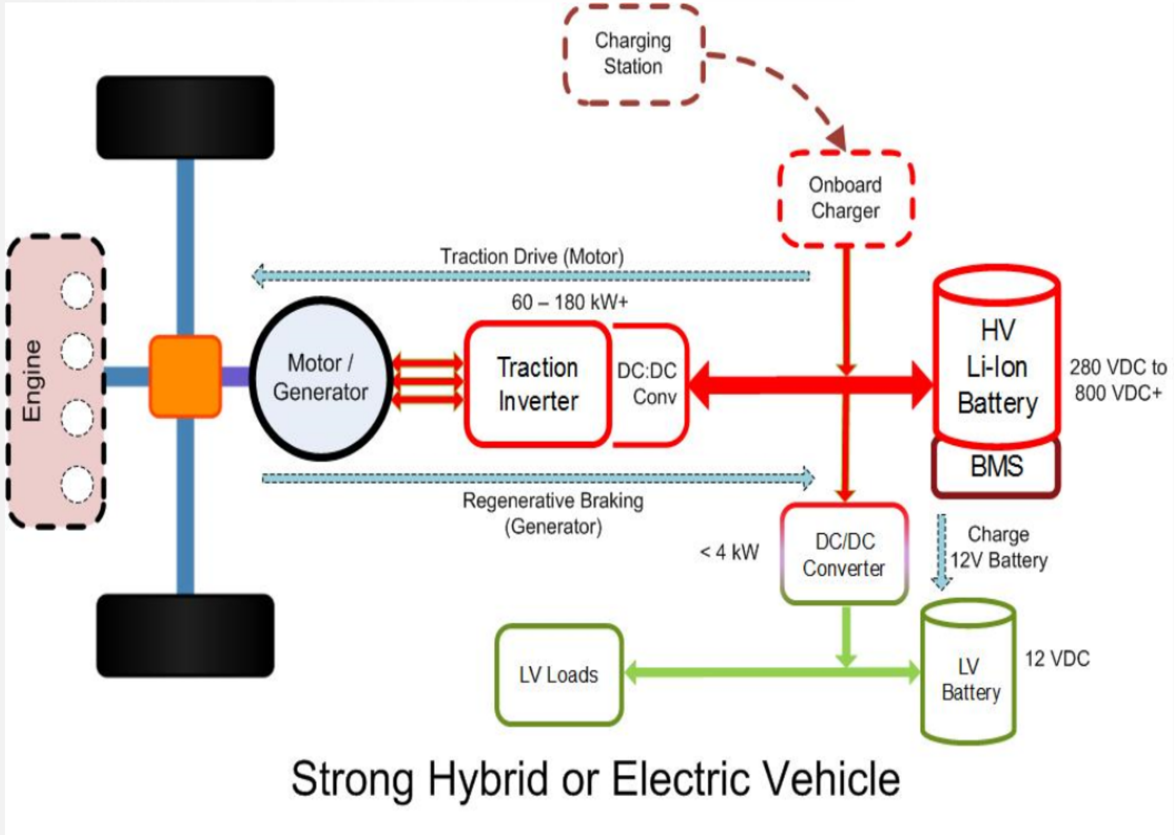
Connecters
- IEC 62196
- GB/T 20234
- SAE J1772

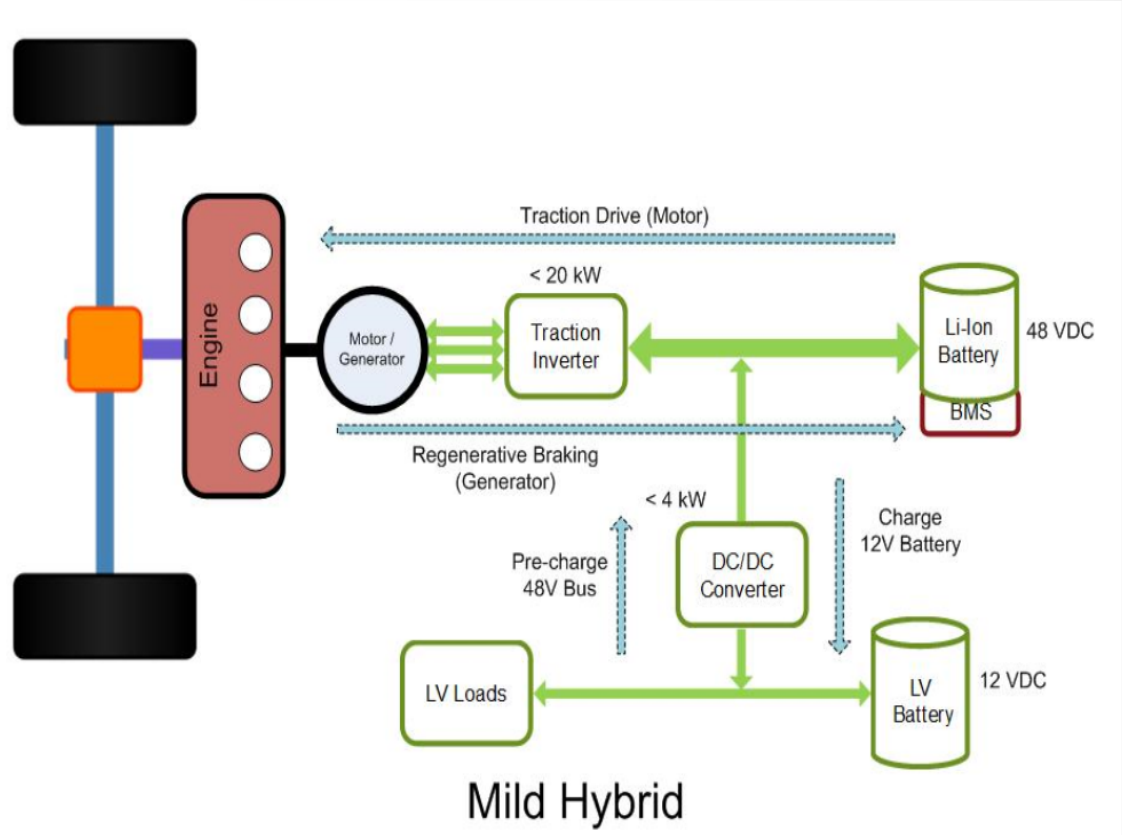
Communication
- ISO 15118
- GB/T 27930
- DIN 70121

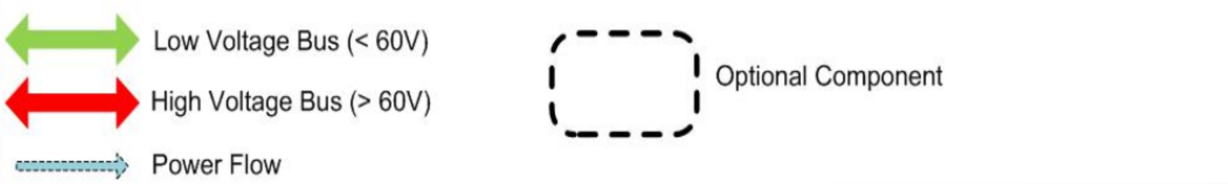
Topology
- IEC 61851
- ISO 17409
- GB/T 18487

