Power Electronics and Energy Conversion Systems Program at Sandia

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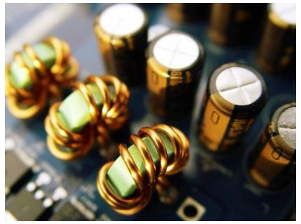
Power Electronics and Energy Conversion Systems

Improve grid operations through the development, adoption, and integration of new power electronics-based systems that are resilient, reliable, and cost-effective.

Three main research areas:

1. Develop and evaluate innovative devices and control strategies for grid applications
2. Understand and improve performance of advanced passive components and wide-bandgap semiconductors
3. Increase the standardization, performance, reliability, and safety of energy storage systems

Existing Labs



Mag Lab
Magnetics Fabrication and Characterization Laboratory
Improve the performance of high frequency magnetics to complement emerging WBG devices.

APEX
Advanced Power Electronic Conversion Systems
Supports the development of advanced power conversion topologies and intelligent control strategies.

DETL
Distributed Energy Technologies Laboratory
Designed to integrate emerging energy technologies into new and existing electricity infrastructure like solar and EV charging

ADL
Advanced Dielectric Laboratories
Develop High reliability, rad-hard capacitors – key elements of grid electronics

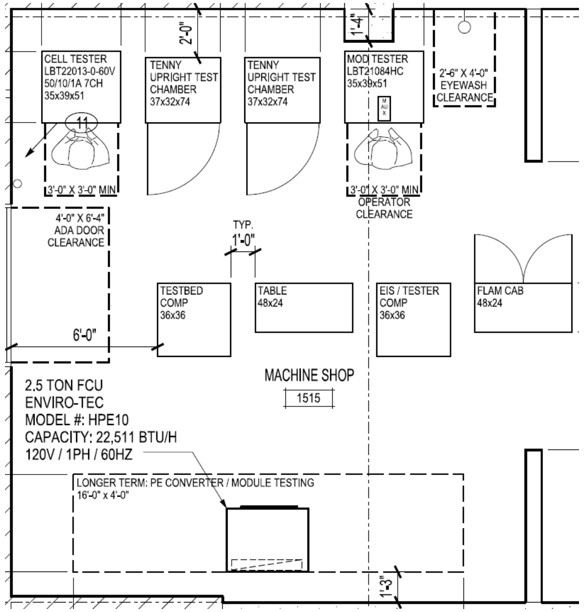
ESCAL
Energy Storage Controls and Analytics Laboratory
Dedicated to the development of next-generation energy storage control systems to increase battery performance and lifetime.

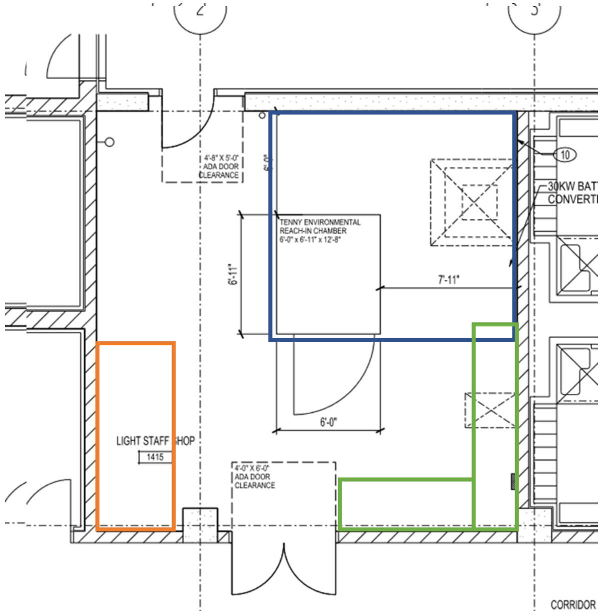
Navajo Nation Demonstration
Bring power to remote areas
Installed batteries developed with DOE Office of Electricity funding to power a remote community

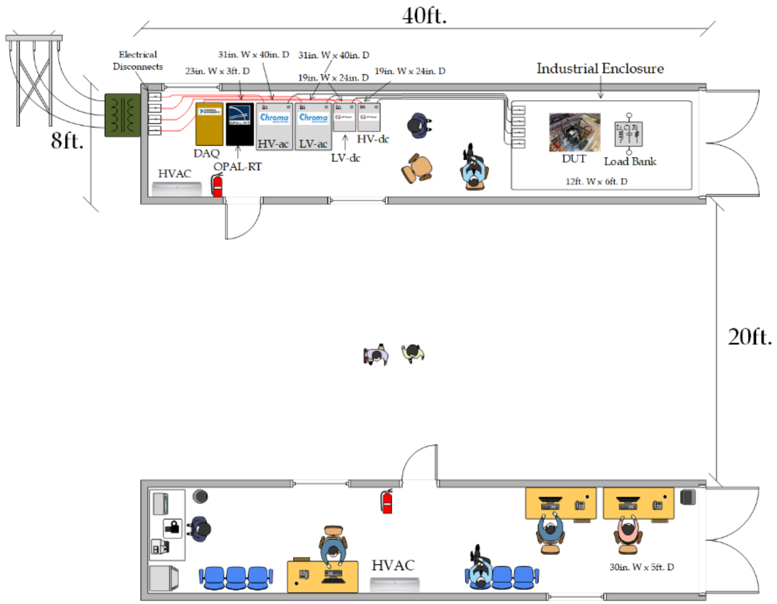
WBG-SC Lab
Wide Bandgap Semiconductor Characterization Laboratory
Determine the reliability of emerging WBG devices. Correlate material physics to reliability of PCS.

ESTP
Energy Storage Test Pad
Provides long-term testing and validation for electrical energy storage systems.

Labs Under Construction (FY23-FY24)







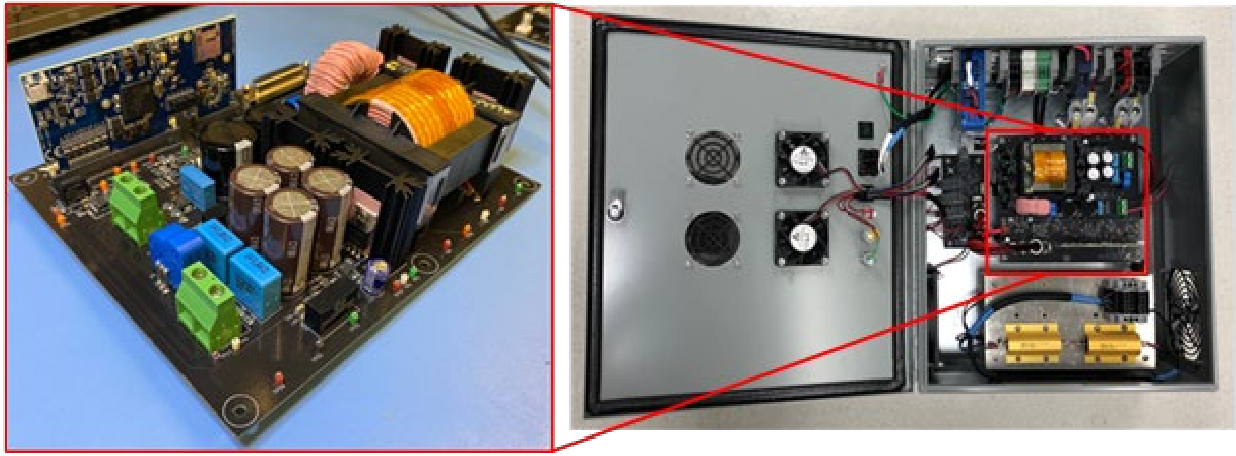
BEST
Battery energy storage test lab
Integrate modules up to 1000V

