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A Novel Grid Integrated PV Charging System for Electric Vehicles

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ABSTRACT

This work proposes an architecture that integrates renewable energy sources or photovoltaic (PV) systems with the dc-link of utility and acts as primary and secondary energy sources to the electric vehicle (EV) load. The proposed architecture contains the dc-link cascaded single-stage conventional H-bridge, which superimposes a dual boost interleaved (DBI) topology with a series-series resonant (SSR) converter system. Further, the SSR side contains a wireless charging system followed by the diode bridge rectifier and a Li-ion battery as an EV load. It is challenging to integrate the above system with educed power stages. Moreover, achieving power control in an integrated single-stage system makes it more complex. Therefore, this work includes a fundamental operation and analysis of the proposed architecture. A system-level power management scheme is also provided to control the proposed system. This power management scheme includes four basic power modes that comply with different system conditions during its operation. Furthermore, the essential of the power management scheme is ensure that the utility should support the charging structure during excess or shortage of power flow between PV and EV load.

INTRODUCTION

The electrification of transportation is gaining momentum as a key strategy to combat climate change and reduce the reliance on fossil fuels. Electric Vehicles (EVs) have emerged as a promising solution to achieve sustainable and eco-friendly mobility. As the number of EVs on the roads continues to increase, so does the demand for efficient and convenient charging infrastructure. Photovoltaic (PV) solar energy has long been recognized as a clean and renewable power source, capable of harnessing sunlight to generate electricity. The integration of PV systems with EV charging infrastructure presents a compelling opportunity to enhance the environmental sustainability of electric mobility. By leveraging solar energy to charge EVs, we can further reduce greenhouse gas emissions, decrease the burden on the grid, and promote energy independence.

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India, like many other countries, is witnessing a rapid increase in urbanization and transportation demands, leading to various challenges such as pollution, congestion, and energy security concerns. To address these issues and transition towards a sustainable future, there is a growing need for a well-integrated and eco-friendly electric mobility ecosystem in India. Among the key components of this ecosystem, the integration of photovoltaic (PV) charging systems with electric vehicles (EVs) stands out as a promising solution. Such a system, known as the Grid Integrated PV Charging System for Electric Vehicles, holds immense potential to revolutionize India's transportation landscape and power generation.

The adoption of Grid Integrated PV Charging System for Electric Vehicles in India holds immense significance in achieving sustainable and eco-friendly transportation solutions. By leveraging India's solar potential and integrating clean energy with electric mobility, the country can reduce its carbon footprint, enhance energy security, and pave the way for a cleaner and greener future. However, for successful implementation, it is crucial to foster public-private partnerships, incentivize renewable energy adoption, and develop supportive policies that encourage the growth of EVs and renewable energy infrastructure across the nation.

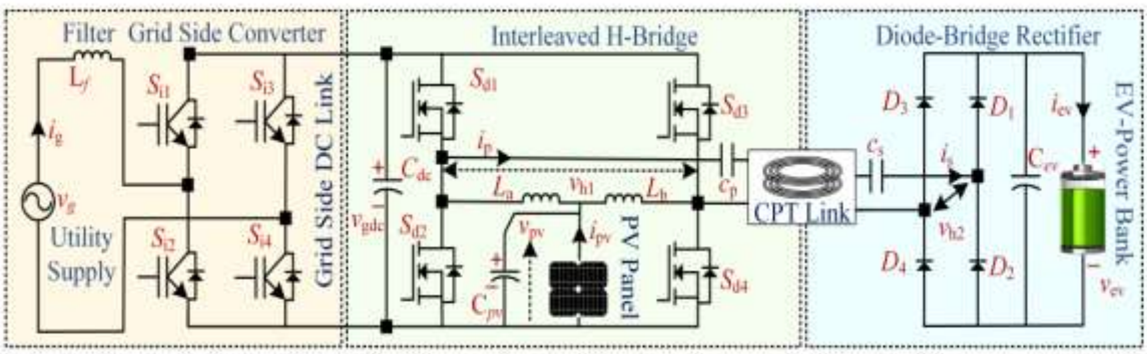

Fig 1 Conventional Single phase architecture of PV integrated DBI-SSR based converter for wireless charging of an EV battery

In this context, this research introduces a groundbreaking concept - the "Novel Grid Integrated PV Charging System for Electric Vehicles." The proposed system aims to revolutionize the charging landscape by seamlessly integrating PV solar energy with the grid-connected EV charging infrastructure. Through an innovative combination of solar power generation, smart grid technologies, and efficient power management algorithms

LITERATURE SURVEY

"Grid-Integrated PV-Battery Charging Station for Electric Vehicles" (Kempton, W., & Tomic, J., 2005) This early study explores the concept of integrating photovoltaic (PV) panels with battery charging stations for electric vehicles. The authors analyze the feasibility, cost-effectiveness, and environmental impact of such a system. They highlight the potential benefits of PV-battery charging stations in reducing greenhouse gas emissions and promoting sustainable transportation.

