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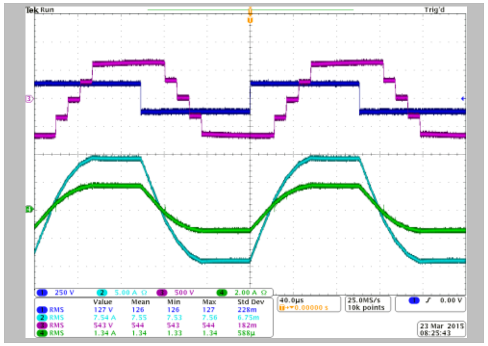

Power Electronics, Energy Storage Technology and Systems

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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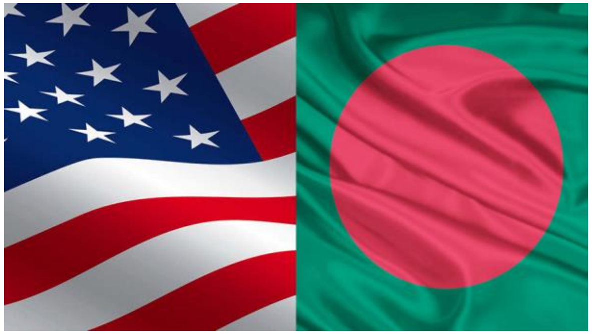
Personal Background

- 2002: Bachelors in Electrical & Electronic Engineering from Bangladesh University of Engineering & Technology (BUET);
- Worked for 3 years as an Assistant Project Manager in a Power System Development Project (New 230/132kV Tr. Line & Substation) in Bangladesh;
- 5 years as an Asstt. Divisional Engineer in a Telecommunication Company in Bangladesh;
- 2010-2016: PhD in Electrical Engineering from Univ. of Texas at San Antonio (UTSA) with Power Electronics major;
- 2017: Joined Sandia National Lab. as a Postdoctoral Appointee in the Energy Storage research group.



Bangladesh University of Engineering and Technology

UTSA The University of Texas at San Antonio™

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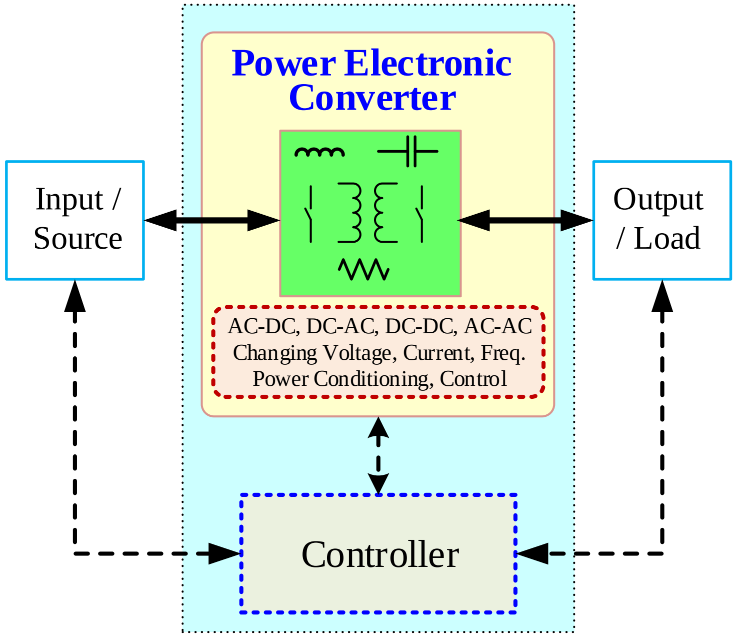
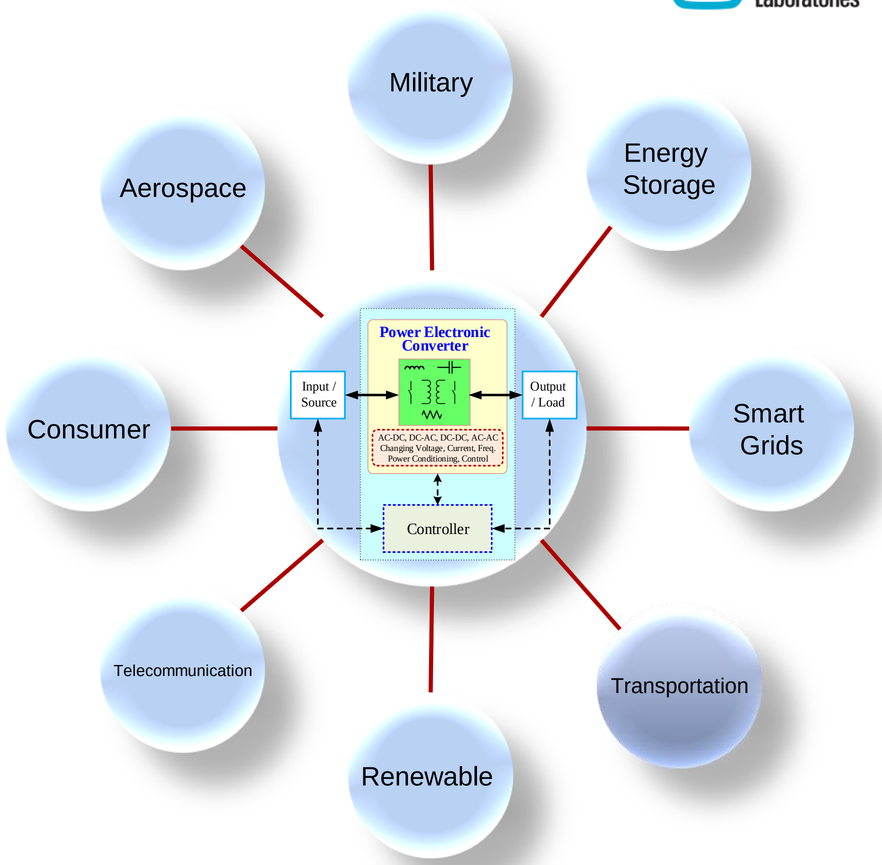
Power Electronics

