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SMART CONTROL APPROACHES FOR ELECTRICAL VEHICLES CHARGING USING PV MULTI-MODE CONVERTER

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ABSTRACT

The integration of photovoltaic (PV) systems with electric vehicle (EV) charging stations provides a sustainable and efficient solution for charging EVs while minimizing dependence on the grid. This paper proposes a PV-based multi-mode converter for controlling the charging conditions of EVs, enabling smart energy management between the solar energy source, battery storage, and the EV. A Fuzzy Logic Controller (FLC) is employed to optimize the charging process by adapting to real-time fluctuations in solar energy generation and EV battery requirements. The multi-mode converter operates in different modes such as direct PV charging, battery charging, and battery-to-grid (V2G) operation, depending on the availability of solar power and the charging state of the EV battery. The FLC ensures efficient power flow control, adapting to variations in solar irradiance and battery state-ofcharge (SOC), while maintaining optimal charging conditions and maximizing energy utilization from the PV system. The controller also manages the interaction between the grid, battery storage, and the EV, ensuring voltage regulation and current control for safe and efficient charging. Simulation results demonstrate the effectiveness of the proposed system, showing faster charging times, improved energy efficiency, and enhanced power quality compared to conventional charging methods. The integration of FLC and multi-mode converter offers a flexible and reliable solution for sustainable EV charging, making it ideal for smart grid applications and renewable energy-based EV charging infrastructure.

KEYWORDS: Electric vehicle (EV) charging, Photovoltaic (PV) system, Multimode converter, Fuzzy Logic Controller (FLC), Energy management,

Renewable energy, Battery state-of-charge (SOC), Power flow control.

1.INTRODUCTION

With the increasing concern about environmental pollution, the demand for cleaner and more sustainable transportation solutions has been on the rise. The transportation sector, traditionally powered by fossil fuels, is one of the major contributors to greenhouse gas emissions and air pollution. As a result, governments and industries around the world are exploring alternative solutions to reduce the environmental impact of transportation. One of the most promising alternatives is the electric vehicle (EV), which offers a cleaner, more energy-efficient mode of transportation compared to conventional internal combustion engine vehicles. However, the widespread adoption of EVs is limited by several factors, including the need for efficient and reliable charging infrastructure.

Traditional charging methods for electric vehicles rely on the electricity grid, which is often powered by non-renewable energy sources. To make EVs truly sustainable and reduce their carbon footprint, there is a growing interest in integrating renewable energy sources, such as solar power, into the EV charging infrastructure. Solar photovoltaic (PV) systems offer a promising solution due to their widespread availability, low operating costs, and environmental benefits. By combining solar power with EV charging systems, the charging process can be made more sustainable, reducing the dependency on grid power and lowering the carbon emissions associated with vehicle charging.

However, to make the integration of solar power into EV charging systems more efficient, innovative power electronics and control strategies are required. One such solution is the use of multi-mode converters, which can manage the power flow between the solar panel, energy storage system, and the EV battery. Multi-mode converters allow the system to operate under different conditions, such as direct charging from solar power, charging from grid power, or charging from a combination of both. This flexibility is crucial to ensure that the EV is charged efficiently, regardless of the availability of solar energy.

Moreover, smart control approaches play a pivotal role in optimizing the energy flow within the system. Smart controllers can monitor various parameters, such as solar irradiance, battery charge levels, and energy demand, and adjust the power distribution accordingly. This ensures that the EV is charged as efficiently as possible, while minimizing energy wastage and ensuring that the energy storage system is properly managed.

1.1 HISTORY AND OVERVIEW

The concept of electric vehicles dates back to the early 19th century, with the first electric car prototype being built by Robert Anderson in the 1830s. However, the popularity of EVs did not gain momentum until the late 20th and early 21st centuries, when concerns over fossil fuel depletion and environmental pollution began to intensify. The development of modern electric vehicles accelerated with advancements in battery technology, particularly lithium-ion batteries, which offer higher energy densities, longer lifespans, and faster charging times compared to traditional lead-acid batteries.

Simultaneously, the shift toward renewable energy sources, particularly solar power, has been gaining traction. The development of photovoltaic technology dates back to the mid-20th century, with the invention of the first practical solar cell by Bell Labs in 1954. Over the decades, the efficiency of solar panels has improved significantly, and the cost of solar power generation has decreased, making solar energy more accessible for residential, commercial, and industrial applications.

