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PERFORMANCE EVALUATION OF MPPT TECHNIQUES FOR A FLEXIBLE ROOFTOP HALF-CUT PHOTOVOLTAIC WPT SYSTEM FOR IN-MOTION EV CHARGING

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ABSTRACT

The rapid adoption of electric vehicles (EVs) has intensified the demand for efficient and sustainable charging solutions. Traditional plug-in charging requires long charging times and extensive infrastructure, while road-embedded wireless power transfer (WPT) systems face challenges such as high installation costs, complex maintenance. Along with these issues to address the large space requirements for solar panels, this project proposes an innovative grid connected overhead WPT system integrated with solar panels.

In this approach, transmitter coils are placed beneath an elevated solar panel structure, positioned at an optimal height above the road, while receiver coils are mounted on the rooftops of EVs. This configuration eliminates the need for embedding coils in roadways, significantly reducing installation and maintenance costs. Additionally, it maximizes land utilization by integrating solar energy harvesting with wireless charging, addressing the space constraints of large-scale solar farms. The system also enhances energy transfer efficiency by reducing misalignment issues and maintaining maximum power transfer between the transmitter and receiver coils.

To enhance efficiency, the project compares different Maximum Power Point Tracking (MPPT) techniques, including Perturb & Observe (P&O) and Adaptive Neuro-Fuzzy Inference System (ANFIS), to determine the most effective approach for maximizing power transfer. By combining renewable energy sources with an efficient WPT mechanism, advanced MPPT algorithms, this solution provides a high-efficiency, sustainable, cost-effective, and scalable alternative for in-motion EV charging, paving the way for a future where electric mobility is seamless and uninterrupted.

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1.INTRODUCTION

1.1 Overview of EV Charging Challenges

The rapid adoption of electric vehicles (EVs) has transformed the automotive landscape, presenting both opportunities and challenges. As governments and consumers increasingly prioritize sustainability and environmental responsibility, the shift from traditional internal combustion engine vehicles to electric vehicles has gained momentum. However, this transition is not without its hurdles, particularly concerning the charging infrastructure necessary to support a growing fleet of electric vehicles.

One of the most significant challenges facing EV adoption is the issue of charging accessibility. Traditional plug-in charging requires high charging time, and the BEV's suffer from "range anxiety". a term used to describe the fear of running out of battery power before reaching a charging station. Range anxiety is a significant barrier to EV adoption, as potential users may hesitate to invest in electric vehicles if they are unsure about the availability of charging options.

Moreover, the time required to charge an electric vehicle at conventional stations can be a considerable inconvenience. While advancements in fast-charging technology have reduced charging times, they still do not compare to the quick refueling times associated with gasoline vehicles. For many consumers, the prospect of waiting for an extended period to charge their vehicle can be a deterrent, particularly for those who rely on their vehicles for daily commuting or long-distance travel.

In addition to accessibility and charging time, the integration of charging infrastructure with existing urban environments poses another challenge. Many cities lack the necessary infrastructure to support a large number of electric vehicles, leading to potential grid overloads during peak charging times. The installation of charging stations can be costly and logistically complex, requiring significant investment and planning. Furthermore, the variability in charging speeds can create disparities in user experience. While some charging stations offer fast charging capabilities, others may only provide slow charging options, leading to frustration among users who may not have the luxury of waiting for extended periods.

The environmental impact of charging infrastructure is also a critical consideration. As the demand for electric vehicles increases, so does the need for sustainable energy sources to power them. The reliance on fossil

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fuels for electricity generation can undermine the environmental benefits of electric vehicles, making it essential to explore renewable energy options for charging infrastructure.

1.2 Need for Wireless In-Motion Charging

As the challenges associated with traditional EV charging methods become increasingly apparent, the need for innovative solutions has never been more pressing. Wireless in-motion charging (WIC) presents a transformative approach to EV charging that addresses many of the limitations of conventional systems. This technology allows for the charging of electric vehicles while they are in motion, effectively eliminating the need for stationary charging stations and significantly enhancing the convenience of EV ownership.

