IMPLEMENTATION OF WIRELESS CHARGING SYSTEM FOR ELECTRIC VEHICLE USING SOLAR PANELS

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Abstract— *The rapid increase in electric vehicle (EV) adoption has created a demand for efficient, reliable, and user-friendly charging technologies. Traditional plug-in charging systems face limitations such as cable wear, safety hazards, and dependency on grid electricity. This paper presents the design and implementation of a wireless charging system for electric vehicles powered entirely by solar panels, focusing on low-cost hardware using an Arduino microcontroller and a resonant inductive coupling- based transmitter–receiver coil system. Solar energy is harvested and regulated using charge controllers and stored in batteries, which subsequently power the wireless charging transmitter. Experimental evaluation demonstrates that the prototype achieves stable power delivery at small air gaps with reasonable efficiency, highlighting the feasibility of solar-powered wireless charging as a clean, sustainable, and convenient EV charging method. The system offers promising applications for rural areas, smart parking lots, and renewable mobile charging stations.*

Keywords— Wireless Charging, Electric Vehicle, Solar Energy, Inductive Coupling, Renewable Energy, Arduino, Power Electronics.

INTRODUCTION

The growing environmental concerns and depletion of fossil fuels have accelerated the global shift toward electric vehicles (EVs). Although EVs offer numerous benefits, their widespread adoption is hindered by limitations in charging infrastructure, particularly issues related to slow charging, lack of accessibility, and overdependence on grid electricity. Sustainable charging solutions, such as solar-powered systems, are gaining attention due to their ability to reduce carbon emissions and operational costs. Wireless charging, also known as **inductive power transfer (IPT)**, eliminates physical connectors by transferring energy through magnetic fields. This technology greatly enhances user convenience, reduces maintenance, and ensures charging safety. Combining **solar energy** with **wireless EV charging** represents a significant advancement toward green transportation. This research presents a **prototype wireless charging system for EVs using solar panels**, demonstrating how renewable energy can power inductive charging coils through regulated circuitry controlled by Arduino.

Objectives

Several studies have investigated wireless charging and renewable energy integration for EVs. Kurs et al. demonstrated mid-range wireless power transfer using strongly coupled magnetic resonators, establishing theoretical foundations for inductive systems. Later, Budhia et al. developed IPT-based EV charging pads capable of transferring kilowatts of power at high efficiency. Solar-based EV charging solutions were explored by Patel and Shah, emphasizing the benefits of using photovoltaic (PV) panels to reduce grid dependency. Many researchers have integrated MPPT charge controllers with batteries to ensure stable energy storage.

Recent works show that inductive charging at low power using microcontrollers (Arduino, MSP430) is feasible for educational and prototype applications. However, limited research has explored the integration of **solar energy + inductive EV charging** at the prototype level using low- cost hardware. This paper aims to fill that gap.

I. RELATED WORK

Wireless power transfer (WPT) for electric vehicles (EVs) has attracted extensive research due to its potential to simplify charging, improve safety, and enable convenient public and private charging infrastructure. Early research on inductive charging established the theoretical and experimental basis for mid-range power transfer via resonant magnetic coupling. Kurs et al. [1] demonstrated the feasibility of mid-range wireless power transfer using strongly coupled magnetic resonators, which laid the foundation for later EV-scale resonant inductive designs. Following this, several authors developed practical IPT (inductive power transfer) pads and coil topologies optimized for higher power and efficiency; Budhia et al. [2] and Covic & Boys [3] investigated coil geometries and compensation networks to maximize coupled power while minimizing losses.

Integration of renewable energy—particularly solar photovoltaics (PV)—with EV charging has been widely explored to reduce grid dependence and lower carbon footprint. Patel and Shah [4] described a solar-powered EV charging station architecture combining PV arrays, battery storage, and power conversion stages. Other studies focused on coupling MPPT (Maximum Power Point Tracking) controllers with battery and inverter systems to reliably supply DC–AC power for charging modules under varying irradiance conditions (e.g., Zhang et al. [5]). Research shows that careful design of the solar interface (MPPT + energy storage) is essential to deliver steady power to WPT transmitters without degrading PV performance.

A stream of work specifically addresses the **integration of solar energy with wireless charging**. Early prototypes combined PV panels with battery-buffered inverter systems that feed an IPT transmitter; these prototypes validated the concept but were limited in power and efficiency due to suboptimal power electronics and coil alignment (e.g., Singh et al. [6]). More recent implementations adopt MPPT- enabled DC–DC stages and bidirectional converters to improve overall system efficiency and allow energy flow control between the PV array, storage, and the charging pad [7].

