Powering Tomorrow’s Systems:

Trends and Challenges from Batteries to Fusion Reactors

Tektronix®

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Powering Tomorrow's Systems!

- Where & Why power testing matters
- Applications
- Battery Testing
- High Dynamic Testing
- Ultra-High Current Testing

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Where high-power testing matters most?

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Energy Storage

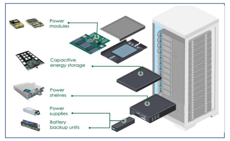
- Battery Quality & Performance
- Battery Management Systems
- Energy Storage
- Low voltage, high current operation

E-mobility

- EVSE – Charging / Lifecycle Mgmnt
- New testing standards
- Battery Performance – new chemistries
- High Voltage Capability

Clean Energy

- Adv Research – Fusion Energy
- Local power distribution (micro-grids)
- Decarbonization of Industrial processes
- Regenerative capabilities
- High power



Power Semiconductor & Datacenter Power Solutions

- Shift from 48V to 800V to power the datacenter
- High Power Requirements for AI chip (low voltage / high current)
- High dynamic performance

Aerospace & Defense

- Directed Energy *drone / missile defense*
- Advanced Research
- Drone battery modules
- Actuator/Positioning Controls

Electrification will growth further!

Applications

- Battery Testing in:
  - Automotive
  - Aerospace & Defense
- AI Datacenter Power
- Clean Energy

BEV complexity unveiled

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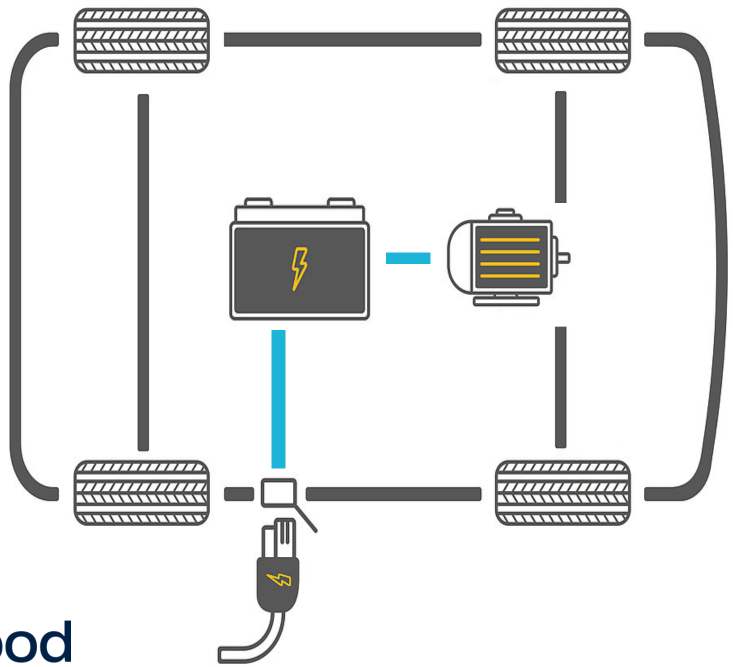
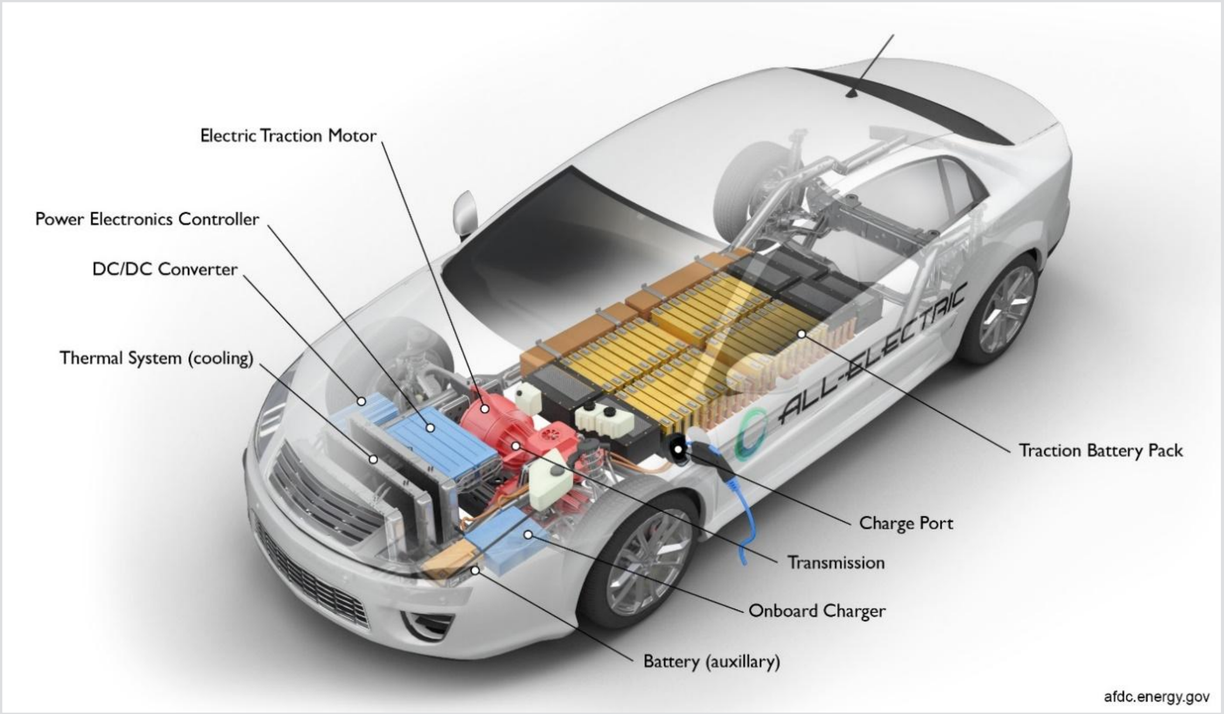
Is it really as simple as that?

- **Battery**
- **Charger**
- **e-Drive train**

…done?





BEV complexity unveiled

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Is it really as simple as that? No, not at all!