Fig: 1 Wireless EV charging**.**

One of the most compelling advantages of wireless in-motion charging is the potential to reduce range anxiety. By enabling vehicles to charge while driving, WIC can extend the effective range of electric vehicles, making them more appealing to consumers. This capability is particularly beneficial for urban environments, where traffic congestion often leads to stop-and-go driving. With WIC, EVs can continuously charge during these periods, ensuring that drivers do not have to worry about finding a charging station.

Additionally, wireless charging systems can be integrated into existing road infrastructure, such as highways and urban streets. This integration can facilitate a seamless charging experience, allowing vehicles to charge without the need for physical connections or interruptions in travel. The implementation of WIC can also lead to more efficient energy use, as vehicles can draw power from the grid during off-peak hours, reducing strain on the electrical grid during peak demand times.

Moreover, the adoption of wireless in-motion charging can contribute to the development of smart cities. By incorporating WIC technology into urban planning, cities can create a more sustainable transportation ecosystem that supports the growth of electric mobility. This approach aligns with global efforts to reduce carbon emissions and

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promote cleaner air quality, making it a vital component of future urban development.

In conclusion, the need for wireless in-motion charging is underscored by the challenges faced by traditional EV charging methods. By providing a convenient, efficient, and sustainable solution, WIC has the potential to revolutionize the way electric vehicles are charged, paving the way for broader adoption and a more sustainable future.

1.3 Introduction to the Roof-Top WPT system

Among the existing technologies, road-embedded wireless power transfer (WPT) systems have been explored for dynamic EV charging. However, these systems face significant drawbacks that hinder their large-scale implementation. The installation of transmitter coils beneath road surfaces requires extensive infrastructure modifications, leading to high initial costs and complex maintenance procedures. Additionally, road-embedded systems are prone to wear and degradation due to constant exposure to vehicular loads and environmental conditions, reducing their long-term efficiency. Another major challenge is the need for a large land area to accommodate solar panels that power the system, increasing the overall cost and spatial requirements. To overcome these limitations, this project proposes an innovative overhead WPT system where the transmitter coils are placed under solar panels at a lower height, and receiver coils are mounted on EV rooftops. This approach eliminates the need for expensive road modifications and maintenance while ensuring a stable and efficient energy transfer process. By integrating solar power generation directly with the WPT system, it optimizes land use and reduces the dependency on external power sources. Additionally, placing the transmitter coils at an elevated position minimizes exposure to environmental and mechanical wear, enhancing system durability.

Fig:2 The proposed Roof-Top based WPT system (AI Generated image)

The proposed system not only addresses the drawbacks of road-embedded WPT but also offers a scalable, cost-effective, and

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sustainable solution for in-motion EV charging. By significantly reducing charging time and infrastructure costs, this approach paves the way for the widespread adoption of EVs, contributing to a cleaner and more energy-efficient future.

1.4 Objectives of the Study

The primary objective of this study is to explore the feasibility and effectiveness of wireless in-motion charging systems for electric vehicles. This research aims to address the challenges associated with traditional charging methods and to evaluate the potential benefits of implementing wireless charging solutions. Specifically, the study will focus on comparing two Maximum Power Point Tracking (MPPT) algorithms: Perturb and Observe (P&O) and Adaptive Neuro-Fuzzy Inference System (ANFIS). The objectives of the study are outlined as follows:

1. **Assessment of Existing Wireless Charging Methods**: This study will conduct a comprehensive review of current wireless charging technologies, analyzing their strengths and weaknesses in the context of electric vehicle charging. By understanding the landscape of existing solutions, the research aims to identify gaps and opportunities for improvement.

2. **Comparative Analysis of MPPT Algorithms**: The research will compare the performance of the P&O and ANFIS-based MPPT algorithms in optimizing power transfer in solar-fed wireless power transfer (WPT) systems. This analysis will focus on key performance metrics such as tracking efficiency, response time, and adaptability to changing environmental conditions.

