Resilient and Cost-Effective Hybrid Li-Ion Battery Energy Storage System for Sites with Solar Generation and Electric Vehicle (EV) Charging

Cooperative Research and Development Final Report

CRADA Number: CRD-19-00799

NREL Technical Contact: Adarsh Nagarajan

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-6A40-92457
December 2024

Resilient and Cost-Effective Hybrid Li-Ion Battery Energy Storage System for Sites with Solar Generation and Electric Vehicle (EV) Charging

Cooperative Research and Development Final Report

CRADA Number: CRD-19-00799

NREL Technical Contact: Adarsh Nagarajan

Suggested Citation
Nagarajan, Adarsh. 2024. *Resilient and Cost-Effective Hybrid Li-Ion Battery Energy Storage System for Sites with Solar Generation and Electric Vehicle (EV) Charging: Cooperative Research and Development Final Report, CRADA Number CRD-19-00799.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A40-92457. https://www.nrel.gov/docs/fy25osti/92457.pdf.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-6A40-92457
December 2024

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

Cooperative Research and Development Final Report

Report Date: December 12, 2024

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Centrica Business Solutions

CRADA Number: CRD-19-00799

CRADA Title: Resilient and Cost-Effective Hybrid Li-Ion Battery Energy Storage System for Sites with Solar Generation and Electric Vehicle (EV) Charging

Responsible Technical Contact at Alliance/National Renewable Energy Laboratory (NREL):

Adarsh Nagarajan | Adarsh.nagarajan@nrel.gov

Name and Email Address of POC at Company:

Fabio Mantovani | Fabio.Mantovani@centrica.com

Sponsoring DOE Program Office(s):

Office of Energy Efficiency and Renewable Energy (EERE), Building Technologies Office

Joint Work Statement Funding Table showing DOE Commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$200,000.00
Year 2, Modification #1	$.00
Year 3, Modification #2	$.00
Year 4, Modification #3	$.00
TOTALS	$200,000.00

Executive Summary of CRADA Work:

The batteries of an energy storage system designed for multiple use-cases are traditionally selected to withstand the highest rate at which a battery is discharged relative to its maximum capacity (C-rate) and cycling requirements of the most intense use-case. However, this is not cost-effective given that the price of the batteries is strongly correlated to C-rate and cyclability. We propose to establish design guidelines for a hybrid energy storage system and test an edge controller that uses high-power and high-energy batteries for high- cyclability use cases such as frequency regulation and electric vehicle (EV) charging and low-cost batteries for low-power and low-cyclability use cases such as summer peak loads. The three main objectives of this proposal are (i) establishing sizing guidelines for such a hybrid storage system, (ii) installing a hybrid storage system in the Energy Systems Integration Facility (ESIF) sized based on those guidelines, and (iii) testing an edge controller specific for the system through hardware tests.

CRADA benefit to DOE, Participant, and US Taxpayer:

- Assists the laboratory in achieving programmatic scope and
- Adds new capability to the laboratory's core competencies, and
- Enhances the laboratory's core competencies, and
- Uses the laboratory's core competencies.

Summary of Research Results:

a. Hybrid Battery System Design

A typical energy storage use-case contains a combination of base-load support, ramping energy support, and fast variations support. These support may include either charging the energy storage or discharging. The existing processes used for energy storage unit design leverages ad hoc energy value and ignores other use-cases. As illustrated in Figure 1 this project provided a fresh look into breaking down the design of an energy storage into below listed three components. The system was designed to incorporate:

- **High-Power Batteries:** Primary use-case will be utilizing high C rate batteries for peak EV charging demand. This will require buying a small size high cost technology for a specific purpose.

- **High-Energy Batteries:** Primary use-case will be for solar demand charge management. This will be a moderately sized battery storage system with focus on demand charge needs of the customer and utility.

- **Second-Life Batteries:** Primary use-case will be for lower-cost alternatives to handle summer peak loads. Second life batteries are highly cost effective and not safe for high C charging. Hence this battery unit gets slow charging and a fixed rate discharge well within the recommended depth of discharge ranges.

