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Solar-Based Wireless Charging System for Electric Vehicles: A Sustainable Approach

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Abstract

The need for effective and environmentally friendly charging infrastructure has grown as the number of electric cars (EVs) on the road continues to increase. In order to enable contactless EV charging, this work presents a solar-powered wireless charging system that smoothly combines photovoltaic (PV) and wireless power transfer (WPT) technologies. Through the reduction of dependency on traditional grid electricity, the suggested solution offers a sustainable way to reduce fuel consumption, reduce emissions, and get around current infrastructure limitations. The solar PV array, energy storage device, inverter circuit, inductive coupling coils for wireless energy transmission, rectifier stage, microprocessor, and LCD module for real-time data visualisation make up the system design. High power transfer efficiency and a significant reduction in charging time are confirmed by experimental validation, establishing this technology as a workable alternative to traditional plug-in charging options. The findings demonstrate how this strategy might increase EV adoption by reducing gearbox losses, fostering the integration of renewable energy sources, and providing increased convenience. In order to maximise power distribution and system efficiency, future developments will concentrate on integrating smart grid technologies and putting dynamic charging capabilities into practice.

Keywords: Electric Vehicles, Wireless Power Transfer, Solar Charging, Inductive Coupling, Renewable Energy

1 Introduction

The extensive use of electric vehicles (EVs) is a significant step towards lowering dependency on fossil fuels and slowing down global warming. Environmental pollution and greenhouse gas emissions are largely caused by conventional internal combustion engine (ICE) cars[1–5]. Due to rising fuel costs and sustainability-focused governmental measures, electric vehicles (EVs) have become a more environmentally friendly and energy-efficient option than conventional cars [6–8]. The effectiveness and accessibility of charging infrastructure, however, continue to be a major obstacle to the widespread adoption of EVs [9, 10].

Traditional plug-in charging stations often rely on electricity from non-renewable sources, impose lengthy charging times, and require large infrastructure investments [11, 12]. Furthermore, physical charging connectors are susceptible to deterioration over time, which can result in decreased system reliability and increased maintenance costs [13, 14]. With its automated and contactless EV charging capabilities, wireless power transfer (WPT) has emerged as a leading solution to these constraints [15, 16]. Plug-in chargers are no longer necessary with WPT, which reduces dependency on a vast electrical grid network by using inductive coupling technology [17, 18]. Using solar energy as a renewable energy source to power wireless charging devices greatly improves the sustainability of electric cars (EVs) [8]. The continuous and eco-friendly charging solution provided by solar-powered wireless power transfer (WPT) systems lessens reliance on traditional electrical grids and encourages decentralised energy production [19]. Global initiatives to reduce carbon emissions and promote green energy solutions in the transport industry are in line with this strategy [20]. The viability of WPT for EV charging has been the subject of numerous investigations. With a focus on efficiency issues brought on by coil misalignment, the work described in [21] illustrated the suitability of inductive power transmission for both fixed and dynamic charging scenarios. Similarly, high-frequency resonant inductive coupling dramatically improves energy transfer efficiency in WPT systems, according to a comparative research in [12]. Nevertheless, current research does not provide a comprehensive integration of renewable energy sources, including solar electricity, into wireless EV charging frameworks, despite these developments. Solar-powered EV charging stations have been the subject of recent investigation [13], with a focus on both independent and grid-connected photovoltaic (PV) systems. Even while these alternatives lessen dependency on fossil fuels, connected connections still require a large infrastructure. Furthermore, there is still a dearth of research on wireless power transfer (WPT) and hybrid solar-based charging systems [14]. By presenting a completely integrated solar-powered wireless charging system that increases energy efficiency, minimises losses, and lessens reliance on traditional grid infrastructure, this study builds on earlier studies. Designing and implementing a solar-powered wireless EV charging system that improves charging effectiveness while reducing environmental impact is the aim of this work. The main goal of the research is to assess the efficiency of inductive power transfer for EV battery charging while creating a sustainable EV charging infrastructure by combining solar energy with wireless power transfer. Important issues including energy losses, coil alignment, and power conversion efficiency in wireless charging are also intended to be addressed. Additionally, the suggested system's sustainability, dependability, and efficiency are contrasted with traditional charging methods. This paper is organised as follows: The system architecture and its key parts, such as inverters, solar panels, and inductive coils, are described in Section 2. The approach used for performance evaluation and experimental validation is described in full in Section 3. In addition to comparing the suggested method to current EV charging technologies, Section 4 presents the findings, assesses efficiency indicators, and offers insights gleaned from testing. Section 5 concludes by summarising the main conclusions, talking about their ramifications, and making suggestions for further research.