GMS
Grid Management and Security
Develop controls for Power Electronics networks (1000V)

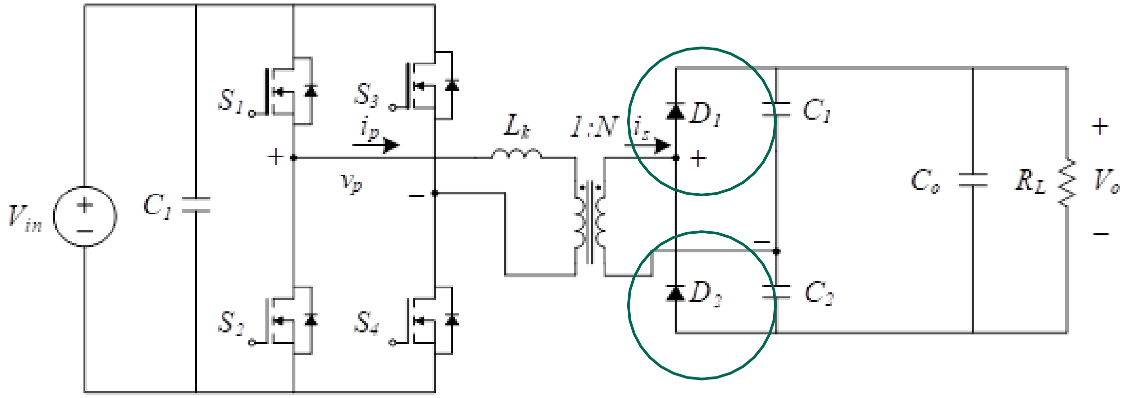
Medium Voltage Lab
Integrate and control Power Electronics components to distribution voltages (15kV)

In-Situ Component Testing

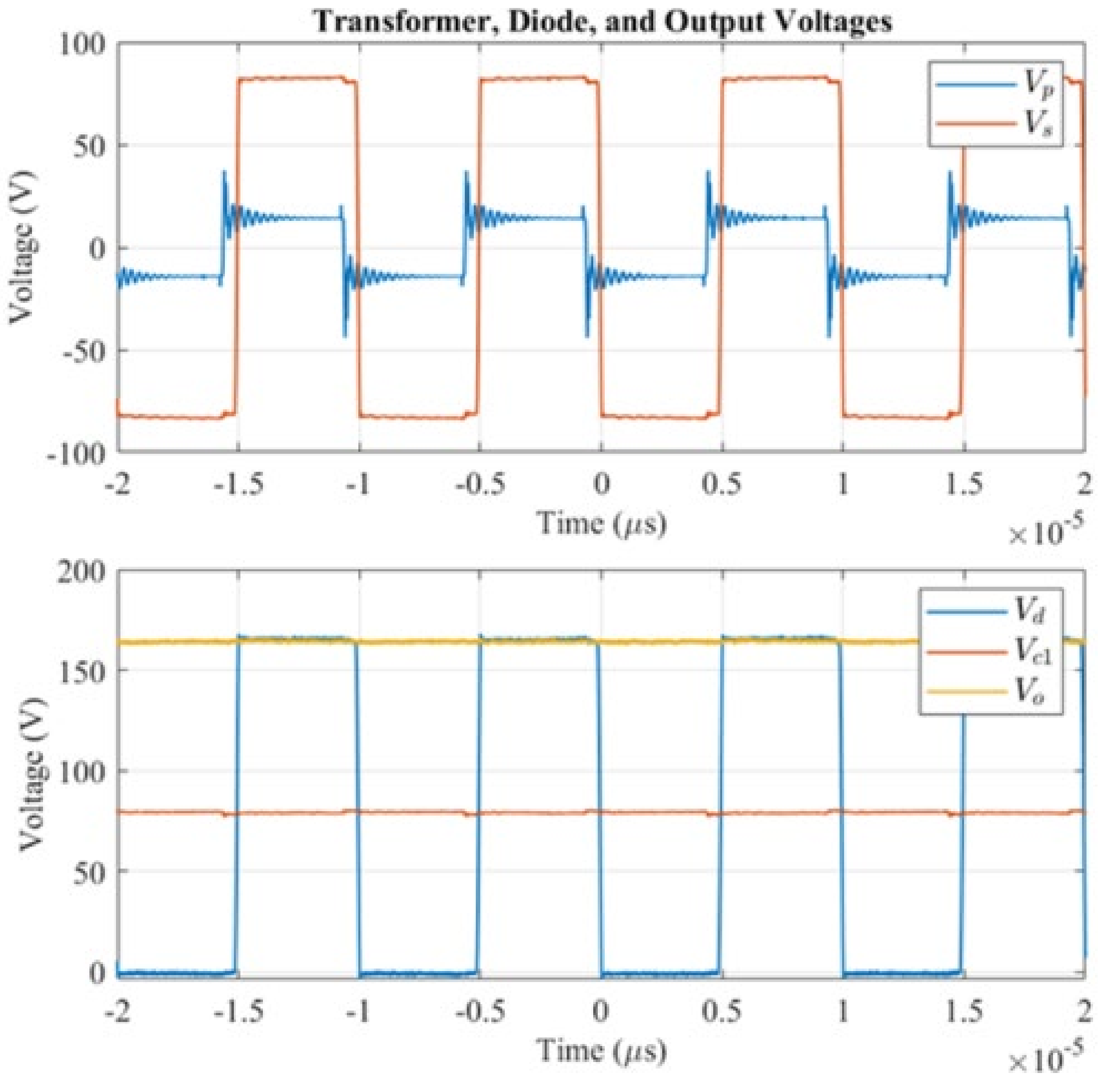
Stressing of WBG Power Devices in Switch-Mode Converter



Custom-designed and built switch-mode power converter used to stress v-GaN diodes from AVOGY



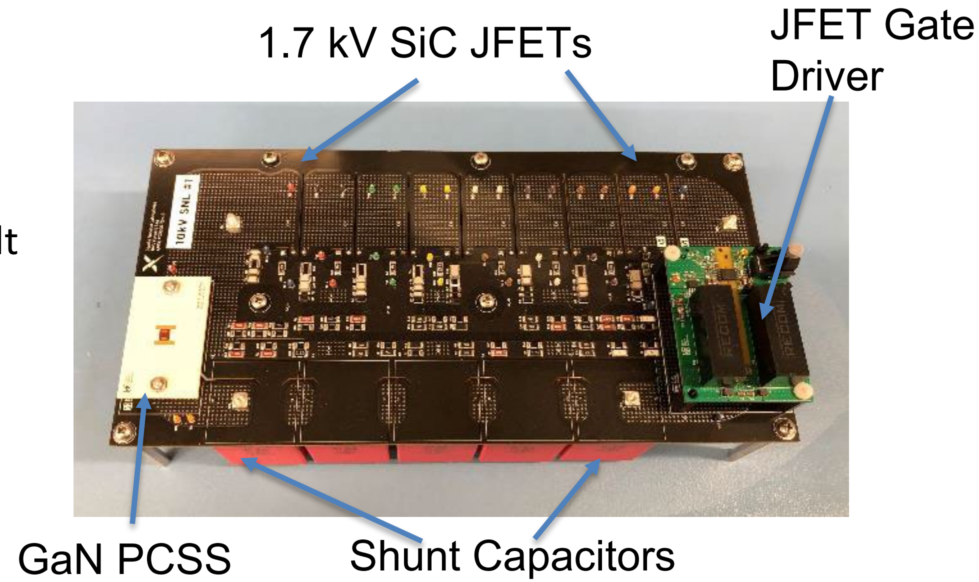
Test system full-bridge DC-DC converter topology



