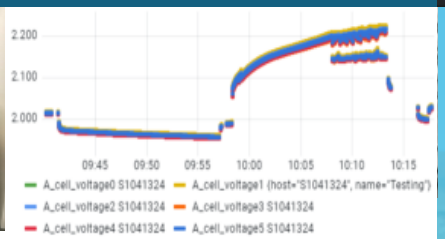
SAND2022-13141C

Sandia National Laboratories

System Development for Optimal Operation of Hybrid Storage Technologies







PRESENTED BY

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DOE OE Peer Review 2022

10/13/2022

Presentation # 803

CORE PROJECT MEMBERS

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Project Overview

SUMMARY: Development of a modular and open-source platform for integrating hybrid energy storage technologies and operating them optimally for grid applications.

SIGNIFICANCE:

Why hybrid batteries?

- Grid applications vary widely in their requirement for response time, power rating, energy capacity, ramp rate, and annual cycling.
- Technologies beyond Li-ion will be required for optimal operation in the different aspects of generation, transmission, and distribution.
- Combining old and new batteries.

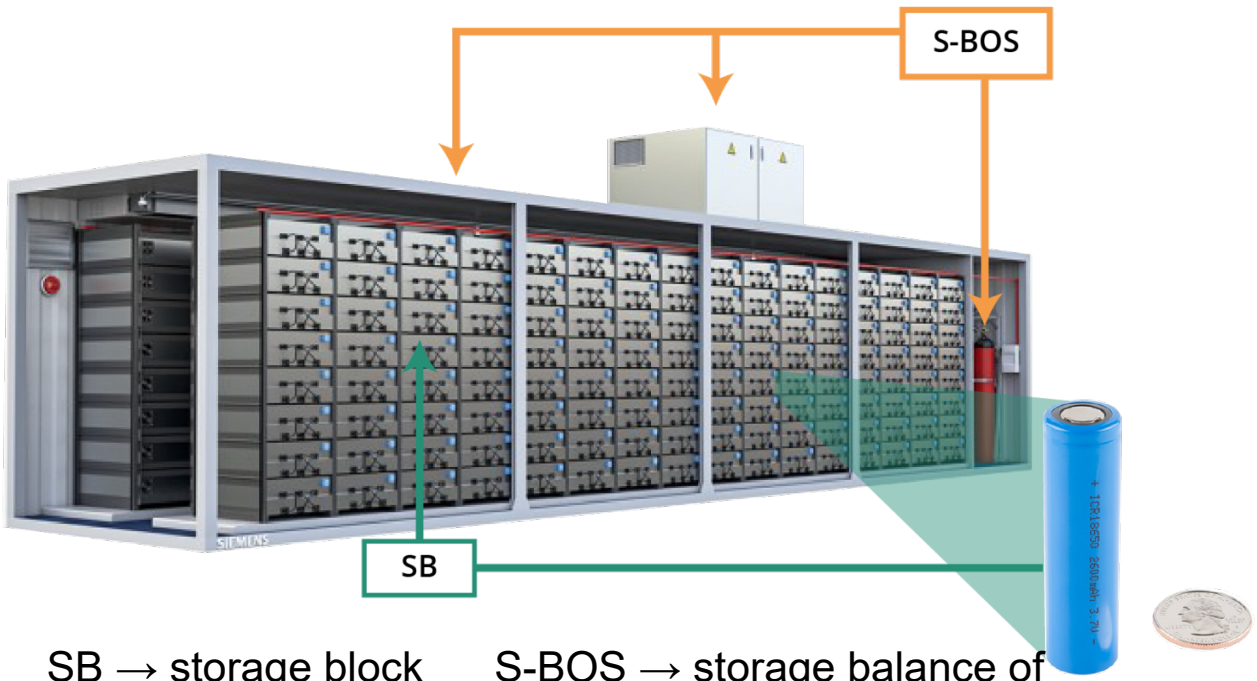
Existing gap in R&D

- Presently, there is no standardization of the power electronic topology, communication protocol, or control software for integrating and operating grid-scale batteries.
- Lack of a readily available system has every battery startup reinvent their own wheel, which has often led to unreliable and inefficient systems.

ALIGNMENT WITH CORE MISSION OF DOE OE:

- Allow safe integration and evaluation of new energy storage technologies in application and demonstration settings.
- Accelerate cost reduction and encourage the adoption of battery based storage technologies.