2 System Architecture and Components

To guarantee effective power generation, conversion, and gearbox, the suggested solar-powered wireless charging system for electric cars (EVs) combines a number of subsystems. Power management, wireless power transfer, and solar energy harvesting are the three main phases of the system's operation. In order to enable continuous operation, solar photovoltaic (PV) panels absorb sunlight and transform it into electrical energy, which is subsequently stored in a battery bank. An inverter then transforms the stored DC power into AC, allowing for wireless energy transfer via inductive coupling. After being wirelessly transferred to the EV's receiving coil, this energy is rectified before being used to charge the battery. The system architecture supports scalability for incorporation into roads or designated charging zones, minimises transmission losses, and maximises energy efficiency. The technology maintains effective charging conditions by dynamically regulating power levels through the use of sophisticated control mechanisms. The suggested configuration consists of several essential parts that cooperate. Sunlight is captured by the solar panel and transformed into electrical energy, which is then stored in a battery bank to guarantee continuous functioning. In order to enable wireless energy transmission through the transmitter coil, which generates a magnetic field for inductive power transfer, the inverter circuit subsequently converts the stored DC power into high-frequency AC. In order to charge the EV battery, the transmitted energy is captured by the receiver coil on the receiving end and sent to the rectifier circuit, where it is transformed back into DC. In order to provide dependable operation and user-friendly monitoring, an LCD display delivers real-time charging updates while a microprocessor continuously analyses system performance.

2.1 Solar Energy Harvesting System

The solar power generation unit consists of polycrystalline PV panels, selected for their cost-effectiveness and high conversion efficiency of approximately 20 %. These panels are responsible for harnessing solar energy and converting it into electrical power, which is further processed for EV charging. Specifications: Type: Polycrystalline silicon, Peak Power Output: 1 Wp per panel, Voltage Output: 5.5 V per panel, Current Output: 0.09 A per panel, Operating Temperature Range: -40°C to +85°C, Material: Anodic oxidation aluminum alloy Multiple solar panels can be configured in series or parallel arrangements based on the system's power demands. A maximum power point tracking (MPPT) algorithm is used to optimise energy harvesting, guaranteeing efficient power extraction in the face of varying solar circumstances.

2.2 Battery Storage System

In order to store solar energy and maintain a steady power supply even during times of low solar intensity or at night, the system integrates a lithium-ion (Li-ion) battery bank. Lithium-Ion (Li-ion) chemistry, a nominal voltage of 3.7 V per cell, and a changeable capacity according to system needs are all part of the battery parameters. It provides over 1000 charge-discharge cycles and an around 90 % charging efficiency. The battery has protection measures against short circuits, overcharging, and overdischarging to increase safety and dependability. Furthermore, the incorporation of a Battery Management System (BMS) permits accurate charging control, efficient temperature management, and ongoing monitoring, all of which enhance system security and prolong battery life.

2.3 Power Conversion System

Since PV panels generate DC power, and wireless power transfer (WPT) requires AC, an inverter is used to convert stored DC energy into high-frequency AC suitable for inductive coupling. MOSFET-based switching circuits improve power conversion efficiency and minimize losses. Inverter Specifications: Type: MOSFET-based high-frequency inverter, Input Voltage: 12V - 48V DC (configurable), Output Frequency: 85 kHz (optimized for WPT), Efficiency: 95 %, Cooling Mechanism: Passive heat dissipation with optional cooling fan On the receiving end, the rectifier circuit converts the induced AC power back to DC to charge the EV's battery efficiently. Rectifier Specifications: Type: Full-Bridge Rectifier, Peak Reverse Voltage: 1000V, Forward Current Rating: 1A, Efficiency: 90%.