Full-bridge DC-DC converter experimental waveforms

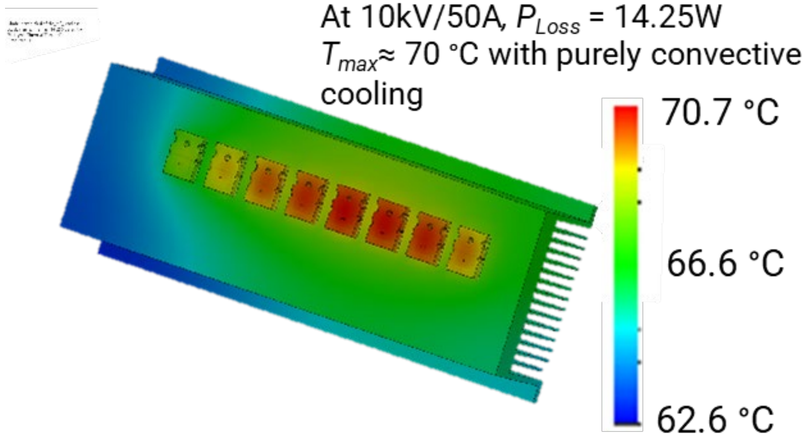
Solid State Circuit Breaker (SSCB) Architecture (ARPA-E)

- Cascaded JFET HV switch topology
- Normally-On JFETs with low on-resistance and low auxiliary drive loss
- Normally-Off Photoconductive semi-conducting switch (PCSS) that triggers immediately after a fault to shunt current
- Capacitor for absorbing + dissipating energy from flyback current
- Control circuit powered from high-side voltage connection

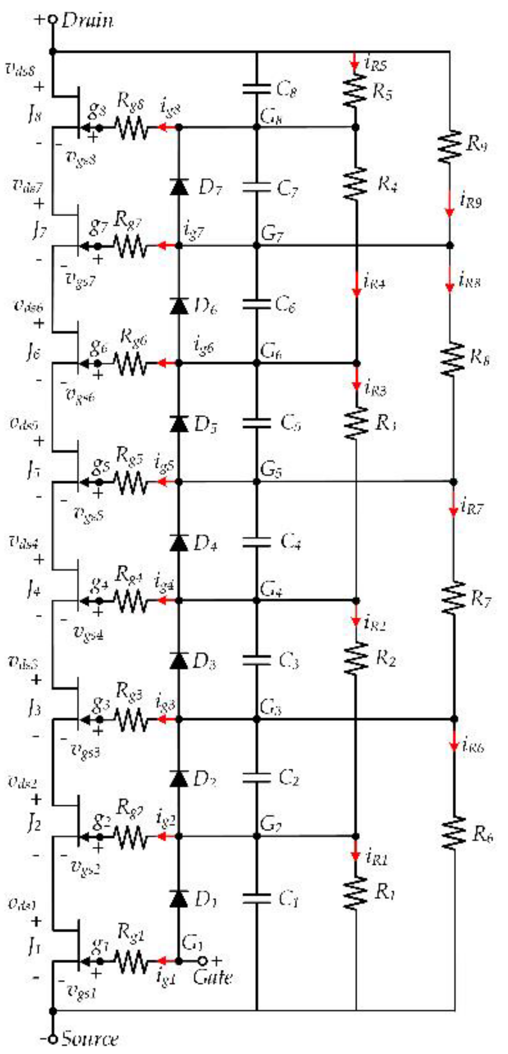


Target Performance

Parameter	Requirement
Blocking Voltage	10 kVDC
Rated Power	1 MW
Efficiency	99.97 %
Response Time	< 500 μs
Life Time	30,000 cycles
Power Density	< 60 MW/m^3

