MEASURING ENERGY AND POWER EXCHANGE FOR PV-ESBS SYSTEM USING MATLAB/SIMULINK

Gurpinder Singh

M. Tech Student
ECE Department , BGIET, Sangrur

Sushil Kakkar

Associate Professor
ECE Department , BGIET, Sangrur

Shweta Rani

Assistant Professor
ECE Department , GZSCCET, MRSPTU, Bathinda

ABSTRACT

The transition to renewable energy, particularly solar photovoltaic (PV) systems, necessitates robust energy storage solutions. To facilitate this shift, accessible models of PV systems integrated with battery storage (ESBS) are crucial for engineers. These models enable the evaluation of technical and economic advantages during system design. This work introduces a comprehensive model that accurately represents power flows and energy exchanges within a PV-ESBS system. It offers two PV generation approaches: a Gaussian model and a meteorological data-based (MDB) model. The MDB model is shown to be more effective for short-term analysis, while the Gaussian model aligns better with long-term measured data. The model is versatile, capable of simulating various energy management strategies, including peak-shaving and maximizing self-consumption, applicable across different PV-ESBS scales. Validation is achieved by comparing simulation results with data from a real-world grid-tied PV-ESBS, demonstrating the model's accuracy and reliability.

1. INTRODUCTION

The urgency of climate change mitigation is undeniable. Extreme weather events are stark reminders of its growing impact on humanity. Swift and decisive action is crucial to minimize these detrimental consequences. Delaying mitigation efforts will only exacerbate the challenges, leading to more severe and irreversible damage. Therefore, immediate implementation of effective strategies is paramount to safeguarding our future and mitigating the escalating risks posed by climate change.

Industrialized nations' unsustainable energy consumption necessitates immediate action to combat climate change. Reducing global energy use and rapidly expanding renewable energy production are vital. Electrification of transportation and heating, while crucial for transition, demands a significant increase in renewable energy capacity and storage.

However, dispersed renewable energy sources can cause overvoltages in low-voltage networks, and increased power demand from electric vehicles and heating can lead to grid congestion. Energy storage systems offer a solution by stabilizing the distribution network, mitigating these potential issues and ensuring a smoother transition to a sustainable energy future.The integration of energy storage with renewable energy is poised for substantial growth. This surge is driven by the necessity to address unsustainable energy consumption and climate change. Among renewable technologies, photovoltaic (PV) energy stands out due to its cost-effectiveness and widespread availability. Consequently, the deployment of PV systems coupled with energy storage is expected to escalate significantly in the coming years. This combination offers a promising pathway towards a more sustainable and resilient energy future, leveraging the abundance of solar resources and the flexibility of storage solutions.

The anticipated dramatic expansion of global photovoltaic (PV) system installations underscores the urgent need for robust design models. These models are essential tools for engineers and practitioners, enabling accurate profitability analyses and energy yield simulations, both crucial for effective system design.

To achieve this accuracy, the models must meticulously simulate the power flow between all PV system components: PV modules, the electrical grid, and the battery pack. Furthermore, these simulations must adhere to the established standards of Energy Management Systems.

By accurately representing the energy exchange within the system, these models facilitate informed decision-making during the design process, optimizing performance and ensuring compliance with industry standards. This ensures that the projected growth in PV installations translates into efficient, reliable, and economically viable renewable energy solutions.

2. PV–ESBS MODEL

Figure 1 presents the open-access system, broken down into key elements. The PV modeling component calculates the generated solar power. This output is then managed by the Energy Management System (EMS), which directs energy flow between all system components based on operational settings.

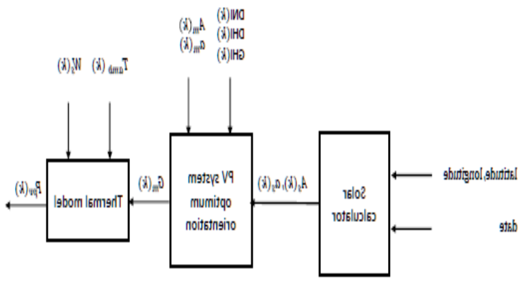

Fig.1 Open-access system

Battery modeling plays a vital role, continuously monitoring the battery's state-of-charge (SoC). This data informs the EMS, determining whether the battery should charge, discharge, or remain inactive.

Additionally, the PV model incorporates an optimization feature, determining the ideal tilt and azimuth of the PV array. This ensures maximum annual energy yield, enhancing the overall efficiency of the system. This modular approach allows for transparent analysis and control of PV-ESBS systems.

Model Based on Meteorological Data

This model for PV system power estimation comprises three main parts: a solar calculator, an optimization block for PV array orientation, and a thermal model. The solar calculator, utilizes the PV system's latitude and longitude, along with the analysis date, as inputs.

It then calculates the sun's position, expressed as azimuth (As) and altitude (as), through a series of steps. These coordinates, determined at each time step (k), are then fed into the optimal orientation block.

This block optimizes the PV array's tilt and azimuth for specific goals, such as maximizing annual yield, winter yield, or peak demand production. By dynamically adjusting the orientation based on the sun's position, the model ensures efficient energy capture.

