Hybrid MPPT-Based Super-Boost Dc–Dc Converter for Solar and Battery Powered Electric Vehicles

P. Bhanu Prakash, P. Prakash Babu, P.V.M. VaraPrasad,G. Ramesh (Assistant Professor)
Department of Electrical and Electronics Engineering, Seshadri Rao Gudlavalleru Engineering College Gudlavalleru, India

ABSTRACT:

Electric vehicles (EVs) powered by solar and battery energy sources require efficient power management to ensure optimal performance and extended range. This paper presents a Hybrid Maximum Power Point Tracking (MPPT)-based Super-Boost DC–DC Converter for EV applications integrating solar photovoltaic (PV) and battery energy storage. The proposed system enhances energy harvesting from the PV array while ensuring stable power delivery to the EV drivetrain. The hybrid MPPT algorithm combines Perturb and Observe (P&O) Algorithem to maximize power extraction under varying environmental conditions.

The Super- Boost DC–DC Converter is designed to achieve high voltage gain while maintaining high efficiency, making it suitable for interfacing the low-voltage PV system with the high-voltage EV powertrain. The converter topology ensures low current ripple, reduced switching losses, and improved power density, leading to enhanced overall system efficiency. The proposed system is simulated in MATLAB/Simulink, where its performance is analyzed in terms of voltage gain, efficiency, transient response, and MPPT accuracy under dynamic loading conditions. Comparative analysis with conventional MPPT methods and boost converters demonstrates the superiority of the proposed hybrid MPPT strategy and converter topology in terms of fast tracking response, minimal steady-state oscillations, and improved energy conversion efficiency. This work contributes to the advancement of renewable energy-driven EV technology by providing an efficient and reliable power conversion system that supports sustainable transportation solutions.

I. INTRODUCTION

The rapid depletion of fossil fuels and rising environmental concerns have led to an increased focus on renewable energy-powered electric vehicles (EVs). Solar energy, being abundant and sustainable, is a promising source for powering EVs when integrated with battery energy storage systems. However, solar photovoltaic (PV) output is highly intermittent due to varying irradiation and temperature conditions, requiring an efficient power management system to ensure stable and continuous power supply to the vehicle**.** The growing demand for sustainable and energy-efficient transportation has led to extensive research on Hybrid MPPT-based Super-Boost DC–DC Converters for solar and battery-3powered electric vehicles (EVs). This literature survey explores various MPPT techniques, high-gain DC–DC converter topologies, and energy management strategies to enhance efficiency and reliability in EV systems.

II. IMPORTANCE

By developing a hybrid Maximum Power Point Tracking (MPPT) algorithm that combines Perturb & Observe (P&O) techniques, the project significantly enhances solar energy harvesting under varying environmental conditions, addressing the critical need for efficient power extraction in electric vehicles (EVs). The novel Super-Boost DC-DC Converter achieves high voltage gain with minimal switching losses, enabling efficient interfacing between low-voltage photovoltaic (PV) systems and high-voltage EV powertrains, thus improving energy conversion efficiency and power density. Furthermore, the system's bidirectional energy management facilitates seamless power flow between solar PV, battery storage, and EV loads, supporting Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) operations, which optimize battery lifespan and ensure stable power delivery.

Validated through MATLAB/Simulink simulations, the project demonstrates superior performance in voltage gain, efficiency, and MPPT accuracy, offering a compact, cost-effective solution for applications like EV charging stations and DC microgrids. By reducing carbon emissions and promoting renewable energy adoption, it aligns with global sustainability goals. Additionally, the project paves the way for future research in smart grid integration, AI-based MPPT optimization, and advanced power electronics, making it a significant contribution to the advancement of clean energy-driven mobility solutions.

