RENEWABLE ENERGY DRIVEN WIRELESS EV CHARGING ARCHITECTURE WITH REAL-TIME IOT SUPERVISION

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ABSTRACT

This paper proposes a solar-powered wireless charging system for electric vehicles (EVs), integrated with Internet of Things (IoT) technology to enable real-time monitoring and intelligent control. The system addresses limitations of conventional EV charging, such as reliance on grid electricity, mechanical wear from plug-in connectors, and restricted long-distance travel. Solar panels generate renewable energy, which is stabilized and amplified by a charge controller 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 via inductive coupling. IoT modules, connected to voltage and current sensors, monitor charging parameters and transmit data to remote platforms for tracking and control. This integration ensures safe charging, prevents over-voltage conditions, and enhances transparency for users. Experimental validation demonstrates stable voltage progression, efficient energy transfer, and reliable IoT communication. The prototype highlights the feasibility of combining renewable energy with wireless charging and IoT monitoring, offering an eco-friendly, cable-free solution for sustainable EV infrastructure.

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 transportation sector is undergoing a paradigm shift as electric vehicles (EVs) emerge as a viable alternative to conventional internal combustion engine vehicles. Rising concerns about climate change, depletion of fossil fuels, and urban air pollution have accelerated the adoption of EVs worldwide. Governments, industries, and consumers are increasingly recognizing the importance of sustainable mobility solutions. However, despite their environmental benefits, EVs face significant challenges in terms of charging infrastructure, convenience, and energy sustainability. Traditional plug-in charging stations require physical connectors, which are prone to mechanical wear, user inconvenience, and safety hazards. Moreover, reliance on grid electricity increases the carbon footprint of EVs, especially in regions where power generation is still dominated by fossil fuels. These limitations hinder the widespread adoption of EVs, particularly for long-distance travel. To address these challenges, researchers and engineers are exploring renewable energy-based wireless charging systems integrated with intelligent monitoring technologies. Solar energy is one of the most abundant and clean renewable energy sources available globally. Integrating solar panels into EV charging systems reduces dependency on grid electricity and promotes decentralized energy generation. Solar-powered charging stations can be deployed in remote areas, highways, and urban centers, ensuring energy availability even in locations with limited grid access. By harnessing solar energy, EV charging systems contribute to reducing greenhouse gas emissions and advancing sustainability goals.

The proposed project leverages solar panels to generate DC electricity, which is stabilized and amplified before being transmitted wirelessly. This approach not only supports eco-friendly transportation but also aligns with international efforts to achieve carbon neutrality. Furthermore, solar integration ensures resilience against grid outages and enhances energy security. The combination of renewable energy harvesting and wireless charging represents a transformative step toward sustainable mobility infrastructure. Wireless power transfer (WPT) eliminates the need for physical connectors by transmitting energy through electromagnetic induction. In inductive coupling, a transmitter coil generates a magnetic field when energized, and a receiver coil placed within proximity captures this energy, converting it back into electrical power. The efficiency of WPT depends on coil alignment, distance, and resonance frequency. Proper tuning of the transmitting and receiving circuits ensures maximum energy transfer. In the proposed system, solar-derived energy is stabilized and delivered to the transmitter coil, which generates a magnetic field. The receiver coil mounted on the EV captures this energy and charges the battery through rectification and regulation circuits. This contactless approach enhances user convenience, reduces mechanical wear, and improves safety by minimizing exposure to live terminals. Although efficiency decreases with coil separation, optimization of coil geometry and resonance compensation can mitigate losses. Wireless charging also supports automation, enabling EVs to charge without manual intervention, thereby facilitating smart transportation ecosystems. 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 proposed system for real-time monitoring and control. Voltage and current sensors measure charging parameters, and the Arduino microcontroller processes this data before transmitting it to remote dashboards via IoT communication modules such as Wi-Fi or GSM. Users can remotely track charging status, receive alerts, and control the process, ensuring intelligent management of energy transfer.