Challenges in operating grid scale battery storage systems

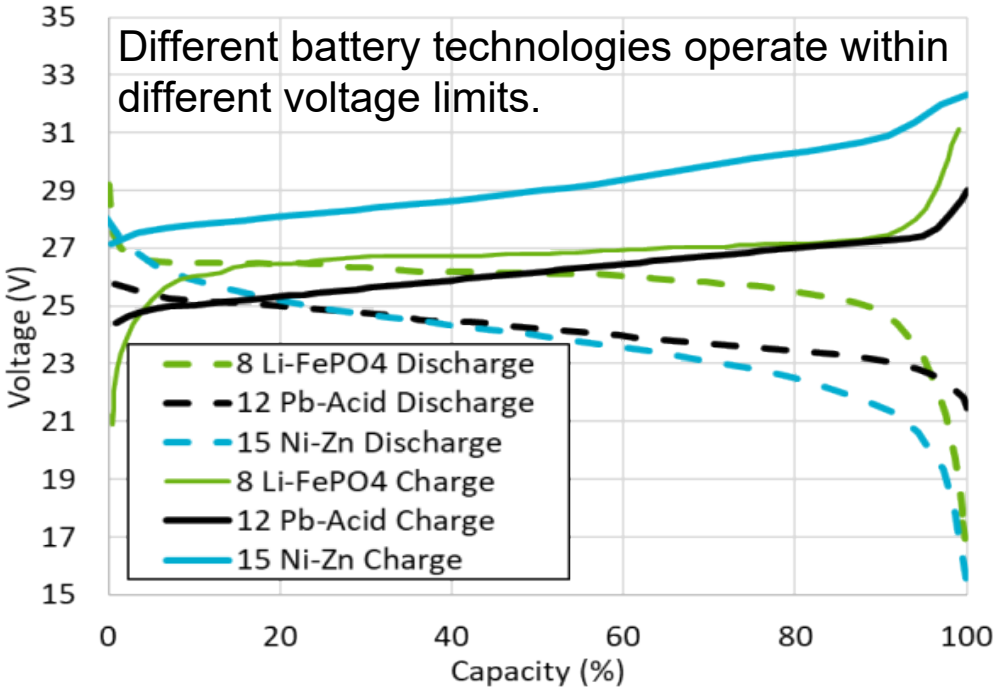


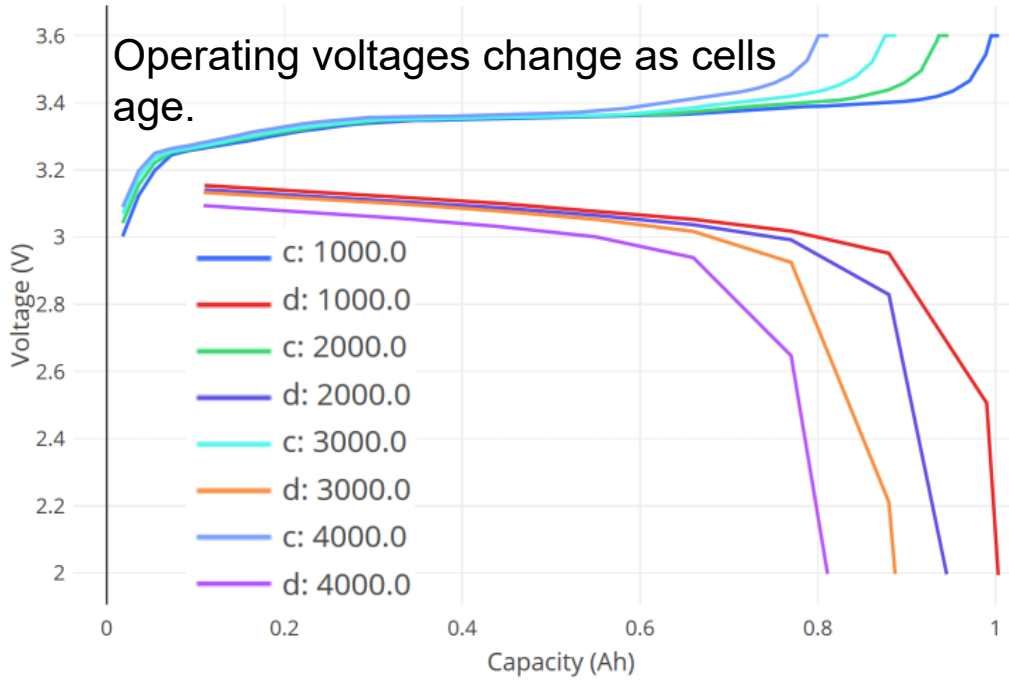
SB → storage block S-BOS → storage balance of system

In an Energy Storage System (ESS), the cell cost accounts for < 30% of the total cost.

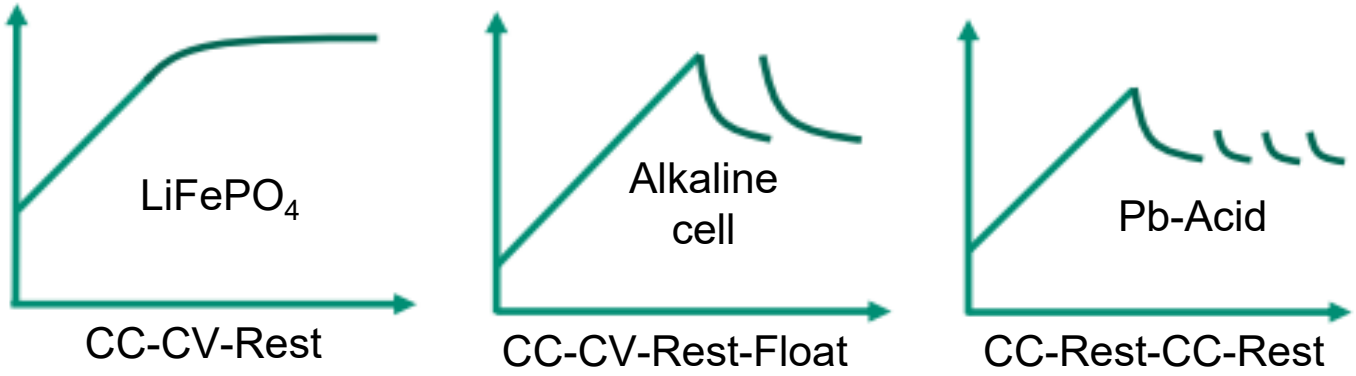
- Stationary storage fires destroy the entire installation.
- Thermal runaway from a single cell propagates through the entire rack.