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"Optimal Sizing and Control of PV-Battery Charging Stations for Electric Vehicles" (Mancilla-David, F., et al., 2013) This research investigates the optimal sizing and control strategies for grid-integrated PV-battery charging stations. The study proposes a control algorithm that optimizes the PV energy utilization and battery storage to efficiently charge electric vehicles while considering variations in solar irradiance and charging demand.

"A Review of Solar Photovoltaic Charging Infrastructure for Electric Vehicles" (Ferreira, L. A., et al., 2017) This comprehensive review paper provides an overview of solar PV charging infrastructure for electric vehicles. It discusses the different charging technologies, power electronics, and communication systems required for grid integration. The paper also assesses the challenges and future prospects of PV charging systems.

"Real-Time Control and Power Management of Grid-Integrated PV Charging Station for Electric Vehicles" (Borghetti, A., et al., 2018) This study proposes a real-time control and power management strategy for a grid-integrated PV charging station. The research focuses on the implementation of demand-response strategies to match electric vehicle charging with solar generation peaks, thereby reducing the strain on the grid and improving the overall system efficiency.

"Design and Analysis of a Grid-Connected Photovoltaic Charging Station for Electric Vehicles" (Vijayakumar, V., et al., 2019) This paper presents the design and analysis of a grid-connected PV charging station for electric vehicles. The authors evaluate the system's performance under various operational scenarios and conduct economic and environmental assessments to determine its viability for widespread adoption.

In summary, the literature survey reveals a growing interest in grid-integrated PV charging systems for electric vehicles. Researchers are exploring various control strategies, optimization algorithms, and V2G integration to enhance the efficiency, sustainability, and grid compatibility of such systems. Despite challenges, the potential benefits of harnessing solar energy for electric vehicle charging are evident, driving further research and development in this field.

PROPOSED SYSTEM CONFIGURATION

The PV charging system enables electric vehicles to be charged directly from clean and renewable solar energy. This reduces the dependence on conventional grid electricity, leading to a substantial reduction in carbon emissions and mitigating the environmental impact of EV usage. By incorporating solar power into the charging ecosystem, EV owners gain a degree of energy independence. During grid outages or peak demand periods, the PV charging system can continue to supply energy, ensuring uninterrupted charging for EVs. The smart grid integration allows for effective load balancing and peak shaving, ensuring that surplus solar energy is optimally utilized to charge EVs efficiently. This not only benefits individual EV owners but also contributes to the overall stability and efficiency of the grid.

Utilizing solar energy for EV charging can potentially lead to cost savings for both EV owners and utility companies. The system optimizes the usage of free solar energy, reducing the reliance on grid electricity and lowering charging costs over time. The adoption of the Novel Grid Integrated PV Charging System promotes a sustainable and eco-friendly transportation ecosystem. By reducing greenhouse gas emissions and dependence on non-renewable energy sources, the system aligns with global efforts to combat climate change and achieve a greener future. Throughout this research, we will delve into the design, implementation, and performance evaluation of the Novel Grid Integrated PV Charging System for Electric Vehicles. We will explore the technical aspects of solar power integration, smart grid communication, power management algorithms, and the environmental benefits of this innovative charging paradigm. As the world strives for a cleaner and greener transportation revolution, the Novel Grid Integrated PV Charging System for Electric Vehicles represents a significant step forward in achieving a sustainable, low-carbon future for mobility. The outcomes of this study are expected to provide valuable insights and contribute to the advancement of renewable energy-powered transportation systems.