Charging Systems


Battery Cells


HV-Batteries


48 V Batteries


48 V Drives


HV-Inverter


HV-Heater


HV Cooling-Systems


Fuel Cells


HV-Fuses


HV-Switches


Charging Cables


HV-Cables & Pluggs


Research


HV-Power-Distribut.


Electric Vehicles


Battery Moduls


Onboard Charger


DC Charging-
Management


Testing Institutes


Energy Storage
Systems

Aerospace & Defense
WHERE RELIABILITY MATTERS

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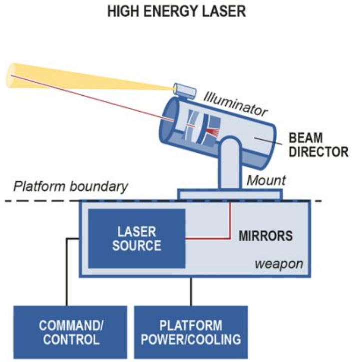
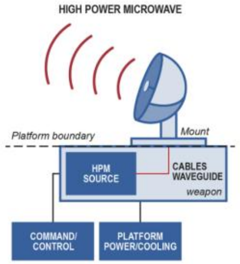
Satellite energy supply system:

- Solar cells in combination with battery systems
- Advanced battery and power management
- Safe and peak-load-ready power conversion required





Directed Energy Weapon Testing

- Laser Technology
- HPM – High-Power Microwaves
- Applications demanding extreme power and reliability

Electrical propulsion requirements

Higher requirements in every aspect compared to ground traffic

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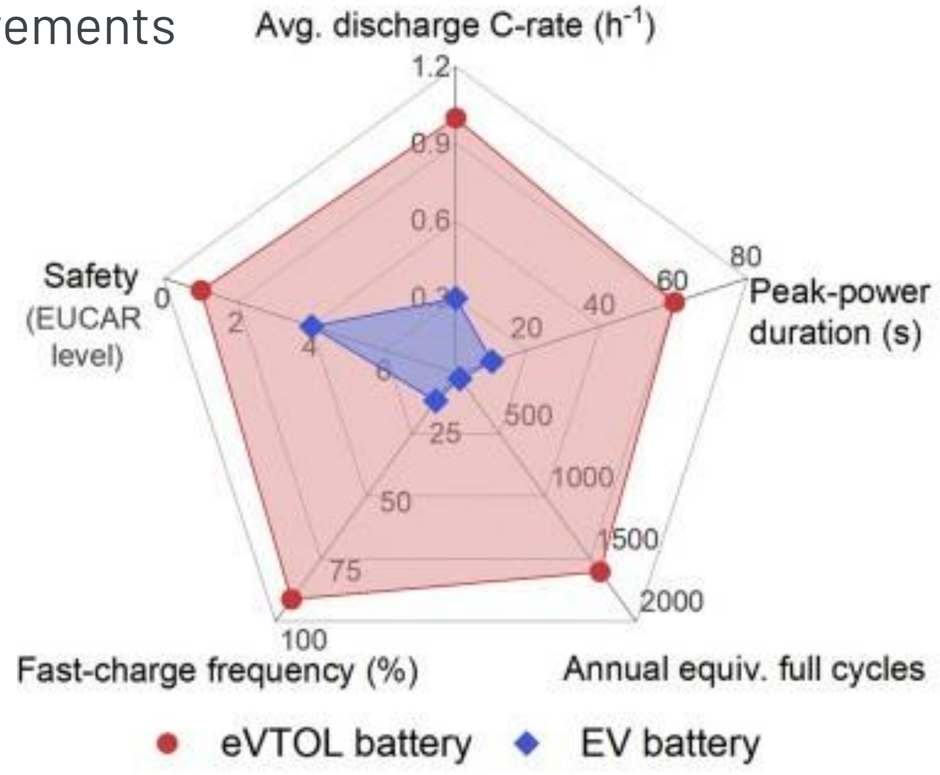
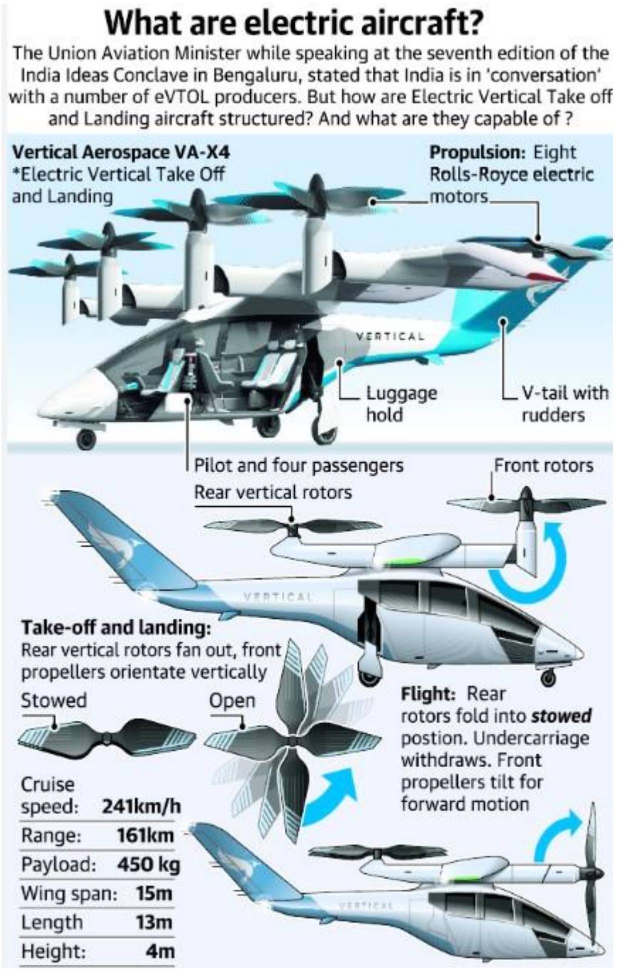
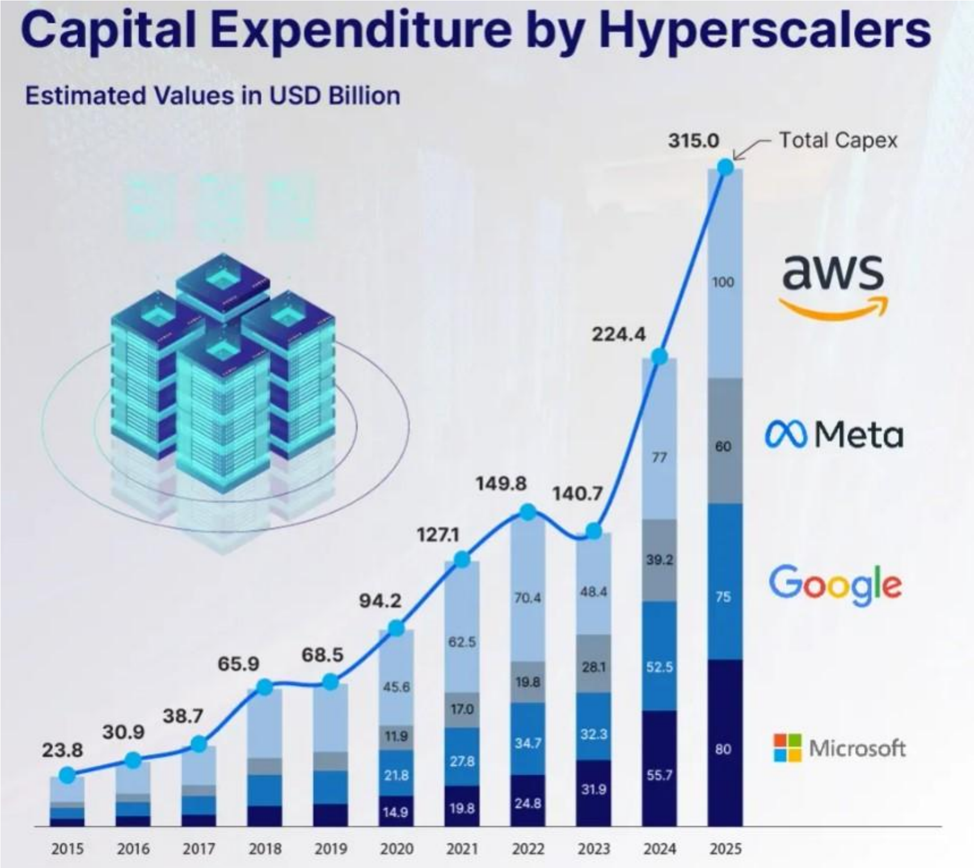
- Superior safety requirements
- Higher reliability demands
- Higher stress requirements





