Sandia National Laboratories

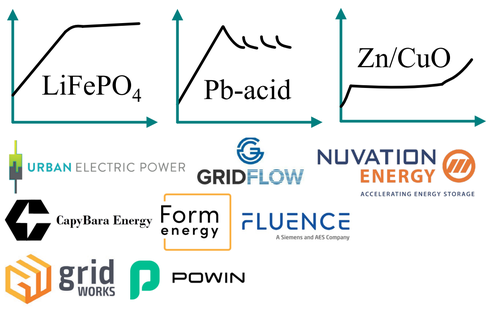
Grid forming batteries: DC-AC Converter Prototype

Oindrilla Dutta, Jacob Mueller, Robert Wauneka, and Babu Chalamala

Contact: odutta@sandia.gov, jmuelle@sandia.gov

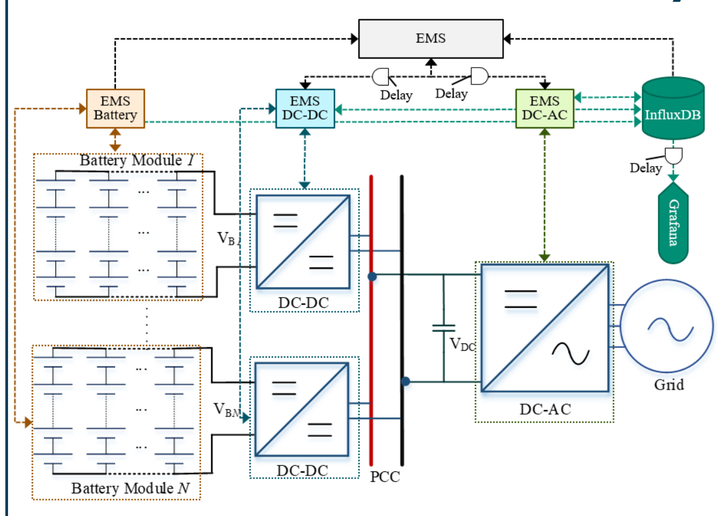
Objective & Motivation

- Design and develop grid forming DC-AC converter prototype that will interface with a DC subsystem of batteries. The prototype is 30kW, with voltage ranging from 400V – 800V DC, 208 – 480 V 3-φ AC.
- Analyze stability & develop control strategies for a system of grid forming batteries (GFBs) in different modes of operation.



- ~ 90% of failures in grid-scale battery installations are due to controls and system integration.[+]
- Every cell chemistry has unique cycling profile and operating voltage ranges that change with ageing.
- Sandia & DOE team interviewed US-based industry system integrators and battery manufacturers.
- These companies echoed that lack of standardization has made integration a key risk with significant custom engineering, investment time and cost, often leading to the company's demise.
- Previously, this team had built prototypes of DC subsystems with their controllers that demonstrated modularity, scalability, and reliability with both commercial and experimental chemistries.
- A grid forming DC-AC converter prototype is the missing piece in this integrated system for GFBs.

GFB System Overview

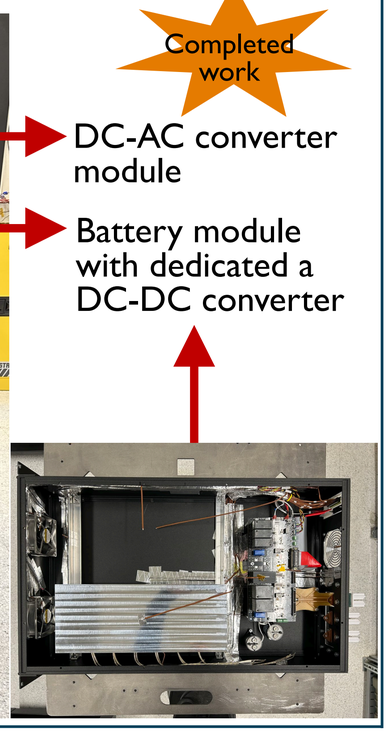


Modular GFB system comprising hybrid batteries, power electronics, hierarchical control software/firmware, CAN communication, protection, cabling, and cooling. This system has cascaded parallel connection of DC modules.

