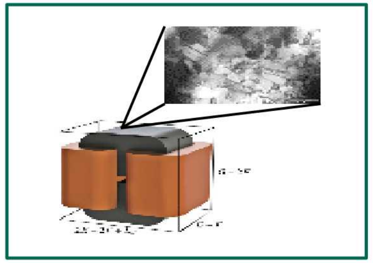
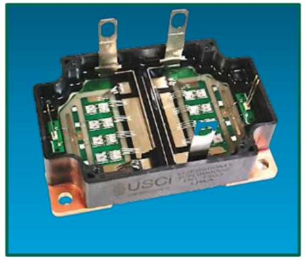
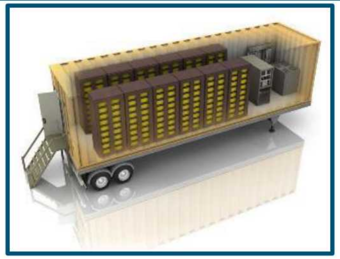
Sandia National Laboratories

SAND2020-10372C

ENERGY STORAGE POWER ELECTRONICS PROGRAM







PRESENTED BY
Stan Atcitty, Ph.D.

U.S. DEPARTMENT OF ENERGY NNSA

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ENERGY STORAGE R&D AT SANDIA

BATTERY MATERIALS
Large portfolio of R&D projects related to advanced materials, new battery chemistries, electrolyte materials, and membranes.

CELL & MODULE LEVEL SAFETY
Evaluate safety and performance of electrical energy storage systems down to the module and cell level.

POWER CONVERSION SYSTEMS
Research and development regarding reliability and performance of power electronics and power conversion systems.

SYSTEMS ANALYSIS
Test laboratories evaluate and optimize performance of megawatt-hour class energy storage systems in grid-tied applications.

DEMONSTRATION PROJECTS
Work with industry to develop, install, commission, and operate electrical energy storage systems.

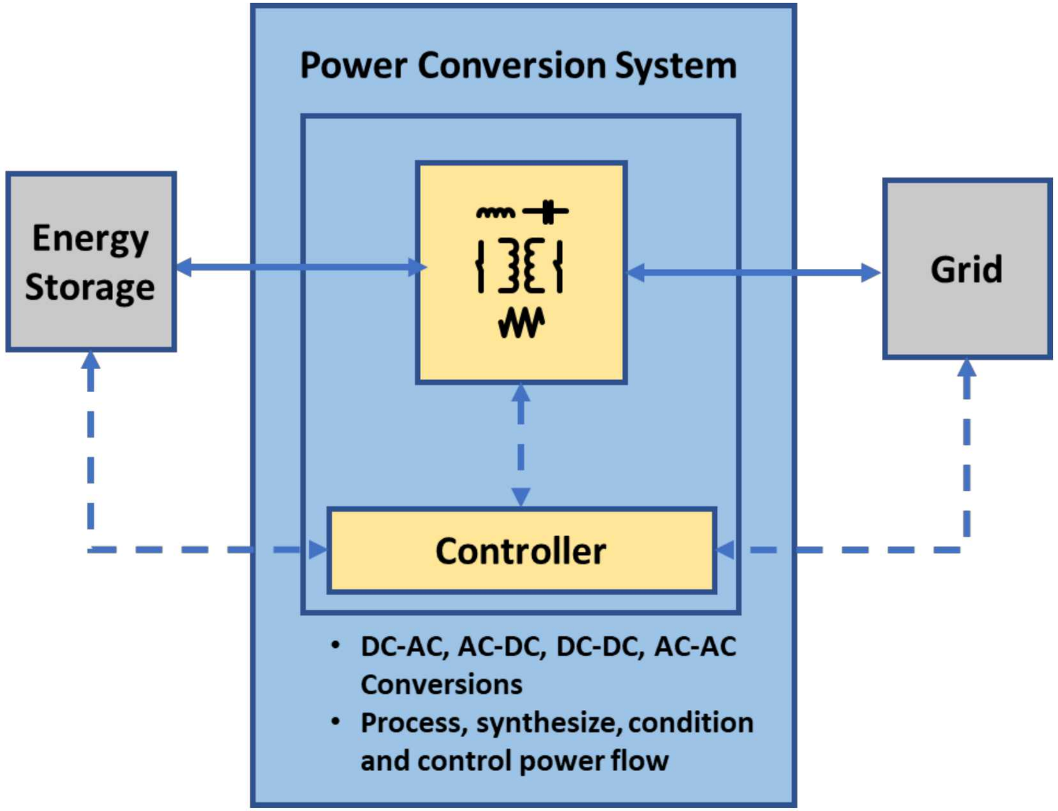
STRATEGIC OUTREACH
Maintain the ESS website and DOE Global Energy Storage Database, organize the annual Peer Review meeting, and host webinars and conferences.