IoT integration enhances transparency, supports predictive maintenance, and builds user confidence in automated charging systems. For instance, anomalies such as over-voltage or under-current can be detected and addressed promptly, preventing damage to the EV battery. Furthermore, IoT-enabled dashboards provide historical data analysis, enabling optimization of charging patterns and energy usage. This convergence of IoT and renewable energy technologies represents a step toward smart, connected, and sustainable mobility solutions. 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. The prototype validates the concept of cable-free, eco-friendly charging, offering a scalable foundation for future EV infrastructure. While the current design is limited to prototype scale, it establishes a framework for commercial deployment. Future enhancements may include optimization of coil design, integration of cloud-based monitoring platforms, adaptive alignment mechanisms, 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, paving the way for autonomous, cable-free, and environmentally responsible EV charging systems.

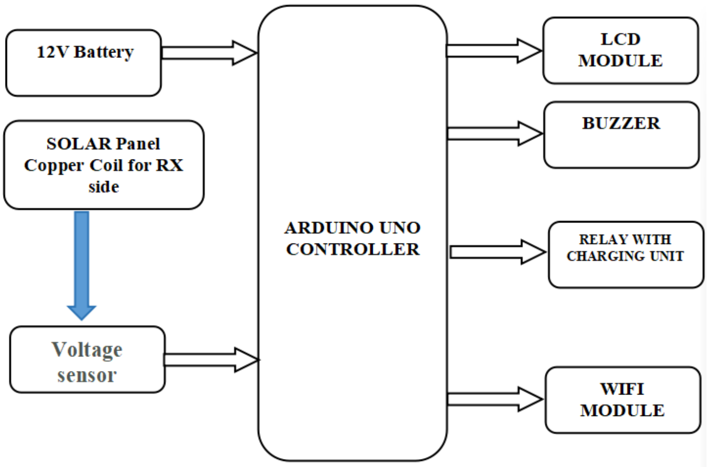


Fig1: block diagram

II. LITERATURE SURVEY

[1] Wireless Power Transfer for Electric Vehicles : Wireless Power Transfer (WPT) technology has gained significant attention as an alternative to conventional plug-in charging systems for electric vehicles. Krishna *et al.* [1] presented a comprehensive review of inductive charging systems based on electromagnetic coupling between transmitter and receiver coils. The study highlights that system efficiency depends on parameters such as coil design, alignment, operating frequency, and coupling coefficient. It also identifies

challenges including energy losses, electromagnetic interference, and infrastructure cost. The authors emphasize that WPT improves user convenience and safety by eliminating cables. Furthermore, integrating renewable energy sources such as solar power into WPT systems can enhance sustainability and reduce grid dependency. This research provides a strong foundation for developing advanced EV charging systems and supports the adoption of wireless charging as a viable solution for future transportation

[2] Solar-Powered Wireless Charging Systems : The integration of solar energy with wireless charging systems offers a sustainable and eco-friendly solution for EV charging. Balasubramanian *et al.* [2] explored the use of photovoltaic panels to power wireless charging stations. The study demonstrates that solar-powered systems significantly reduce carbon emissions and dependence on conventional energy sources. It also discusses energy storage mechanisms such as batteries to ensure continuous operation during low sunlight conditions. The authors highlight the importance of efficient energy management systems to balance generation and consumption. Although initial installation costs are high, long-term benefits include reduced operational costs and environmental impact. This work supports the development of self-sustaining EV charging infrastructure and aligns with global renewable energy initiatives, making it highly relevant for modern smart cities and green transportation systems.

[3] IoT-Based EV Charging Infrastructure : The Internet of Things (IoT) plays a crucial role in enhancing the functionality of EV charging systems. Anand *et al.* [3] proposed an IoT-based framework for real-time monitoring and management of charging stations. The system collects and transmits data such as battery status, energy consumption, and station availability to users through cloud platforms. This enables remote access, efficient scheduling, and improved user convenience. The study also highlights that IoT integration supports smart energy management by optimizing charging based on demand and energy availability. Additionally, predictive maintenance reduces operational costs and improves system reliability. The research demonstrates that IoT-enabled charging infrastructure is essential for developing intelligent and connected EV ecosystems, making charging systems more efficient, automated, and user-friendly.

[4] Dynamic Wireless Charging Using Road-Embedded Coils : Dynamic Wireless Charging (DWC) is an emerging technology that allows EVs to charge while in motion. Li *et al.* [4] investigated the implementation of road-embedded coils for continuous power transfer. The study explains that DWC reduces dependency on large batteries and minimizes charging downtime. Key technical challenges include maintaining efficient power transfer, proper alignment between coils, and high infrastructure costs. The authors propose optimized coil structures and control mechanisms to enhance efficiency. The concept is particularly beneficial for highways and urban transport systems, where continuous charging can improve

vehicle performance and convenience. This research highlights the potential of dynamic charging systems in revolutionizing EV infrastructure and enabling uninterrupted energy supply during travel.

