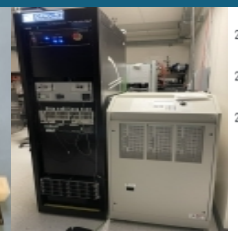
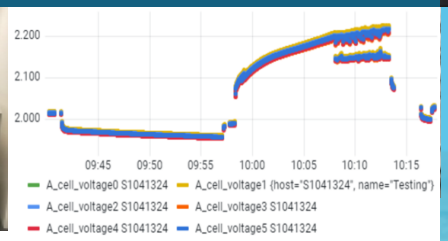
SAND2024-07574C

Sandia National Laboratories

A Modular Prototype of Hybrid Storage Technologies for Grid Applications



PRESENTED BY

Valerio De Angelis

SPEEDAM 2024
Advances in Grid ESS solutions

06/19/2024

CORE PROJECT MEMBERS

O. Dutta, J. Mueller, R. Wauneka, A.R.R. Dow, and V. De Angelis

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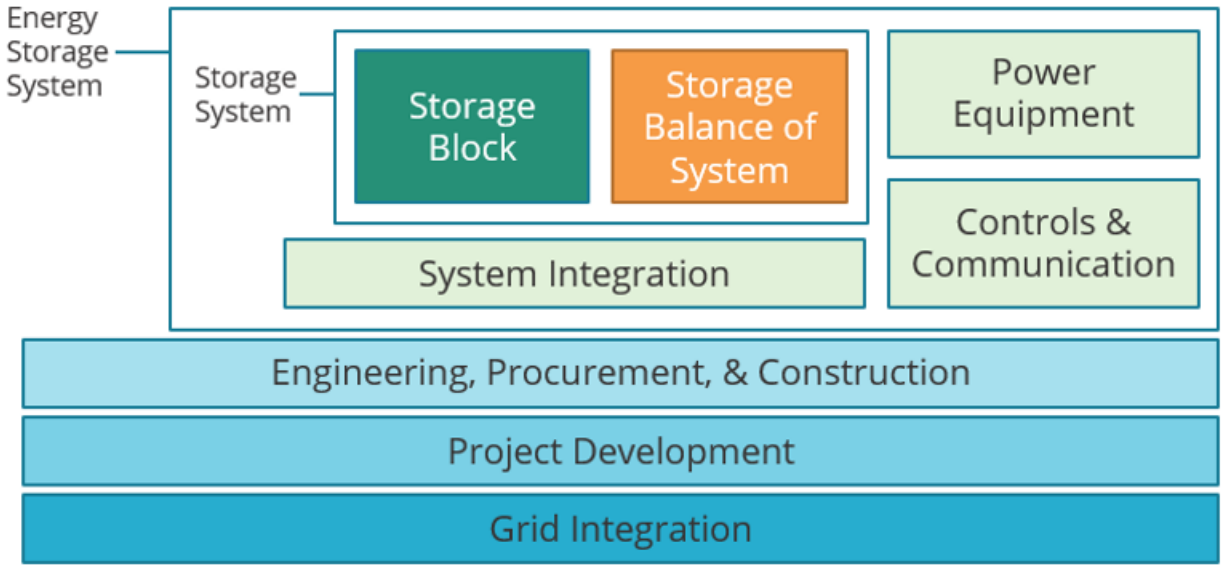
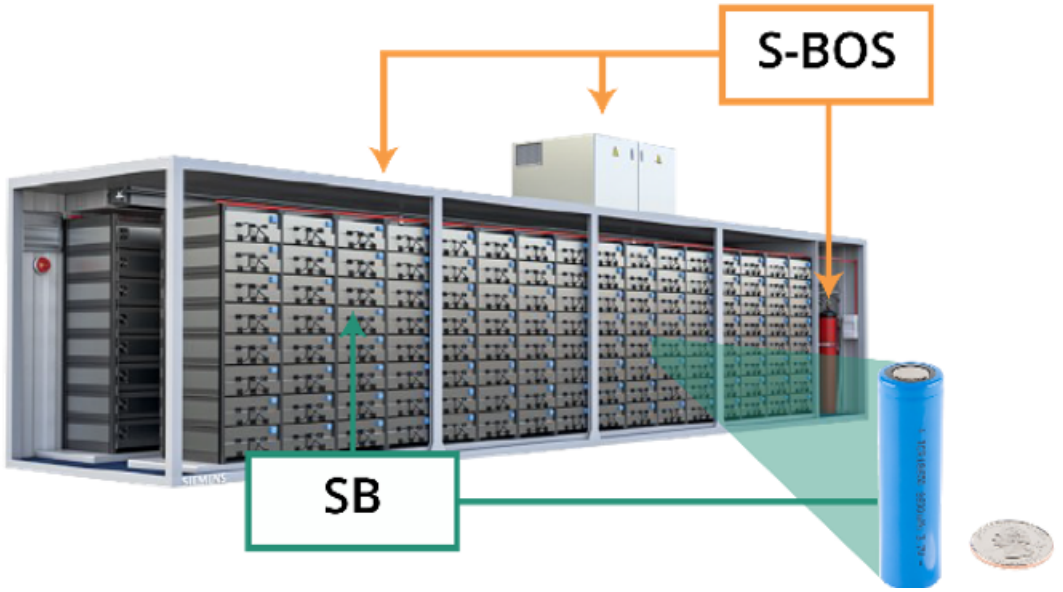
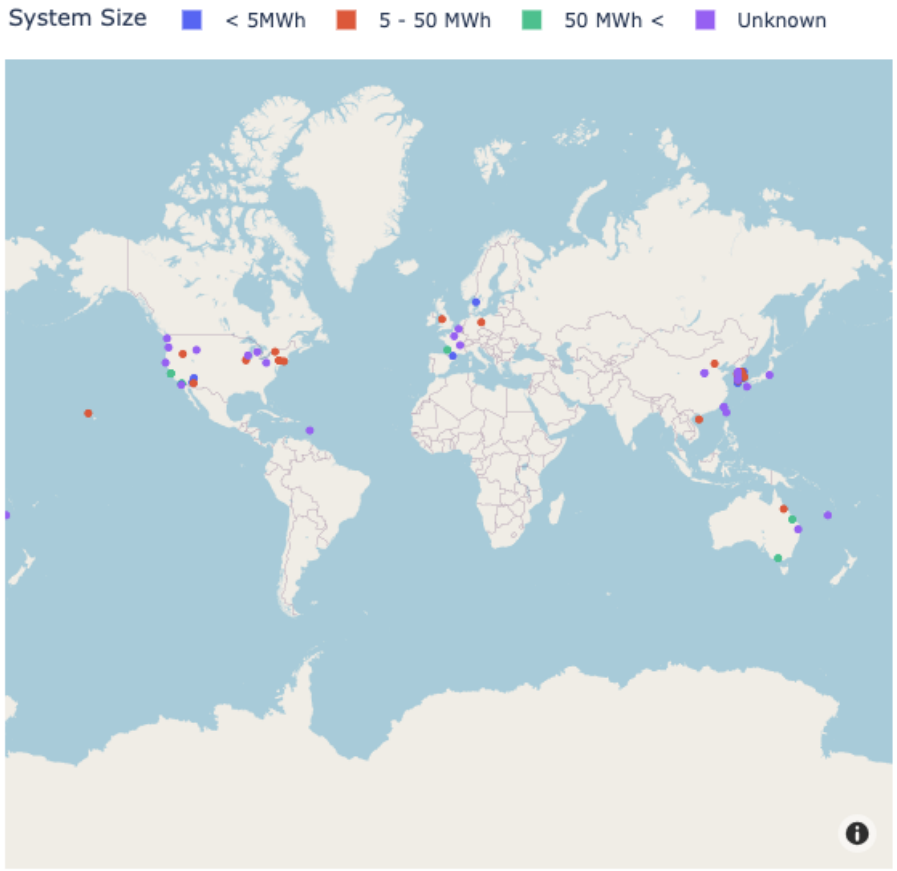
Energy storage systems include multiple components