GRID ANALYTICS
Analytical tools model electric grids and microgrids, perform system optimization, plan efficient utilization and optimization of DER on the grid, and understand ROI of energy storage.

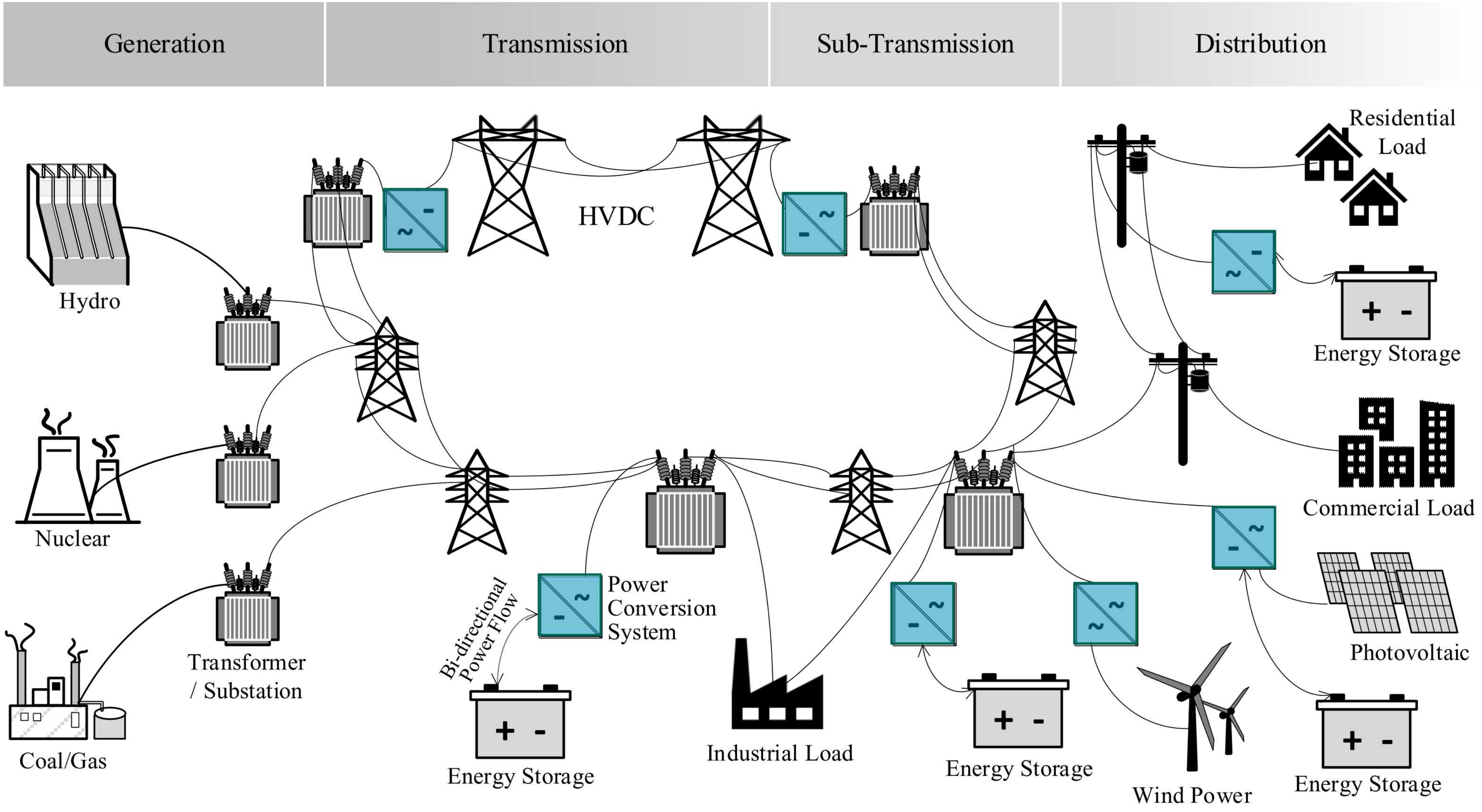
Wide ranging R&D covering energy storage technologies with applications in the grid, transportation, and stationary storage

