AMERICAN JOURNAL OF MANAGEMENT AND IOT MEDICAL COMPUTING
Peer Reviewed, Referred & Indexed Journal
E-ISSN: 3069-0110
Vol.4, No. 2(2025)
www.ajmimc.com

Battery Energy Storage System Sizing for Peak Shaving and Renewable Energy Integration

[1]Bathula Gopal

[1]Associate Professor, Department of Electrical and Electronics Engineering, Priyadarshini Institute of Science and Technology for Women, Complete college address, including PIN code: Sai Prabath Nagar, Khammam, Telangana, 507003

[1]Email: bgopal49@yahoo.com

ABSTRACT

The increasing penetration of renewable generation and the growth of variable electrical demand are creating a need for flexible energy resources that can respond quickly to changes in system conditions. Battery Energy Storage Systems (BESS) can absorb surplus renewable energy, discharge during high-demand periods, and reduce the instantaneous power drawn from the grid. This project presents a coordinated framework for determining BESS power and energy ratings for peak shaving while supporting renewable-energy integration. The proposed approach combines load-profile analysis, renewable generation forecasting, state-of-charge constraints, battery operating limits, and an energy-management controller. The sizing process considers both the required discharge power for limiting grid peaks and the usable energy required to sustain that support over the target interval. A simulation-oriented architecture is developed to compare grid-only operation, renewable-assisted operation, and renewable-plus-BESS operation. Performance is assessed using peak grid demand, renewable utilization, battery throughput, state-of-charge range, and operational cost indicators. The framework demonstrates how appropriately sized storage can shift renewable energy toward periods of higher demand, reduce peak loading, and improve the controllability of a renewable-integrated electrical system.

Keywords: Battery Energy Storage System, BESS Sizing, Peak Shaving, Renewable Energy Integration, Energy Management, State of Charge, Load Shifting, Photovoltaic Generation, Smart Grid, Energy Optimization.

I. INTRODUCTION

Modern power systems are experiencing a rapid increase in renewable generation, particularly photovoltaic and wind resources. These sources reduce dependence on conventional generation but introduce variability because their output changes with weather and operating conditions. At the same time, commercial, industrial, and residential loads can produce short-duration demand peaks that increase network stress and electricity costs. Coordinating renewable generation with battery storage provides a practical way to manage this mismatch.

Peak shaving refers to the controlled reduction of grid import during periods when electrical demand approaches a high threshold. A BESS can charge when demand is low or renewable output is abundant and discharge when the load rises. The effectiveness of this operation depends strongly on selecting a suitable battery power rating and energy capacity. An oversized system can increase investment and unused capacity, while an undersized system may fail to meet the required peak limit.

Renewable-energy integration creates an additional sizing consideration. During periods of high solar or wind production, surplus electricity may be curtailed if local demand and export capacity are limited. Storage can capture part of this surplus and release it later, thereby increasing renewable utilization. The battery must therefore be sized not only around the load peak but also

Received: 07-05-2025 | Accepted: 16-06-2025 | Published: 23-06-2025

around the expected duration and magnitude of renewable-energy surplus.

This project develops a coordinated BESS sizing and operating framework in which load demand, renewable generation, grid limits, battery state of charge, charge-discharge efficiency, and operating reserve are considered together. The proposed model provides a structured method for selecting candidate battery ratings and evaluating them using technical and economic indicators.

The study is intended as a practical reference for renewable-integrated facilities, microgrids, commercial buildings, and distribution-level applications where peak demand and renewable variability must be managed simultaneously. The same architecture can later be extended with electricity-market participation, demand response, forecasting, battery degradation models, and grid-support services.

II. LITERATURE SURVEY

Research on energy-storage planning has established that optimal sizing and placement can improve distribution-network performance while reducing the need for network reinforcement. Das et al. reviewed storage applications in distribution networks and highlighted sizing, placement, operation, and power-quality considerations as important planning dimensions [1]. Yang et al. reviewed BESS size-determination methods for renewable systems and emphasized that the suitable sizing criterion depends on the application and system scale [2].

Peak-shaving research commonly treats the battery as a controllable resource that changes the timing of grid electricity consumption. Peak-load-shaving reviews identify energy storage, demand-side management, and flexible loads as major approaches for reducing peak demand [3]. More recent work has explored degradation-aware sizing and joint sizing-dispatch optimization, recognizing that battery cycling and lifetime can materially affect the economic result [4].