Safety
- IEC 60364
- IEC 60529
- IEC 61140
- IEC 62040
- ISO 6469-3

Market Challenge: Bidirectional Power Flow

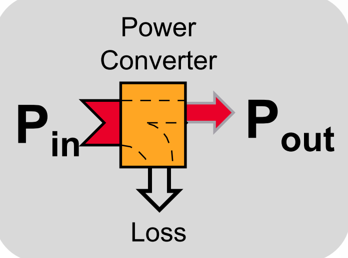


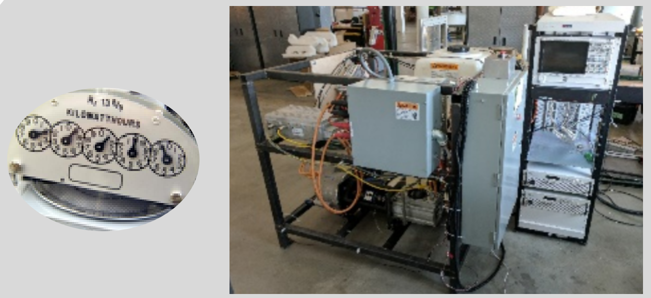




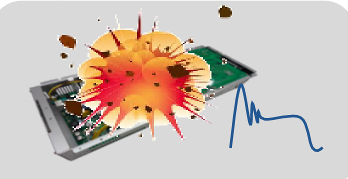
Summary: Market Pressures → Design/Test Challenge

– Cost Pressure to compete with ICE
  - Maximize Power Converter Efficiency (η)
  - High Voltage/Power Converters (+500V, 3kW–200kW)
  - Test System Cooling Requirements
  - Safety Regulations




Cost of Power Consumption & Cooling

– Technology Disruption - WBG Semiconductors
  - Less Reliable Simulation
  - More Prototype Iterations
  - Safety



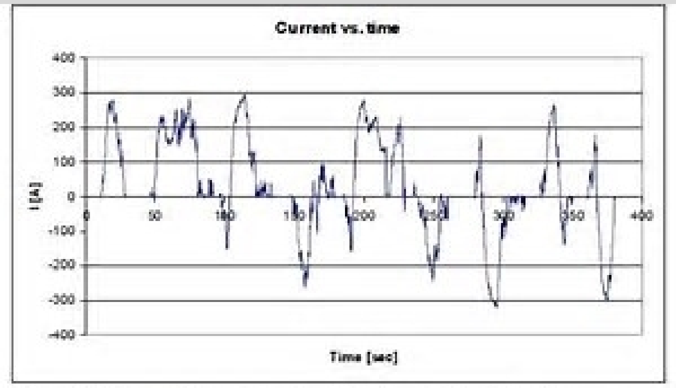
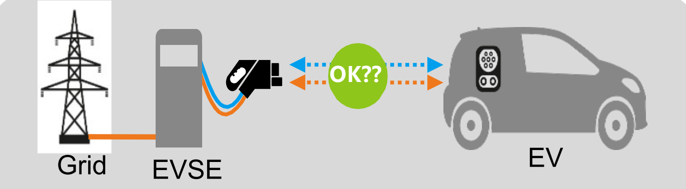
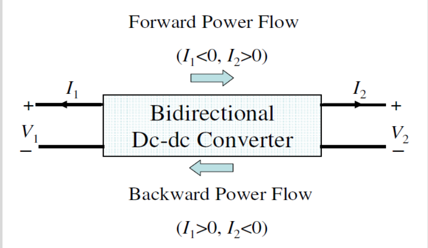


Figure 6: A logged current profile of an electrical vehicle in movement. Note the negative current during recuperation.

– Evolving/Competing Charging Standards
  - Worldwide Pre-Compliance Test



– Bidirectional Energy Flow
  - Inverters
  - EVSE
  - Mild Hybrid DC:DC Converters
  - Integrated Power Converters (OBC + DC:DC Cons)



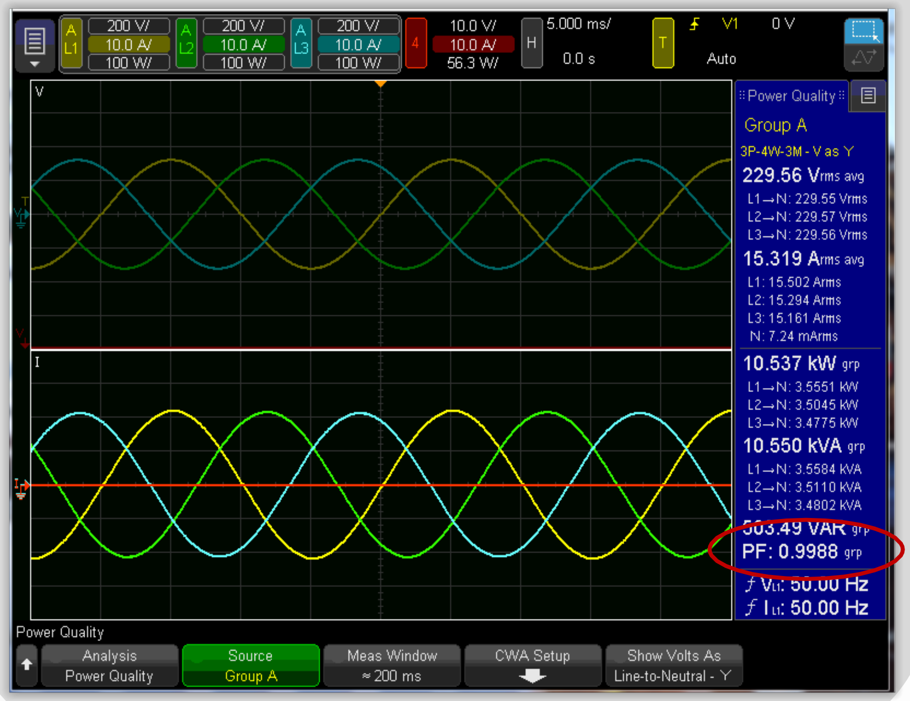
KEYSIGHT TECHNOLOGIES

Emerging Solution : Clean Power Regeneration

SAVE ENERGY AND COOLING COSTS

Signal Integrity – low THD

Power Factor ~ 1.0

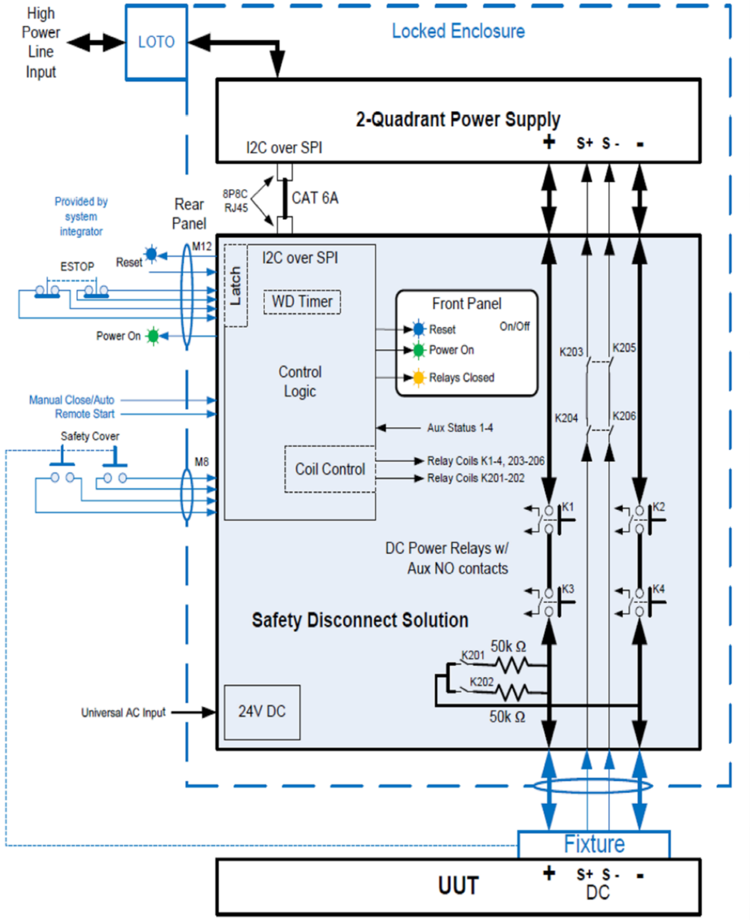


- 95% efficient power converters, why lose all that energy to heat (electronic load)?
- Why not put the energy back?
- Needs to be clean (low THD with PFC)
- New power sources can regenerate power cleanly and with power factor correction (PFC)
- Saves energy by returning power to the grid
- Saves cooling costs by generating less heat