AI Datacenter Power

AI WORKLOADS DRIVING DEMAND FOR HIGH-POWER



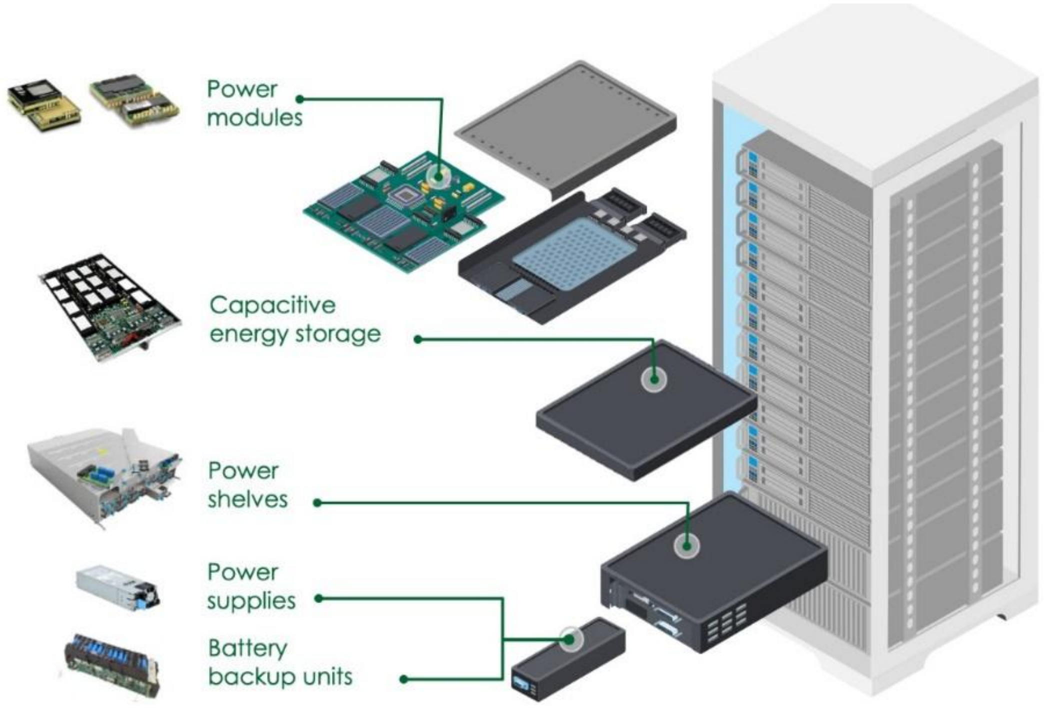
- **AI workloads are accelerating** hyperscaler expansion, driving demand for high-power infrastructure
- **Exploding power consumption** is forcing step-changes in efficiency and system architecture, from grid level all the way down to computing element
- **At megawatt power levels**, regenerative capability is no longer optional. It is essential for sustainable, scalable, and cost-effective testing

These new power architectures require advanced, high-power test solutions to validate performance, reliability, and compliance

