Solar World Congress 2025

PERFORMANCE OF A 200 KWH ENERGY STORAGE SYSTEM WITH FIRST AND SECOND LIFE LITHIUM-ION BATTERIES

Summary

This study evaluates the performance of a 200-kWh energy storage system composed of two lithium-ion battery banks: one using first-life modules and the other assembled from second-life modules recovered from electric vehicles. Both subsystems were tested under similar operating conditions to compare round-trip efficiency, voltage behavior, and usable capacity. The second-life bank presented a high average round-trip efficiency of 96% over ten cycles, despite internal resistance, cell voltage differences, and PCS voltage constraints limiting its effective capacity. Compared to the first-life system, which showed higher current capability and tighter cell voltage uniformity, the second-life modules remained technically viable but underperformed in usable energy due to integration constraints. Results highlight key technical barriers and optimization opportunities for a reliable and cost effective second-life battery deployment in commercial on-grid storage.

Keywords: Second-life batteries, energy storage, performance analysis.

1. Introduction

The widespread adoption of electric vehicles is expected to generate a significant volume of end-of-life lithium-ion batteries in the coming years, which are no longer suitable for automotive traction once their capacity falls below 70–80% of the original (Mirzaei Omrani and Jannesari, 2019). Despite this reduction, these batteries often remain functional and can be repurposed for less demanding stationary energy storage applications. This concept, known as second-life batteries, has gained attention as a cost-effective and environmentally responsible solution to meet growing energy storage demands (Assunção et al., 2016; Faria et al., 2025).

Several studies have highlighted the economic and environmental benefits of second-life Li-ion batteries when integrated into residential, commercial, and utility-scale storage systems (Campos et al., 2019; Mirzaei Omrani and Jannesari, 2019). However, practical implementation still presents challenges related to module heterogeneity, increased internal resistance, limited access to original Battery Management System (BMS) controls and data, and the lack of standardized testing protocols. Moreover, ensuring compatibility with commercial Power Conversion Systems (PCS) and maintaining operational safety remain critical issues (Zago Cantú et al., 2022).

This study aims to assess the performance of a 200-kWh stationary energy storage system comprising two independent battery banks: one built with new, first-life lithium-ion modules, and the other using repurposed modules recovered from decommissioned electric vehicles. Both subsystems were installed in a controlled environment and operated under similar conditions, enabling a direct and consistent comparison. The analysis focuses on key performance indicators such as real usable capacity, roundtrip efficiency, individual cell voltage and temperatures and operational constraints, aiming to identify technical challenges and opportunities associated with the deployment of second-life batteries in commercial on-grid applications.

2. Experimental Setup and Methodology

The evaluated system consists of a 200-kWh stationary energy storage installation that has been in operation since 2021 and is composed of two independent lithium-ion battery subsystems, each connected to a shared PCS. One system is composed of new, first-life modules from Samsung SDI’s M2F family, while the second system was assembled using second-life LMO battery modules recovered from Nissan LEAF electric vehicles decommissioned after approximately five years of operation. The modules were sorted and tested and a State of Health (SoH) of around 60% was obtained (Hohmann et al., 2022). This means that the actual capacity of the system is estimated at 63 kWh. Each battery bank is housed in a dedicated rack structure within a climate-controlled container located in Florianópolis/SC, in the south of Brazil. The thermal management system maintains ambient conditions at 23 °C and relative humidity below 60%, with fire suppression, air conditioning, and safety control systems in place to ensure reliable operation.

The first-life bank consists of two racks of 68 kWh each, totaling 136 kWh nominal capacity, with nominal voltage of 728 V. These modules feature integrated multi-level BMS provided by the manufacturer. In contrast, the second-life bank is composed of two racks of 105 modules each from five vehicles, totaling a nominal capacity of 105 kWh, with a nominal voltage of 787 V. A third-party BMS (Lithiumate from Elithion) was implemented for cell-level monitoring and passive balancing in the second-life system. Controlled charge and discharge tests were performed at a constant rate of 0.3C (30 kW) between 10% and 95% state of charge (SOC). Measurements were collected in the DC bus and at the point of grid connection, accounting for all auxiliary loads such as BMS operation, HVAC, and internal consumption from the control system. The energy delivered and stored was calculated by integrating power over time. Based on the methods of the IEC (INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC), 2022), metrics like round trip efficiency (RTE), SoH and internal resistance were calculated. Both banks were tested under identical operational procedures, enabling a direct comparison.

3. Results

Fig. 1 presents a representative full cycle of the second-life battery bank, highlighting both cell-level and system-level behavior. On the upper figure, the BMS tracks the evolution of maximum and minimum cell voltages throughout the cycle. Near the end of charging, the voltage spread between cells reaches approximately 36 mV, with the highest cell at 4.144 V and the lowest at 4.108 V. This deviation activates the BMS's passive balancing mechanism, which slows down the final stage of charging and limits further energy input.

