

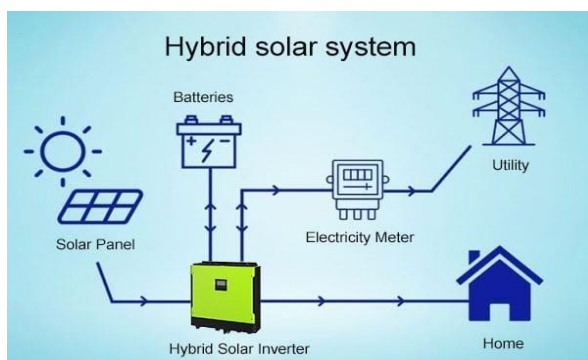
A Review of Battery Energy Storage Systems: Recent Research Trends for Hybrid End-User Applications

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Abstract - Battery energy storage systems (BESS) are increasingly used with solar photovoltaic (PV) systems to make renewable electricity available when it is needed. By storing surplus generation and supplying it later, a hybrid PV-BESS installation can increase on-site use of solar energy, reduce electricity drawn from the grid during peak periods, and provide limited backup during interruptions. This review considers end-user applications in residential, commercial and industrial settings. It discusses system configuration, battery performance, energy management, peak shaving, load shifting, self-consumption and demand response. The reviewed material indicates that performance depends not only on battery energy capacity, but also on power rating, customer load profile, electricity tariffs, weather conditions and the control strategy. An energy management system can coordinate charging and discharging while respecting battery operating limits. Initial cost, ageing, safety and communication requirements remain important considerations when planning a practical installation.

Keywords: Battery energy storage system; solar photovoltaic; energy management system; peak shaving; load shifting; self-consumption.



1. INTRODUCTION

The growing use of renewable energy is changing how electricity is generated and consumed. Solar photovoltaic (PV) systems can reduce the amount of electricity purchased from the utility grid, but their output is highest during daylight hours and may not coincide with a building's demand. A battery energy storage system can store surplus solar generation and release it later, helping to address this mismatch.

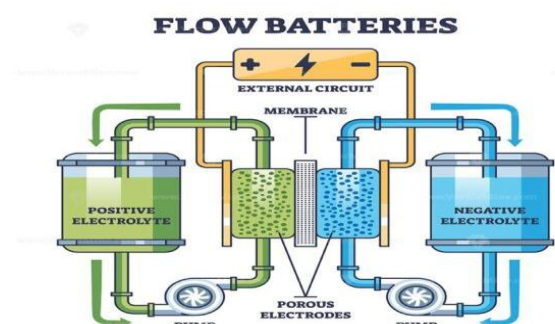
The benefit obtained by an end user depends on several connected factors: the customer's electricity-use profile, PV generation capacity, battery power and energy ratings, tariff structure, and the way the system is controlled. For this reason, assessment of a hybrid installation should consider coordination, sizing and economics rather than battery installation alone. This paper reviews hybrid systems that combine PV generation, battery storage, electrical loads, the utility grid and an energy management system. Its purpose is to summarise the main configuration choices, potential benefits and practical limitations described in the material reviewed.

2. REVIEW OF RELATED RESEARCH

2.1 End-user PV-BESS configuration

A typical hybrid PV-BESS installation consists of a PV array, battery bank, bidirectional converter, electrical loads, an energy management system (EMS) and a connection to the utility grid. When PV generation exceeds the immediate load, surplus energy may be directed to the battery, subject to system settings and applicable rules. When PV output is insufficient or demand increases, stored energy can be supplied to the load.

The operating objective varies by customer. A self-consumption strategy prioritises local use of PV electricity and stored energy to reduce grid imports. A peak-shaving strategy discharges the battery when grid demand approaches a defined limit. The most suitable configuration therefore depends on the intended application and the customer's demand pattern.



2.2 Battery technologies and performance

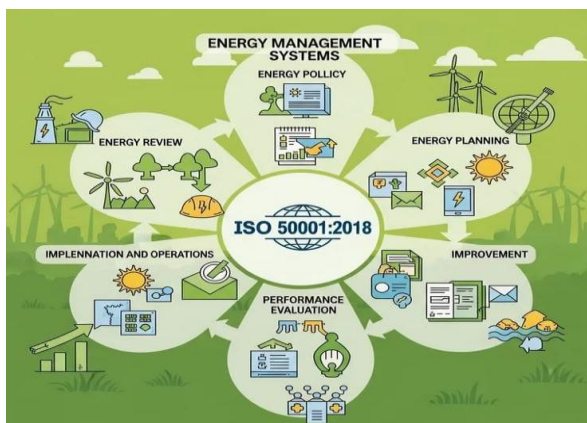
Battery selection should account for energy capacity, power capability, round-trip efficiency, allowable depth of discharge, operating-temperature range, cycle life, safety, cost and maintenance. Lithium-ion batteries are widely used because of their performance and controllability, although other battery types may suit particular applications.