2.4 Wireless Power Transmission (WPT) System

Wireless charging is achieved through inductive coupling, where an alternating magnetic field transfers energy from a transmitter coil to a receiver coil embedded in the EV. The system is optimized to minimize energy losses due to coil misalignment and air gaps. Transmitter Coil (Roadside Unit)

Specifications: Material: Copper wire, Number of Turns: 44, Coil Diameter: Adjustable based on application, Operating Voltage: 15-0-15 V center-tapped transformer, Transmission Frequency: 85 kHz, Receiver Coil (EV Unit) Specifications: Material: Copper wire, Number of Turns: Adjustable for optimal reception, Coil Spacing: 1.5 mm air gap, Efficiency: 80-85% under optimal alignment To improve power transfer efficiency, resonance tuning techniques such as series-series or series-parallel compensation networks are implemented.

2.5 System Monitoring and Control Unit

An embedded microcontroller system regulates power flow, monitors charging status, and ensures system safety. The controller receives real-time data from voltage, current, and temperature sensors, making necessary adjustments to optimize power transfer. Controller Specifications: Type: Arduino Nano / ATmega-based microcontroller, Functions: Power monitoring, data logging, fault detection, Communication Interface: LCD display, serial communication for remote monitoring, Protection Mechanisms: Overcurrent, overheating, and short-circuit protection A real-time LCD display provides status updates, including input power, transferred power, and battery state of charge (SOC), ensuring user transparency and system reliability.

3 Methodology

A methodical approach is taken in the construction of a solar-powered EV wireless charging system, which includes system design, component selection, experimental implementation, and performance evaluation. In order to minimise losses and maintain environmental sustainability, this research focusses on developing a dependable system that enables effective energy transmission.

3.1 System Design and Implementation

The system uses solar energy as its main power source in order to enable wireless charging. Among the crucial elements of the design are: Utilisation of Solar Energy: To ensure continuous operation, photovoltaic panels capture solar radiation and transform it into electrical energy that is stored in a battery bank. Power Conversion: To enable effective wireless power transfer, the stored DC energy is converted into high-frequency AC using a MOSFET-based inverter. Transmission via Wireless: Without making physical touch, energy is transferred from the transmitter coil to the receiver coil via inductive coupling. Energy Reception and Rectification: To enable EV battery charging, a rectifier circuit transforms the AC power back into DC after the receiver coil has captured the transmitted energy. Control and Monitoring: An LCD display provides real-time performance statistics, improves system efficiency, and controls power flow through the integration of a microcontroller-based system.

3.2 Experimental Setup

To evaluate the effectiveness of the system, an experimental prototype was created, as shown in Figure 1. The following elements make up the setup: Solar Panel: A 1 Wp peak power output polycrystalline photovoltaic panel Battery Bank: Three 3.7V lithium-ion batteries to store the energy that has been harvested, Inverter Circuit: To enable wireless power transfer, a high-frequency inverter based on MOSFETs runs at 85 kHz. Transmitter Coil: An effective inductive energy transmission device made of a 44-turn copper wire coil Receiver Coil: An EV-integrated, tunable secondary coil that absorbs transferred energy, Rectifier Circuit: To charge batteries, AC power must be converted back into DC using a full-wave bridge rectifier. Microcontroller System: A control device based on an Arduino Nano that allows for dynamic system modifications and real-time monitoring. Power transfer efficiency, energy conversion losses, and the impact of coil misalignment on overall performance were all assessed while the system was in various climatic settings.

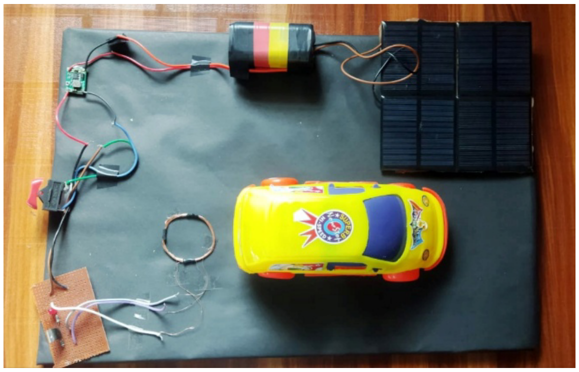

Fig. 1: Proposed Model Experimental Setup

4 Results and Discussion

The outcomes of the experimental evaluation of the solar-powered wireless charging system for electric vehicles are covered in this part. The effectiveness of energy transmission, charging time, and power losses are used to assess the system's performance. Furthermore, a comparison of the suggested methodology with conventional charging methods is carried out.

