Sandia National Laboratories

Enhancing Resilience: Upgrades and Integration Strategies for a Hybrid Energy Storage System (HESS)

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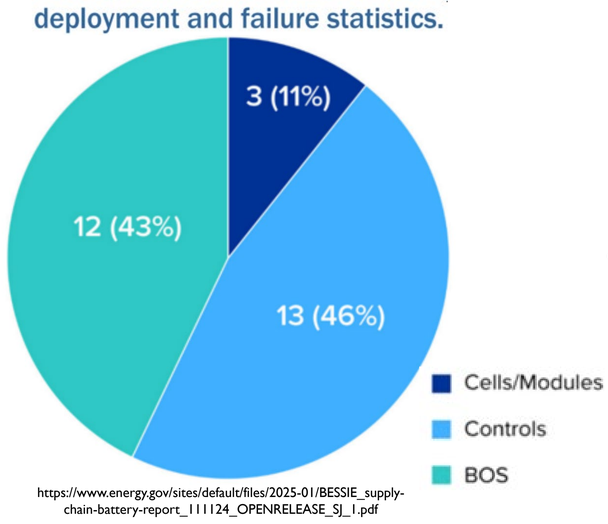
Why is System Integration Important?

• ~ 90% of failures in grid-scale battery installations are due to controls and system integration.

Global grid-scale BESS deployment deployment and failure statistics.



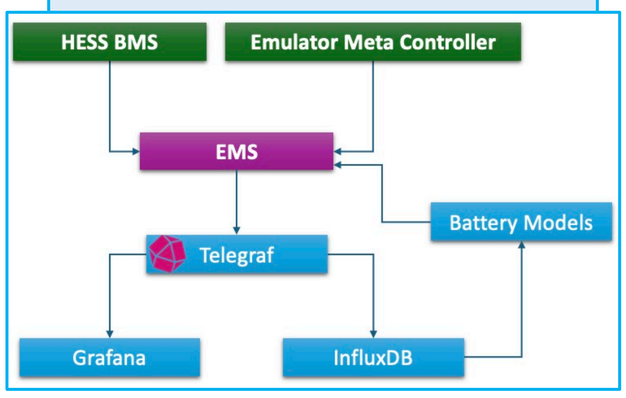
https://www.energy.gov/sites/default/files/2025-01/BESSIE_supply-chain-battery-report_111124_OPENRELEASE_SJ_1.pdf

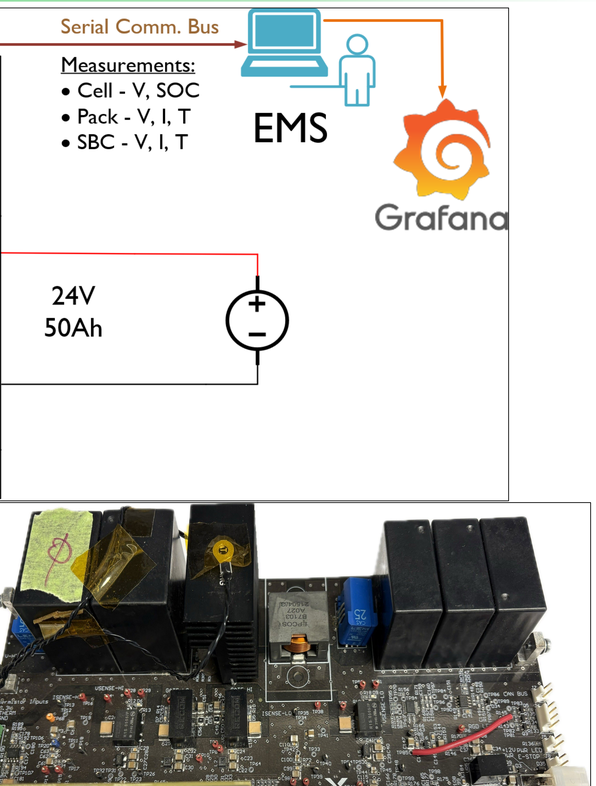
- As emerging energy technologies push the boundaries of modern grid infrastructure, our system will offer a **secure and resilient open source platform** for testing and refining innovative battery **energy storage solutions** in a controlled yet realistic environment.
- By upgrading the HESS with real-time data acquisition, optimized firmware, system emulation, and an open-source interface, **we accelerate research workflows. This cuts down development time which improves system reliability** and unlocks new insights into mixed-chemistry performance that drive faster, **more reliable grid-scale deployments.**