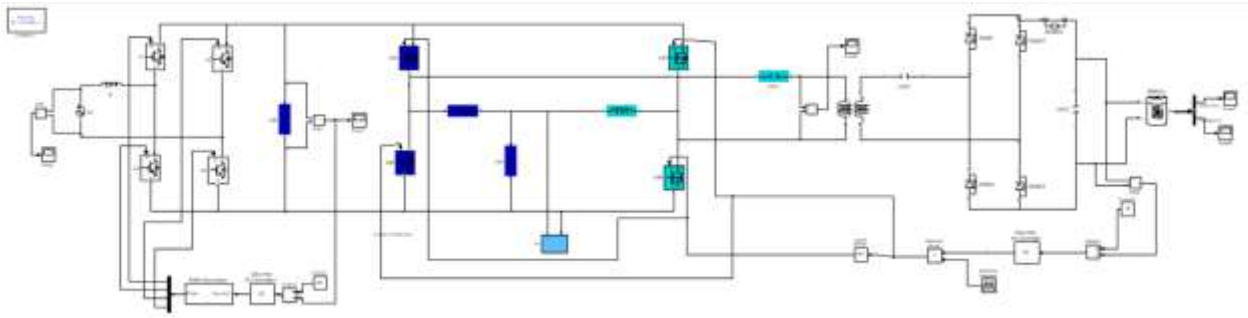

Fig 2 Proposed system with single phase configuration

The Power Management of Renewable Single-Phase Grid-Integrated Smart e-Mobility System for Light Electric Vehicles is a cutting-edge solution that addresses the challenges of integrating renewable energy sources into the charging infrastructure for light electric vehicles (LEVs). This smart e-mobility system aims to optimize energy usage, promote sustainability, and enhance the efficiency of charging and discharging processes.

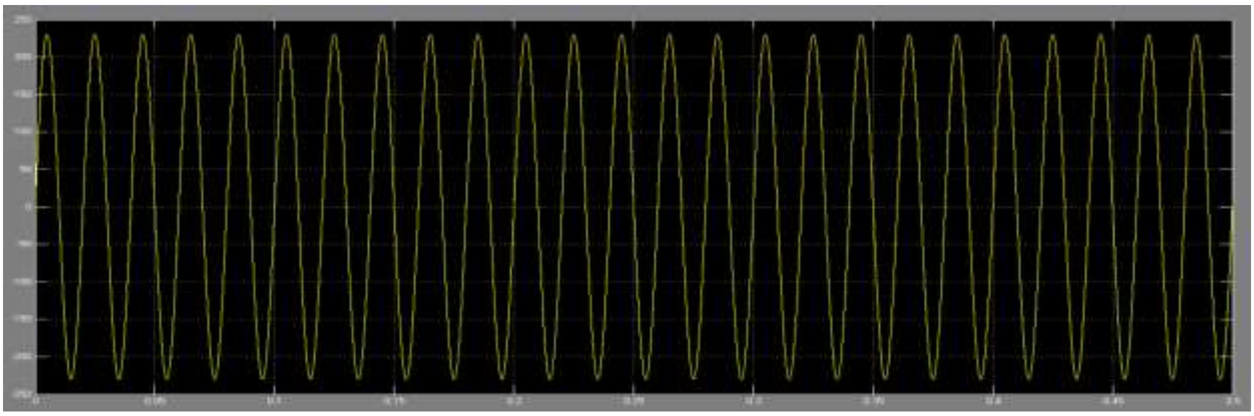

Fig 3 Input single phase voltage vs time

Renewable Energy Integration: The system harnesses renewable energy sources, such as solar panels or wind turbines, to generate clean electricity. By utilizing green energy, the environmental impact of charging electric vehicles is reduced, making it a more sustainable alternative to traditional power sources.

Grid Integration: The smart e-mobility system is designed to connect to the single-phase grid. This allows bidirectional power flow, enabling the system to both charge the LEVs and feed excess energy back into the grid, enhancing grid stability and balancing power demand.

The system incorporates advanced power management algorithms to efficiently distribute energy to charging stations and optimize the charging process for multiple LEVs simultaneously. These algorithms consider factors like renewable energy availability, charging demands, and grid conditions to ensure efficient operation.

Fig 4 Dc link voltage 230V vs time

To prevent grid overloads and ensure even distribution of power, the system implements dynamic load balancing techniques. This enables intelligent distribution of charging loads among different charging stations based on real-time demand and available renewable energy. The smart e-mobility system supports Vehicle-to-Grid (V2G) technology, allowing bi-directional power flow between the electric vehicles and the grid. This enables LEVs to act as energy storage devices, providing grid support during peak demand periods or emergencies.

The system is equipped with communication interfaces and control mechanisms to interact with charging stations, LEVs, and the grid. Real-time data exchange allows for seamless integration and efficient power flow management. The system includes smart charging and scheduling features, allowing users to schedule charging times, track charging status, and receive notifications. This optimizes energy utilization, reduces peak load stress, and enhances user convenience.