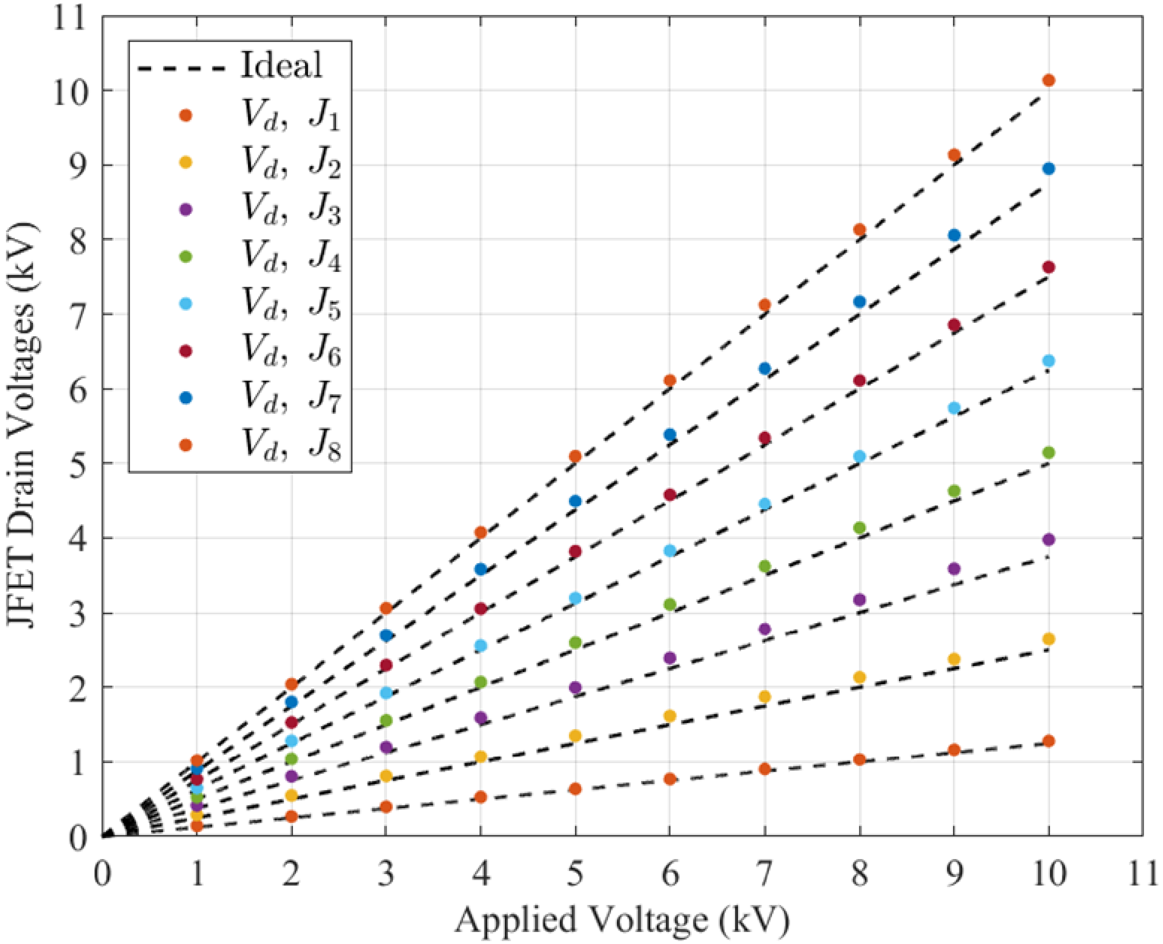


Cascaded JFET Circuit

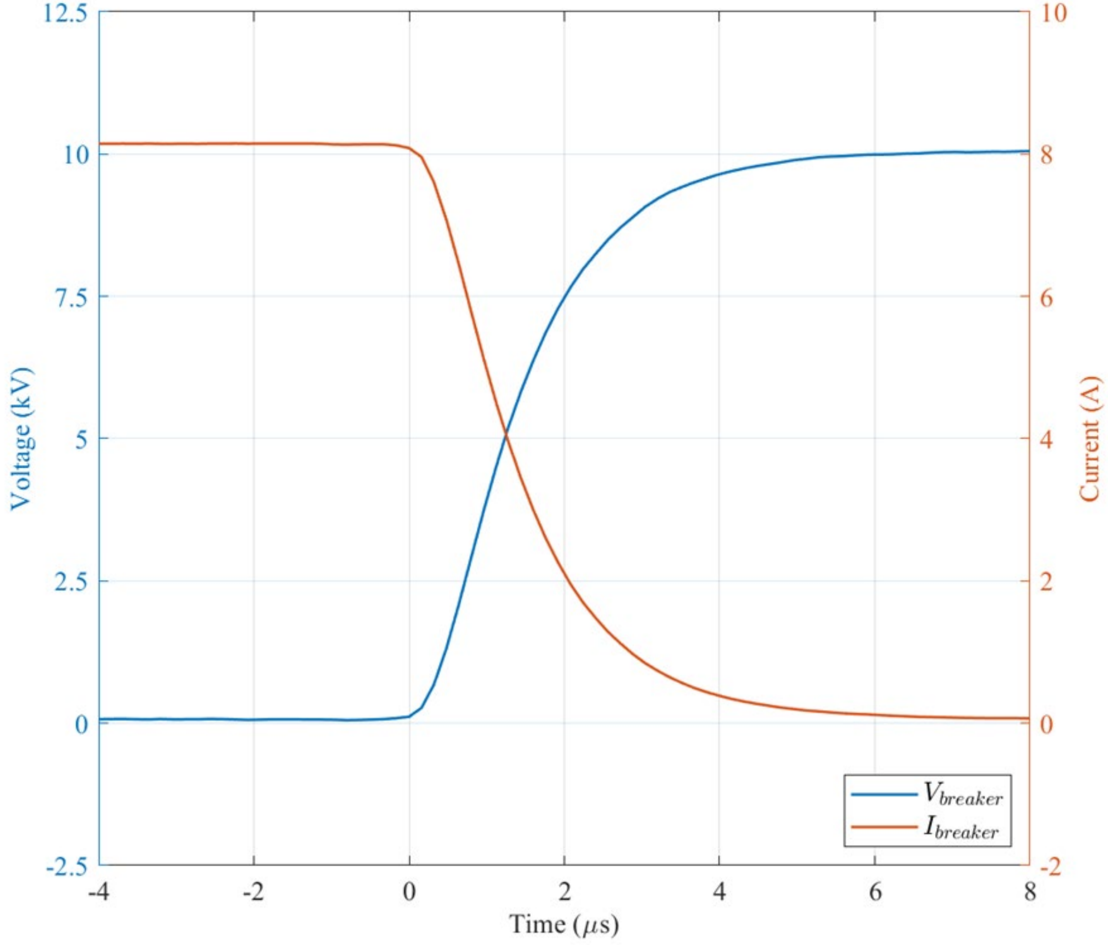


SiC JFET Forward Leg Results at 10kV/8A

Steady-state voltage balancing

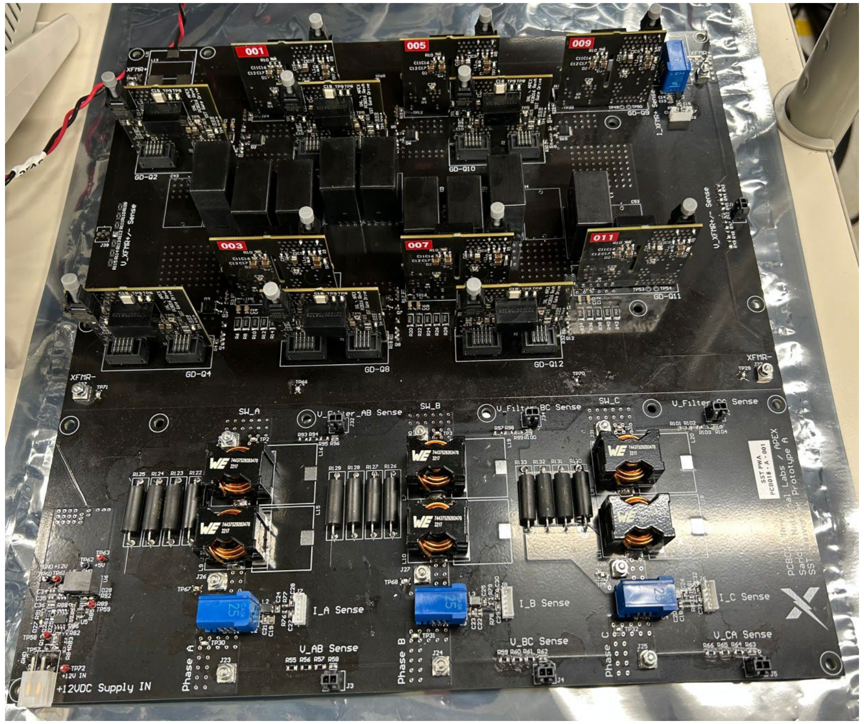


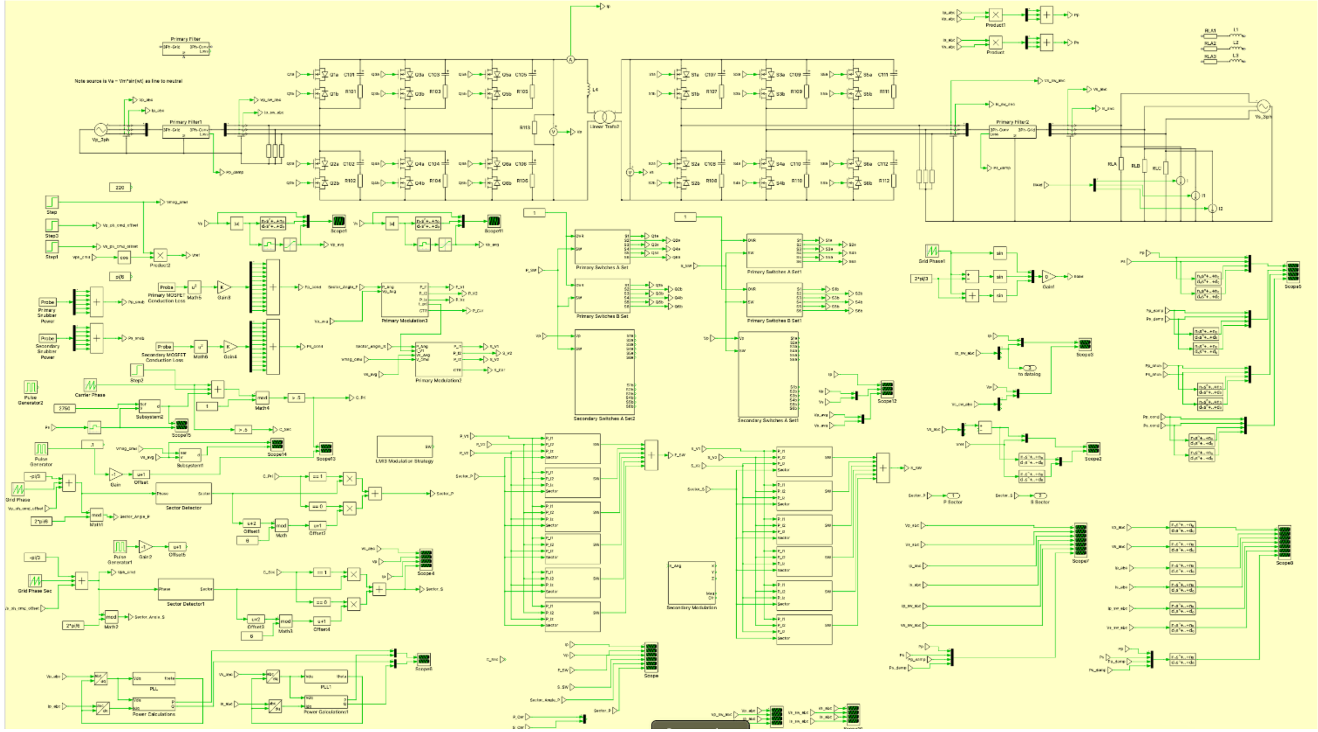
Turn-off transition

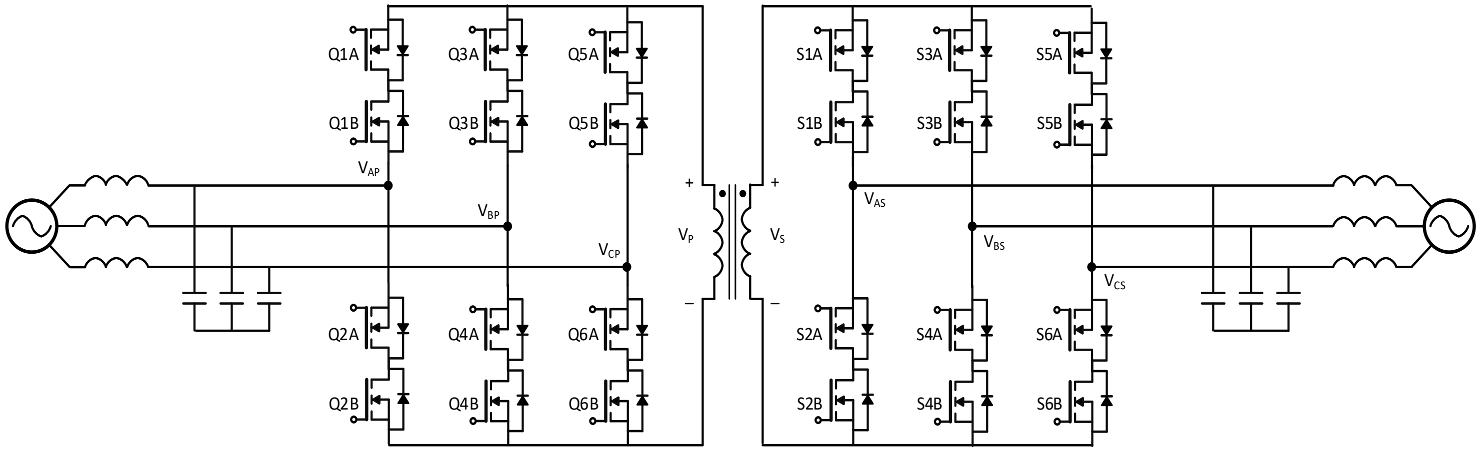


Solid State Transformer Project

- 3-year project funded by the Sandia Mission Campaign (LDRD)
- Select topology and run simulations
- Build control software
- Utilize and Improve SiC BiDFETs
- Improve magnetics and capacitors
- Build to 30kW 3p







Solid state transformer project roadmap

Circuit Simulation, Design, and Fab