Challenges in operating hybrid battery technologies



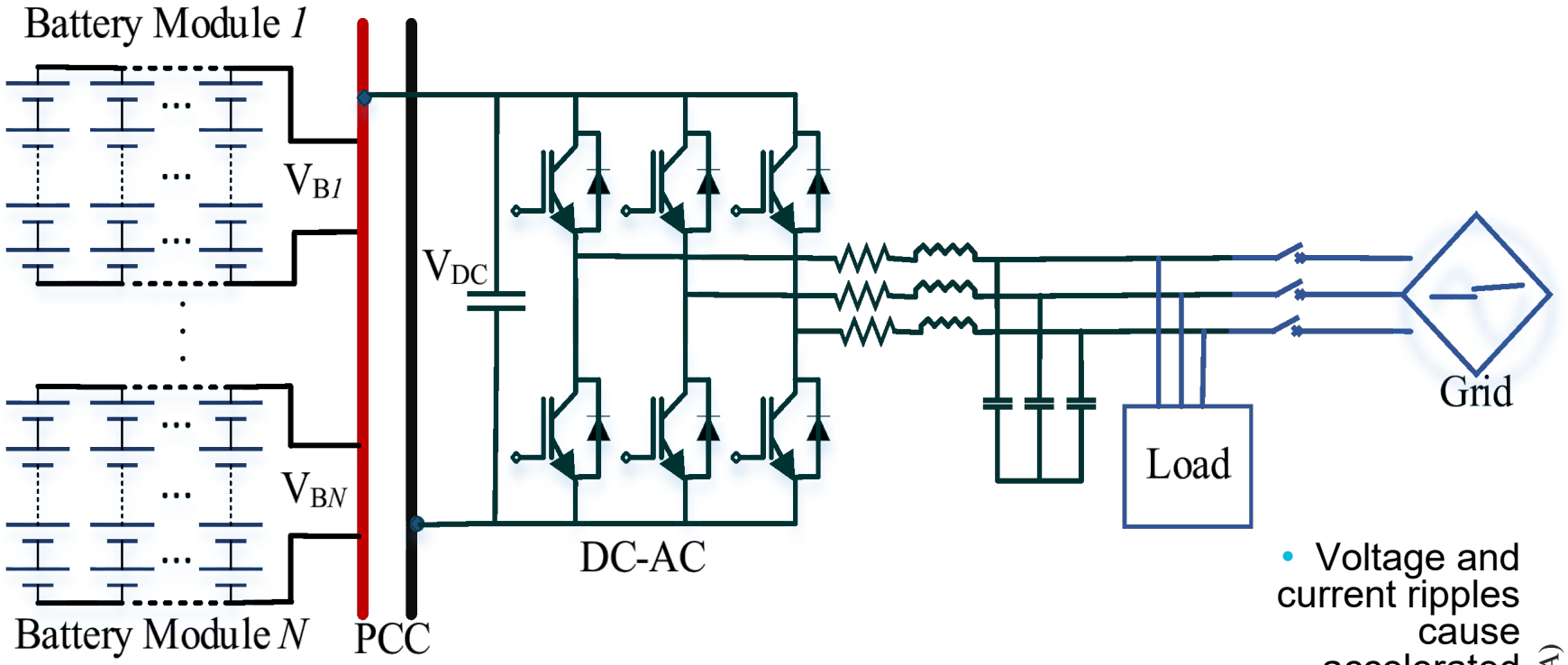


Different battery technologies operate with different charge-discharge protocol



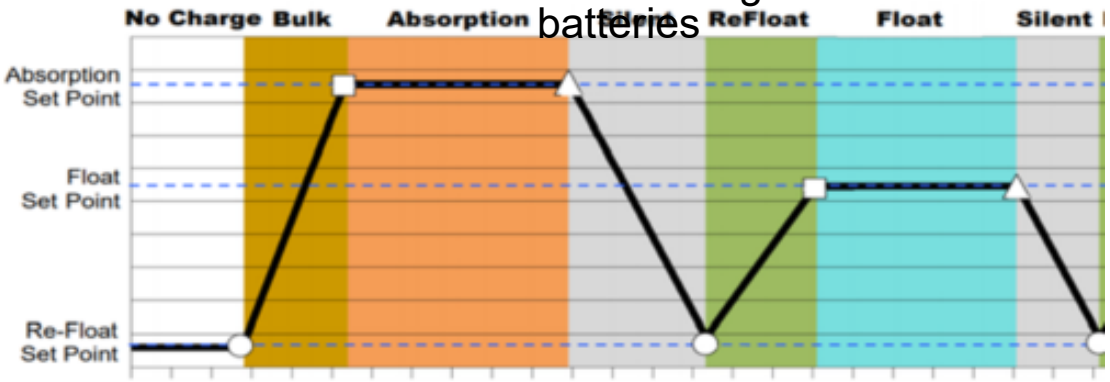
CC- Constant Current CV- Constant Voltage

Commercially Existing: Passive Topology

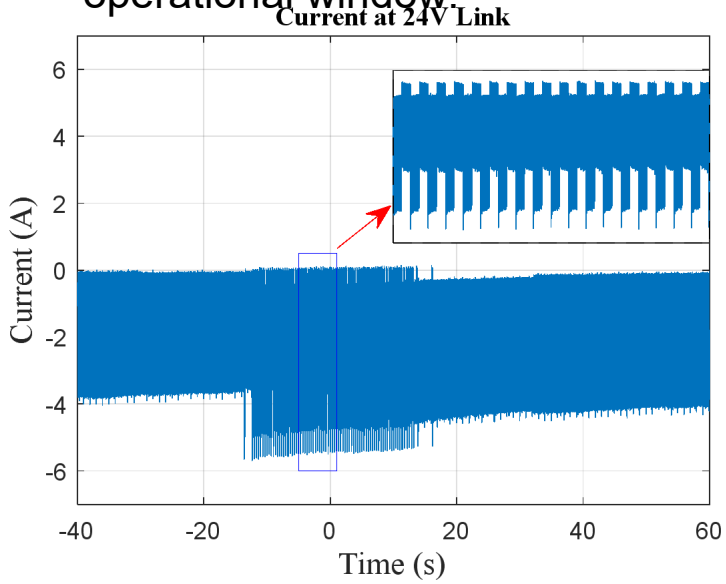


- Batteries have to be connected to the DC-AC at all times.
- No room for 'hot swap' replacement of aged/damaged batteries.
- Active or passive balancing is required to increase the operational window.

DC-AC converter control designed for Pb-acid batteries

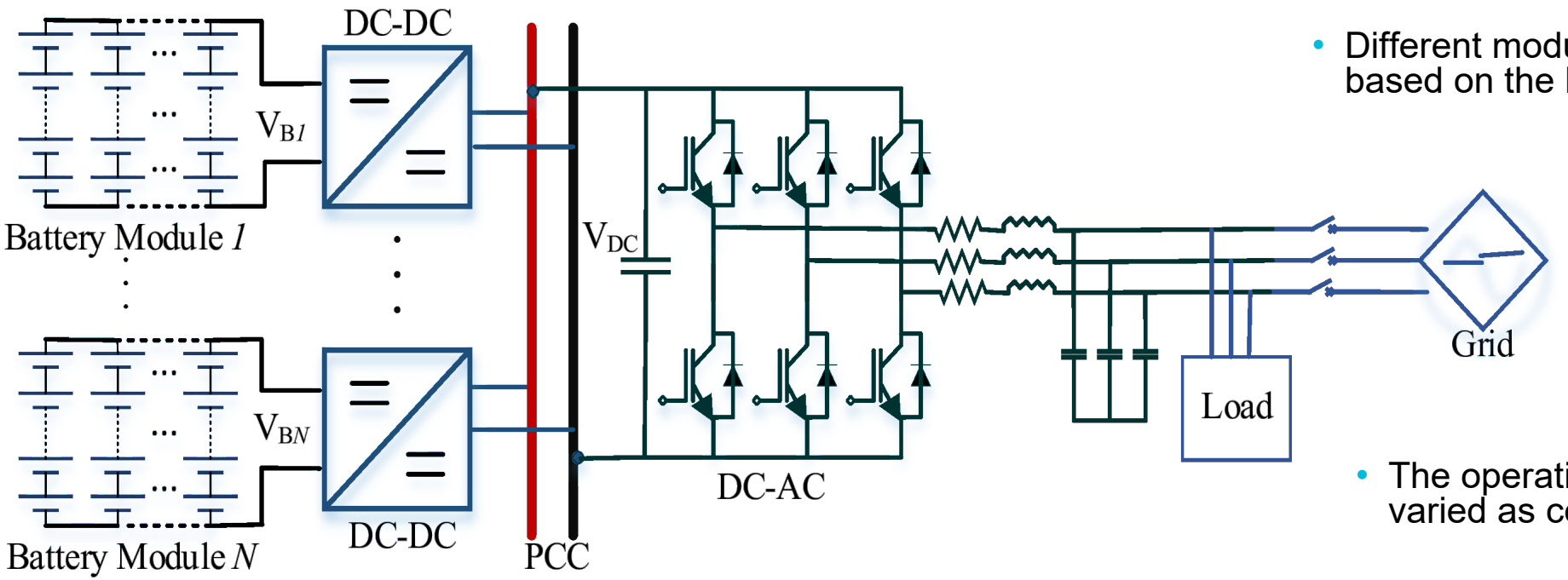


- Voltage and current ripples cause accelerated degradation of battery cells.
- DC-AC converters need to be compatible with the type of battery (implement charge/discharge protocols specific to a particular technology).



Current measured at the DC link of a commercial DC-AC converter for Pb-acid batteries.