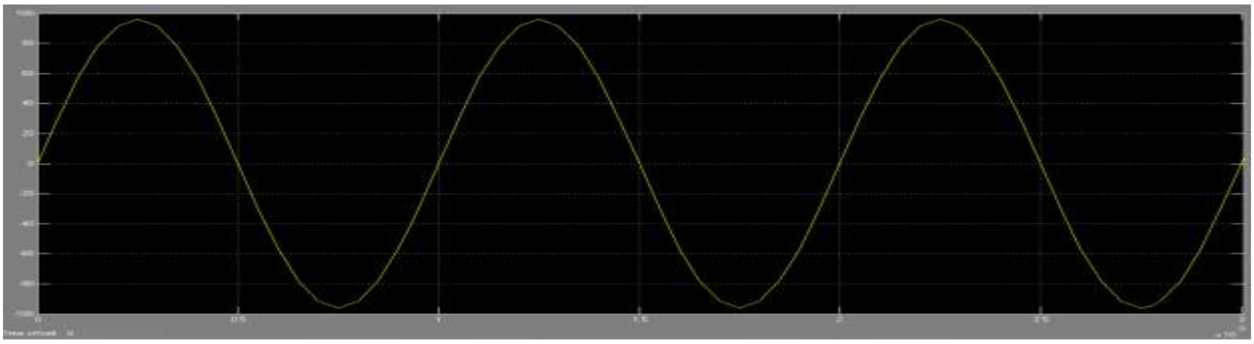

Fig 5 primary voltage vs time

By utilizing renewable energy sources, the system significantly reduces greenhouse gas emissions and contributes to a greener and more sustainable transportation ecosystem. The system's grid integration and V2G capabilities enable it to support the grid during peak demand, improving grid stability and reliability.

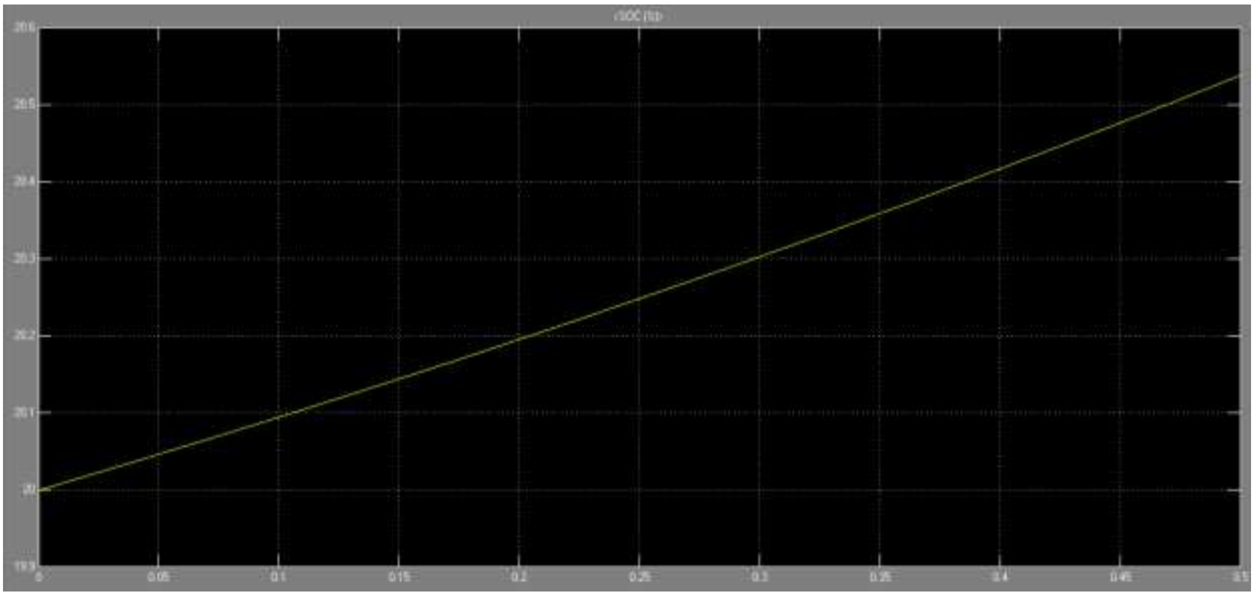

Fig 6 Battery SoC vs time

Utilizing renewable energy sources can lead to reduced electricity costs for both the charging infrastructure operators and LEV owners. The power management algorithms and load balancing ensure efficient charging, maximizing the use of renewable energy while minimizing wastage.