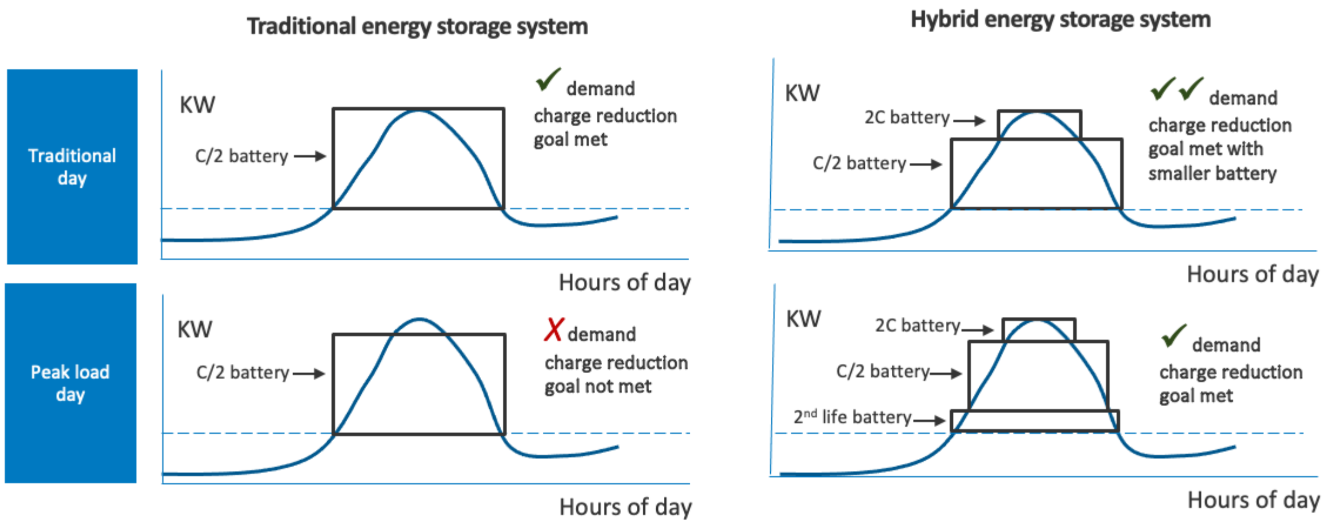

Figure 1 – Conceptual illustration of a hybrid energy storage system in comparison to the traditional system.

b. HYBRED Tool

NREL developed the Hybrid Battery Robust Energy Design (HYBRED) tool to optimize the size and performance of the hybrid storage system. The tool uses mixed-integer linear programming to simulate various use cases and optimize battery configurations.

c. Key Use Cases

1. **Demand Charge Management (DCM):** The hybrid system achieved up to **46.6% demand charge savings** under synthetic load conditions, compared to a traditional battery system.

2. **EV Charging:** Integrating EV charging with solar and demand charge management provided additional savings, especially when managed smartly through a V1G charging strategy.

3. **Resilience:** The system effectively provided power during outages, demonstrating its potential for backup power applications.

d. Project Conclusions

The hybrid battery energy storage system demonstrated significant benefits in terms of resilience, cost reduction, and efficiency in demand charge management. The project met its core objectives of designing, testing, and optimizing a cost-effective solution for sites with solar generation and EV charging infrastructure.

Key takeaways include:

- **37.6% Increase in Revenue**: From regulatory service participation when using hybrid batteries compared to single battery systems.
- **Up to 30% Reduction in System Capital Costs**: By optimizing the hybrid system's configuration, incorporating second-life batteries as a cost-saving alternative.
- **Improved System Utilization**: The hybrid system outperformed traditional systems in both power and energy utilization, particularly under managed EV charging scenarios.

Task 1: NREL identifies chemistries

NREL first identified storage chemistries that, when combined into a single unit, could meet multiple grid objectives at low cost. This involved engaging with ongoing NREL research to leverage existing insights. The focus was on determining which chemistries were optimal for high-power use cases, which were ideal for high-energy applications, and which could serve as low-cost alternatives for scenarios that didn’t require high power or energy density.