POWER CONVERSION SYSTEM

- Power conversion systems (PCS), sometimes referred to and used interchangeably as power electronics, are a key enabling technology for energy storage.
- In a grid-tied energy storage system, the PCS controls the power supplied to and absorbed from the grid, simultaneously optimizing energy storage device performance and maintaining grid stability.
- There are multiple types of energy storage technologies, and each has their own characteristics and control parameters that must be managed by the PCS.
- An energy storage installation may be tasked with a variety of different grid support services; the PCS is responsible for controlling the flow of energy to meet the requirements of the intended grid support application.
- The major electrical components of a PCS are semiconductor switches, capacitors, magnetic devices such as inductors and transformers, and a controller.



POWER CONVERSION SYSTEM – KEY ENABLING TECHNOLOGY



BATTERY ENERGY STORAGE SYSTEM ELEMENTS

Battery Storage	Battery Management System (BMS)	Power Conversion System (PCS)	Energy Management System (EMS)	Site Management System (SMS)	Balance of Plant
• Modules • Racks • $/KWh	• Battery Management & BESS Protection	• Bi-directional Inverter • Inverter control • Interconnection / Switchgear • $/KW	• Charge / Discharge • Load Management • Ramp rate control • Grid Stability • Monitoring • $ / ESS	• Distributed Energy Resources (DER) control • Synchronization • Islanding and microgrid control • $ / microgrid	• Transformer/ POC switchgear • BESS container • Climate control • **Fire protection** • Construction and Permitting • $ / project

NOTE: Important to have single entity responsible for the ESS integration.

Source: UtilityDrive

DOE OE POWER ELECTRONICS DEVELOPMENT

2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020

2003 – World's First Fiber Optic Electrical Transducer to Pass Military Vibration and Shock Certification
Exceeds 30Mhz
Capable of Operating up to 34.5kV without additional Insulation, Isolation, or Cooling
R&D 100

2003 – World's First Voltage Controlled 4500V/400A Turn-Off Thyristor
4500V and 400A rated
Integrated Si MOSFET and GTO
Embedded Current Sensing Capability
R&D 100

2005 – World's First High Temperature SiC Single-Phase Inverter
3 kW (1200 V/150 A peak)
250 °C Junction Temperature
Integrated Gate Driver

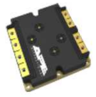
2009 – World's First High Temperature SiC Power Module
50 kW (1200 V/150 A peak)
250 °C Junction Temperature
Integrated HTSOI Gate Driver
R&D 100

2010 – World's First Highly Accelerated Lifetime Testing (HALT) of High Voltage SiC Modules
Dramatically Accelerates Design Cycle
-100 °C to 250 °C (1.7 °C/s Ramp)
48 in × 48 in Table Size
6 axis 75 gRMS Vibration