Year 3

Prototype C
3ϕ, 30 kW
Cascaded Prototype B

Parallel/Cascaded multi-module system with BiDFETs, custom passives

Year 2

Prototype B
208:480V, 3ϕ, 15kW
Paralleled Prototype A

Year 1

Prototype A
208:480V, 3ϕ, 3kW
Single SST Module

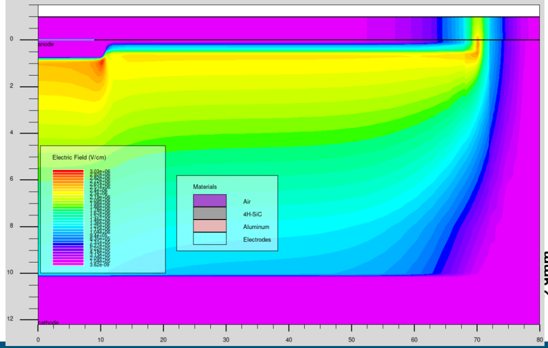
COTS devices with individual drain connected switches

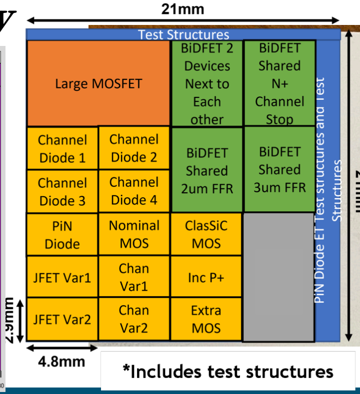
BiDFET Fab

Year 3:
- *1.2kV, 50 mΩ (25 A) SiC BiDFETs demonstrated*
- Gen 2 devices evaluated in *Prototype C*

Year 2:
- Gen 1 devices evaluated in *Prototype A*
- *Gen 2 to Foundry*

Year 1:
- Process simulation and design
- Transfer process to SiC foundry
- *Gen 1 BiDFET to Foundry*



