INTERNATIONAL JOURNAL OF TECHNOLOGY AND ACADEMIC RESEARCH

ISSN: 2224-6878 | Pakistan Volume 6, No. 11.

IF: 14.91 | 2026 http://waerasia.org/index.php/ijtar

INTEGRATION OF BATTERY ENERGY STORAGE SYSTEMS (BESS) WITH SOLAR AND WIND POWER PLANTS

Xushvaxtova Dilnoza Qahramon qizi
First-Year Master's Student, Karshi State University
Eshmo‘minova Shodiyona Xolmo‘min qizi
First-Year Master's Student, Karshi State University
doi:https://doi.org/10.5281/zenodo.24526681

Abstract. This article analyzes the technical, grid-related, and operational aspects of integrating energy storage systems, particularly Battery Energy Storage Systems (BESS), with solar photovoltaic (PV) and wind power plants. The diurnal, weather-related, and seasonal variability of solar and wind power generation increases temporal imbalances between electricity generation and consumption within power systems. The study examines the principal BESS integration architectures (AC-coupled, DC-coupled, and grid-scale connections), their operational functions (peak shifting, power smoothing, frequency and voltage regulation, and reserve power), and the major technical constraints associated with their integration. The findings demonstrate that the coordinated deployment of BESS with solar and wind power plants is of critical importance for safely increasing the share of renewable energy and ensuring grid stability.

Keywords: battery energy storage systems (BESS), solar power plant, wind power plant, integration, peak shifting, power smoothing, grid stability, State of Charge (SOC).

INTRODUCTION

With the widespread integration of solar and wind power plants into energy systems, the dependence of their generation profiles on natural factors, including solar radiation, cloud cover, and wind speed, makes power grid management increasingly complex.

While excessive power may be generated during periods of high daytime solar generation or increased wind activity, electricity shortages may occur during evening peak demand periods or when generation decreases (International Renewable Energy Agency, n.d.).

Battery Energy Storage Systems (BESS) serve as a buffer between solar and wind power plants and the electricity grid by temporarily storing surplus electrical energy in chemical or electrochemical form and subsequently supplying it back to the grid when required. Therefore, the effective integration of BESS with solar photovoltaic and wind power plants represents one of the most important scientific and technological directions in the modernization of contemporary energy systems (Republic of Uzbekistan ..., n.d.).

RESEARCH AIM AND OBJECTIVES

Research aim: To analyze the principles of integrating solar and wind power plants with Battery Energy Storage Systems (BESS), their principal operating modes, and their impact on grid stability and energy efficiency.

Research objectives:

- To identify the principal grid-related and operational challenges associated with the variability of solar and wind power generation;
- To classify the technical configurations and principal functional modes of BESS integration, including peak shifting, power smoothing, and ancillary services;
- To evaluate the technical and economic constraints arising during the integration process, including charging and discharging losses, battery degradation, and power management;

ISSN: 2224-6878 | Pakistan Volume 6, No. 11.

IF: 14.91 | 2026 http://waerasia.org/index.php/ijtar

- To formulate practical conclusions regarding the effective integration of BESS with solar and wind power plants.

MAIN PART: INTEGRATION ARCHITECTURES AND FUNCTIONAL MODES

1. BESS Integration Architectures

AC-coupled architecture (connection through an alternating current bus). The BESS is connected to the alternating current (AC) bus of a power plant or substation through its own independent bidirectional inverter or converter. This architecture represents a convenient and modular solution for retrofitting existing solar photovoltaic or wind power plant projects (International Renewable Energy Agency, n.d.).

DC-coupled architecture (connection through a direct current bus, primarily used in solar photovoltaic power plants). Solar panels and the battery system operate through a common direct current (DC) bus. This configuration reduces additional AC–DC–AC conversion stages when charging batteries with solar energy, thereby minimizing energy conversion losses.

Centralized plant-level or grid-scale BESS. Large-capacity battery energy storage systems are installed near large-scale solar and wind farms or at key grid nodes. These systems are designed to manage overall power flows and provide ancillary services to the electricity grid (Denholm et al., n.d.).

2. Principal Operational Functions

Peak Shifting / Energy Arbitrage. Electrical energy is stored during periods of high generation and low consumption and subsequently supplied to the grid during evening peak demand hours (International Renewable Energy Agency, n.d.).