2011 – World's First Commercially Available Ultra-High-Voltage SiC Thyristor
Rating exceed 6.5kV, 200kHz, 80A
> 200°C junction temperature
R&D 100

2012 – World's First Monolithically Integrated Single Chip Transistor
Integrated SJT/Diode Chip at 1200V

2013 – World's First High Voltage, High Temperature, Reworkable SiC Half-Bridge Power Module
> 15 kV / 100 A, > 200 °C
Reworkable
Wire Bond Free,
Low Parasitic Design
Device Neutral
HV Isolated Gate Driver



2014 – World's First High Frequency, High Temperature, SiC Half-Bridge Power Module
15 kV/100 A, 20 kHz, 200C
Reworkable
Low Parasitic Design
Device Neutral
HV Isolated Gate Driver

2015 – World's Highest Voltage Normally Off SiC JFET
6.5 kV, 20kHz, 60A
200°C Junction Temperature
R&D 100

2018 – World's First Avalanche Rugged Multi-kV Power MOSFET
1 Joule at 5000V

2019 – World's First Commercial Monolithic Switch
1.2 kV SiC Device
Green Tech Gold
2019 R&D 100 Winner

2020 – World's First High Power Modular GaN-Based Inverter
20 kW per Module
Integrated GaN Gate Driver
Stackable to 100 kW

ENERGY STORAGE POWER ELECTRONICS PROGRAM – INDUSTRY PROJECTS

GeneSiC Semiconductor

InnoCit

Aegis Technology, Inc.

Bonneville Power Administration

Creare

DRS Research

Mainstream Engineering

PneumatiCoat Technologies

Powdermet

RnS

Princeton Power Systems

Sigma Technologies

Silicon Power

Satcon

TPL, Inc.

USCi United Silicon Carbide, inc.

Wolfspeed

TRS Technologies

Airak Corp.

ENERGY STORAGE POWER ELECTRONICS PROGRAM – UNIVERSITY PROJECTS

University of Arkansas

NM State University

UAF University of Alaska Fairbanks

Ohio State

Georgia Tech

SMU

University of Houston

Texas — The University of Texas at Austin

ASU Arizona State University

MIT Massachusetts Institute of Technology

Missouri S&T

NC State University

Virginia Tech

ADVANCED POWER ELECTRONIC CONVERSION SYSTEMS (APEX) LAB

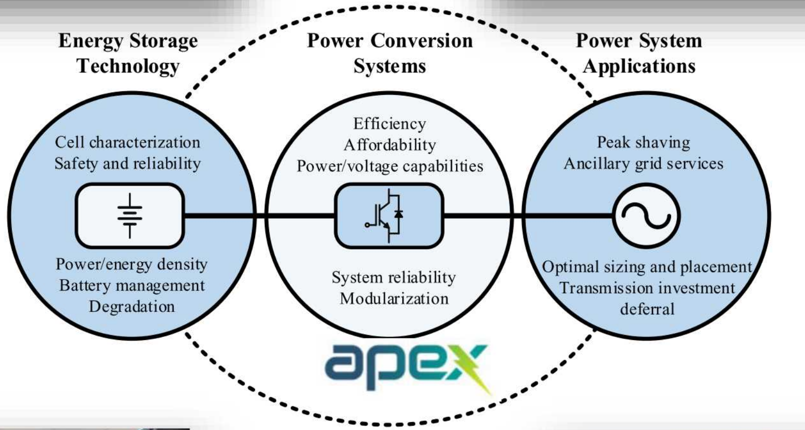
Contact: Jake Mueller (jmuelle@sandia.gov), Stan Atcitty (satcitt@sandia.gov)

Problem: New power conversion solutions are needed to support the expanding role of energy storage in the grid

SNL Approach: Develop new power conversion topologies and intelligent control strategies; leverage the capabilities of advanced components and materials; verify performance through hardware experimentation