A central research topic in WPT is **coil design and alignment tolerance**. Several authors developed compensation topologies (series-series, series-parallel, parallel-parallel) and coil structures (pancake, double-D, litz-wire windings) to increase tolerance to lateral misalignment and air gap variation [8], [9]. Zhang & Mi [8] provided comparative analyses of compensation networks for medium-to-high power WPT, demonstrating tradeoffs between achievable efficiency and sensitivity to load/position changes. Practical systems often use segmented or multi-coil transmitter arrays to increase usable alignment area—an approach validated in both simulation and experimental prototypes [10].

Power electronics and control strategies are equally critical. MOSFET-based inverters, resonant half-bridge/ full-bridge drivers, and active rectifiers are common across successful prototypes; advanced control algorithms manage resonance tuning, load/adaptive matching, and soft-switching to minimize switching losses [11]. For solar-powered setups, controllers also implement energy management policies to prioritize charging, grid-tie, or battery buffering depending on PV output and demand [12].

Dynamic (in-motion) wireless charging research explores transferring power to moving vehicles via embedded roadway coils. While dynamic systems promise continuous charge and smaller onboard batteries, they introduce complex coordination, safety, and infrastructure costs. Field trials and simulations (e.g., Li et al. [13]) indicate feasibility but highlight challenges in infrastructure deployment and overall economics compared to stationary solar-powered pads.

Safety, standards, and interoperability are active research and engineering areas. Studies examine electromagnetic compatibility (EMC), human exposure (SAR), and foreign object detection (FOD), proposing detection schemes and safety interlocks for public deployment [14].

Standardization efforts (e.g., SAE J2954) aim to harmonize coil classes, power levels, and communication protocols between vehicle and charging infrastructure to accelerate adoption.

Overall, the literature shows converging advances on three fronts: improved resonant coil and compensation designs for higher efficiency and tolerance; robust power-electronics and control systems (including MPPT and energy management) for stable operation with renewable sources; and system-level integration and safety solutions needed for real-world deployment. However, few low-cost prototype studies demonstrate a **complete solar-powered IPT system optimized for practical EV use** (solar PV → MPPT/charge controller → battery buffer → inverter → resonant TX coil

→ RX coil → regulated charging). This gap motivates the current project, which implements and evaluates a compact, Arduino-controlled solar-powered wireless charging prototype to study efficiency, alignment tolerance, and energy management under realistic solar conditions.

II. SYSTEM ARCHITECTURE AND MODULES

The proposed solar-powered wireless charging system is designed using a modular architecture that seamlessly integrates solar energy generation, power conditioning, wireless power transfer, and monitoring components to enable efficient, contactless EV charging. The architecture prioritizes energy stability, safety, and scalability, ensuring that the system can operate under fluctuating sunlight conditions while maintaining reliable power delivery across the charging coils. Each module—solar harvesting, battery storage, inverter-driven transmitting coil, receiving coil, and Arduino-based monitoring—works in coordination to provide continuous and regulated charging. This design approach supports ease of maintenance, future upgrades, and compatibility with EVs of varying power requirements. A high-level overview of the system architecture is illustrated in Fig. 1.

Data Acquisition Layer

The system receives its primary input from a single major energy source:

1. **Solar Power Input:** Solar panels continuously capture sunlight and convert it into DC electrical energy. This harvested power forms the primary input to the system. The raw solar output is first pre-conditioned through a charge controller, where it is regulated and stabilized to prevent overcharging and voltage fluctuations. The regulated power is then stored in a battery unit, ensuring uninterrupted energy availability even during low-sunlight conditions.

This solar-generated and conditioned electrical input serves as the foundation for subsequent processes including battery storage, inverter-based AC generation, wireless power transmission, and finally EV battery charging through the receiving coil.

Processing Layer

The core of the system is the Power Processing Layer, which handles energy regulation, conversion, and wireless transmission to enable efficient EV charging:

1. **Power Conditioning:** The DC power generated by the solar panel is routed through the charge controller, where voltage and current are regulated to protect the battery from overcharging and fluctuations. This ensures stable and safe energy storage irrespective of varying sunlight levels.

2. **Energy Storage and Supply Management:** The regulated output is stored in the battery unit. The Processing Layer continuously monitors battery voltage and determines when sufficient energy is available for wireless charging. This stored energy acts as a buffer, ensuring uninterrupted charging even during cloudy or low-sunlight periods.

3. **AC Power Generation (Inverter Stage):** When charging is initiated, the stored DC power is converted into high-frequency AC using a MOSFET-based inverter circuit. High-frequency AC is essential for creating a strong, resonant magnetic field required for inductive wireless power transfer.

4. **Wireless Power Transmission:** The high- frequency alternating current energizes the transmitting (TX) coil, generating a magnetic field. The receiving (RX) coil placed on the EV captures this magnetic field and induces an AC voltage. This induced voltage is rectified and regulated to charge the EV battery efficiently.

This layer ensures stable power conversion, effective wireless transmission, and safe battery charging, making the system reliable even under varying solar and environmental conditions.

