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A Novel Controller for Electric Vehicles Charging at Workplaces using Solar Energy

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ABSTRACT

This paper presents a MATLAB-based simulation framework for a Photovoltaic (PV) grid-integrated Battery Energy Storage System (BESS) combined with an Electric Vehicle (EV) charger. The proposed simulation model aims to evaluate the performance and feasibility of integrating renewable energy sources, energy storage, and EV charging infrastructure within a grid-connected system. The PV system generates electricity from solar irradiance, while the BESS stores excess energy for later use or EV charging. The EV charger facilitates bidirectional power flow, enabling Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) operations. The simulation framework incorporates dynamic modeling of PV generation, battery storage, EV charging/discharging, and grid interaction, considering factors such as weather conditions, grid demand, and user behavior. Key performance metrics including energy efficiency, grid stability, and economic viability are analyzed under various scenarios and operational conditions. The simulation results provide insights into the system's behavior, optimal operation strategies, and potential challenges, guiding the design and implementation of real-world PV-BESS-EV charging systems. This research contributes to the advancement of sustainable energy solutions by demonstrating the feasibility and benefits of integrating PV generation, energy storage, and EV charging infrastructure into grid-connected environments, fostering a more resilient and eco-friendly energy ecosystem.

Keywords: Photovoltaic (PV), Grid, Battery Energy Storage System (BESS), Electric Vehicle (EV), Charger, Sustainability, Renewable Energy.

INTRODUCTION

The integration of renewable energy sources, such as photovoltaic (PV) systems, with energy storage technologies and electric vehicle (EV) chargers presents a promising solution for sustainable energy management. This paper introduces a MATLAB-based simulation framework for analyzing the performance and feasibility of a PV-grid-battery energy storage system (BESS) integrated with an EV charger. The proposed system aims to optimize energy utilization, enhance grid stability, and promote the adoption of electric vehicles through efficient and renewable energy-powered charging infrastructure. The simulation model encompasses the dynamic interaction between PV generation, grid power supply, battery storage, and EV charging, enabling comprehensive analysis of system behavior under various operating conditions and control strategies. This paper provides a detailed overview of the simulation framework, including component modeling, control algorithms, and performance evaluation metrics. Simulation results demonstrate the effectiveness and benefits of the integrated PV-grid-BESS-EV charger system in terms of energy efficiency, grid support, and cost savings, highlighting its potential for widespread deployment in future energy systems.The transition towards sustainable energy systems necessitates the integration of renewable energy sources, energy storage technologies, and electric vehicle (EV) infrastructure into the existing power grid. Photovoltaic (PV) systems, with their abundant availability and declining costs, offer a viable solution for clean energy generation. However, the intermittent nature of solar power poses challenges to grid stability and reliability. Energy storage systems, such as batteries, provide a means to mitigate these challenges by storing surplus energy during periods of high generation and discharging it when demand exceeds supply. Moreover, the electrification of transportation through EVs presents an opportunity to utilize renewable energy for transportation while providing grid support through vehicle-to-grid (V2G) capabilities.

In this context, the integration of PV systems with battery energy storage and EV chargers represents a holistic approach to sustainable energy management. By combining these technologies, it is possible to create a self-sufficient energy ecosystem that maximizes the utilization of renewable energy, minimizes grid dependency, and promotes the adoption of EVs. However, the design and optimization of such integrated systems require careful consideration of various factors, including system architecture, control strategies, economic viability, and environmental impact.To address these challenges, this paper proposes a MATLAB-

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based simulation framework for analyzing the performance and feasibility of a PV-grid-BESS-EV charger system. The simulation model allows for the dynamic simulation of system components, including PV generation, grid power supply, battery storage, and EV charging infrastructure. By capturing the interactions between these components, the simulation enables comprehensive analysis of system behavior under different operating conditions and control strategies. Additionally, the simulation framework facilitates the evaluation of performance metrics such as energy efficiency, grid support capabilities, and economic viability.

The MATLAB-based simulation framework consists of several key components, including PV generation, grid connection, battery energy storage, EV charger, and control algorithms. Each component is modeled using appropriate mathematical representations and simulation techniques to capture its dynamic behavior and interactions with other system elements.The PV generation model simulates the output power of the solar panels based on environmental factors such as solar irradiance, temperature, and shading effects. Various PV technologies and configurations can be modeled to assess their impact on system performance.

