Design and Test Challenges of EV/HEV

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Business Development

SEP 11,2018

KEYSIGHT TECHNOLOGIES

Our Expectations Are Growing: The Car Industry

LAST 220+ YEARS (1770 – 1997)

1770 → 1885 → 1997 →

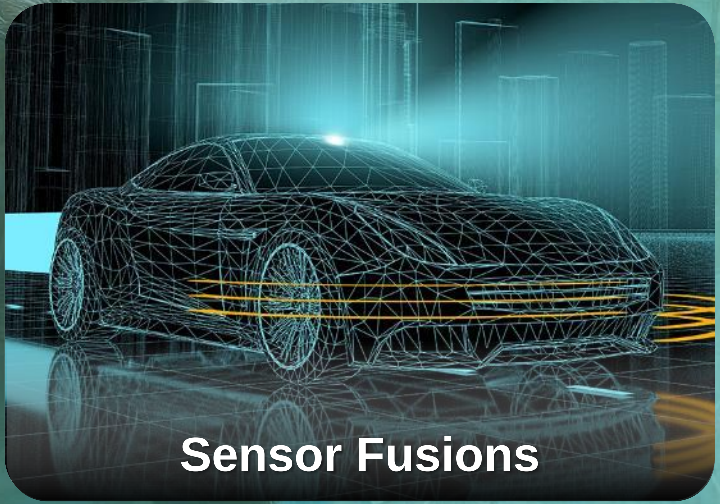
Progress was electromechanical in the first **220+ Years**

KEYSIGHT TECHNOLOGIES

Pace of Innovation is Accelerating

LAST 20+ YEARS

2004



2016

2020+

Innovation has completely **revolutionized** the industry

Automotive Trends

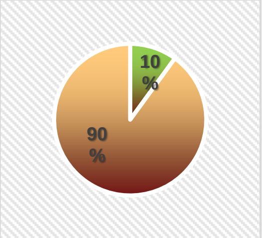
New Energy Driven

- **Technology**: Battery, Motor, MCU
- **Participator: OEMs, Battery manufacturers:**

25EV Year:2020

Produce 600k EV/HEV Year:2020

- **Government(China):**



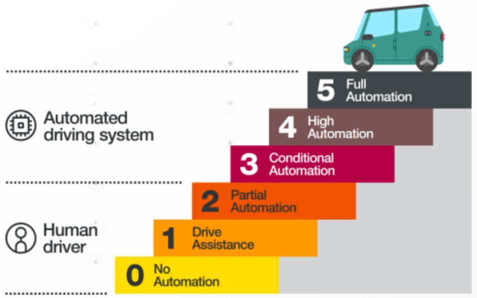
Annual sales over 30k units need to comply Need to obtain 10% of credits for NEVs in 2019

Connected car

- **Technology:** DSRC,LTE-V
- **Participator:** Communication Enterprises, OEMs, Tier1, Government
- **5GAA:**

Autonomous Driving

- **Technology:** Sensor + Data fusion
- **Participator:** Communication Enterprises, OEMs, Tier1, Government
- **Level 5 Autonomous Cars**



Car Sharing

- **New business mode**

Innovation is Cross-Domain

KEYSIGHT HAS LONG STANDING EXPERTISE ON ALL DOMAINS

Wireless RF
- 2G / 3G / 4G / 5G
- 802.11p DSRC
- Bluetooth, NFC

mmWave
- Automotive Radar
- 5G
- mmWave backhaul

Optic
- In-Vehicle Communication
- Long-hall Communication
- Datacenter

Energy / Power
- Battery
- Power Converter
- Grid

INVERTER

High Speed Digital
- Automotive Serial Bus
- Computer
- Smart Device

Power Component
- Power Semiconductor
- Wideband Gap
- Packaging

Our insight, Our solutions, Our focus

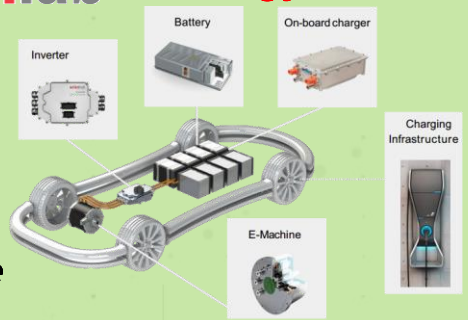
HARDWARE+SOFTWARE+PEOPLE=INSIGHT

New Energy

KEYSIGHT TECHNOLOGIES + scienlab = **Energy solutions**

Including:

BMS
Battery
Inverter
OBC
Charing Infrastructure



Services

KEYSIGHT TECHNOLOGIES = Accelerate Technology Adoption , **Lower costs**

One-Stop Calibration Services

Uptime Support

Asset Management

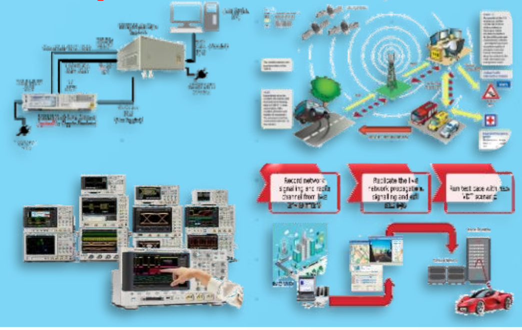
KEYSIGHT TECHNOLOGIES = **Leading brand**