AI Datacenter Power

EVOLVING POWER ARCHITECTURES

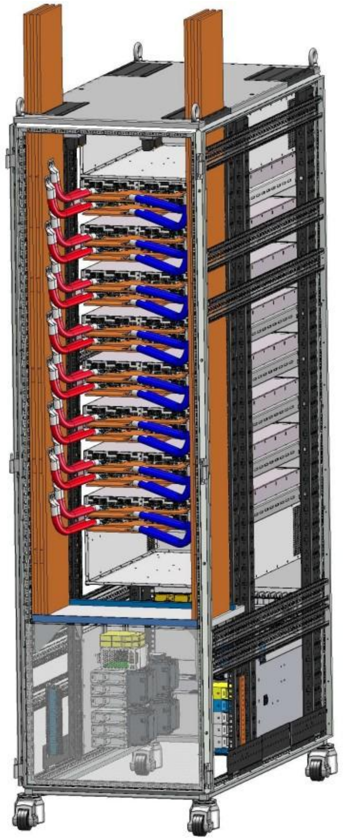
- **Shift to higher DC voltages** to reduce current, losses, and copper complexity
- **Fewer conversion stages** to improve overall efficiency and reliability
- Built-in redundancy and **battery backup (BESS)** to ensure uptime and resilience
- **Highly dynamic load profiles** driven by AI accelerators, with fast and deep power transients

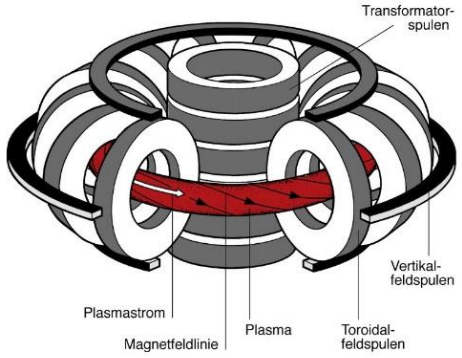


Clean Energy

DRIVING SUPERCONDUCTIVE MAGNETS FOR THE FUSION ERA

- High-Temperature Superconductors need ultra-high current to drive toroidal field magnets in fusion reactors
- Spectacular scaling up to **50.000 A**
- **True 4-Quadrant operation needed**
- A 4Q instrument can supply and absorb power in both voltage polarities to keep control about the current and back EMF





Battery Testing

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Sophisticated Battery Testing

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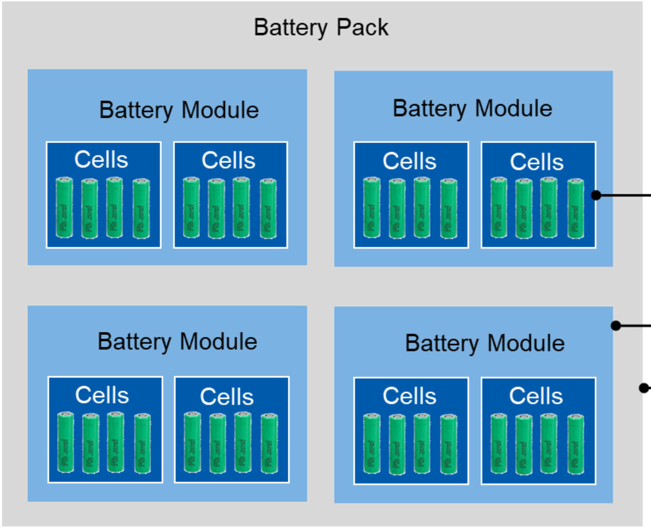
Key Testing Needs:

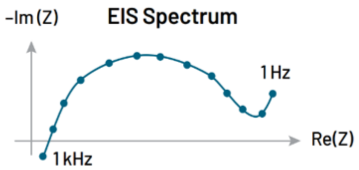
- Capacity and Efficiency Testing
- Thermal Behavior Analysis
- Reliability and Lifecycle Testing
- High-Fidelity Simulation of Mission Scenarios



	Key tests performed	EA product variant
Cell	▪ Cell characterization ▪ Charge and discharge ▪ Capacity ▪ Efficiency	▪ BT 20010-400 Triple ▪ BT 20010-600 Triple ▪ BT 20010-1000 ▪ […]
Module	▪ Charge ▪ Discharge ▪ High voltage protection ▪ Durability	▪ BT 20060-340 Triple ▪ BT 20080-340 Triple ▪ BT 20060-1000 ▪ BT 20080-1000 ▪ BT 20200-420
Pack	▪ Safety features ▪ Performance ▪ Battery management system ▪ Battery cooling	▪ BT 20920-40 Triple ▪ BT 20920-120 ▪ BT 21000-80 ▪ BT 21500-60 ▪ BT 22000-40

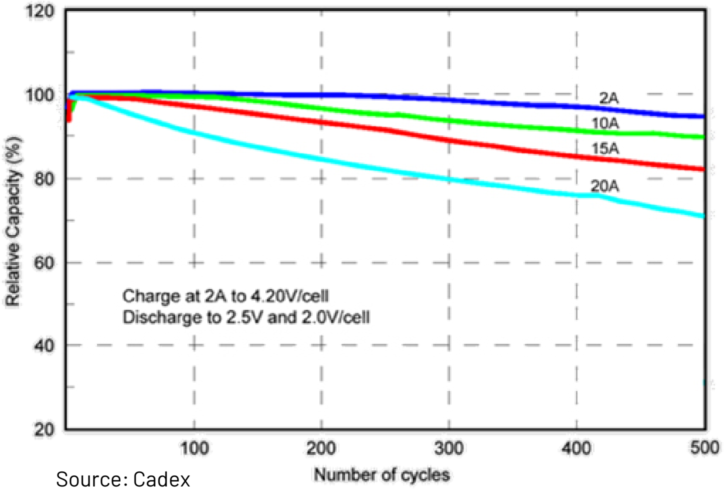
Sophisticated Battery Testing Solutions:

- Validation, aging, and reliability testing from cell to module to pack level
- Rapid state-of-health determination enabled by high-speed impedance spectroscopy



Challenges for Battery Testing

Source: JRC – European Comission



Source: Cadex

- Battery testing is a crucial part of battery development
- Reason is shown in right-hand graph :
  the degradation of battery capacity is dependent on the discharge rate

- Performing hundreds of cycles to synthetically age a battery is time and cost consuming
- Companies who do testing more efficiently have a time-to-market and cost benefit
- Electrochemical impedance spectroscopy offers a very fast and cost-efficient way to predict the battery quality

Validation, aging, and reliability testing

WHY DO I NEED A CELL CYCLER?