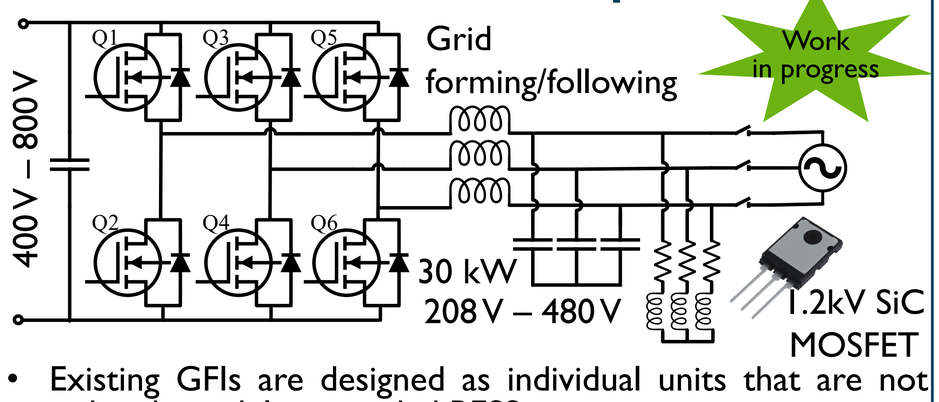
Completed work

DC-AC converter module

Battery module with dedicated a DC-DC converter



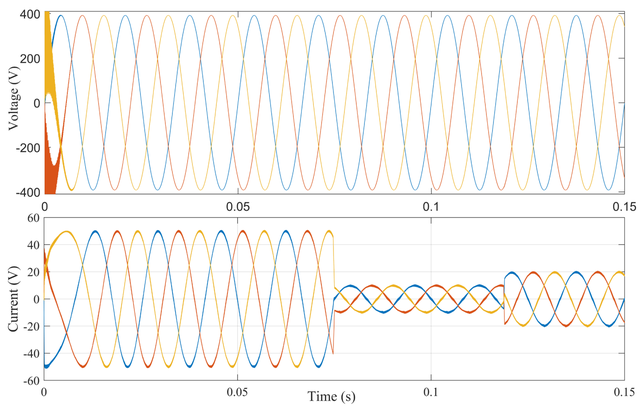
Innovation & Impact



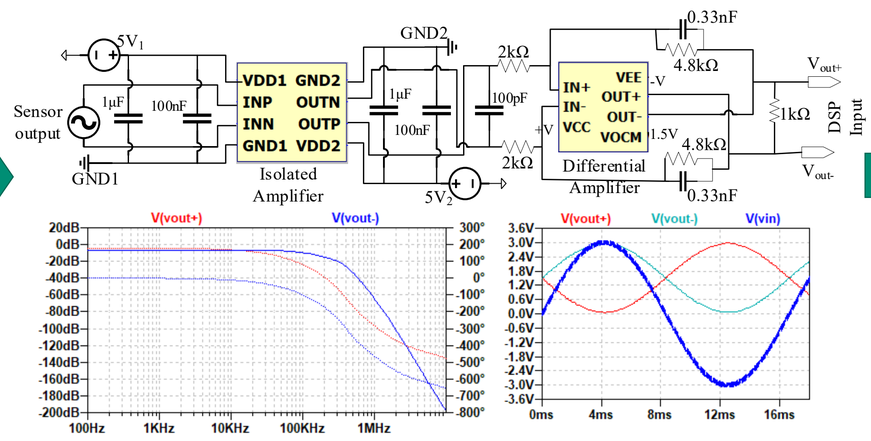
- Existing GFIs are designed as individual units that are not tested with modular cascaded BESSs.
- Standards exist for AC side (grid interconnection), but DC side (battery interface) is overlooked. Poor quality of current injected into batteries cause accelerated ageing. [++]
- Who regulates point of common coupling (PCC) voltage during various modes of operation, such as fault ride through, black start, charging/discharging, pulse testing, etc.?
- This requires in-depth stability analysis of the controllers.

Methodology & Results

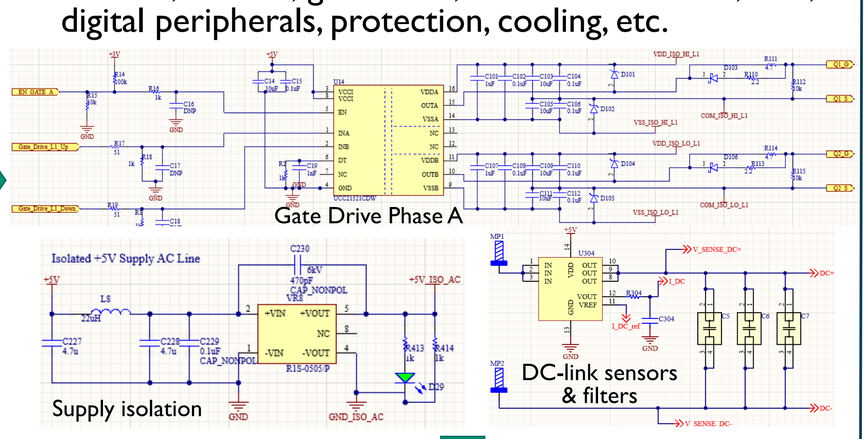
I. EMT simulation in PLECS with 100kHz switching. This base simulation will be updated with PCC control strategies.