Mobile Chipsets · *Devices* · *Network Access* · *Core Network* · *Data Center*

Connected Car

KEYSIGHT TECHNOLOGIES = **Comprehensive Solutions**

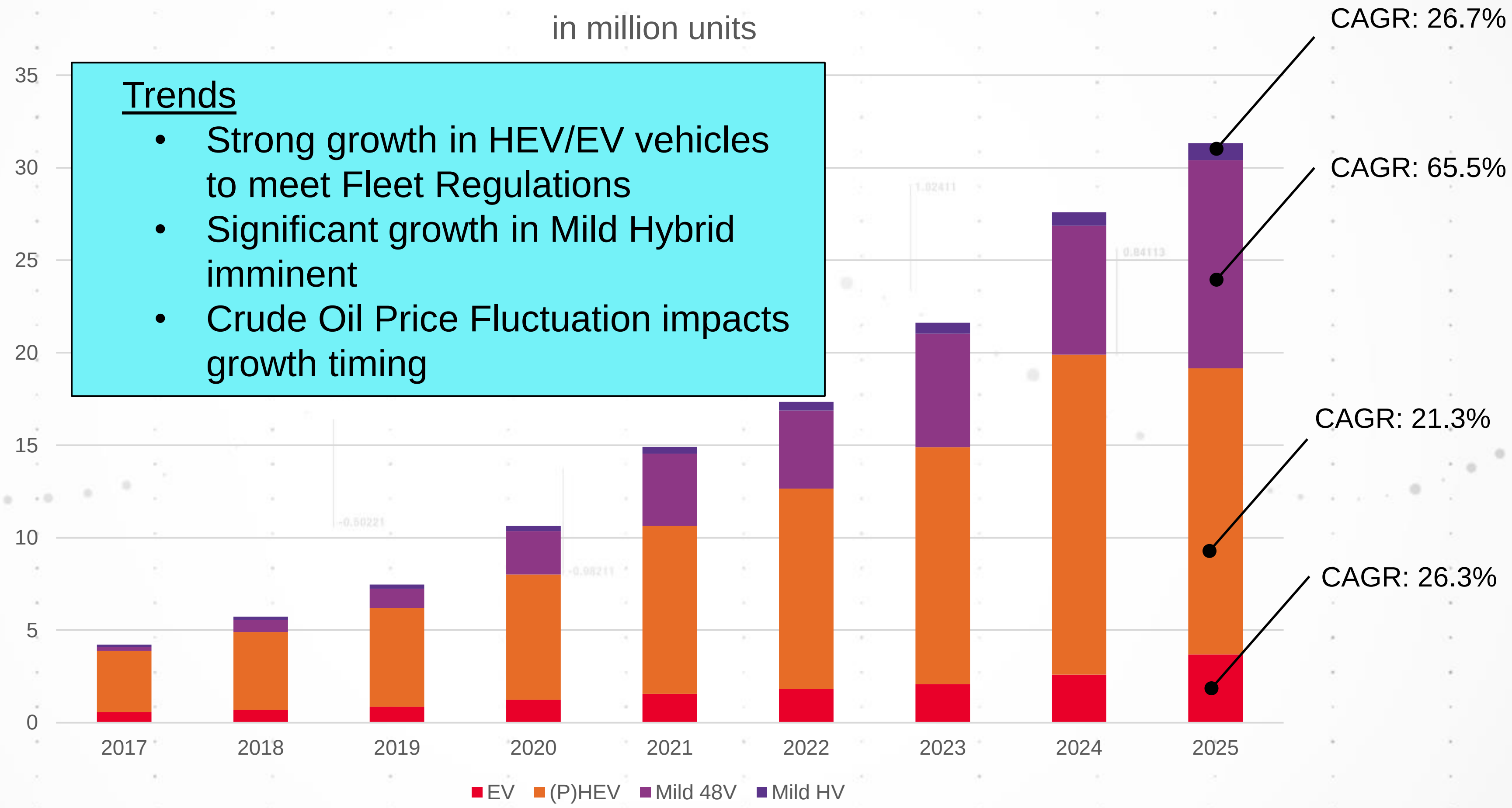
Radar
eCall
Car Ethernet
VDT
And More…



Autonomous Driving

Energy & Automotive: Worldwide Forecast

HEV/EV Worldwide Forecast

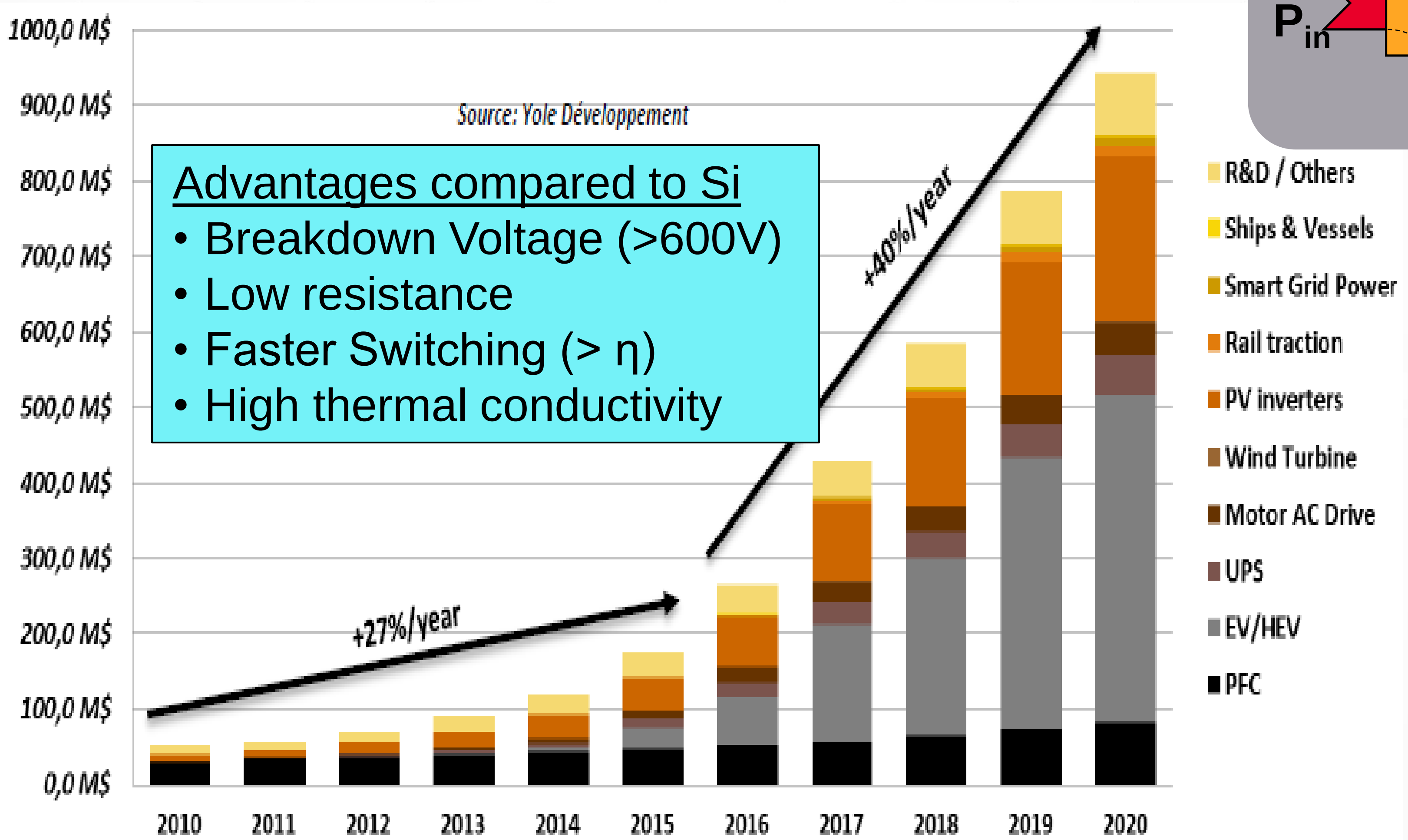


Trends
- Strong growth in HEV/EV vehicles to meet Fleet Regulations
- Significant growth in Mild Hybrid imminent
- Crude Oil Price Fluctuation impacts growth timing

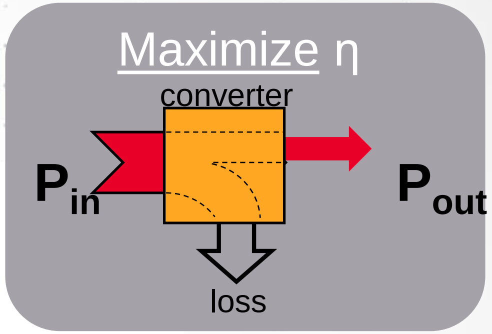
Source: Average of multiple reports (Navigant, Yole, ,etc.)

Wide Bandgap (WBG) Technology Adoption

SIC PROJECTED GROWTH

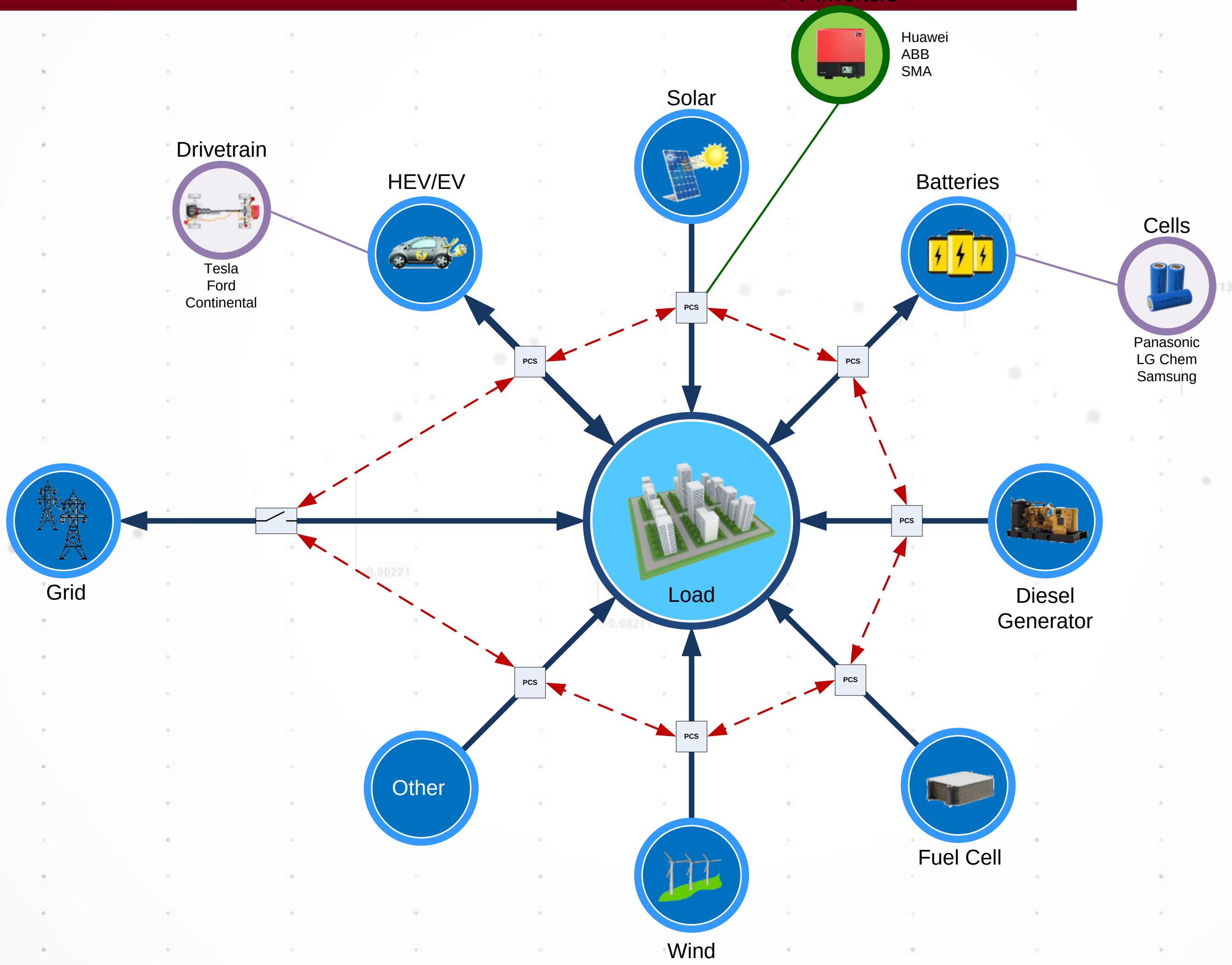


Advantages compared to Si
- Breakdown Voltage (>600V)
- Low resistance
- Faster Switching (> η)
- High thermal conductivity



Automotive & Energy Segments

SMART GRID, HEV/EV, BATTERIES



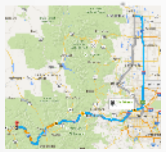
HEV/EV Economic Drivers/Constraints

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



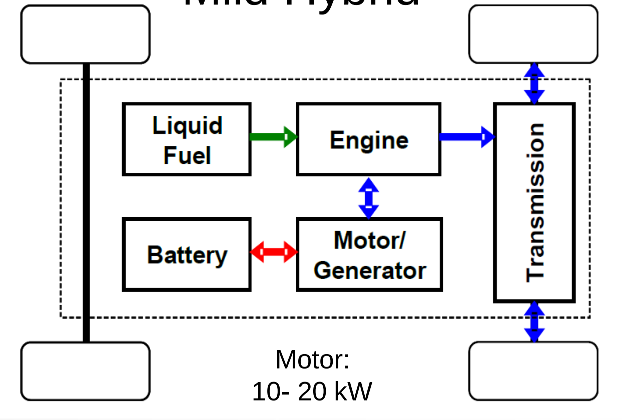
Range Anxiety - Even people who never drive beyond 80 miles in a day want the option to do so.
Source Quora