Emerging Solution: Integrated Safety Disconnect System

POWER SOURCE + SAFETY

- Redundant Fault Tolerance
- E-STOP monitoring
- Fixture Cover monitoring
- Communication with Power Supply for fault conditions
- DC Disconnect Relays w/ mechanical coupled sense relays
- Watchdog timer
- DUT input discharge
- Remote/Local Indicator lamps
- Controls additional external Relays

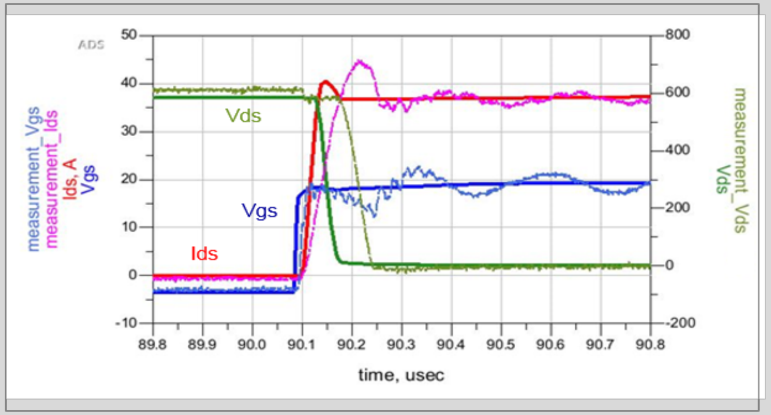


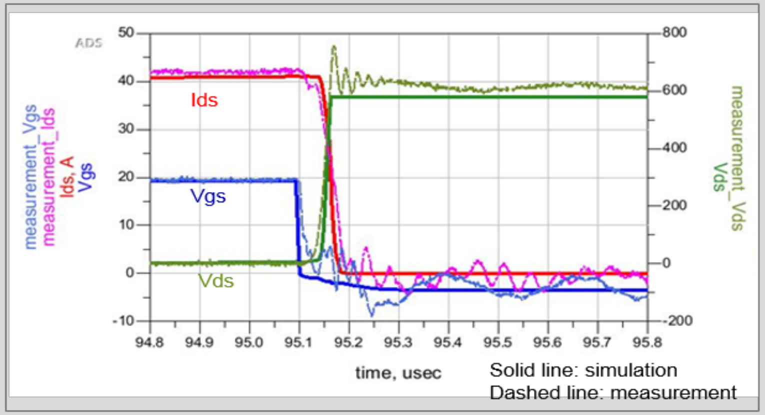
- Integrated safety off-the-shelf
- No need to design and support
- Keep your people safe at high voltages

KEYSIGHT TECHNOLOGIES

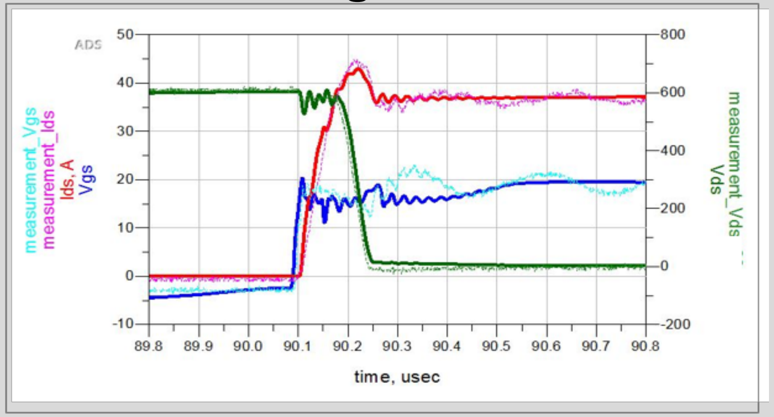
Emerging Solution: Accurate WBG Models / Simulation

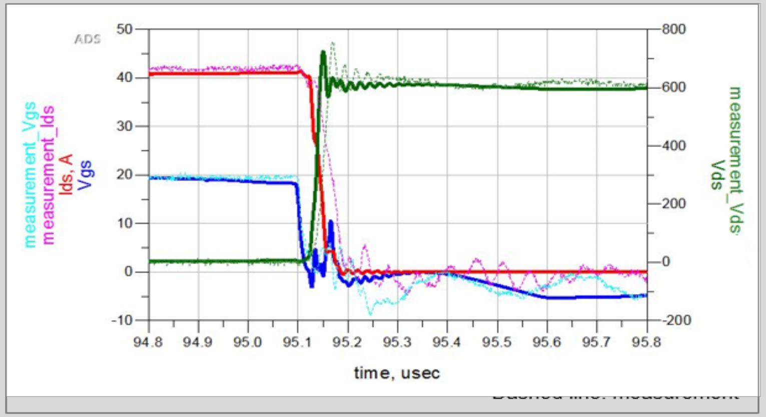
Traditional Modeling/Simulation





'Electro Magnetic Aware' Modeling/Simulation





- Create your own accurate WBG model with real measurements
- Accurate simulation
- Fail in simulation, not on the road
- Reduce design cycles
- Get to market faster
- Save time and money