Proposed: Active Topology

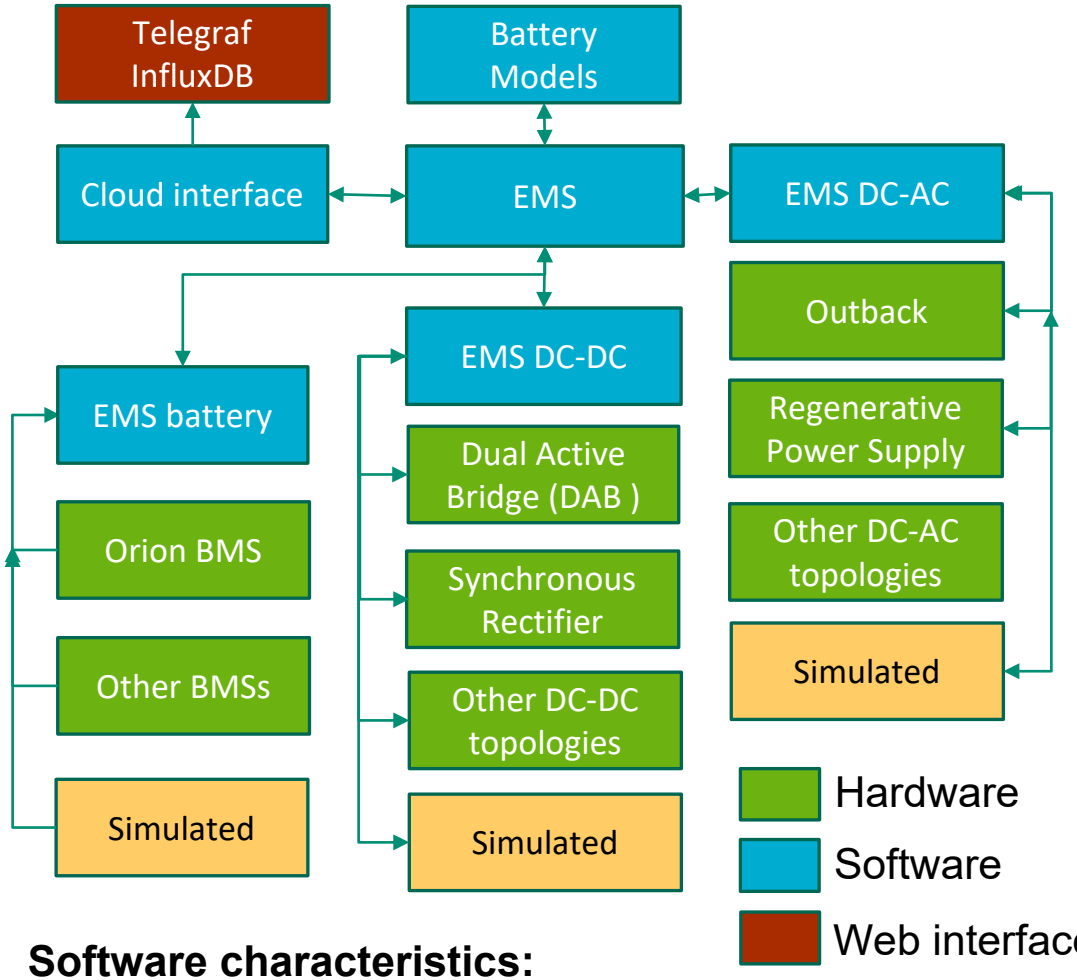


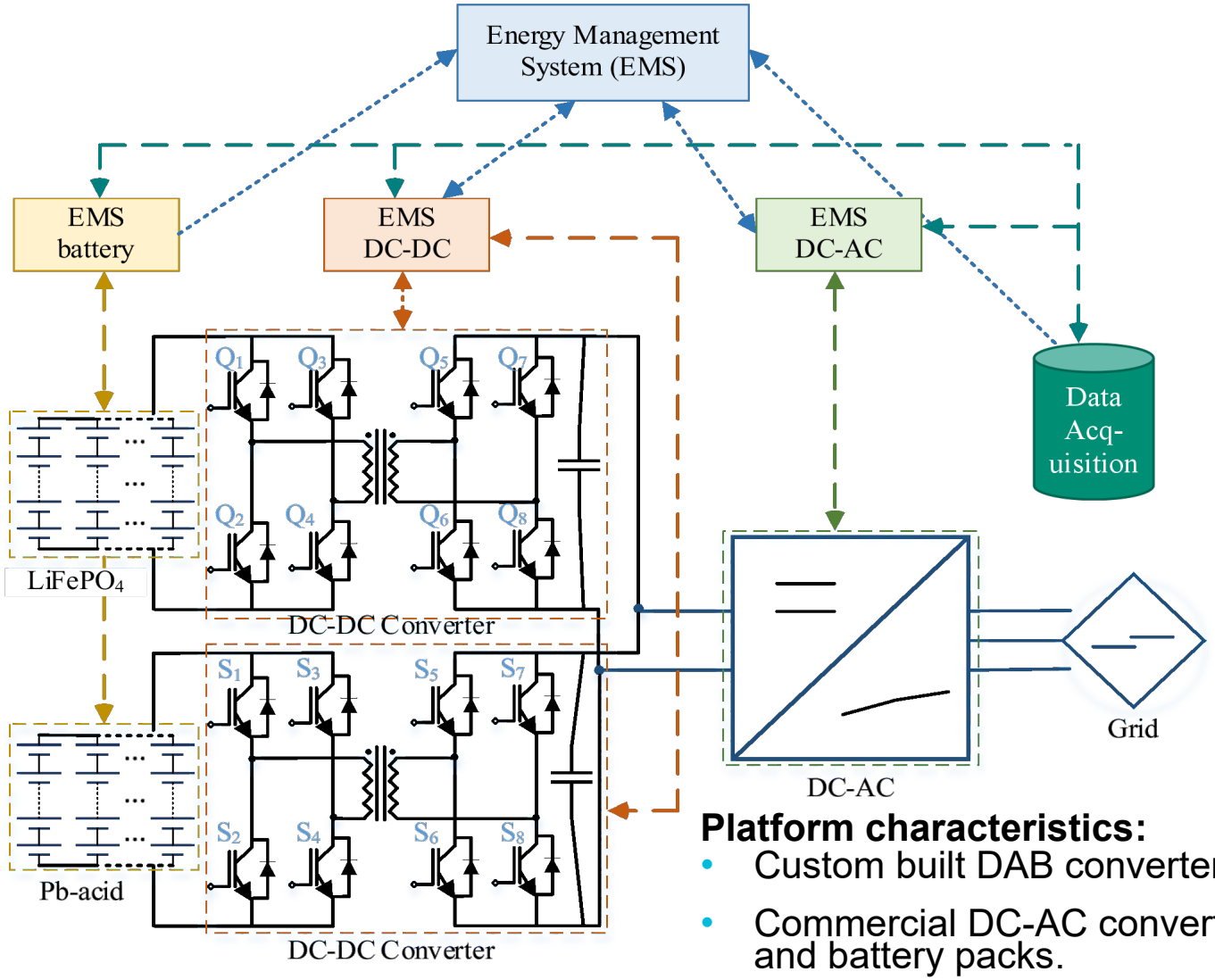
- Different modules can be cycled differently based on the battery technology.
  - Improved current quality since commercial DC-AC converters introduce ripple current into the batteries.
  - Increased modularity: Uninterrupted replacement of aged batteries. Mix old and new batteries.
- The operating range of the batteries can be varied as cells age.