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

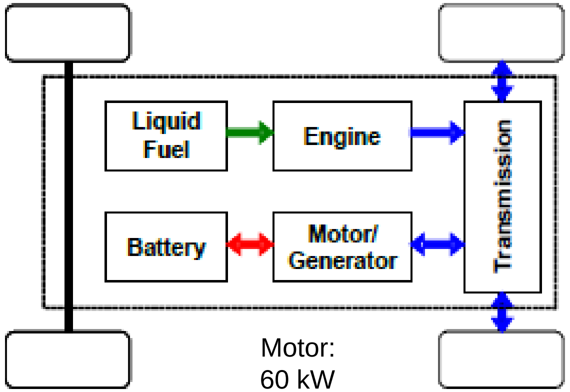
HEV/EV Powertrain Architectures

Mild Hybrid



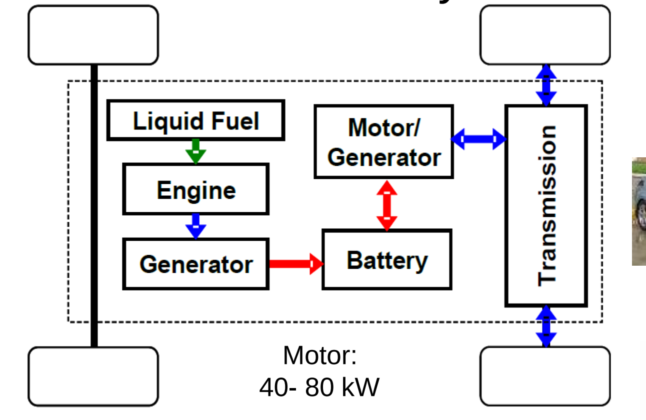
Honda Insight

Full/Parallel/Strong Hybrid



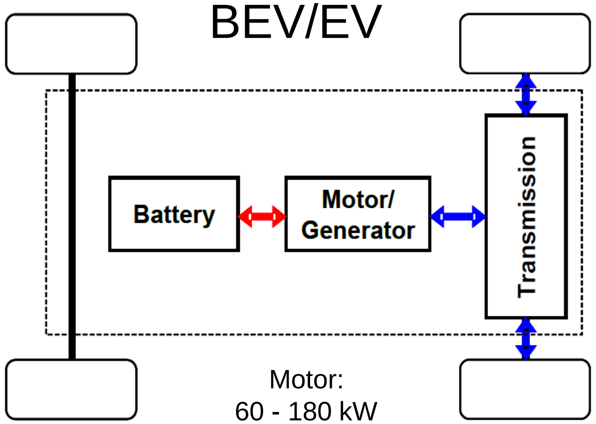
Toyota Prius

eREV/Series Hybrid



GM Volt

BEV/EV



Ford Focus

Source: MIT Electric Vehicle Team, April 2008

Components:
Challenges & Countermeasures

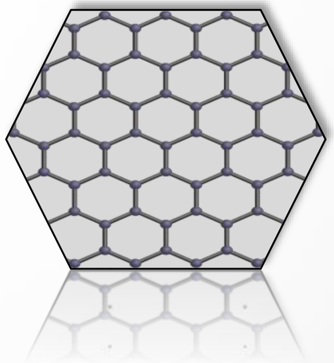
From Now to the Future

WHY LI-ION BATTERY

- **Li-ion Battery**

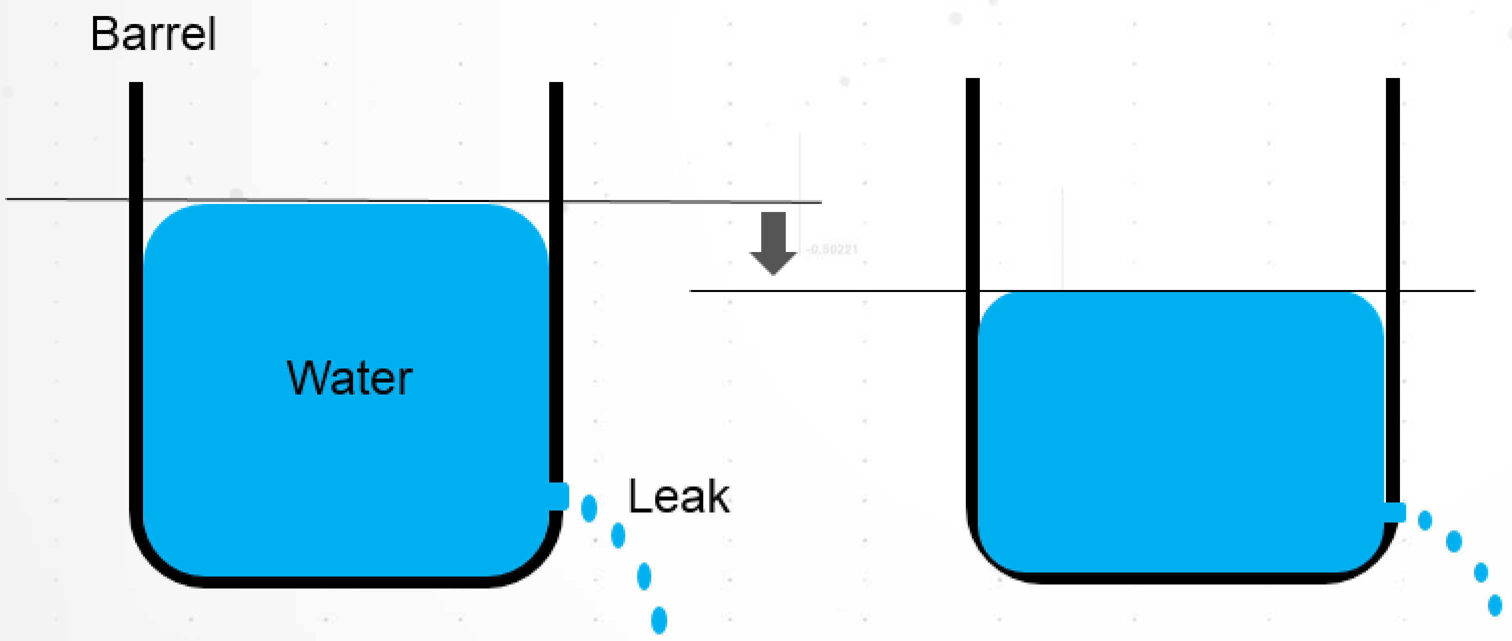
- **Fuel Cell Battery**

- **Graphene**



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.



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

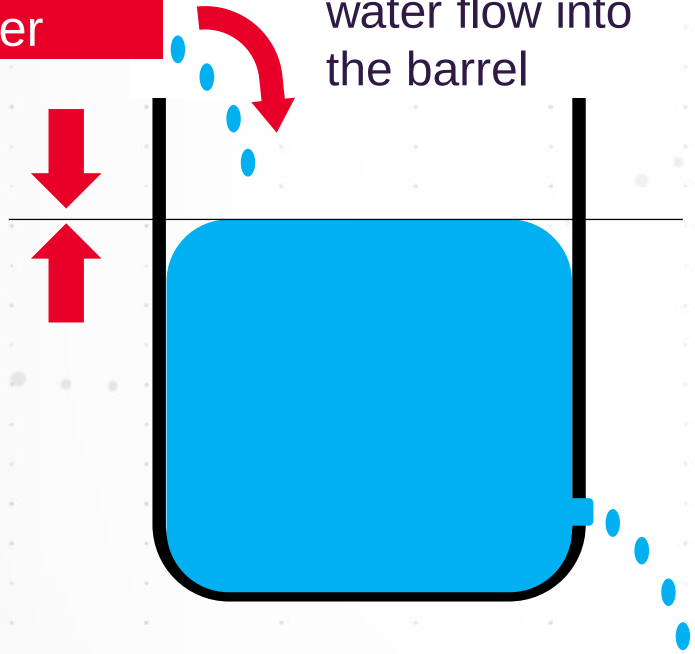
Potentiostatic self-discharge measurement

DIRECTLY MEASURE CURRENT, ELIMINATING NEED TO WAIT DAYS/WEEKS

Keysight Self-Discharge Analyzer

1. Hold water level constant

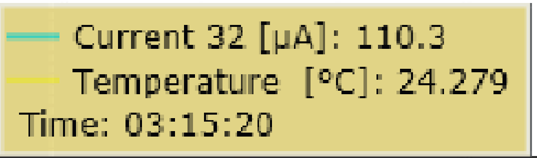
2. Source and measure the water flow into the barrel



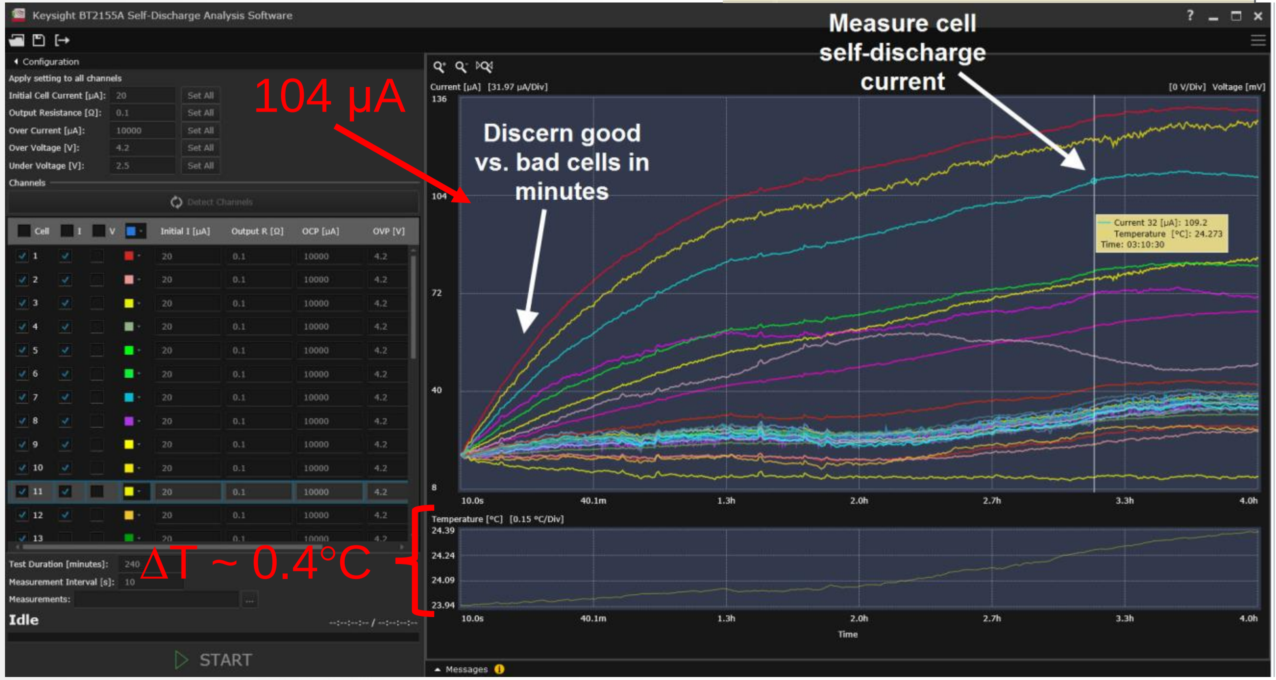
- If water level is held constant, *rate of water in = rate of water out*
- This is the potentiostatic method
- If voltage is held constant, *current into the cell = discharge current*