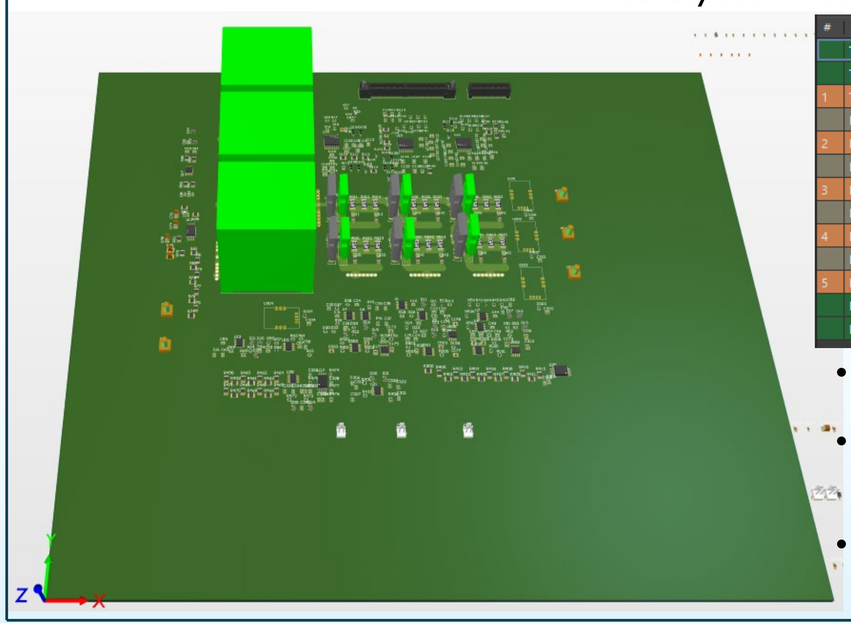
II. Board planning, component selection, power tree design, sensor actuation circuit simulations in LTspice.



III. Schematic design in Altium for power stage, sensors, ADCs, gate drive, CAN transceivers, DSP, digital peripherals, protection, cooling, etc.



IV. PCB Layout in Altium Designer (in progress)

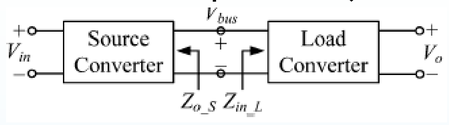


#	Name	Material	Type	Thickness	Dk	Df	Weight
	Top Overlay		Overlay				
	Top Solder	Solder Resist	Solder Mask	0.4mil	3.5		
1	Top Layer		Signal	4.134mil			3oz
	Dielectric 1	PP-006	Prepreg	2.8mil	4.1	0.02	
2	Layer 2	CF-004	Plane	4.134mil			3oz
	Dielectric 2	FR-4	Dielectric	63mil	4.8		
3	Layer 3	CF-004	Signal	4.134mil			3oz
	Dielectric 3	PP-006	Prepreg	2.8mil	4.1	0.02	
4	Layer 4	CF-004	Signal	1.378mil			1oz
	Dielectric 4	PP-006	Prepreg	2.8mil	4.1	0.02	
5	Bottom Layer		Signal	4.134mil			3oz
	Bottom Solder	Solder Resist	Solder Mask	0.4mil	3.5		
	Bottom Overlay		Overlay				

- High current is the primary challenge in this PCB layout.
- Trace width have been reduced using parallel traces in multiple layers that are separated by ground plane to reduce EMI.
- Completed switching loop and gating loop to minimize parasitic capacitance & inductance.

Next Steps

- Complete PCB layout followed by PCB building, calibration, and testing.
- Complete controller stability analysis for cascaded parallel connection. Report as a journal publication.



- Implement control design in C2000.

References

[+] 3002030360_Insights from EPRI_s Battery Energy Storage Systems _BESS_ Failure Incident Database_ Analysis of Failure Root Cause.pdf.

[++] O. Dutta, J. Mueller, R. Wauneka, V. De Angelis and D. Rosewater, "Integrated power converters for optimal operation of hybrid battery packs," *IEEE PESGM*, 2022.

U.S. Department of Energy
National Nuclear Security Administration

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.
SAND No. SAND2026-23950C

This material is based upon work supported by the U.S. Department of Energy, Office of Electricity (OE), Energy Storage Division.

ESCAL
Sandia National Laboratories