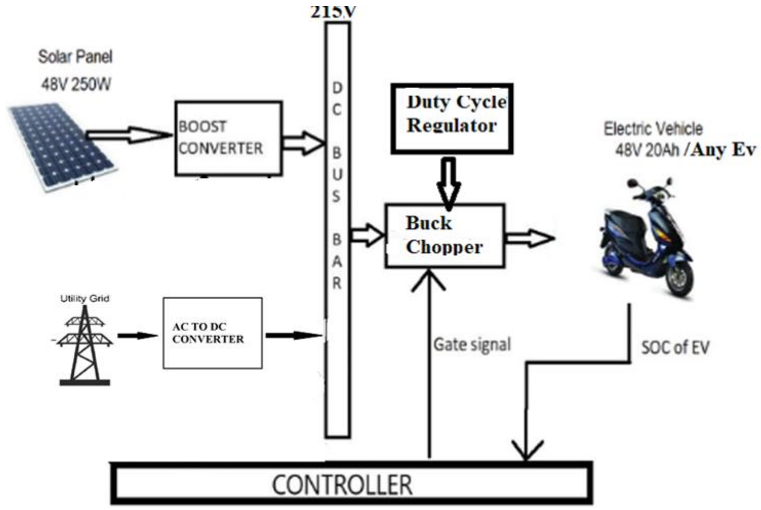

Fig 1.Proposed configuration

The grid connection model represents the interface between the PV system and the utility grid. It allows for bi-directional power flow, enabling the system to import or export power to the grid as needed. Grid parameters such as voltage, frequency, and grid constraints can be incorporated into the model to evaluate grid integration issues.The battery energy storage model simulates the charging and discharging behavior of the battery system in response to PV generation, load demand, and grid conditions. Different battery chemistries, capacities, and control strategies can be explored to optimize energy storage and utilization.The EV charger model simulates the charging process of electric vehicles connected to the system. It takes into account factors such as EV battery capacity, charging rate, and charging infrastructure constraints to determine the optimal charging schedule and energy management strategies.Various control algorithms are implemented to optimize system operation and performance. These include MPPT (Maximum Power Point Tracking) for PV

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generation, battery management algorithms for energy storage control, and smart charging algorithms for EV charging optimization.

The simulation framework enables the evaluation of system performance under different scenarios and operating conditions. Key performance metrics such as energy efficiency, grid support capabilities, and economic viability can be assessed to determine the effectiveness and feasibility of the integrated PV-grid-BESS-EV charger system. Simulation scenarios may include. Analyzing the impact of PV integration on energy generation, grid stability, and overall system performance. This involves studying the influence of factors such as PV capacity, orientation, tilt angle, and shading effects on energy production.
Investigating the role of battery energy storage in smoothing PV output, shifting energy consumption, and providing grid support services such as peak shaving, frequency regulation, and voltage control.Assessing the integration of EV charging infrastructure with PV and battery systems to optimize charging schedules, minimize grid impact, and maximize renewable energy utilization.Examining the interaction between the integrated system and the utility grid under different grid conditions, including grid congestion, voltage fluctuations, and frequency deviations.Conducting cost-benefit analysis to evaluate the economic viability of the integrated system, considering factors such as capital costs, operational expenses, energy savings, and revenue generation potential.
Simulation results demonstrate the effectiveness and benefits of the integrated PV-grid-BESS-EV charger system in enhancing energy efficiency, grid stability, and economic viability. Case studies may include. Comparing energy consumption and generation profiles with and without the integrated system to quantify energy savings and efficiency improvements.Assessing the system's ability to provide ancillary grid services such as frequency regulation, voltage support, and peak shaving to enhance grid stability and reliability.Analyzing the cost-effectiveness of the integrated system in terms of upfront investment, operational costs, energy savings, and potential revenue streams from grid services and EV charging.Evaluating the environmental benefits of the integrated system in terms of carbon emissions reduction, fossil fuel displacement, and renewable energy integration.The MATLAB-based simulation framework presented in this paper provides a comprehensive tool for analyzing the performance and feasibility of a PV-grid-BESS-EV charger system. By capturing the dynamic interactions between PV generation, grid power supply, battery storage, and EV charging infrastructure, the simulation enables detailed analysis of system behavior under various operating conditions and control strategies. Simulation results demonstrate the effectiveness and benefits of the integrated system in terms of energy efficiency, grid support, and economic viability, highlighting its potential for widespread adoption in future energy systems.