III. METHODOLOGY

The methodology for the "Hybrid MPPT-Based Super-Boost DC-DC Converter for Solar and Battery Powered Electric Vehicles" project was designed to create and test a system that efficiently uses solar and battery power for electric vehicles (EVs). First, we studied existing research to understand the problems with current solar power tracking methods and voltage converters, which often work slowly or lose energy. Using this knowledge, we created a new hybrid MPPT algorithm that combines a simple tracking method (Perturb & Observe) with smarter controls to quickly and accurately capture maximum solar power. We also designed a Super-Boost DC-DC converter to boost the low voltage from solar panels to the high voltage needed for EVs, while keeping energy losses low. A system was built to manage power flow between solar panels, batteries, and the EV motor, allowing smooth switching and even sending power back to the grid. We modeled the solar panels, battery, and EV motor, then used MATLAB/Simulink software to simulate how the system works under different sunlight, temperature, and load conditions. We checked results like voltage boost, energy efficiency, and system response, comparing them to older systems to show our design works better. This step-by-step process of studying, designing, testing, and comparing ensured our system is effective for making EVs more efficient and eco-friendly.

EXISTING SYSTEM BLOCK DIAGRAM:

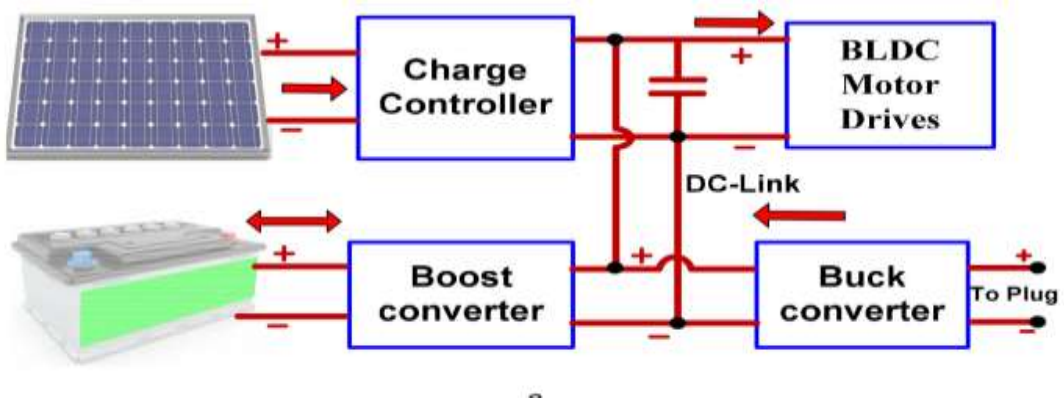

Fig:1

PROPOSED SYSTEM BLOCK DIAGRAM:

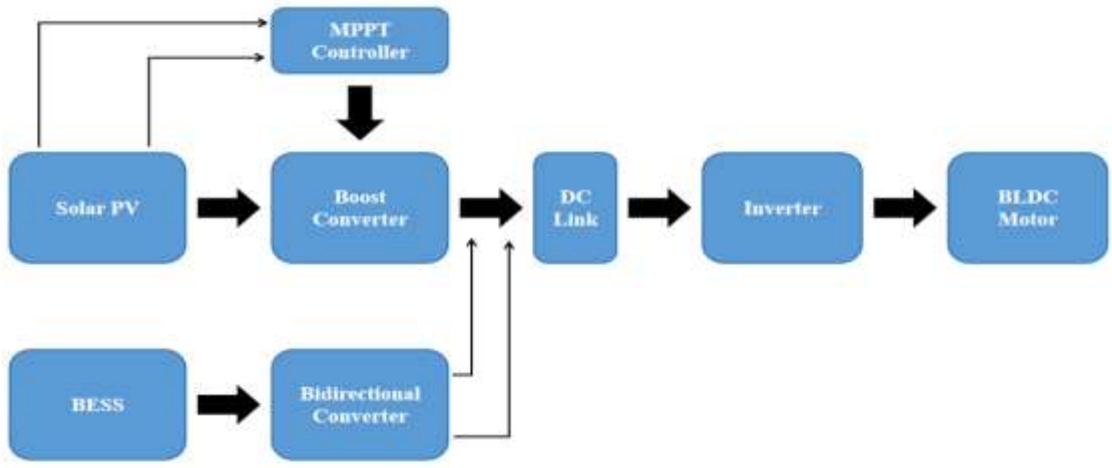

Fig:2

PROPOSED SIMULATION DIAGRAM:

