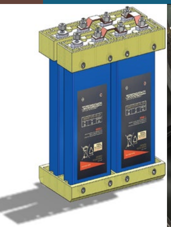
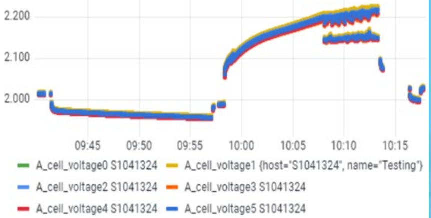
System Development for Optimal Operation of Hybrid Storage Technologies





PRESENTED BY

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CORE PROJECT MEMBERS

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U.S. DEPARTMENT OF ENERGY NNSA

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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 batteries with disparate state of health, e.g. old and new cells.

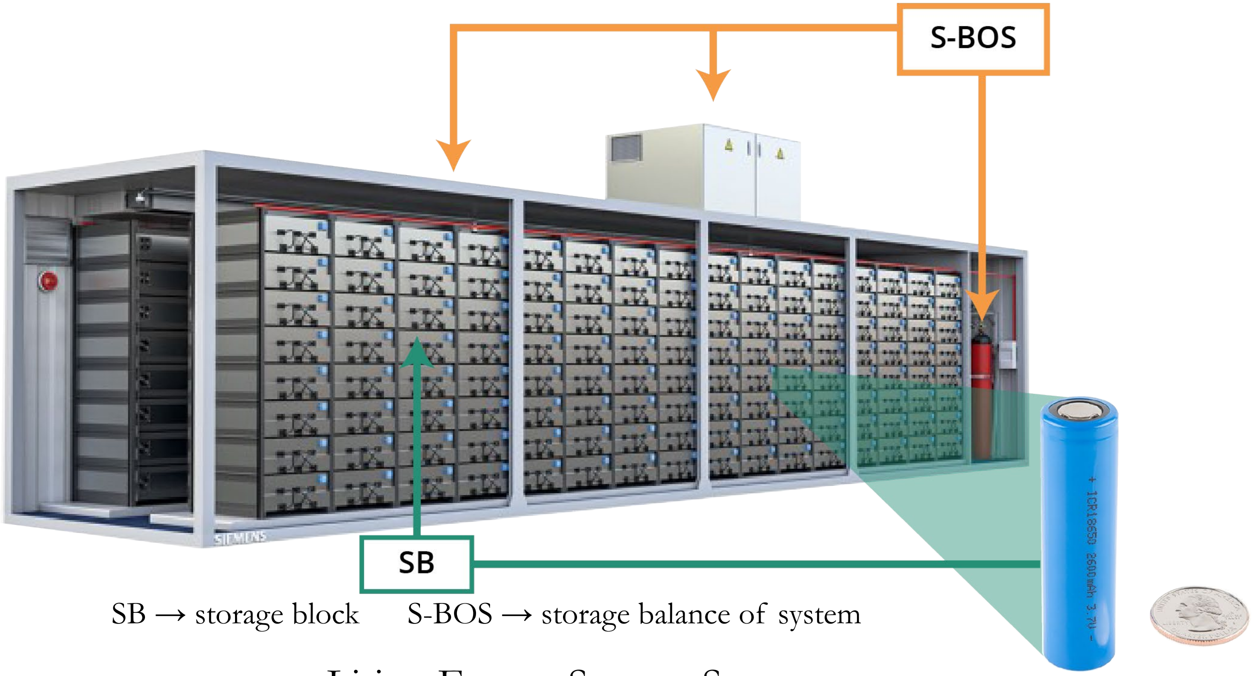
Existing gap in R&D

- Presently, there is no standardization of the power electronic topology, communication protocol, or control software for safely integrating and operating grid-scale batteries.
- Lack of a readily available system has every battery startup reinventing 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

Li-ion Energy Storage System

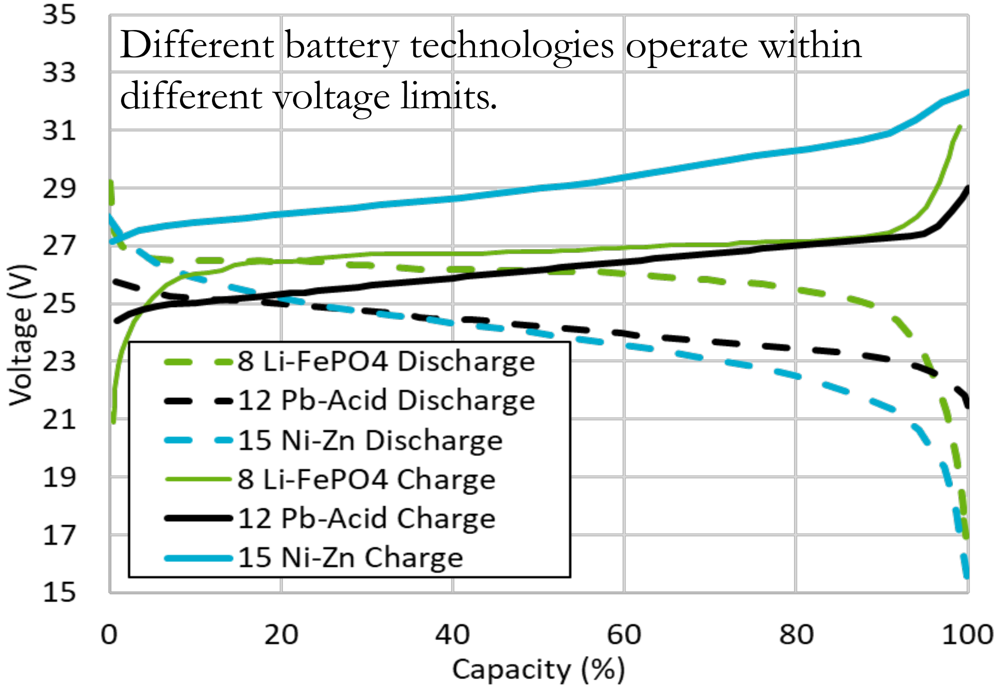
- Energy storage system (ESS) components: SB, SBOS, Power Equipment, Controls & Communication, System Integration.
- In an ESS, the cell cost accounts for < 30% of the total cost.