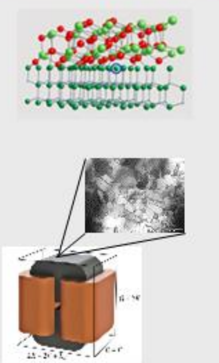




- Power Electronics is an enabling technology;
- It synthesizes, processes, converts, conditions and controls the power flow;
- Approximately 30% of all electric power currently generated uses PE somewhere between the point of generation and distribution. By 2030, it is expected that 80% of all electric power will flow through PE.

OE Power Electronics Program

Materials R&D



- Gate Oxide R&D
- Advanced Magnetics

Devices

- ETO
- SiC Thyristors
- Monolithically integrated SiC transistors
- WBG Characterization & Reliability
- High energy dielectric capacitors

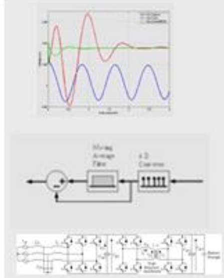
Power Modules

- SiC High Temp/density Power Module
- HV SiC JFET Module
- HV, HT Reworkable SiC half-bridge modules

Power Conversion System

- Dstatcom plus energy storage for wind energy
- Optically isolated MW Inverter
- High density inverter with integrated thermal management
- High temp power inverter

Applications



- FACTS and Energy Storage
- Power smoothing and control for renewables
- Dual active bridge for advanced energy storage system designs

- Led by Stan Atcitty
- Started 1998
- Five R&D 100 Awards
- Five US Patents, three pending
- Over 50 technical publications
- Power Electronics for Renewable & Distributed Energy Systems book

@ SNL Energy Storage PE Lab:

- High performance computing lab;
- Simulation Software (Matlab®/Simulink®, PLECS®, PSIM®;
- Hardware in the loop (HIL) forthcoming.