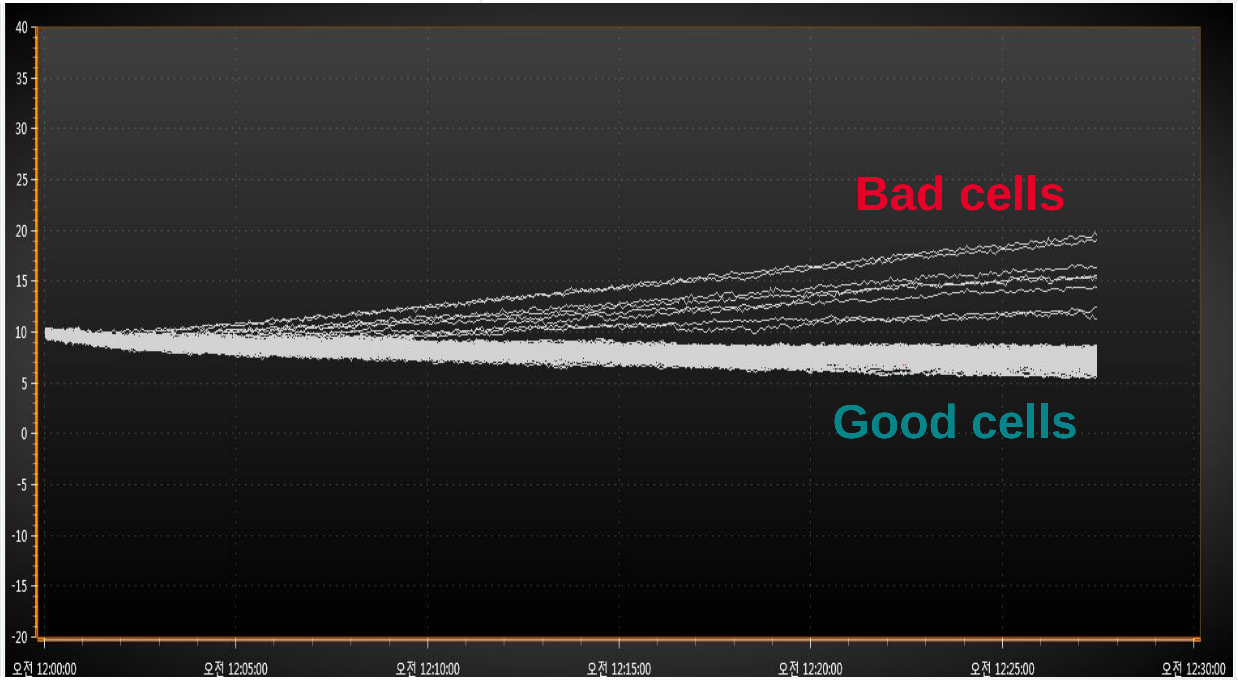
Test results - Self-discharge measurement

- 32x 18650 cells; 4-hour test. Some have resistor in parallel to simulate leakage.
- Stable results in ~3 hours; discern good vs. bad in 20 minutes.



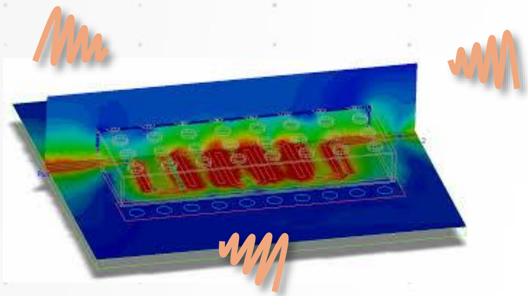
- 18650 cells: differentiate good vs. bad in just 15 minutes
- 248 cells are **good cells**. They stay clustered together.
- 8 cells are **bad cells**. They quickly present themselves outside of the cluster



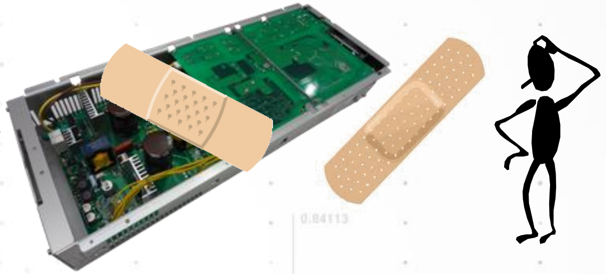


Challenges in power circuit design

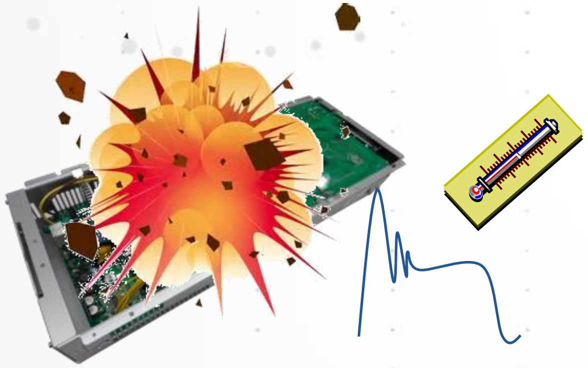
Lack of EDA tools for circuit design with WBG (SiC/GaN)



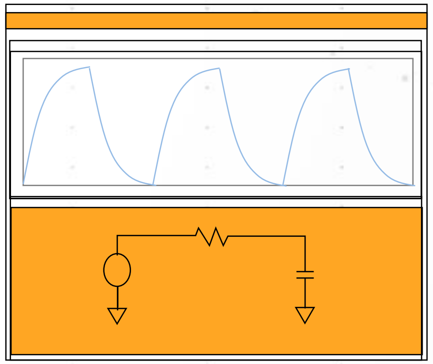
High switching frequency along with high frequency components in waveform causes unexpected EMI



High switching frequency and associated surge/ringing cause malfunction



Prototype circuit explosion due to unexpected surge



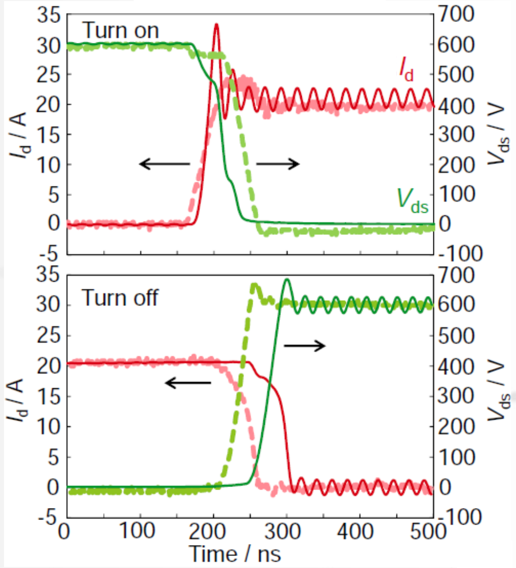
Lack of power circuit simulation tool. Conventional tool may work for low frequency circuit but not for WBG device circuit

Enabling technology – Promising simulation

ADS, Keysight math model and measurement results can change the world

Simulation with a conventional model

Dotted: Measured
Solid: Simulation



Waveforms don't match.
Exact waveform match is critical for noise calculation as waveform contains high frequency components

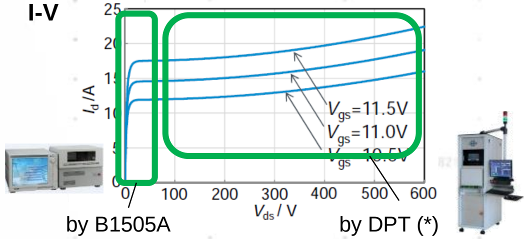
Apply Keysight mathematical model and key measurement data

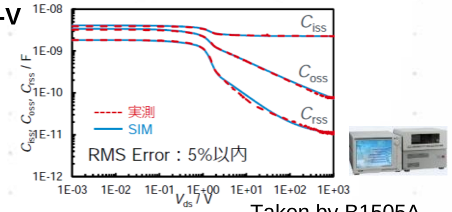
Keysigh math basic current equation

$$I_{ds} = I_{pk0} \times (1 + \tanh(\varphi)) \times \tanh(\alpha \times V_{ds}) \times (1 + \lambda \times V_{ds})$$

- Specially developed mathematical model uses tanh in current equation or capacitance equation
- Good convergence
- Easy to represent complex IV or CV
- Less number of parameters (< 100)
- Generic and applicable regardless of material or structure