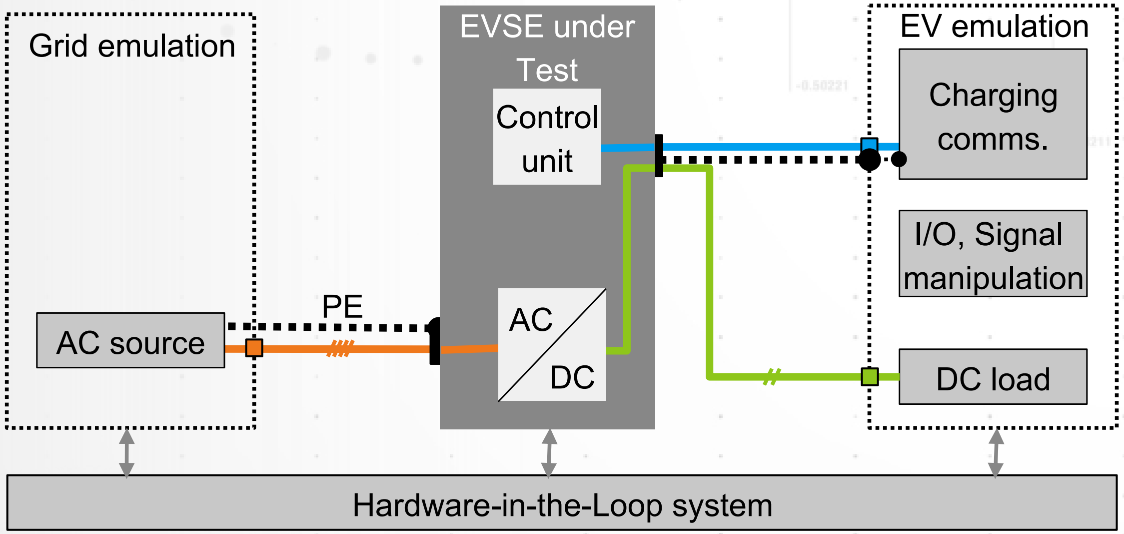
Source: Rohm Semiconductor

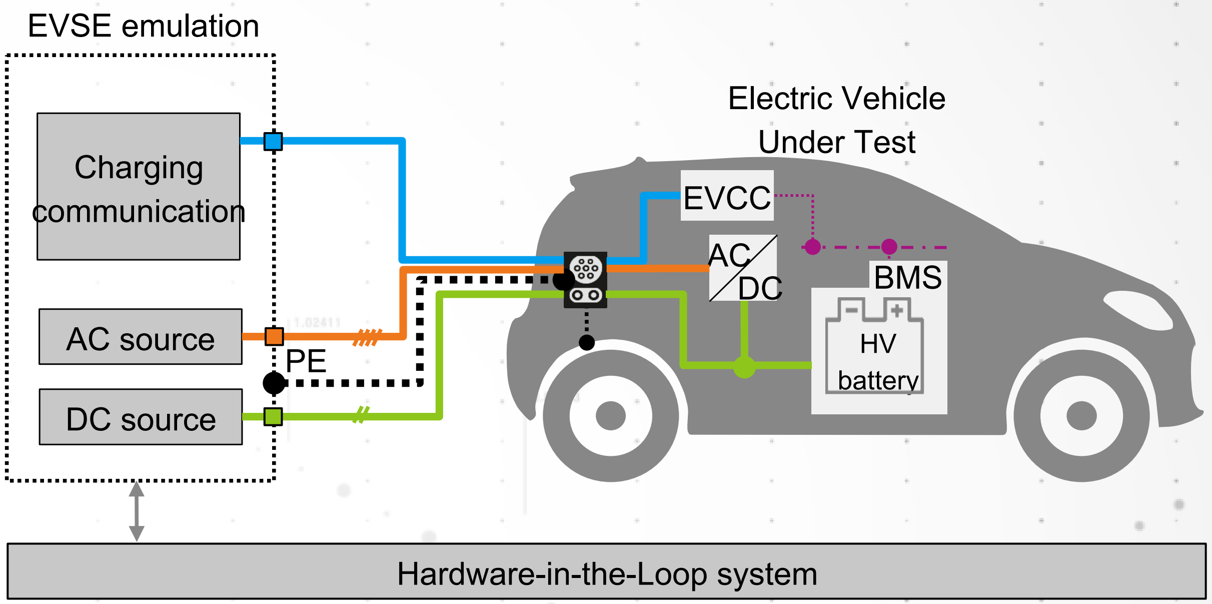
KEYSIGHT TECHNOLOGIES

Emerging Solution: Flexible, Modular EVSE / OBC Test

EVSE Test

- Emulation of worldwide power grids
- Emulation of different EVs
- Support of worldwide charging standards
- Support of all authorization and payment methods
- Safety function validation
- Bi-directional power flow
- Controlled fault injection



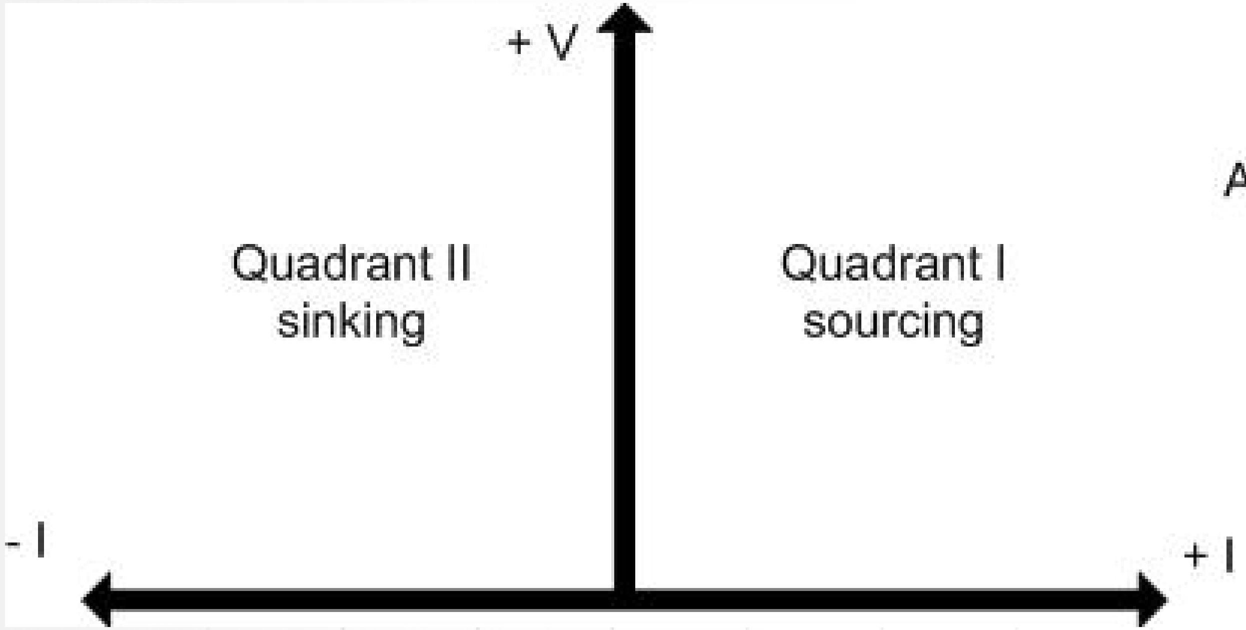


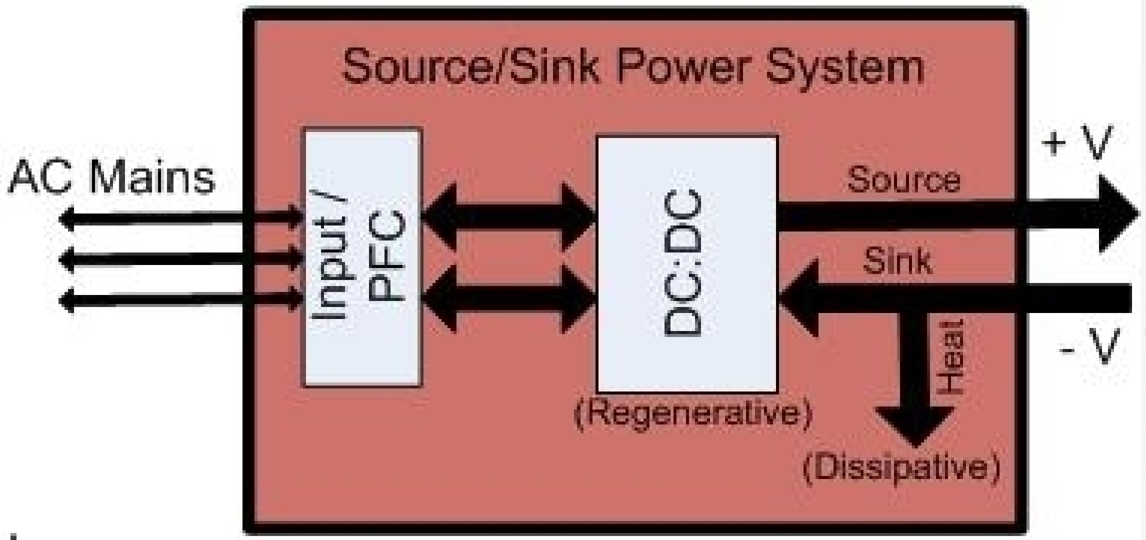
On-board Charger (OBC) Test

- Emulation of different EVSE
- Support of worldwide charging standards
- Support of AC and DC charging
- Support of all authorization & payment methods
- Safety function validation
- Bi-directional power flow
- Controlled fault injection