For renewable integration, optimization methods have been developed to determine storage capacity under variable generation and uncertain demand. Studies have considered stochastic programming, scenario reduction, mixed-integer formulations, and metaheuristic approaches. These methods help account for uncertainty in solar output, wind generation, electricity prices, and network operating constraints [5], [6].

Recent reviews also show increasing interest in intelligent optimization and data-driven energy management. Mathematical programming, evolutionary algorithms, and machine-learning-based strategies can be used for storage sizing, scheduling, placement, and coordinated control [7], [8]. Research on PV-connected storage has further shown that storage planning should consider voltage limits, line constraints, PV curtailment, and the economic value of exported electricity rather than treating the battery as an isolated device [9].

Overall, the literature indicates that BESS sizing is a multi-objective planning problem. A technically suitable solution must provide enough power to reduce demand peaks, enough energy to sustain the discharge interval, and sufficient charging headroom to absorb renewable surplus. The proposed work combines these requirements within one application-oriented sizing and energy-management framework.

III. EXISTING SYSTEM

In a conventional grid-connected facility, electrical demand is supplied directly by the distribution network. During high-load periods, the grid must provide the complete instantaneous requirement. If renewable generation is installed, its output is normally consumed locally when available, while excess generation may be exported or curtailed depending on the interconnection arrangement.

A renewable-only configuration cannot guarantee peak reduction because renewable output may be low when the load reaches its maximum. Likewise, a battery system operated without coordinated sizing may discharge too early, reach its minimum state of charge before the peak period ends, or remain underutilized for long periods. These limitations make integrated planning essential.

Traditional sizing methods may rely on a single peak value or a simple autonomy assumption. Such methods can overlook the duration of the peak, renewable surplus patterns, battery efficiency, allowable depth of discharge, and future operating conditions.

A more representative approach should use time-series load and renewable profiles together with operational constraints.

The existing arrangement therefore lacks a unified mechanism that links the selected BESS capacity to both peak-shaving requirements and renewable-energy utilization. The proposed system addresses this gap by evaluating candidate power and energy ratings through chronological simulation and coordinated dispatch.

Disadvantages of Existing System

High grid demand during short-duration load peaks.

Limited ability to shift renewable energy from surplus periods to later demand periods.

Risk of battery under-sizing when only instantaneous peak power is considered.

Risk of over-sizing when conservative autonomy assumptions are used without time-series analysis.

Limited consideration of battery efficiency, SOC limits, and degradation in simple sizing methods.

Weak coordination between renewable generation, storage operation, and grid import limits.

IV. PROPOSED SYSTEM

The proposed system introduces a time-series BESS sizing and energy-management framework for peak shaving and renewable-energy integration. The main components are renewable generation, a bidirectional power-conversion system, battery modules with a battery-management system, the electrical load, the utility grid, and a supervisory energy-management controller.

The sizing process begins by defining the desired grid-import limit. For every time interval, the controller calculates the difference between load demand and renewable generation. If the net demand exceeds the selected grid limit, the BESS is scheduled to discharge subject to its maximum power rating and available state of charge. If renewable generation is greater than local demand, the controller can charge the battery when spare capacity is available.

The required battery power rating is determined from the largest discharge requirement observed in the target operating profile. The usable energy requirement is determined from the accumulated energy needed during consecutive peak periods after accounting for conversion efficiency and allowable depth of discharge. Candidate capacities are then tested against the complete time series rather than a single design point.

The energy-management controller continuously monitors load, renewable output, grid power, battery SOC, charge and discharge power, and system constraints. It prioritizes renewable utilization while maintaining sufficient battery headroom for future peak support. The controller also prevents charging or discharging when the battery reaches its predefined operating limits.

The proposed framework can be extended to multiple renewable sources and multiple BESS units. Additional objectives such as electricity-price arbitrage, demand-response participation, network congestion relief, reserve provision, and battery degradation cost can be included in the optimization function without changing the basic architecture.

V. SYSTEM ARCHITECTURE

The system architecture contains renewable generation, load demand, grid interface, bidirectional power conversion, BESS, battery management, and supervisory energy management. Renewable generation supplies local demand first when practical. Surplus renewable power can be routed to the battery, while the grid supplies any remaining demand when the battery cannot maintain the target grid limit.

The BESS subsystem contains battery cells or modules, a battery-management system, protection circuits, thermal supervision, and a bidirectional converter. The BMS tracks voltage, current, temperature, and SOC and communicates operating limits to the energy-management controller. The converter controls the direction and magnitude of power exchanged with the battery.

The sizing module evaluates load and renewable time series and generates candidate combinations of battery power and energy capacity. Each candidate is simulated under the same dispatch rules. Solutions that violate SOC, power, grid-import, or charging constraints are rejected, while feasible solutions are compared using cost and performance indicators.