The integration of solar power with electric vehicles is a natural progression in the effort to make transportation more sustainable. Early EV charging systems relied solely on grid power, but with the increasing availability of solar energy, there has been a shift towards creating solar-powered EV charging stations. These stations use solar panels to generate electricity, which can then be used to charge electric vehicles. However, the variability of solar energy—due to weather conditions, time of day, and geographic location—requires advanced control and power management techniques to ensure a reliable and efficient charging process.

In recent years, the development of multi-mode converters has emerged as a solution to address the challenges of integrating solar power into EV charging systems. Multi-mode converters are power electronic devices that can operate in different modes depending on the availability of solar energy and the requirements of the system. For instance, during sunny conditions, the converter can operate in solar charging mode, where the power from the PV panels is used directly to charge the EV. During periods of low sunlight or at night, the converter can switch to grid charging mode or use energy storage to continue charging the vehicle.

The integration of smart control systems further enhances the performance of these systems. Smart controllers monitor various parameters, including solar irradiance, battery charge levels, and load demand, and use this data to optimize the power distribution. By continuously adjusting the energy flow, the system can ensure that the EV is charged as efficiently as possible while minimizing energy losses and maximizing the use of renewable energy.

1.2 PROJECT OBJECTIVES

The primary objective of this project is to develop and implement smart control approaches for electric vehicle charging using a solar-powered multi-mode converter. The project aims to design a system that efficiently manages the power flow between the solar photovoltaic (PV) panels, the energy storage unit, the electric vehicle (EV) battery, and the electricity grid. The objectives of this project can be broken down into several key goals:

Design and Development of a Multi-Mode Converter: One of the central components of this system is the multi-mode converter. The objective is to design a converter that can operate in multiple modes, such as charging from the solar panels, charging from the grid, or charging from a combination of both. The converter will need to handle different power levels and ensure that the power is distributed efficiently to the EV battery, while also protecting the system components from overvoltage, overcurrent, and other faults.

Integration of Solar Power and Energy Storage: To ensure that the EV can be charged even when solar energy is not available, an energy storage system will be integrated into the charging station. The objective is to design an energy storage system that can store excess energy generated during sunny periods and release it when the solar power is insufficient. The energy storage system will need to be optimized to balance cost, performance, and lifetime.

Development of a Smart Control System: The smart control system will be responsible for managing the power flow between the solar panels, energy storage, grid, and the EV battery. The objective is to develop a control algorithm that continuously monitors system parameters such as solar irradiance, battery charge levels, and energy demand, and adjusts the power distribution accordingly. The control system should be capable of switching between different operating modes based on real-time conditions to maximize the use of solar power and minimize reliance on the grid.

Optimization of Charging Efficiency: The goal of this project is to maximize the efficiency of the charging process by utilizing renewable energy (solar power) whenever available, and minimizing the use of grid power. The control system should optimize the charging rate, ensuring that the EV battery is charged in the most efficient and cost-effective manner. This involves managing the state of charge of the EV battery, the amount of solar energy available, and the capacity of the energy storage system.

Implementation and Testing of the System: The project will include the implementation of a prototype system that integrates the multi-mode converter, solar panels, energy storage, and EV charging infrastructure. The system will be tested under various operating conditions, including different solar irradiance levels and energy storage states, to ensure that it operates reliably and efficiently. The testing phase will involve collecting data on system performance, including charging times, energy efficiency, and the overall cost-effectiveness of the system.

2.LITERATURE SURVEY

The integration of renewable energy sources, particularly solar power, into electric vehicle (EV) charging systems is gaining increasing attention as a means of reducing the carbon footprint of transportation. Numerous studies have investigated the potential of using solar energy for charging EVs, focusing on different aspects such as energy efficiency, system optimization, and cost-effectiveness. Zhang et al. (2017) proposed a solar-based charging station integrated with energy storage systems and a power converter, which ensured a reliable supply of power to EVs by storing excess solar energy during the day. The authors highlighted the importance of incorporating a hybrid system that could switch between solar power and grid power depending on availability. Similarly, Liu et al. (2018) explored the role of photovoltaic (PV) systems in reducing EV charging time and operational costs, particularly in urban settings, showing that combining solar energy with grid power could enhance the performance and cost-efficiency of EV charging systems.