Methodology

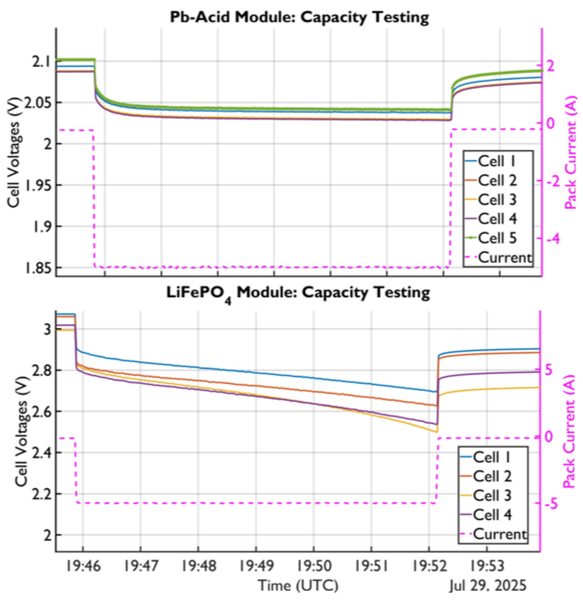
Emulation of System Communications

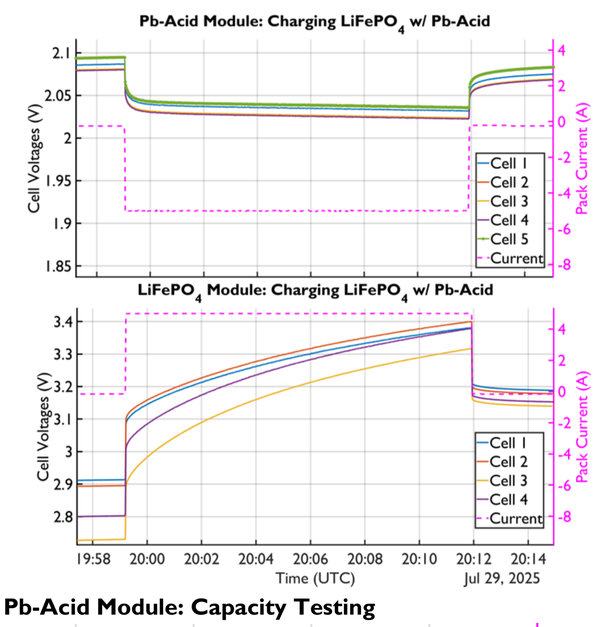
- Emulating converter-BMS stacks in a virtual environment allow for validation of:
  - **Stress-testing command sequencing**
  - **Fault handling**
  - **BMS telemetry**
  - **SOC Estimation**
  - **Cell balancing strategies**
  - **Power-delivery strategies**



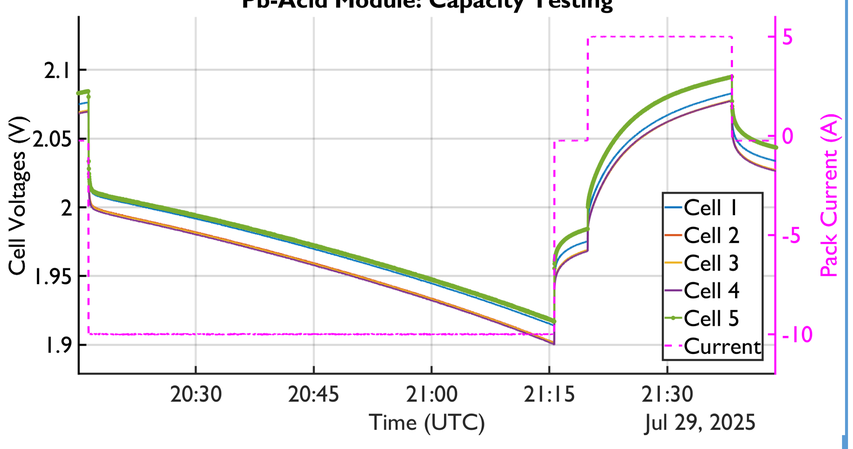


System Validation Results





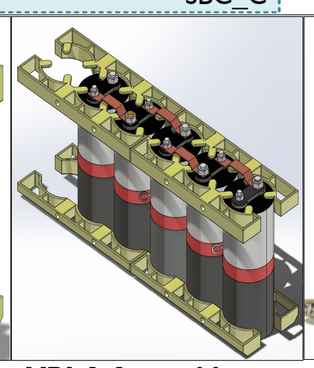
- **Top Left:** New Pb-acid at ~90 % SOC shows uniform cell voltages with minimal sag, while the older LFP pack depletes rapidly under the same load.
- **Top Right:** Pb-acid module charges the LFP pack, demonstrating bidirectional power-flow control.
- **Bottom Right:** Continued Pb-acid discharge confirms its full-depth capacity and stable voltage performance.



Battery Module Parameters									
$LiFePO_4$					VRLA				
Nominal		Measured			Nominal		Measured		
OCV	R (mΩ)	Cap. (Ah)	OCV	R (mΩ)	OCV	R (mΩ)	Cap. (Ah)	OCV	R (mΩ)
12.8	<50	0.625	12.2641	129	2	<40	12.5	2.1	48.4