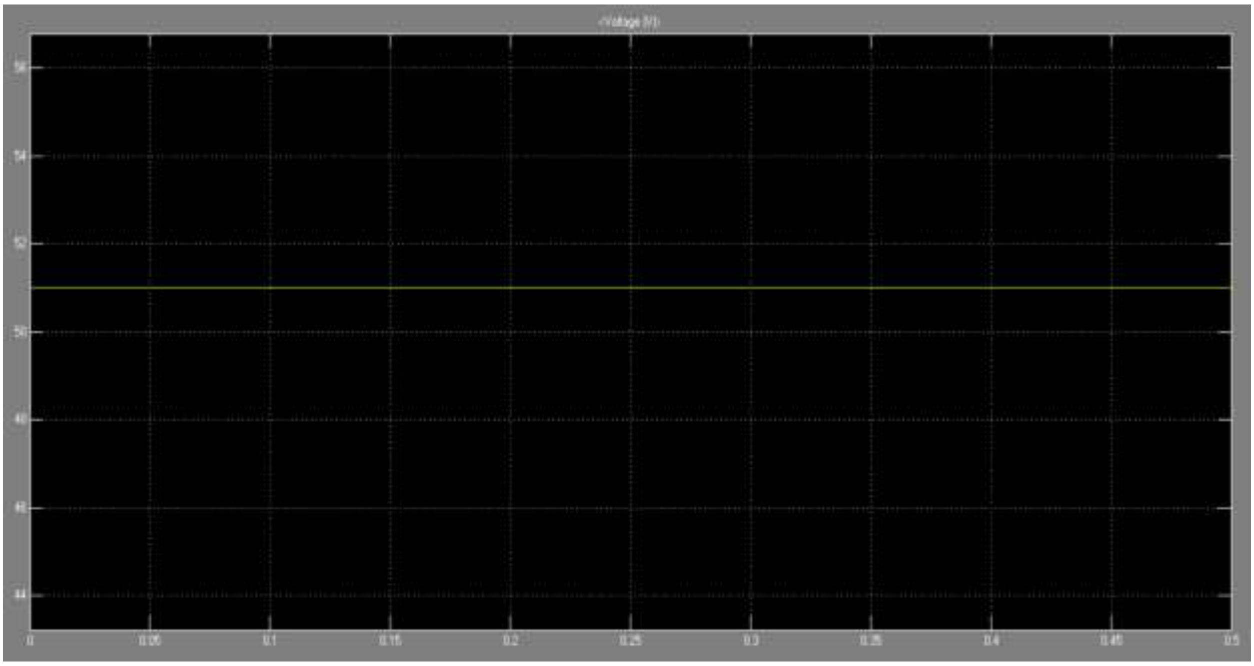

Fig 7 Battery voltage vs time

Overall, the Power Management of Renewable Single-Phase Grid-Integrated Smart e-Mobility System for Light Electric Vehicles represents an intelligent and sustainable solution for advancing the adoption of electric vehicles and promoting renewable energy integration in the transportation sector.

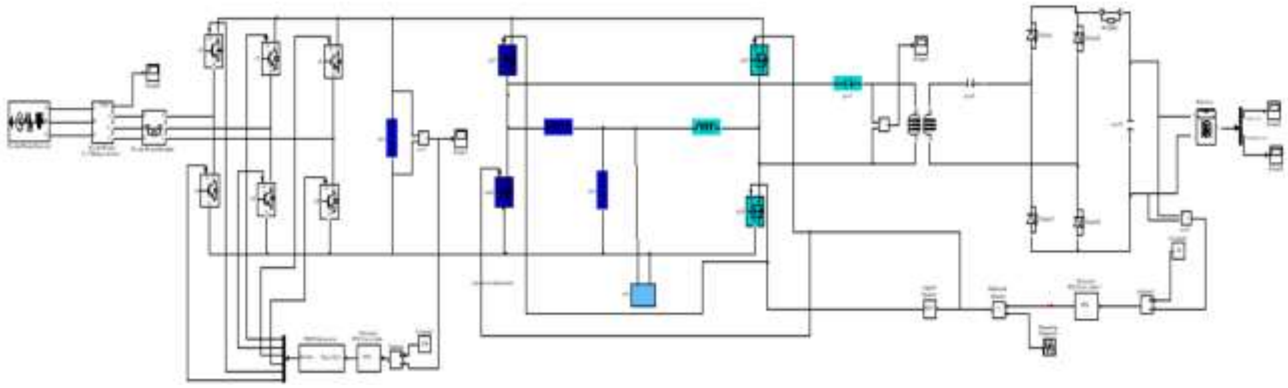

Fig 8 proposed Three phase system

Power management of renewable energy in grid-integrated light electric vehicles (LEVs) is a crucial aspect of their operation to ensure efficient and sustainable performance. There are two main configurations for grid integration based on the power system used in the vehicles: three-phase and single-phase grid integration.