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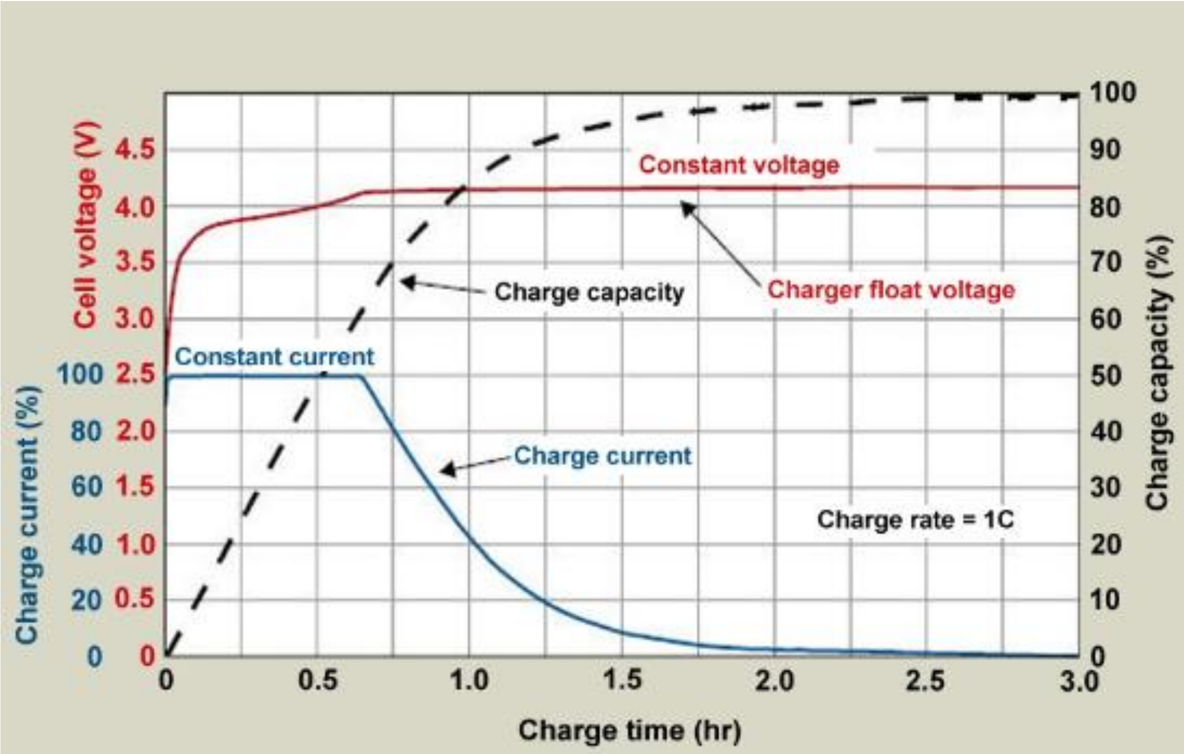
Charging a Li-Ion battery

- An empty cell needs to be charged with constant current (CC) within the manufacturer's specifications
- When the maximum cell voltage is reached, the charging method needs to switch to constant voltage (CV)
- The cell is now only ~ 80 % charged and the current will asymptotically drop until the cell is fully charged
- The State-of-Health (SOH) is determined by the ratio