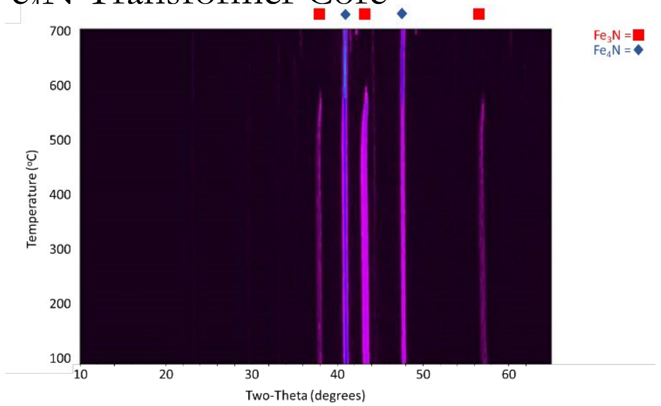


Passive Materials Magnetics/Capacitors

Year 3:
- Fe_4N magnetic core in *Prototype C*

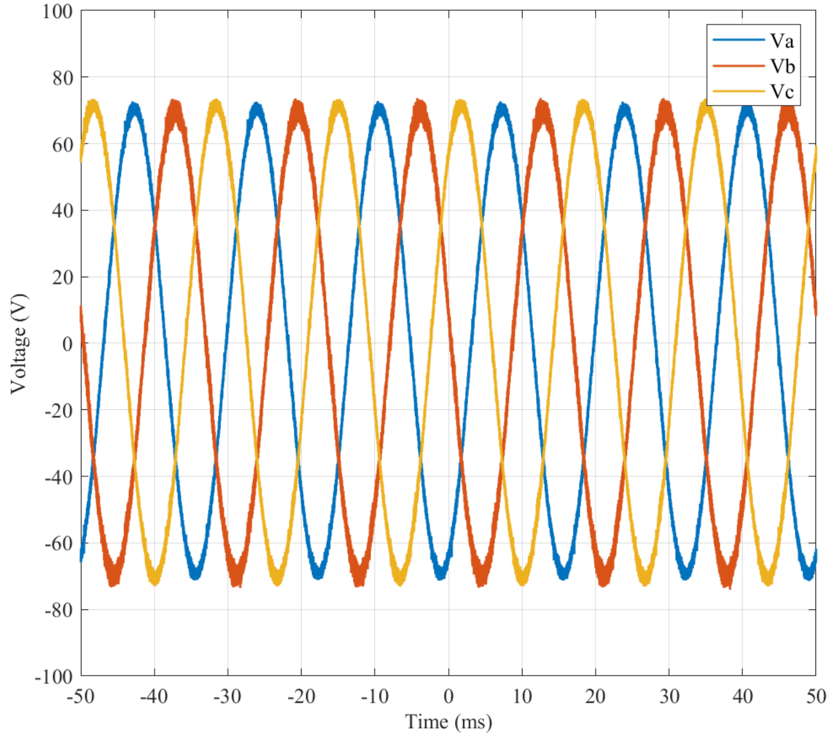
Year 2:
- Fe_4N magnetic core in *Prototype A*

Year 1:
- Ball milling/powder purification Fe_4N powder at scale
- Production of Fe_4N Transformer Core

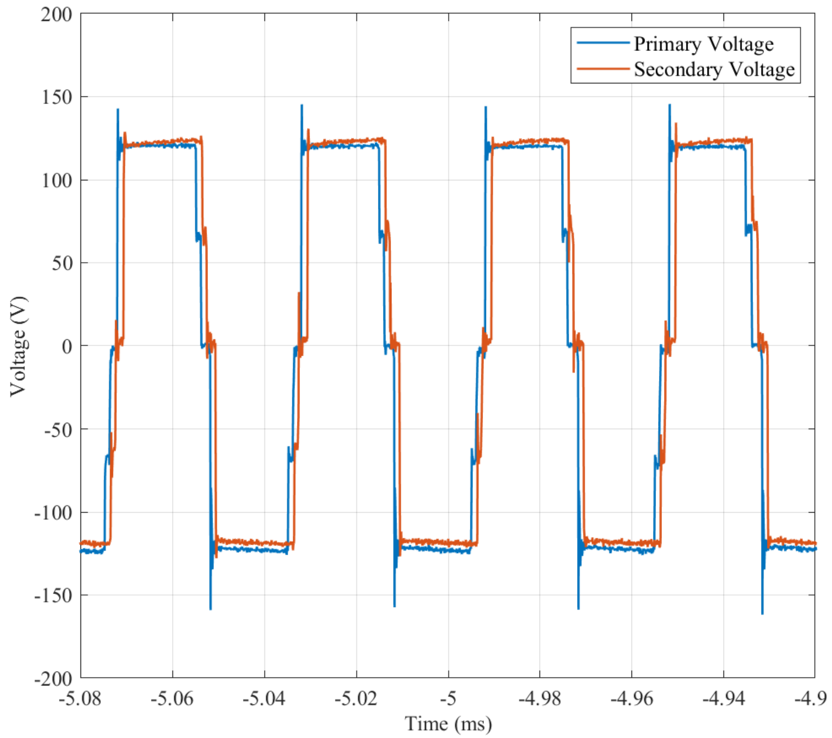


Power control

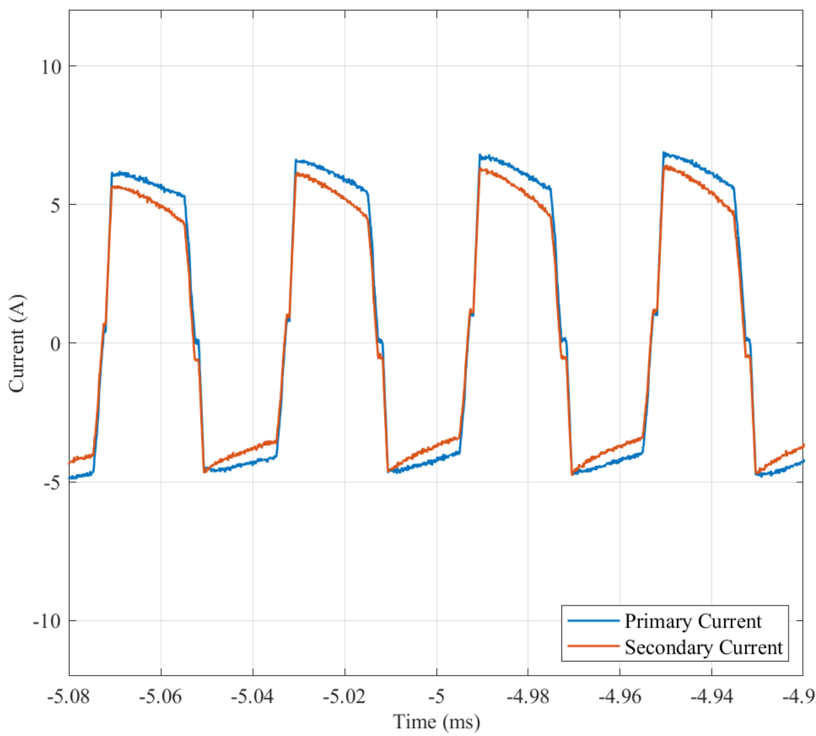
AC Voltage (Primary and Secondary)



