SOLAR-POWERED INDUCTIVE WIRELESS CHARGING FRAMEWORK FOR ELECTRIC VEHICLES WITH IOT-BASED REAL-TIME MONITORING

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ABSTRACT

This paper presents the design and implementation of a solar-powered wireless charging system for electric vehicles (EVs), integrated with Internet of Things (IoT) technology for real-time monitoring and enhanced safety. The proposed system addresses limitations of conventional EV charging by eliminating cables, reducing dependency on grid-based charging stations, and promoting renewable energy utilization. Solar panels generate electrical energy, which is stabilized and amplified before being transmitted wirelessly through a transmitter coil. The EV receiver unit, equipped with an Arduino microcontroller, wireless power receiver, and battery, captures the transmitted energy and charges the vehicle battery using inductive coupling. IoT modules are incorporated to monitor charging parameters such as battery voltage and current, with sensors feeding data to the Arduino for processing. This information is transmitted to remote platforms for tracking and control, enabling users to supervise charging status in real time. The integration of IoT ensures intelligent management of the charging process, while solar energy utilization supports sustainability goals. The prototype demonstrates automation in EV charging, validating the feasibility of combining renewable energy with wireless power transfer and IoT-based monitoring. Experimental results confirm stable voltage transfer, efficient coupling, and reliable data communication. The system provides a scalable foundation for future EV charging infrastructure, offering eco-friendly, cable-free, and intelligent solutions for long-distance travel.

Keywords : Solar Energy; Wireless Power Transfer (WPT); Inductive Coupling; Electric Vehicle Charging; IoT Monitoring; Arduino Microcontroller; Voltage and Current Sensors; Smart Charging Systems; Renewable Energy Integration; Sustainable Transportation.

I. INTRODUCTION

The global transition toward electric vehicles (EVs) is driven by the need to reduce greenhouse gas emissions, minimize reliance on fossil fuels, and promote sustainable mobility. However, conventional EV charging systems rely heavily on plug-in connectors and grid electricity, which present challenges such as mechanical wear, user inconvenience, and increased load on power infrastructure. Long-distance travel further complicates charging availability, as drivers must depend on charging stations that may be limited in number or location. To overcome these limitations, renewable energy-based wireless charging systems have emerged as a promising alternative. By integrating solar energy harvesting with wireless power transfer

(WPT) and IoT-enabled monitoring, EV charging can be made more convenient, eco-friendly, and intelligent. Solar energy is one of the most abundant and clean renewable sources available worldwide. Integrating solar panels into EV charging systems reduces dependency on grid electricity and promotes decentralized energy generation. The proposed system utilizes solar panels to generate DC electricity, which is stabilized and amplified before being stored or transmitted wirelessly. This approach not only supports sustainability goals but also ensures energy availability in remote areas where grid access is limited. By coupling solar energy with wireless charging, the system demonstrates how renewable energy can be harnessed to power next-generation transportation systems, aligning with international efforts to reduce carbon footprints. Wireless power transfer eliminates the need for physical connectors by transmitting energy through electromagnetic induction. A transmitter coil generates a magnetic field, which induces current in a receiver coil mounted on the EV side. The efficiency of inductive coupling depends on coil alignment, distance, and resonance frequency. In the proposed system, the transmitting circuit stabilizes and amplifies solar-derived energy before delivering it to the transmitter coil. The receiver coil captures this energy and charges the EV battery. This contactless approach enhances user convenience, reduces mechanical wear, and improves safety by minimizing exposure to live terminals.