3. **Evaluation of PV-IWPT Systems**: The study will investigate the benefits of photovoltaic-integrated wireless power transfer (PV-IWPT) systems, examining their potential to enhance the sustainability and efficiency of electric vehicle charging. This evaluation will consider factors such as energy generation, operational costs, and environmental impact.

4. **Development of System Architecture**: The research will propose a comprehensive system architecture for wireless in-motion charging, detailing the integration of photovoltaic panels, transmitter coils, and receiver coils. This architecture will serve as a foundation for the implementation of the proposed charging solution.

5. **Exploration of Height Adjustment Strategies**: The study will explore various height adjustment strategies for transmitter coils to ensure optimal power transfer

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efficiency. This includes investigating multi-layered coil designs and AI-based height detection methods to accommodate variations in vehicle height and alignment.

6. **Analysis of Compensation Methods**: The research will delve into compensation methods for misalignment and safety, evaluating series-series, LCC, and hybrid compensation techniques to enhance system reliability. Understanding these methods is crucial for maintaining efficient power transfer in real-world applications.

7. **Investigation of Fast Charging Capabilities**: The study will assess high-power transfer strategies and adaptive impedance tuning to improve the fast charging capabilities of wireless systems. This investigation will focus on optimizing the charging process to reduce wait times for users.

8. **MATLAB Simulation Process**: The study will utilize MATLAB simulations to model the proposed system, analyze key parameters, and predict expected outcomes, including efficiency analysis. This simulation process will provide valuable insights into the performance of the proposed charging solution.

9. **Performance Evaluation**: The research will evaluate the performance of the proposed wireless in-motion charging system, focusing on power transfer efficiency, maximum power point tracking (MPPT) performance, and the impact of misalignment. This evaluation will be critical for determining the viability of the proposed solution.

10. **Future Research Directions**: Finally, the study will outline potential future research directions, emphasizing the importance of continued innovation in wireless charging technologies and their integration into smart city frameworks. This will include exploring hybrid approaches that combine the strengths of both MPPT algorithms and investigating the role of AI in optimizing charging systems.

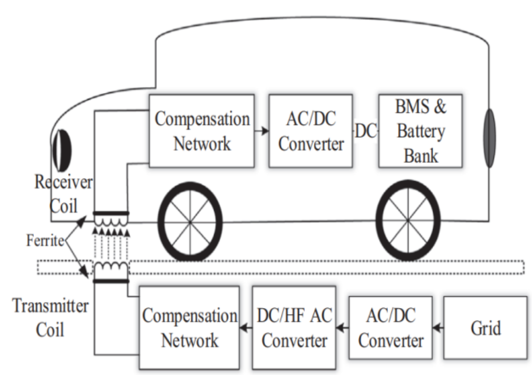

Fig: 3 Basic block diagram of wireless charging system for EVs.

2.LITERATURE SURVEY

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In recent years, the shift toward electric vehicles (EVs) has led to considerable advancements in technology for sustainable and efficient transportation. One of the most significant advancements is the use of wireless power transfer (WPT) systems for in-motion electric vehicle charging, which aims to eliminate the need for stationary charging infrastructure and provide continuous power while the vehicle is in transit. A key component of this technology is the integration of flexible rooftop half-cut photovoltaic (PV) panels, which can be charged dynamically using sunlight while the vehicle is in motion.

Photovoltaic energy harvesting systems have witnessed significant progress in terms of efficiency and cost reduction. Half-cut solar cells, which are essentially standard solar cells that are divided into two equal parts, have shown promising improvements in performance, particularly in areas with high shading and partial light conditions. Several studies have explored the performance of these solar cells in flexible configurations. According to P. P. Mukherjee et al. (2019), half-cut solar cells exhibit higher power output, better thermal performance, and increased shading tolerance compared to full-sized solar cells. This makes them an ideal choice for rooftop applications, where partial shading can be a significant problem.