Transformer Voltages

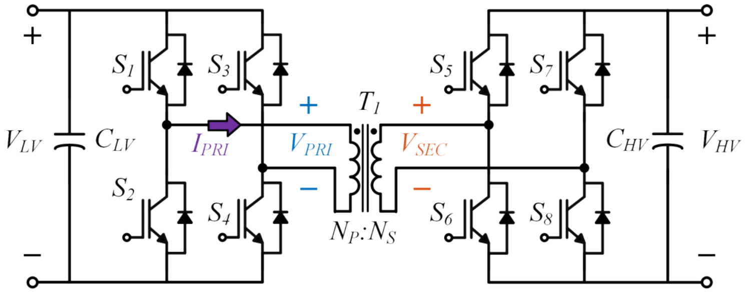


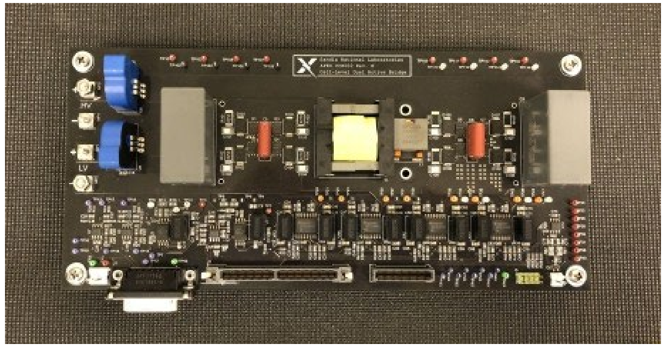
Transformer Currents



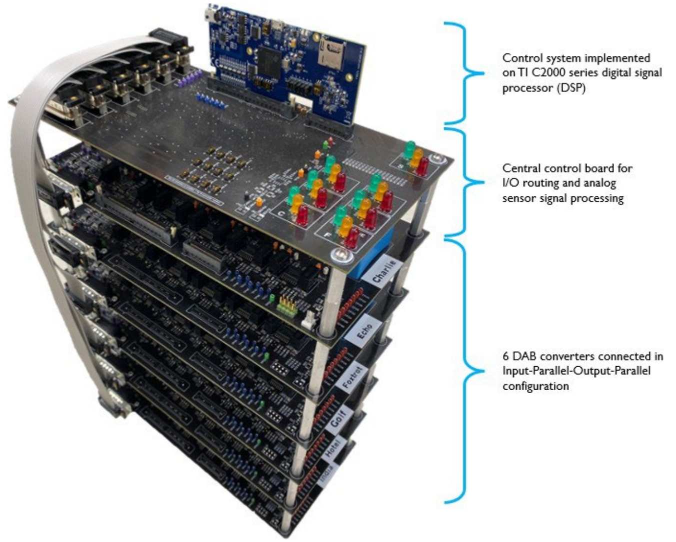
Multi-Level DC-DC Converters

Connect energy storage to Medium Voltage





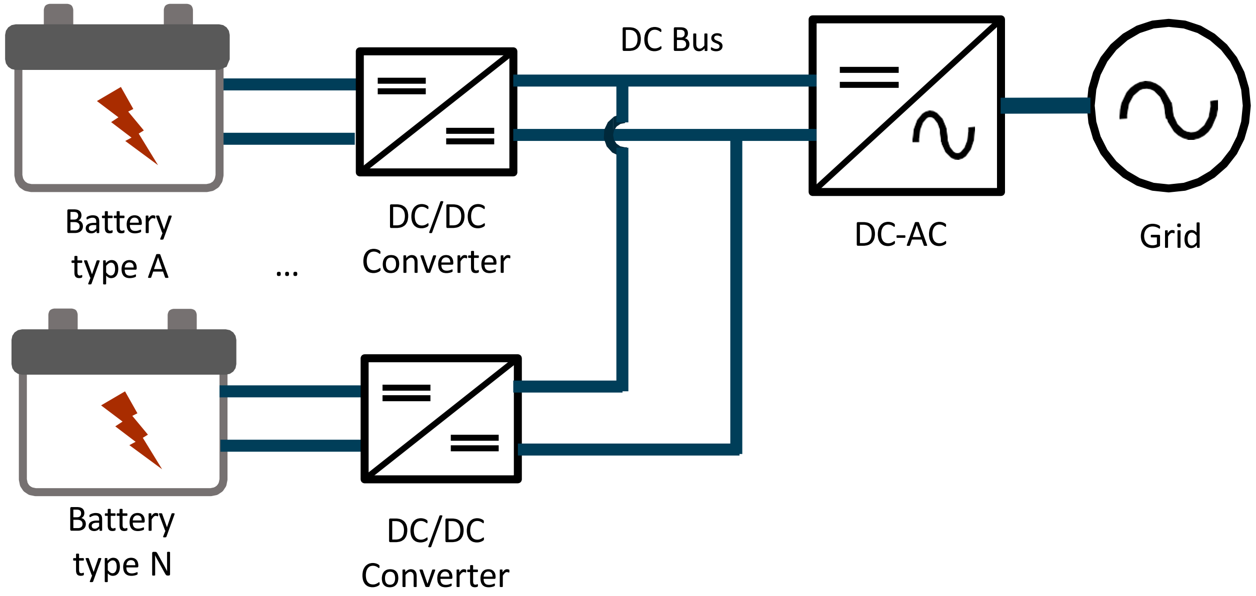
Converter Specifications	
Low-Side Voltage (V_{LV})	12V nom
High-Side Voltage (V_{HV})	72V nom
Switching Freq (f_{sw})	100 kHz
Rated Power (P)	±80W
Turns Ratio (N_P:N_S)	5:30