Toward the end of discharge, this spread increases significantly. At the lowest state of charge observed in the test, the minimum cell voltage dropped to 3.418 V, while the maximum remained at 3.748 V, a difference of 0.33 V. This voltage difference caused the discharge process to be interrupted before all the available energy could be extracted from the healthiest cells, reducing the overall usable capacity of the system.

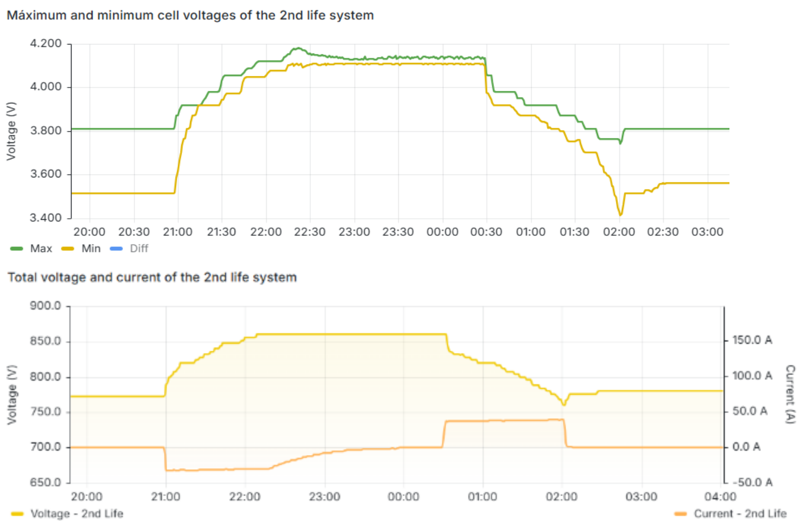

Fig. 1: Full charge and discharge cycle of the second-life battery system. Upper: Maximum and minimum cell voltages (green and yellow). Lower: System voltage (yellow) and current (orange) measured at the DC bus. The graphs illustrate the evolution of the system throughout the charge plateau, balancing phase, and discharge process.

The lower graph in Fig. 1 shows the total pack voltage and current measured at the DC bus. At the beginning of the charge, a rapid change of the voltage from 772 V to 788V is visible. This difference is caused by the internal resistance of the battery, that according to these data can be estimated at around 0.48 ohms. In the discharge phase, the system drops from 860 V to 816 V under 37.6 A, indicating an internal resistance of approximately 1.17 ohms. Nonetheless, system-level constraints significantly limit the usable energy. PCS-imposed voltage cutoffs capped the upper operating point at 860 V, while discharging stopped well above the theoretical lower voltage limit.

Given the constraints, in the observed cycle, the energy charged to the battery was 47.63 kWh, while the discharged energy was 45.27 kWh, which corresponds to 43% of the nominal capacity and 76% of the actual capacity of the system. This results in an RTE of 95.03%. This value confirms that, at the cell level, the system retains high energy conversion efficiency. However, the effective energy delivered to the grid is lower, as PCS losses and auxiliary loads are not included in this RTE. Over ten charge-discharge cycles, the system presented an average RTE of 96%, the electrochemical robustness of the repurposed cells.

On the other hand, the first-life system voltage, during full charge, reached 772 V, while the minimum voltage recorded during discharge dropped to 684 V. This voltage drop suggests a significantly lower internal resistance than that observed in the second-life system. Unlike the latter, the voltage sag under load was more gradual and less pronounced, confirming better dynamic behavior and reduced ohmic losses. This translates into RTEs over 99% on the DC bus.

Cell-level data reinforces this stability. At the end of charge, the voltage spread among cells was minimal — only 0.036 V, with the highest cell reaching 3.937 V and the lowest at 3.901 V. Even near the end of discharge, the maximum and minimum cell voltages remained close (e.g., 3.499 V and 3.454 V, respectively), indicating good uniformity and effective balancing, with no early cut-off caused by individual cell limits. This behavior contrasts with the second-life bank, where the voltage spread near end-of-discharge exceeded 0.33 V, directly impacting the available capacity.

This analysis shows that second-life lithium-ion batteries present specific technical challenges, such as increased internal resistance, limited voltage operating windows, and cell voltage differences that reduces usable capacity. However, their high round-trip efficiency, consistent behavior across cycles, and adaptability to stationary applications demonstrate that, when properly integrated, second-life systems can be a reliable and sustainable alternative. With dedicated system design, including customized BMS strategies and PCS adjustments, these batteries can support commercial-scale energy storage while promoting circular economy principles and extending the lifecycle of EV battery technologies.

3. References

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