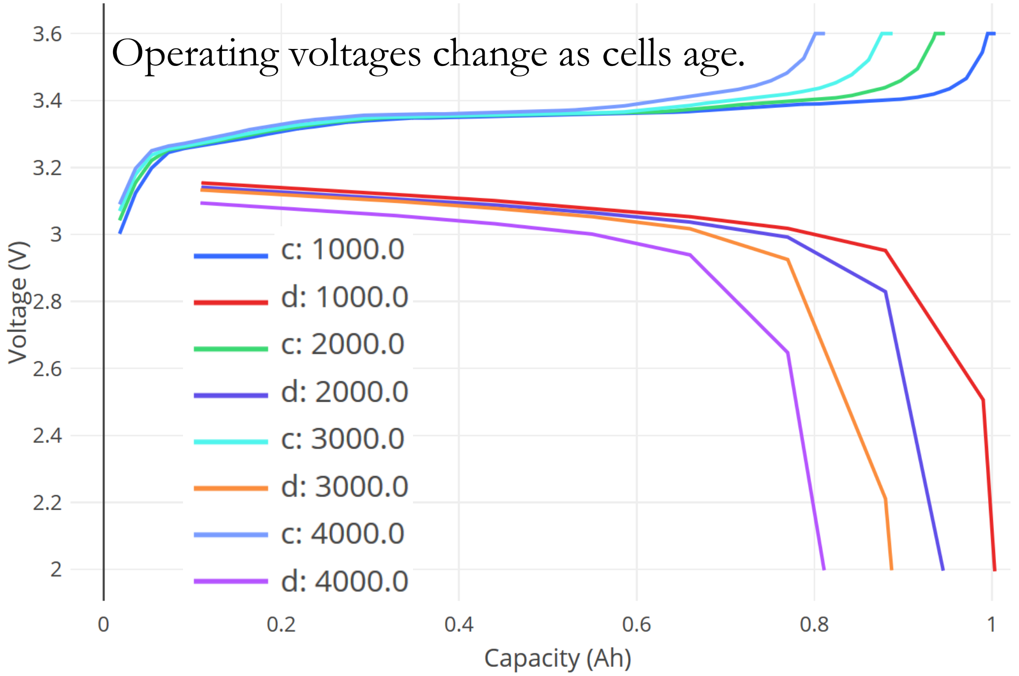
Battery fire: EPRI BESS Failure Event Database*

- Stationary storage fire destroys an entire installation, as thermal runaway from a single cell quickly propagates through an entire rack.
- Cost is overridden by safety requirements for critical indoor applications.

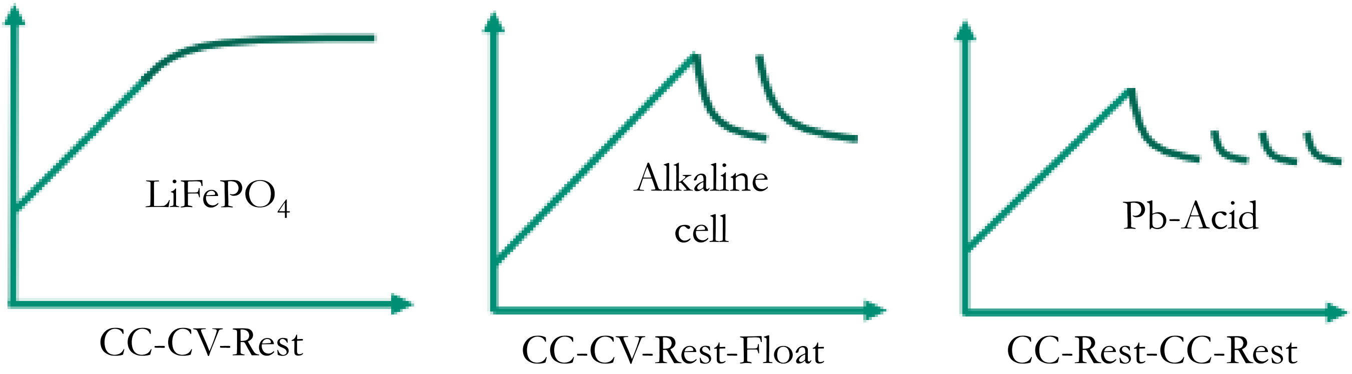
*https://storagewiki.epri.com/index.php/BESS_Failure_Event_Database