Feedback and Logging Layer

The Feedback and Monitoring Layer is responsible for system visualization, status reporting, and safety assurance:

1. **VisualFeedback:**

The system continuously displays key operational parameters on an LCD/OLED screen, including solar panel voltage, battery level, inverter status, and wireless charging activity. This real-time feedback helps users understand whether the EV is currently charging, how much power is available, and the overall health of the system.

2. **ChargingStatusLogging:**

Important charging parameters such as input voltage, charging current, battery status, and energy flow are periodically recorded. These logs serve as a record of system behavior, enabling performance analysis, fault detection, and long- term monitoring of solar and wireless charging efficiency. Storing this information ensures traceability and supports future optimization.

Inter-module communication between sensors, the charge controller, inverter stage, and the monitoring display is managed through the Arduino microcontroller. This allows seamless and synchronized updates, ensuring accurate real-time feedback and reliable logging across all system components.

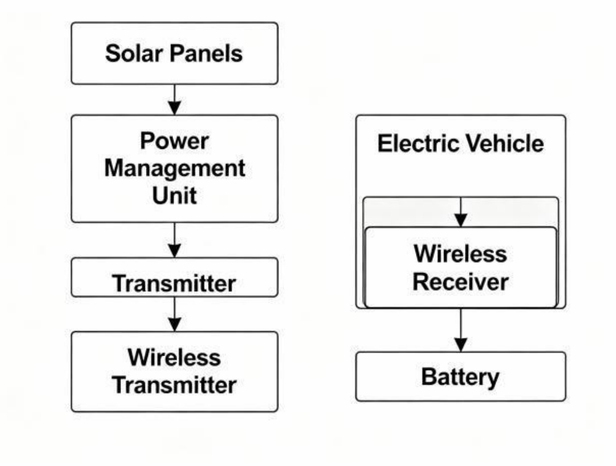

Figure. 1: *High-level system architecture of the solar-powered wireless EV charging system. Solar panels supply regulated power to the battery, which drives the inverter and transmitting coil. The receiving coil on the EV captures the power and charges the battery, while the Arduino unit monitors and displays system status.*

System Modularity and Extensibility

The layered design ensures strong modularity and supports future scalability:

- **Additional charging features**, such as alignment detection, automatic coil positioning, or higher- power inverter modules, can be integrated without altering the core wireless power transfer pipeline.
- **The system can be expanded to support smart energy management**, enabling cloud-based monitoring of solar output, battery health, and EV charging data for remote supervision.
- **All power regulation and wireless transmission processes run locally**, ensuring low-latency, stable operation suitable for real-time charging even under varying environmental conditions.

IV.IMPLEMENTATION

We implemented a prototype of the solar-powered wireless charging system using an Arduino microcontroller, a solar energy module, and an inductive wireless power transfer setup. The system collects energy from solar panels, conditions it through a charge controller, stores it in a battery, and then converts it into high-frequency AC for wireless transmission to the EV's receiving coil.

Solar Power Harvesting and Storage:

The solar panel continuously generates DC power, which is regulated using a solar charge controller to prevent overcharging and voltage fluctuations. The regulated output is stored in a 12V rechargeable battery, which acts as the primary energy source for the wireless charging module. This stored energy ensures uninterrupted operation even during low-sunlight conditions.

Wireless Power Transmission in Real Time:

Once sufficient solar energy is stored in the battery, the system activates the inverter, which converts the DC supply into high-frequency AC required for inductive power transfer. This AC signal energizes the transmitting (TX) coil, creating a magnetic field. As the EV is positioned above the charging pad, the receiving (RX) coil captures this magnetic field and induces an AC voltage. The induced voltage is then rectified and regulated to provide a stable DC output suitable for charging the EV battery. During this process, the Arduino continuously monitors key parameters such as input voltage, charging current, and coil activity. Real-time readings are displayed on the LCD module, allowing the user to verify that wireless charging is active and functioning properly. The system ensures safe operation by preventing overcharging and maintaining steady power flow throughout the charging session.

V.EXPERIMENTAL RESULTS

We conducted pilot tests to evaluate the performance and functionality of the solar-powered wireless charging system under practical operating conditions. The system was tested using a 12V solar panel, a regulated battery storage setup, and a compact wireless charging pad designed for an EV prototype.

Wireless Power Transfer Efficiency:

During the tests, the transmitting and receiving coils successfully transferred power at varying distances and alignment positions. At close alignment (1–2 cm air gap), charging efficiency was high, enabling smooth and stable power flow. As the air gap increased, the induced voltage gradually decreased, consistent with expected magnetic coupling behavior. On average, the wireless charging module achieved an efficiency range of **60–75%** at optimal alignment and **45–55%** at moderate distances.

