

Analysis of Battery Energy Storage System for Optimised Load Management

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Abstract – In regions where a reliable power supply is critically required, such as rural areas, hospitals, and essential service facilities, conventional diesel-based power generation has been widely used. However, diesel generators are associated with high operational costs and adverse environmental impacts, making them unsuitable as a long-term sustainable solution. To address these challenges, renewable energy sources such as solar and wind energy offer a viable alternative. Among these, solar photovoltaic (PV) systems are preferred due to their cost-effectiveness, ease of installation, and adaptability to various building infrastructures. In this work, a solar PV system integrated with a bidirectional inverter and a battery energy storage system (BESS) is proposed. Unlike earlier grid-connected PV systems that primarily supplied power during daylight hours, the inclusion of BESS enables energy storage for use during nighttime and emergency conditions. Furthermore, the proposed system can operate in off-grid mode, making it particularly suitable for remote locations where extending transmission lines is impractical due to geographical or climatic constraints.

Key Words: Maximum power point tracking system (MPPT), Photovoltaic (PV), Battery Energy Storage System (BESS), Total harmonic distortion (THD), Super capacitor

1. INTRODUCTION

Solar Photovoltaic energy is one form of Nonconventional energy which is attracted in the last years have interest because of its free accessibility and eco-friendly nature to its easy use as compared to other electricity sources, and their inexpensive operation on the whole earth. So it's necessary to attracts their operation, application and evolution, its benefits, and moreover its capability to resolve many issues on the electrical grid. Now a days, the employment of renewable energy is considerably increasing day by day in various countries, because of the fast growing of energy demand and continues depletion of fossil-fuel reserves. Among of all remaining resources, the PV energy is one of the best suited for domestic application as compared with alternative resources as a result of low price of installation and maintenance. The disadvantage of PV energy is that the output power depends on the weather and cell temperature. The output of PV falls in case a little a part of PV module or PV

array is shaded though it is within the sunlight. Therefore, there is a limit to provide stable power to the load and grid. So, the Battery energy storage system has been enforced in order to beat these inherent drawbacks. However, in domestic applications, a grid connected Photovoltaic systems, contrary to the complete systems, has many benefits. It provides power from Batteries to native load once it generates power from PV. Therefore, the grid-connected system is comparatively stable and effective to share load as compared with stand-alone system and has the economic potency since it will sell power generated by PV once the utility rates are severally pricy. [1]

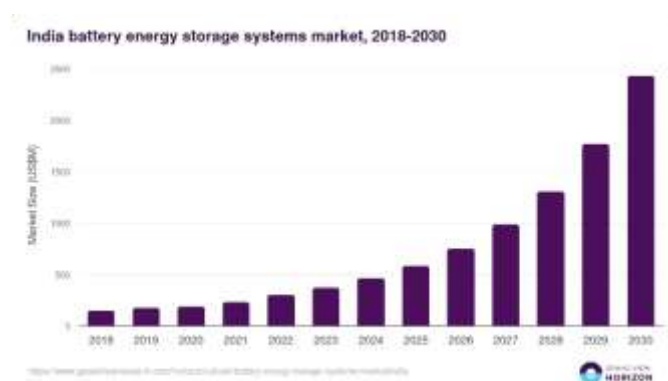


Fig -1: India battery energy storage system market 2018-30

2. Status of BESS in India

Battery Energy Storage Systems (BESS) are rapidly gaining importance in India as the country transitions toward a cleaner and more reliable power system. With the increasing penetration of renewable energy sources such as solar and wind, the need for efficient energy storage has become essential to address intermittency and ensure grid stability. BESS helps in storing excess energy generated during peak production periods and supplying it during demand peaks or when renewable generation is low, thereby improving overall energy reliability. In India, BESS is being actively promoted through various government initiatives and policies led by organizations like Ministry of Power and NITI Aayog. Programs such as the National Mission on Transformative Mobility and Battery Storage aim to boost domestic manufacturing of advanced batteries and reduce dependence on imports. Additionally, schemes supporting large-scale renewable integration are encouraging the deployment of grid-scale battery storage systems. BESS plays a crucial role in multiple applications across India, including grid stabilization, frequency regulation, peak load management, and rural

electrification. It is particularly beneficial for remote and off-grid areas, where reliable electricity supply is a challenge. Integration of BESS with solar PV systems in mini-grids has proven effective in providing uninterrupted power to rural and island communities. Despite its advantages, the adoption of BESS in India faces challenges such as high initial investment costs, limited domestic manufacturing capacity, and concerns related to battery recycling and lifecycle management. However, with falling battery prices, technological advancements, and strong policy support, BESS is expected to play a vital role in achieving India's renewable energy targets and ensuring a sustainable and resilient power infrastructure.