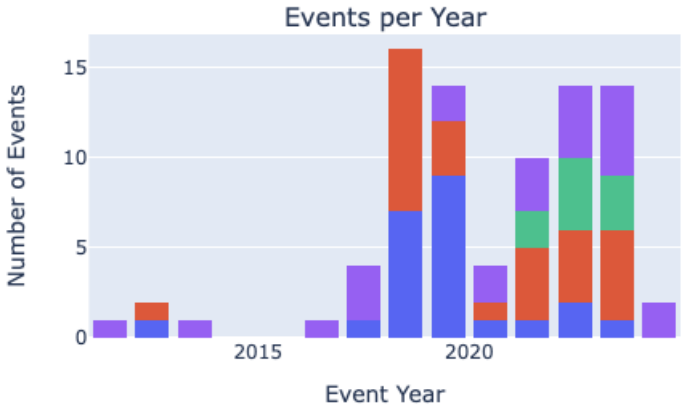


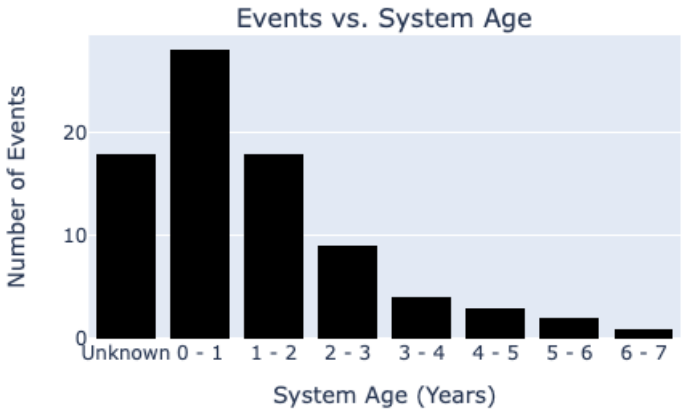


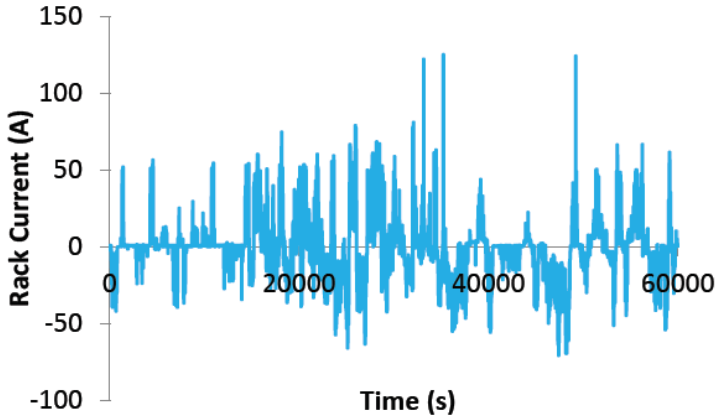
SB → storage block S-BOS → storage balance of system