$$SOH = \frac{current\ capacity\ [Ah]}{nominal\ capacity\ [Ah]}$$



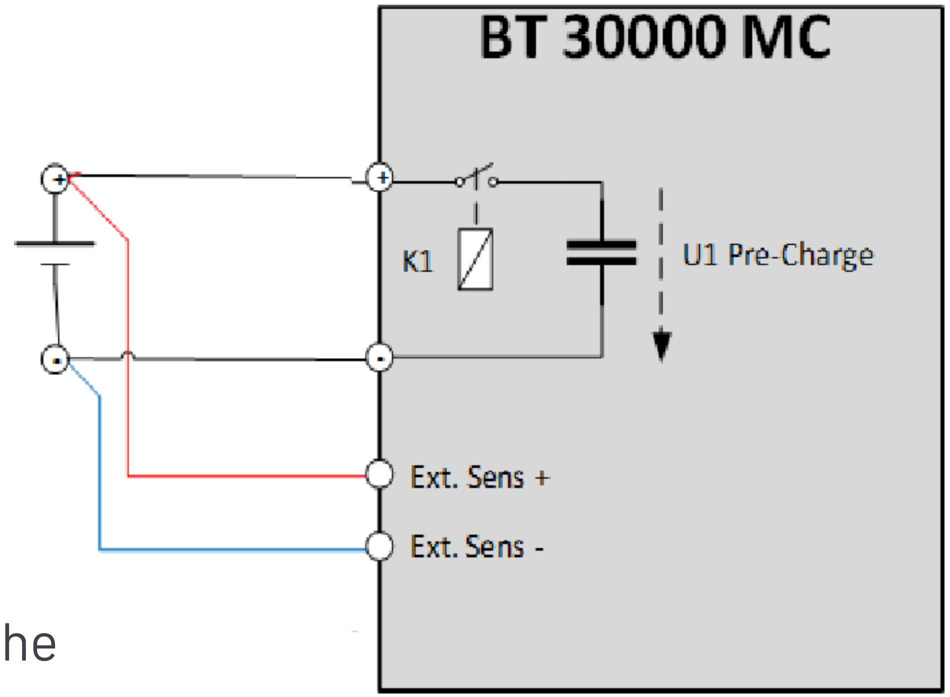
Source: Cadex

Active pre-charge & DC shut-off

INTEGRATED DC SHUT-OFF

Active pre-charge will minimize unwanted inrush currents

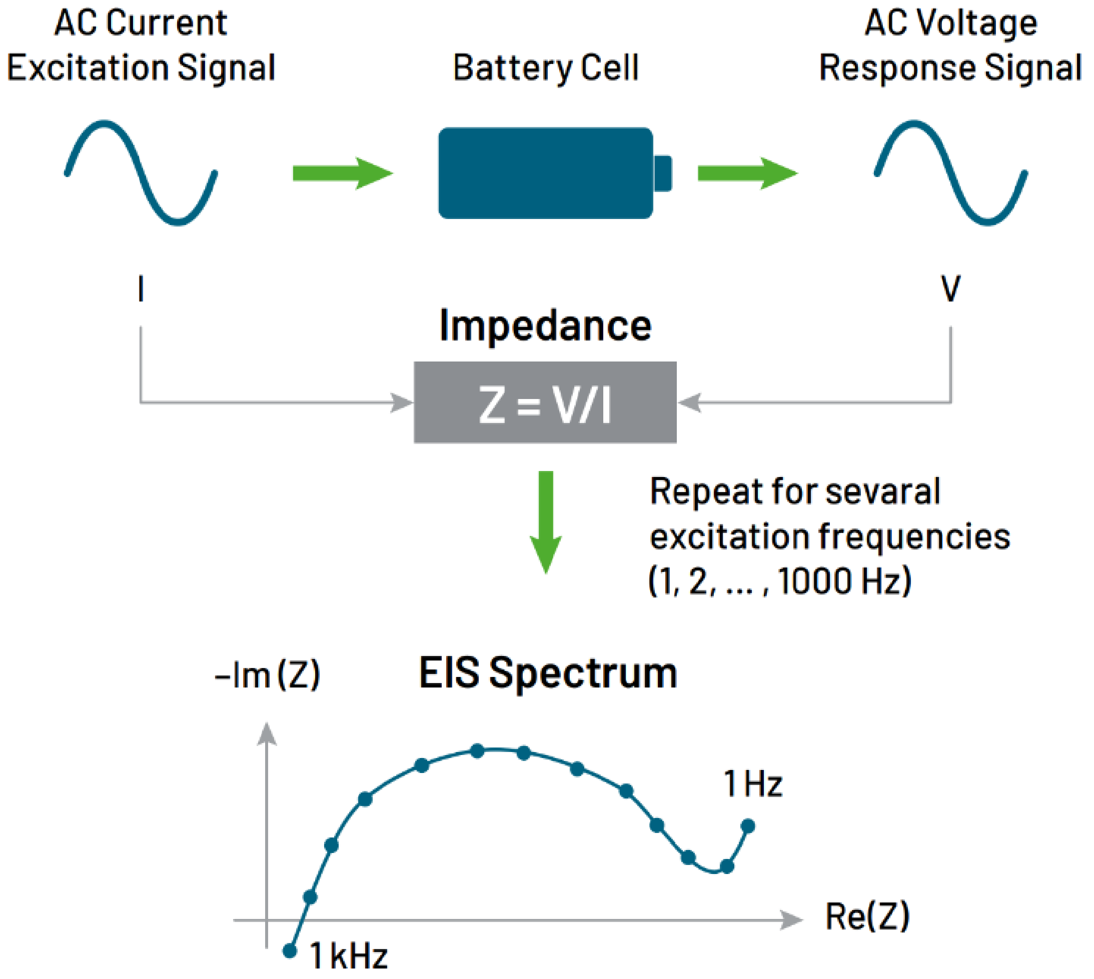
- The inrush current could damage the battery or the test equipment
- Operators are concerned because they observe sparks when connecting the DUT
  → pre-charge of the output capacitor is needed!
- Active pre-charge offers accurate measurement not taking any energy from the test object
- DC shut-off prevents leakage currents from discharging the cell under test during the rest phase



State-of-health determination by impedance spectroscopy

ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY – HOW DOES IT WORK?

- An AC current signal with a specified frequency is passed across the cell terminals
- The cell's voltage response to the AC current excitation is measured
- The cell's impedance is calculated from the voltage response and the current excitation signal at that frequency
- This is repeated for several frequencies to get a spectrum of impedances for the cell