Key Outcomes: Modular and fault-tolerant hardware architectures improve the reliability, scalability, efficiency, and flexibility of utility-scale storage

Key Capabilities: Real-time simulation; rapid prototyping and electrical fabrication; energy storage emulation at cell, module, and system level; converter analysis in 30 kW bidirectional hardware-in-the-loop testbed, fault insertion and destructive testing



ADVANCED COMPONENTS: SEMICONDUCTORS

Contact: Bob Kaplar, rjkapla@sandia.gov

Problem:

- Reliability remains one of the major factors impending the widespread adoption of wide bandgap (WBG) power devices
- In particular, power circuit designers need to be confident in the devices' reliability
- Need to design, fabricate, and characterize WBG switching devices as a neutral third party

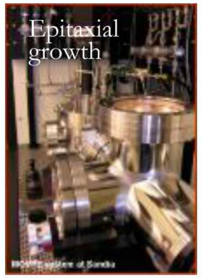
Approach:

- Utilize a range of techniques from atomic-scale characterization to reliability testing in switching circuits
- Stressing WBG power devices, measuring their change in performance, modeling the results, and ascertaining the impact on the system
- Examining new devices as they have been introduced such as SiC MOSFETs, GaN HEMTs, vertical GaN

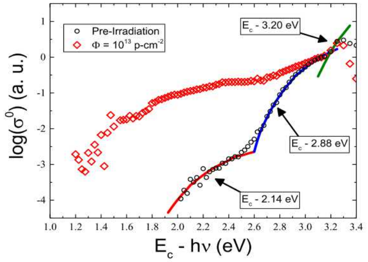
Key Outcomes:

- The ability to correlate materials physics to the impact of device degradation on the power conversion system

WBG Material and Device Fabrication and Characterization

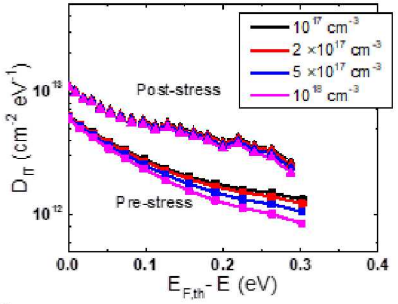


Defect Spectroscopy



Reliability Physics

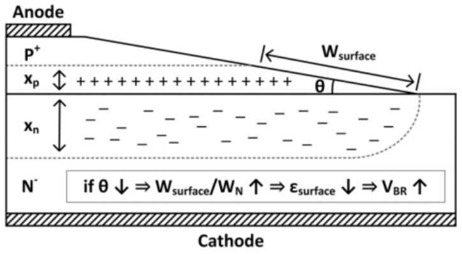
Switching Reliability Testing

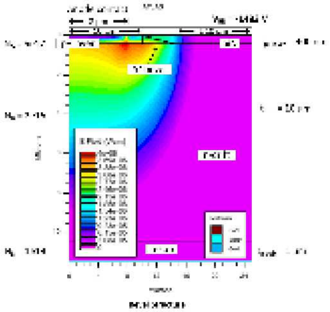


SiC MOSFET Reliability

Device Simulation

Novel Edge Terminations





ADVANCED COMPONENTS: MAGNETICS

Contact: Todd Monson (tmonson@sandia.gov)

Problem:

- Current soft magnetic materials do not meet all the requirements of emerging power electronics topologies
- Significant volume reduction and increased reliability in power conversion systems will be enabled by advanced magnetics.