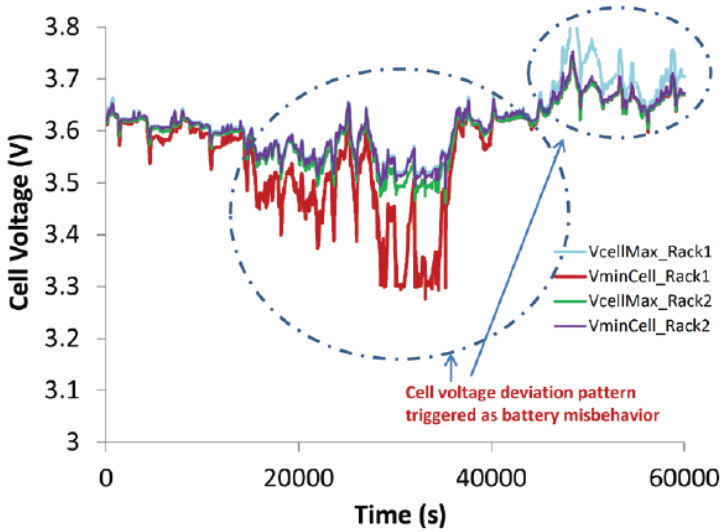
Systems fail early





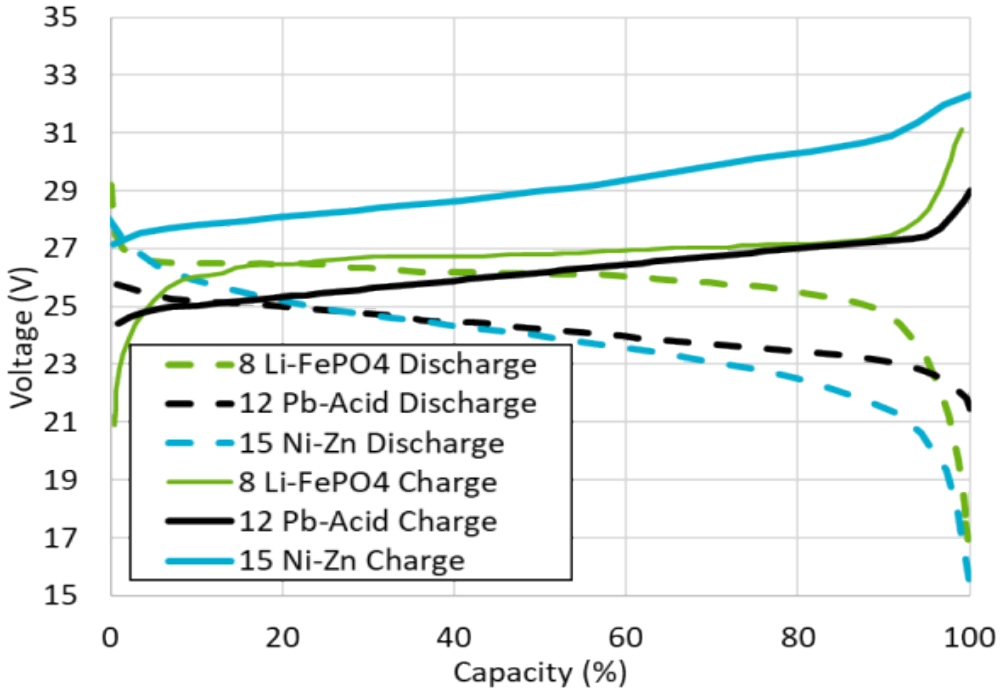




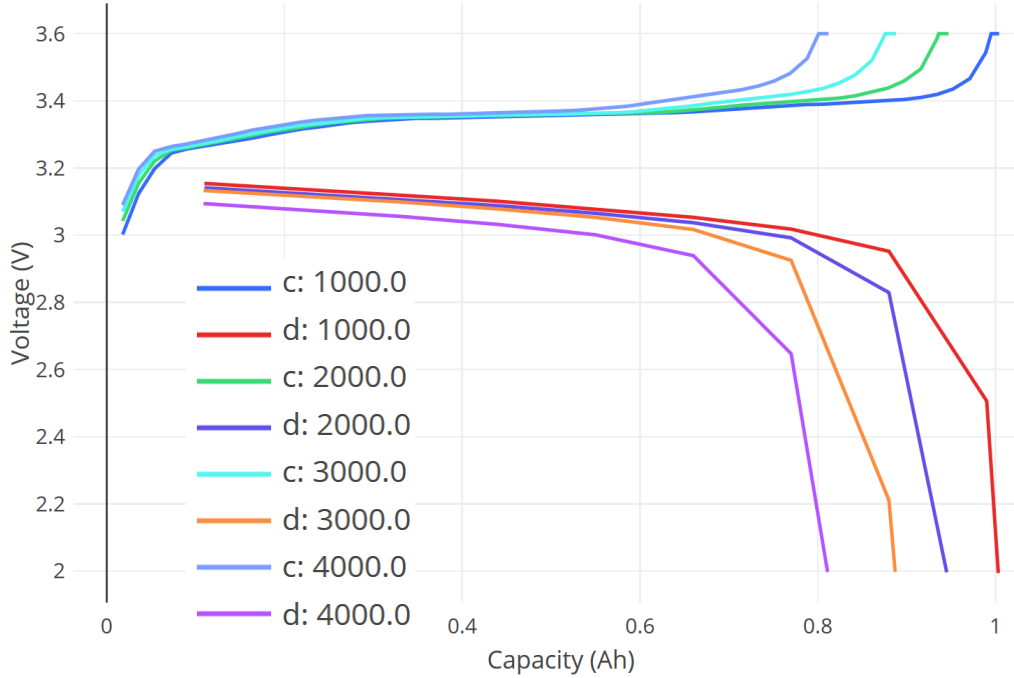


https://storagewiki.epri.com/index.php/BESS_Failure_Event_Database

Electrochemical systems have specific charge/discharge requirements

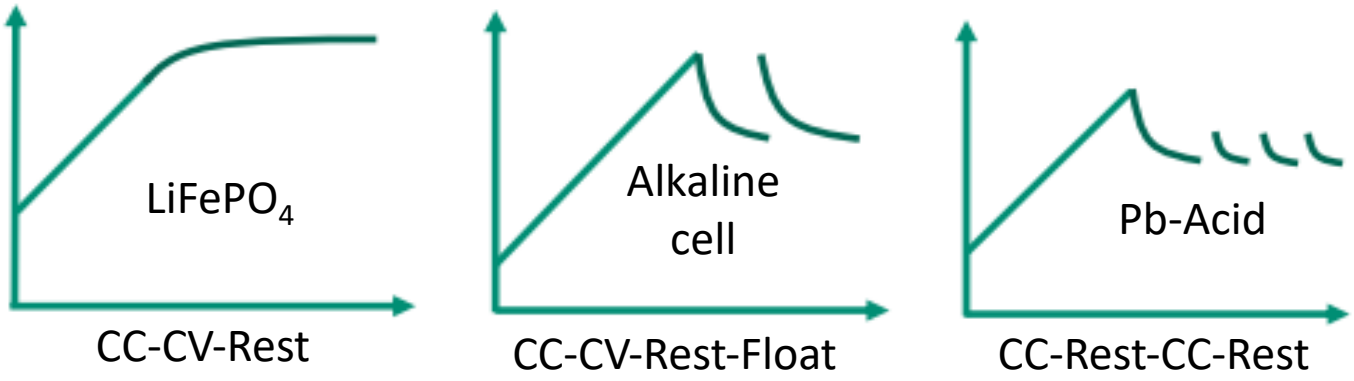


Different battery technologies operate within different voltage limits.



Operating voltages change as cells age.

Different battery technologies operate with different charge-discharge protocol



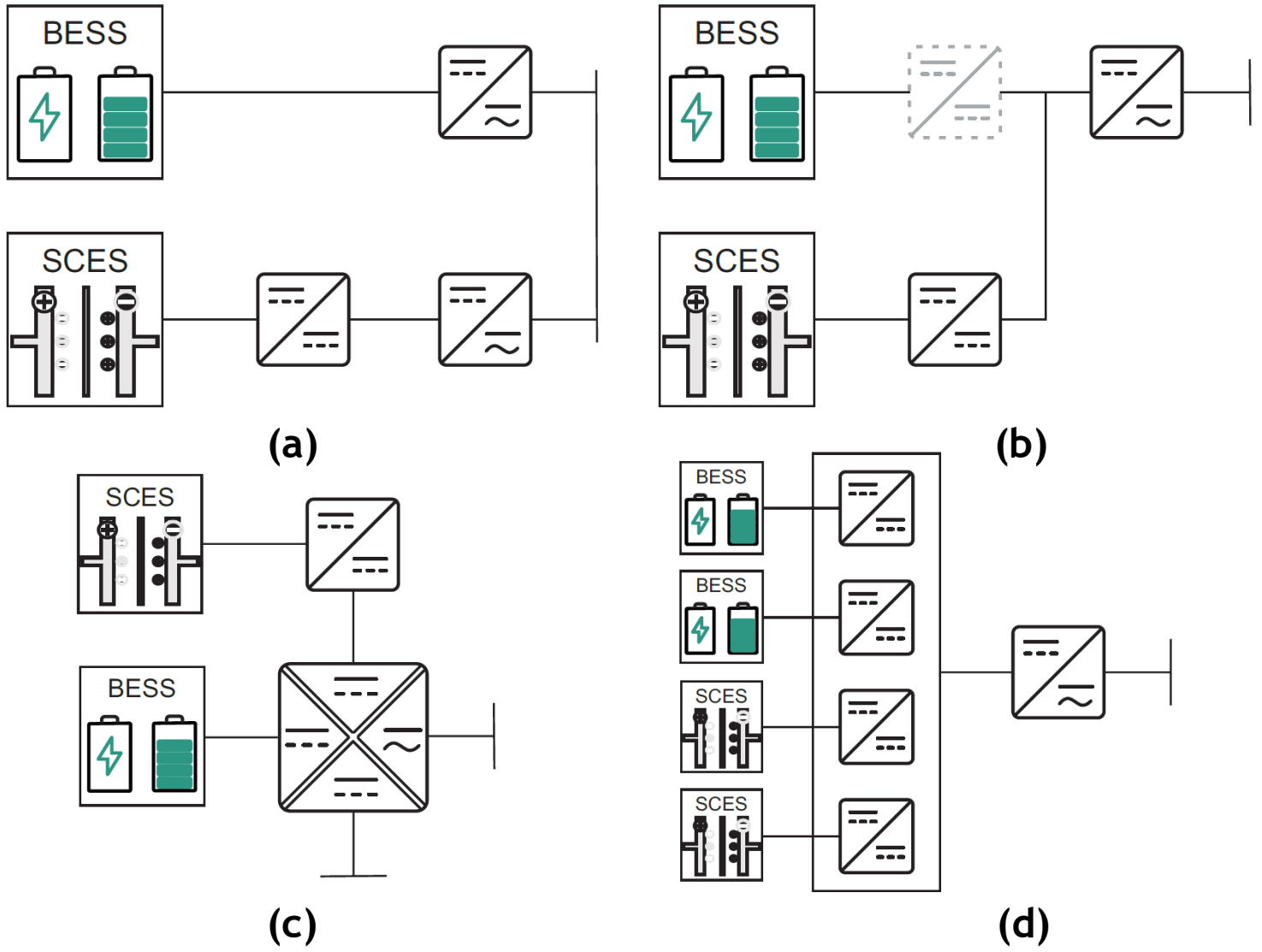
CC- Constant Current

CV- Constant Voltage

Power electronics solutions for energy storage systems

Connection topologies

- AC (a)
  - Standard, off-the-shelf
  - Not optimized
  - Needs to be tuned for each battery system
- DC (b)
  - More efficient, cheaper
  - Not standardized
  - Needs to be tuned for each battery system
- Multi-port Converter (c)
  - Fully integrated
  - Not scalable
  - Needs to be tuned for each battery system
- Modular Multi-Level (d)
  - Fully optimized
  - Complexity, protection
  - Can accept multiple types of batteries



Additional benefits of Modular Multi Level solutions

Cell monitoring and balancing

Standard solutions (a)

