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Second-Life EV Battery Energy Storage for Distribution Grid Applications

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ABSTRACT

Electric vehicle batteries are commonly removed from traction service after their available capacity or power capability falls below automotive requirements, even though a substantial amount of useful electrochemical capacity can remain. Second-life deployment provides a pathway for reusing these retired batteries as stationary energy storage for distribution networks. This project presents a second-life EV battery energy storage framework designed to support distribution-grid operation through peak shaving, renewable-power smoothing, load shifting, voltage support, and controlled energy exchange. The proposed system includes battery screening and grading, a second-life battery management system, bidirectional power conversion, an energy management system, distribution-feeder monitoring, and protection functions. Battery state of charge (SOC), state of health (SOH), temperature, voltage, current, and feeder conditions are continuously considered during operation. The controller determines charging and discharging commands according to feeder demand, renewable generation, network limits, and battery operating constraints. The project emphasizes that second-life batteries cannot be treated exactly like new batteries because capacity variation, cell-to-cell differences, ageing history, and reliability must be considered during sizing and control. The resulting architecture provides a structured approach for converting retired EV batteries into a flexible stationary resource for distribution-grid applications.

Keywords: Second-Life EV Batteries, Battery Energy Storage System, Distribution Grid, State of Health, State of Charge, Peak Shaving, Renewable Energy Integration, Voltage Support, Battery Management System, Energy Management System.

I. INTRODUCTION

The rapid growth of electric mobility is creating a future stream of batteries that will eventually leave vehicle service. A battery can become unsuitable for automotive use because its capacity, power capability, or other performance characteristics no longer satisfy vehicle requirements, while still retaining useful storage capability for less demanding stationary applications. Research on battery second use therefore examines how retired EV batteries can be assessed, repackaged, controlled, and operated in energy storage systems. [1], [2]

Distribution networks are experiencing additional operational requirements because of increasing electrification, distributed photovoltaic generation, variable loads, and EV charging. Energy storage placed at suitable distribution locations can absorb surplus energy, release stored energy during high-demand intervals, and reduce rapid changes in net feeder power. Second-life batteries are particularly relevant to this role because stationary applications can be designed around the characteristics of batteries that are no longer appropriate for traction service. [3], [4]

However, second-life batteries introduce challenges that are less pronounced with newly manufactured battery packs. Retired packs can arrive with different degradation histories, remaining capacities, internal resistances, thermal conditions, and module configurations. Consequently, a practical second-life system requires screening, grading, balancing, a suitable BMS, conservative operating limits, and replacement strategies. Recent work on distribution-network planning also highlights reliability and flexibility as important factors in determining second-life battery size. [5]

The proposed project develops a distribution-grid storage framework in which second-life EV batteries are connected through bidirectional power converters and coordinated by an EMS. The system monitors grid conditions and battery states and then selects charging or discharging actions for peak shaving, renewable smoothing, load shifting, and voltage-oriented support. The architecture is intended for simulation or prototype development and provides a common workflow from retired-battery assessment to grid-level operation.

II. LITERATURE SURVEY

1. "Battery Second Life: Hype, Hope or Reality? A Critical Review of the State of the Art"

Authors: Ana Martínez-Laserna et al.

Abstract: This review examines technical, economic, and environmental aspects of reusing automotive lithium-ion batteries in stationary applications. It explains the concept of battery second life and identifies technical and market conditions that influence whether retired batteries can provide useful grid-connected storage. [1]

2. "Potential of Electric Vehicle Batteries Second Use in Energy Storage Systems: The Case of China"

Authors: Jingxuan Geng, Suofen Gao, Xin Sun, Zongwei Liu, Fuquan Zhao, and Han Hao

Abstract: The study evaluates the interaction between EV battery retirement and future energy-storage demand. It models battery flows with and without second use and shows the potential of repurposed EV batteries to reduce demand for newly manufactured storage batteries. [2]

3. "Repurposed Electric Vehicle Battery Performance in Second-Life Electricity Grid Frequency Regulation Service"

Authors: C. J. Martinez-Laserna et al.

