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PERFORMANCE ASSESSMENT OF SOLAR OFF-GRID LIGHT POLES USING SECOND-LIFE BATTERIES

Summary

The expected number of end-of-life lithium-ion batteries from electric vehicles in the coming years presents both environmental challenges and opportunities for sustainable reuse. This study evaluates the feasibility of integrating second-life Nissan Leaf batteries into off-grid solar light poles as a low-cost, efficient storage solution. Six hybrid systems were deployed in Florianópolis, Brazil, combining photovoltaic modules, LED lights, and MPPT controllers with 6S2P battery packs. Electrical characterization—capacity, internal resistance, SoC, and SoH—was used to select compatible modules and ensure safe operation. Real-time monitoring demonstrated system stability, even under varying solar conditions. Results show that show that the slightly oversized battery configuration allow for good performance even on cloudy days. It also limits depth of discharge, thus extending battery lifespan. The findings support the adoption of second-life batteries in decentralized lighting, promoting circular economy practices and improving access to clean energy.

Keywords: second-life batteries, off-grid systems, photovoltaic, lithium-ion, circular economy

1. Introduction

As electric vehicles get increasingly popular, a significant volume of lithium-ion batteries is expected to reach the end of their first life in the coming years, as their capacity drops below the thresholds required for automotive use. Although no longer suitable for that, many of these batteries retain enough capacity for reuse in stationary applications (Hossain et al., 2019). One promising reuse strategy is their integration into off-grid systems, such as solar-powered light poles, which offer decentralized lighting solutions for both remote and urban areas. Hybrid systems combining photovoltaics and second-life batteries have already demonstrated technical and economic viability in rural electrification projects—for instance, in Lake Victoria, Tanzania (Falk et al., 2020).

Another promising application for these batteries is in off-grid lighting systems, such as solar-powered light poles, which offer solutions not only for areas with limited access to electricity but also for urbanized cities. Integrating second-life batteries into off-grid solar lighting infrastructure not only extends the lifecycle of battery materials but also supports more sustainable use of resources that would otherwise take a long time to degrade.

This study investigates the technical viability of repurposing second-life batteries from Nissan Leaf EVs in off-grid solar lighting poles by analyzing a system installed in Florianópolis/SC, in the south of Brazil. Electrical characterization tests—such as internal resistance, capacity, and estimates of State of Charge (SOC) and State of Health (SOH)—were conducted to ensure performance, safety, and compatibility (Hohmann, 2024).

2. Method

This study is based on six off-grid solar light poles installed in Florianópolis, Brazil. Each system includes a 255 W photovoltaic module, a 30 W LED light, an MPPT charge controller (EPEVER 20 A), and a 6S2P battery pack composed of second-life Nissan Leaf modules (Fig.1). The chosen configuration prioritizes higher voltage and lower current to reduce thermal and electrical stress on aged cells and improve system efficiency. To validate battery performance and safety, electrical characterization tests were conducted using a programmable power supply and electronic load. Tests included capacity, internal resistance, State of Charge (SOC), and State of Health (SOH), enabling selection of well-matched modules for each pack.

A custom monitoring (Fig. 1) and control system was developed using an ESP32 microcontroller, which communicates with the MPPT controller via Modbus RTU. The system collects and transmits operational data—such as PV input, battery status, and load behavior—via Modbus TCP. It also manages relay control, time synchronization, and thermal monitoring to ensure stable and safe operation.

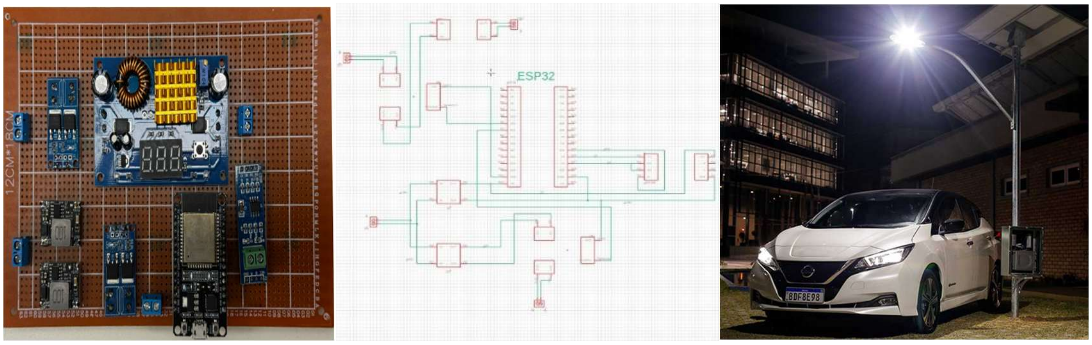

Fig. 1: Custom control system hardware (left) and schematic (center) and off-grid solar light pole (right).

3. Results and discussion

Each battery module originally had a nominal capacity of 500 Wh, but initial SoH measurements indicated an average of 60% remaining capacity. The system was evaluated under different solar conditions, as shown in Fig. 2 and 3. On April 8th (Fig. 2), a cloudy day with highly variable irradiance, the photovoltaic generation was insufficient to fully charge the battery. The battery charged up to 96% of its SOC but did not reach full capacity, and data anomalies from the ESP32 were observed—such as abrupt SOC jumps—that were filtered in the post-processing phase.