The lifetime of power electronics and solar panels is 10-20 years. Over the lifetime of an installation, batteries will be completely or partially replaced at the least twice.

System integration for Active Topology is challenging from a control perspective.

Development of Open source and modular platform





Software characteristics:

- Hardware vendors only need to provide the green blocks.
- Supports CAN, Modbus, TCP/IP, Serial communication.
- Will support Simulink and PLECS models of hardware components.

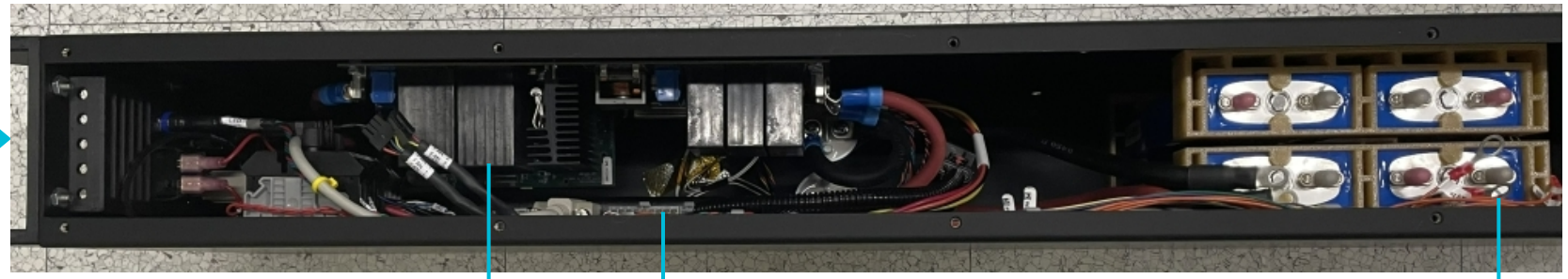
Platform characteristics:

- Custom built DAB converters
- Commercial DC-AC converte and battery packs.
- Development of modular software in Python.
- Firmware developed in C.

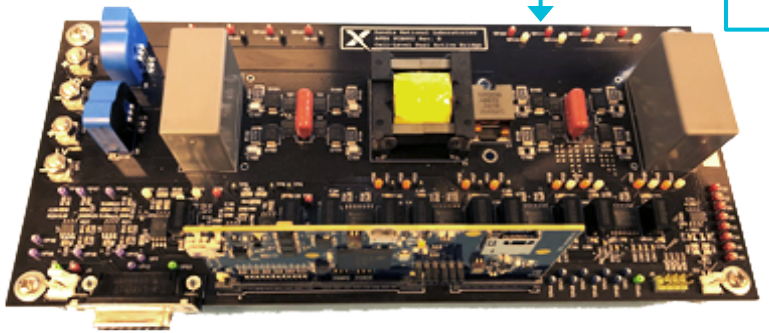
Hardware Platform: Modular system built to UL 1973 specifications

4 parallel modules

- Two modules are populated.
- Low voltage side is connected to different battery packs.
- High voltage side is connected to a **24V DC link**.
- 24V DC link is regulated by a Regenerative Power Supply



- Top view of a module
- Battery packs, DC-DC converter, BMS, Fans, E-stop Contactors, Power and Communication cables



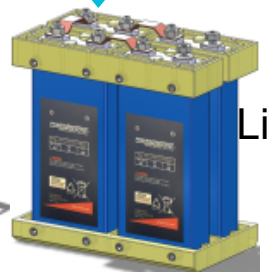
DC-DC converter

- Nominal power: **75W**
- Nominal voltages: **12V/24V**
- Switching frequency: **100 kHz**
- Maximum efficiency: **95%**
- Can be operated in both **current** and **voltage controlled** modes.

Orion Battery Management System (BMS)