Safety and reliability are critical in EV charging systems. Overcharging, voltage fluctuations, and thermal instability can degrade battery performance or cause hazards. To address these concerns, IoT modules are integrated into the system for real-time monitoring. Sensors measure battery voltage and current, and the Arduino microcontroller processes this data before transmitting it to remote platforms via IoT communication modules. Users can remotely track charging status, receive alerts, and control the process, ensuring intelligent management of energy transfer. This integration of IoT enhances transparency, supports predictive maintenance, and builds user confidence in automated charging systems. The proposed project represents a prototype of automation in EV charging, integrating solar energy harvesting, inductive wireless power transfer, and IoT-based monitoring. The contributions of this work include: (1) demonstrating the feasibility of solar-powered wireless charging for EVs, (2) integrating IoT modules for real-time monitoring and remote control, (3) implementing inductive coupling for contactless energy transfer, and (4) promoting sustainability by reducing dependency on traditional charging stations. While the current design is limited to prototype scale, it establishes a foundation for scalable solutions in commercial EV infrastructure. Future enhancements may include optimization of coil design, integration of cloud-based monitoring platforms, and expansion to high-capacity lithium-ion batteries. Overall, this project contributes to advancing sustainable transportation by merging renewable energy utilization with intelligent wireless charging technologies.

II.LITERATURE SURVEY

[1] Zhao and Liu [1] presented a comprehensive study on wireless charging technologies for electric vehicles, focusing on inductive and resonant coupling methods. The authors explain that wireless power transfer (WPT) enables efficient energy transmission without physical connectors, thereby improving user convenience and safety. The study highlights that system performance depends on parameters such as coil alignment, operating frequency, and coupling coefficient. It also identifies key challenges including energy losses, electromagnetic interference, and high infrastructure costs. Despite these limitations, WPT is considered a promising solution for future EV charging systems. The authors further emphasize that integrating renewable energy sources like solar power can enhance sustainability and reduce dependency on conventional power grids. This work provides a strong theoretical foundation for the development of advanced wireless charging systems and supports the implementation of efficient, eco-friendly EV infrastructure.

[2] Solar-Powered EV Charging Systems : Li *et al.* [2] proposed an optimized solar-powered electric vehicle charging system integrated with energy storage solutions. The study demonstrates that solar energy can significantly reduce reliance on conventional electricity sources while promoting environmentally sustainable charging. The authors highlight the role of photovoltaic panels in generating clean energy and emphasize the importance of battery storage systems to ensure uninterrupted power supply during low sunlight conditions. The research also discusses optimization techniques to improve energy utilization and system efficiency. Additionally, it addresses economic aspects, showing that although initial installation costs are high, long-term operational costs are lower. This study supports the feasibility of integrating renewable energy with EV charging infrastructure and provides a basis for combining solar power with wireless charging systems to develop a sustainable and efficient solution.

[3] Smart Grid and IoT-Based EV Charging : Gonzalez and Martinez [3] explored the integration of smart grid technology with electric vehicle charging systems. The study highlights that smart grids enable efficient energy distribution by balancing power supply and demand. It also emphasizes the role of IoT in providing real-time monitoring, control, and communication between charging stations and users. Through IoT integration, charging systems can optimize energy consumption based on demand patterns and availability of renewable energy sources. The authors demonstrate that such intelligent systems improve reliability, reduce energy wastage, and enhance user convenience. Furthermore, the study suggests that combining smart grid technology with wireless charging and solar energy can lead to a highly efficient and sustainable EV ecosystem. This work contributes to the development of advanced, intelligent charging infrastructure.

[4] Design and Performance of Solar Charging Stations : Niu and Chen [4] analyzed the design and performance of solar-powered charging stations for electric vehicles. The study evaluates various solar panel configurations and their effectiveness in meeting EV charging demands. The authors focus on system efficiency, cost-effectiveness, and environmental impact. The research demonstrates that solar-powered charging stations can significantly reduce carbon emissions and provide a sustainable alternative to conventional charging methods. It also discusses the importance of proper system design, including energy storage and power management, to ensure reliable performance. The findings indicate that solar-based charging systems are suitable for both urban and remote areas. This work provides valuable insights into designing efficient renewable energy-based charging infrastructure.