Rapid state-of-health determination enabled by high-speed impedance spectroscopy

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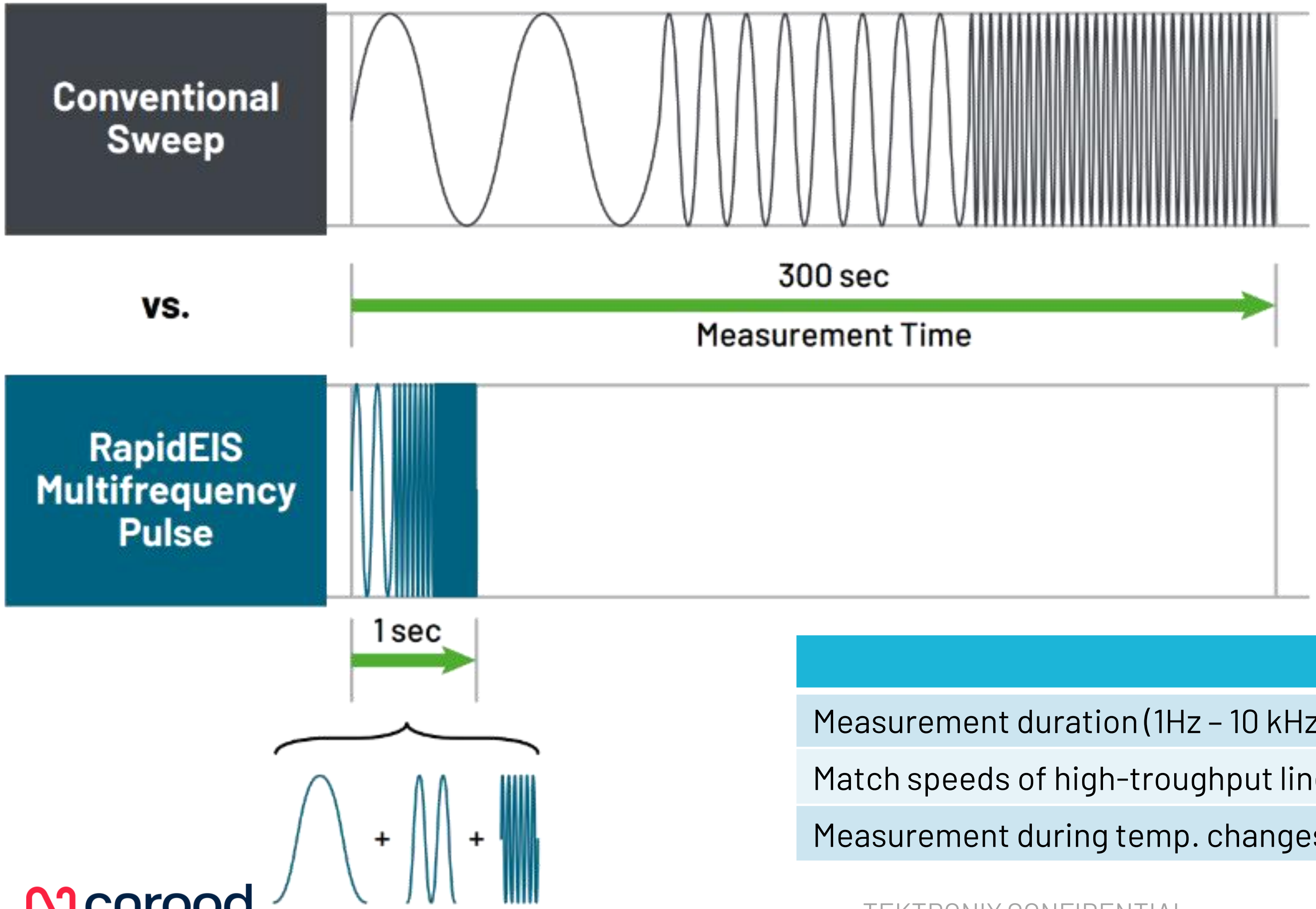
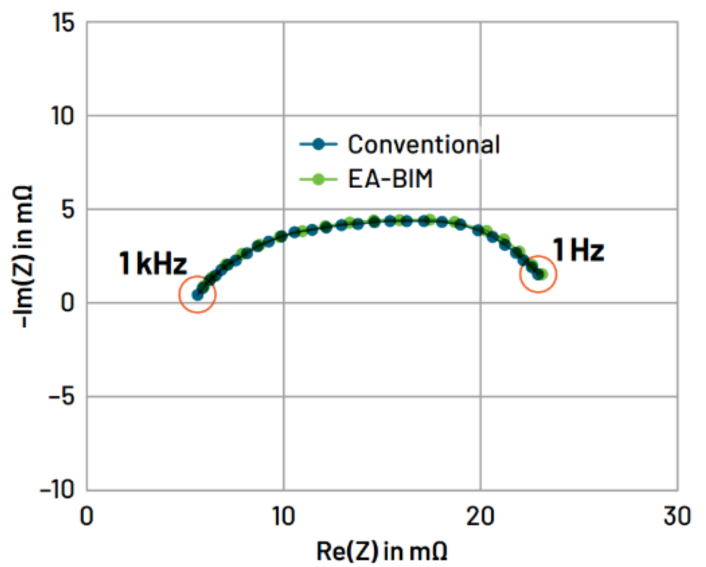


Same accuracy



	Conventional EIS	rapidEIS
Measurement duration (1Hz – 10 kHz)	**Minutes**	1 second
Match speeds of high-troughput lines	✖	☑
Measurement during temp. changes	✖	☑

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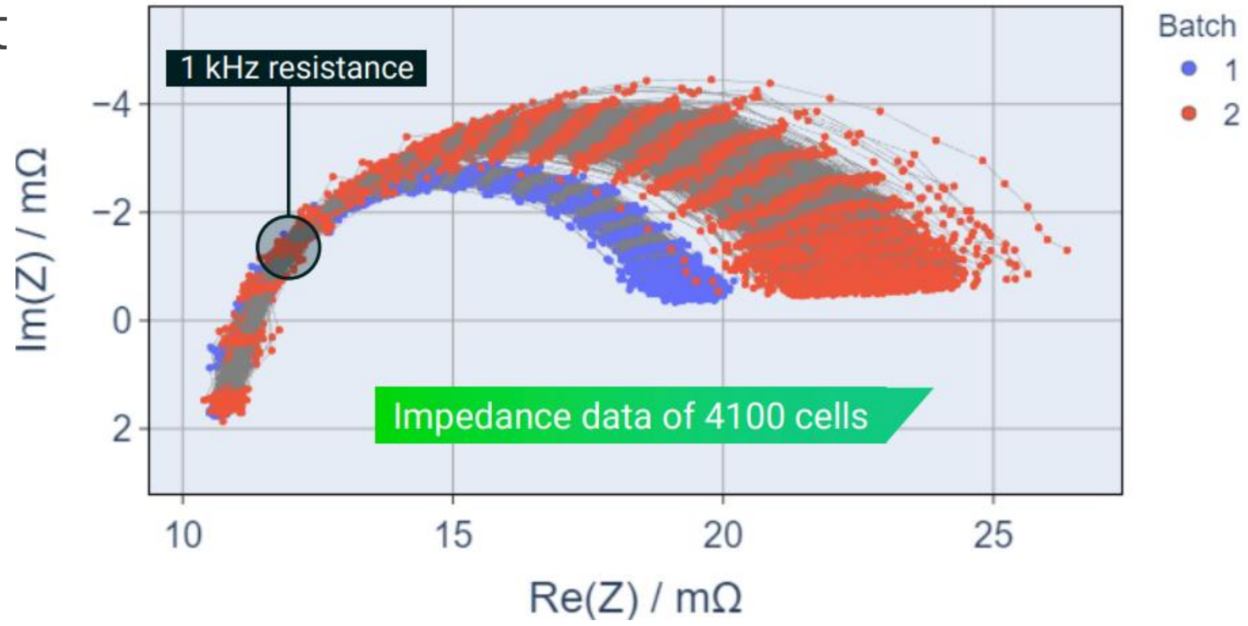
State-of-health determination by impedance spectroscopy