The integration of Maximum Power Point Tracking (MPPT) algorithms with PV systems is another area of great interest. MPPT algorithms are essential for ensuring that the PV system operates at its maximum power output under varying environmental conditions, including changes in sunlight intensity, temperature, and load demand. Numerous MPPT algorithms have been proposed in the literature, including Perturb and Observe (P&O), Incremental Conductance (IC), and the more advanced Particle Swarm Optimization (PSO)-based MPPT techniques. The P&O and IC methods are among the most widely used due to their simplicity and fast response to environmental changes. However, both methods face challenges in terms of efficiency during rapidly changing light conditions, making the application of more advanced MPPT techniques, such as PSO, ANFIS, crucial for improved performance.

The concept of wireless power transfer (WPT) has gained momentum in the last few years for charging electric vehicles in motion. The concept of dynamic wireless charging (DWC) allows EVs to be charged while driving, essentially providing an

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uninterrupted charging experience. A study by A.shahin [8] discusses how WPT technology can be integrated with flexible PV panels to optimize energy harvesting. In [9]-[12] They noted that WPT systems depend heavily on the efficiency of energy transfer and the alignment of the transmitting and receiving coils, which can vary based on road conditions, the vehicle's speed, and position. Therefore, careful optimization of the MPPT algorithms used in conjunction with WPT technology is necessary for maintaining efficient charging during the vehicle's motion.

Recent developments have seen the integration of MPPT techniques with WPT systems to improve the energy harvesting process for in-motion EV charging. In [10] it presents a combined approach using P&O MPPT along with WPT for efficient power delivery to electric vehicles. The use of MPPT allows the PV system to track maximum power under varying environmental conditions, while WPT technology enables wireless charging during transit. These systems have been proven to enhance the overall energy efficiency of EVs by ensuring that power is continuously supplied, even during motion. The use of flexible PV panels on the vehicle's rooftop adds an additional layer of complexity, as the panels must be able to operate efficiently under different physical conditions such as wind and vibration.

In conclusion, various studies have contributed to the development of PV-based WPT systems for in-motion EV charging, with an emphasis on MPPT techniques that ensure maximum power efficiency. As the demand for electric vehicles continues to grow, the role of MPPT algorithms, half-cut PV cells, and WPT technology in developing efficient and sustainable EV charging systems will become increasingly important.

3.METHODOLOGY

The proposed system is designed to improve the efficiency of energy harvesting for in-motion electric vehicle (EV) charging by combining flexible rooftop half-cut photovoltaic (PV) panels with wireless power transfer (WPT) technology. The system also integrates advanced Maximum Power Point Tracking (MPPT) techniques to ensure that the PV system operates at its maximum efficiency despite the variable environmental conditions that are typical of on-road applications.

The first step in the methodology involves the design and integration of the flexible rooftop half-cut PV panels. These PV panels are

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selected because of their enhanced performance under partial shading conditions. These flexible panels are installed above the road lanes at a height. Under thsese panels transmitter coils are equipped. vehicle's roofs are equipped with receiver coils and connected to a power conversion system.

The second step focuses on the integration of the WPT system. The WPT system comprises transmitting and receiving coils that allow for the transfer of power to the vehicle while it is in motion. The alignment of these coils is crucial, and this alignment is monitored using sensor-based systems that adjust the positioning of the coils for maximum efficiency. The WPT system operates in conjunction with the PV panels, transferring the energy generated by the panels to the vehicle's battery through wireless charging.

The coupling coefficient of wireless power transfer system is derived as

$$k = \frac{M}{\sqrt{(L1 \times L2)}}$$

where, k= coupling coefficient, M= mutual inductance between the two coils, L1, L2 are the self-inductances of transmitter and receiver coils respectively.