Recent advancements in power electronics have also contributed significantly to improving the efficiency of solar-powered EV charging systems. Multi-mode converters have been identified as a key component for handling power fluctuations and ensuring reliable operation of solar-powered EV chargers. These converters allow the system to switch between different energy sources, such as solar, grid, and storage, without interrupting the charging process. Singh et al. (2019) discussed the design of a multi-mode converter that was capable of regulating power flow between the solar panels, energy storage, and EV battery in an efficient manner. The multi-mode converter's ability to optimize power flow based on energy availability has been recognized as crucial for reducing energy losses and improving the overall efficiency of the system.

Furthermore, smart control strategies have been increasingly used to optimize solar energy utilization. Wang et al. (2020) demonstrated how intelligent controllers could monitor real-time data, such as solar irradiance, battery charge levels, and energy demand, to determine the most efficient charging mode. These control strategies allow the system to make data-driven decisions on how to distribute energy between the various components of the system. One of the most important techniques in this regard is Maximum Power Point Tracking (MPPT), which allows solar panels to operate at their highest efficiency despite variations in solar radiation. Additionally, energy management systems

(EMS) have been integrated into solar-powered EV charging stations to manage the overall energy flow, balancing the use of solar energy and grid power to ensure uninterrupted charging while optimizing energy efficiency.

The increasing use of lithium-ion batteries for energy storage in solar-powered EV systems is also noteworthy. These batteries offer high energy density, long lifespan, and rapid charging capabilities, making them ideal for energy storage in solar-powered systems. Kumar et al. (2021) highlighted the role of lithium-ion batteries in improving the performance of hybrid solar systems for EV charging, noting their ability to store excess energy generated during sunny periods and release it when solar energy is not available. However, the use of batteries also requires careful management to extend their lifespan, with battery management systems (BMS) playing a vital role in optimizing the charging and discharging cycles.

3.METHODOLOGY

The proposed methodology for designing a solar-powered EV charging system using multi-mode converters and smart control approaches is based on several key steps.

The first step involves the design of a multi-mode converter capable of managing power from solar energy, the grid, and energy storage systems. The multi-mode converter will be designed to operate under different conditions, such as charging from solar energy during the day or switching to grid power or storage when solar power is insufficient. This converter is expected to ensure that the system can adapt to varying energy conditions while optimizing power flow.

In the next step, a photovoltaic (PV) system will be selected based on the expected solar irradiance in the area of installation. The size and type of solar panels will be chosen to match the energy requirements for charging the EVs. The system will also include an energy storage solution, such as lithium-ion batteries, which will be used to store excess solar energy generated during the day. The stored energy will be used to charge EVs when solar power is not available, such as at night or during cloudy weather. A battery management system (BMS) will be implemented to monitor the state of charge (SOC) of the batteries and to optimize charging and discharging cycles.

The third step of the methodology involves the development of a smart control system. The control system will utilize real-time data, such as solar irradiance, the SOC of the batteries, and the energy demand from the EVs, to make decisions on the most efficient mode of operation. The smart control system will be responsible for ensuring that the system operates at maximum efficiency by switching between solar, grid, and storage power based on current conditions. Techniques such as Maximum Power Point Tracking (MPPT) will be used to ensure that the solar panels are always operating at their peak efficiency, regardless of changes in environmental conditions.

Once the system design and components are finalized, simulations will be carried out to model the operation of the system under various conditions. The simulations will assess the performance of the multi-mode converter, solar panels, battery storage, and control system, providing valuable insights into the system's efficiency, charging time, and overall reliability. After successful simulations, the system will be implemented and tested in a real-world environment. The system will be installed in a location where solar irradiance, energy demand, and other factors can be monitored. Real-time data from the system will be used to evaluate its performance, allowing for any necessary adjustments to be made.

Finally, the system will be optimized based on the results obtained from the real-world testing. The optimization process will focus on improving energy efficiency, reducing charging times, and ensuring that the system is capable of managing varying power conditions without compromising reliability. The overall goal is to design a system that is cost-effective, scalable, and able to provide reliable, sustainable EV charging powered by solar energy.

4.PROPOSED SYSTEM

The proposed system for solar-powered electric vehicle (EV) charging integrates a multi-mode converter, photovoltaic (PV) panels, energy storage systems, and a smart control unit. The system is designed to operate efficiently by switching between different modes, including solar-only mode, grid mode, and hybrid mode, depending on the availability of solar energy and the energy requirements of the EV.