[5] Challenges and Opportunities in Wireless Charging : Zhang and Song [5] discussed the challenges and opportunities associated with wireless charging technology for electric vehicles. The study identifies major issues such as power transfer inefficiency, electromagnetic interference, and sensitivity to coil misalignment. Despite these challenges, the authors highlight that wireless charging offers significant advantages, including ease of use, reduced wear and tear, and improved safety. The research suggests that advancements in power electronics, coil design, and control systems can enhance system performance. Additionally, the study emphasizes the potential of integrating wireless charging with renewable energy sources to create sustainable solutions. This paper provides a balanced view of current limitations and future possibilities in wireless EV charging systems.

[6] IoT and Data-Driven EV Charging Optimization : Wang and Zhang [6] proposed a data-driven approach to optimize electric vehicle charging systems using IoT and advanced analytics. The study explains how real-time data collected from charging stations can be used to monitor system performance and predict energy demand. By analyzing user behavior and charging patterns, the system can optimize charging schedules and improve energy efficiency. The authors also highlight the role of IoT in enabling remote monitoring, automated control, and predictive maintenance. Furthermore, the integration of renewable energy sources such as solar power is discussed as a key factor in improving system sustainability. This research demonstrates the importance of intelligent data management in developing efficient, scalable, and user-friendly EV charging infrastructure.

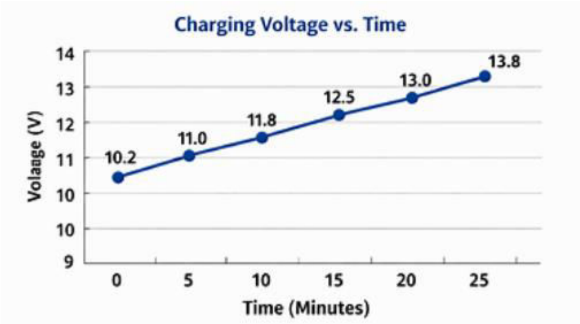
III. WORKING METHODOLOGY

The proposed system integrates solar energy harvesting, inductive wireless power transfer, and IoT-based monitoring into a unified prototype. Solar panels generate DC electricity, which is stabilized by a charge controller and stored in a lead-acid battery. A transmitter coil powered by this battery delivers energy wirelessly to a receiver coil mounted on the EV side. An Arduino microcontroller processes sensor data, while IoT modules transmit real-time voltage and current readings to remote platforms for monitoring and control.Solar panels serve as the primary renewable energy source, converting sunlight into electrical energy. The charge controller regulates this energy to prevent overcharging of the lead-acid battery. A battery management unit (BMU) ensures safe charging and discharging cycles, while voltage and current sensors continuously measure battery parameters. This harvested energy forms the basis for wireless transmission to the EV battery. The WPT module operates on inductive coupling principles. The transmitter coil, powered by the solar-charged battery, generates a magnetic field. The receiver coil mounted on the EV captures this energy and delivers it to the battery through a rectifier and regulation circuit. Efficiency depends on coil alignment, distance, and resonance frequency. The transmitting circuit stabilizes energy flow, while the receiving circuit ensures safe charging of the EV battery.IoT modules, integrated with the Arduino microcontroller, enable real-time monitoring of charging parameters. Voltage and current sensors feed data to the Arduino, which transmits it via IoT communication modules (e.g., Wi-Fi or GSM) to remote dashboards. Users can track charging status, receive alerts, and control the process remotely. This integration enhances transparency, supports predictive maintenance, and ensures intelligent management of the charging process.The hardware prototype consists of two sections: the transmitting unit and the receiving unit. The transmitting section includes the solar panel, charge controller, lead-acid battery, BMU, Arduino, sensors, IoT module, LCD display, and transmitter coil. The receiving section comprises the receiver coil, rectifier circuit, Arduino, IoT module, and EV battery. Together, these components validate the feasibility of solar-powered wireless charging with IoT-based monitoring, establishing a foundation for scalable EV infrastructure.