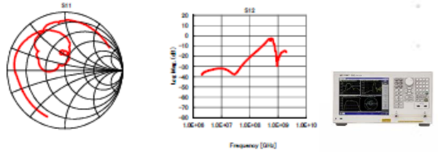
Polynomial model based on a math model



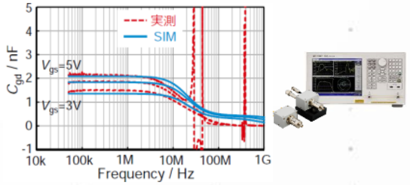


Taken by B1505A

S-parameters for circuit parasitic

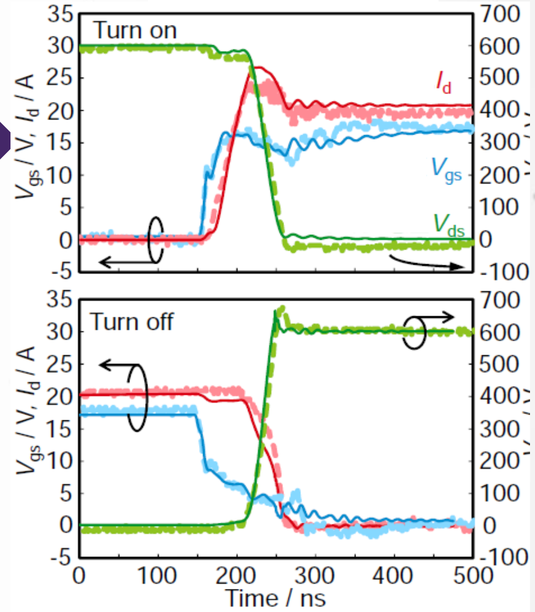


On-state C-V through S-parameters



Simulation with the Keysight math model

Dotted: Measured
Solid: Simulation

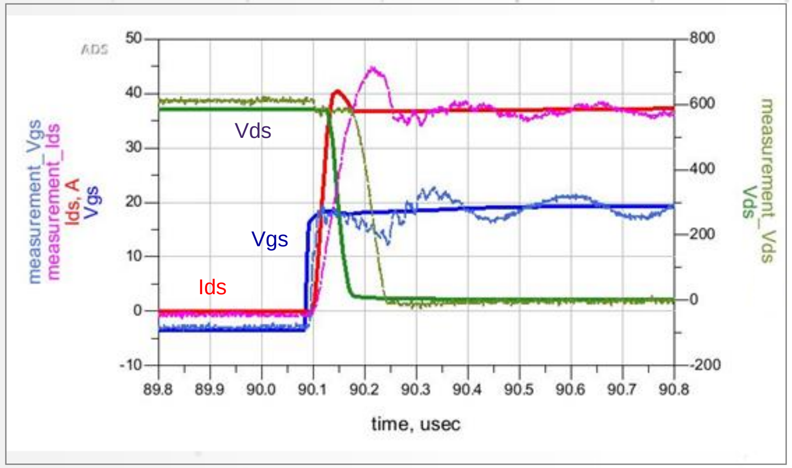


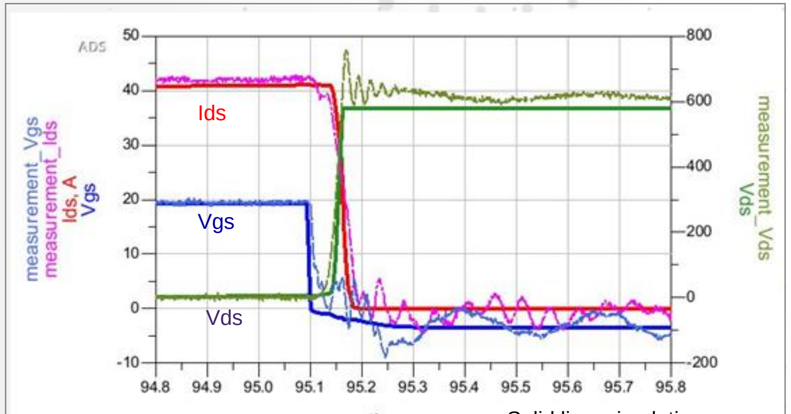
Excellent matching between simulation and measurement

* DPT = Double pulse test

Circuit simulation based on the model and electromagnetic analysis

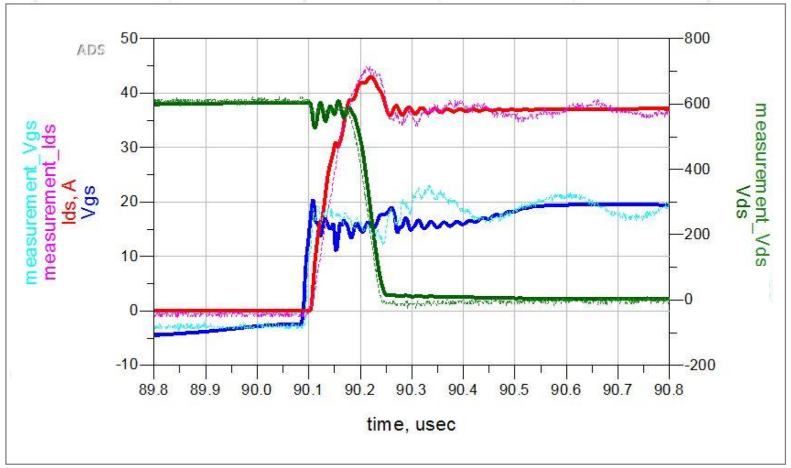
Conventional

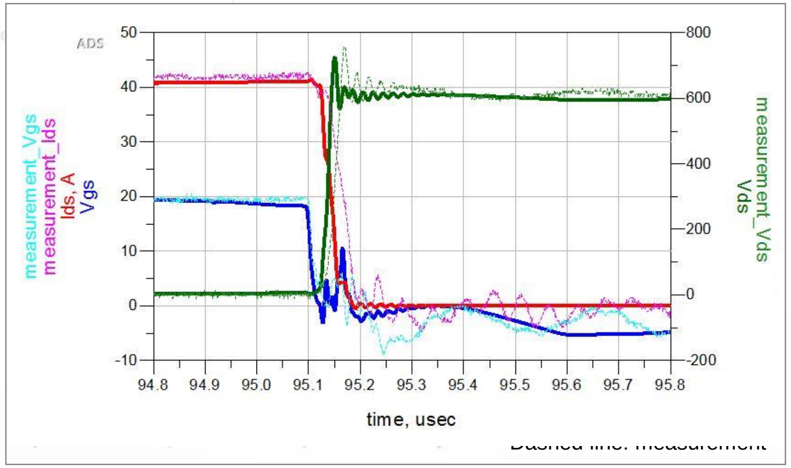




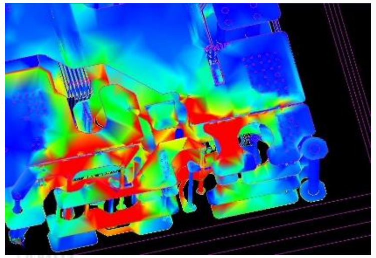
Solid line: simulation
Dashed line: measurement

New method

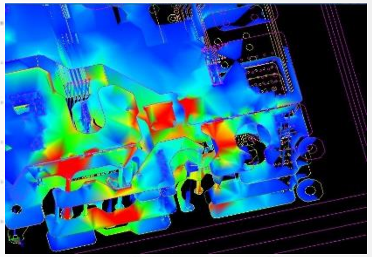




Current density analysis over frequency using this method

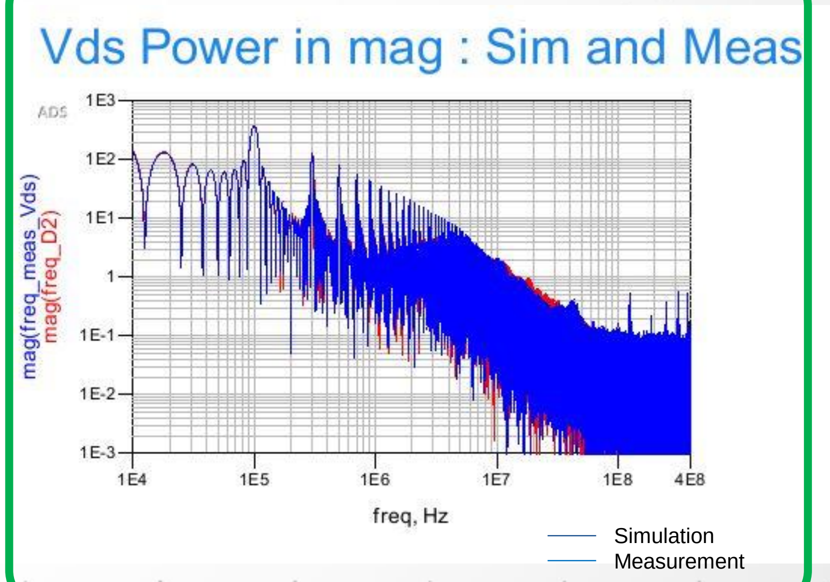


F=100kHz



F=900kHz

Frequency characteristics



Systems:
Challenges & Countermeasures

New Energy, New Test Requirement

KEYSIGHT TEST SOLUTION

Test environments for innovative components in the automotive and industrial sector.