Challenges in operating hybrid battery technologies



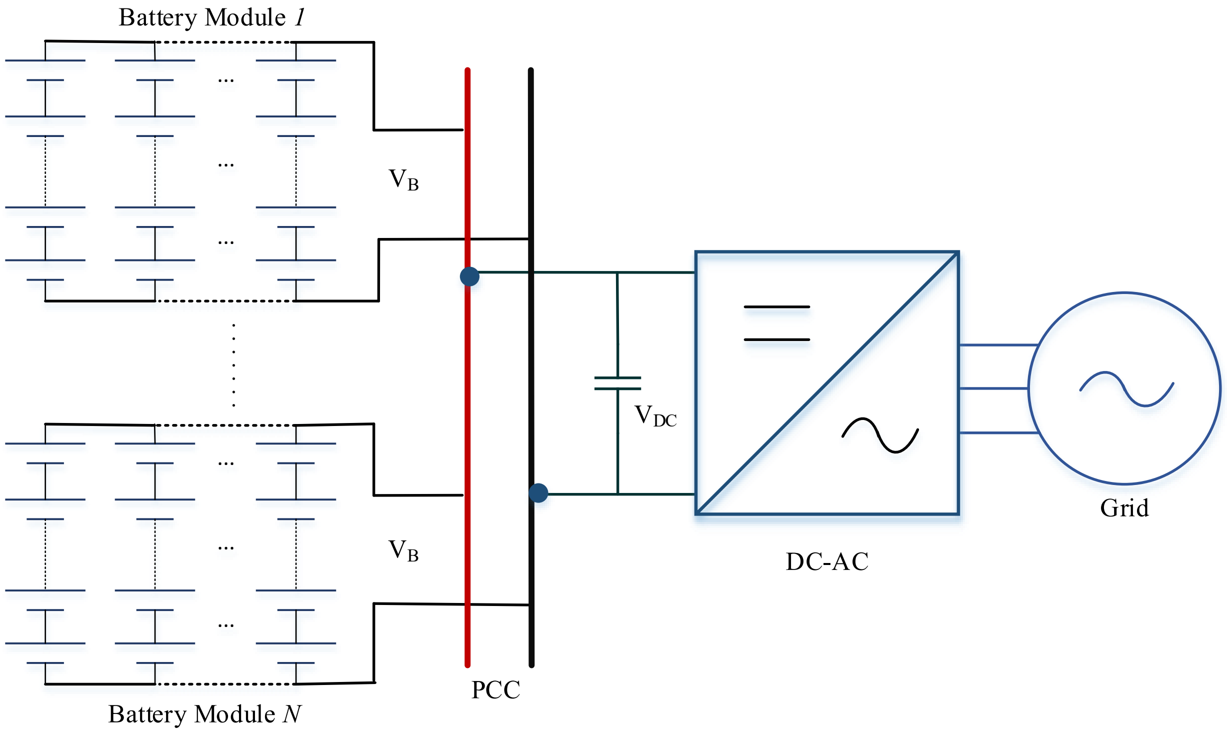


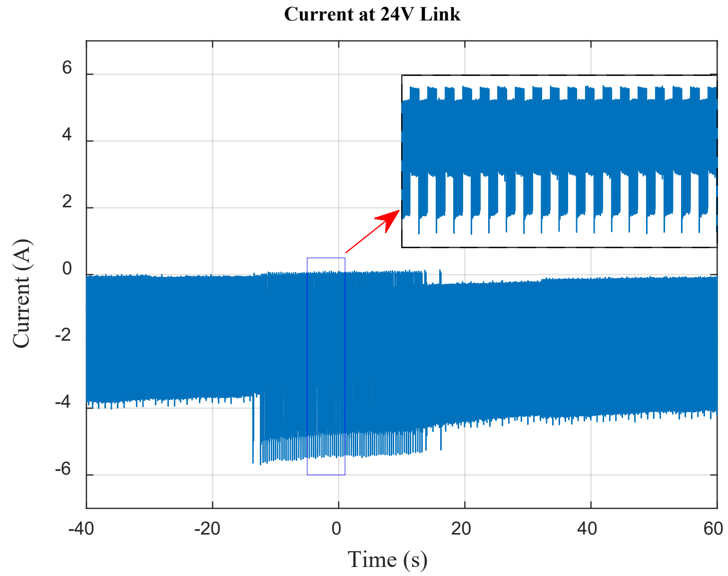
Different battery technologies operate with different charge-discharge protocol



CC- Constant Current CV- Constant Voltage

Commercially Existing: Passive Topology



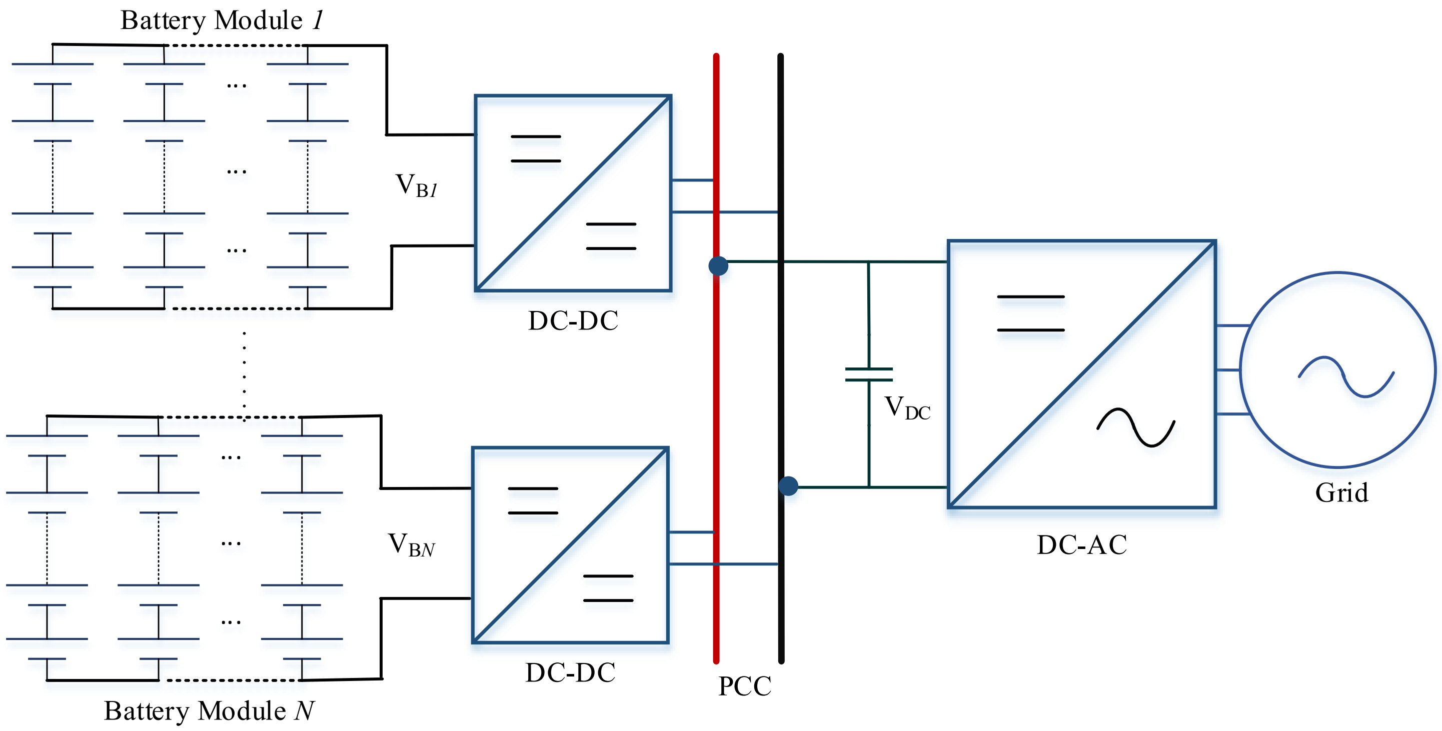


Current measured at the DC link of a commercial DC-AC converter for Pb-acid batteries.[+]

- Batteries have to be connected to the DC-AC at all times.
- If one cell shorts, all the modules will have to be replaced- Single point of failure.
- No room for 'hot swap' replacement of aged/damaged batteries.
- DC-AC converters need to be compatible with the type of battery (implement charge/discharge protocols specific to a particular technology).
- Voltage and current ripples cause accelerated degradation of battery cells.

[+] O. Dutta, *et al., IEEE PES General Meeting*, 2022.