Ultimately, this task concluded that limiting the approach to lithium-ion battery technology was most effective due to the economic benefits derived from its scalability, maturity, and cost efficiency. This foundational step guided further efforts in optimizing a hybrid energy storage system, tailoring it to meet various grid and operational requirements.

Task 2: NREL optimizes storage unit sizing

NREL optimized the sizing of the storage unit by integrating multiple battery chemistries into a single system. The optimization process focused on finding the best mix of high-power, high-energy, and low-cost batteries to reduce system costs while still meeting different energy demands. High-power and high-energy stacks utilized batteries with maximum C-rates around 2C, while the low-cost stack included new and second-life batteries with a C-rate of C/2. This step allowed NREL to explore how existing storage technologies could be combined to meet cost-reduction targets, such as those set by NREL's Behind the Meter Storage (BTMS) initiative. Additionally, NREL assessed whether the storage system would serve resiliency purposes as part of the analysis.

Key Actions:

- Optimized battery storage system for multiple use cases.
- Ensured optimal system size to balance performance and cost.
- Developed hybrid battery storage incorporating various chemistries to minimize the levelized cost of electricity (LCOE).
- Simulated control and system behavior for better design and analysis.

This approach helped demonstrate how hybrid battery systems could meet diverse energy requirements while achieving cost-effectiveness.

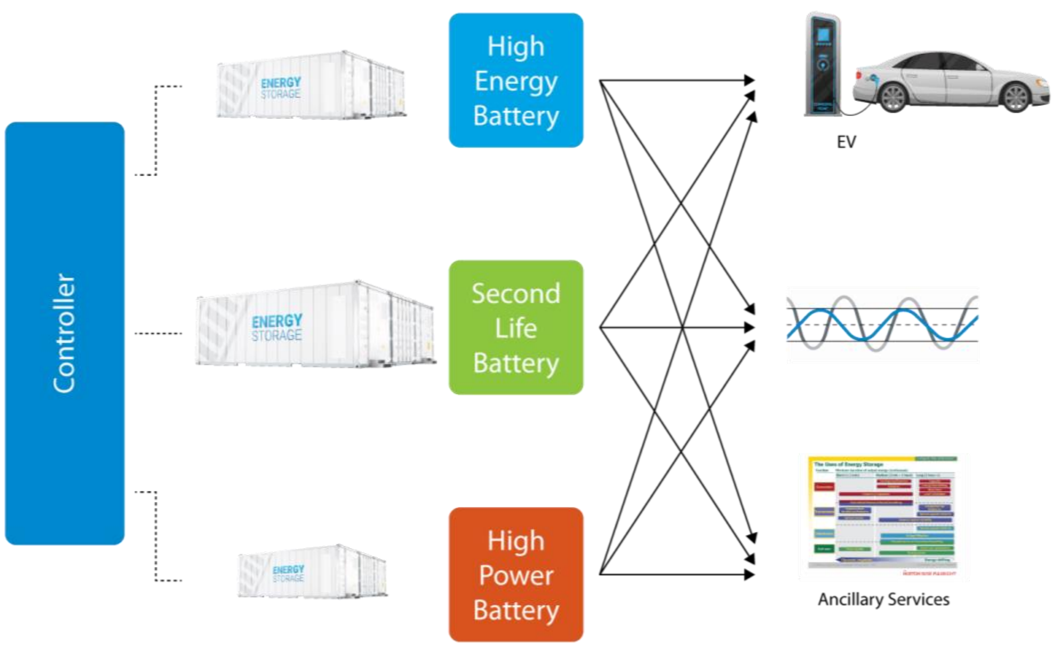

Figure 2 - Illustration of linking multiple battery stacks to optimize control behavior.

Task 3: NREL receives and installs hybrid storage unit and unit-specific edge controller

NREL received and installed a hybrid storage unit built by Centrica Business Solutions, following the sizing guidelines established in the previous step. In addition, NREL installed an edge controller from Centrica, which was specifically adapted to work with the hybrid storage unit. This controller optimized battery usage by leveraging the strengths of each battery type based on the end-use application.