Mixed-Chemistry Testing and Validation

LFP Assembly: 4s1p, $12.8V_{nom}$, 25Ah



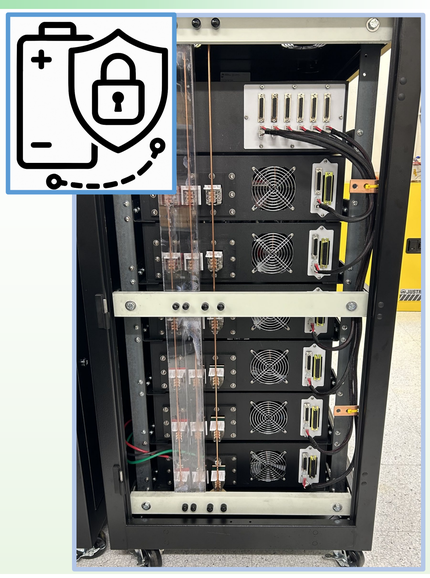
VRLA Assembly: 5s1p, $10V_{nom}$, 25Ah

Synchronous Buck Converter (SBC): 24V/12V, 25A

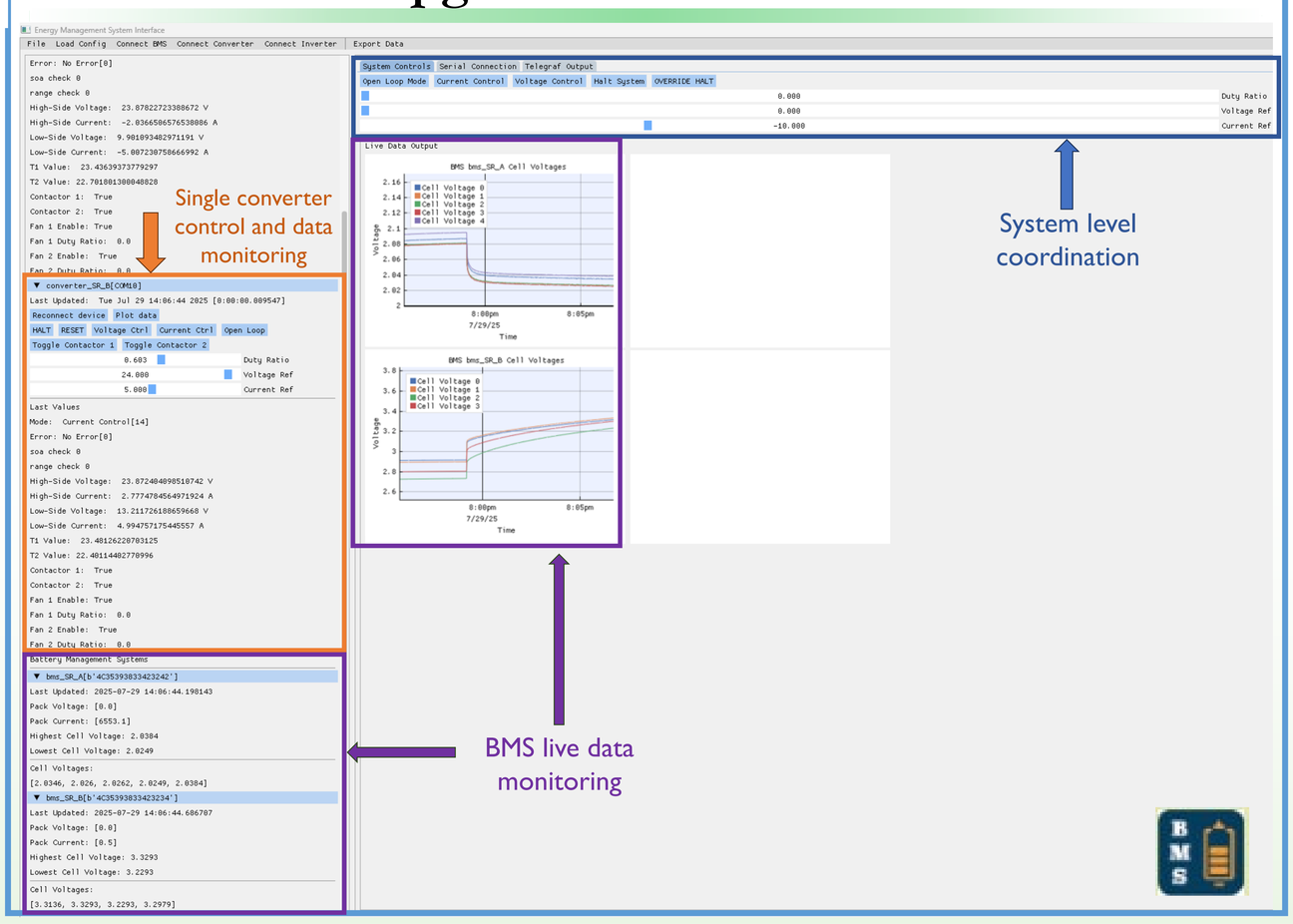
The enabling technology for interconnection of varying battery chemistries and voltages!

Summary & Future Work

- Our work advances a HESS as an experimental platform for integrating various battery chemistries, power converters and controls, and open source software. Recent upgrades bolster system readiness for real-world testing while fostering collaborative, resilient energy management solutions.
- Future research will focus expanding the system and integrating advanced battery models for parameter estimation, and cybersecurity validation. This allows for assignment of optimized charging and discharging profiles. An inverter will also be interfaced to the HESS to explore advanced control strategies when connecting to the grid.



Upgraded EMS Interface



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