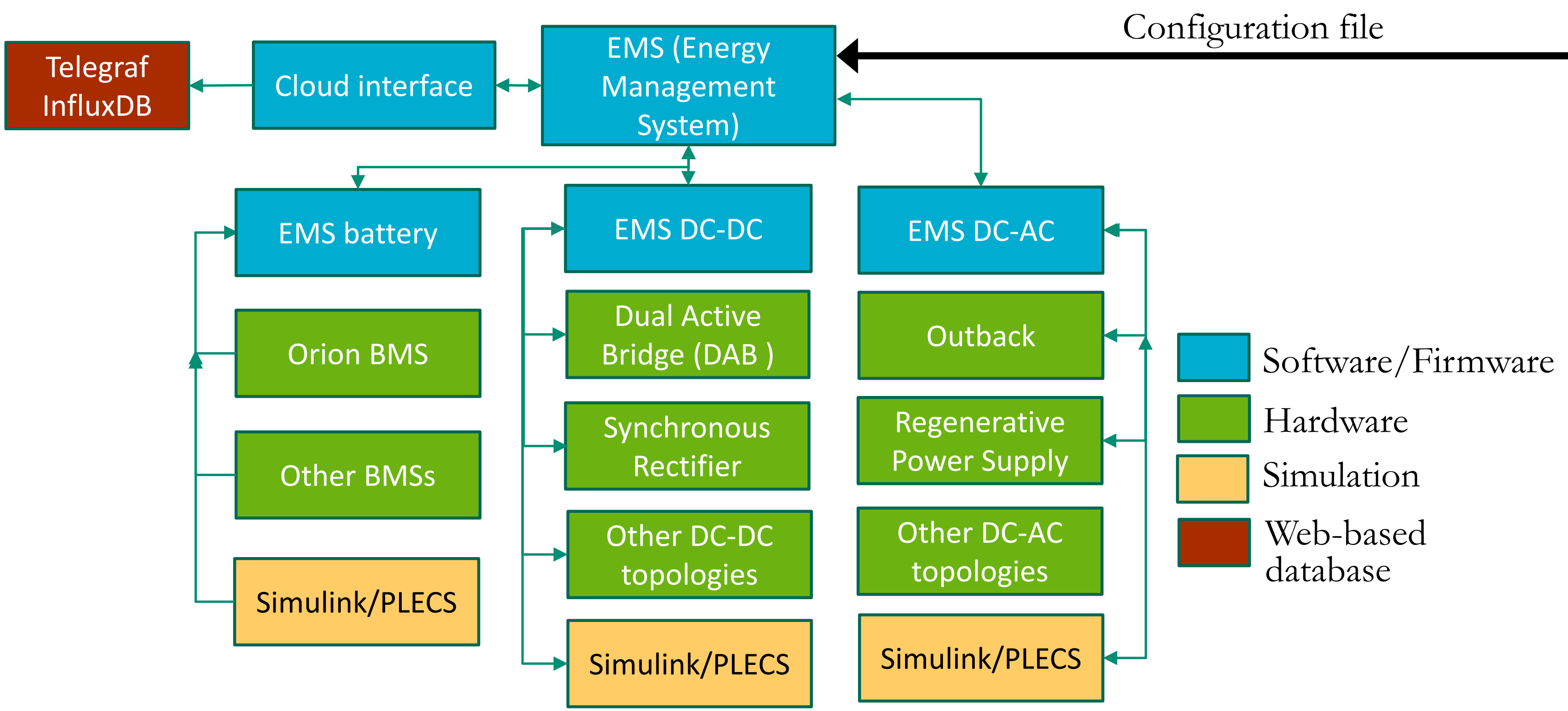
Proposed: Active Topology



- 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.
- Supports “hot swap” and energy redistribution.

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.

Development of an Open-source and Modular platform

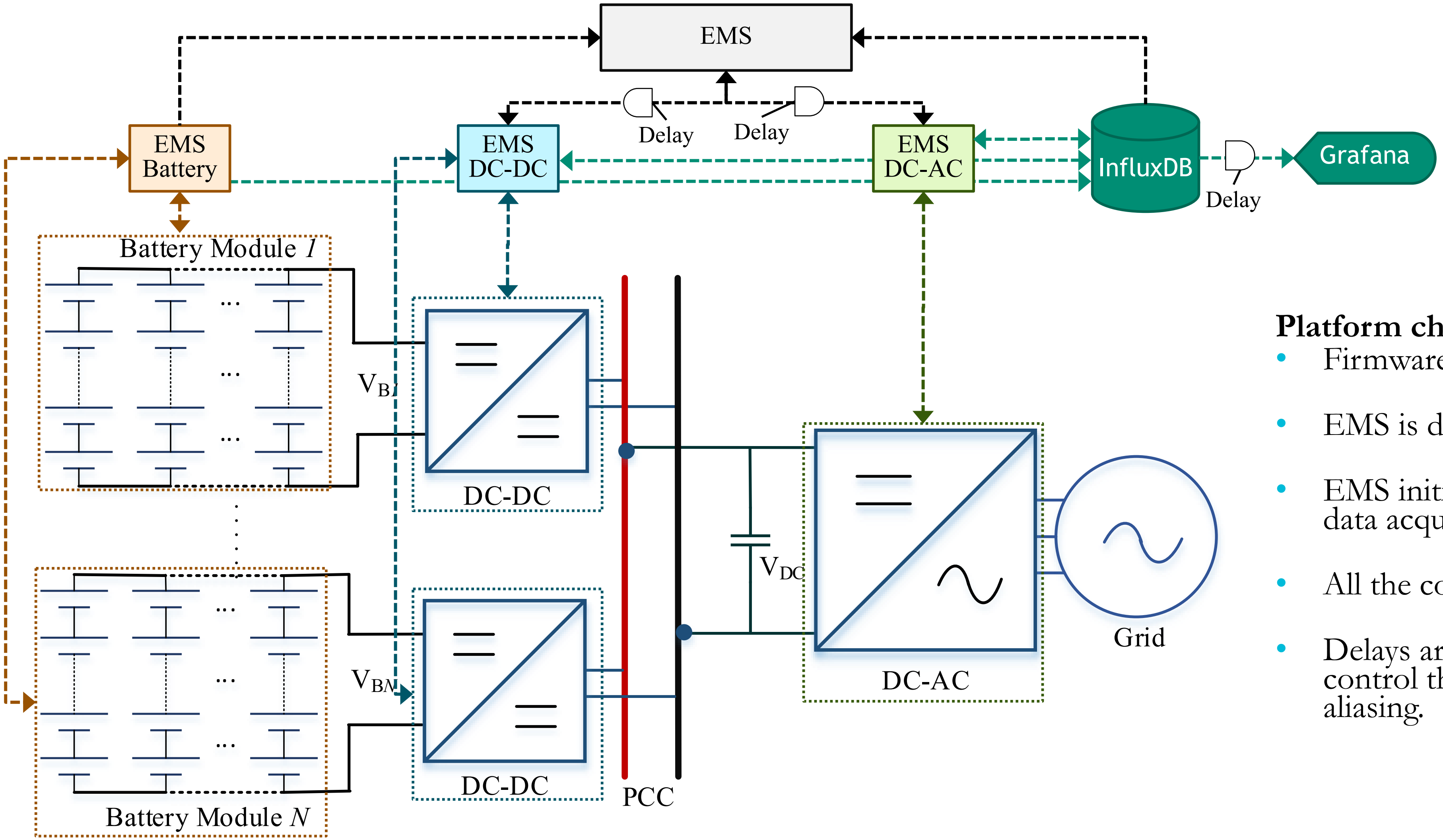



```
[DCAC]
Name = RPS

[Protocol]
Type = Loop
Charge = 95
Rest = 60
Discharge = 95

[COMMUNICATION]
communication_type = Serial

[BATTERY PACKS]
Packs = 1

[Pack_A]
Series = 4
Parallel= 1
CellName = PowerSonic
BMSModel = OrionBMS
CellType= LiFePO4
MaxCurrentCharge= 6.0
MaxCurrentDischarge= -6.0
Ah = 25
NomVoltage = 3.2
MaxVoltage= 3.65
MinVoltage= 2.54
MaxSoC= 95.0
MinSoC= 15.0
current = 1.0
DCDC = DAB
cell_voltages = 3.2
serial_port = COM8

[Pack_A_DAB]
conv_id = 1
serial_port = COM9

[Pack_B_DAB]
conv_id = 2
serial_port = COM7

[Data_Logger]
type = telegraf
sn
[RPS]
invtype = 208-3P
maxpowercharge = 125.0
maxpowerdischarge = -125.0
maxrampup = 20.0
maxrampdown = -20.0
hz = 60.0
t_env = 25
```

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.