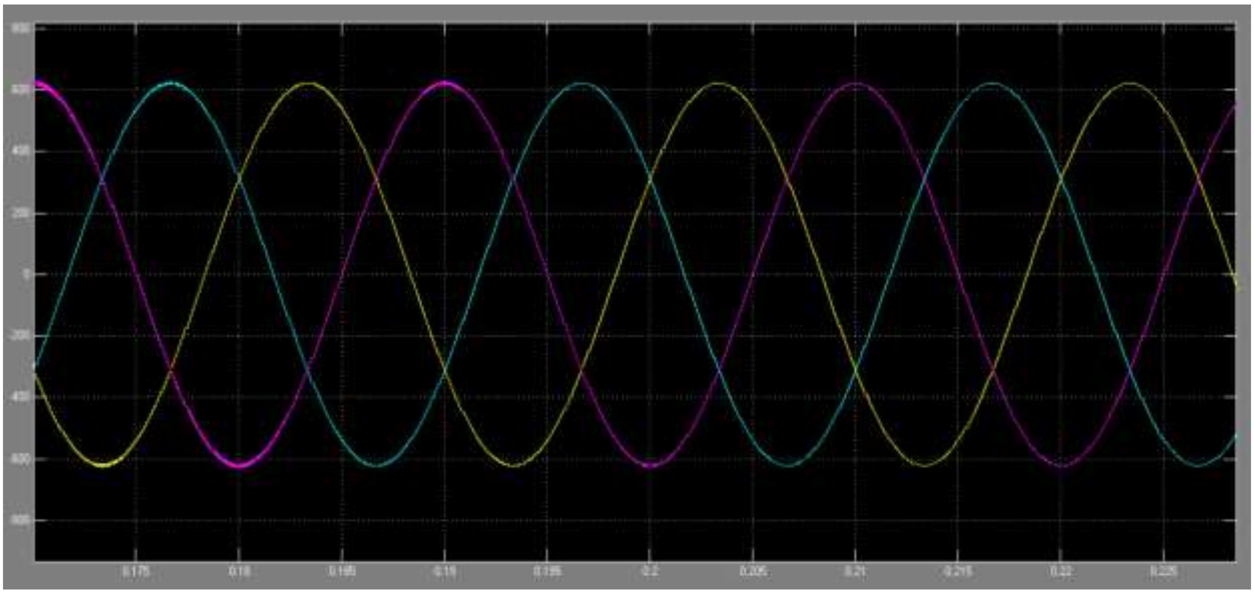

Fig 9 proposed Three phase system input voltage

In a three-phase grid integrated system, the power electronics and control systems are designed to work with three-phase AC power sources. This configuration is typically found in larger electric vehicles or commercial electric fleets. Here's how power management works in three-phase grid-integrated LEVs