Emerging Solution : 2-Quadrant Power System

SEAMLESS SOURCE / SINK CAPABILITY





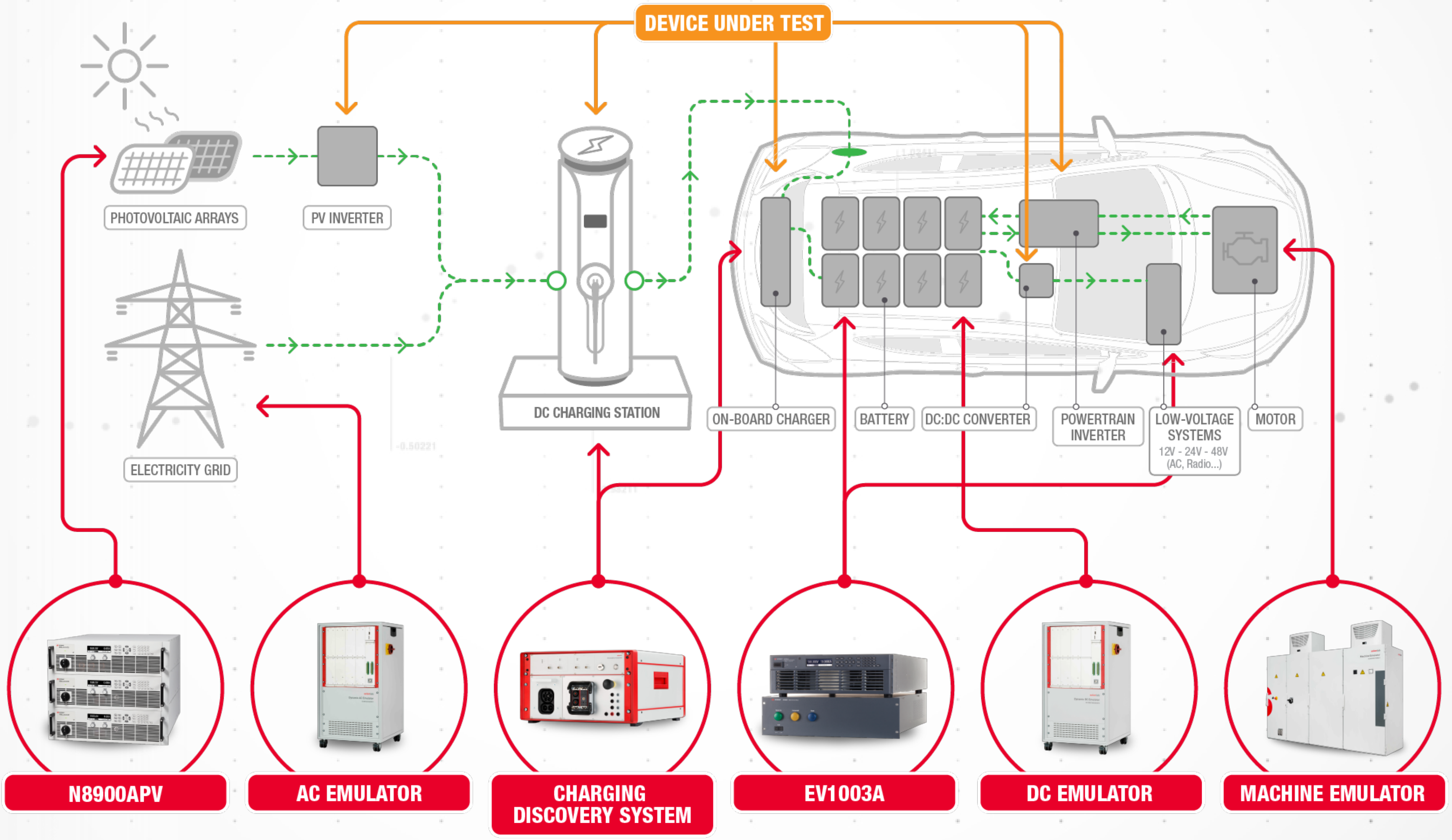
Seamless power supply / electronic-load

- Power sourcing and sinking in one
- Seamless transition from positive (+) to negative (–) current and vice versa

- Eliminates the need for extra test equipment (eLoad), reducing test complexity and cost
- Couple with regeneration of power to increase saving, reduce test system size

Keysight,s Portfolio of eMobility Ecosystem Solutions

SOLUTIONS “FROM THE GRID TO THE ROAD”



KEYSIGHT TECHNOLOGIES

Battery Measurement

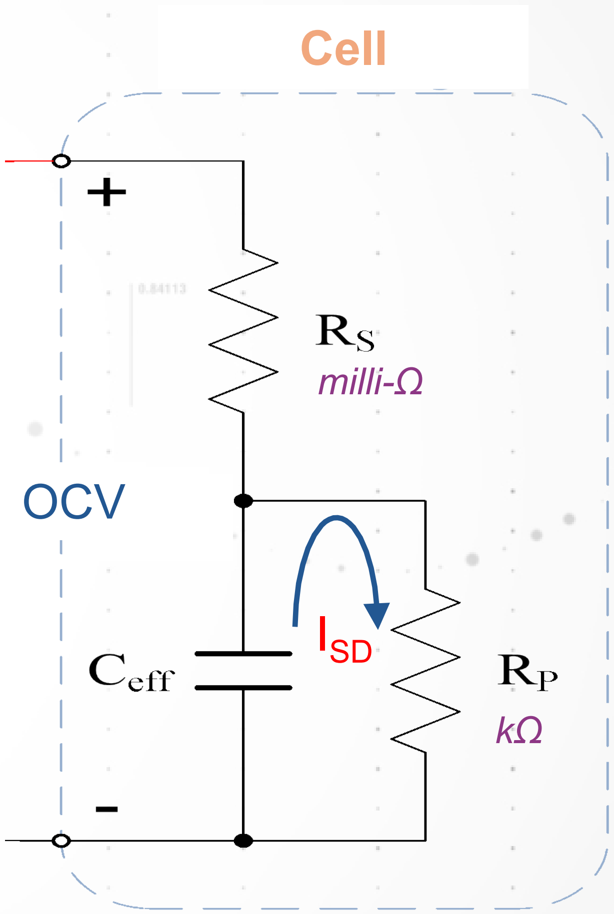
CELL / FORMING

What is self-discharge and why think about it?