Development of an Open-source and Modular platform



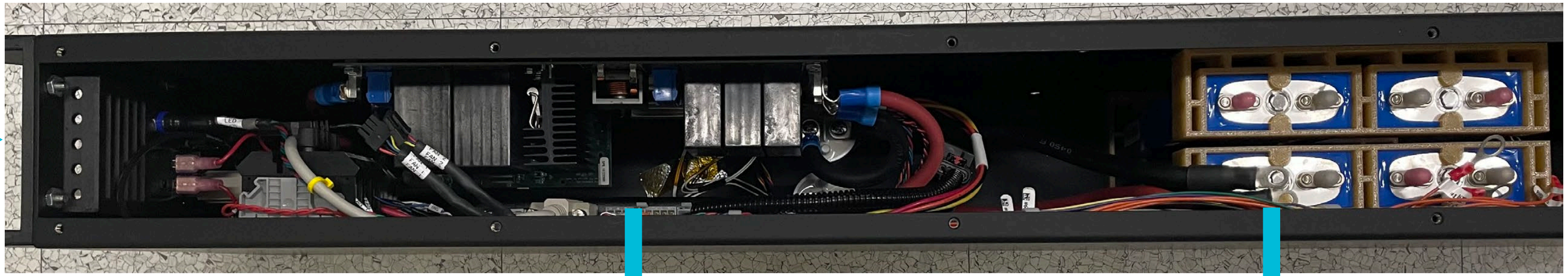
Platform characteristics:

- Firmware libraries are developed in C/SCPI.
- EMS is developed in Python.
- EMS initiates control threads for each device, data acquisition, and system protection.
- All the control threads are executed in parallel.
- Delays are introduced for synchronizing the control threads and prevention of sample aliasing.

Hardware Platform: Modular system built to UL 1973 specifications

4 parallel modules

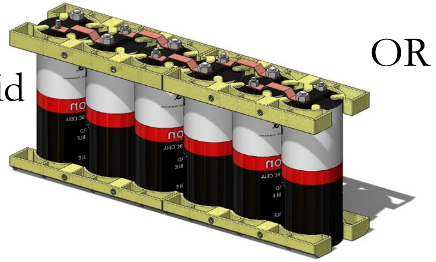
- Low voltage side is connected to different battery packs.
- High voltage side is connected to an inverter’s DC link.



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

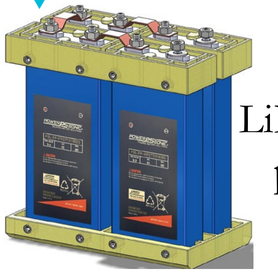
Orion Battery Management System (BMS)

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

Hardware Platform: Modular system built to UL 1973 specifications

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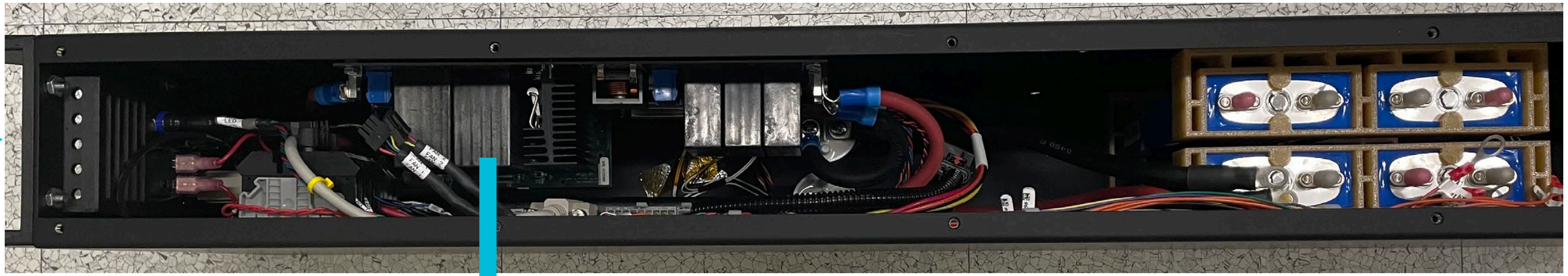
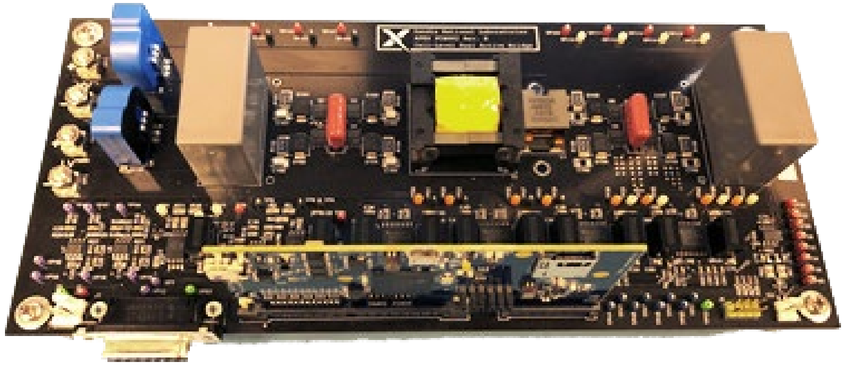


Synchronous Rectifier DC-DC converter

Custom built to following specifications:

- Nominal power: 300W
- Nominal voltages: 12V/24-48V
- Switching frequency: 100 kHz
- Maximum efficiency: 96%
- Can be operated in both current and voltage controlled modes.