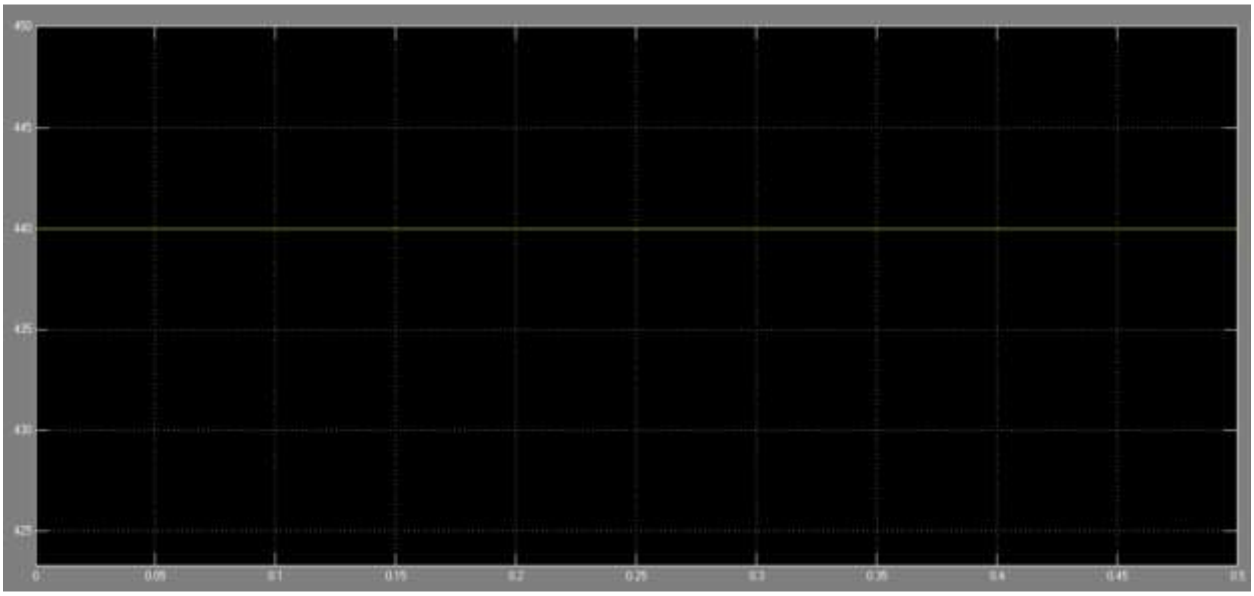

Fig 10 proposed Three phase system DC link voltage

Three-phase grid-integrated LEVs can use renewable energy sources, such as solar panels or wind turbines, to harvest electricity. The harvested energy is typically converted into DC power using power converters. When the LEV needs to

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charge its batteries from the grid, it can do so using a three-phase AC charger. Three-phase charging can provide higher power transfer rates compared to single-phase charging, reducing charging times.

The power converter in the LEV is responsible for converting the harvested DC energy or grid AC power into the appropriate voltage and current levels required to charge the batteries. Advanced control algorithms ensure efficient power transfer and battery charging. In a three-phase system, power is distributed evenly among the three phases, helping to balance the load and reduce voltage fluctuations. This results in more stable and reliable operation of the LEV's electrical components.

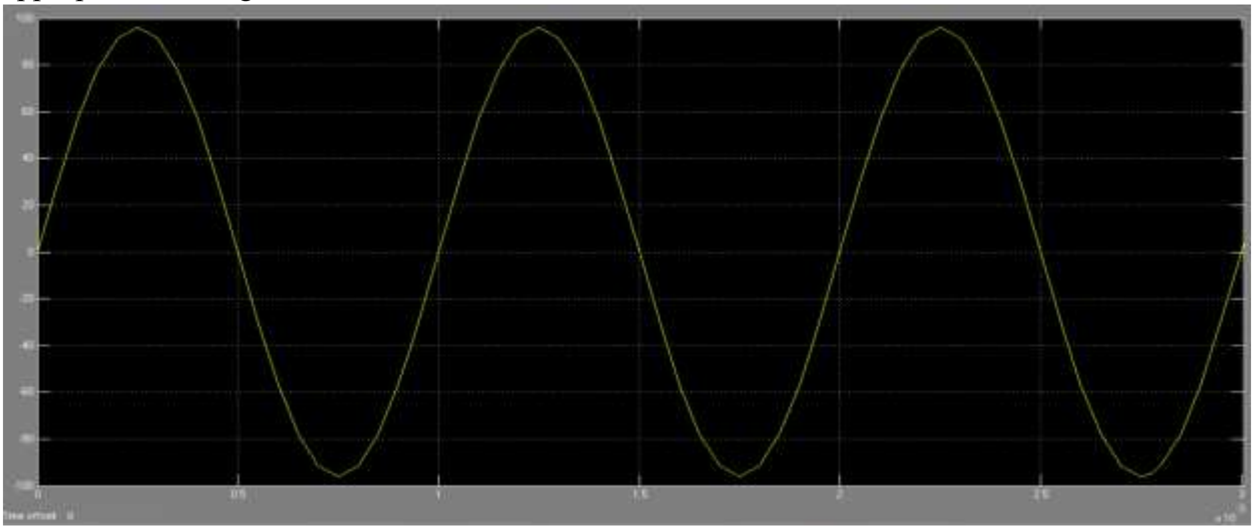

Fig 11 primary voltage vs time

In a single-phase grid integrated system, the LEV is designed to operate with a single-phase AC power source. This configuration is commonly found in smaller and lighter electric vehicles, including electric bikes and scooters. The power management in single-phase grid-integrated LEVs follows these principles. Similar to three-phase systems, single-phase grid-integrated LEVs can harness renewable energy through solar panels or wind turbines. The harvested energy is converted to DC power using appropriate converters.