- Li-Ion cells will gradually self-discharge …
  even when they are not connected to anything
- This loss of stored energy leads to lower-than-desired available capacity
- When cells are assembled into multiple-cell battery packs,
  differing rates of self-discharge leads to cell voltage imbalances within the battery
  - Typical battery management systems will discharge all the cells
    to the voltage level of the lowest cell, decreasing effective battery life
  - The battery pack, therefore, is only as good as the weakest cell in the pack
- Self-discharge is also an issue when cells are used in devices that must be stored for long periods of time, as the cell will be partially depleted when the device is put into service, resulting in poor device run time

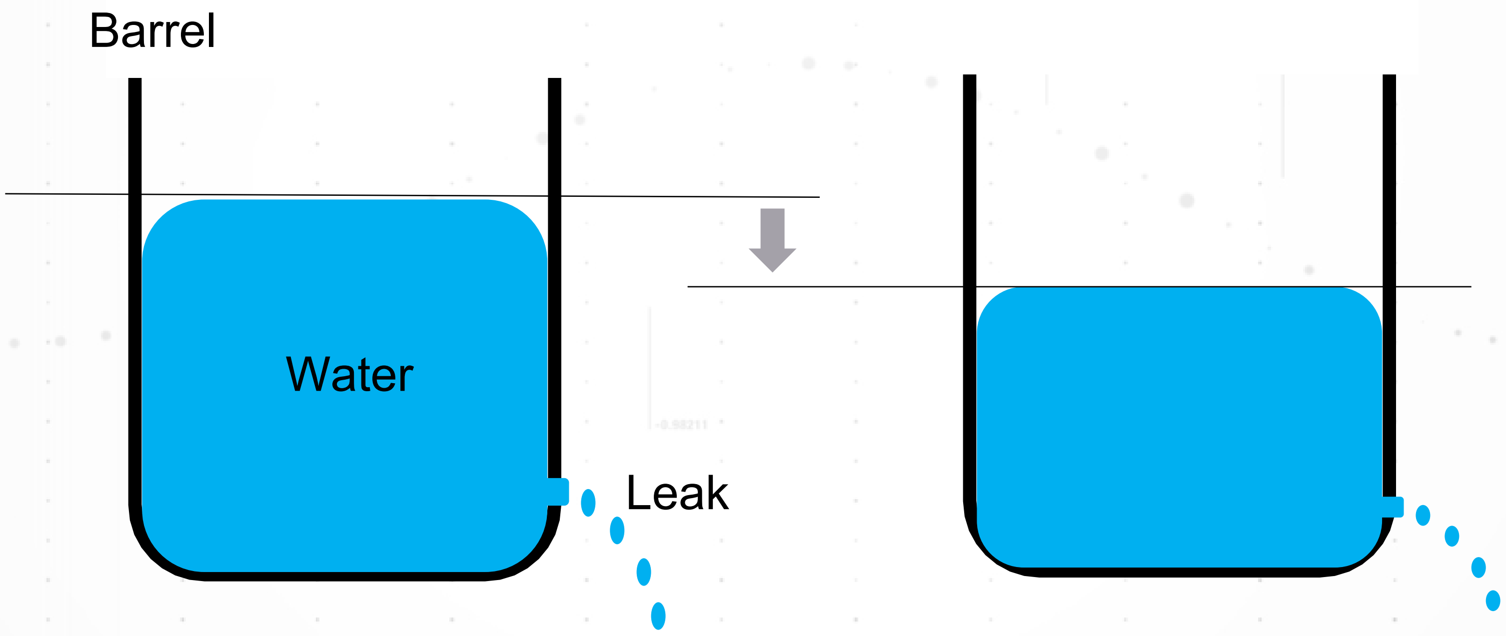
Understanding self-discharge in Li-Ion cells

- When at rest, the cell's Open Circuit Voltage (OCV) will drop over time
- Can be modeled as self-discharge of cell through parallel resistance R_p (typically 10's of kΩ)
- The normal self-discharge current I_{SD} is typically 1 -10's of µA for small cells or 10 – 100's of µA for large cells.
- I_{SD} represents the self-discharge behavior of the cell and causes the cell's State of Charge (SoC) to drop
- Slow process – it takes days or weeks for the cell's SoC to drop enough to observe a change in the cell's OCV
- A poor quality or "bad cell" could exhibit 2 - 10x more self discharge than normal, causing its OCV to drop off more quickly



Self-discharge: water barrel analogy

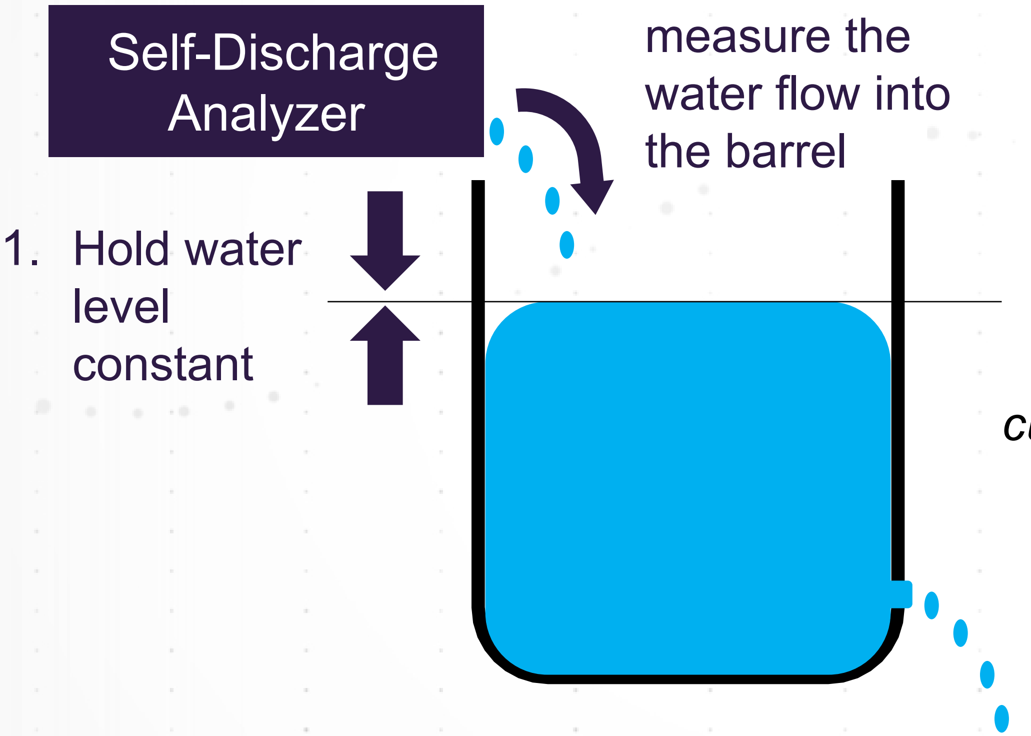
• Barrel of water filled to a level.	→	• Water level is cell OCV.
• The water leaks out of hole.	→	• Flow is the self discharge current.
• Eventually the level drops.	→	• Change in OCV vs time.



You can only measure the change in water level over a long time.
How fast is the water dripping out? You can't tell.