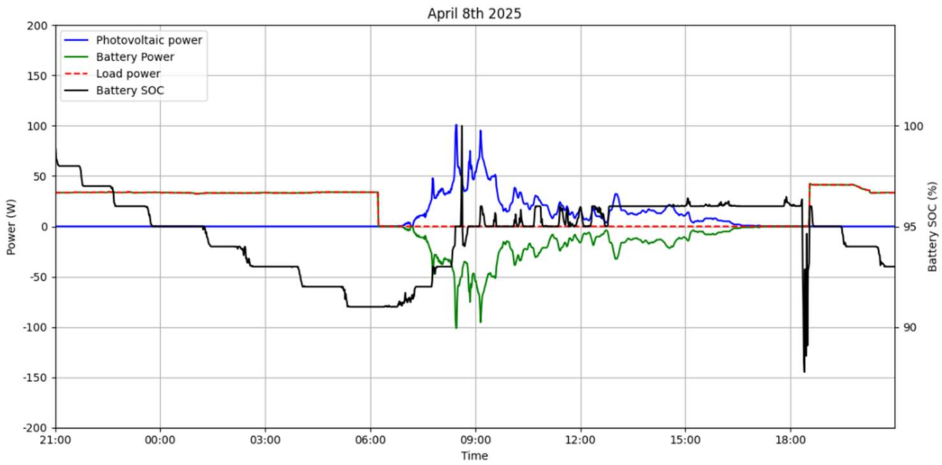

Fig. 2: PV module power, battery power, load power and battery SOC on April 8th, 2025.

April 29th presented a more favorable scenario (Fig. 3), with PV power rising steadily to a peak of ~170 W and the battery reaching 100% SOC near the peak of PV production. After this peak, small oscillations in PV output were likely due to the BMS using a pulsating charging method to maintain full SOC. Once the load was activated around 21:00, a sudden SOC drop was again recorded due to communication errors.

Throughout the tests, the system maintained high round-trip efficiency at the DC level and exhibited stable operational behavior, with only minor data anomalies from the MPPT controller communication. These were isolated and did not affect system integrity.

Although the battery bank is slightly oversized in relation to the load and generation profile, this configuration is actually advantageous in the context of second-life use. By limiting the depth of discharge and avoiding high current demands, the system reduces stress on the battery cells, which can significantly extend their operational lifetime and overall reliability.

Previous versions of the light pole used a 6P2S battery configuration to prioritize capacity. In this project, a 6S2P layout was adopted to increase voltage and reduce current, maintaining the same power output. Operating at lower currents minimizes electrical and thermal stress, improving system safety—especially important for second-life batteries. This change also enhances efficiency by reducing conduction losses and improving transmission efficiency (G. A. Saccol, 2022).

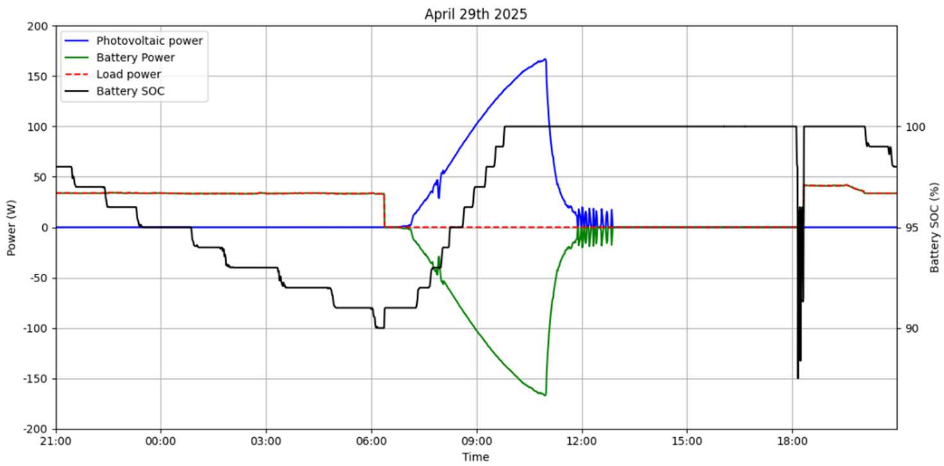

Fig. 3: PV module power, battery power, load power, and battery SOC on April 29th, 2025.

4. Conclusion

This study confirms that second-life lithium-ion batteries, when properly tested and integrated, can deliver safe and reliable performance in off-grid solar lighting systems. Despite an average 60% SoH, the batteries operated efficiently under both cloudy and sunny conditions, demonstrating resilience and stable energy delivery. The slightly oversized battery bank—relative to the load—proved beneficial by reducing depth of discharge and stress on aged cells, which is a key strategy to extend operational lifespan in second-life applications. This extends the useful life of critical materials, delays the environmental challenge associated with battery recycling or disposal, and significantly reduces the lifecycle cost of energy systems.

In the context of off-grid lighting—particularly in rural or underserved areas—the integration of second-life batteries can ensure access to clean and reliable energy at a fraction of the cost of new storage technologies. The reduced dependency on centralized power infrastructure also supports energy resilience and autonomy, especially in regions vulnerable to grid instability or without electrification. From a technological perspective, the study reinforces the importance of accurate diagnostic tools to evaluate the remaining useful life of EV batteries, allowing safe integration into new systems without compromising efficiency.

5. References

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