The core of the system is the MPPT algorithm, which ensures that the PV panels operate at their peak efficiency. The MPPT technique used in this system is a Adaptive Neuro-Fuzzy Inference System (ANFIS) algorithm based maximum power point tracking technique. This AI-based optimization technique fine-tunes the system's performance by analyzing historical data and making real-time adjustments to maximize energy extraction from the panels.

The system's performance is tested in various real-world driving conditions, including different weather conditions, road types, and vehicle speeds. Data is collected from various sensors and is used to evaluate the efficiency of the combined MPPT-WPT system in providing continuous charging to the EV. Additionally, simulations are run to predict the system's performance under different scenarios.

4.PROPOSED SYSTEM

The proposed system integrates flexible rooftop half-cut photovoltaic (PV) panels with wireless power transfer (WPT) technology and advanced Maximum Power Point Tracking (MPPT) techniques for efficient in-motion EV charging. The flexible PV panels are installed on the roof of the vehicle and generate electricity from sunlight

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while the vehicle is in motion. This electricity is then transferred wirelessly to the vehicle's battery via a WPT system, ensuring that the vehicle can charge continuously without needing to stop for recharging.

The half-cut PV panels are chosen for their superior performance in partial shading conditions and high efficiency. They are designed to be flexible, lightweight, and capable of withstanding the vibrations and stress encountered during driving. These panels are connected to a power converter that converts the DC power generated by the panels into a form suitable for wireless transfer.

Wireless power transfer is achieved using a set of transmitting and receiving coils. The transmitting coil is embedded in the roadway, while the receiving coil is installed in the vehicle. The WPT system operates at a specific frequency to optimize energy transfer efficiency and minimize power loss. To ensure continuous charging, the system uses real-time feedback to adjust the alignment of the coils based on the vehicle's speed, position, and driving conditions.

The system's key innovation lies in the integration of MPPT algorithms with WPT technology. The MPPT algorithm ensures that the flexible PV system operates at the maximum power point despite variations in sunlight and temperature. This is particularly important in dynamic environments, where the intensity of sunlight can change rapidly. By using suitable MPPT technique, the system can dynamically adjust the operating point of the PV panels to extract maximum energy from the available sunlight.

5.EXISTING SYSTEM

Existing systems for in-motion EV charging typically rely on static charging infrastructure such as charging stations or inductive charging pads embedded in the road. These systems do not provide continuous charging while the vehicle is in motion, which can lead to power shortages and range anxiety for electric vehicle users.

The most commonly used method in existing systems is inductive wireless power transfer (IWPT), where a set of coils embedded in the road surface transmits power to a corresponding set of coils in the vehicle. While IWPT systems can deliver power to the vehicle during motion, they are limited by several factors such as the alignment of the coils, power efficiency, and the need for significant infrastructure investment. Moreover, these systems do not integrate renewable energy sources like PV panels,

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relying on conventional power sources for charging.

In terms of MPPT, existing systems mainly use basic algorithms such as Perturb and Observe (P&O) or Incremental Conductance (IncCond) to track the maximum power point of solar panels. However, these methods often struggle with fast changes in sunlight or environmental conditions, leading to suboptimal performance in real-world driving scenarios.

Another limitation of current systems is the lack of flexibility in terms of energy harvesting from renewable sources. While some systems have attempted to integrate PV panels, they typically face challenges in terms of power conversion efficiency, shading issues, and the mechanical limitations of traditional solar panels on moving vehicles.

In summary, the existing systems are limited by static charging solutions, inefficient MPPT techniques, and lack of integration with renewable energy sources. The proposed system addresses these issues by combining flexible PV panels, wireless power transfer, and advanced MPPT algorithms for efficient in-motion EV charging.