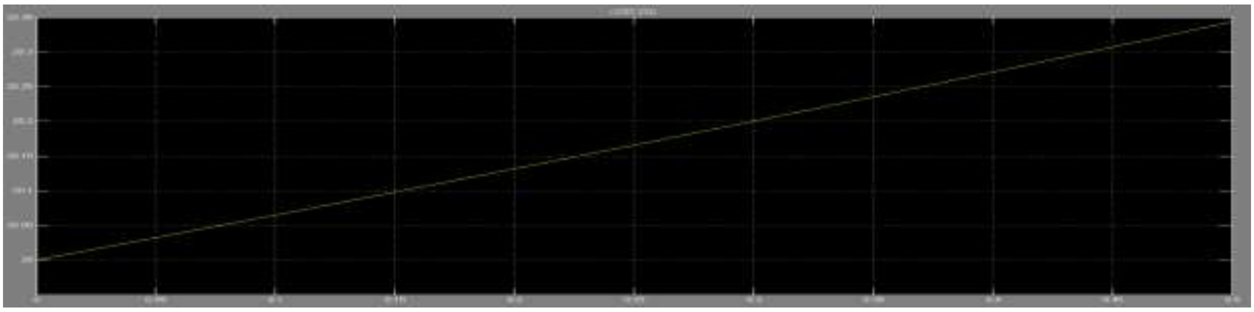

Fig 12 battery SoC for proposed system

When charging from the grid, these LEVs use single-phase AC chargers. Single-phase charging is simpler and more commonly available in residential areas. The power converter in the LEV converts the harvested DC energy or grid AC power

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into the necessary voltage and current levels for battery charging. Control systems optimize power transfer efficiency. In single-phase systems, load balancing is not as straightforward as in three-phase systems. Proper management is required to ensure the load distribution among different components is balanced to avoid overloading.

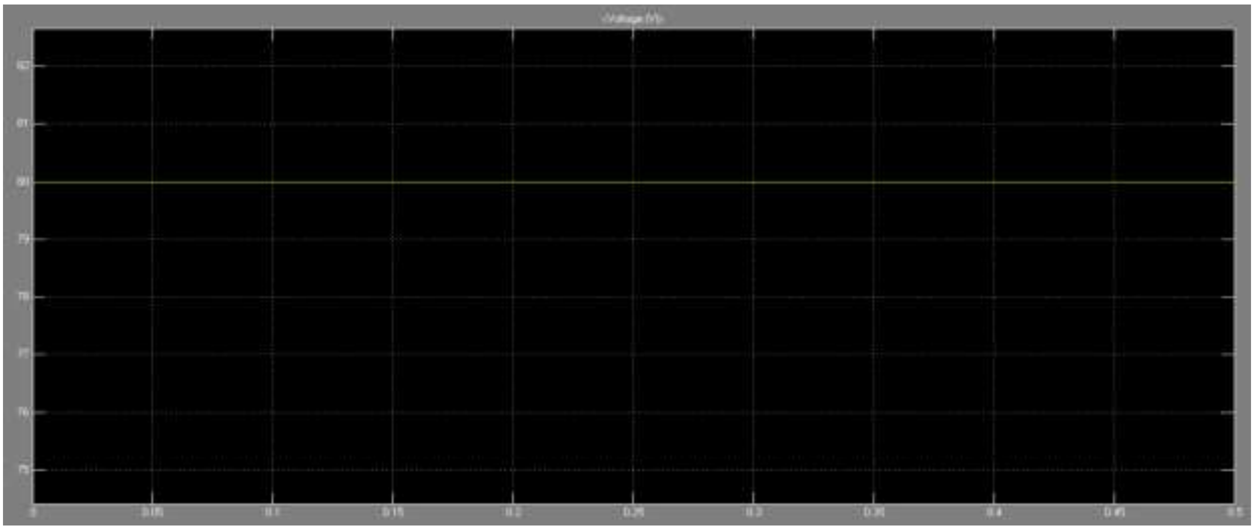

Fig 13 proposed system battery voltage vs time

The choice between three-phase and single-phase grid integration depends on the power requirements, vehicle size, and specific use case of the light electric vehicle. Both systems can effectively harness renewable energy and optimize battery charging for sustainable and eco-friendly transportation.

CONCLUSION

This research presents a novel grid-integrated PV charging system designed specifically for electric vehicles. The main objective of this study was to develop an efficient and sustainable charging solution that harnesses renewable energy and optimizes the charging process for electric vehicles. In conclusion, the presented novel grid-integrated PV charging system represents a sustainable and innovative solution to address the challenges of electric vehicle charging. Its ability to harness renewable energy, support V2G capabilities, optimize energy management, and provide economic benefits make it a promising technology for the future of electric mobility and the transition towards greener transportation systems. Further real-world validation and deployment are warranted to confirm its practical feasibility and performance in diverse operational scenarios. As the world strives for a more sustainable future, the integration of renewable energy sources in electric vehicle charging infrastructure remains a critical aspect, and this research contributes to this vision by presenting a robust and effective solution.

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