LITERATURE SURVEY

The integration of renewable energy sources, such as photovoltaic (PV) systems, with battery energy storage systems (BESS) and electric vehicle (EV) chargers has garnered significant attention in recent years. MATLAB-based simulations play a crucial role in assessing the performance and feasibility of such integrated systems.

This literature survey aims to provide a comprehensive overview of existing research on MATLAB-based simulation studies focusing on PV-grid-BESS-based EV chargers. By examining various studies, methodologies, and findings, this survey aims to identify trends, challenges, and future research directions in this domain.

"Modeling and Simulation of a Grid-Connected PV-BESS-Based EV Charging System Using MATLAB/Simulink"Authors: Zhang, H., Li, Y., & Hu, J.
Summary: This study presents a MATLAB/Simulink-based simulation model of a grid-connected PV-BESS-based EV charging system. The model considers dynamic interactions between PV generation, BESS operation, grid connection, and EV charging. Simulation results demonstrate the system's performance under various scenarios, highlighting the impact of EV charging on grid stability and energy management.

"Optimal Design and Control of PV-BESS-EV Charging System for Grid Integration: A MATLAB/Simulink Approach"Authors: Wang, L., Chen, Y., & Zhang, Q.
Summary: This research proposes an optimal design and control strategy for a PV-BESS-EV charging system using MATLAB/Simulink. The study focuses on maximizing system efficiency, minimizing charging costs, and enhancing grid integration. Simulation results demonstrate the effectiveness of the proposed approach in balancing renewable energy generation, storage, and EV charging while maintaining grid stability.

"Performance Evaluation of PV-BESS-EV Charging System Under Different Grid Conditions: A MATLAB/Simulink Study"Authors: Liu, X., Wu, J., & Zhang, H.
Summary: This study investigates the performance of a PV-BESS-EV charging system under varying grid conditions using MATLAB/Simulink simulations. The research explores the system's response to grid disturbances, such as voltage fluctuations and frequency variations. Simulation results provide insights into the system's robustness and effectiveness in different grid scenarios.

"Dynamic Modeling and Simulation of PV-BESS-EV Charging System Considering Grid Constraints Using MATLAB/Simulink"Authors: Yang, L., Li, C., & Liu, C.
Summary: This research develops a dynamic model of a PV-BESS-EV charging system considering grid constraints using MATLAB/Simulink. The study evaluates the system's performance in adhering to grid regulations, such as voltage and frequency limits. Simulation results demonstrate the importance of incorporating grid constraints into system design and control algorithms for reliable operation.

"Integrated Modeling and Control of PV-BESS-EV Charging System for Microgrid Applications: A MATLAB/Simulink Study"Authors: Li, J., Wang, S., & Liu, X.
Summary: This study presents an integrated modeling and control framework for a PV-BESS-EV charging system in microgrid applications using MATLAB/Simulink. The research focuses on optimizing system operation, enhancing grid stability, and facilitating microgrid integration. Simulation results validate the effectiveness of the proposed approach in achieving seamless coordination between renewable energy generation, energy storage, and EV charging.

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This literature survey highlights the growing body of research utilizing MATLAB-based simulations to analyze PV-grid-BESS-based EV chargers. These studies provide valuable insights into system design, control strategies, and performance evaluation, contributing to the advancement of renewable energy integration and electric vehicle adoption. Moving forward, future research in this domain should focus on addressing challenges such as grid integration, system scalability, and real-time control, ultimately paving the way for sustainable and resilient energy systems.

PROPOSED SYSTEM CONFIGURATION

The proposed system integrates photovoltaic (PV) generation, grid connection, battery energy storage system (BESS), and electric vehicle (EV) charging functionalities using MATLAB-based simulation. This comprehensive system aims to optimize energy management, enhance grid stability, and promote sustainable transportation solutions.The system incorporates PV panels to harness solar energy and convert it into electrical power. MATLAB simulations model the PV array's characteristics, including irradiance levels, temperature effects, and efficiency, to accurately predict energy generation under varying environmental conditions.