SNL Approach:

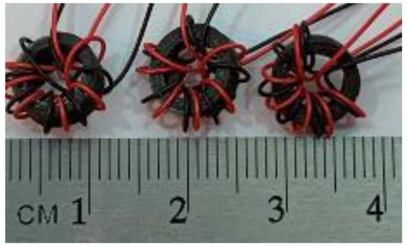
- Develop new high magnetization, low loss magnetic cores for high frequency transformers
- Going beyond state of the art through the implementation of iron nitride ((Fe_4N)

Key Outcomes:

- New high magnetization, low loss soft magnetic core materials capable of operating in conjunction with wide bandgap semiconductor based power electronics

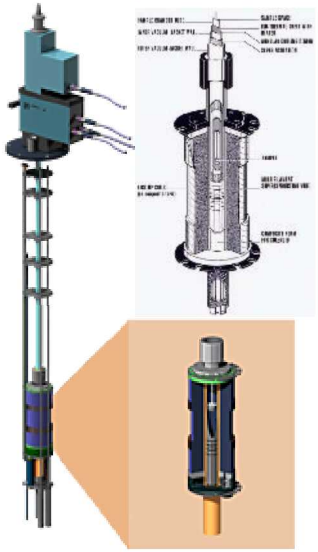
γ'-Fe_4N toroidal inductive cores

Composite magnetic cores wound for B-H analysis

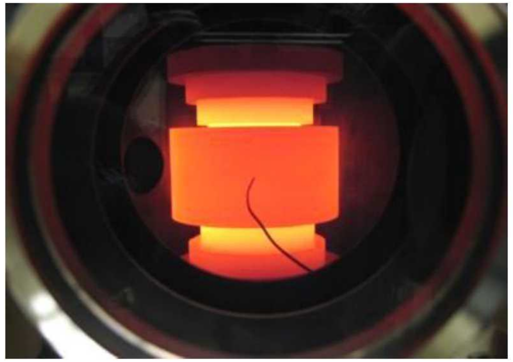


Iwatsu B-H analyzer

Quantum Design Magnetic Property Measurement System (MPMS)



Spark Plasma Sintering (in collaboration with UC Irvine)



ADVANCED COMPONENTS: CAPACITORS

Contact: Jon Bock, jabock@sandia.gov

Problem:

- DC-link capacitors are prone to failure and can negatively impact the adoption of power conversion systems used in distributed energy and renewable systems
- Dielectric breakdown and temperature limitations caused by excessive heating from electrical losses and degradation are of key concern for high-reliability systems from Space, MIL, and Grid

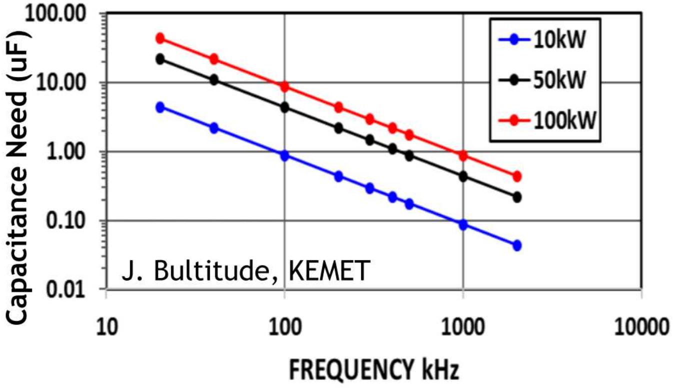
SNL Approach:

- Perform reliability assessment on commercial capacitors, understand failure physics for better reliability models, and develop next-gen capacitor materials
- Evaluating reliability of current gen ceramic capacitors for DC-link applications (KC-Link, Ceralink, X7R)
- Evaluate next-gen high temperature capacitors under realistic ripple waveform seen in power electronics

Key Outcomes:

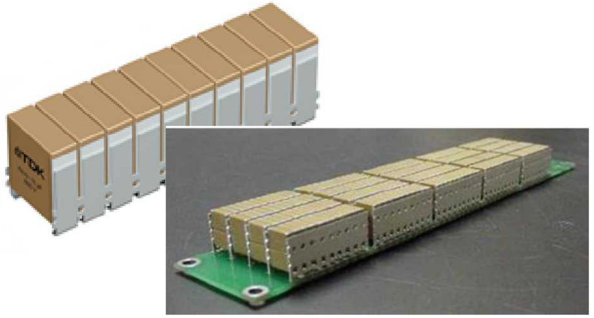
- Understanding of reliability and root cause of failures leads to capacitor design changes, circuit-level reliability estimates, expanded capacitor capabilities leading to increase performance of power conversion systems