Abstract: This research experimentally investigates repurposed EV batteries under grid frequency-regulation service. It considers different battery chemistries and thermal-management arrangements and evaluates efficiency and performance differences that are important for stationary second-life operation. [3]

4. "Second-Life Batteries: A Review on Power Grid Applications, Degradation Mechanisms, and Power Electronics Interface Architectures"

Authors: Review study in Batteries

Abstract: The paper reviews second-life battery applications in power grids, including frequency regulation, power smoothing, peak shaving, and energy arbitrage. It also examines degradation, power-electronic interfaces, and battery-management requirements for grid-connected second-life systems. [4]

5. "Reliability–Flexibility Integrated Optimal Sizing of Second-Life Battery Energy Storage Systems in Distribution Networks"

Authors: Hui Lu, Kaigui Xie, Bo Hu, Changzheng Shao, Yu Wang, and Congcong Pan

Abstract: This work develops an optimal sizing framework that considers both operational reliability of second-life batteries and flexibility from EVs. The study uses distribution-network models to investigate investment, replacement, and dispatch decisions under second-life battery constraints. [5]

6. "Optimal Sizing and Lifetime Investigation of Second Life Lithium-Ion Battery for Grid-Scale Stationary Application"

Authors: Abraham Alem Kebede, Md Sazzad Hosen, Theodoros Kalogiannis, and Henok Ayele Behabtu

Abstract: The research combines storage sizing, cycling-profile definition, prolonged ageing tests, and lifetime modelling for retired battery cells and modules. A renewable-power smoothing profile is used to investigate the technical performance of second-life batteries in stationary grid applications. [6]

7. "Design and Analysis of the Use of Re-Purposed Electric Vehicle Batteries for Stationary Energy Storage in Canada"

Authors: John W. A. Catton et al.

Abstract: This study investigates the practical reuse of EV batteries for stationary storage and examines technical barriers, codes, standards, and failure-related considerations. A bench-test setup is used to evaluate the feasibility of repurposed EV battery packs. [7]

8. "Energy and Environmental Benefits of Circular Economy Strategies: The Case Study of Reusing Used Batteries from Electric Vehicles"

Authors: Life-cycle assessment research team

Abstract: The study evaluates a circular-economy pathway in which used EV batteries are transferred to stationary applications before final treatment. The analysis considers environmental performance and demonstrates why reuse can be relevant to sustainable energy-storage strategies. [8]

III. EXISTING SYSTEM

Existing distribution-grid storage systems generally use newly manufactured battery energy storage systems, often connected through power-conditioning equipment to medium- or low-voltage feeders. These systems can perform functions such as peak shaving, time shifting, renewable-energy smoothing, backup supply, and voltage-related support. The BESS controller typically receives feeder measurements and dispatches the battery according to a predefined operating strategy.

In a conventional new-battery system, the cells or modules are usually manufactured with relatively consistent specifications and the BMS is designed around known electrical and thermal characteristics. Stationary operation can therefore be planned using rated energy, rated power, efficiency, SOC limits, and expected ageing characteristics.

Some existing approaches consider retired EV batteries, but the reuse process is often treated separately from distribution-grid planning. Battery collection, testing, grading, repackaging, SOH estimation, converter sizing, protection, and replacement planning can become separate engineering activities. Without coordinated treatment of these stages, the resulting system may not fully account for heterogeneity and reliability changes among second-life modules.

IV. DISADVANTAGES OF EXISTING SYSTEM

1. New-battery BESS projects can involve substantial battery manufacturing and material requirements.
2. Conventional systems do not directly exploit the remaining value of retired EV batteries.
3. Retired-battery systems can suffer from heterogeneous capacity and resistance characteristics.
4. Battery SOH uncertainty complicates sizing and long-term reliability assessment.
5. Different battery histories can cause unequal ageing between modules.
6. Simple dispatch strategies may ignore replacement and degradation constraints.
7. Inadequate screening or repackaging can create safety and protection challenges.
8. Distribution-grid planning may not coordinate storage reliability with feeder flexibility.

V. PROPOSED SYSTEM

The proposed system introduces a second-life EV battery energy storage system specifically coordinated with distribution-grid requirements. The framework begins with retired EV battery collection and characterization. Individual modules or packs are tested for capacity, internal resistance, voltage consistency, thermal behavior, and SOH. Based on the test results, compatible units are grouped into second-life battery strings or racks. A dedicated BMS supervises cell and module limits, while the power-conversion system provides controlled bidirectional energy exchange with the distribution feeder.

The second stage is battery-state estimation. The controller continuously tracks SOC and estimates SOH using measured voltage, current, temperature, and historical operating information. Because second-life packs can contain different degradation levels, the operating window is selected conservatively and may be adjusted as the battery ages.

The third stage is distribution-grid energy management. Feeder demand, renewable generation, voltage, transformer loading, and battery conditions are used to determine a dispatch command. During high-demand intervals, the second-life BESS can discharge to reduce feeder loading. During low-demand periods or renewable surplus, it can charge. For renewable integration, the system can absorb short-term excess generation and release energy when generation falls.