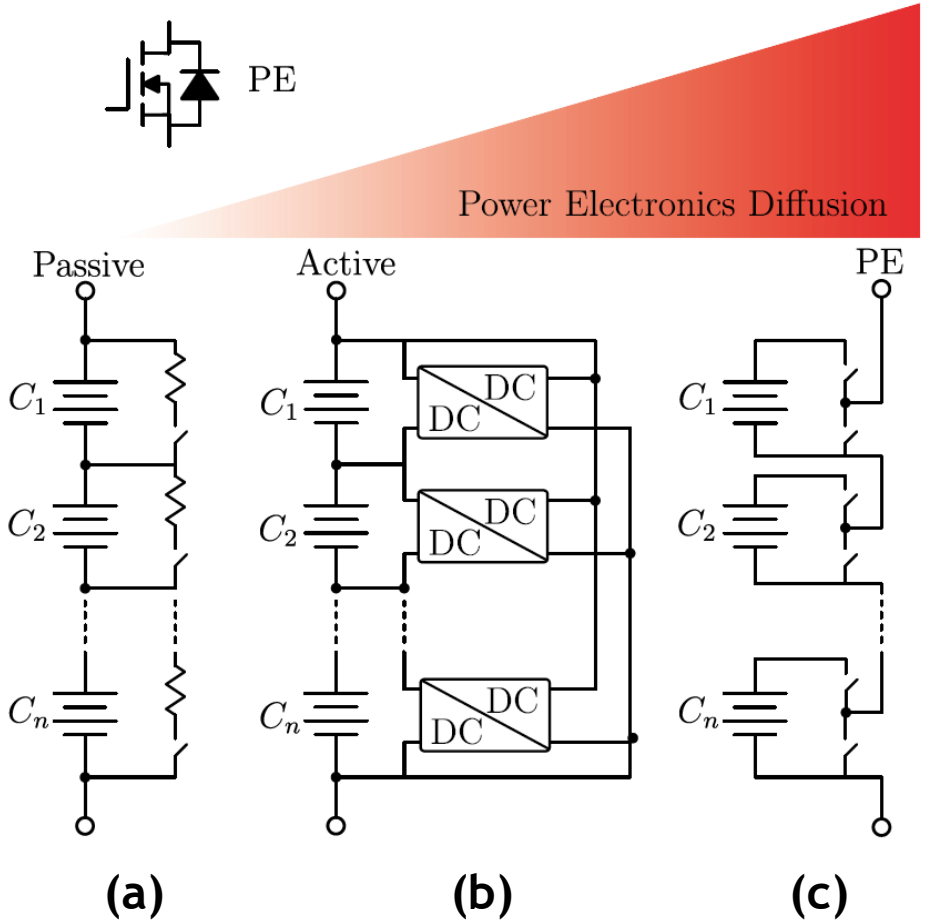
- Passive, switches connected to resistors,
- Applied in industry
- Only works for Li-ion cell requirements

Active solutions (b)

- Converter-connected cells
- More flexibility, more components

Power Electronics-integrated solutions (c)

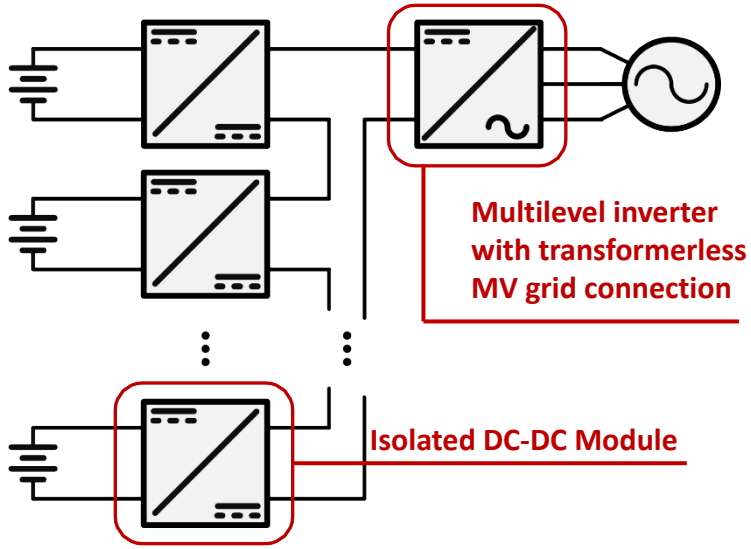
- Tailored solutions for ESS cells
- More complex, but optimized for different types of batteries and modular

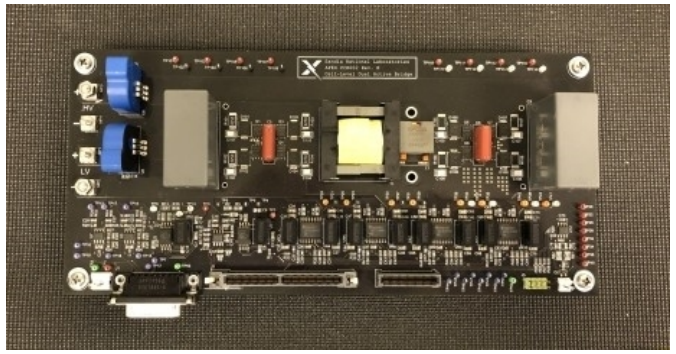


Z. Zhao, H. Hu, Z. He, H. H. -C. Iu, P. Davari and F. Blaabjerg, "Power Electronics-Based Safety Enhancement Technologies for Lithium-Ion Batteries: An Overview From Battery Management Perspective," in *IEEE Transactions on Power Electronics*, vol. 38, no. 7, pp. 8922-8955, July 2023, doi: 10.1109/TPEL.2023.3265278

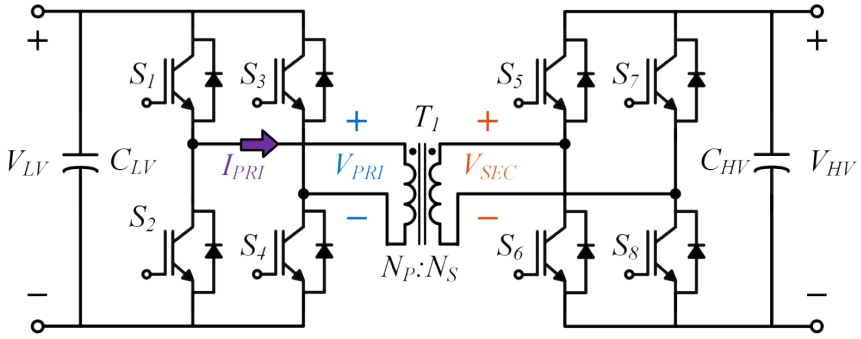
Modular power electronics: an open-source approach

- Inherently low-voltage/high-current storage devices must interface with high-voltage/low-current power systems
- Conventional grid-tied storage is limited to working voltages on the order of 1000V DC and 480V AC
- Connect low-voltage storage resources directly into medium voltage grids using modular power electronics
- Isolated DC-DC converter building blocks modules connected in series/parallel arrangements for high voltage gain