Fig 2- Battery Energy Storage System

The selected location is the capital of the state in India called as a Raipur city. For the analysis a software used and feed the data of the location we can easily find out the wind speed direction and other weather details like solar radiation intensity, humidity, precipitation and degrees of the wind. While designing the whole system all these data retrieved taken into consideration for the maximum utilisation of solar radiations in the generation plant. In below details we can easily find out the monthly basis solar radiation intensity.

Weather Data Summary												LOCATION: Raipur, Chhattisgarh, IND	
21° 07' 50" N 81° 30' 00" E; Time Zone from Greenwich: GMT+5:30; 2023/01/01 00:00:00; 2023/01/01 00:00:00													
MONTHLY MEANS													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Solar Radiation (kWh/m²)	100	110	120	130	140	150	160	170	180	190	200	210	220
Direct Solar Radiation (kWh/m²)	80	90	100	110	120	130	140	150	160	170	180	190	200
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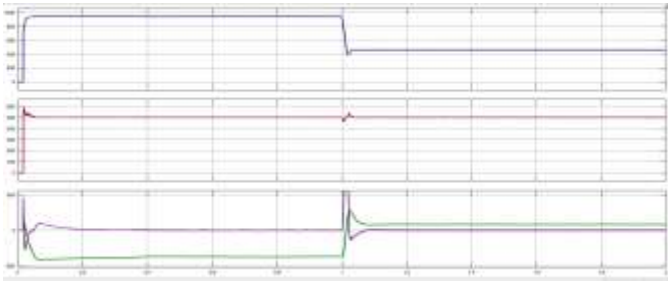


Fig -8 Power PV, Power load, Power battery, Power Supercapacitor

The given PV scope outputs illustrate the dynamic performance of a solar photovoltaic system integrated with a power electronic converter and control mechanism. The top waveform represents the voltage profile, which initially shows a small transient during system startup and then stabilizes around a constant value with minor switching ripples. Around 1 second, a disturbance occurs—likely due to a sudden change in load, solar irradiance, or battery operation—causing a brief dip and overshoot before the voltage quickly returns to a steady state, indicating effective voltage regulation. The middle waveform shows the current response, which initially stabilizes at a higher value and then drops significantly at the same instant (around 1 second), suggesting a reduction in load demand or a shift in operating conditions such as battery charging or discharging. The bottom waveform represents the output power, which initially reaches a high value, confirming proper maximum power point tracking (MPPT) operation, and then decreases sharply in response to the disturbance, settling at a lower steady-state level. Overall, the results demonstrate that the system responds rapidly to changing conditions, maintains stability, and effectively adapts its operating point, ensuring reliable performance under varying environmental or load scenarios.

The top waveform (Power PV) indicates the power generated by the solar photovoltaic system. Initially, the PV power quickly rises and stabilizes at a high level (around 900–1000 W), showing effective maximum power point tracking (MPPT). At approximately $t = 1$ second, there is a sharp drop in PV power to nearly half its value, which suggests a sudden reduction in solar irradiance or a change in operating conditions. After this disturbance, the PV output stabilizes at a new lower level. The middle waveform (Power Load) represents the power demanded by the load. It remains almost constant throughout the operation at around 500 W, indicating a steady load condition. A small disturbance is observed near $t = 1$ second, but the system quickly maintains the required load power, highlighting the reliability of supply. The bottom waveform shows Power Battery (green) and Power Supercapacitor (purple). Initially, the battery supplies a significant portion of power (negative sign indicating discharge), supporting the load along with the PV system. The supercapacitor handles small fluctuations and transient ripples due to its fast response capability. At $t = 1$ second, when the PV

power suddenly drops, the supercapacitor responds immediately with a sharp spike, compensating for the sudden power deficit. Simultaneously, the battery increases its contribution more gradually to meet the sustained power demand. After the transient period, both storage elements settle into a new steady-state, with the battery supplying the majority of the deficit and the supercapacitor managing minor variations. Overall, the results demonstrate effective energy management in the hybrid system: the PV system serves as the primary energy source, the battery provides long-term energy support, and the supercapacitor handles fast transient responses, ensuring continuous and stable power supply to the load even under sudden disturbances

5. CONCLUSION

A solar photovoltaic (PV) model has been designed and simulated using a series-parallel combination of PV strings to achieve the desired voltage and current levels. The generated PV voltage is stepped up using a DC-DC boost converter to meet the load and system requirements. The complete system is modelled and analysed in MATLAB/Simulink, where the simulation results demonstrate that the battery energy storage system (BESS) exhibits a fast dynamic response without interruption, ensuring stable and reliable power output. The proposed system is particularly suitable for rural, peri-urban, and isolated regions, including small islands that are not connected to the national grid. In such areas, an AC mini-grid system can be effectively implemented to provide an independent and decentralized power distribution network for local communities. The integration of battery storage enhances system efficiency and reliability by storing excess energy generated from renewable energy sources (RES) and supplying it during periods of low or insufficient generation. This ensures a continuous and dependable electricity supply, reducing dependence on conventional power sources and enabling sustainable energy access.

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