The fourth stage is reliability-aware operation. The EMS avoids excessive cycling and keeps the battery inside its allowed SOC, current, voltage, and temperature ranges. Modules showing abnormal behavior can be isolated or scheduled for replacement. This arrangement connects battery-level safety with feeder-level operational objectives and provides a more complete second-life energy-storage workflow.

VI. ADVANTAGES OF PROPOSED SYSTEM

1. Reuses EV battery capacity that remains available after automotive retirement.
2. Provides a flexible stationary resource for distribution-grid support.
3. Supports peak shaving and load shifting at feeder level.
4. Can smooth variable renewable generation and reduce rapid power changes.
5. Incorporates SOH and degradation information into operational decisions.
6. Enables modular battery replacement as individual groups age.
7. Creates a pathway for circular use of battery materials and infrastructure.
8. Supports coordinated BMS, power-converter, and grid-level energy management.

VII. SYSTEM ARCHITECTURE

The system architecture follows the sample document's staged presentation from input data and system resources through processing, control, evaluation, and deployment. The first block contains the utility distribution grid, distributed renewable sources, and local loads. A power-conditioning stage connects these elements to the storage system and controls bidirectional power exchange.

The second block is the second-life battery ESS. Retired EV modules are first screened and grouped according to electrical and health characteristics. The BMS monitors the resulting battery rack, while a bidirectional power-conversion system controls charging and discharging. The EMS receives battery and feeder measurements and generates operating commands according to the selected grid-support objective.

The third block represents distribution-grid services. The storage system can be dispatched for peak shaving, renewable smoothing, load shifting, voltage-oriented support, and controlled backup operation. Measurements such as feeder voltage, feeder current, battery SOC, SOH, temperature, and converter power are used for feedback.

Figure 5.1 presents the overall architecture. The implementation can be realized in MATLAB/Simulink, Python-based data analysis, embedded controllers, or a web-based monitoring application depending on the project scope.