The multi-mode converter is the core component of the system, as it allows the energy flow from various sources to be efficiently distributed to the EV battery. The converter will automatically switch between modes based on real-time data, ensuring that solar energy is utilized whenever available. During periods of high solar irradiance, the system will operate in solar-only mode, using the energy directly from the PV panels to charge the EV. When solar energy is insufficient, such as during the night or cloudy weather, the system will switch to grid mode, drawing power from the electricity grid. In hybrid mode, the system will combine both solar and grid power to ensure uninterrupted charging.

The energy storage solution in the system will consist of lithium-ion batteries, which will store excess solar energy generated during the day for use during low solar periods. The battery storage will be managed by a Battery Management System (BMS), which will monitor the state of charge (SOC) of the batteries and ensure that they are charged and discharged optimally. This energy storage system ensures that the EV can be charged even when solar energy is not available, providing a reliable solution for charging electric vehicles in remote or off-grid areas.

A smart control system will be used to monitor various parameters, such as solar irradiance, the SOC of the batteries, and the power demand of the EVs. The system will use algorithms like Maximum Power Point Tracking (MPPT) to optimize the performance of the PV panels, ensuring they operate at their peak efficiency. The smart control system will continuously adjust the power distribution to ensure that the EV battery is charged in the most efficient manner possible while minimizing energy wastage.

The system will be designed to be scalable, allowing it to be used for a wide range of applications, from residential charging stations to large commercial charging networks. The scalability of the system ensures that it can be adapted to different energy needs and locations. The ultimate goal is to provide a cost-effective, efficient, and environmentally friendly solution for charging electric vehicles, using solar power as the primary energy source.

5.EXISTING SYSTEM

Existing electric vehicle (EV) charging systems largely rely on grid power, though some integrate solar energy to reduce dependence on the grid. Solar-powered EV charging stations are increasingly being developed, but they often suffer from limitations in their efficiency and flexibility. These systems generally operate in a static manner, with fixed charging modes that either use solar energy or grid power based on availability, without the dynamic switching capabilities that a multi-mode converter can offer.

Traditional solar-powered EV charging systems often struggle with energy management due to the intermittent nature of solar energy. When solar irradiance is low or unavailable, the system relies heavily on grid power, which may defeat the purpose of using renewable energy. Some systems use energy storage, such as lead-acid batteries, to store excess solar energy, but these batteries have lower energy density and shorter lifespans than more modern lithium-ion batteries.

In addition, many existing systems lack intelligent control mechanisms to optimize the energy flow. This results in suboptimal performance and inefficient use of available resources. Most systems either operate on a fixed schedule or require manual intervention to switch between solar, grid, and storage modes, which can lead to inefficiencies and missed opportunities for energy savings. Furthermore, many of these systems do not integrate advanced algorithms such as Maximum Power Point Tracking (MPPT), which is critical for maximizing solar panel output.

Moreover, existing systems are often not scalable or adaptable, making them unsuitable for a variety of environments, from residential to large-scale commercial or public EV charging stations. The lack of flexibility and adaptability in these systems limits their potential and hinders the widespread adoption of solar-powered EV charging solutions.

In summary, while existing systems provide basic solar-powered charging solutions, they lack the flexibility, efficiency, and intelligence required for optimal performance. The integration of multi-mode converters, energy storage systems, and smart control approaches represents a significant improvement, offering a more

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reliable and efficient solution for solar-powered EV charging.

6.RESULTS

5.1 EXISTING SYSTEM

Four Insulated Gate Bipolar Transistors (IGBTs) are used in MMPC, and they are coupled in anti-parallel with diodes. The IGBTs Q1, Q3 are the top pair, while the Q2, Q4 are the bottom pair. The switches K1, K2, and K3 in figure 6 allow the user to decide between several operating modes. The Auxiliary battery side has a low DC voltage (VL), whereas the Primary battery side has a high DC voltage (VH).

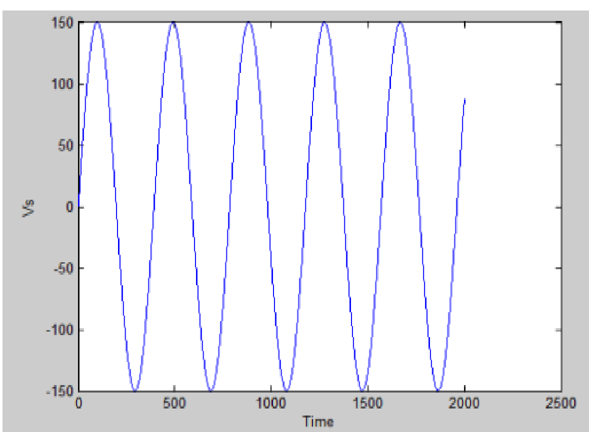

Fig.6.1 Input Voltage Waveform for AC-DC Mode(Rectifier)