6. SIMULINK RESULTS & OUTPUTS

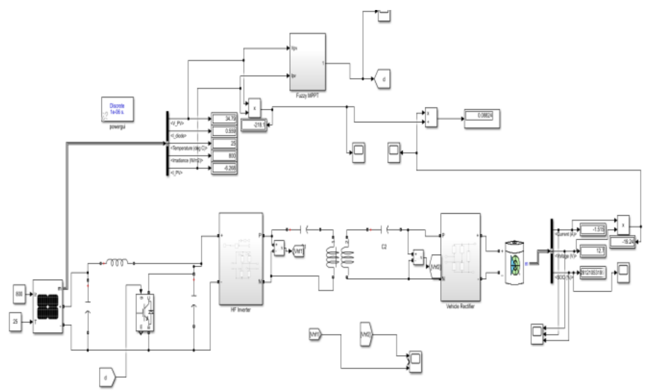

Fig 4. Simulation circuit using ANFIS based mppt

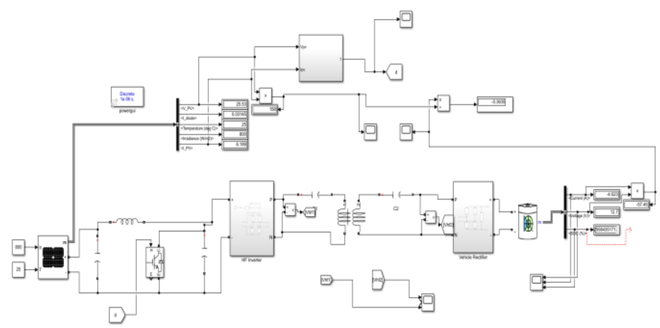

Fig 5. Simulation circuit using P & O based mppt

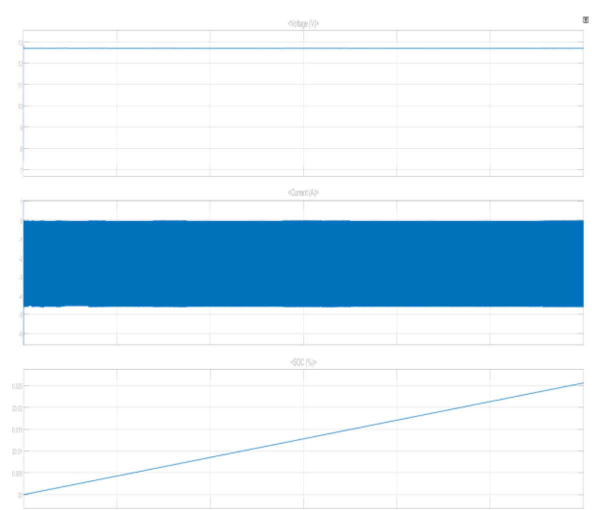

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Fig 6. Battery voltage current and soc using P & O based mppt

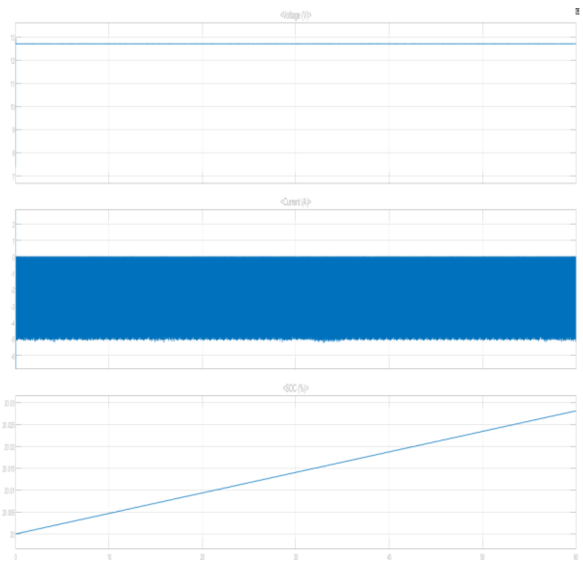

Fig 6. Battery voltage current and soc using ANFIS based mppt

From the results it is found that for a 100ah battery using P and o algorithm charge % for 1 minute is found to be 20-20.0255%

using Neuro fuzzy algorithm charge % for 1 minute is found to be 20-20.0283% charging characteristic.

