Sandia National Laboratories

PROJECT PROFILE
Topic: Power Electronics | Vertical: Safety & Reliability
Strategic Pathway: Grow
Project start and finish: FY25-FY27

SINGLE-STAGE ENERGY STORAGE CONVERTER INTERFACE USING BIDIRECTIONAL SEMICONDUCTOR DEVICES

OPTIMIZATION OF STORAGE CONVERTER INTERFACE

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PROBLEM

Bidirectional semiconductor (BDS) switches are a promising new technology for utility-scale energy storage conversion but **require validation of new converter topologies and control strategies** before industry adoption.

- **Now**: First devices hit the market in early-2026; storage converters still rely on conventional multistage conversion w/ unidirectional devices
- **Opportunity:** BDS switches enable a new single-stage, isolated converter topology with ~50% fewer devices (lower loss/cost, higher reliability) for modular energy storage interfacing
- **Challenge:** BDS-enabled converters remain largely unproven in industry **requiring difficult application-specific control development**

RESULTS

Experimental open-loop charge and discharge control results successfully demonstrate modulation/control viability.

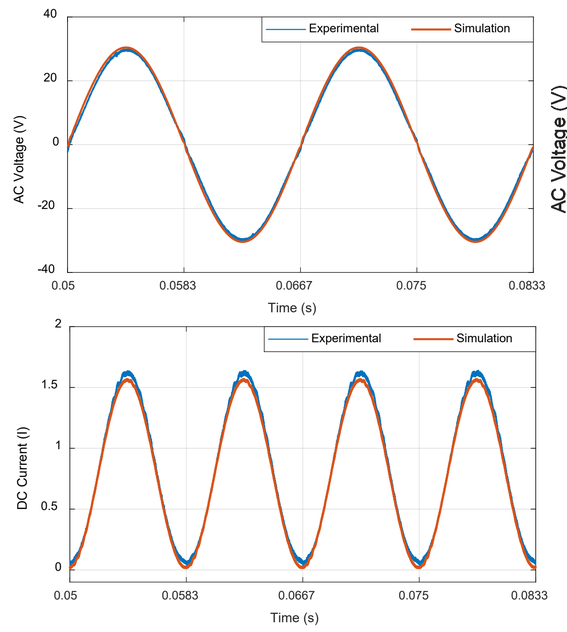


Fig. 1. Discharge Control

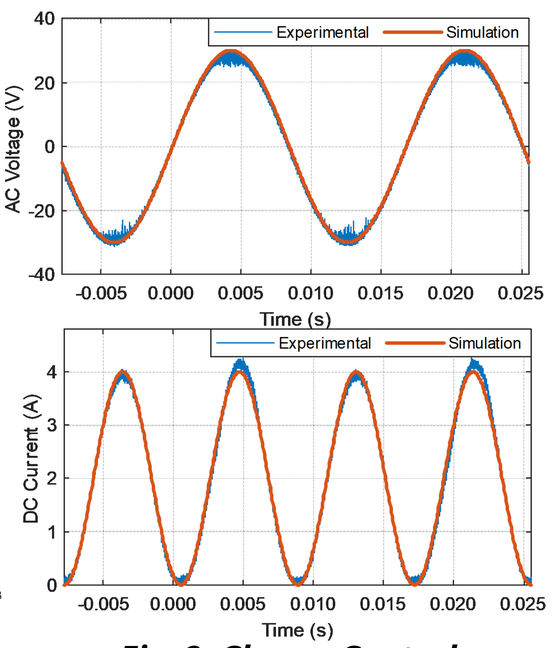


Fig. 2. Charge Control

FY26

Topology Selection → **Control Formulation** → **Module Hardware** → **System-Level Modeling** → **System-Level Hardware** → **Scaled to MV**

APPROACH

A single-stage DC–AC DAB storage interface is explored. Its nontraditional BDS-enabled design makes conventional modulation and control inapplicable.

- **New bidirectional charge and discharge modulation schemes** are developed in simulation and validated on a hardware module prototype.

Low Voltage Test Ratings	
DC voltage, V_{dc}	12 V
AC voltage, $V_{ac,pk}$	30 V
Output power, P_o	90 W
Switching frequency, f_{sw}	50 kHz
TX Turns Ratio, n	1:3

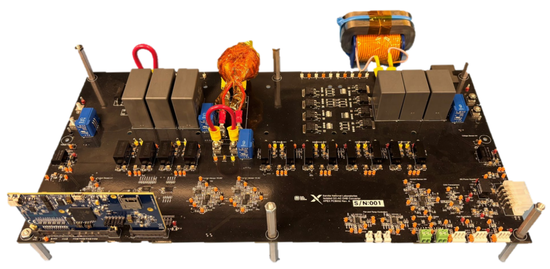
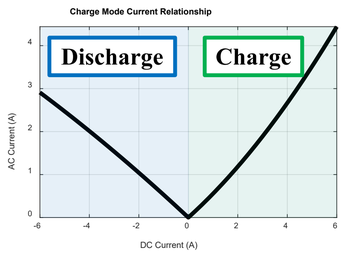


Fig. 3. DC-AC DAB Hardware Prototype

Modulation Scheme Overview

Mode I: $v_4 \geq 0$ and $i_2 \geq 0$,
Mode II: $v_4 \geq 0$ and $i_2 < 0$,
Mode III: $v_4 \leq 0$ and $i_2 \leq 0$,
Mode IV: $v_4 \leq 0$ and $i_2 > 0$.



Current Setpoint Relationship

$$y = \begin{cases} -0.009x^2 - 0.539x, & \text{for } x < 0 \\ 0.037x^2 + 0.518x, & \text{for } x \geq 0 \end{cases}$$

where y is the AC current and x is the DC current

CONCLUSIONS & IMPACT

Experiments on the low-voltage prototype demonstrate stable operation in open-loop for both charge and discharge.

- **Confirms feasibility** for controlling a BDS-enabled, single-stage DC–AC DAB converter in hardware
- **Provides baseline** waveforms/data to validate models and inform closed-loop control design
- **Reduces risk for scaling** toward modular, utility-relevant storage interfaces with fewer power devices

FUTURE DIRECTIONS

Next, we'll transition from open-loop feasibility tests to validated closed-loop control and scaled evaluation.

- **Implement and validate** closed-loop charge and discharge control under nominal conditions
- **Scale testing** toward full system ratings ($48V_{dc}$:$240V_{ac}$)
- **Model system-level** simulation of series-connected modules on a shared AC bus

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