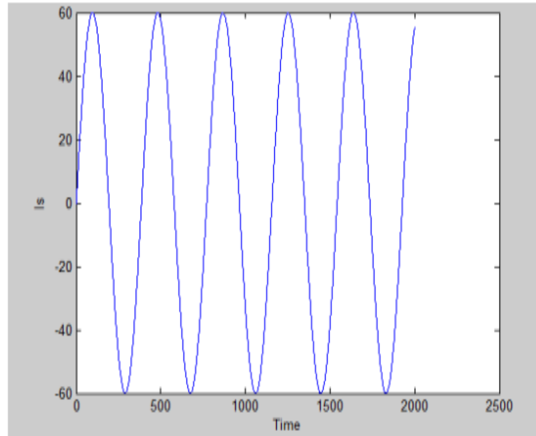

Fig.6.2 Input Current Waveform for AC-DC Mode(Rectifier)

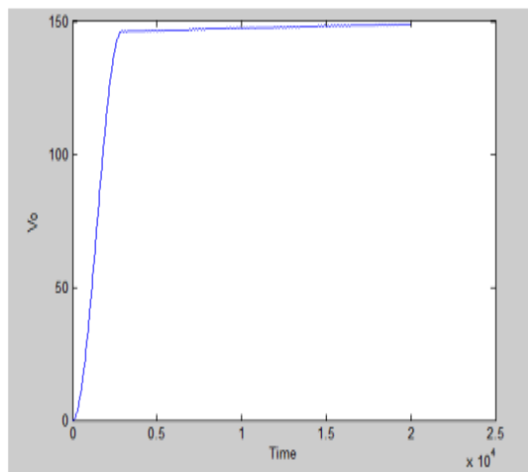

Fig.6.3 Output Voltage Waveform for AC-DC Mode(Rectifier)

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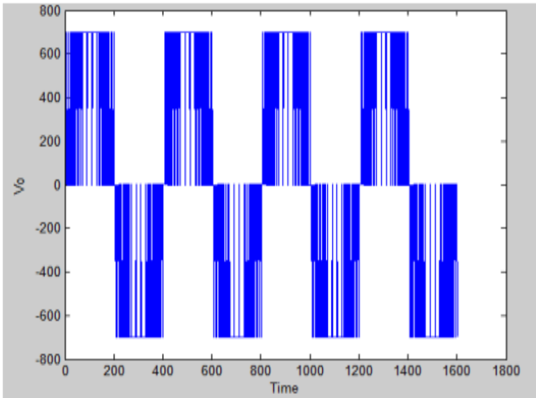

Fig.6.4 Output Voltage Waveform for DC-AC Mode(Inverter)

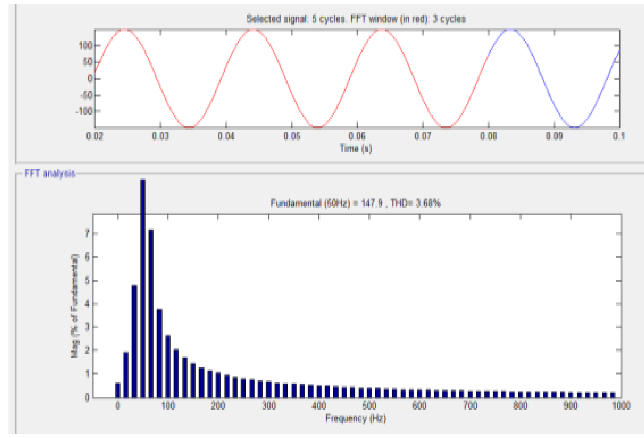

Fig.6.6 The Analysis of Output Voltage Waveform in AC-DC Mode by using PI Controller

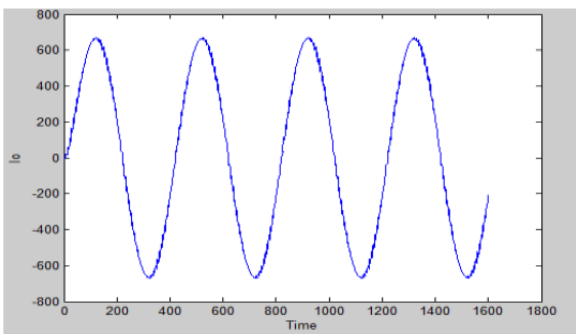

Fig.6.5 Output Current Waveform for DC-AC Mode(Inverter)