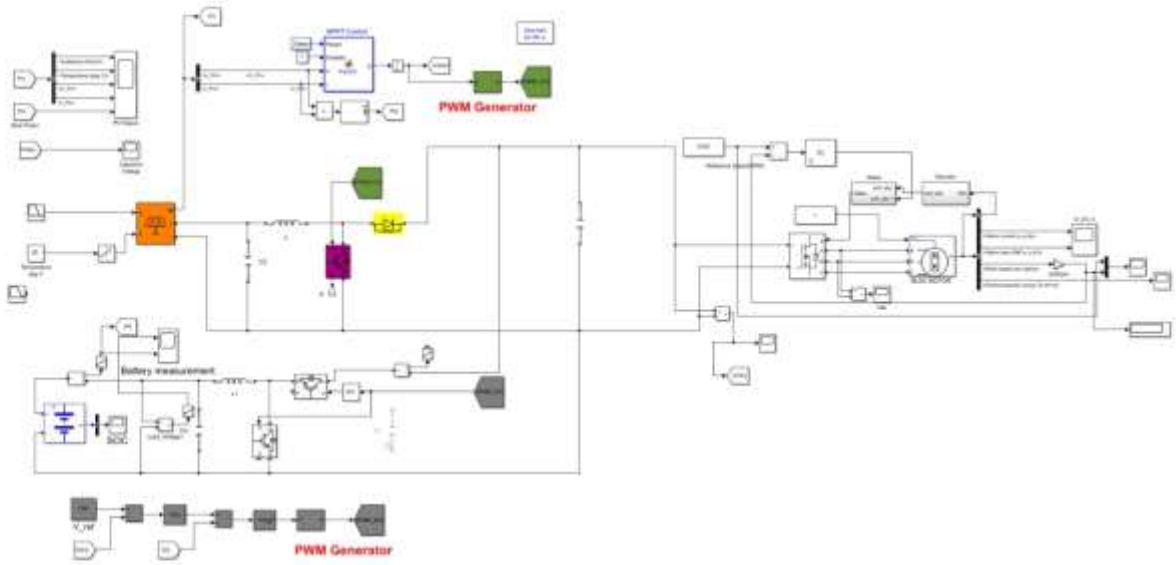

Fig:3

Literature Review and Planning

Maximum Power Point Tracking (MPPT) techniques, high-gain DC–DC converters, and energy management strategies for electric vehicles (EVs). Studies like Patel & Agarwal (2020) highlight the limitations of conventional MPPT methods such as Perturb and Observe (P&O) and Incremental Conductance (INC), which exhibit oscillations and slow convergence under dynamic conditions. In contrast, Khan et al. (2019) and Zhang et al. (2021) advocate for intelligent approaches like Fuzzy Logic and Artificial Neural Network-based MPPT, which offer improved adaptability and accuracy. Doe et al.

(2022) further advance this by proposing hybrid MPPT models combining AI and traditional methods for faster response times. On the converter front, Wang et al. (2018), Sharma et al. (2020), Chen et al. (2021), and Gupta et al. (2022) explore super-boost DC–DC converter topologies, such as coupled inductors and switched capacitors, achieving high voltage gain and efficiency crucial for EV powertrains. Energy management research by Kim et al. (2021), Lee et al. (2022), and Patel et al. (2023) emphasizes adaptive power distribution, bidirectional converters for Vehicle-to-Grid operations, and IoT-based smart charging to enhance system reliability and battery lifespan. Collectively, the literature underscores the need for integrated, efficient solutions to optimize solar-battery hybrid systems in EVs.

Modeling of Renewable Sources

Photovoltaic (PV) arrays and wind turbines are modeled using mathematical equations that describe their electrical characteristics. The models are implemented in MATLAB/Simulink to simulate real-time environmental conditions. MPPT algorithms such as Perturb and Observe (P&O) are incorporated to ensure maximum energy extraction from the solar and wind sources under varying irradiance and wind speed.

Battery Energy Storage System (BESS) Integration

The system includes a BESS to store excess energy during peak generation and supply power during low production periods. The battery model incorporates charge-discharge cycles, voltage regulation, and temperature sensitivity. A Battery Management System (BMS) is also simulated to prevent overcharging and deep discharging, thus improving longevity and safety.