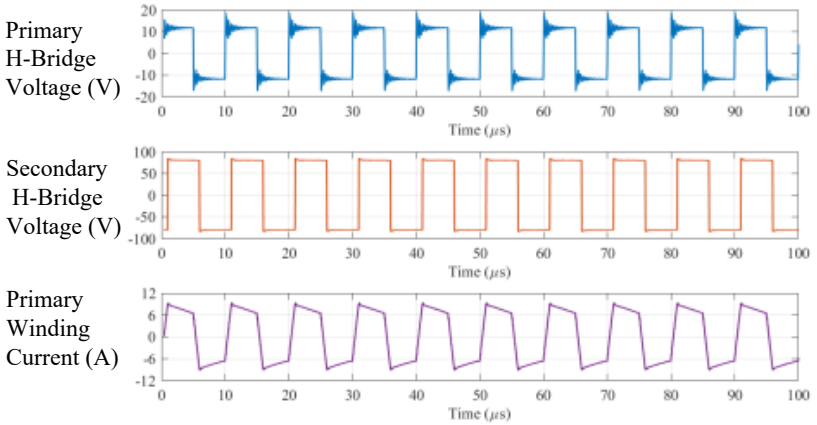




Converter Module Prototype

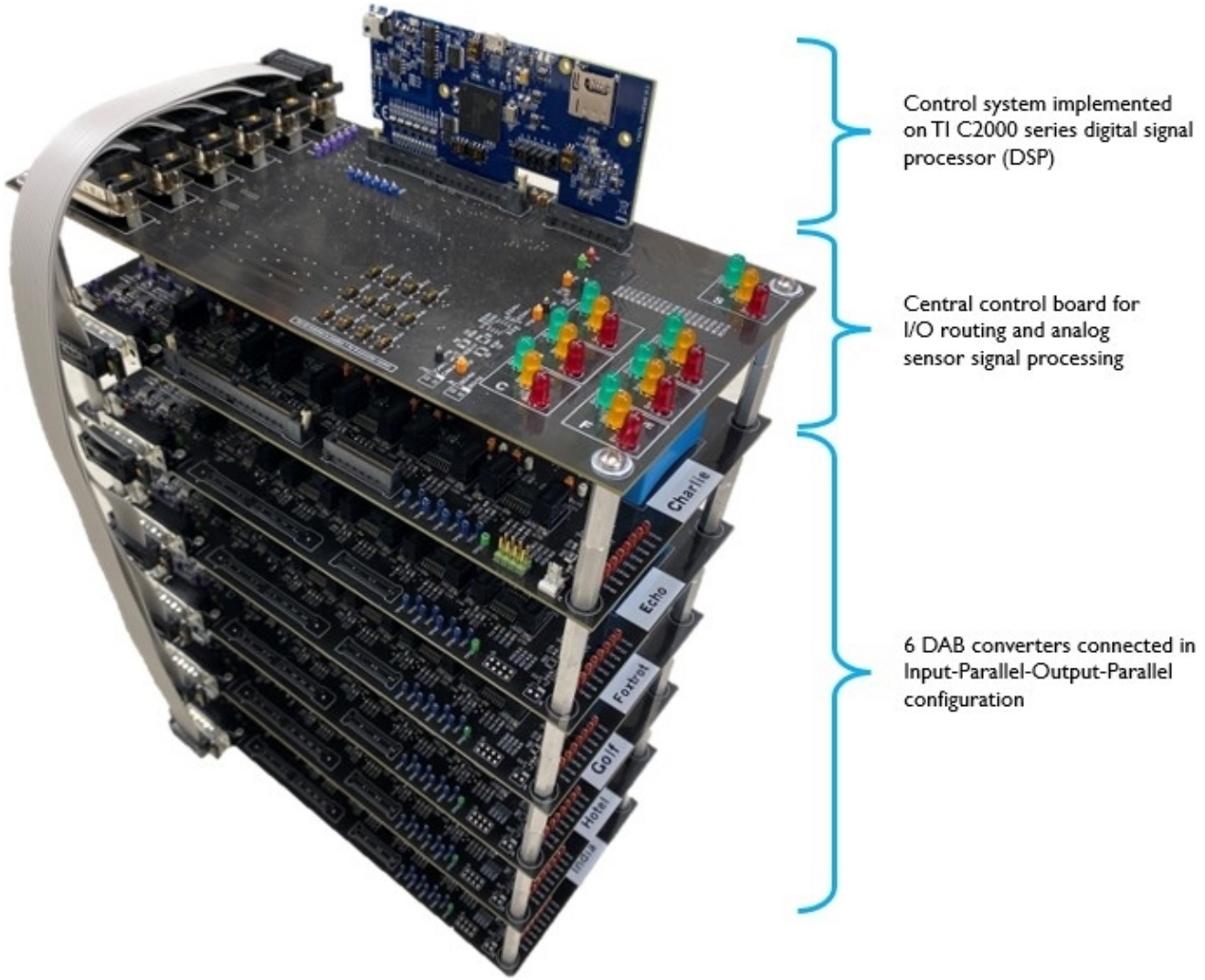


Dual Active Bridge DC-DC Converter



1st version of DAB and series topology

Gen. 1 System Prototype (FY22)
Independent Input Parallel Output Configuration

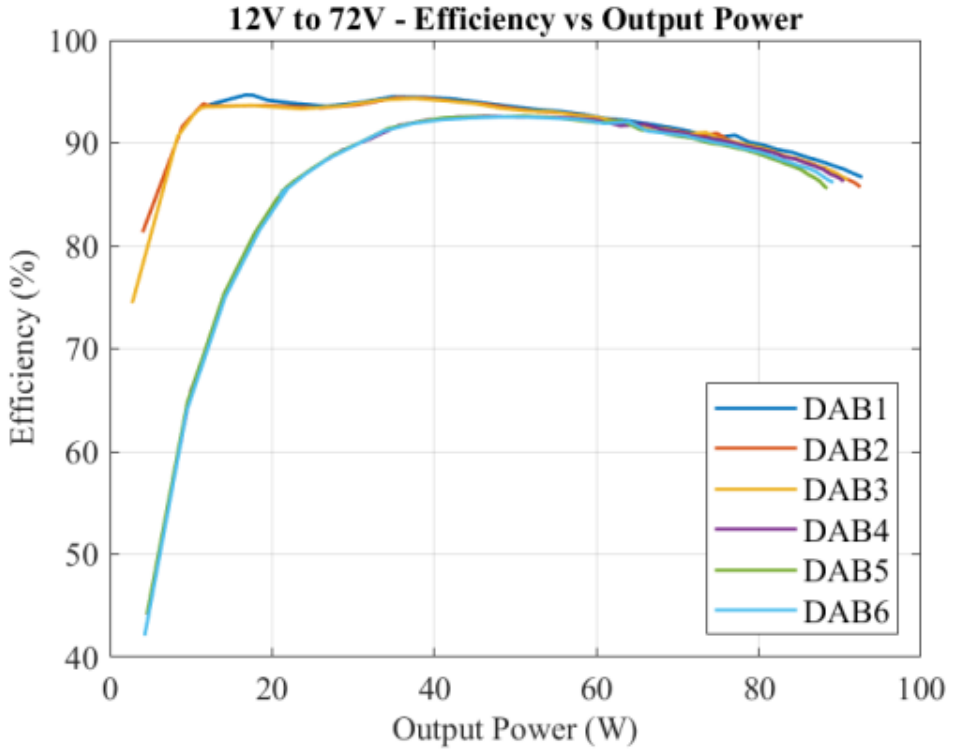


Control system implemented on TI C2000 series digital signal processor (DSP)

Central control board for I/O routing and analog sensor signal processing

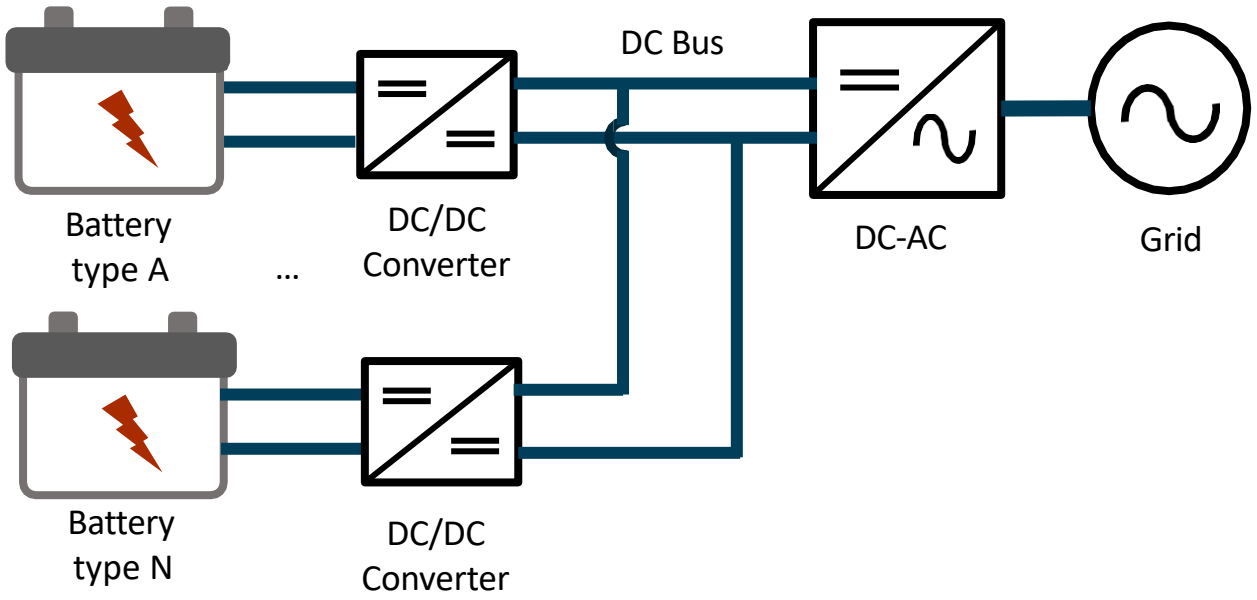
6 DAB converters connected in Input-Parallel-Output-Parallel configuration