OR



Dual Active Bridge (DAB) DC-DC converter

Custom built to following specifications:

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

Hardware Platform: Modular system built to UL 1973 specifications

4 parallel modules

- Low voltage side is connected to different battery packs.
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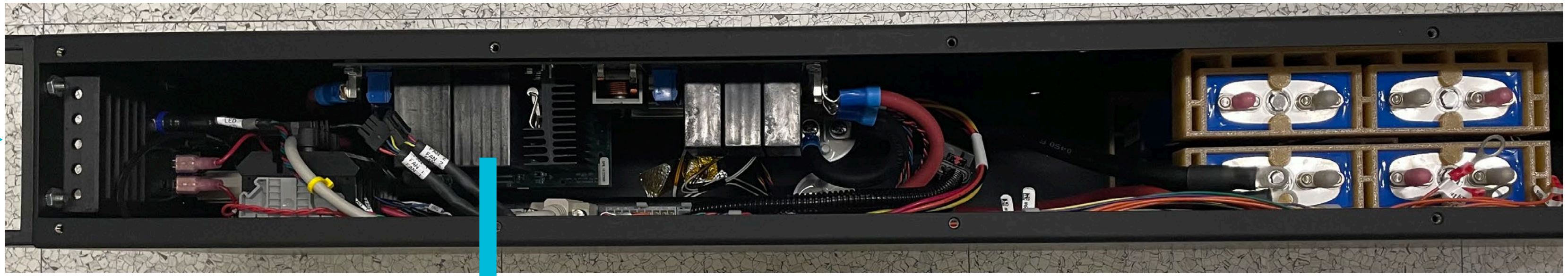

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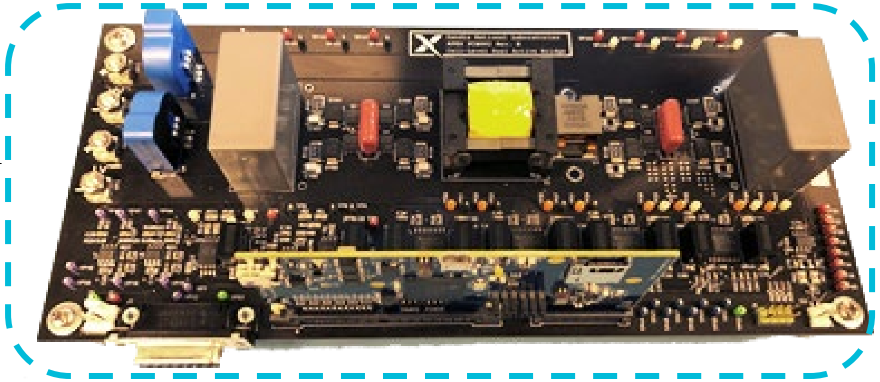

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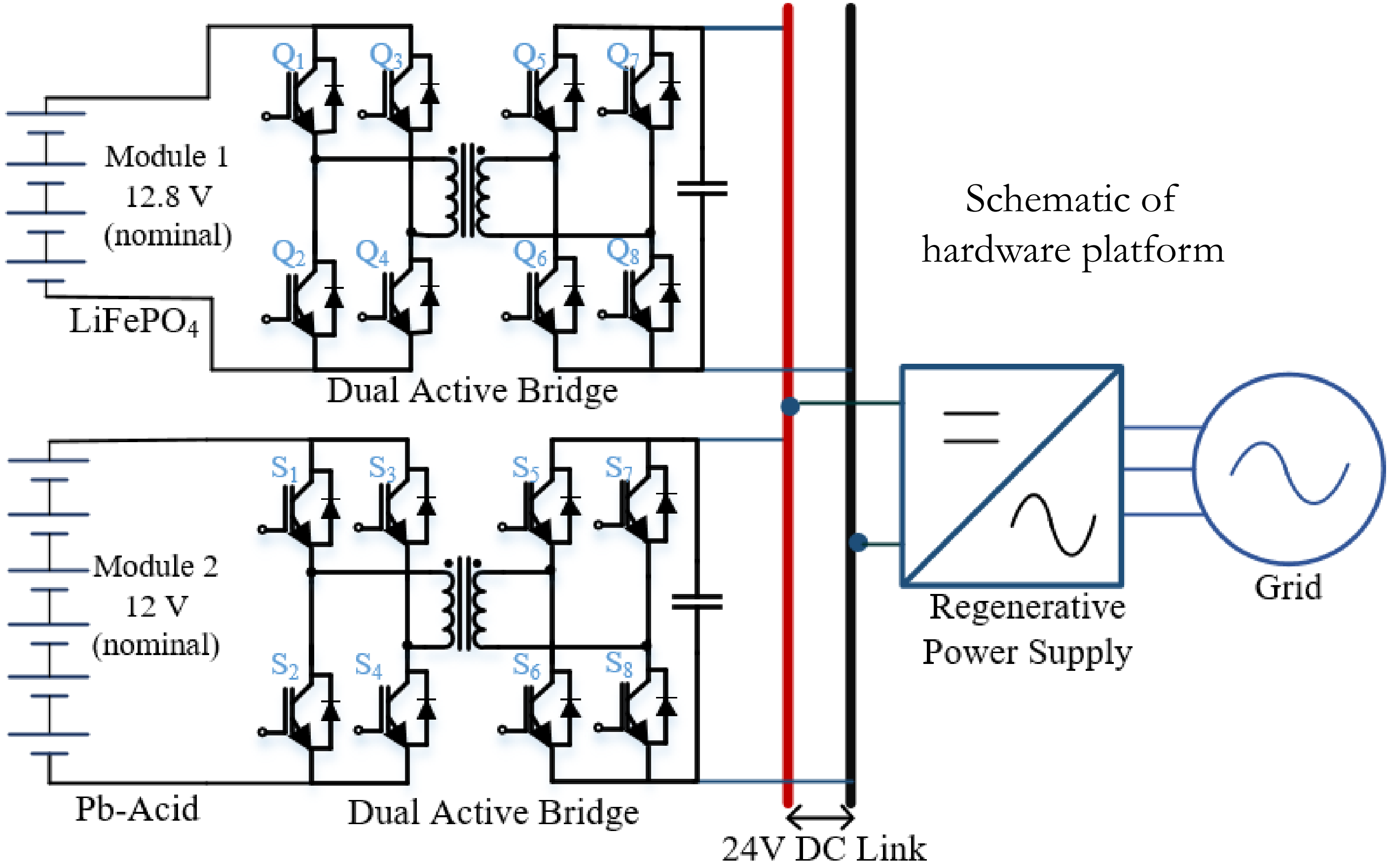
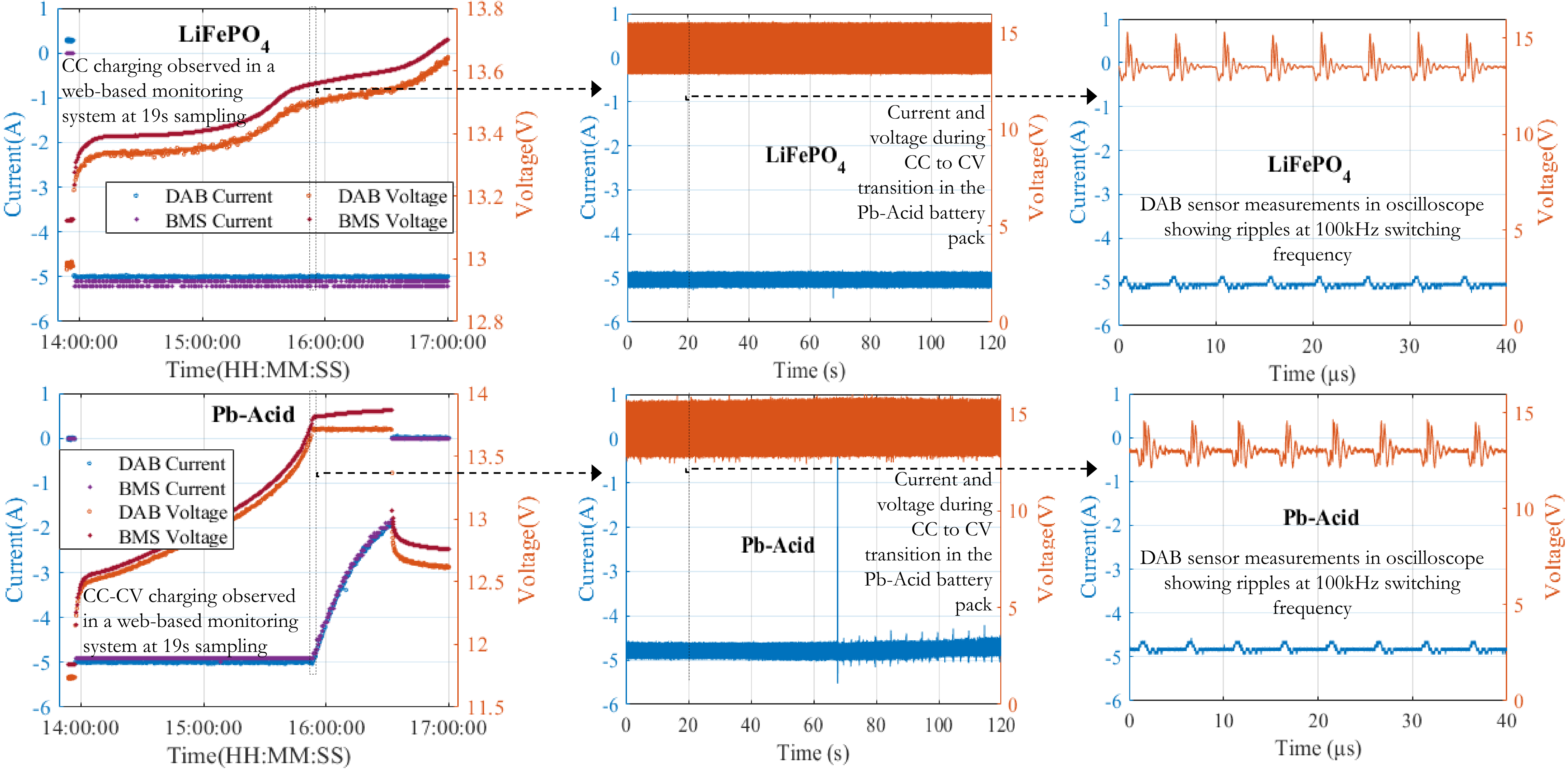
Case Study: $LiFePO_4$ and Pb-acid battery packs