The installation took place at the ESIF. For example, the edge controller directed high-power batteries for use cases requiring high power while avoiding their use in lower-power scenarios to prevent unnecessary degradation. In such cases, high-energy or low-cost batteries were deployed. The controller considered both short-term opportunity costs and long-term degradation costs, which varied based on the battery chemistry, ensuring an efficient and cost-effective operation of the hybrid system.

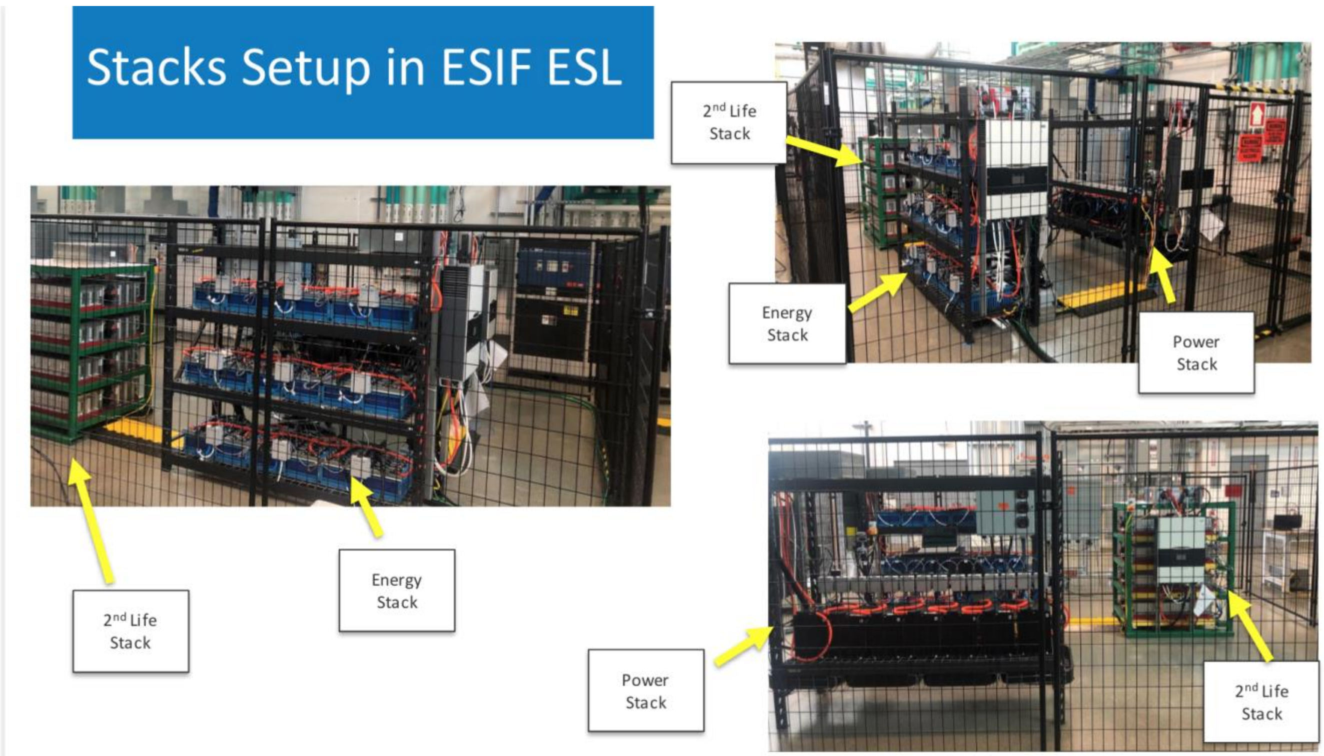

Figure 3 - Pictures of battery stack at NREL's ESIF

Task 4: NREL evaluates hybrid storage unit and controller through hardware testing

NREL evaluated the performance of the hybrid storage unit and the edge controller through multiple phases of hardware testing. Each phase focused on different use cases, such as frequency regulation, electric vehicle (EV) charging, and demand charge management. These tests allowed NREL to assess the system's ability to manage various operational demands while optimizing battery usage across different chemistries. This comprehensive testing provided insights into the system’s real-world performance and its capacity to meet both grid-level and localized energy needs efficiently.