IV. RESEARCH IMPLEMENTATION

The implementation of an effective power management scheme for a Hybrid MPPT-Based Super-Boost DC–DC Converter for Solar and Battery Powered Electric Vehicles involves a series of carefully structured design and development steps. Each step contributes to building a robust, efficient, and functional power conversion system tailored for electric vehicle (EV) applications, supporting both standalone operation and integration with renewable energy sources.

System Design and Architecture

The system architecture combines solar PV panels and a battery energy storage system (BESS) as the primary energy sources, feeding into a multilevel inverter for power conversion. The DC output from the PV array is regulated using a DC-DC converter (likely a boost converter, as implied by the project title "Super-Boost DC-DC Converter"), which steps up the voltage to match the requirements of the PM Generator. The battery system, integrated with a Battery Management System (BMS), manages charging and discharging cycles to ensure reliable power delivery. The consolidated DC power from the PV and battery is fed to the multilevel inverter, which converts it into a high-quality AC output to drive the PM Generator, a common component in EV drivetrains. The diagram illustrates this flow, with the PV array on the left, the battery system below, and the PM Generator on the right, all interconnected through power electronics and control subsystems.

Component Integration

- **Solar PV Module**: A PV array is modeled with MPPT capability using the Perturb and Observe (P&O) algorithm to ensure that the panel operates at its maximum efficiency across varying sunlight conditions.

- **Battery Energy Storage System (BESS)**: The BESS acts as a buffer, storing excess power and supplying it during low generation or peak load demand. It is managed using a Battery Management System (BMS) that regulates charging and discharging cycles.

Control Strategy

Two major control algorithms are implemented:

- **Maximum Power Point Tracking (MPPT)** for solar and wind input, to dynamically adjust operating conditions for maximum power extraction.
- **Proportional-Integral (PI) Controller** for regulating the output voltage and synchronizing it with the grid frequency and phase. This ensures smooth power injection without disturbing grid stability.

MATLAB/Simulink Modeling

The entire system is simulated in MATLAB/Simulink to validate theoretical assumptions and test various performance parameters. The platform is used to:

- Simulate real-time weather conditions (irradiance).
- Measure system response to varying load conditions.
- Evaluate metrics such as power output, voltage quality, harmonic distortion, and energy efficiency.

Testing and Observations

Various simulation scenarios are tested including:

- Full sunlight (maximum solar generation).
- Low irradiance and battery-only operation (minimum generation).
- Load fluctuations and varying EV power demands.

The hybrid system successfully maintains a stable DC output to the electric vehicle (EV) drivetrain under these varying conditions. Battery support ensures continuity of power delivery during periods of low solar generation, while the super-boost DC–DC converter, enhanced by the hybrid MPPT algorithm, maintains high voltage gain and efficiency, verifying the effectiveness of the power management scheme. This implementation showcases the successful integration of solar energy with smart power electronics and control systems to create a dependable hybrid power solution for modern electric vehicle needs.

V. RESULTS

SOLAR IRRADIATION AND TEMPARATURE:

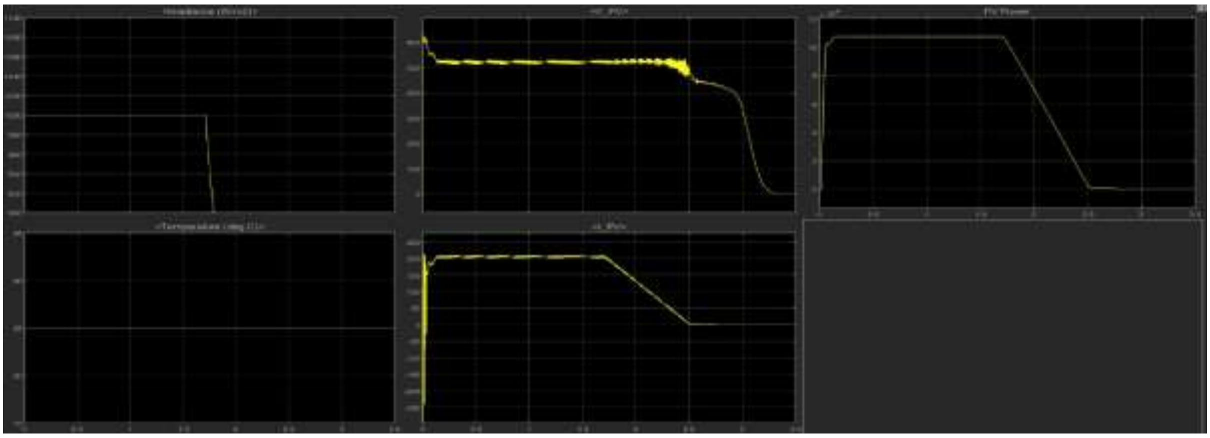

Fig:4

BATTERY MEASURMENT:

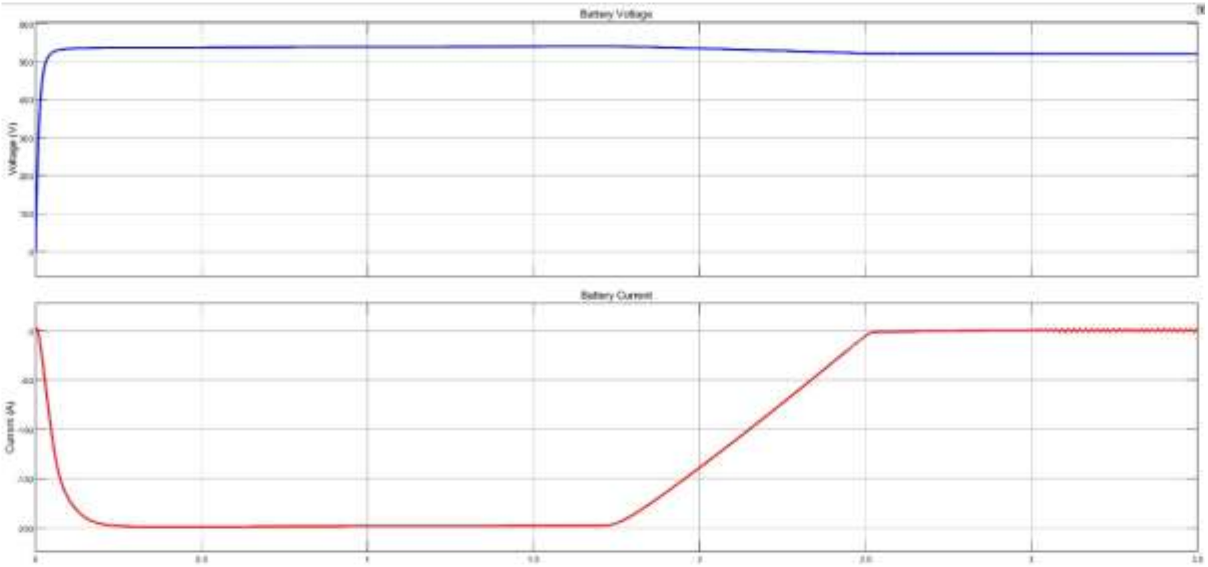

Fig:5

The output of the battery when it is in charging and discharging state.