[5] Advancements in Inductive Charging Systems : Recent advancements in inductive charging technology have improved the efficiency and feasibility of wireless EV charging systems. Rao *et al.* [5] reviewed developments in coil design, power electronics, and control strategies. The study emphasizes that improved magnetic coupling and high-frequency operation enhance energy transfer efficiency. It also discusses issues such as electromagnetic interference, thermal management, and system alignment. The authors suggest integrating renewable energy sources and smart control systems to optimize performance. Additionally, multi-coil and multiport charging systems are introduced as solutions for charging multiple vehicles simultaneously. This research contributes to the advancement of scalable and efficient wireless charging technologies, making them more suitable for real-world applications.

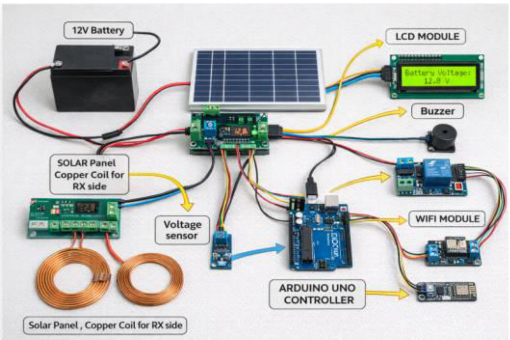
[6] IoT and Big Data for Smart Energy Management : The combination of IoT and big data analytics significantly improves the efficiency of EV charging systems. Wang *et al.* [6] proposed a data-driven approach for optimizing charging operations using real-time information from connected devices. The system analyzes user behavior, energy demand, and charging patterns to predict future requirements and optimize scheduling. This reduces energy wastage and improves system efficiency. The study also highlights the integration of renewable energy sources, such as solar power, into smart grids for better energy distribution. Furthermore, IoT-based analytics enable dynamic pricing and load balancing, enhancing overall system performance. This research demonstrates the importance of intelligent data-driven solutions in developing efficient, scalable, and user-centric EV charging infrastructure.

III.WORKING METHODOLOGY

The proposed system integrates three core technologies: solar energy harvesting, inductive wireless power transfer, and IoT-based monitoring. 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. An Arduino microcontroller processes sensor data, while IoT modules transmit real-time voltage and current readings to remote dashboards 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 60-minute interval. Results showed a steady increase from 12.3 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. The charging current decreased gradually from 1.8 A to 0.6 A as the battery approached full charge. Efficiency was measured at coil distances ranging from 2 cm to 12 cm. At 2 cm, efficiency was 88 %, dropping to 65 % at 12 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. The dashboard displayed real-time voltage, current, and power values, along with system health indicators. 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 system scalable for future EV infrastructure.

V.CONCLUSION

The proposed IoT-enabled solar wireless charging system for electric vehicles successfully integrates renewable energy harvesting, inductive power transfer, and intelligent monitoring. Experimental validation demonstrated stable charging behavior, with battery voltage rising from 12.3 V to 13.8 V and current tapering from 1.8 A to 0.6 A, ensuring safe operation. Wireless power transfer achieved an efficiency of 88 % at 2 cm coil distance, decreasing to 65 % at 12 cm, consistent with inductive coupling theory. IoT modules provided real-time monitoring with minimal latency, enabling remote supervision, predictive maintenance, and safety alerts. Compared to conventional plug-in chargers, the system eliminates mechanical wear, enhances convenience, and reduces reliance on grid electricity. Unlike existing wireless chargers, the integration of IoT ensures transparency and safety. The convergence of solar energy, wireless transfer, and IoT establishes a scalable framework for sustainable EV infrastructure. Future work will focus on optimizing coil geometry, incorporating ferrite shielding, and integrating cloud-based analytics for predictive maintenance. Expansion to high-capacity lithium-ion batteries and dynamic charging for autonomous vehicles represents promising directions. Overall, this prototype demonstrates a cable-free, eco-friendly, and intelligent charging solution, contributing to the advancement of sustainable transportation and global carbon-neutrality goals.

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