Six Cascaded DAB Converters with Controller

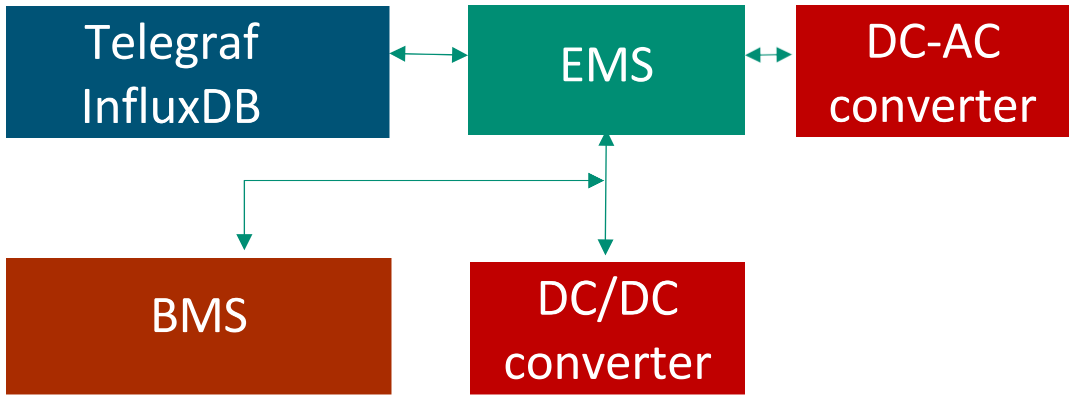
Hybrid Energy Storage System

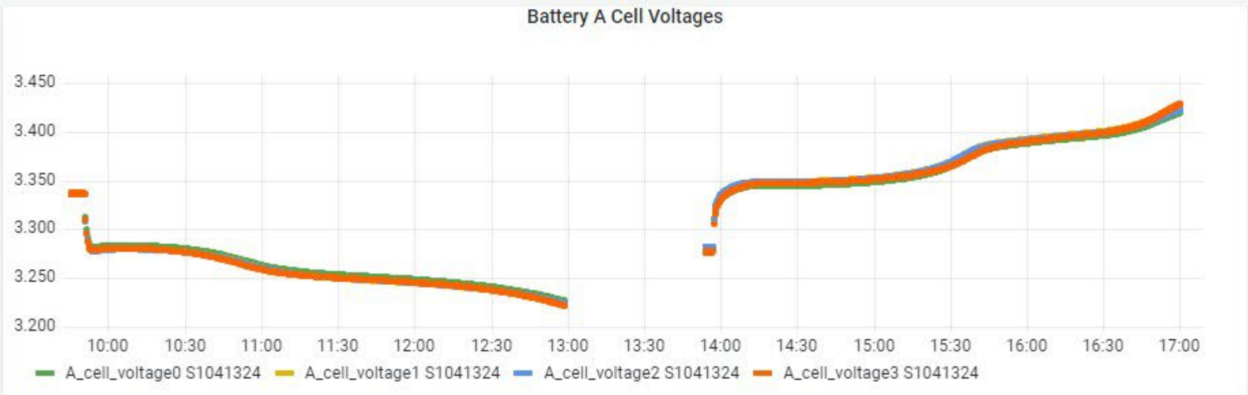
- Batteries operate in different voltage ranges and their V-P curves change as they age
- Each controller be set to a different charging/discharging current or voltage, and can be disconnected at different voltage levels.
- Aging batteries can be replaced without turning the string off
- If one battery fails, all the other batteries can still be used (mix old and new batteries)
- Long Duration Energy Storage (LDES) pack can keep power batteries charged

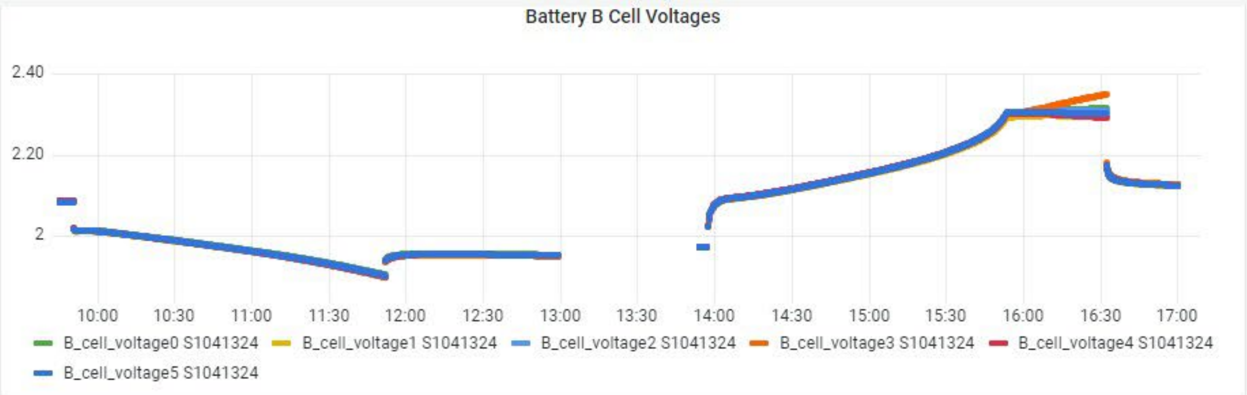


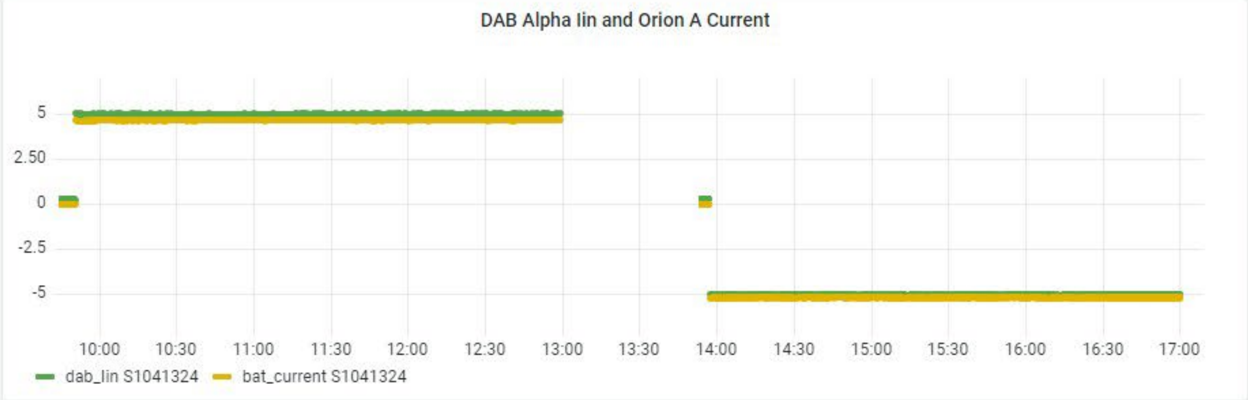
Modular Energy Storage Management System

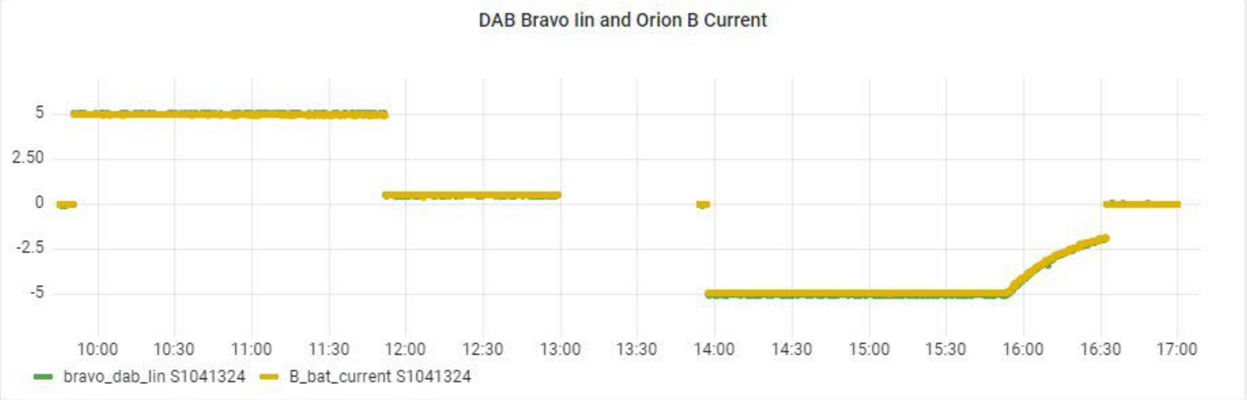
Develop libraries for common hardware components











Summary

Develop components, sub-systems, and fully integrated systems for the electric grid:

1. Development and evaluation of components within Sandia and with partners:
    1. Magnetics
    2. Capacitors
    3. BiDFET
    4. PCSS
    5. Wide bandgap-based power modules

2. Development and integration of systems and subsystems:
    1. DC/DC converters
    2. Breakers
    3. Solid State Transformers
    4. Energy storage systems
    5. Integration of software API from embedded to cloud systems

Principal investigators: Jack Flicker, Jake Mueller, Luciano Garcia Rodriguez, Andrew Dow, Oindrilla Dutta, Bob Kaplar, Todd Monson
Upcoming event: Sandia Power Electronics Workshop (Albuquerque (NM), 8/2-8/3)
Funding: DOE OE Energy Storage (Dr. Gyuk), TRAC, ARPA-E, LDRD