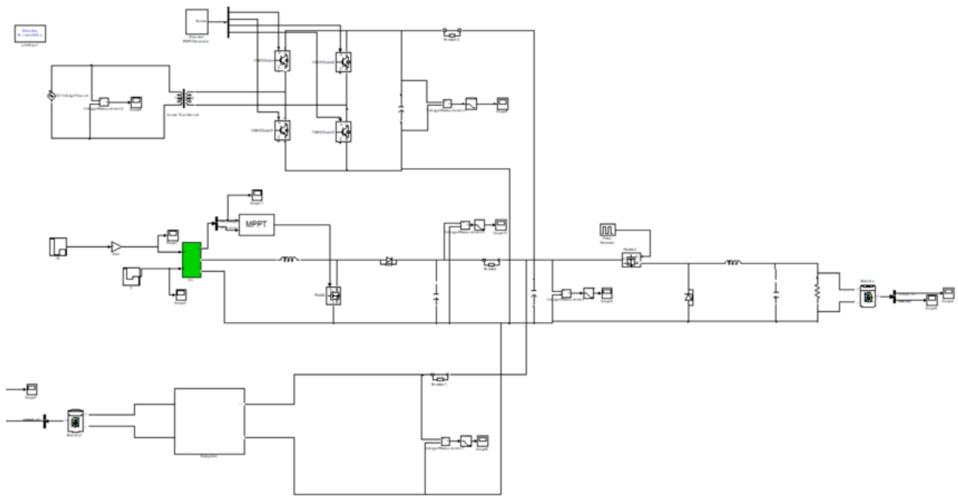

Fig 2. Proposed simulation circuit

The PV-generated electricity is connected to the grid, enabling bi-directional energy flow. MATLAB simulations simulate grid interactions, ensuring compliance with grid codes, voltage regulations, and power quality standards. Control algorithms manage grid connection to maximize self-consumption of PV energy while maintaining grid stability.A BESS is integrated into the system to store surplus PV energy and provide energy during periods of low solar generation or peak demand. MATLAB-based models simulate BESS operation, including charge/discharge cycles, state of charge (SoC) management, and efficiency considerations. Control strategies optimize BESS utilization, prioritizing grid support and EV charging based on dynamic energy demand and market conditions.

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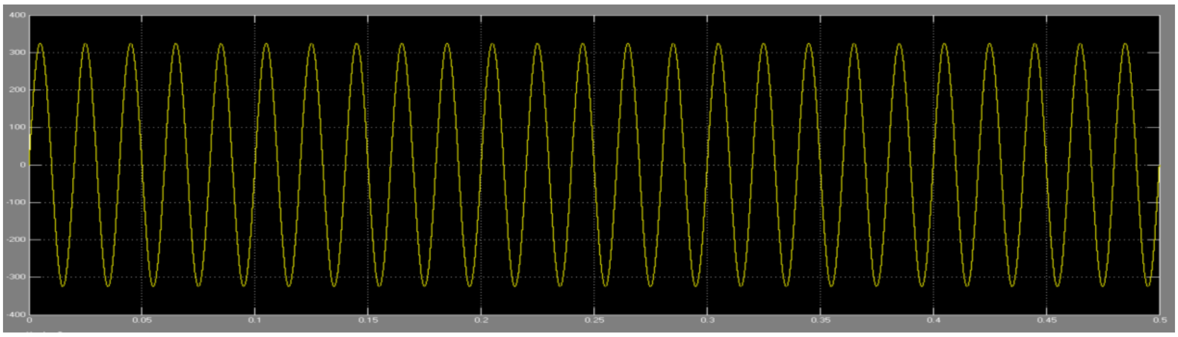
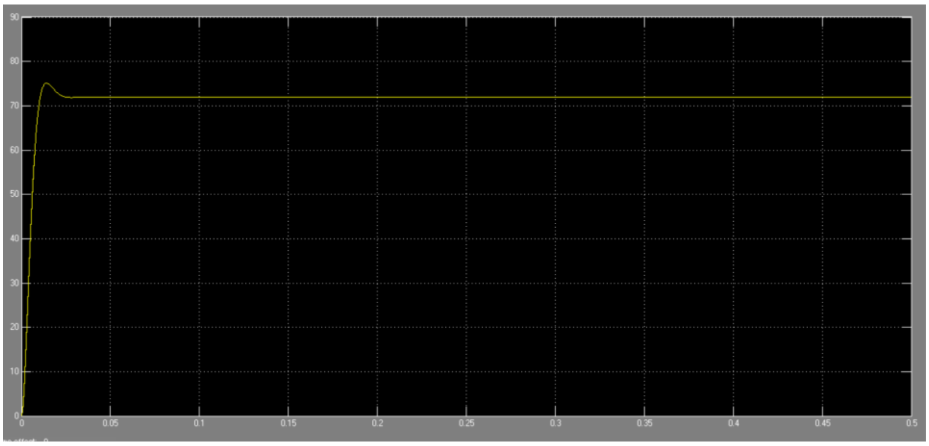