To calculate the total irradiance (Gm) on a PV module, the model utilizes the module's azimuth (Am) and inclination (am), alongside annual irradiance data. The optimization block adjusts Am and am to find the combination yielding maximum annual energy (kWh/m²). This allows for analysis of modules with non-ideal orientations due to installation constraints, like roof alignment. By simulating various orientations, the model assesses energy production under real-world limitations, ensuring accurate performance predictions even when ideal placement isn't feasible.

While the impact of PV array tilting is often overlooked, this meteorological data-based model addresses it by offering flexibility in tilt angle calculations. It can determine the optimal tilt for maximum energy yield or evaluate output at any given tilt, accommodating real-world installation limitations where ideal angles aren't always achievable. This feature is crucial for designers adapting to diverse site conditions.

The model's input requirements align with advanced techniques, utilizing essential meteorological data—temperature, irradiance, longitude, and latitude—along with PV and ESBS ratings. Its non-iterative nature ensures low computational costs, making it efficient for various applications.

ISSN: 2350-1278
Peer Reviewed & Refereed Journal (IF: 7.9)
Journal Website www.nrjitis.in

However, the model's reliance on historical data can lead to inaccuracies in real-time applications. To mitigate this, using current measurements as input significantly enhances output precision. Similarly, for forecasting purposes, the accuracy of temperature and irradiance predictions directly impacts the model's reliability. Therefore, careful consideration of data quality and source is essential for achieving accurate and dependable results.

In essence, this model offers a valuable tool for PV system design, balancing flexibility, efficiency, and data-driven accuracy. Its ability to handle varying tilt angles and its compatibility with standard meteorological data make it a practical asset for engineers and practitioners.

3. RESULTS AND DISCUSSION

To thoroughly analyze the PV-ESBS system, the simulation explored three operational scenarios: continuous PV power generation, ESBS discharge when PV output is insufficient, and ESBS charging when PV output exceeds demand. These scenarios, reflecting real-world system behavior, are implemented according to the flowchart detailed in Figure 2.

This approach provides a comprehensive understanding of how the PV-ESBS system responds to varying power availability, showcasing its ability to balance energy supply and demand through the dynamic interaction between PV generation and battery storage.

Case 2: PV supplies constant power, ESBS has no impact

In this simulation, the utility grid, the electrical load, and the PV-ESBS system are connected in a parallel configuration. The photovoltaic array operates at its maximum capacity, generating 100 kW of power. Under these conditions, the battery energy storage system (ESBS) plays a minimal role in the overall energy flow.

The ESBS primarily intervenes during transient periods, specifically when the PV system is stabilizing its output. This limited activity signifies that the PV array effectively meets the load demand.

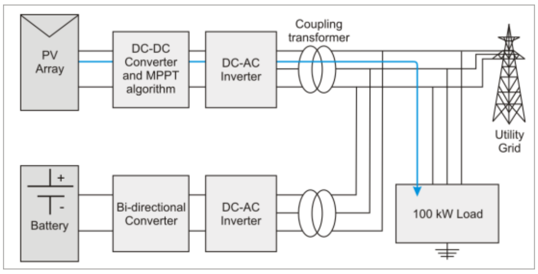

Figure 2. Energy flow for PV-ESBS System

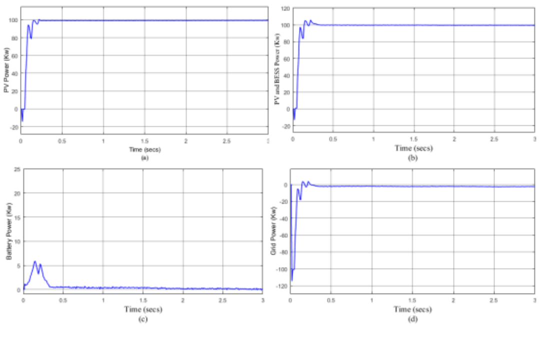

Figure 3. Power (a) PV (b) Battery (c) PV and Battery (d) Grid

Case 3: ESBS discharging due to change in PV

This simulation explores the PV-ESBS system's response to fluctuating solar irradiation. The PV output power is modeled to vary significantly, decreasing from 1000 W/m² to 150 W/m² at defined intervals. This variation simulates real-world conditions where cloud cover or other factors can impact solar energy generation.

ISSN: 2350-1278
Peer Reviewed & Refereed Journal (IF: 7.9)
Journal Website www.nrjitis.in

To ensure a consistent power supply to the load, the ESBS, assumed to be pre-charged, discharges its stored energy. This compensatory action bridges the gap between the reduced PV output and the load's demand..

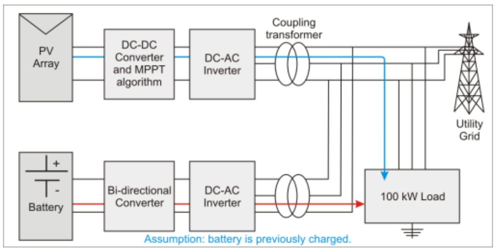

Figure 4. Energy flow for the PV-ESBS System

Case 3 examines the system's response when PV generation falls short of the load demand. To compensate, the battery discharges, ensuring the load's power requirements are met.