Energy Storage Technologies

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Energy

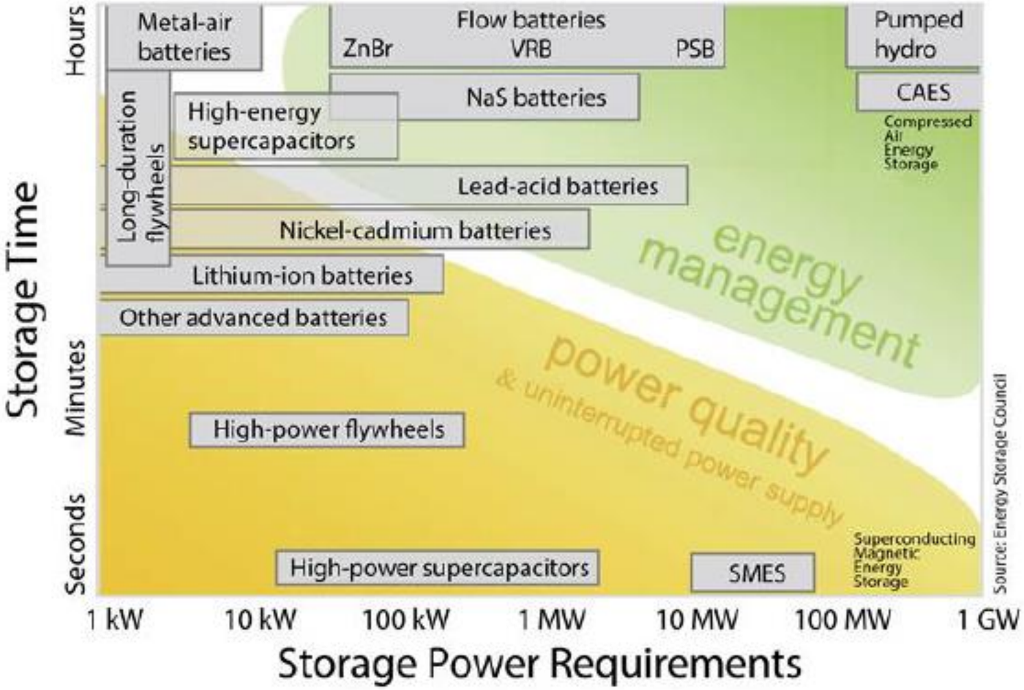
- Pumped Hydro
- Compressed Air Energy Storage (CAES)
- Batteries
  - Sodium Sulfur (NaS)
  - Flow Batteries
  - Lead Acid
  - Advanced Lead Carbon
  - Lithium Ion
- Flywheels
- Superconducting magnetic energy storage (SMES)
- Electrochemical Capacitors

Power

Two regimes, multiple technologies:

Power – short discharges (sec to min): flywheels, capacitors, SMES, some batteries

Energy – long discharges (min to hr): batteries, H_2 fuel cells, CAES, pumped hydro