Charging technology

BMS

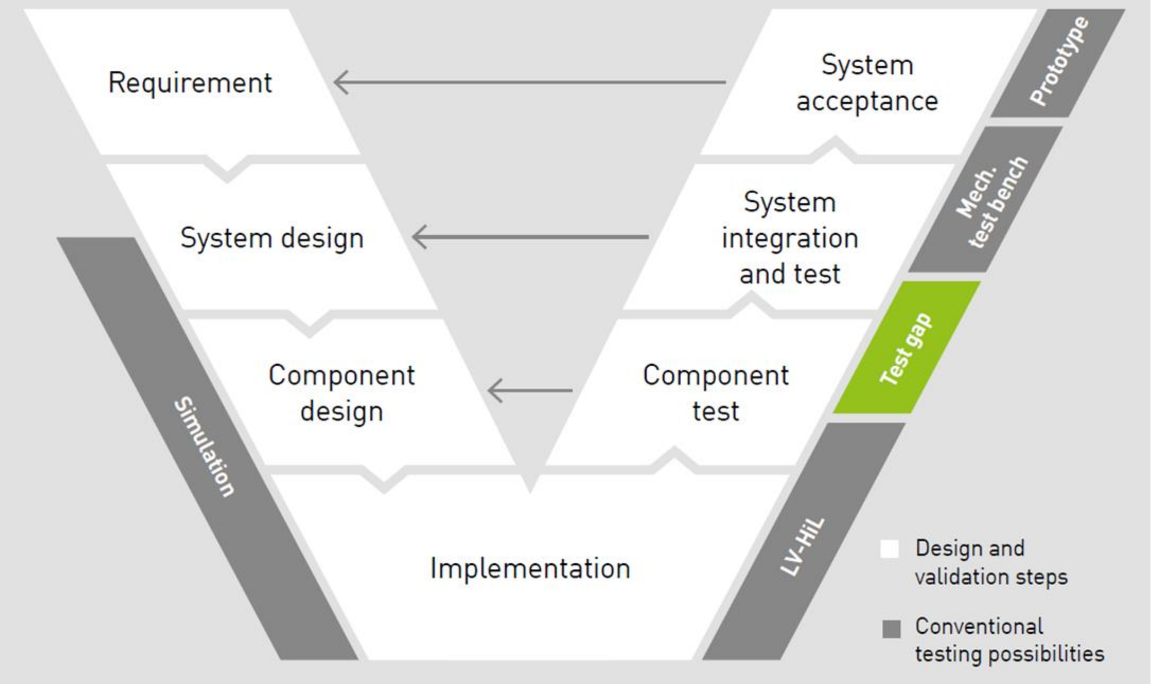
Energy storages

Inverters

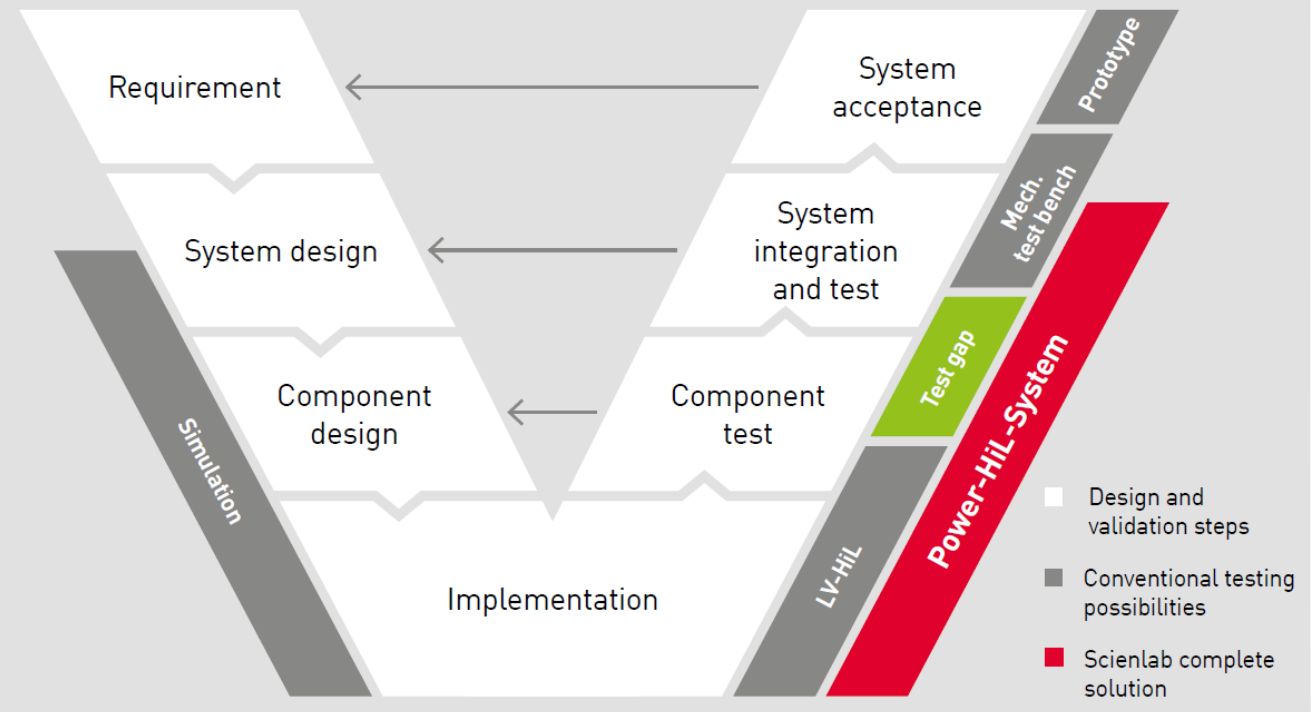
48 V

Common Rail

Development and testing along the V model



- Close the test gap using a Power-HiL system



Different test scenarios for inverters

CHALLENGES OF INVERTER TESTING

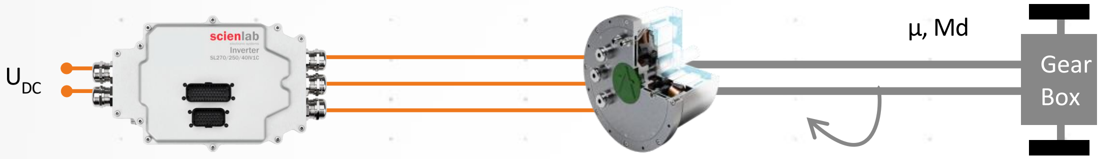
- Dynamic tests in complex test scenarios with modifiable variables and parameters
- Modern inverters include due to security requirements partially intelligent error detection mechanisms that require a dynamic and simultaneously precise emulation of all signals and variables under real conditions
- Intrusion of complex failure scenarios
- Simulation of recorded measurement profiles (e.g. WLTP, ARTEMIS)
- Evaluation of the control accuracy, efficiency under reproducible conditions
- Test automation to achieve a high test coverage

Inverter test scenarios

Communication	Functional verification	Efficiency	Precision
Sensor	Software verification	Thermal	Dynamics
Maximal range (speed - torque)	Safety	Signal (line break & short circuit detecti	Durability

Functional tests
Quality & Performance tests

Application Based Requirements



Inverter requirements

Emulation requirements

Inverter controlls machine torque (current) → Torque dynamics are limited by power train mechanics

Inverter change torque in several ms, not in µs → Torque bandwidth of 1 kHz or less

Requirement for inverter testing = Emulation of machine torque of max. 1 kHz

Requirement for machine emulation = Machine emulator with max. 20 kHz

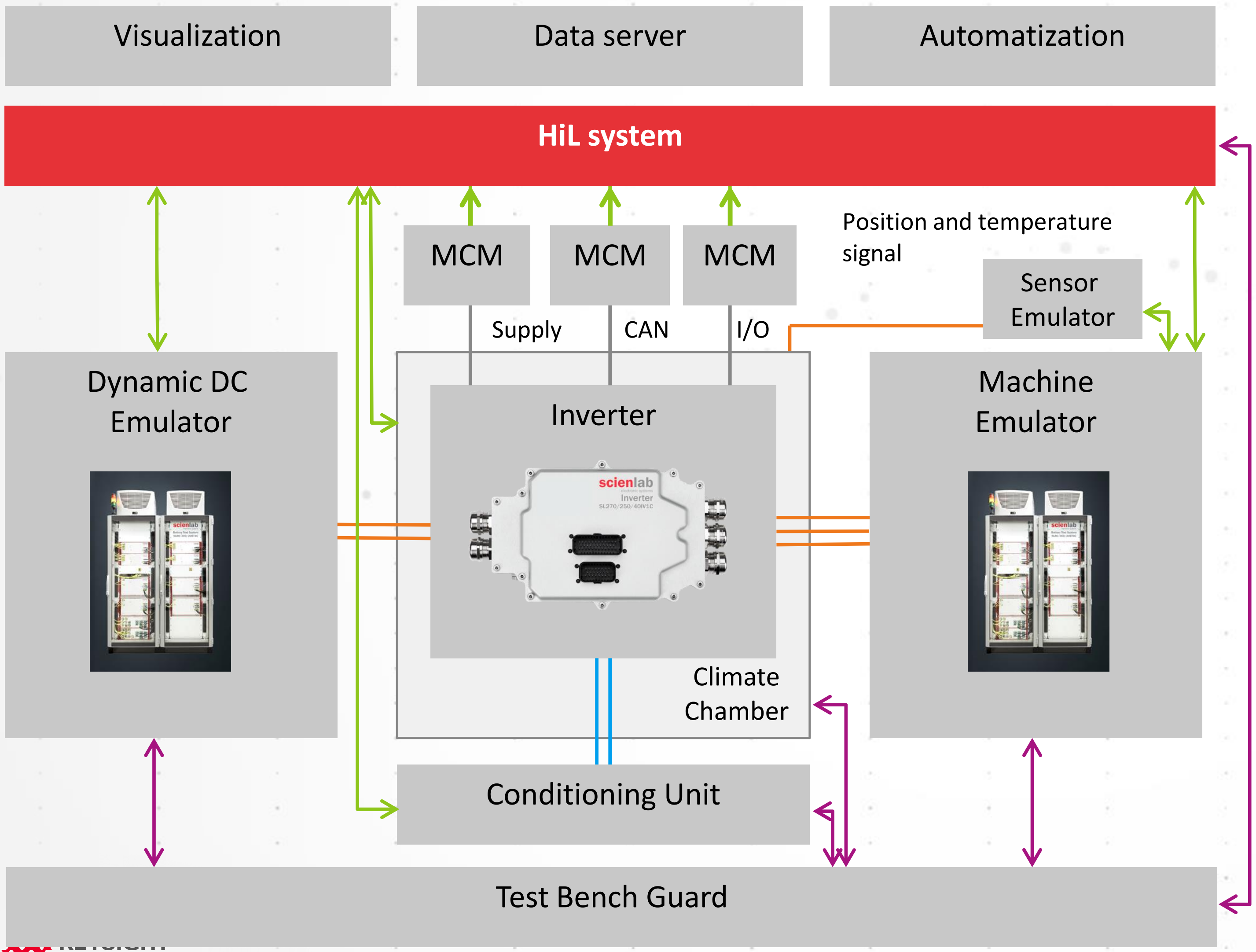
Scienlab Machine Emulator:
Update of the emulator voltages with 20 kHz can emulate all relevant machine effects