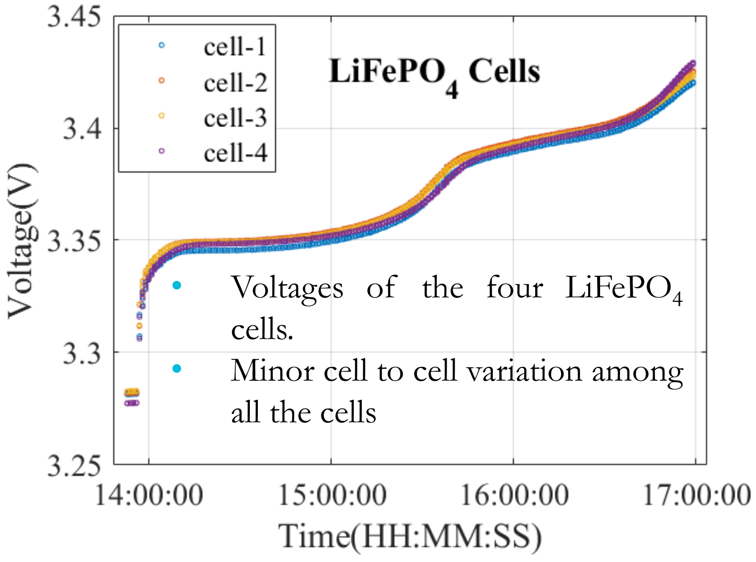
- Custom built DAB converters.
- Commercial DC-AC converter and battery packs.
- 2 parallel modules. Module 1: 4 $LiFePO_4$ cells in series.
  Module 2: 6 Pb-acid cells in series.
- 24V DC link is regulated by Regenerative Power Supply (RPS).
- RPS is powered by a grid emulator providing a fixed 3-φ 208V 60Hz grid voltage.
- Serial communication is used in the hardware platform.

Case Study: Remote access, open-source data acquisition and monitoring

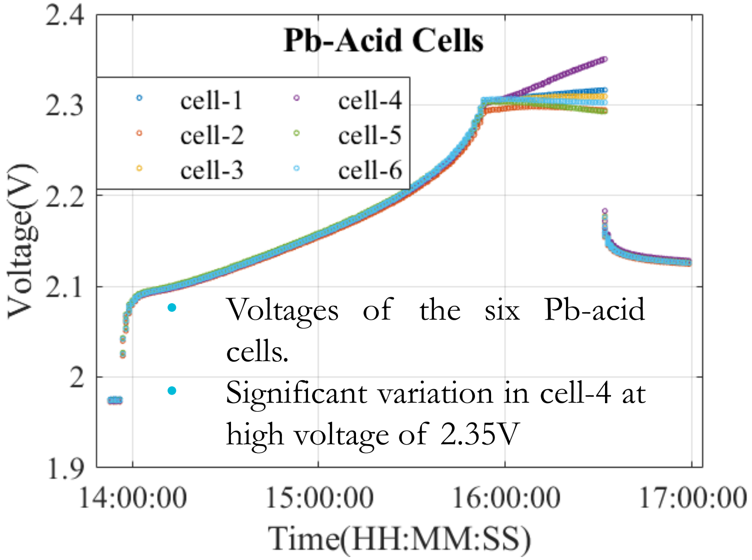
Results: Hybrid charging of $LiFePO_4$ and Pb-acid packs