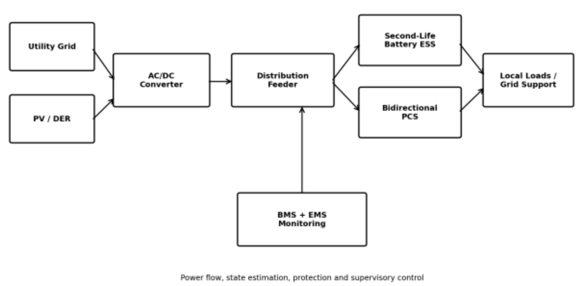

Fig 7.1: System Architecture

VIII. IMPLEMENTATION

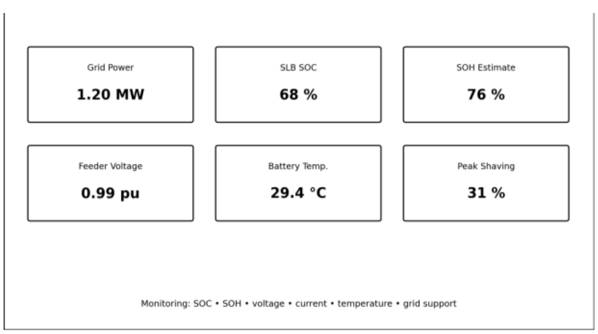

Fig 8.1: Distribution Grid Dashboard

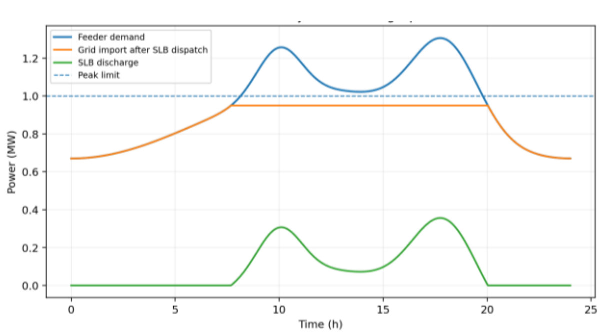

Fig 8.2: Peak-Shaving Operation

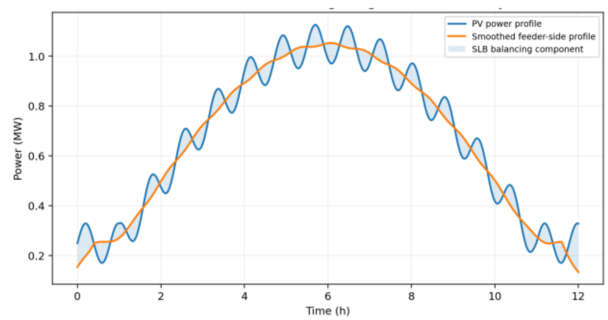

Fig 8.3: Renewable Power Smoothing

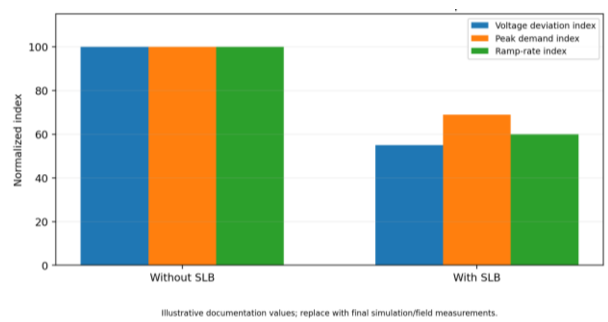

Fig 8.4: Performance Evaluation

Implementation begins with retired-battery data acquisition. The dataset can include pack identification, chemistry, nominal voltage, nominal capacity, measured capacity, internal resistance, SOC, SOH, temperature, cycle count, and test results. Data preprocessing removes invalid measurements and groups batteries with compatible electrical characteristics.

The second module performs battery grading. Capacity and resistance measurements are compared with acceptance thresholds, and modules with abnormal behavior are excluded from the proposed storage rack. SOH is calculated from measured capacity relative to the selected reference capacity, while SOC is updated using current integration and corrected with voltage-based information.

The third module performs grid-load analysis. The EMS calculates the difference between feeder demand and the desired grid operating profile. When feeder demand exceeds the selected peak limit, the SLBESS discharges. When demand is low or renewable generation is available in excess, the BESS can charge, subject to SOC and power limits.

Figure 6.1 presents a dashboard-style interface containing grid power, SLB SOC, estimated SOH, feeder voltage, temperature, and peak-shaving information. Figure 6.2 demonstrates an example of peak-shaving behavior, while Figure 6.3 illustrates renewable-power smoothing. Figure 6.4 provides an illustrative comparison of normalized grid indicators. The numerical values in that figure are documentation examples and should be replaced by final simulation or field measurements.

Performance evaluation can include peak-demand reduction, voltage deviation, renewable-energy utilization, round-trip efficiency, battery throughput, SOH change, thermal behavior, and availability. A comparison against a baseline without second-life storage helps identify the effect of the proposed system on distribution-grid operation.

IX. CONCLUSION

The proposed second-life EV battery energy storage framework provides a structured method for reusing retired traction batteries in distribution-grid applications. Instead of treating an EV battery as unusable immediately after automotive retirement, the framework evaluates its remaining electrical capability and transfers suitable modules into a controlled stationary storage system.

The architecture combines battery screening, SOH estimation, BMS supervision, bidirectional power conversion, EMS dispatch, distribution-feeder monitoring, and protection. Through coordinated charging and discharging, the second-life BESS can support peak shaving, renewable smoothing, load shifting, and other grid-management functions.

An important feature of the proposed approach is that reliability and degradation are included in the operating concept. Second-life batteries are not identical to new batteries, so capacity variation, ageing history, thermal conditions, and replacement requirements must be considered during system design. The final performance should therefore be validated with the actual retired-battery data, selected converter ratings, feeder model, and operating scenarios.

X. FUTURE SCOPE

Future work can improve the proposed system by developing more accurate SOH and remaining-useful-life estimation methods for heterogeneous second-life battery modules. Machine-learning and physics-informed models can be evaluated using laboratory ageing data and real operating measurements. Digital twins can also be developed to predict module-level degradation before the batteries are deployed in the distribution network.

Another research direction is reliability-aware optimal sizing. Future models can jointly optimize battery energy, converter power, feeder location, replacement intervals, degradation cost, and network constraints. Multi-objective optimization can include technical performance, lifecycle cost, environmental impact, and battery availability.

The system can also be extended to advanced distribution-grid functions such as volt/VAR support, frequency-related services, congestion management, black-start support, microgrid operation, and coordination with EV charging stations. Integration with photovoltaic generation, wind generation, demand response, and vehicle-to-grid resources can create a coordinated flexibility platform.

Finally, future prototypes should address standardized battery interfaces, cybersecurity, fault diagnosis, thermal runaway prevention, module isolation, fire protection, and automated replacement planning. These developments can help move second-life battery systems from controlled demonstrations toward reliable and scalable distribution-grid infrastructure.

XI. REFERENCES

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