Optional:
If torque bandwidth is > 5 kHz Scienlab offers a variant of the Machine Emulator with 100 kHz switching frequency

KEYSIGHT TECHNOLOGIES

Inverter verification:

EMULATED TEST ENVIRONMENT



MCM = Measurement & Control Module

Test Bench Guard

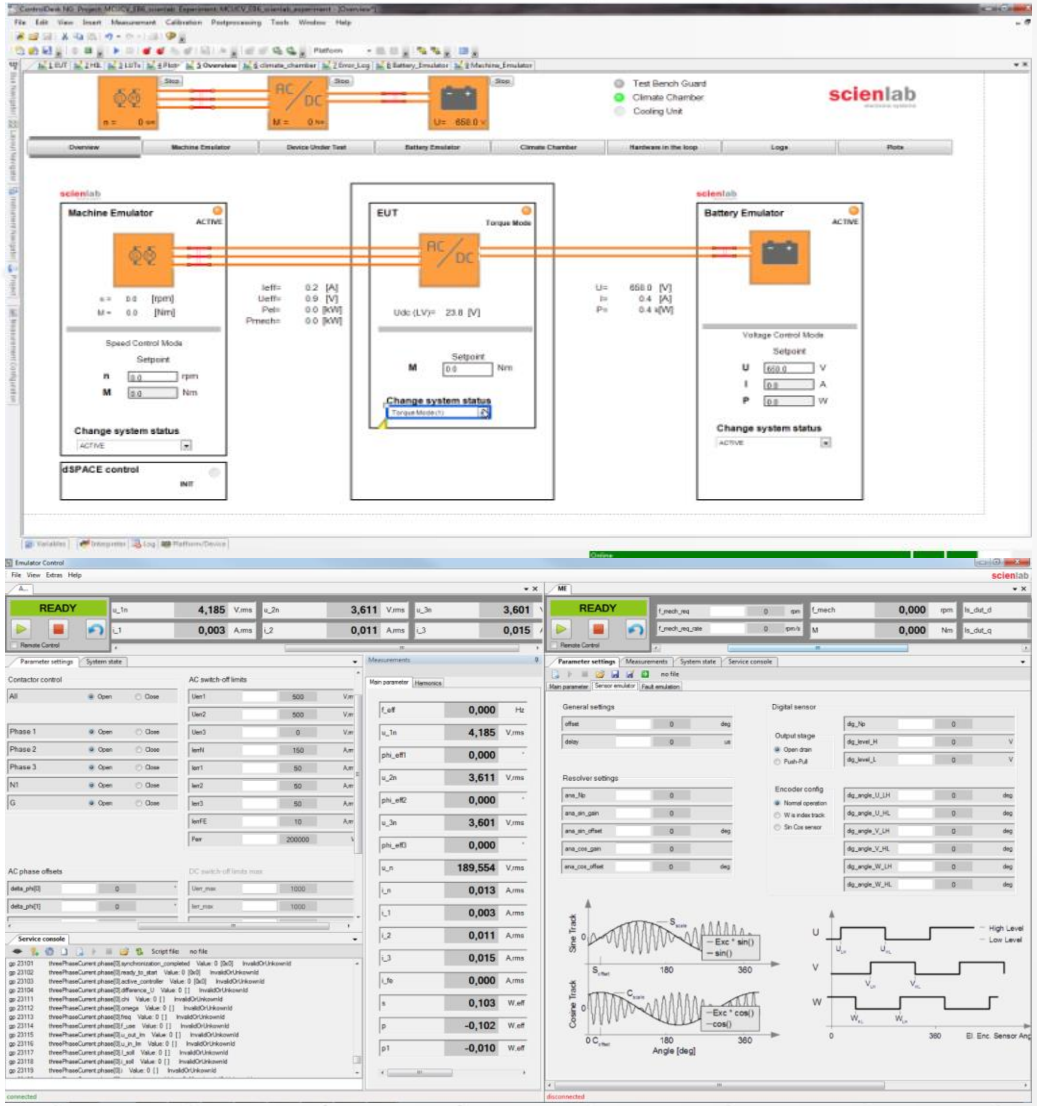
TECHNOLOGIES

MCM = Measurement & Control Module

Powerful software solutions

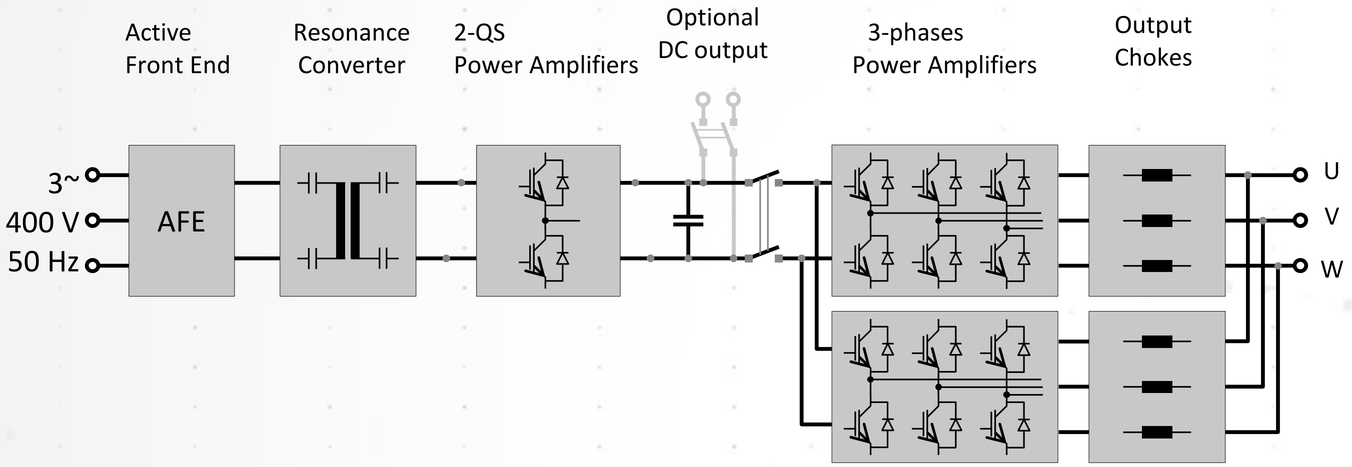
- Basis software projects, including models or interface-libraries for following open platforms:
- Vector CANoe
- dSPACE ControlDesk
- ETAS Labcar
- National Instruments driver
- Beckhoff driver

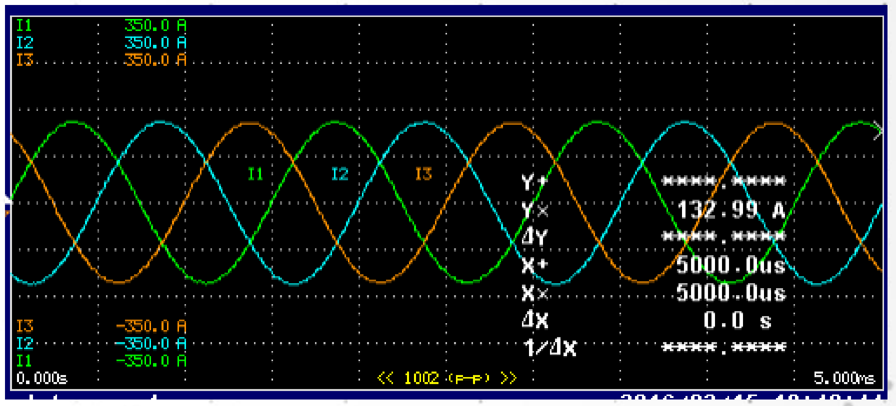
- Other software easily adaptable through open and well documented protocols
- Scienlab solution for manual use:
- Software Emulator Control