Pb-Acid pack

O R

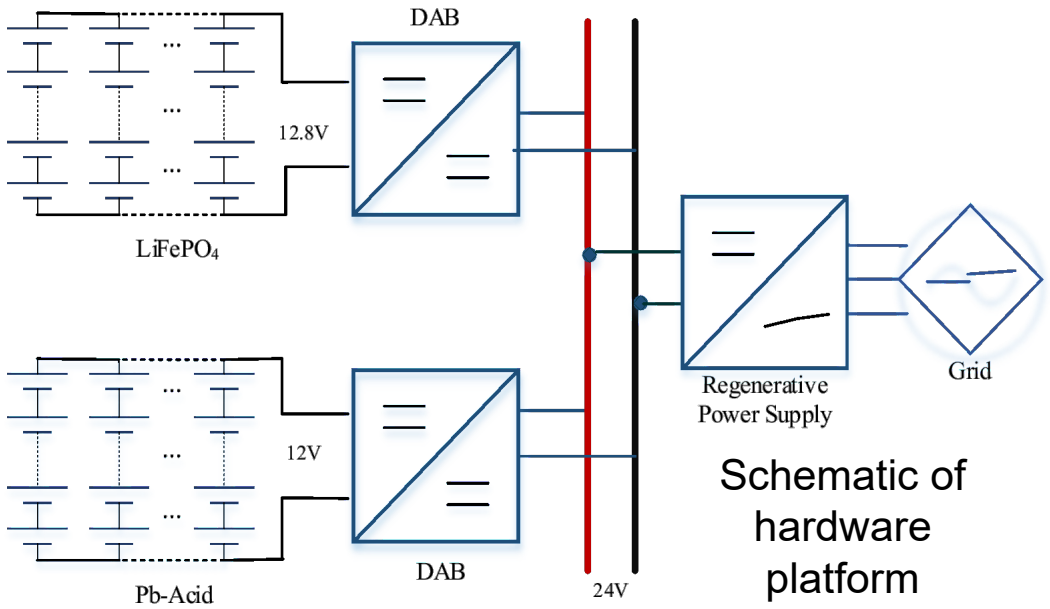


$LiFePO_4$ pack

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

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

Hardware Platform: Modular system built to UL 1973 specifications



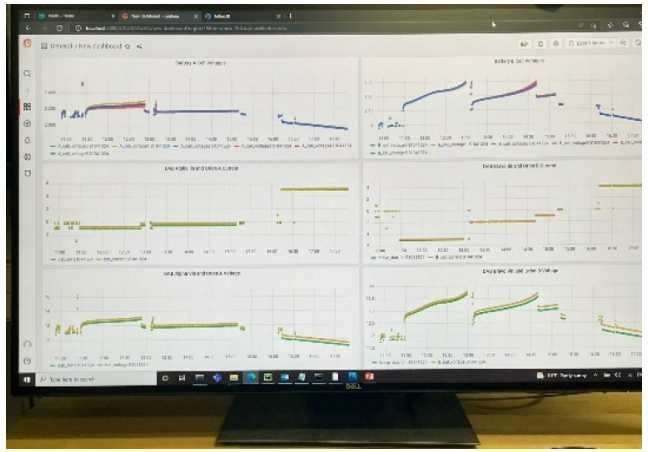
Schematic of hardware platform

2 parallel modules

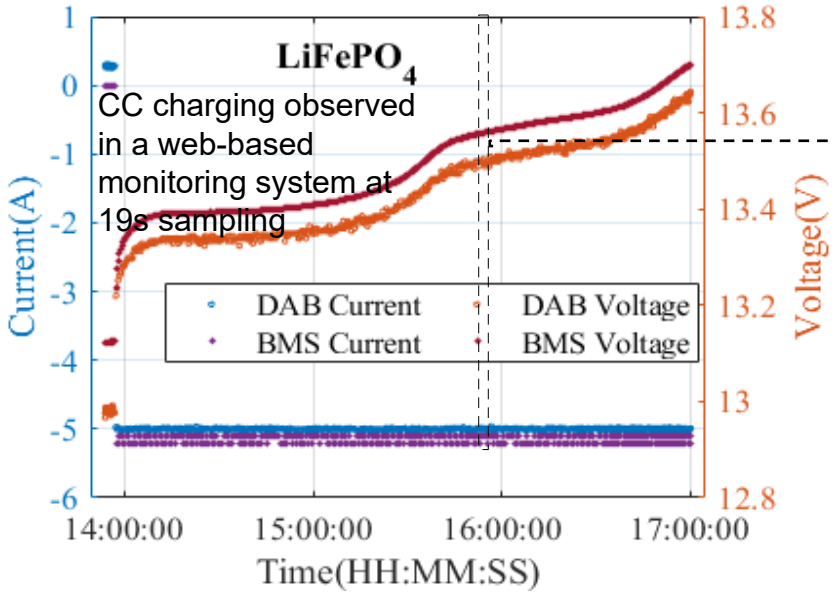
Regenerative Power Supply (RPS)

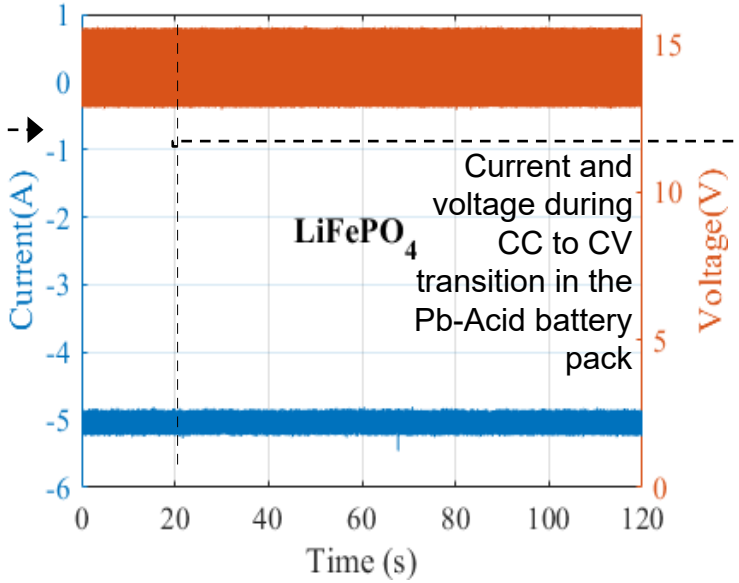
- 24V DC link is regulated by RPS
- RPS is powered by a grid emulator providing a fixed 3-φ 208V 60Hz grid voltage.

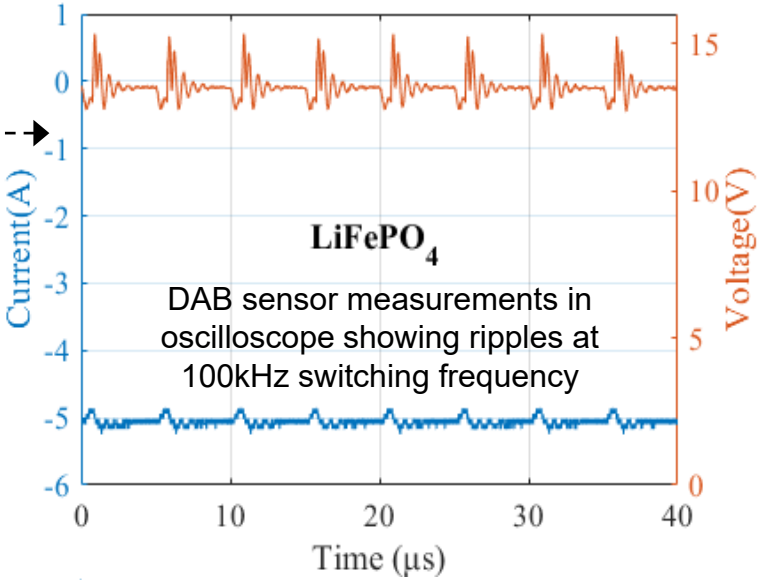
Energy management system control software and web based monitoring