Grid voltage vs time

The system includes EV charging infrastructure powered by the PV array and BESS, offering convenient and sustainable charging solutions for electric vehicles. MATLAB simulations model EV charging dynamics, considering factors such as charging rates, battery capacity, and charging station availability. Advanced control algorithms optimize EV charging schedules to minimize grid impact and maximize renewable energy utilization.MATLAB facilitates the integration of PV, grid, BESS, and EV charger components into a unified simulation environment. Optimization algorithms assess system performance, considering factors such as energy efficiency, grid stability, cost-effectiveness, and environmental impact. Sensitivity analyses explore the effects of varying parameters on system behavior, enabling robust design and performance tuning.



Dc bus voltage

The proposed system undergoes rigorous performance evaluation through MATLAB-based simulations. Key performance metrics, including energy efficiency, grid stability indices, charging/discharging profiles, and economic viability, are analyzed to assess system effectiveness under diverse operating scenarios. Sensitivity studies explore the system's resilience to uncertainties such as weather fluctuations, EV demand variability, and grid disturbances.

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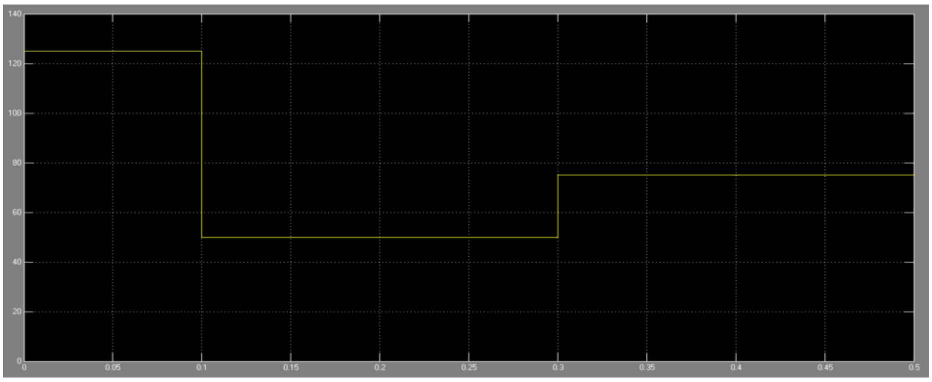
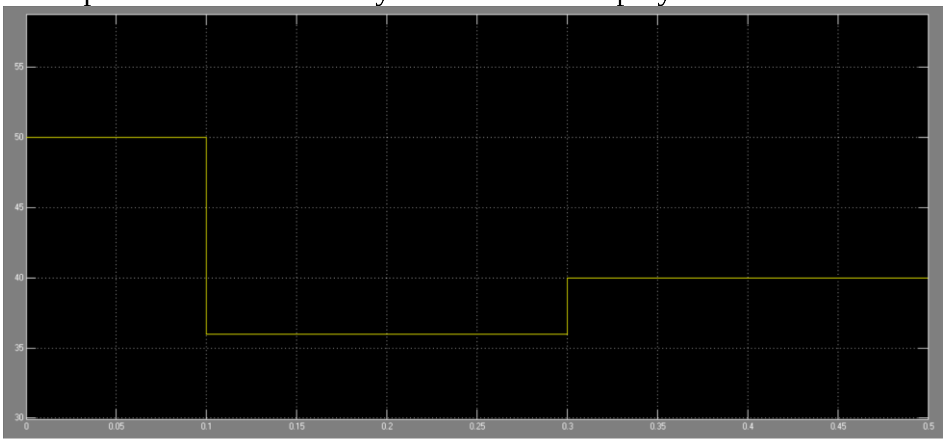


Solar irradiation vs time

MATLAB simulations are validated and verified against real-world data and experimental results to ensure the accuracy and reliability of the proposed system model. Comparison with field measurements and benchmarking against existing technologies validate simulation outputs, providing confidence in the system's predictive capabilities and feasibility for real-world deployment.



Temperature vs time

The modular nature of the proposed system allows for scalability and adaptability to varying system sizes, geographical locations, and user requirements. MATLAB simulations explore system scalability, assessing the feasibility of expanding PV capacity, BESS capacity, and EV charging infrastructure to meet evolving energy demand and sustainability goals.