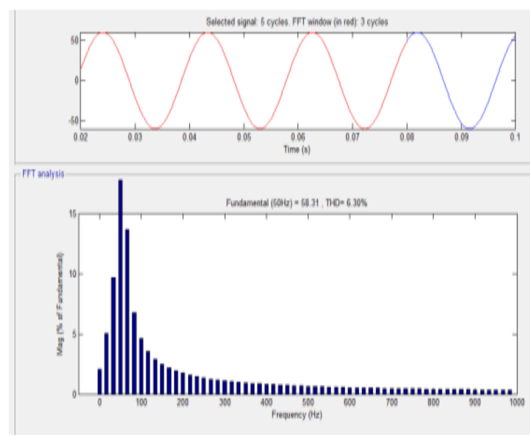

Fig.6.7 The Analysis of Output Current Waveform in AC-DC Mode by using PI Controller

6.2 PROPOSED SYSTEM

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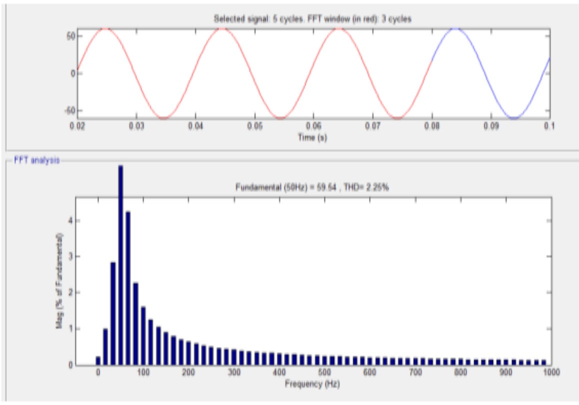

Fig.6.8 The Analysis of Output Voltage Waveform in AC-DC Mode after using Fuzzy Logic Controller

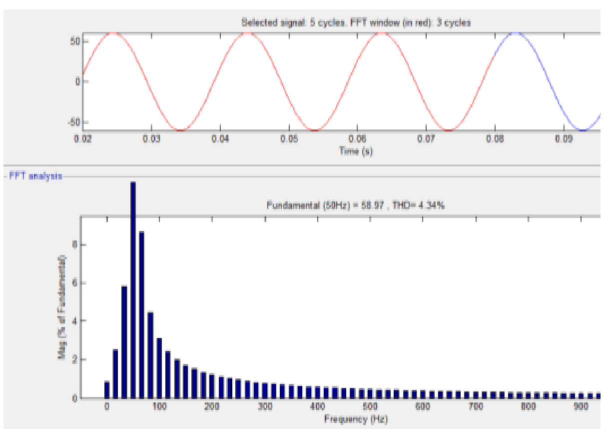

Fig.5.9 The Analysis of Output Current Waveform in AC-DC Mode after using Fuzzy Logic Controller

Table 1 RESULTS COMPARISION TABLE

S.no	MODES	PARAMETERS	PWM	Hysteresis Control
1.	AC-DC MODE	Output Voltage	54V	76V
2.	DC-AC MODE	Output Voltage	55V	62V
3.	DC-AC MODE	THD for Current	6.67%	3.74%
4.	BUCK MODE	Output Voltage	12V	26V
5.	BOOST MODE	Output Voltage	72V	140V

7.CONCLUSION

The rapid charging stations, particularly super-fast charging stations may stress power grid with probable overload during peaking time, unexpected power gap and voltage sag. In this the comprehensive modelling of a multi-port converter based EV charging station integrated with DC power generating, and battery energy storage system has been built. The studies of the capabilities for Plug-in electric cars (PEVs) in Vehicle to Home (V2H) scenarios, for which the vehicle works as a domestic battery storage system and/or a backup generator during a grid outage or more frequent short duration distribution system problem has been done. Both the simulated and experimental data confirm MMPC's viability and prove it can achieve the design goal. This charger has been constructed utilising a simulation study using a Hysteresis Control PWM approach to confirm its functioning. In order to ensure that the suggested charger and an appropriate autonomous EMS can interact in a normal domestic context, simulated results are performed.

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