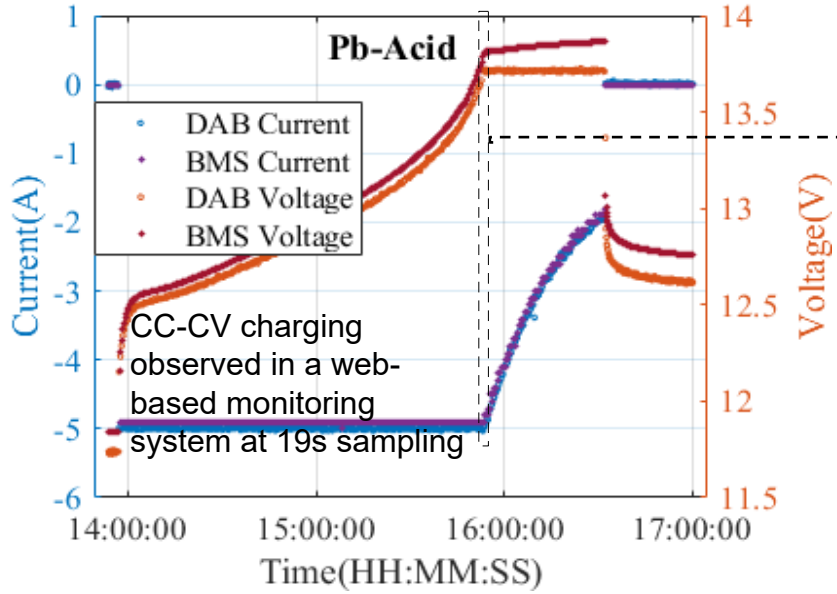


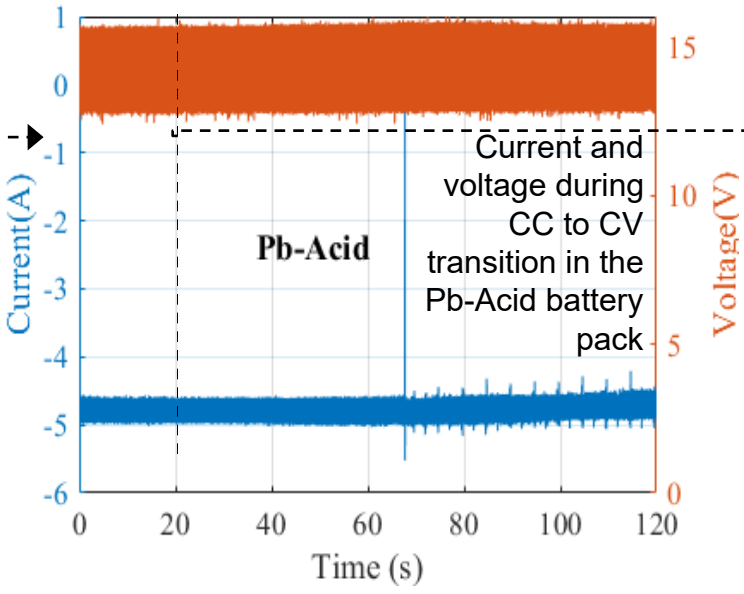
Results: Hybrid charging of $LiFePO_4$ and Pb-acid packs

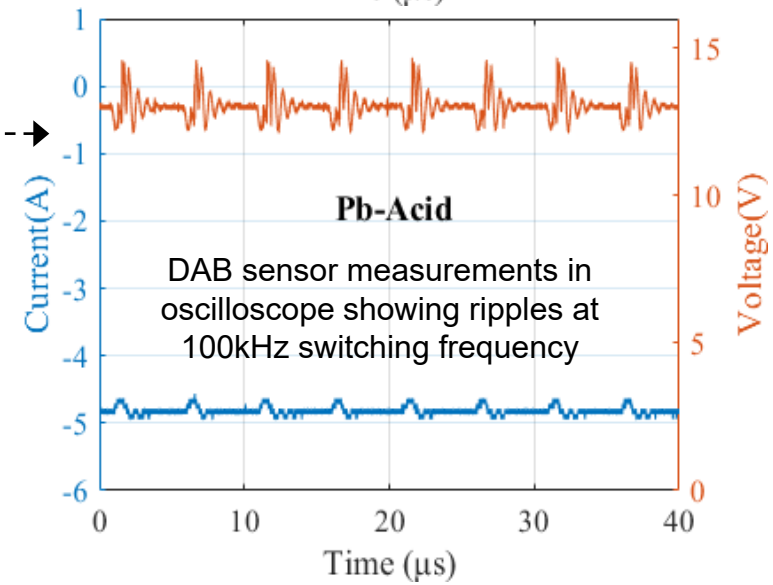




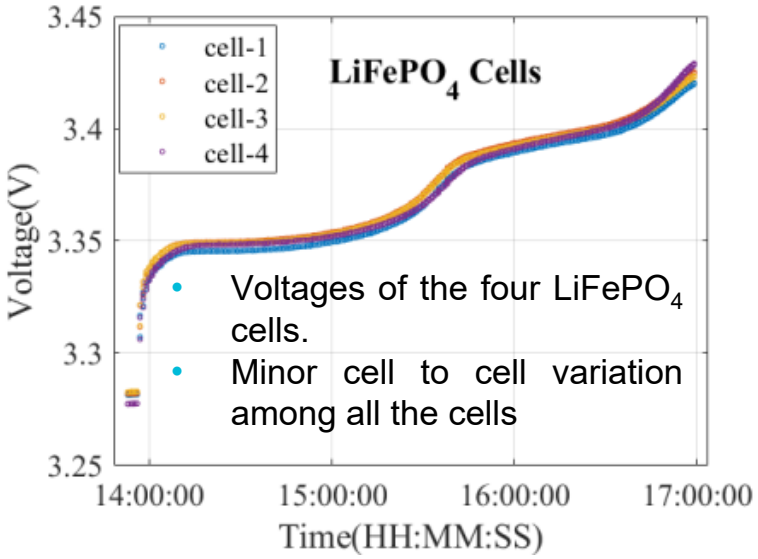




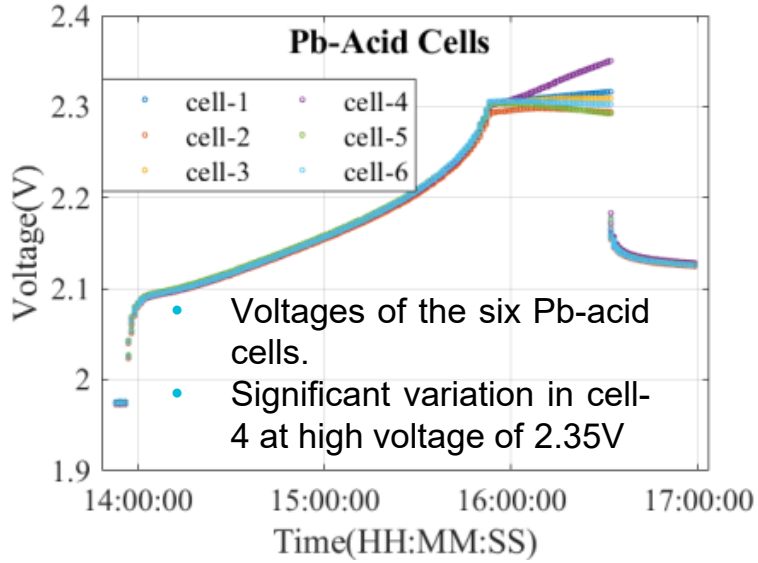




Results: Hybrid charging of $LiFePO_4$ and Pb-acid packs cont.

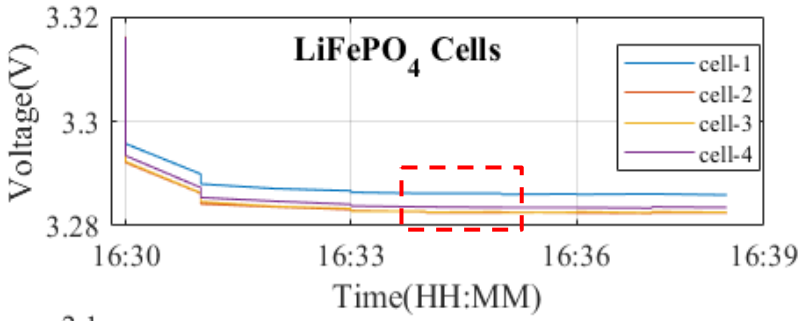


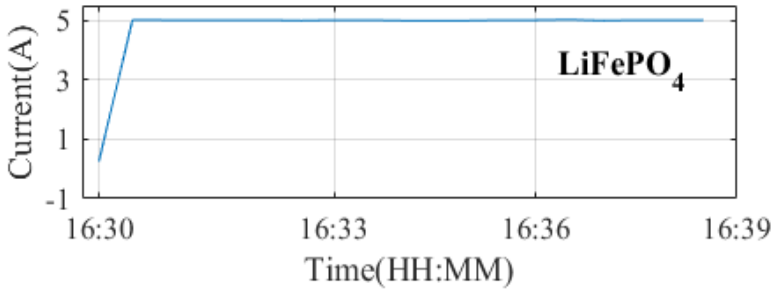
- Voltages of the four $LiFePO_4$ cells.
- Minor cell to cell variation among all the cells