System Specifications	
Low-Side Voltage	12V nom
High-Side Voltage	72V nom
Switching Freq	100kHz
Rated Power (Module)	±85W
Transformer Turns Ratio	1:6
System Voltage Gain	6



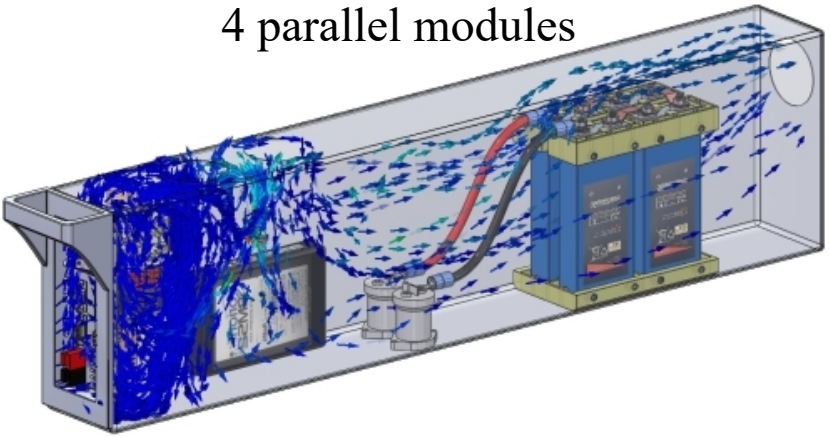
Parallel DC bus with different types of batteries

- 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)



Modular system built to meet UL standards

4 parallel modules



- Low voltage side is connected to different battery packs.
- High voltage side is connected to an inverter's DC link.

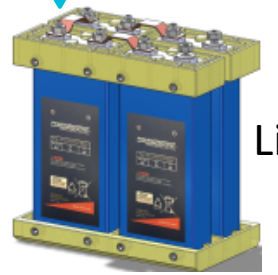
- Battery packs, DC-DC converter, BMS, Fans, E-stop Contactors, Power and Communication cables

Orion Battery Management System (BMS)

Pb-Acid pack

- 6 cells connected in series.
- Nominal Voltage of a cell: 2V
- Cell capacity: 25Ah

OR

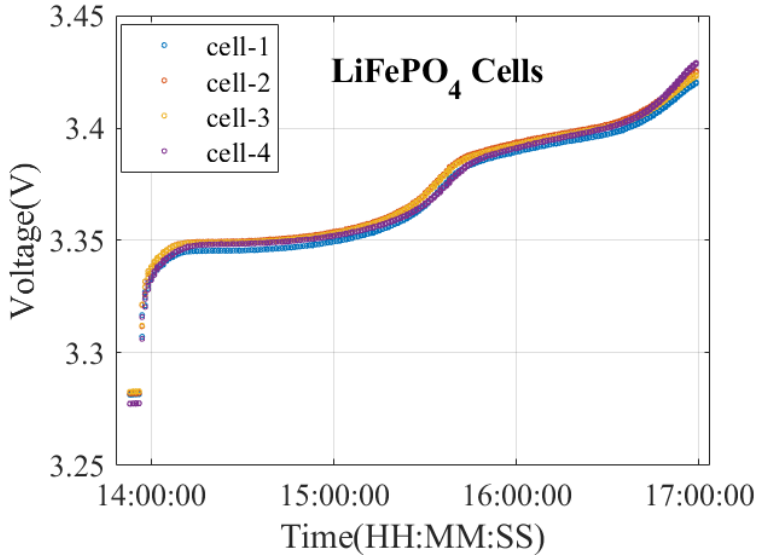


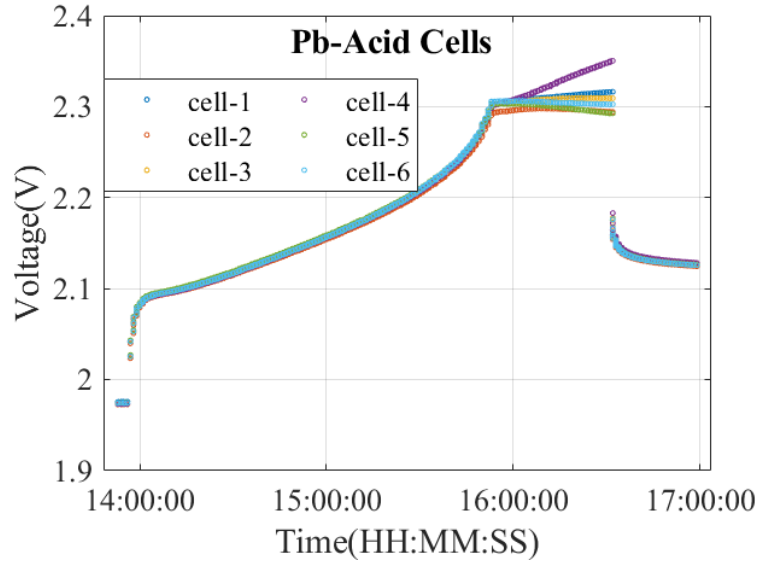
$LiFePO_4$ pack

- 4 cells connected in series
- Nominal Voltage of a cell: 3.2V
- Cell capacity: 25Ah