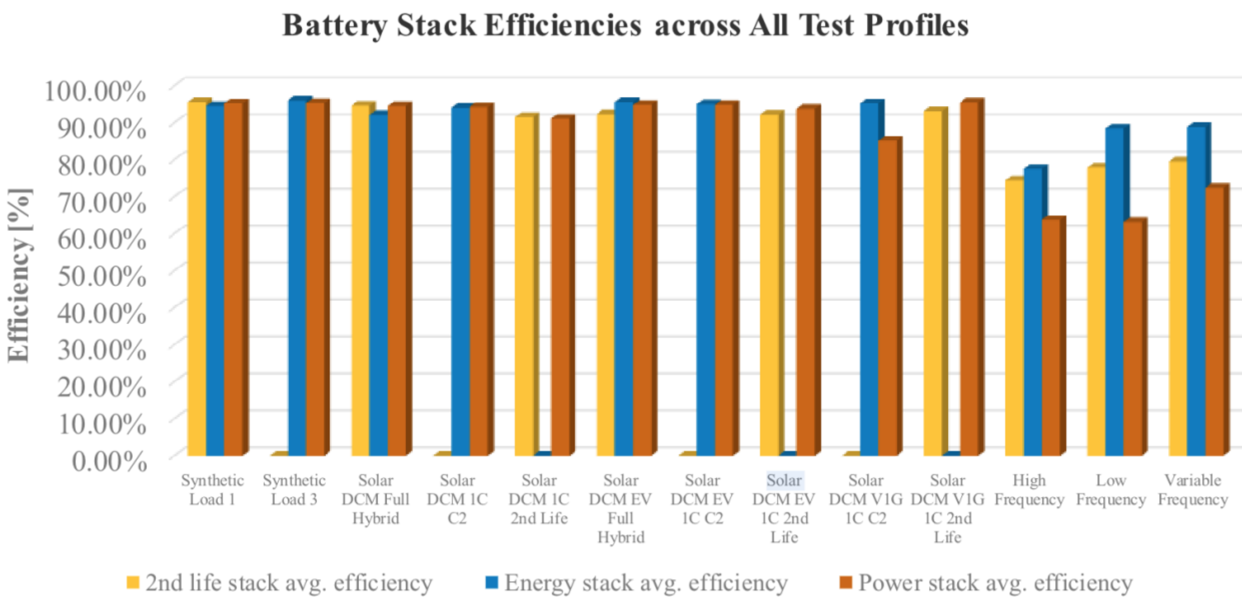

Figure 4 - Battery stack efficiency outputs at ESIF

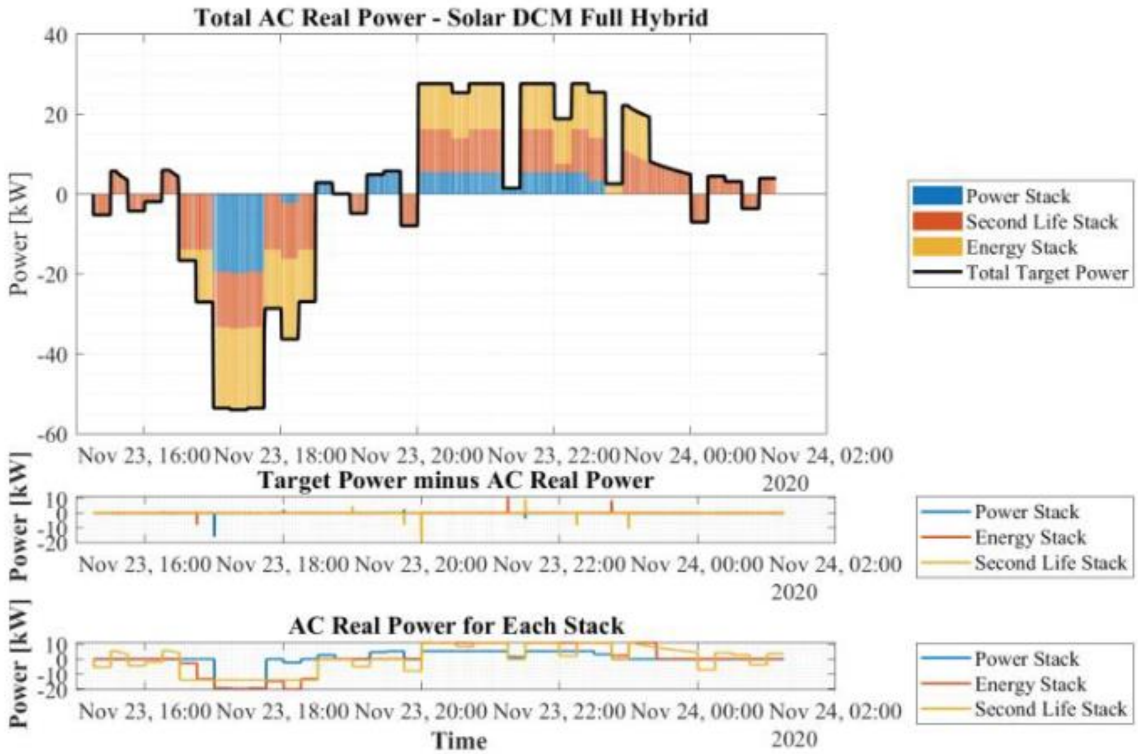

Figure 5 - Illustrates hybrid battery behavior