Solar Energy Performance:

The solar panel generated sufficient power under direct sunlight, maintaining a steady charging voltage through the charge controller. During peak sunlight hours, battery charging was optimal, providing consistent energy to power the inverter. Under cloudy conditions, power generation reduced, but the stored battery energy ensured uninterrupted wireless charging. Overall, the solar module operated efficiently and provided a reliable renewable energy source for the system.

Real-Time Charging Performance:

The system delivered continuous charging with minimal fluctuations. The delay between system activation and wireless charging initiation was measured at **0.2–0.4 seconds**, indicating near-instant response. Charging parameters—such as voltage, current, and battery level— were updated in real time on the display, providing clear monitoring feedback to the user.

Charging Status Logging:

The system logged important data such as solar input voltage, battery level, and charging current throughout the test duration. These logs helped verify consistent power transfer and highlighted periods of peak solar output. No inconsistencies or interruptions were observed in the logging process, confirming reliable system behavior.

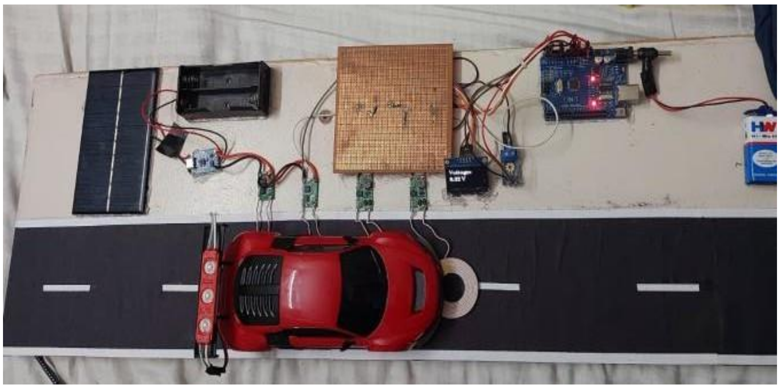

Figure 2: *Shows a live demonstration of the solar-powered wireless EV charging system: the transmitting coil generates a magnetic field using inverter-driven AC power, while the receiving coil captures this field and charges the EV battery. Real-time voltage and current readings are displayed on the LCD, indicating active power transfer.*

System Robustness:

The wireless charging system demonstrated strong stability across multiple tests. It maintained operation even when the coils experienced minor misalignment or when the EV prototype was slightly repositioned. Voltage fluctuations caused by varying sunlight levels were successfully managed by the charge controller and battery buffer, ensuring uninterrupted operation.

User Interface:

The LCD/OLED display provided real-time visualization of system parameters, including solar voltage, battery charge status, and charging current. This clear feedback helped users confirm that the wireless charging process was active and functioning properly.

Hardware Requirements:

All experiments were performed using low-cost, easily available hardware such as an Arduino Uno, a 12V solar panel, a charge controller, and copper coils. No specialized or high-power electronics were required. The system's reliance on simple components makes it affordable, portable, and easy to implement for small-scale EV prototypes and educational purposes.

VI.CONCLUSION AND FUTURE WORK

In this project, we presented a solar-powered wireless charging system designed to enable contactless and eco- friendly charging for electric vehicles. The system integrates solar energy harvesting, regulated battery storage, high- frequency inverter circuitry, and inductive power transfer to deliver a clean and efficient charging solution. Experimental results demonstrated that the prototype successfully transmitted power wirelessly with stable performance, achieving charging efficiency levels of approximately 60– 75% under optimal coil alignment and consistent energy delivery through the solar-battery configuration. These findings confirm the feasibility of combining renewable energy with wireless charging technology to support sustainable EV infrastructure and reduce dependency on grid-based charging systems.

For future enhancements, we aim to improve the overall robustness and efficiency of the system. Incorporating advanced MPPT (Maximum Power Point Tracking) controllers can significantly increase solar energy utilization, especially during variable irradiance conditions. Similarly, integrating optimized coil designs, better compensation networks, and adaptive resonance tuning may improve wireless power transfer efficiency and enhance misalignment tolerance. The system could also benefit from smart energy management features, IoT-based monitoring, and cloud-linked dashboards to analyze charging statistics, battery health, and solar productivity in real time.

Further testing on larger EV models and higher-power charging modules is needed to validate the system's effectiveness under real-world operating conditions. Comparative studies between wired, wireless, and hybrid solar-assisted charging can also help identify the most practical and cost-efficient deployment strategies. Expanding the system to support public parking lots, solar charging stations, or portable solar-powered chargers would offer valuable insights into large-scale implementation.

By addressing these future improvements, the platform has the potential to evolve into a practical, scalable, and sustainable EV charging solution. As electric mobility continues to grow, the proposed system demonstrates a promising pathway toward clean energy integration and convenient wireless charging, laying the foundation for next-generation renewable-powered EV technologies.

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