Figure 4-5 illustrates the fluctuating PV power output, ranging from 100 kW to 15 kW, reflecting changes in irradiance between 0 and 8 seconds. Figure 3 shows the corresponding power discharged from the battery, demonstrating its role in supplementing the PV output.

Figure 4 presents the combined power delivered to the load by both the PV array and the ESBS, highlighting the seamless integration of these energy sources. Figure 5 shows that the grid supplies zero power in this scenario. Finally, Figure 6 provides a consolidated view of the combined power flow, showcasing the dynamic interplay between PV generation and battery discharge in maintaining a stable power supply.

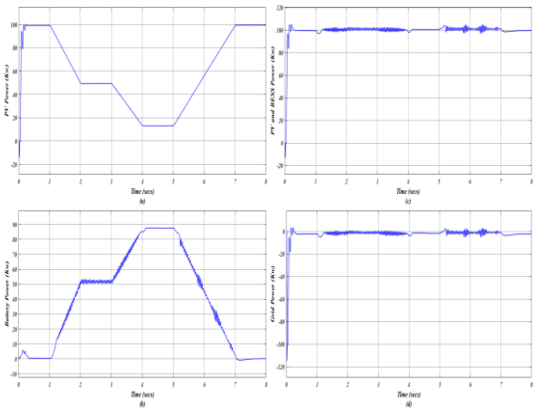

Figure 5. Power generated from (a) PV (b) Battery (c) PV and Battery (d) Grid.

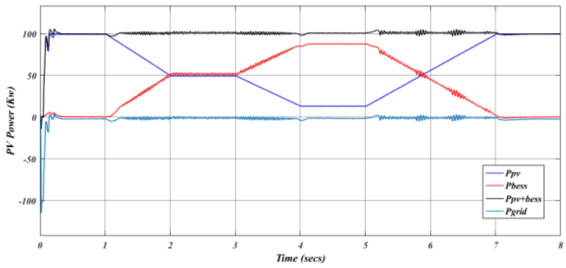

Figure 6 Power generation of the whole system in one diagram

4. CONCLUSION

This paper extensively simulated a combined PV-ESBS system using MATLAB/Simulink. The PV system model encompassed several key components: a PV array, a boost-type DC/DC converter implementing an incremental conductance MPPT algorithm with integral regulation, a three-phase VSC-type DC/AC inverter, and a coupling transformer connecting to both the load and the point of common coupling with an equivalent power grid.

The ESBS model was similarly detailed, comprising a battery pack, a VSC-type DC/AC inverter, a Cuk-type bi-directional DC/DC converter, and a coupling transformer, also linked to the common coupling point. This comprehensive modeling approach allowed for in-depth analysis of the integrated system's performance.

The central objective of this paper was to evaluate the performance of an integrated PV-ESBS system under dynamic temperature and irradiance conditions, while maintaining a consistent power supply to an AC load. During the modeling process, it was found that connecting the ESBS in parallel with the PV system, rather than linking both DC/DC converters to a shared DC/AC inverter's DC bus, significantly simplified the model's complexity. This design choice streamlined the simulation and analysis, facilitating a more efficient investigation of the system's performance..

5. REFERENCES

1. H. Ritchie and M. Roser, "Energy Production & Changing Energy Sources," OurWorldInData.org, 2022
2. S. Hegedus and A. Luque, "Achievements and challenges of solar electricity from photovoltaics," in Handbook of Photovoltaic Science and Engineering, John Wiley & Sons, Ltd, 2021, pp. 2-38.
3. I. E. AGENCY, "World Energy Outlook 2020.," 2021.
4. I. E. Agency, "Snapshot Of Global Photovoltaic Markets," 2020
5. REN21, "Renewables 2017 Global Status Report "Market And Industry Trends"," 2017.
6. J. V. Appen, M. Braun, T. Stetz, K. Diwold and D. Geibel, "Time in the Sun: The Challenge of High PV Penetration in the German Electric Grid," IEEE Power and Energy Magazine, vol. 11, no. 2, pp. 55-64, March-April, 2018.
7. D. Spiers, "Batteries in PV Systems," in Practical Handbook of Photovoltaics, Elsevier, December 2020, pp. 721-776.
8. R. Corkish, M. A. Green, M. E. Watt and S. R. Wenham, Applied Photovoltaics, 2nd ed., Earthscan, 2021.
9. G. Dzimano, Modeling Of Photovoltaic Systems, Doctoral Paper, The Ohio State University, 2008.
10. M. R. SUNNY, "Sizing An Energy Storage To Be Used In Parallel With PV Inverter To Balance The Fluctuations In Output Power From PV Generator Msc, Paper," Tampere University of Technology, 2021.
11. R. Messenger and A. Abtahi, Photovoltaic Systems Engineering, Fourth ed., CRC Press, 2017.