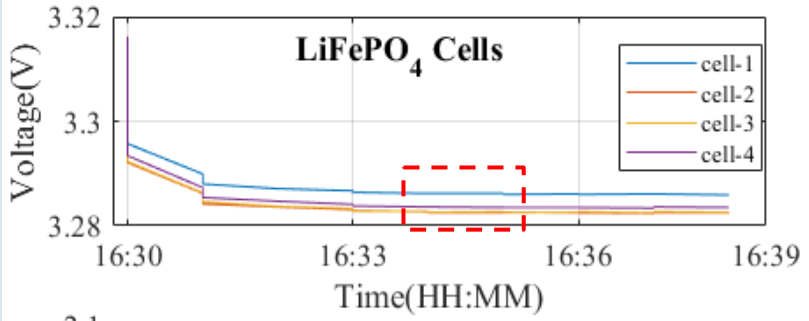
Modules cycling

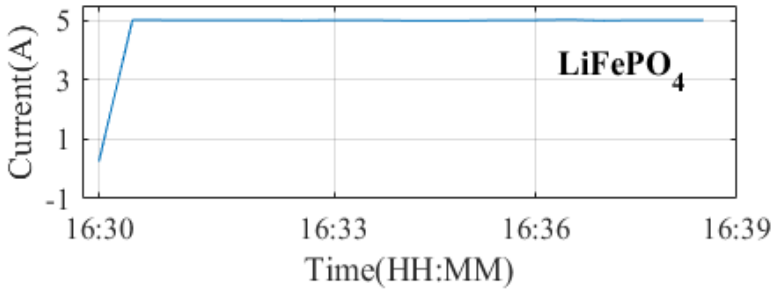
Independent operation of modules

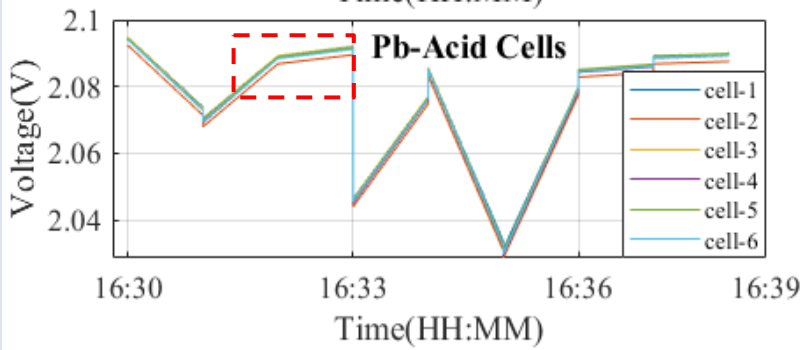


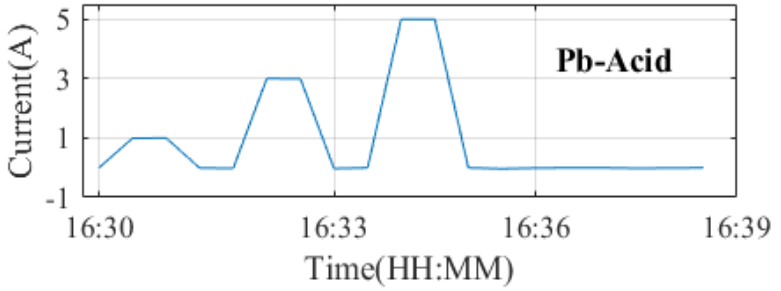


Pulse discharging of Pb-Acid and CC discharging of LiFePO4



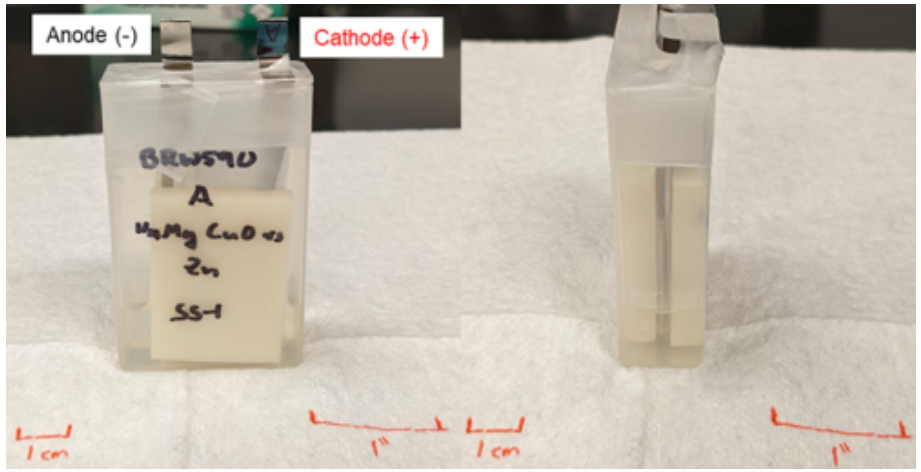




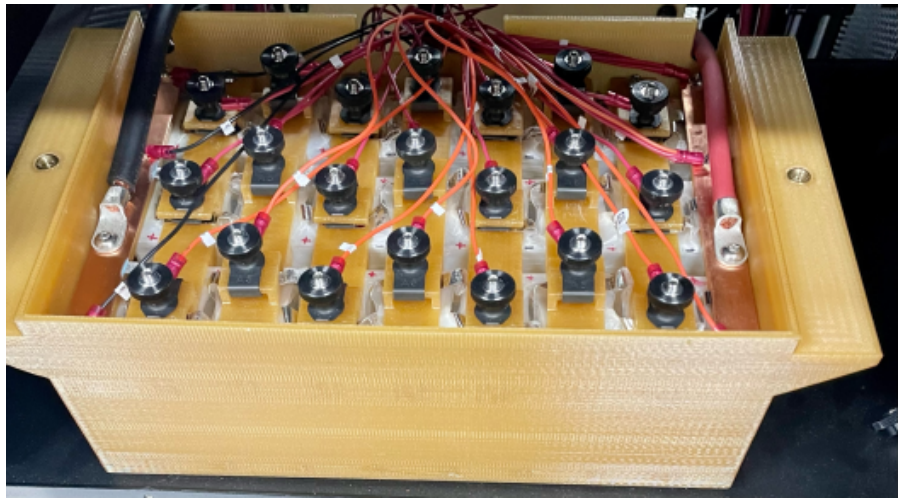


$LiFePO_4$ battery pack is discharged at 5A while pulse test is performed on the Pb-acid battery. Pulse test is used for running quality control test on selected stacks.

Using experimental battery systems



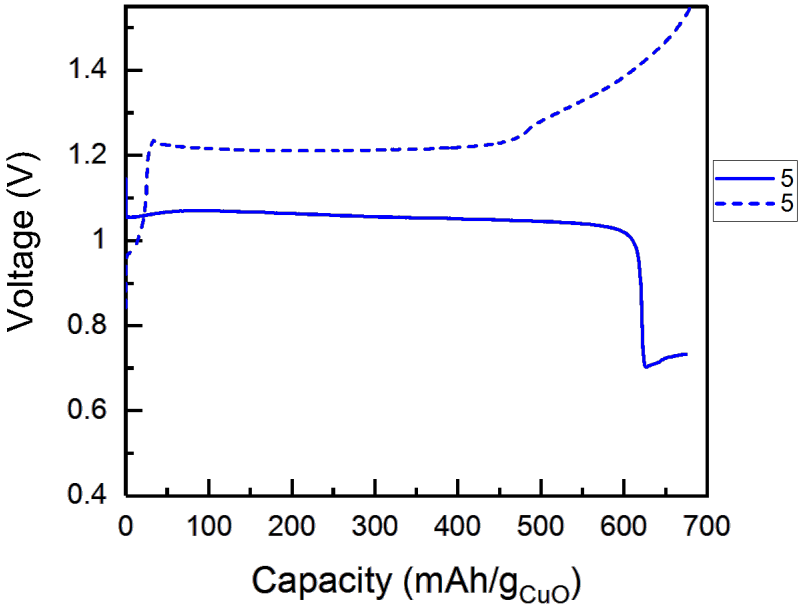
Cathode: Ni mesh current collector, Ni foil tab
Anode: Cu mesh current collector, Ni foil tab



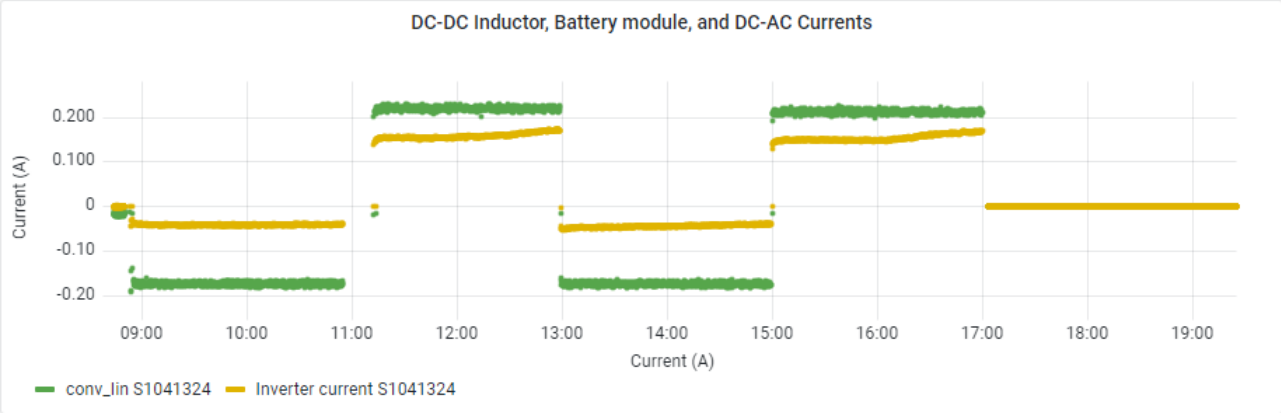
Module comprising 3 parallel blocks with 8 cells each