Potentiostatic self-discharge measurement

DIRECTLY MEASURE CURRENT, ELIMINATING NEED TO WAIT DAYS/WEEKS



If water level is held constant,
rate of water in = rate of water out

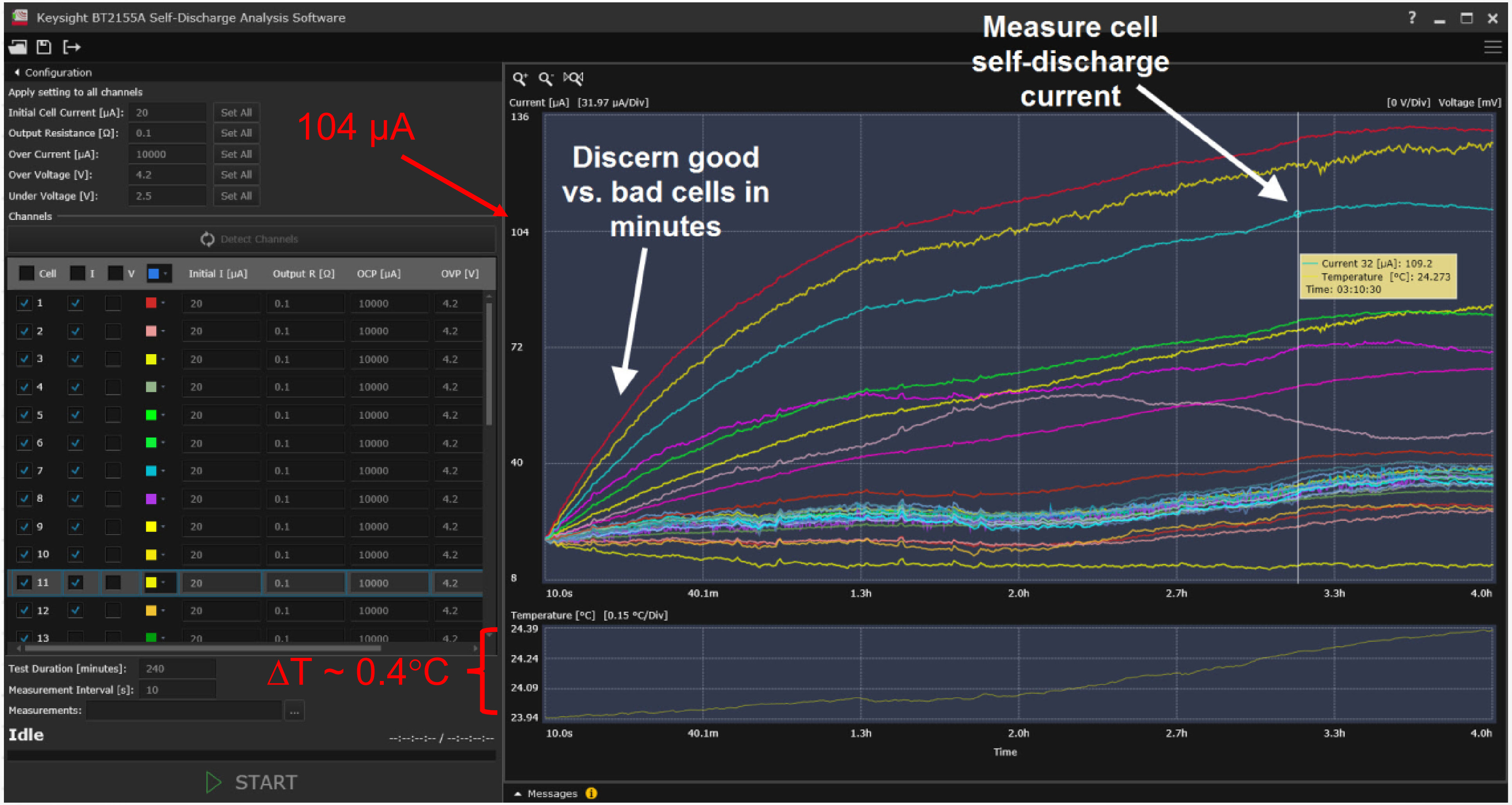
This is the potentiostatic method

If voltage is held constant,
current into the cell = discharge current

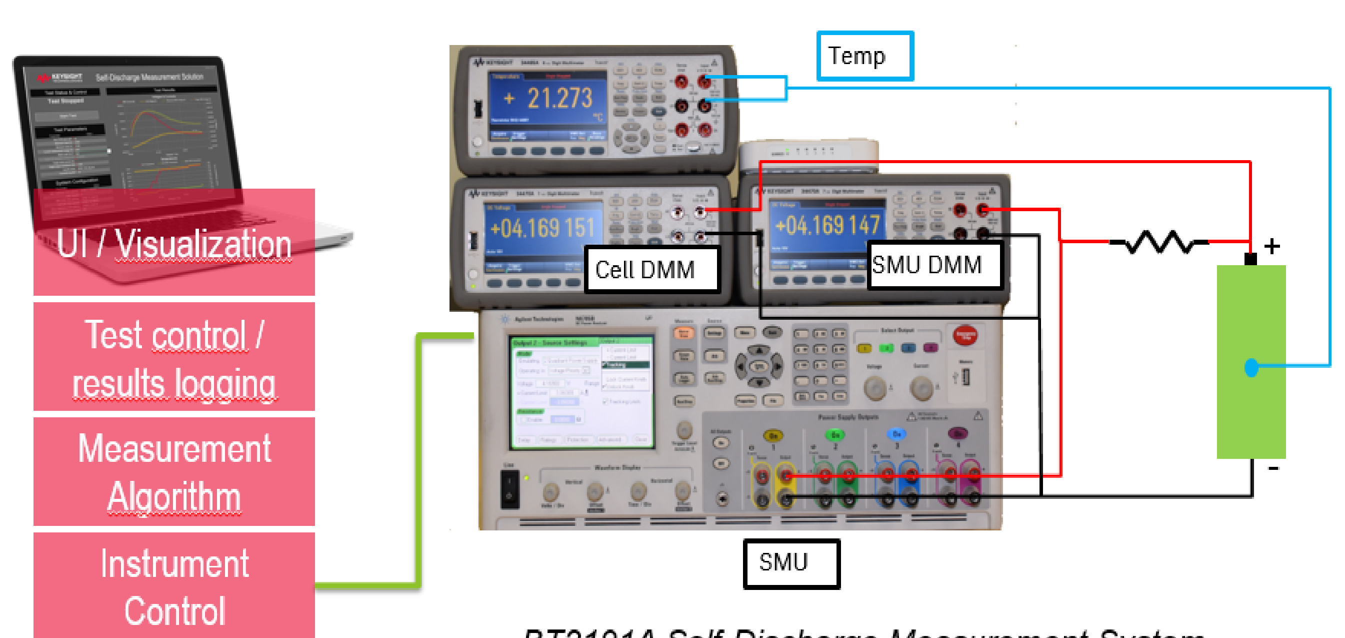
Accurately measures low-level self-discharge currents ±0.025% - ±0.33%

Test results - Self-discharge measurement

DISCERN GOOD VS. BAD IN 20 MINUTES



BT2191A Self-Discharge Measurement System



BT2191A Self-Discharge Measurement System

- 1 channel self-discharge measurement system for cell design and evaluation
- Great reduction of time required to measure cell self-discharge
  - Typically characterize self-discharge in hours vs. weeks of storage time
  - Faster evaluation results, faster design iterations
- Software for control, graphing, logging, and storage of results