The supervisory controller is the central decision layer. It receives measurements and forecasts, determines the required battery operating state, and sends power references to the converter. This structure separates planning-level sizing from real-time control while allowing both functions to use the same system constraints.

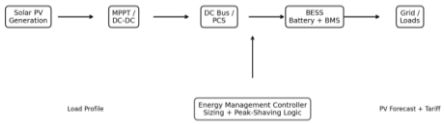


Fig 5.1: System Architecture

VI. IMPLEMENTATION

The proposed system can be implemented in MATLAB/Simulink, Python, OpenDSS, PSCAD, or another suitable power-system simulation environment. The input data consist of time-series load demand and renewable-generation profiles, together with battery efficiency, minimum and maximum SOC, maximum charge-discharge power, grid-import limit, and economic parameters.

The implementation begins with data preparation. Load and renewable profiles are aligned to a common time step and checked for missing or abnormal values. A net-load profile is calculated as local demand minus renewable generation. Candidate BESS power and energy ratings are then generated within engineering limits.

At each simulation interval, the energy-management algorithm checks whether the net load exceeds the grid-import threshold. If it does, the BESS discharges within its power and SOC limits. If renewable generation creates a surplus, the battery charges when usable capacity remains. Otherwise, the surplus can be exported or curtailed according to the selected operating scenario.

Battery SOC is updated using charge and discharge efficiencies. The operating window is intentionally restricted to avoid excessive depth of discharge and to preserve headroom for renewable absorption. A degradation-aware version can additionally estimate cycle throughput and assign an equivalent cost to battery usage.

The system is evaluated using peak grid import, peak reduction percentage, renewable-energy utilization, curtailed renewable energy, battery throughput, SOC range, unmet peak-shaving intervals, and estimated operating cost. Baseline cases such as grid-only and renewable-without-storage are compared with the proposed PV/wind-plus-BESS configuration.

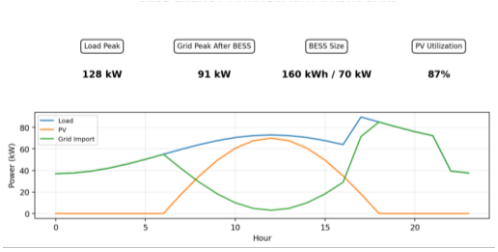


Fig 6.1: Energy Management Dashboard

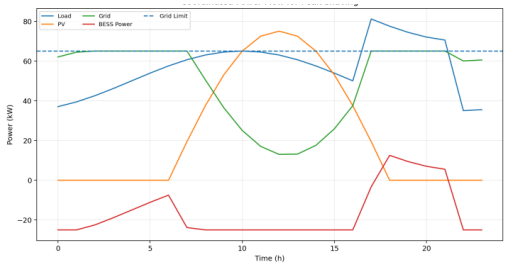


Fig 6.2: Coordinated Power Flow

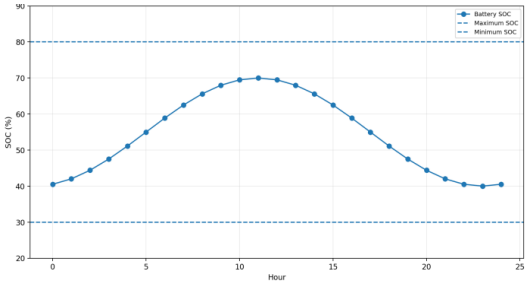


Fig 6.3: Battery SOC Monitoring

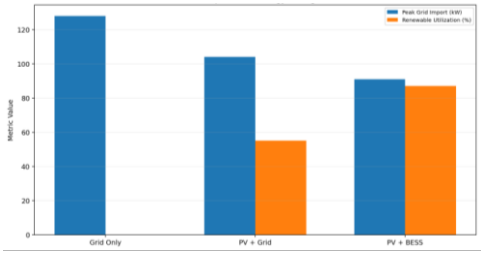


Fig 6.4: Performance Evaluation

VII. CONCLUSION

The proposed BESS sizing framework provides a coordinated method for reducing grid demand peaks while improving the use of variable renewable generation. Instead of

selecting battery capacity from a single peak value, the approach evaluates chronological load and renewable profiles together with power, energy, SOC, efficiency, and grid-import constraints.