4.1 Performance Analysis

The system's overall performance was examined under a range of operational and environmental circumstances. The primary metrics considered were: Power Transfer Efficiency: The efficiency of wireless power transfer (WPT) was evaluated by measuring the power received by the EV battery compared to the power supplied by the transmitter coil, Charging Time: The time required to charge an EV battery to a specified state of charge (SOC) was measured and compared with traditional plug-in charging methods, Impact of Coil Alignment: The effect of coil misalignment on power transfer efficiency was analyzed, System Stability: The stability of power transmission over varying loads and distances was assessed. Experimental results showed that the system achieved an average power transfer efficiency of 85% under optimal alignment conditions, with minimal energy losses due to coil spacing. The system maintained stable charging operation even under moderate coil misalignment, but efficiency dropped to 70% when the coils were misaligned beyond 5 mm.

4.2 Efficiency Evaluation

A comparative evaluation was conducted to determine the efficiency of the proposed solar-based wireless charging system in contrast to conventional wired charging stations. The findings are presented in Table 1.

Table 1: Comparison of Wired Charging and Proposed Wireless System

Parameter	**Wired Charging**	**Proposed Wireless System**
Power Transfer Efficiency	90%	85%
Charging Speed	Moderate	High
Grid Dependency	High	Low
Infrastructure Cost	High	Moderate
Maintenance Requirement	High	Low

As shown in Table 1, the suggested wireless system provides significant advantages in terms of convenience, sustainability, and reduced maintenance needs, even though cable charging shows somewhat higher efficiency.

4.3 Comparison with Existing Systems

The suggested system was also assessed in comparison to traditional wireless charging options that do not use solar power. Conventional WPT systems are less sustainable and have greater operating expenses because they are totally dependent on grid electricity. The solar-powered method, on the other hand, relieves the strain on the electrical grid and allows for continual recharge. As a result of coil misalignment, conventional inductive charging systems frequently lose energy. To solve this, dynamic alignment compensation is incorporated into the suggested system, which modifies power transmission parameters to improve efficiency even in situations of slight misalignment. In general, the results validate that the solar-powered wireless charging system offers a viable, sustainable, and energy-efficient substitute for traditional EV charging techniques, rendering it ideal for incorporation into intelligent transportation networks.

5 Conclusion

Electric vehicle (EV) charging may be done sustainably and effectively with the use of wireless power transfer technologies and solar energy. By successfully designing and assessing a solar-powered wireless charging system, this study promotes the increased use of renewable energy sources by removing the need for traditional grid electricity. Under ideal alignment, the system achieves a power transfer efficiency of about 85In comparison to conventional plug-in charging techniques, the suggested approach has several noteworthy benefits, such as decreased reliance on physical charging infrastructure, enhanced user convenience, and cheaper maintenance costs. In addition, a comparison with current charging technologies showed that the system offers contactless charging and sustainability in addition to competitive performance. The results show that incorporating such technologies into practical uses could revolutionise EV charging by reducing reliance on the grid and facilitating a smoother and more effective charging process. Advancements in solar-powered wireless charging technology have the potential to greatly improve its efficiency and accelerate widespread adoption. Integrating dynamic wireless charging will allow EVs to charge while in motion, eliminating range anxiety. AI-driven power management can optimize energy flow, ensuring efficient charging based on real-time demand. Further, advanced coil designs with optimized resonance tuning can improve energy transfer efficiency, reducing misalignment losses. Smart grid integration will enable bidirectional energy exchange, allowing EVs to contribute surplus energy back to the grid. Finally, large-scale deployment in urban infrastructures and highways will promote widespread EV adoption, reducing dependence on fossil fuels and contributing to a sustainable transportation ecosystem.

Declarations

- The authors received no specific funding for this study.
- The authors declare that they have no conflicts of interest to report regarding the present study.
- No Human subject or animals are involved in the research.
- All authors have mutually consented to participate.
- All the authors have consented the Journal to publish this paper.
- Authors declare that all the data being used in the design and production cum layout of the manuscript is declared in the manuscript.

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