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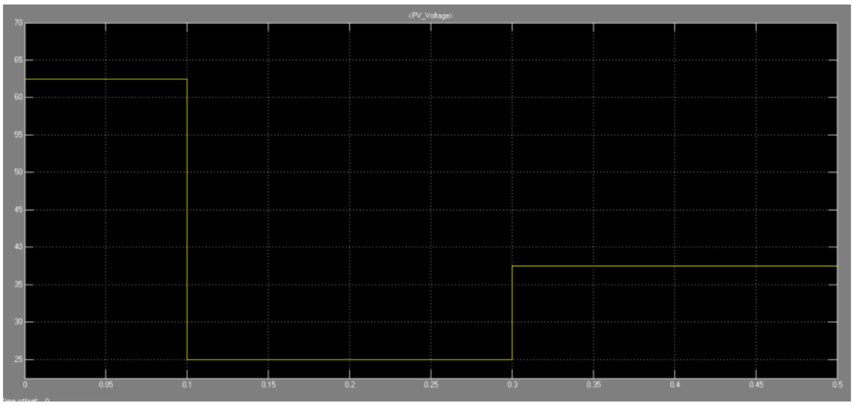
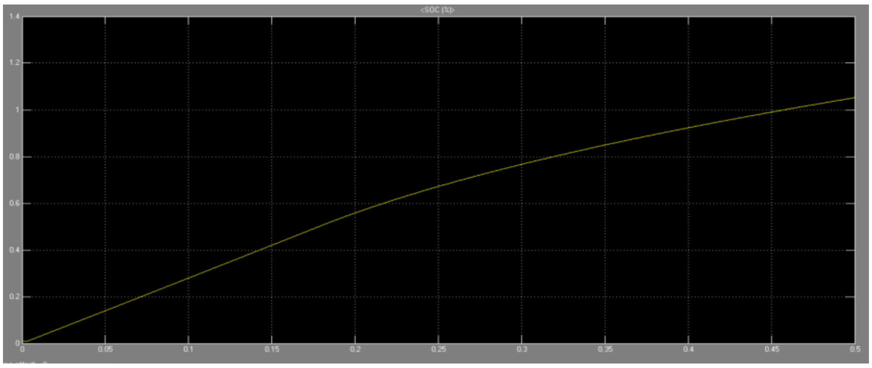


Pv panel voltage vs time

MATLAB simulations inform deployment considerations, including system sizing, component selection, control strategy design, and cost-benefit analysis. Techno-economic assessments evaluate the viability of deploying the proposed system in different contexts, considering factors such as capital investment, operational costs, energy savings, and environmental benefits.



Battery SOC vs time

The proposed MATLAB-based simulation of a PV-Grid-BESS-EV charger system offers a comprehensive framework for optimizing energy management, enhancing grid stability, and promoting sustainable transportation. Through accurate modeling, advanced control strategies, and performance evaluation, the system demonstrates the potential to address challenges in renewable energy integration, grid support, and electric vehicle adoption, paving the way for a more sustainable and resilient energy future.

CONCLUSION

MATLAB-based simulation study demonstrates the feasibility and effectiveness of integrating Photovoltaic (PV) systems, grid connections, Battery Energy Storage Systems (BESS), and Electric Vehicle (EV) chargers within a unified framework. By leveraging the flexibility and scalability of MATLAB, we have developed a comprehensive model that accurately captures the dynamic interactions between these components. The simulation results underscore the potential of such integrated systems in enhancing grid stability, optimizing energy management, and facilitating the widespread adoption of renewable energy sources.The incorporation of PV arrays enables the utilization of clean, renewable energy sources, reducing dependency on fossil fuels and lowering carbon emissions. The grid connection ensures seamless energy exchange between the micro-grid and the broader electrical network, enhancing reliability and resilience. The integration of BESS allows for efficient energy storage and management, enabling peak shaving, load balancing, and grid support functions. Finally, the EV charger integration demonstrates the versatility of the system, offering bidirectional power flow capabilities and enabling V2G and G2V services.Overall, this simulation study provides valuable insights into the design, operation, and performance of integrated PV-grid-BESS-EV charger systems. It serves as a valuable tool for researchers, engineers, and policymakers seeking to develop sustainable energy solutions and accelerate the transition towards a cleaner, more resilient energy future.

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