The results framework shows that battery power rating determines how aggressively the system can limit instantaneous grid demand, while energy capacity determines how long that support can be sustained. Renewable generation adds another sizing dimension because the battery needs sufficient charging headroom to capture surplus production without compromising its ability to respond during later demand peaks. The overall design should balance technical performance, capital cost, battery lifetime, renewable utilization, and local grid requirements. A practical sizing decision should therefore be based on a complete operating profile and sensitivity analysis rather than a single deterministic assumption.

VIII. FUTURE SCOPE

Future work can incorporate probabilistic forecasts for renewable generation and load demand so that BESS sizing remains robust under uncertainty. Scenario-based optimization can evaluate seasonal weather variation, unusual demand peaks, and changes in renewable penetration.

Advanced optimization can jointly determine battery size, renewable capacity, dispatch schedule, and grid-import limits. Multi-objective formulations can include capital expenditure, electricity cost, renewable curtailment, battery degradation, emissions, and reliability as simultaneous planning criteria.

Artificial intelligence and reinforcement-learning methods can be investigated for adaptive dispatch, while model predictive control can update the battery schedule using short-term forecasts. Hybrid storage using batteries with supercapacitors may also be explored for applications with frequent high-power fluctuations.

Future implementations can include hardware-in-the-loop testing, real battery aging measurements, thermal models, cybersecurity protection, communication delays, and interoperability with utility energy-management platforms. Field trials can validate the sizing methodology under real operating conditions and changing tariff structures.

IX. REFERENCES

[1] C. K. Das, O. Bass, G. Kothapalli, T. S. Mahmoud, and D. Habibi, “Overview of energy storage systems in distribution networks: Placement, sizing, operation, and power quality,” Renewable and Sustainable Energy Reviews, vol. 91, pp. 1205–1230, 2018. DOI: 10.1016/j.rser.2018.03.068.

[2] Y. Yang, S. Bremner, C. Menictas, and M. Kay, “Battery energy storage system size determination in renewable energy systems: A review,” Renewable and Sustainable Energy Reviews, vol. 91, pp. 109–125, 2018. DOI: 10.1016/j.rser.2018.03.047.

[3] M. J. H. Sharif and M. H. R. Shayeghi, “A review on peak load shaving strategies,” Renewable and Sustainable Energy Reviews, vol. 82, pp. 3323–3332, 2018. DOI: 10.1016/j.rser.2017.10.056.

[4] M. Bucciarelli, S. Paoletti, and A. Vicino, “Optimal sizing of energy storage systems under uncertain demand and generation,” Applied Energy, vol. 225, pp. 611–621, 2018. DOI: 10.1016/j.apenergy.2018.03.153.

[5] Z. Guo, “Optimisation methods for dispatch and control of energy storage with renewable integration,” IET Smart Grid, vol. 5, no. 3, pp. 137–160, 2022. DOI: 10.1049/stg2.12063.

[6] “Battery energy-storage system: A review of technologies, optimization objectives, constraints, approaches, and outstanding issues,” Journal of Energy Storage, vol. 42, 103023, 2021. DOI: 10.1016/j.est.2021.103023.

[7] “Modelling and optimal energy management for battery energy storage systems in renewable energy systems: A review,” Renewable and Sustainable Energy Reviews, vol. 167, 112671, 2022. DOI: 10.1016/j.rser.2022.112671.

[8] “Optimal sizing and siting of energy storage systems considering curtailable photovoltaic generation in power distribution networks,” Applied Energy, vol. 339, 120955, 2023. DOI: 10.1016/j.apenergy.2023.120955.

[9] R. Chedid and A. Sawwas, “Optimal placement and sizing of photovoltaics and battery storage in distribution networks,” Energy Storage, vol. 1, e46, 2019. DOI:

10.1002/est2.46.
[10] R. Nematirad, A. Pahwa, B. Natarajan, and H. Wu, "Optimal sizing of photovoltaic-battery system for peak demand reduction using statistical models," Frontiers in Energy Research, vol. 11, 1297356, 2023. DOI: 10.3389/fenrg.2023.1297356.
[11] S. Parashar, A. Swarnkar, K. R. Niazi, and N. Gupta, "Multiobjective optimal sizing of battery energy storage in grid-connected microgrid," The Journal of Engineering, 2019. DOI: 10.1049/joe.2018.9237.
[12] M. Ban, J. Yu, M. Shahidehpour, and D. Guo, "Optimal sizing of PV and battery-based energy storage in an off-grid nanogrid supplying batteries to a battery swapping station," Journal of Modern Power Systems and Clean Energy, vol. 7, pp. 309–320, 2019. DOI: 10.1007/s40565-018-0428-y

Received: 07-05-2025 | Accepted: 16-06-2025 | Published: 23-06-2025