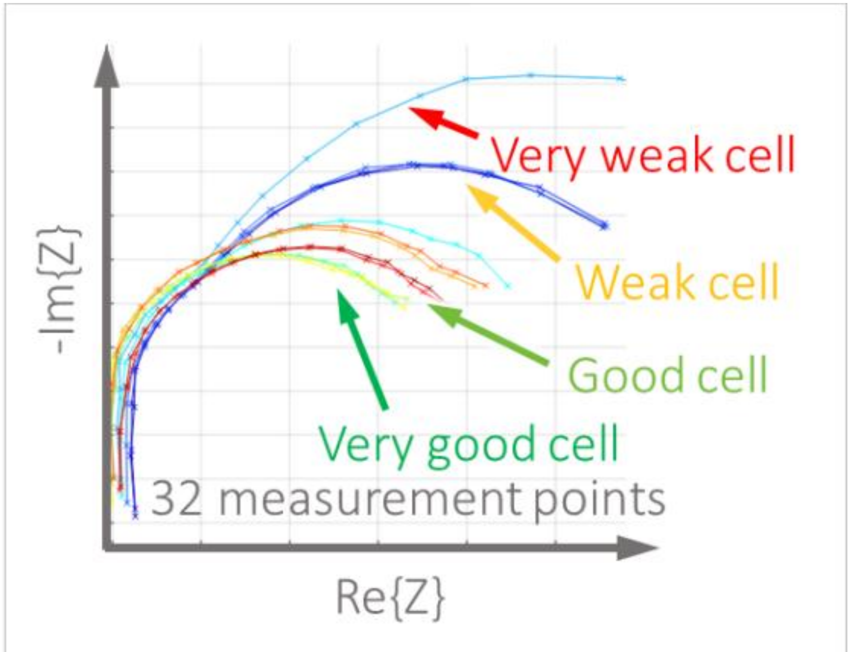
THE 1KHZ POINT DOES NOT TELL THE WHOLE STORY!

- The 1kHz impedance measurement (ACIR) comes from the lead-acid technology used in internal combustion engines
- It does not make sense to use this as the only characteristic for Li Ion batteries!
- Only by measuring a lot more frequencies will give the whole picture of the cell quality



Rapid state-of-health determination in cell aging

- Because of the various aging influences of LiB cells, manufacturers need to predict the ageing through either electrical stressing or environmental stressing or both
- These tests need to be accompanied by a reproducible method of State-of-Health (SOH) monitoring
- The RapidEIS provides a quick and non-destructive method to monitor the SOH throughout the ageing



Source: Safion

High Dynamic Testing

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Fast current slew rate

NEED FOR HIGH DYNAMIC ELECTRONIC LOADS

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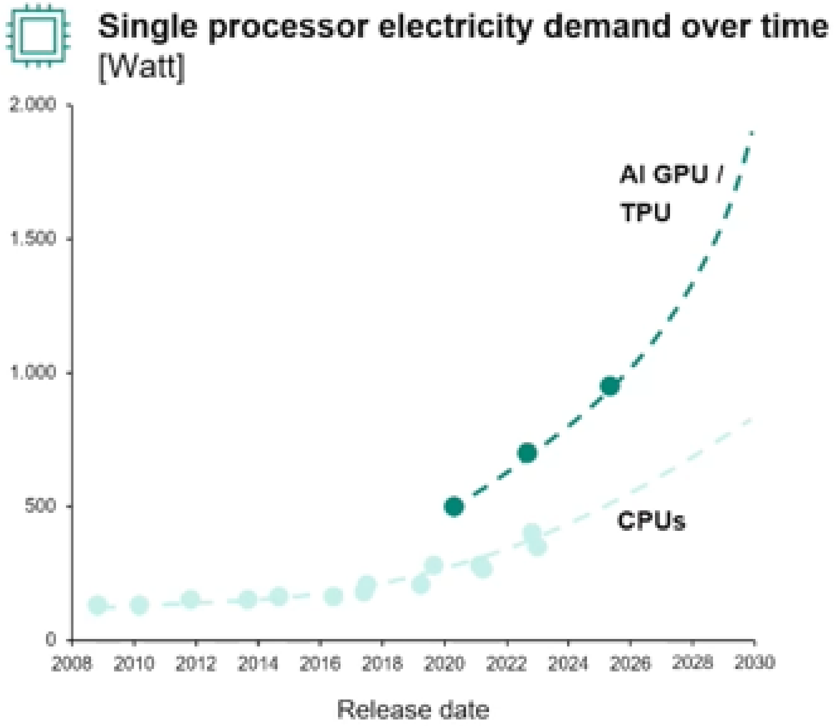
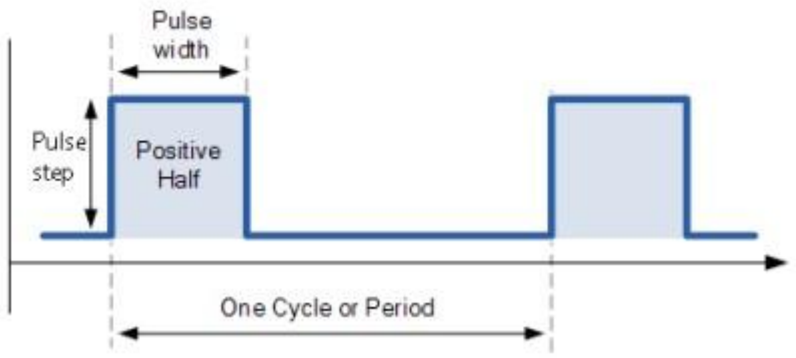
- Power levels for GPU´s and CPU´s are rising fast in datacenters
- The GPU´s and CPU´s are operating and very low voltages (around 0.7V) and high currents (in kA range)
- IT workloads create rapid and large load transients
- The power supplies inside of the data center need to provide very high current slew rates to ensure voltage stability, performance and reliability at GPU/CPU level



Challenges in Data Center Power Testing:

- Extreme slew rate requirements
- Dynamic overload capability
- System-level stability under high dynamics
- Customers still often request dissipative loads as these are historically connected with fast rates

No.	Low load	High load	Duty cycle	Frequency
1	10%	60%	50%	20Hz, 100Hz, 500Hz, 1kHz
2	50%	100%	50%	
3	10%	100%	50%	
4	10%	150%	50%	
5	10%	60%	50%	10kHz
6	50%	100%	50%	10kHz
7	10%	100%	50%	6.5kHz
8	10%	150%	50%	4kHz



Ultra-High Current Testing

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Ultra-High Current Source: 50.000 A

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THANK YOU

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