Increased Frequency and Voltage
Lowers Capacitance Needs

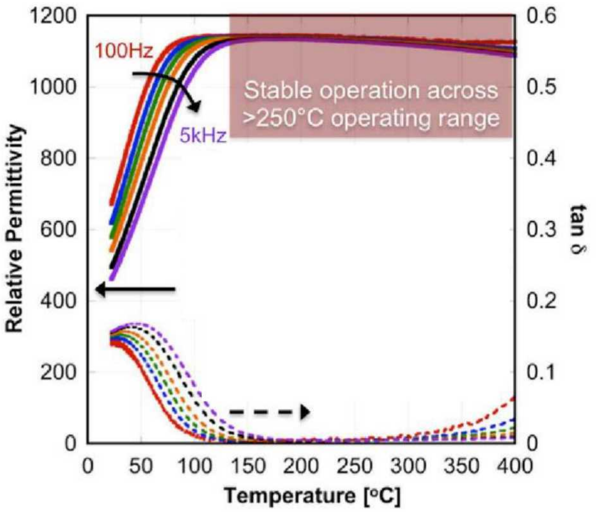


In-Depth Lifetime Evaluation of Current-Gen Technologies

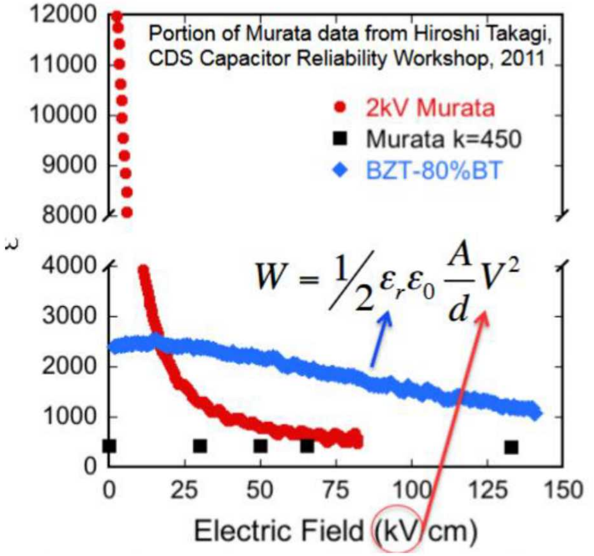
KC-Link and Ceralink



High Permittivity Dielectrics >150°C



High Permittivity *at high field*



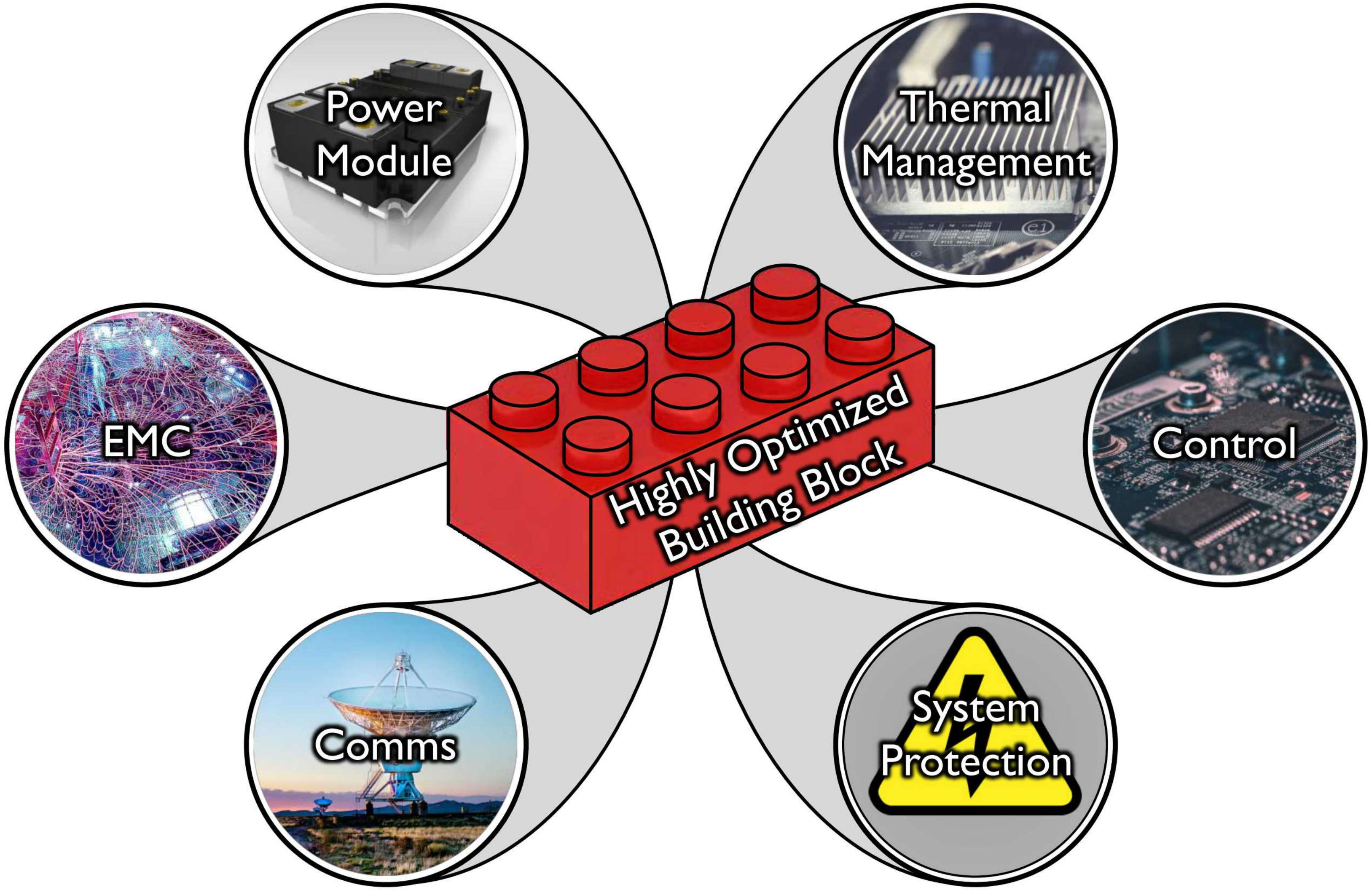
SYSTEM INTEGRATION

New components are important, but not the whole story

Advanced Topologies: Modular, fault-tolerant hardware architectures

Advanced Control Systems: Methods for detecting and reacting to internal failures in real time

Design-For-Reliability: Computational tools for assessing reliability and remaining time-to-failure based on application-specific operating conditions



LOOKING FORWARD

Target Research Areas

- Power conversion system for scalable energy storage deployments
  - Modular topologies for direct MV grid connection
  - Integration of storage in existing and emerging power electronic energy infrastructure
- Uninterruptible converter topologies for critical storage assets
  - Fault-tolerant and reconfigurable hardware architectures
  - Hot-swap capable converters and storage systems
- Applications of power electronics in storage system safety
  - Stranded energy extraction
  - Active response to thermal runaway
- Integration of advanced components
  - Wide bandgap devices
  - Advanced magnetics
  - Advanced capacitors

The Energy Storage Power Electronics Program is supported by Dr. Imre Gyuk and the Energy Storage Program in the DOE Office of Electricity.

Questions?

Thank You!