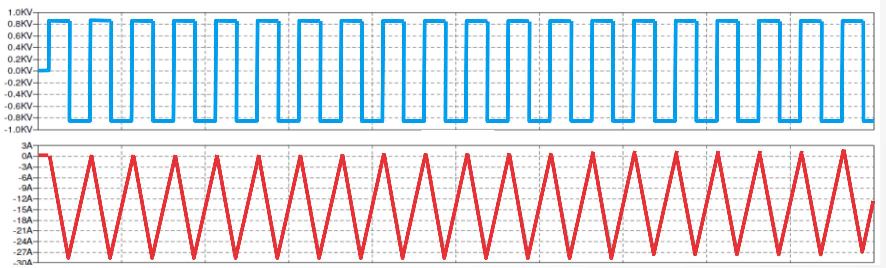


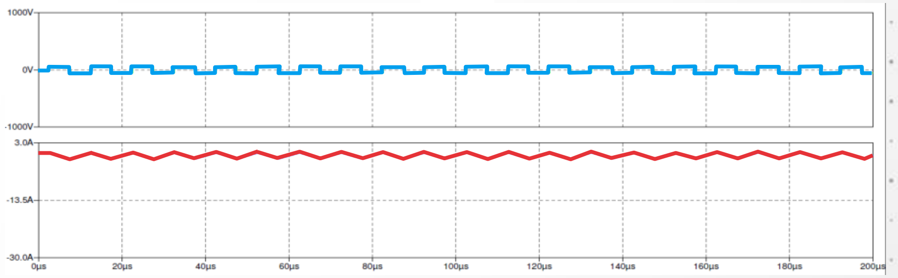
Machine Emulator

INTERNAL STRUCTURE









- Dynamic internal DC voltage for improved efficiency
- Switching frequency pro IGBT:
  5 kHz - dimensioned for long lifespan
- Update per IGBT – 2 x per period
- Interlaced power stages (phase-shift) –
  for update every 20 kHz
- Non-PWM modulation for event-based switching

Torque Jump Test

Torque Jump

0→150Nm,

200Nm/S,

@2500rpm

Torque Jump

10→150Nm,
200Nm/s,

@2500rpm

Speed Change

50→2500rpm,

300rpm/s,

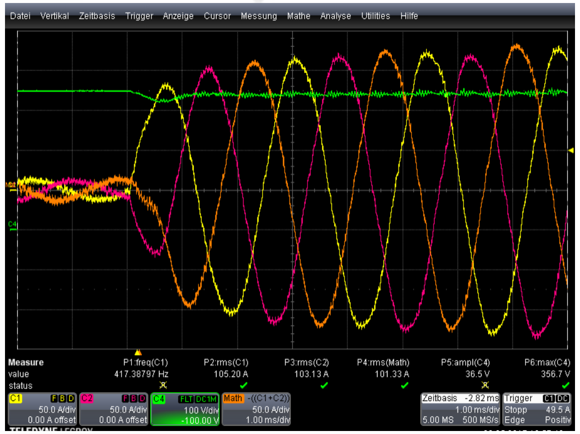
@150Nm

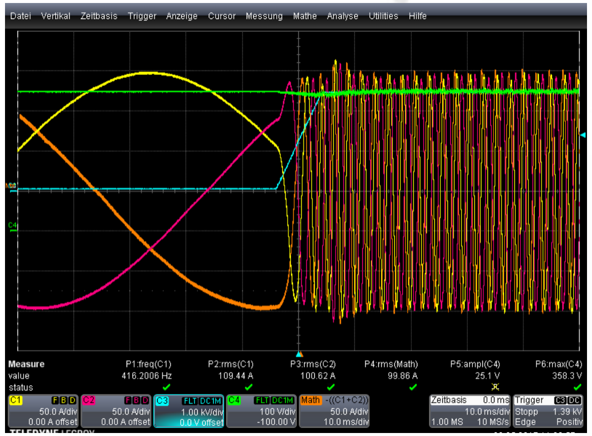
Speed Change

2500→50rpm,

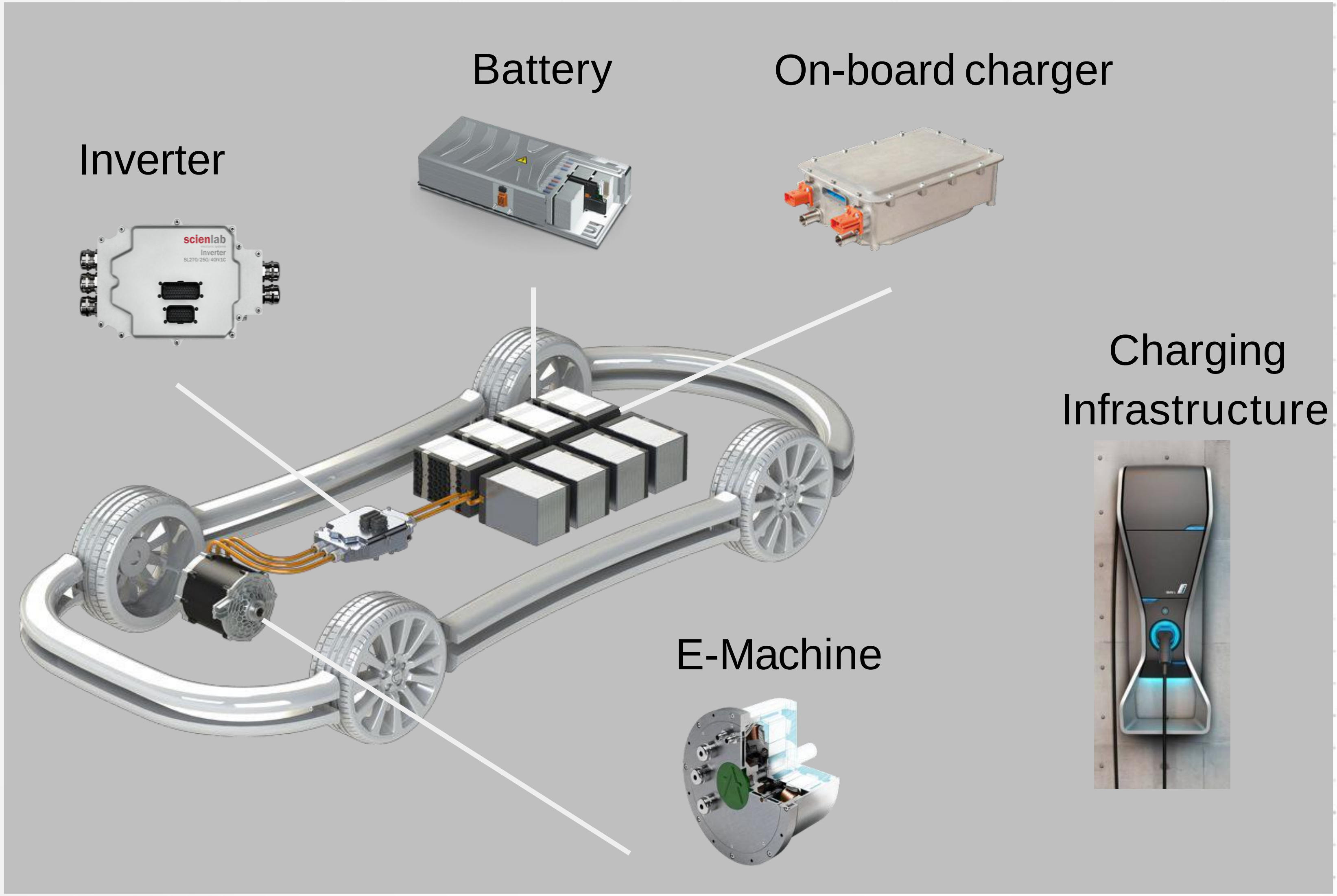
300rpm/s,

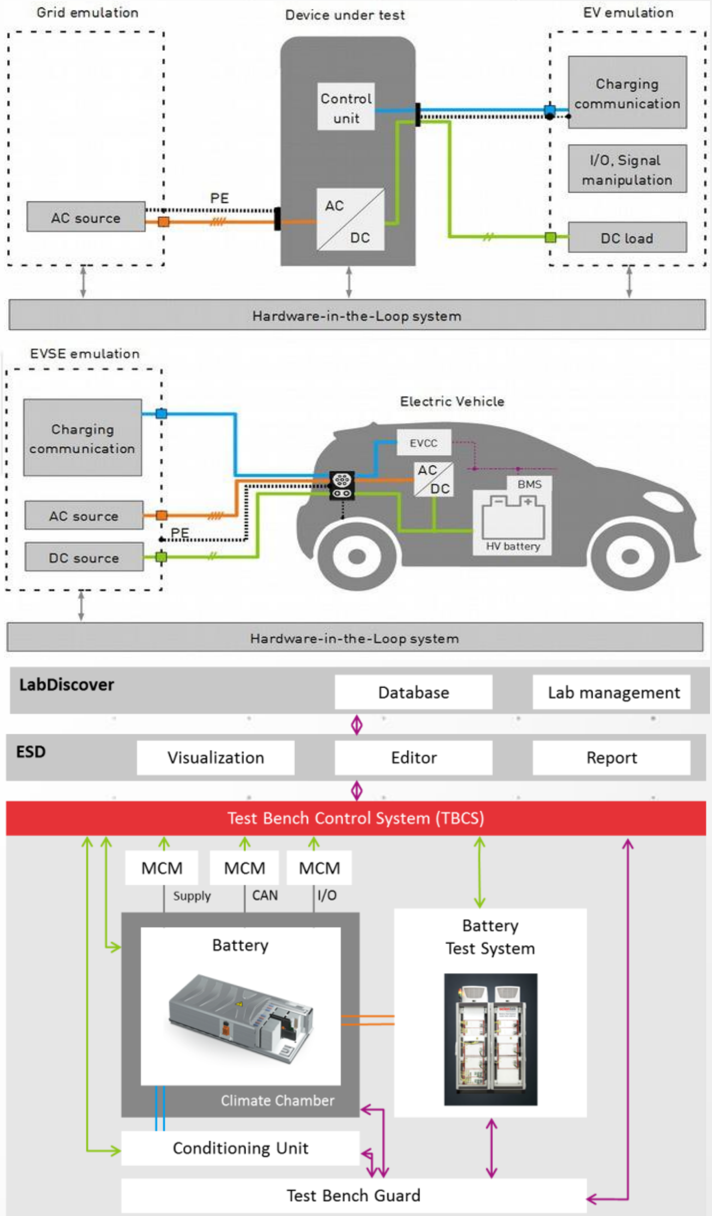
@150Nm





Testing the components of the electrified drivetrain





Q&A
Thanks