Courtesy: Stan Atcitty, SNL

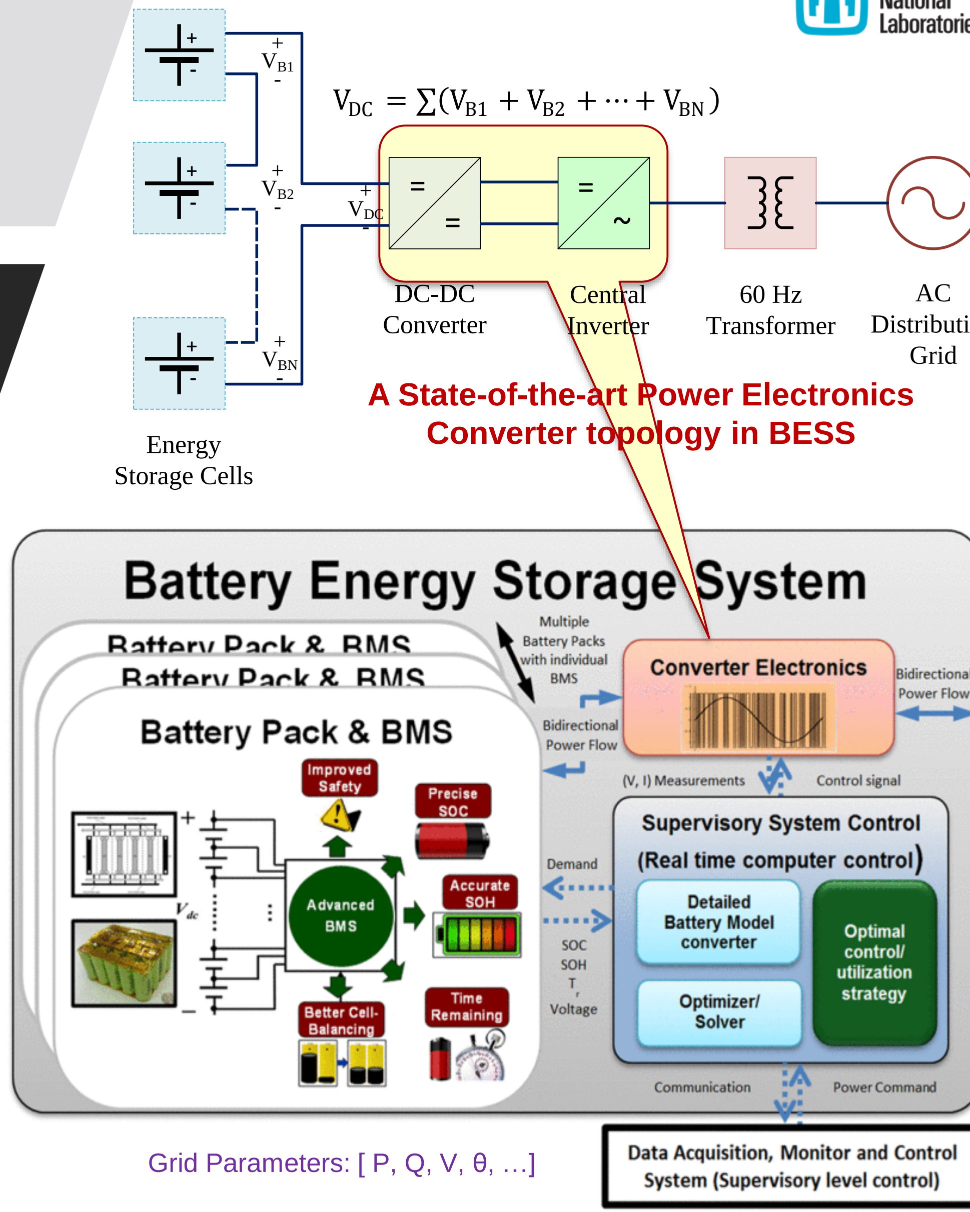
Grid Energy Storage Challenges

- Cost competitive storage technology - Life-cycle cost, efficiency, ED, cycle life, capacity fade etc.
  - Lack of understanding in ES cell performance in grid-level system,
  - Optimization and efficient coupling between electro-chemistry of storage medium and power electronics for grid interface,
- Validated reliability and **safety** – essential for user confidence;
- Equitable regulatory environment – reducing institutional and regulatory hurdles;
- Industry acceptance – industry should have confidence that storage will deploy as expected, and deliver as predicted and promised.

Source: Grid Energy Storage – U.S.DOE, December 2013

State-of-the-art PE Converters in ESS

- Typically works at a series-string level or a battery-pack of series-parallel combination of Cells;
- This topology doesn't optimize Cell-level control;
- No ready data available to identify faulty Cell(s);
- Doesn't analyze pre- and post-safety issues;



BMS Image reproduced with permission from M.T.Lawder et al.

PE Research for ESS @ SNL (Org. 8811)

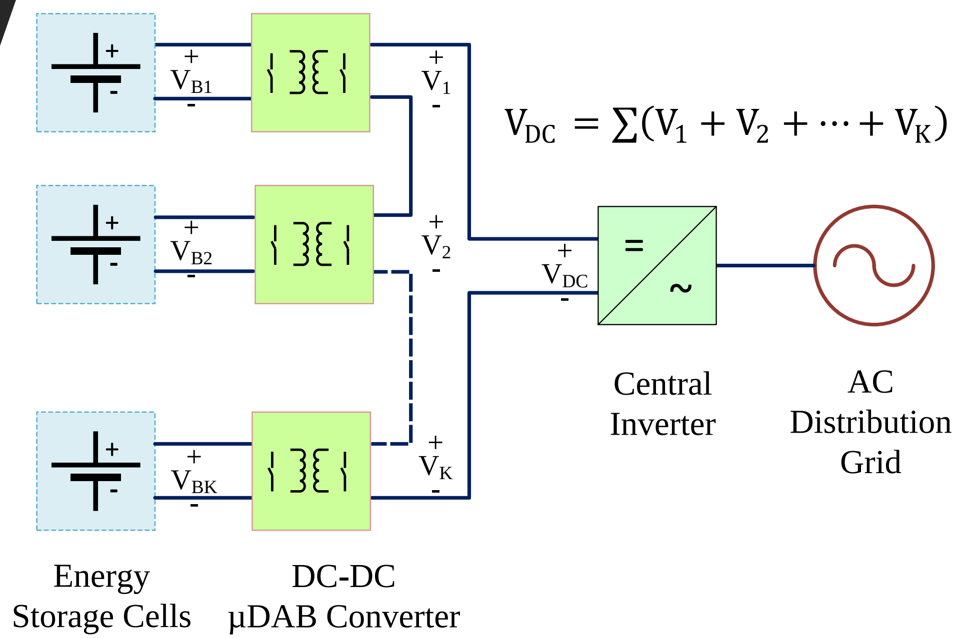
- The **lithium cobalt oxide**/graphite system has been chosen as a benchmark chemistry in developing the BMS ;
- Through **Sandia-developed technology** significant insights into degradation can be discovered, previously unachievable;
- Meaningful data, thus obtained, will be used to design control-algorithm for BMS;