7.CONCLUSION

The integration of flexible rooftop half-cut photovoltaic (PV) panels with wireless power transfer (WPT) technology and advanced Maximum Power Point Tracking (MPPT) techniques represents a significant advancement in the field of in-motion electric vehicle (EV) charging. As the adoption of electric vehicles continues to rise, the need for innovative charging solutions becomes more pressing. Traditional charging methods, such as stationary charging stations, pose several limitations, including the need for vehicles to stop and recharge, which can be time-consuming and inconvenient. In contrast, the proposed system offers a dynamic and sustainable solution that allows for continuous charging while the vehicle is in motion, contributing to the growth of a more efficient and reliable EV charging infrastructure. The flexible half-cut PV panels selected for the proposed system offer several advantages over traditional solar panels. Their enhanced performance under partial shading conditions, along with their flexibility and lightweight characteristics, make them an ideal choice for rooftop installations on vehicles. The ability to generate electricity from sunlight while the vehicle is in transit ensures that the vehicle's battery can be recharged without the need for external charging infrastructure. This feature eliminates range anxiety and makes long-distance travel more feasible for electric vehicle owners. Wireless power transfer (WPT) plays a crucial role in the proposed system by enabling power transmission from the road to the vehicle without the need for physical connectors. This method not only

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simplifies the charging process but also reduces wear and tear on the vehicle's charging components. However, efficient power transfer in a dynamic environment, where vehicle speed, position, and alignment with the WPT system are constantly changing, requires careful optimization. By integrating WPT technology with MPPT algorithms, the system can ensure that the power transmitted to the vehicle is maximized, even under variable environmental conditions. Maximum Power Point Tracking (MPPT) is another critical component of the system. By utilizing advanced MPPT algorithms, the proposed system can dynamically adjust the operating point of the flexible PV panels to extract the maximum possible energy from the sunlight, even when light intensity fluctuates. The hybrid MPPT algorithm, which combines Perturb and Observe (P&O) with artificial intelligence-based optimization techniques, enables the system to respond to real-time changes in sunlight and temperature, thus improving the overall performance and energy efficiency of the system.

8.FUTURE SCOPE

The proposed system of flexible rooftop half-cut photovoltaic (PV) panels combined with wireless power transfer (WPT) technology and advanced Maximum Power Point Tracking (MPPT) techniques for in-motion electric vehicle (EV) charging represents a transformative approach to EV charging. While the current system offers significant improvements over traditional charging methods, there are several areas for further development and optimization. As technology continues to evolve, the future scope of this system encompasses advancements in several key domains, including efficiency, scalability, integration with smart infrastructure, and the development of next-generation components. These advancements have the potential to revolutionize the EV charging landscape and contribute to the widespread adoption of electric vehicles.

One of the primary areas for future enhancement is the efficiency of wireless power transfer (WPT). Current WPT systems, while functional, still face challenges related to power loss during transmission, especially in dynamic environments where the alignment of the coils can be affected by vehicle speed, position, and road conditions. Research into more efficient WPT technologies, such as resonant inductive coupling and magnetic resonance, could significantly improve the

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power transfer efficiency. Additionally, innovations in the design of transmitting and receiving coils, such as using higher-frequency operation or employing adaptive coil positioning mechanisms, could help maintain optimal energy transfer during vehicle motion. These advancements would result in higher power delivery efficiency and less energy loss, which is critical for the long-term viability of in-motion charging systems.

Another key area for future development is the integration of more advanced MPPT algorithms. While the current hybrid MPPT system that combines Perturb and Observe (P&O) with artificial intelligence (AI) optimization techniques offers significant performance improvements, further research can lead to even more sophisticated algorithms that are better suited to the dynamic nature of in-motion charging. For instance, machine learning techniques, such as reinforcement learning, could be employed to dynamically adjust the operating parameters of the PV system based on real-time environmental data, including changes in weather, road conditions, and vehicle performance.

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