for demand charge management

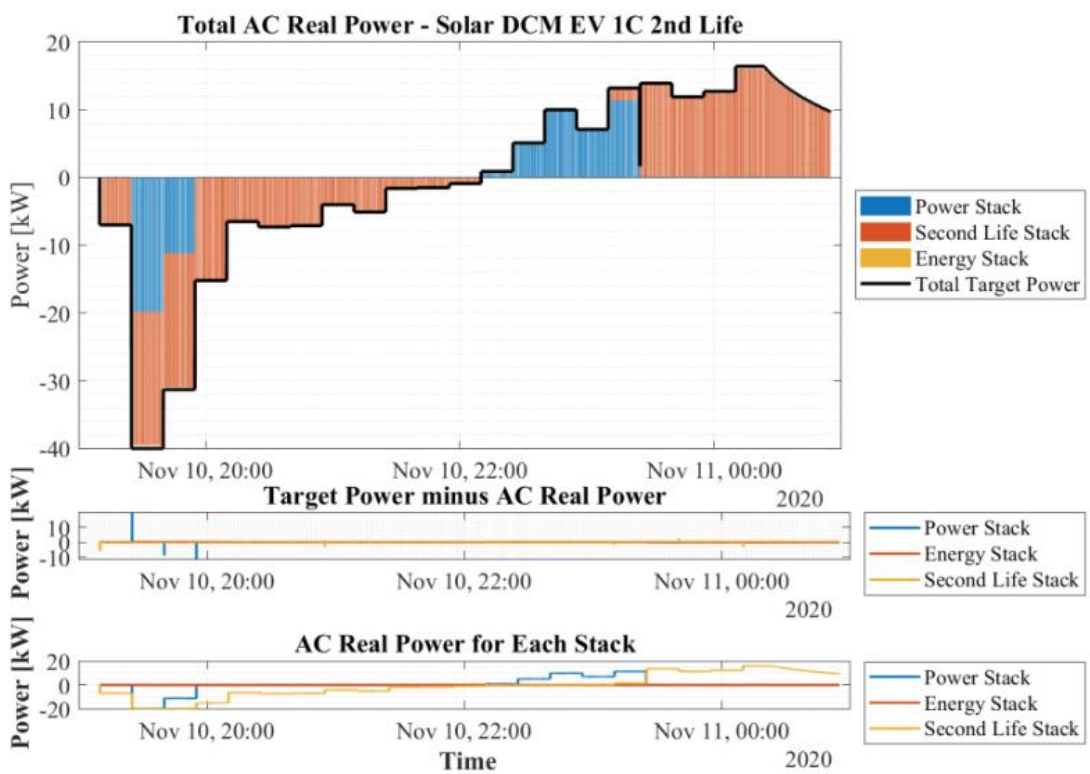

Figure 6 - Illustrates hybrid battery behavior at ESIF test lab for EV charge management with demand charge