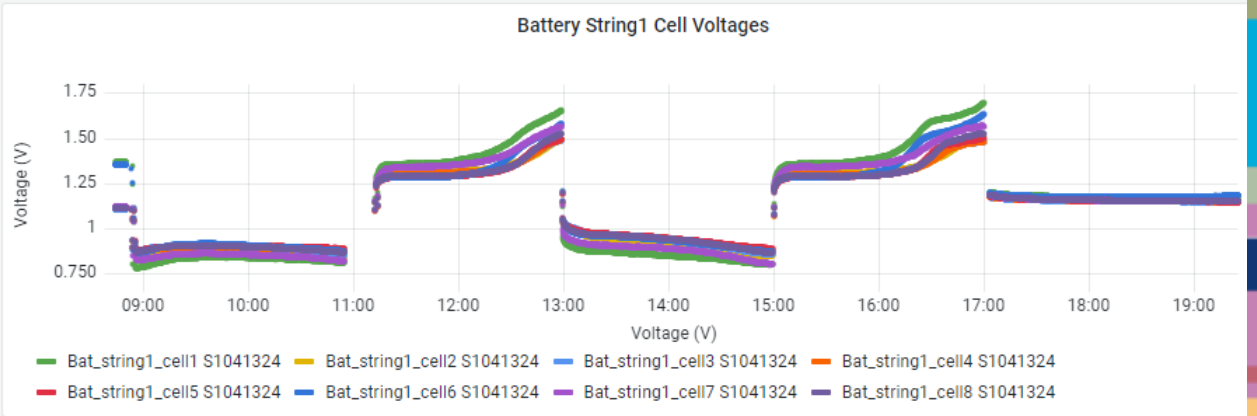
<u>Single Cell Metrics</u>

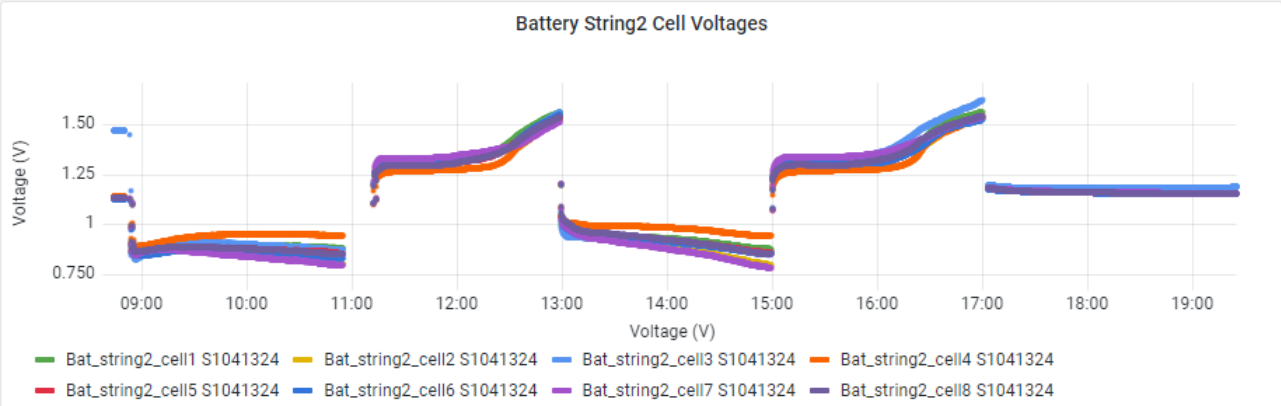
Average cycled capacity: 120 mAh
Average discharge voltage: 1.027 V
Charge/Discharge current: 12mA
Voltage Range: -0.7 – 1.55 V

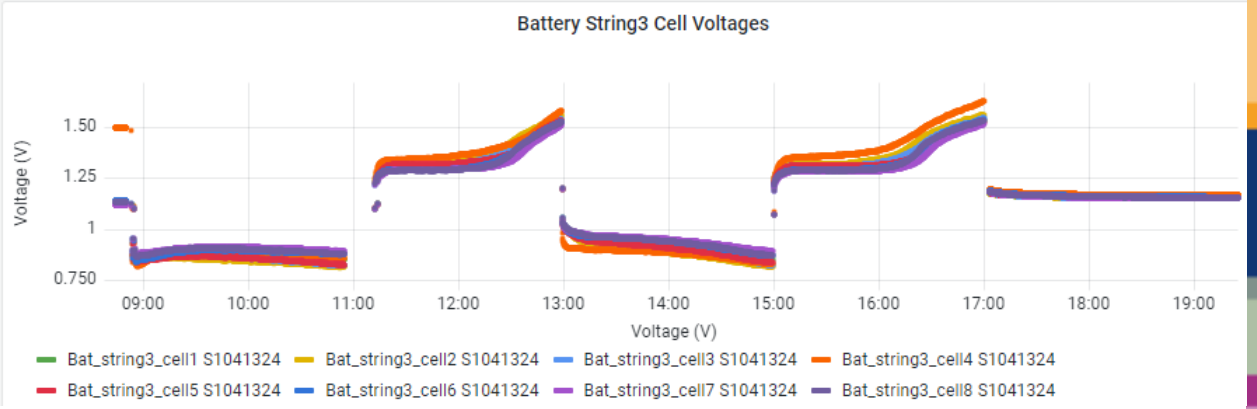


Using the same data framework for visualization





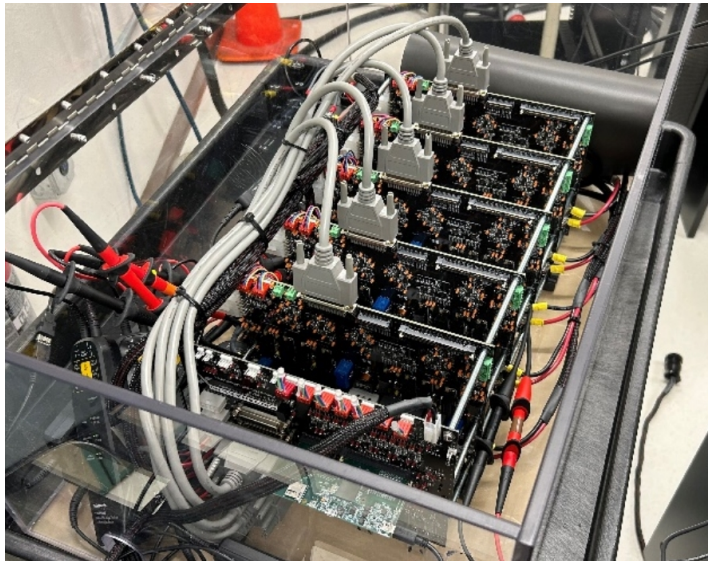




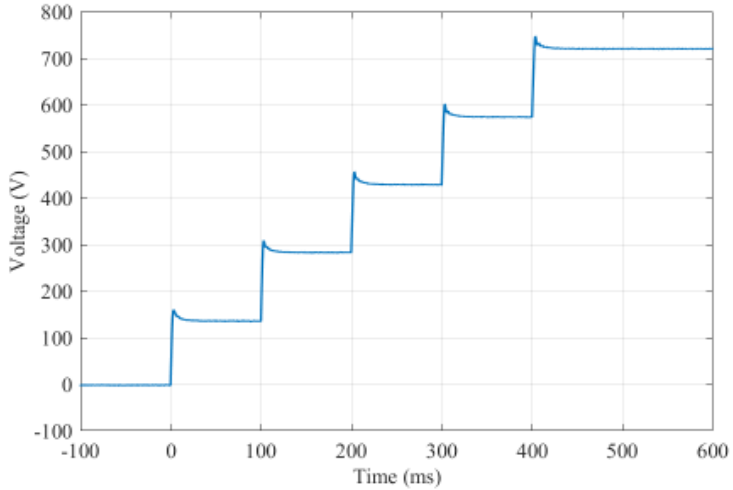
At-scale version of the system

- Demonstrated 24V to 720V conversion with 5 converter stack (6th converter assembly in progress)
- Signal integrity and power stage improvements in Gen 2 converter and control board designs enable significant extensibility
- Target for FY24 is system-level output voltage of 5kV

System Specifications	
Low-Side Voltage	24V nom
High-Side Voltage	144V nom
Switching Freq	100kHz
Rated Power (Module)	±350W
Transformer Turns Ratio	1:6
System Voltage Gain	**36**



System Output Voltage



Acknowledgments

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MEMBER CONTRIBUTIONS

- Oindrilla Dutta: System integration, software and firmware development.
- Jacob Mueller: DC-DC converter design, fabrication, and firmware.
- Robert Wauneka: Mechanical and electrical construction.
- Andrew Robert Roy Dow: DC-DC converter design, assembly and testing.
- Valerio De Angelis: Principal Investigator.

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