$Li\text{-}CoO_2$ Batteries under testing condition

Photo Courtesy: Heather Barkholtz, SNL

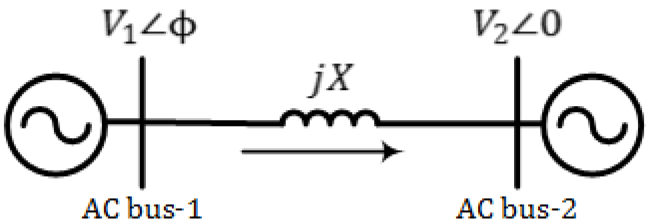
Proposed Solution

- A novel **GaN-based** micro DAB **(µDAB) DC-DC converters** will be considered for **cell-level monitoring** and to achieve better **efficiency**;
- This topology eliminates the need of a bulky 60Hz transformer at grid interface, thus **reduces size** and **increases overall power density**;
- This will enable real-time monitoring and management for **safer** and more reliable operation by expending and **predicting cycle life**, as well as understand the **earliest indications of failure**;



Proposed Cell-level Power Electronics Topology for BESS

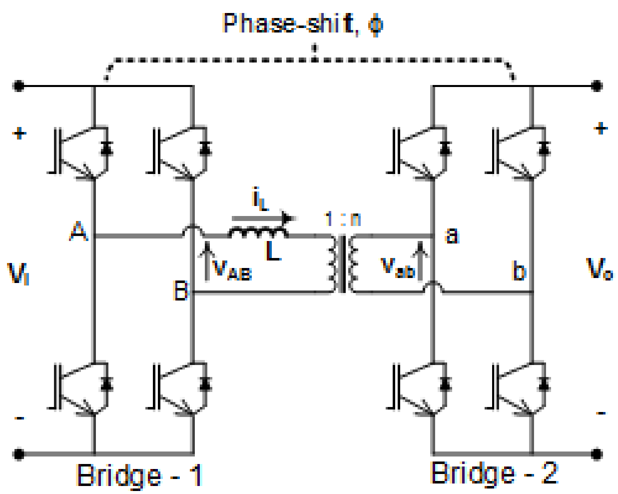
How Dual Active Bridge (DAB) Works!



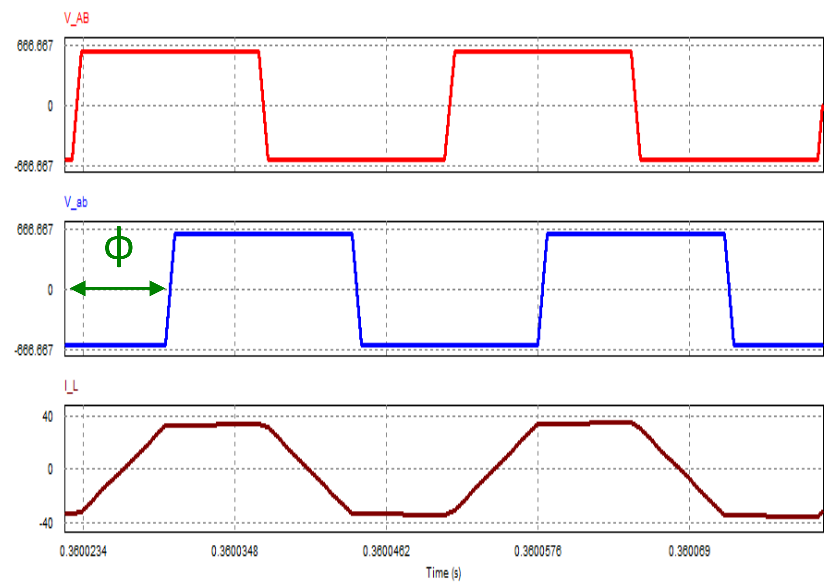
$$P = \frac{V_1 V_2}{X}\sin\phi$$

Power-flow through a transmission line

- Dual active bridge has similar power-flow principle; *[R. W. DeDoncker et al. - 1991]*
- Two phase-shifted square waves;
- Phase-shift controls the power flow;
- At *d=1*, full soft-switching range ($0<\phi<90^0$)



$$P = \frac{V_i^2}{X_L} d\phi\left(1 - \frac{|\phi|}{\pi}\right); \quad d = \frac{V_o}{nV_i}$$



Future Research on Power Electronics for ESS

- As per the requirement of storage medium and the load (/grid), novel PE converter topologies can be explored;
- Adopting the advantages from advanced device (e.g. SiC, GaN) and components (e.g. magnetics, capacitors);
- Designing PE converters targeting cost, power density, efficiency, reliability;
- Control optimization of PE converters;
- Ensuring safety in ESS using power electronics;

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THANK YOU

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