Self-Discharge Measurement in Manufacturing

FOR LI-ION CELL PRODUCERS

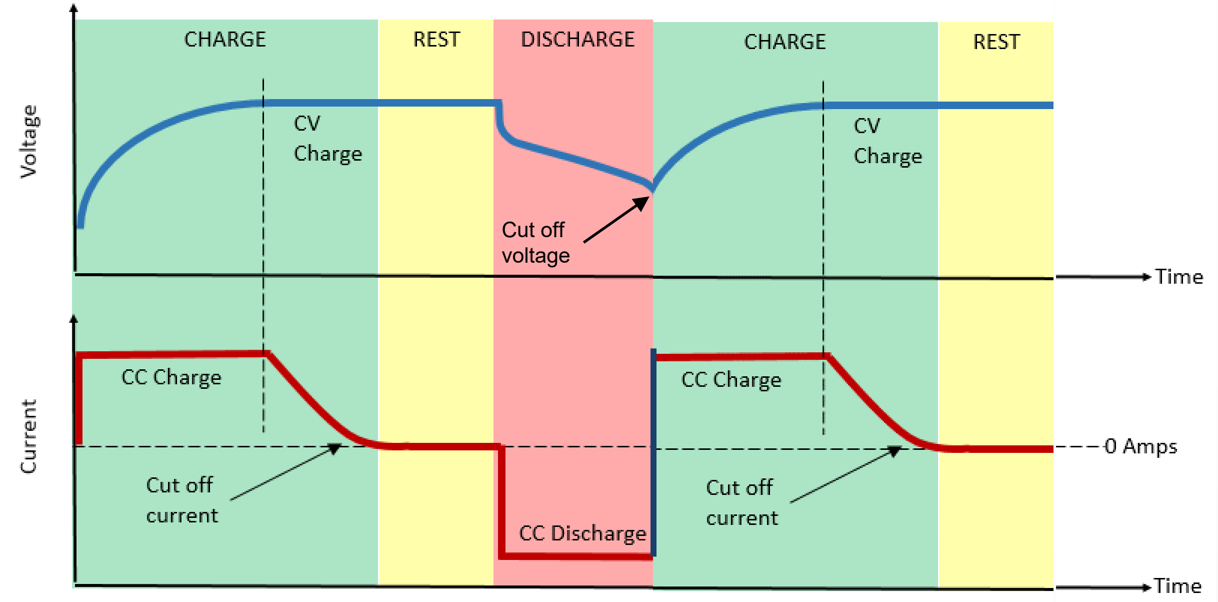
- Self-Discharge Analyzer – a new type of analyzer that measures self-discharge current on a large number of cells simultaneously
- Provides a revolutionary reduction in the time required to discern good vs. bad cell self-discharge performance
- Reduces work-in-progress (WIP), working capital, and facility costs
- 4 to 32 channels in 4 channel increments

BT2152A Self-Discharge Analyzer

32 channels, 2U rack mount

What is Cell Formation? How is it Done?

- Formation is process applying the initial charge/discharge cycles to a cell. Formation electronics are integrated with cell fixturing, material handling, and factory automation.
- Transforms assembled, non-energized cell into an electrically energized cell ready for use. Forming creates the solid electrolyte interface (SEI) layer in the cell.
- Duration, extent (full vs. partial), and number of cycles vary widely by cell type, capacity, and manufacturer. Typically closely guarded and proprietary information.
- Measurements are an important part of the forming process: The amount of charging, discharging, when to stop each, and net charge consumed are all critical.



Charge Discharge Formation Cycles

BT2200 Charge-Discharge System for Li-Ion Cell Formation

Amperage/cell	Max cells/chassis
6A	256 channels
60A	24 channels
100A	16 channels
200A	8 channels

Competitive advantages:

- Regenerative design with industry-leading energy efficiency
- High channel count in small package that is adaptable for cell sizes
- Flexible, straight-forward programming simplifies even complex set ups
- High-accuracy output sourcing and measurement
- Extensive protection features

Keysight HEV / EV Charging Infrastructure Test Solutions

ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE)

- Grid emulation for charging station test: Keysight/Scienlab Dynamic AC Emulator (ACE)
  - Product page: http://www.scienlab.com/products/dynamic-ac-emulator?product-finder=2427
  - Brochure: www.scienlab.com/sites/default/files/scienlab_dynamic_ac_emulator_0.pdf
- Photovoltaic (PV) / Solar Array Simulation for PV inverter test: Keysight N8900APV
  - Product page: http://www.keysight.com/find/N8900APV
  - Brochure: https://literature.cdn.keysight.com/litweb/pdf/5992-0999EN.pdf?id=2818560
  - Software: https://www.keysight.com/find/SAScontrolSoftware
  - Videos: https://www.youtube.com/playlist?list=PL2XuMA5AwNUwYj7oLO84xp-Kk0o-cW_1P
- Test to charging standards: Keysight/Scienlab Charging Discover System (CDS)
  - Product page: http://www.scienlab.com/products/chargingdiscoverysystem?product-finder=2427
  - Brochure: http://www.scienlab.com/sites/default/files/scienlab_chargingdiscoverysystem_0.pdf
  - Software: http://www.scienlab.com/products/software-chargingdiscover
  - Video: https://youtu.be/nZy6KbGGnCE

Keysight HEV / EV Power Converter Test Solutions

BATTERY CHARGING AND LOW-VOLTAGE SYSTEMS

- On-Board Charger (OBC) Test
  - Keysight EV1003A Power Converter Test Solution for HEV/EV and HEMS
    - Product page: https://www.keysight.com/find/EV1003A
    - Brochure: https://literature.cdn.keysight.com/litweb/pdf/5992-2283EN.pdf?id=2857541
    - Videos: https://www.youtube.com/playlist?list=PLvQ5Bzr3tM50KiGhVimx5ALOy5pBDylaX
  - Keysight/Scienlab Dynamic DC Emulator (DCE)
    - Product Page: http://www.scienlab.com/products/dynamic-dc-emulator?product-finder=2427
    - Brochure: http://www.scienlab.com/sites/default/files/scienlab_dynamic_dc_emulator_0.pdf
- Low-Voltage Systems Test
  - Keysight EV1003A (details above)
  - Keysight/Scienlab DCE (details above)
  - Keysight N3300A DC Electronic Loads
    - Product page: https://www.keysight.com/en/pc-1000000453%3Aepsg%3Apgr/n3300a-configurable-dc-electronic-load-mainframe-series?cc=US&lc=eng
    - Brochure: https://literature.cdn.keysight.com/litweb/pdf/5980-0232E.pdf?id=1000070562:epsg:dow
    - Videos available on YouTube

Keysight HEV / EV Powertrain Test Solutions

Powertrain inverter test (bi-directional)

- DC side: Battery emulation with Keysight EV1003A or Keysight/Scienlab DCE
  - Keysight EV1003A suited for mild hybrid (48 V)
  - Keysight/Scienlab DCE suited for mild hybrid and higher voltage / higher power
- AC side: Keysight/Scienlab Machine Emulator
  - Product page: http://www.scienlab.com/products/machine-emulator?product-finder=1872
  - Brochure: http://www.scienlab.com/sites/default/files/scienlab_machine_emulator_0.pdf

Keysight Wide-Bandgap Semiconductor Modeling Soln.

POWER CONVERTER DESIGN

- Wide-bandgap semiconductor modeling – power electronics design simulation
  - www.keysight.com/find/PD1000A
  - www.keysight.com/find/PEMG
  - www.keysight.com/find/EDA

KEYSIGHT
TECHNOLOGIES