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

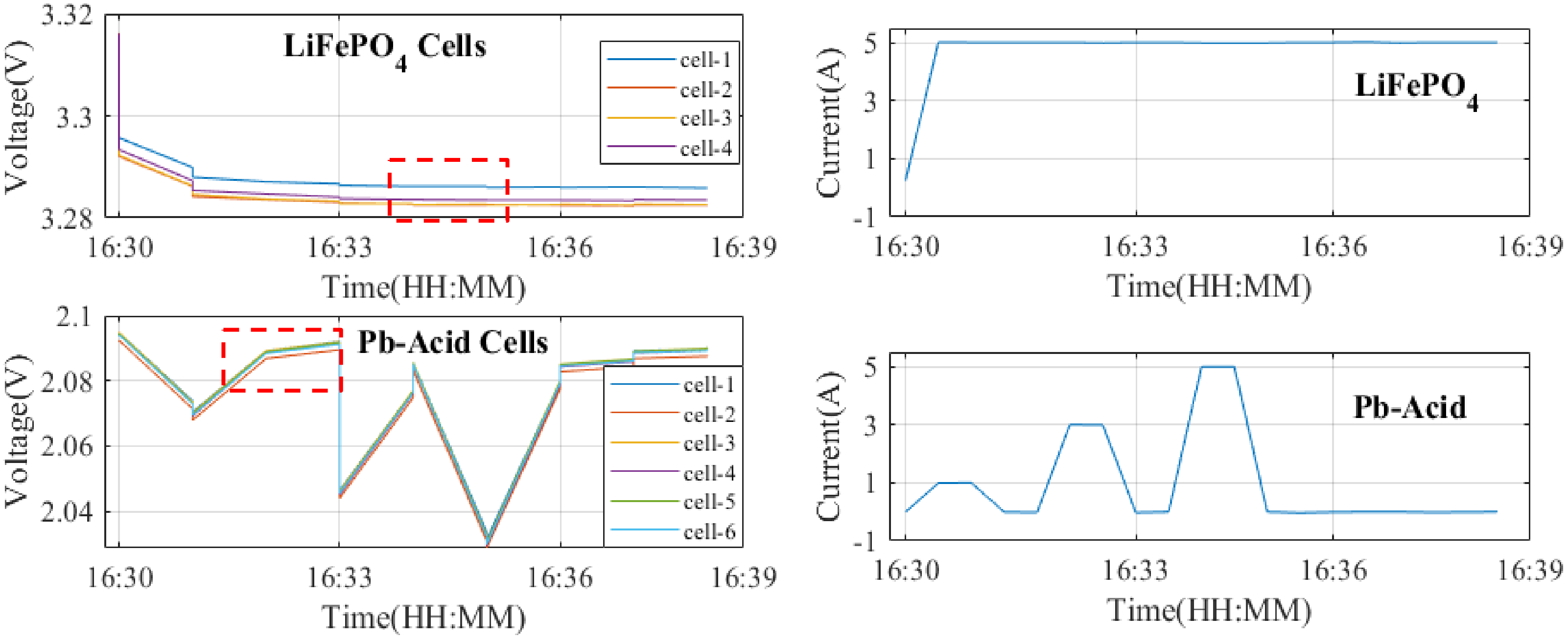


- Voltages of the four $LiFePO_4$ cells.
- Minor cell to cell variation among all the cells



- 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

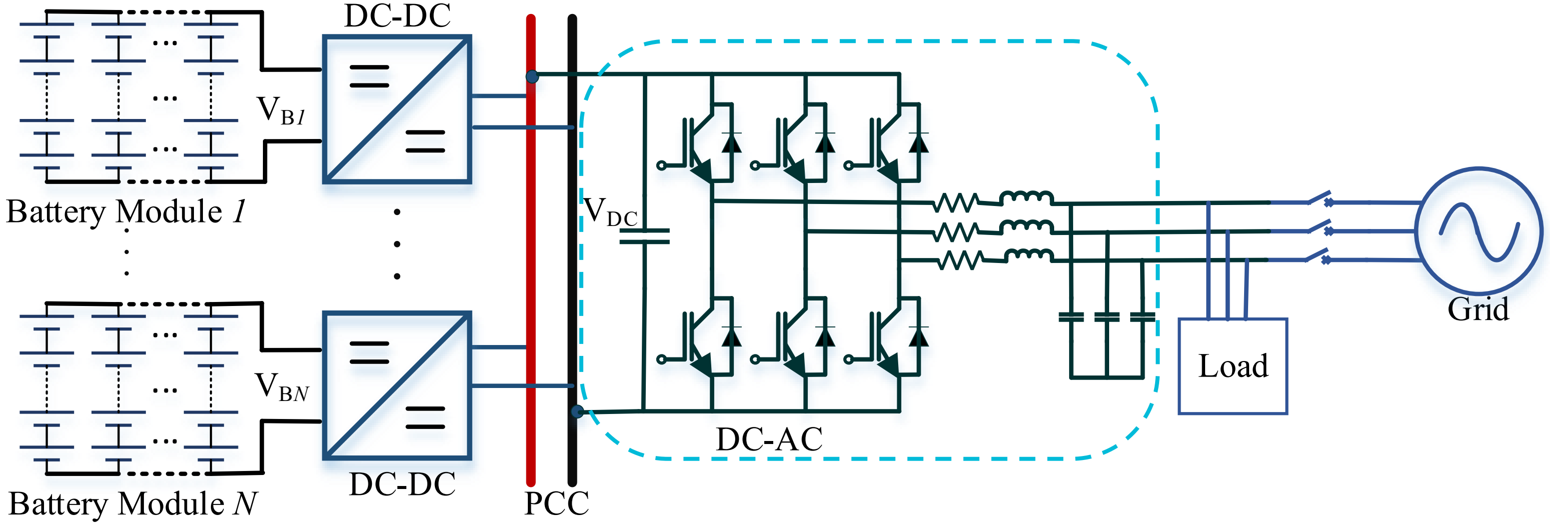


- $LiFePO_4$ battery pack is discharged at 5A while pulse test is performed on the Pb-acid battery pack.
- Pulse test is used for running quality control test on selected stacks.

Conclusion and Future Work:

1. Operating more than two modules with CAN communication.

2. Development of a low-cost DC-AC converter hardware with a high DC/AC 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.

4. Add additional sensors to the BMS for advanced safety.

5. Make the system available to universities as a research platform and companies as a robust system to deploy new battery technologies in the field.

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

For questions about this presentation: odutta@sandia.gov

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.

EXPERIMENTAL 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.
- Technical Advancement: 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.