Energy capacity alone does not determine whether a battery can meet a load. The available energy, charging and discharging power, and operating limits must all match the application. Battery performance also changes with age, so an assessment should consider capacity degradation over the expected service life rather than relying only on initial specifications.

2.3 Energy management system

An EMS coordinates PV generation, battery operation, customer demand and interaction with the utility grid. Depending on the installation, its decisions may use battery state of charge, current PV output, load demand, grid conditions and electricity prices.

For self-consumption, the controller can serve local demand from PV generation first, charge the battery with surplus PV energy, and discharge the battery when PV output cannot meet demand. For peak shaving, the EMS can discharge the battery when grid demand rises above a selected target. Appropriate control can improve the usefulness of stored energy while avoiding unnecessary battery cycling and respecting operating constraints.



2.4 Peak shaving and load shifting

Peak shaving reduces the maximum power drawn from the grid. A battery may be charged when demand or electricity prices are relatively low and discharged during periods of high demand or higher prices. This

approach can be valuable for customers whose electricity bills include demand charges.

In a PV-equipped building, surplus daytime generation can be stored for use later instead of being exported or curtailed. The stored energy can then help meet evening demand and reduce grid imports. The extent of the benefit depends on the battery rating, the timing and duration of peak loads, tariff rules and the availability of stored energy.

2.5 Self-consumption and renewable-energy use

Self-consumption describes the share of locally generated renewable electricity that is used by the consumer. PV production and electricity demand often occur at different times, so a battery can store some of the surplus generation for later use. This can increase the proportion of solar electricity consumed on site.

Reliable performance estimates require suitable input data. Weather conditions affect PV output, while household routines and commercial or industrial operations influence demand. If generation or load profiles are represented inaccurately, the resulting estimates may differ substantially from the performance of the real installation. Careful selection of weather and demand data is therefore important when comparing system options.

2.6 Demand response and prosumer operation

Customers with both PV panels and battery storage can act as prosumers: they consume electricity while also producing it. Their interaction with the grid may change as generation, demand, battery state of charge and electricity prices vary. Battery control can support flexible demand by shifting some electricity use away from periods of high grid demand.

The supplied draft introduces demand response and prosumer operation but does not provide detailed examples, quantitative results or a full discussion of control methods in this subsection. These aspects should be expanded with specific studies if the paper is intended for formal publication.

3. DISCUSSION

The reviewed topics show that a hybrid PV-BESS system should be designed around the user's objective rather than battery capacity alone. A system intended to increase self-consumption may require a different operating schedule from one intended to reduce peak demand. Power rating determines how quickly the battery can respond, while energy capacity affects how long it can support a load. Tariffs, local weather and the

customer's load profile influence the value of both ratings.

Energy management is central to coordinating these factors. However, expected savings should be considered alongside capital cost, battery ageing, safety and maintenance. A sound evaluation should use representative PV and load data, realistic battery operating limits and the applicable electricity tariff. The supplied paper does not include numerical case studies or comparative cost results, so no quantitative performance ranking can be established from the available material.

4. CONCLUSION

Battery energy storage can help end users make better use of solar PV generation, reduce grid imports during selected periods and manage peak demand. The overall result depends on the combination of battery power and energy ratings, customer load, tariff structure, weather and EMS control strategy. Battery technology and ageing, installation cost, safety and maintenance also need to be considered. Before selecting a system, users should evaluate it against their specific objective using reliable generation and demand data. Further work should include clearly documented case studies, economic comparisons and complete bibliographic references to support the review.

REFERENCES

The source PDF cites references [3]–[6], but their bibliographic details were not included in the supplied document. To avoid inventing sources, the reference list has not been fabricated. Insert the full author names, article titles, publication or journal names, volume/issue, pages and year for each cited work before submitting the paper. Ensure that every in-text citation matches a complete entry in the final reference list.

Illustrative Images of Hybrid PV-BESS Systems

Images added to support the discussion of solar photovoltaic and battery storage systems.



Figure 1. Solar PV panels integrated with battery energy storage equipment.



Figure 2. Closer view of battery storage cabinets and associated equipment.

Note: Illustrative images; not experimental data from the reviewed studies.