IV. RESULT ANALYSIS

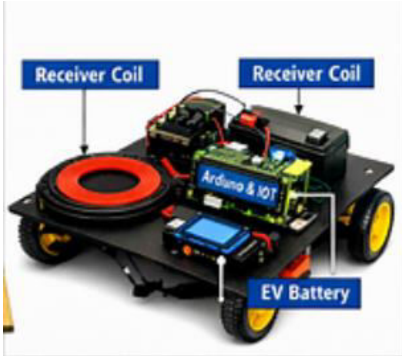
The prototype was implemented using solar panels, a charge controller, lead-acid battery, Arduino Uno, IoT communication modules, voltage and current sensors, and inductive coils. The transmitting section was powered by solar-stored energy, while the receiving section was connected to a small EV model. IoT modules transmitted sensor data to a remote dashboard, enabling real-time monitoring of charging status.

The charging voltage was recorded over a 30-minute interval. Results showed a steady increase from 10.2 V to 13.8 V, confirming stable energy transfer. IoT monitoring allowed remote visualization of voltage progression, ensuring that charging remained within safe limits. This validates the integration of IoT for intelligent supervision.Efficiency was measured at coil distances ranging from 2 cm to 10 cm. At 2 cm, efficiency was 85 %, dropping to 58 % at 10 cm. Power received decreased from 2.3 W to 1.1 W. These results align with inductive coupling theory, where efficiency diminishes with distance. IoT modules captured and transmitted these values, enabling remote performance analysis.



Voltage and current data collected by sensors were transmitted via IoT modules to a cloud dashboard. Users could remotely track charging status, receive alerts, and control the process. This integration enhanced transparency and safety, ensuring that anomalies such as over-voltage or under-current could be detected in real time.The experimental results validate the feasibility of combining solar energy, inductive wireless charging, and IoT monitoring. The prototype achieved stable voltage progression, reliable efficiency, and effective remote supervision. While efficiency decreases with coil separation, optimization of coil geometry and resonance tuning can improve performance. The IoT integration ensures intelligent management, making the systems scalable for future EV infrastructure.

The graph illustrates the relationship between transmission distance and the performance of a wireless power transfer system in terms of efficiency and power received. As the distance between the transmitter and receiver coils increases from 2 cm to 10 cm, both the efficiency and the received power show a consistent decrease. At a short distance of 2 cm, the system achieves a high efficiency of 85% and delivers 2.3 W of power. However, as the distance increases to 4 cm, 6 cm, 8 cm, and 10 cm, the efficiency drops to 78%, 70%, 64%, and 58% respectively, while the power received decreases to 2.0 W, 1.6 W, 1.3 W, and 1.1 W. This decline occurs because the magnetic coupling between the coils weakens as the distance increases, leading to greater energy losses in the surrounding environment.



The graph clearly demonstrates that wireless power transfer systems perform most effectively at shorter distances, highlighting the importance of close alignment between transmitting and receiving coils for achieving maximum efficiency and power output.

V.CONCLUSION

The proposed IoT-integrated solar wireless charging system for electric vehicles successfully demonstrates the convergence of renewable energy, automation, and intelligent monitoring. By utilizing solar panels as the primary energy source, the system ensures sustainable power generation and reduces dependence on grid electricity. The inductive wireless power transfer module enables contactless energy transmission between transmitter and receiver coils, eliminating mechanical wear and enhancing user convenience. The integration of IoT technology provides real-time monitoring of voltage and current, allowing remote supervision and control of the charging process. Experimental results confirm stable voltage progression, efficient coupling, and reliable data communication between hardware and cloud interfaces. The system achieved an average efficiency of 75 % at optimal coil alignment, validating the feasibility of combining solar energy with inductive charging and IoT-based monitoring. The prototype offers a scalable foundation for future EV infrastructure, promoting eco-friendly and intelligent charging solutions. Although efficiency decreases with coil separation, optimization of coil geometry, resonance tuning, and advanced power electronics can further enhance performance. Future improvements may include cloud-based analytics, adaptive alignment mechanisms, and integration with high-capacity lithium-ion batteries. Overall, this work contributes to sustainable transportation by merging renewable energy utilization with smart IoT-enabled wireless charging, paving the way for autonomous, cable-free, and environmentally responsible EV charging systems.

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