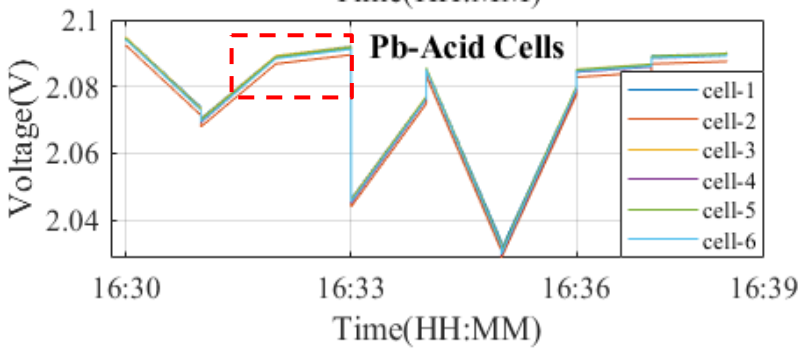


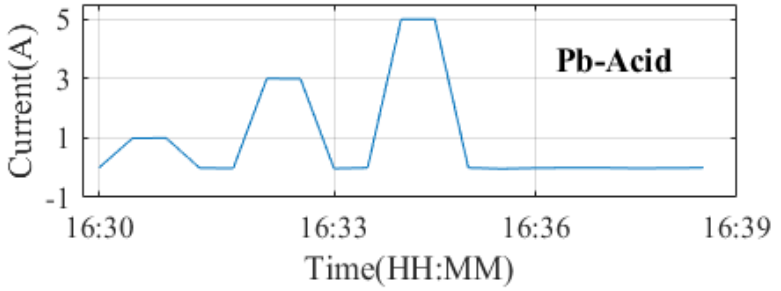
- Voltages of the six Pb-acid cells.
- Significant variation in cell-4 at high voltage of 2.35V

Pulse Discharging of Pb-Acid and CC discharging of LiFePO4







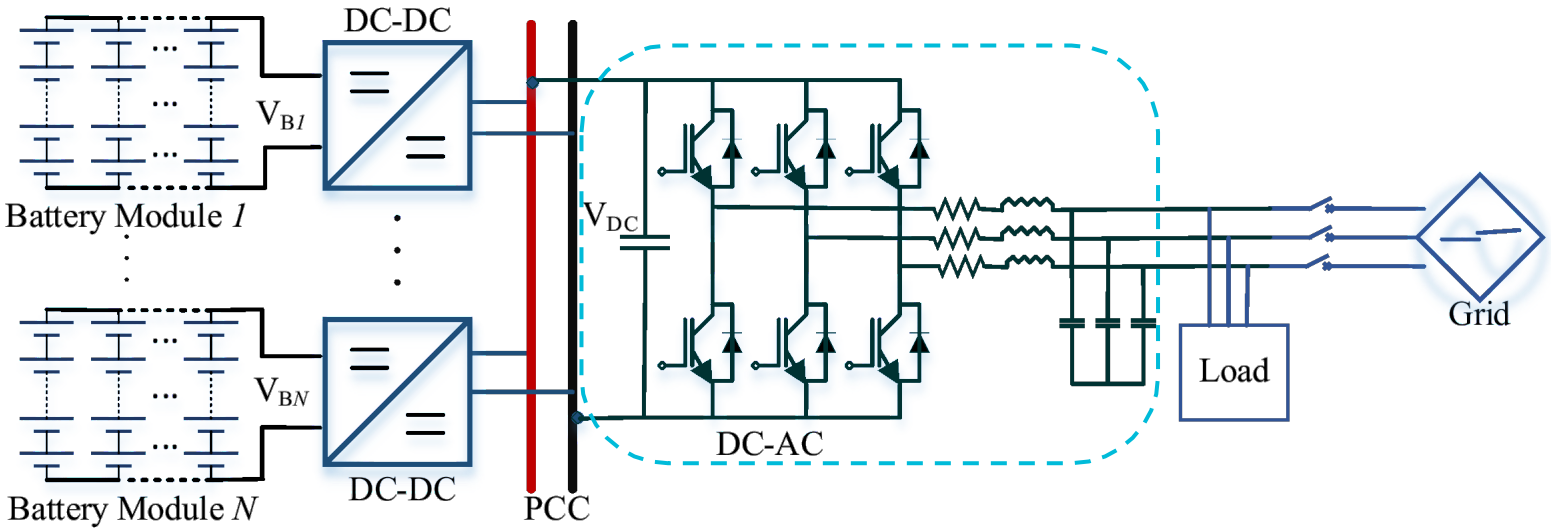


- $LiFePO_4$ battery pack is discharged at 5A while pulse test is performed on the Pb-acid battery pack.
- Pulse test is used for running quality control test on selected stacks.

Future Work:

1. Operating four modules with CAN communication.

2. Development of a low-cost DC-AC converter hardware with a high AC/DC Voltage ratio and a control strategy that is suitable for integrating BESSs to the grid.



3. Integrating parameter estimation algorithm with the development software platform, for reducing cell degradation by providing adaptive cycling set points to battery modules.

Summary

SUMMARY:

- Developed and validated a modular open-source platform for testing and operating any commercial battery technology using custom built DC-DC and commercial DC-AC converters.
- The platform will be made available to other groups and university partners interested in using it for their research.

HARDWARE DEVELOPMENT

- Modular platform that can accommodate different types of batteries, battery management systems, DC-DC converters, protection devices and communication methods.
- Stable performance with hybrid cycling of two different battery technologies.

SOFTWARE DEVELOPMENT

- Public web interface and database to remotely consolidate data from multiple systems for further analysis.
- Python based Energy Management System capable of integrating with multiple battery technologies, BMSs, DC-DC converters, DC -AC converters, and communication protocols.
- Firmware libraries for the different constituents.

EXPERIMENT OUTCOME

- Control charging/discharging of hybrid batteries at different voltage levels.
- Reduced ripple in battery cycling current.
- Demonstrated that batteries can be disconnected by the string.

SELECTED ACCOMPLISHMENTS

- O. Dutta, J. Mueller, R. Wauneka, V. De Angelis, and D. Rosewater, “Integrated Power Converters for Optimal Operation of Hybrid Battery Packs”, *IEEE PES GM*, 2022.
- V. De Angelis, J. Mueller, and O. Dutta, "Integrated Power Converters for Optimal Operation of Hybrid Battery Packs," *US Application No. 63/392,359*. July 26, 2022.

Acknowledgement:

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SANDIA PROGRAM
- Power Electronics Thrust Lead: Stan Atcitty
- Energy Storage Program Manager: Babu Chalamala

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 assembly and testing.
- Valerio De Angelis: Project management.

For questions about this presentation: odutta@sandia.gov