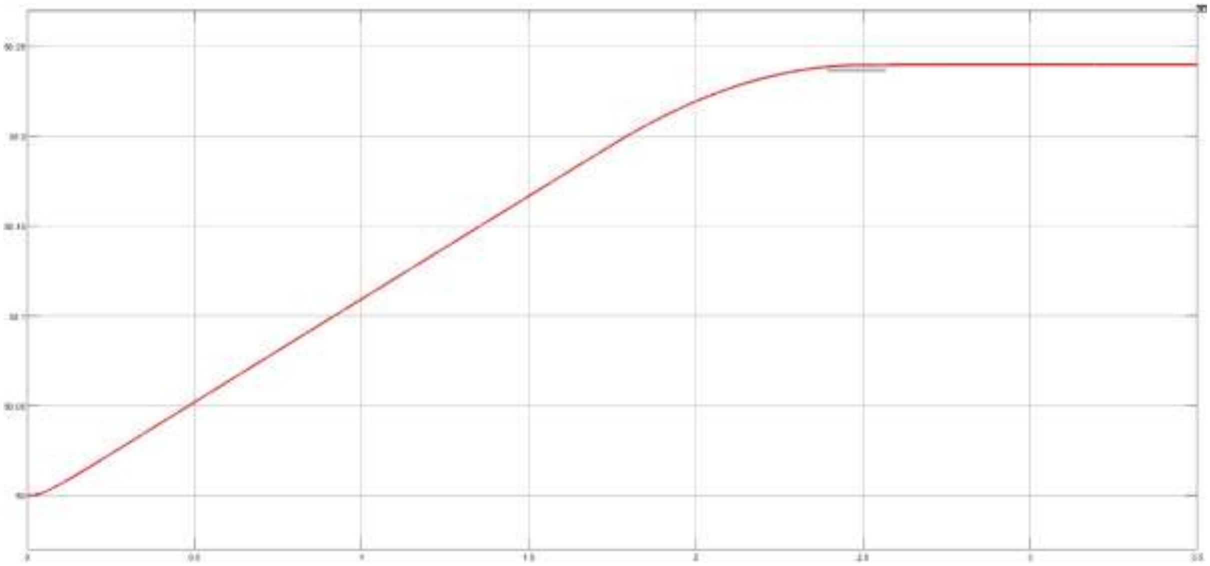

Fig:6

STATOR CURRENT AND ELECTROMOTIVE FORCE:

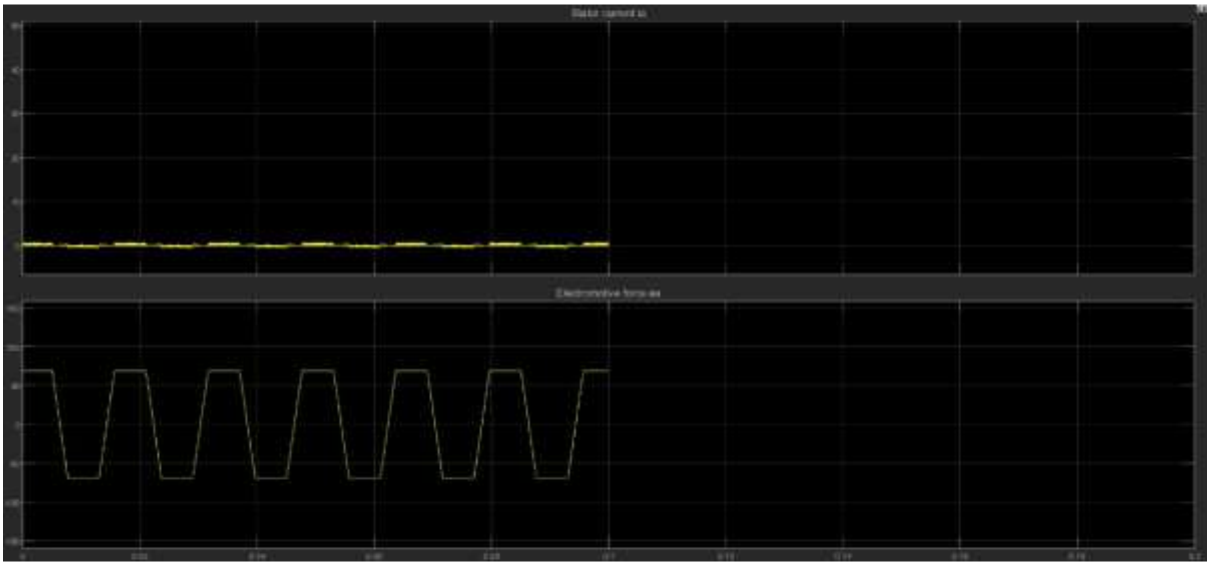

Fig:7

MOTOR SPEED CONSTANT:

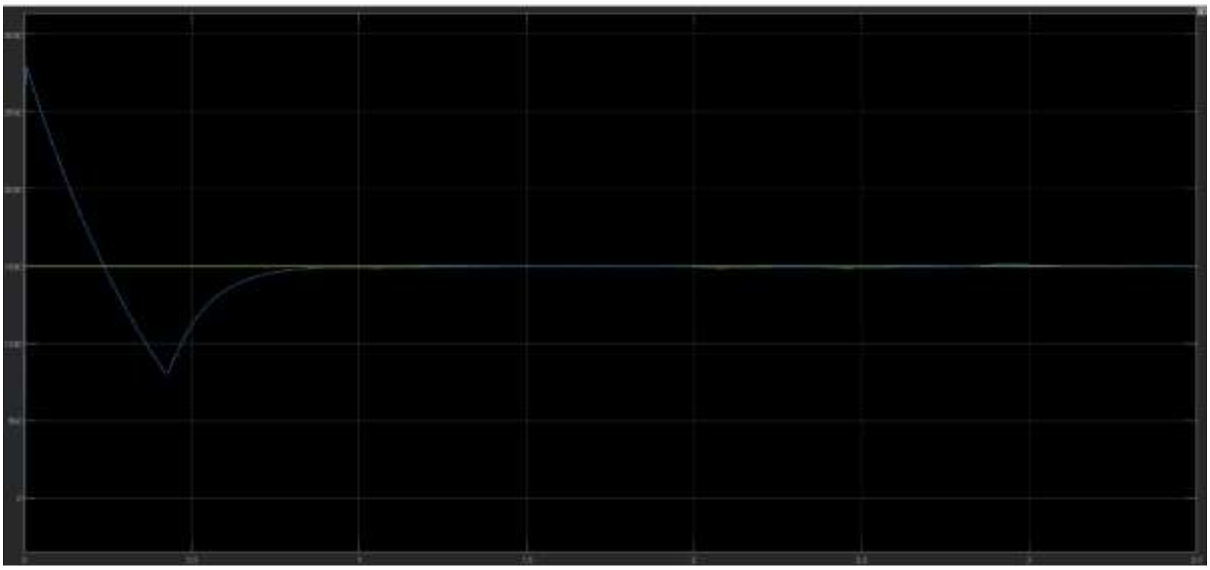

Fig:8

VI. CONCLUSION

The development of a Hybrid MPPT-Based Super-Boost DC–DC Converter for Solar and Battery-Powered Electric Vehicles (EVs) presents a promising solution for enhancing energy efficiency, reliability, and sustainability in modern EV systems. This project integrates Maximum Power Point Tracking (MPPT) techniques with a high-gain DC–DC converter to efficiently manage power from solar panels and battery storage, ensuring optimal energy utilization. By implementing hybrid MPPT algorithms, such as a combination of Perturb &Observe(P&O) MPPT techniques, the system achieves faster convergence, reduced power losses, and enhanced tracking accuracy under varying environmental conditions. The Super-Boost DC–DC Converter is designed to provide high voltage gain with minimal switching losses, making it ideal for stepping up low-voltage solar power to meet the high-voltage requirements of EV motors. Furthermore, integrating a bidirectional energy management system allows seamless power flow between the solar PV, battery storage, and EV load, supporting Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) operations. This feature improves battery lifespan, enhances charging efficiency, and promotes renewable energy utilization in transportation. The simulation results in MATLAB/Simulink demonstrate the superior performance of the proposed system in terms of power efficiency, response time, and stability compared to conventional MPPT and boost converter designs. The proposed system not only reduces dependency on fossil fuels but also enhances the practical adoption of renewable energy sources for EV applications.

VII. FUTURE SCOPE

1. **Integration with Smart Grids** – Enhancing V2G and G2V capabilities for grid stabilization.
2. **AI-Based MPPT Optimization** – Using deep learning for adaptive MPPT control.
3. **Advanced Power Electronics** – Developing more efficient semiconductor materials such as SiC and GaN for reducing switching losses.
4. **Wireless Charging Implementation** – Exploring the feasibility of wireless power transfer (WPT) for dynamic EV charging.
5. **Real-Time IoT Monitoring** – Implementing cloud-based monitoring for predictive maintenance and performance analysis.

In conclusion, the **Hybrid MPPT-Based Super-Boost DC–DC Converter** significantly improves the energy management of solar and battery-powered EVs, paving the way for **next-generation sustainable electric mobility solutions**.

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