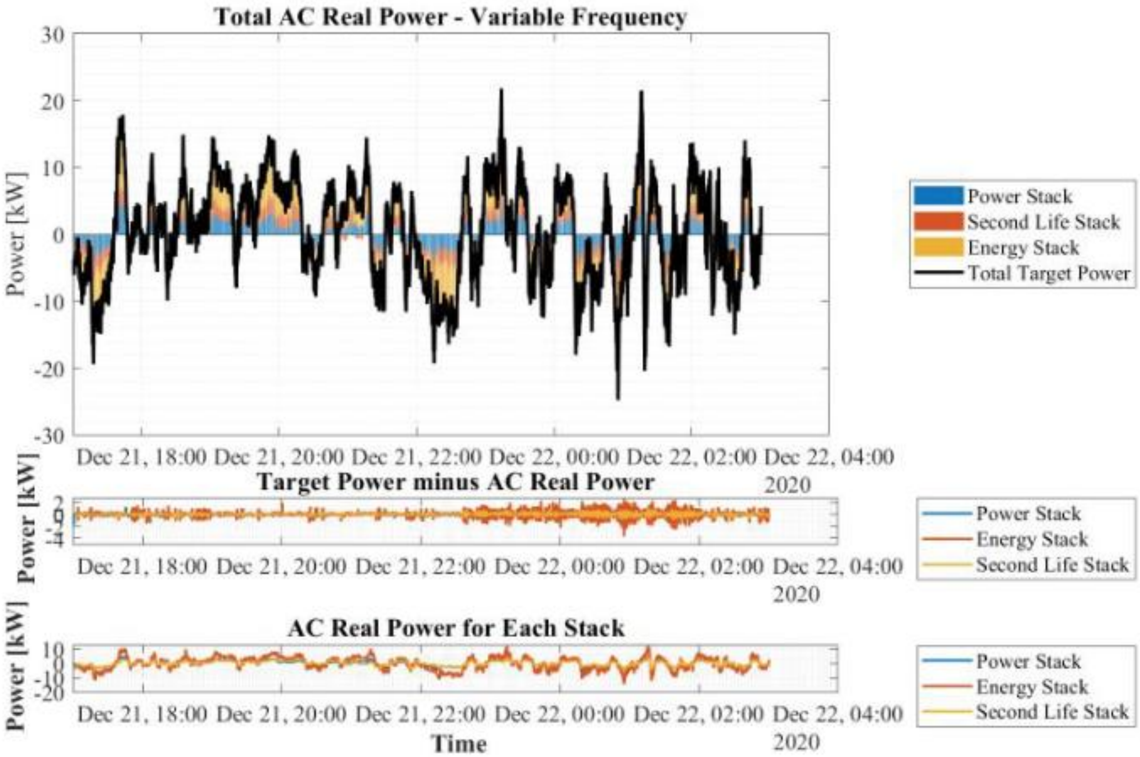

Figure 7 - Illustrates comparison of three stacks for frequency regulation.

Task 5: NREL disseminates results through white papers and conferences

- Mariya Koleva, Ying Shi, Killian McKenna, Michael Craig, Adarsh Nagarajan; "Optimal Strategies for Hybrid Battery-Storage Systems Design," Wiley Public Access research article.
- News article by Centrica - https://www.prnewswire.com/news-releases/centrica-business-solutions-partners-with-nrel-on-hybrid-battery-storage-300860062.html
- ESIF newsletter: https://www.nrel.gov/esif/esi-news-201906.html

This report serves to meet the requirement for the CRADA Final Report with preparation and submission in accordance with the agreement's Article X.

References: None

Software Record (SWR): SWR 19-52 (HYBRED Robust Energy Storage Design Tool)

Subject Inventions Listing: None

ROI#: None