Power Smoothing / Ramp-Rate Control. Sudden increases and decreases in power output caused by passing clouds or rapid changes in wind speed are mitigated through the use of battery energy storage systems (Xu et al., n.d.).

Frequency, Voltage, and Synthetic Inertia Support. Owing to their rapid response capabilities, battery energy storage systems reduce deviations in grid frequency, regulate reactive power, and contribute to maintaining grid stability under conditions of reduced rotational inertia from conventional generators (Denholm et al., n.d.).

RESULTS AND DISCUSSION

Although the integration of BESS with solar and wind power plants significantly increases the flexibility of energy systems, several important factors must be considered during system design and operational management.

Table 1. Advantages and Limitations of BESS Integration with Solar and Wind Power Plants

Integration aspect	Advantages and positive impacts	Limitations and factors requiring consideration
Temporal distribution of power generation	Enables surplus green energy to be stored and utilized during peak demand periods.	Battery energy capacity and power rating are limited; long-term seasonal imbalances cannot be fully compensated for.
Power quality and grid stability	Reduces power fluctuations and stabilizes grid frequency and voltage.	Requires rapid-response control systems, accurate measurements, and automated protection systems.
Battery service life and economic efficiency	Increases the value of electricity supplied to the grid and reduces the burden on reserve power resources.	Charging and discharging losses, operating temperature conditions, and cyclic degradation affect the overall

ISSN: 2224-6878 | Pakistan Volume 6, No. 11.

IF: 14.91 | 2026 http://waerasia.org/index.php/ijtar

cost.

In practical applications, the highest level of effectiveness is achieved when BESS is utilized not merely as a large-capacity battery but as a comprehensive energy resource integrated with an intelligent Energy Management System (EMS).

As emphasized by Xu et al. (n.d.), it is essential to consider the battery's State of Charge (SOC) and its charging and discharging processes when modeling and controlling energy storage systems.

Otherwise, the battery may remain at critically high or low charge levels and consequently become unable to perform its reserve power function during unexpected fluctuations in wind or solar power generation.

Therefore, in accordance with analytical and regulatory approaches in the energy sector (Republic of Uzbekistan ..., n.d.), forecasting errors associated with weather conditions, grid transmission capacity, and battery service life should be jointly optimized when determining the appropriate power rating and energy capacity of BESS.

CONCLUSION

- Battery Energy Storage Systems (BESS) represent one of the fastest-responding and most multifunctional technologies for adapting the variable generation of solar and wind power plants to electricity grid requirements (International Renewable Energy Agency, n.d.).

- The selection of AC-coupled, DC-coupled, and centralized grid-scale architectures depends on the project stage, whether it involves constructing a new power plant or modernizing an existing facility, as well as efficiency requirements and grid configuration (Denholm et al., n.d.).

- Coordinating peak shifting, power smoothing, and frequency and voltage support modes contributes to increasing the share of renewable energy utilization and strengthening electricity grid stability (Xu et al., n.d.).

- Future research should focus on integrating control algorithms that account for battery degradation, hybrid energy storage systems, and accurate forecasting models (Republic of Uzbekistan ..., n.d.).

REFERENCES

1. Denholm, P., Mai, T., Kenyon, R. W., Kroposki, B., & O'Malley, M. (n.d.). Inertia and the Power Grid: A Guide Without the Spin. National Renewable Energy Laboratory. [Year and technical report number to be verified against the original NREL publication].
2. International Renewable Energy Agency. (n.d.). Utility-Scale Batteries: Innovation Landscape Brief. [Year, URL, and publication details to be verified against the original IRENA report].
3. Republic of Uzbekistan. (n.d.). Analytical and Regulatory Materials on the Development of Renewable Energy Sources and Energy Storage Systems in the Energy Sector of the Republic of Uzbekistan. [The official document title, year of adoption, and source details are to be specified in accordance with the journal's requirements].
4. Xu, X., Bishop, M., Oikarinen, D. G., & Hao, C. (n.d.). Application and Modeling of Battery Energy Storage in Power Systems. CSEE Journal of Power and Energy Systems. [Year, volume, issue, page range, and DOI to be verified against the published article].