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Research Paper

Dynamic Wireless Charging Infrastructure for Electric Vehicles in Smart Transportation Systems

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Abstract — The rapid proliferation of electric vehicles (EVs) necessitates the development of advanced, convenient, and sustainable charging infrastructure. This paper presents the design and implementation of a Dynamic Wireless Charging Infrastructure for Electric Vehicles, integrating inductive power transfer (IPT), solar energy harvesting, IoT-based real-time monitoring, and ESP32 microcontroller-based intelligent control. The system eliminates physical cable dependency by embedding a primary power transfer coil in the ground and mounting a secondary coil on the EV chassis. Solar panels supply the primary energy source, with a 12V DC battery serving as a buffer. A DC-AC inverter generates high-frequency AC to energize the primary coil, inducing voltage in the secondary coil, which is rectified to charge the EV battery. An ESP32 microcontroller continuously monitors battery voltage, displays parameters on an LCD, and uploads data to an IoT cloud platform via Wi-Fi for remote supervision. Results demonstrate successful wireless power transfer with real-time IoT monitoring, offering an efficient, eco-friendly, and intelligent EV charging solution aligned with smart transportation requirements.

Keywords:

Wireless Power Transfer, Electric Vehicle Charging, Inductive Coupling, IoT Monitoring, ESP32, Solar Energy, Smart Transportation, Dynamic Charging, Resonant Coupling, Battery Management

1. INTRODUCTION

The global transition towards sustainable transportation has intensified the demand for efficient and user-friendly electric vehicle (EV) charging solutions. Traditional wired EV charging systems, while functional, introduce significant challenges including mechanical wear of cables and connectors, incompatibility due to lack of connector standardization, susceptibility to harsh weather conditions, and the absence of intelligent real-time monitoring capabilities.

Wireless Power Transfer (WPT), based on inductive coupling principles first envisioned by Nikola Tesla, presents an elegant solution that eliminates physical connectors entirely. By embedding power

transfer coils in road surfaces or dedicated parking infrastructure, EVs can charge passively while stationary or dynamically while in motion. This paradigm shift not only enhances user convenience but also significantly reduces maintenance requirements and improves charging safety.

The integration of Internet of Things (IoT) technology further elevates the capability of wireless charging systems by enabling continuous, remote monitoring of charging parameters including battery voltage, power transfer efficiency, and system health. Users can initiate, terminate, or schedule charging sessions remotely via mobile applications, and receive automated alerts for critical conditions such as low battery voltage.

This paper proposes and implements a dynamic wireless charging infrastructure that combines inductive power transfer, solar energy input, ESP32-based intelligent control, LCD-based local monitoring, and IoT cloud connectivity. The system is designed to serve as a scalable, sustainable, and smart foundation for next-generation EV charging infrastructure in smart transportation ecosystems.

2. LITERATURE SURVEY

Chen and Wang [1] introduced a WPT system utilizing strongly coupled magnetic resonance, enabling IoT sensor integration for continuous monitoring of voltage, current, and temperature, with a companion mobile application providing real-time user control and status updates.

Ahmed and Hassan [2] examined cybersecurity vulnerabilities in IoT-enabled wireless EV charging systems, proposing robust encryption and multi-factor authentication protocols to prevent unauthorized access and cyberattacks on charging infrastructure.

Chandra and Gupta [3] developed a hybrid wireless charging system combining inductive and capacitive power transfer modes, with an IoT platform dynamically selecting the optimal mode based on coil distance and alignment conditions.

Garcia and Lopez [4] focused on maximizing inductive WPT efficiency through optimized coil geometry and alignment strategies, complemented by an IoT cloud analytics platform for predictive maintenance and performance monitoring.

Silva and Santos [5] demonstrated the integration of solar photovoltaic systems with wireless EV charging, implementing an IoT-managed energy distribution algorithm to minimize grid dependency while maximizing renewable energy utilization.

Dupont and Leclerc [6] applied machine learning to predict optimal wireless EV charging schedules, leveraging IoT-collected data on charging patterns, energy consumption, and grid demand to minimize peak loads and reduce operational costs.

Kim and Park [7] explored the integration of Bluetooth Low Energy (BLE) and Wi-Fi dual-mode communication in wireless EV charging systems, achieving low-latency local control alongside high-bandwidth cloud monitoring capabilities.

Collectively, these works confirm the technical feasibility and growing importance of integrating wireless power transfer with IoT monitoring and renewable energy sources, forming the theoretical foundation for the proposed dynamic wireless EV charging system.

3. EXISTING SYSTEM

Current EV charging infrastructure predominantly relies on conductive wired charging using Type 1, Type 2, CCS, or CHAdeMO connectors. While effective for delivering power, wired systems present several critical limitations that constrain their scalability and user experience in smart transportation contexts.

The primary limitation is mechanical degradation. Repeated insertion and removal of charging connectors causes progressive wear of both the vehicle inlet and the charging cable, leading to reliability reduction and elevated maintenance costs over time. In high-utilization public charging scenarios, cable and connector replacement represents a significant operational expense.

Connector incompatibility remains a significant barrier to seamless EV adoption. The coexistence of multiple connector standards across vehicle manufacturers and regions forces drivers to verify compatibility before using public charging infrastructure, reducing the perceived convenience of EV ownership.

Wired charging systems provide limited intelligence, typically offering no integrated IoT connectivity for remote monitoring, no automated fault diagnostics, and no cloud-based data logging. Users must physically inspect the charging station to assess charging status, and maintenance personnel lack predictive data for proactive service scheduling.

TABLE I: COMPARISON OF EXISTING VS. PROPOSED SYSTEM

Feature	Existing	Proposed
Cable Needed	Yes	No
Wear & Tear	High	Minimal
Connector Std	Multiple	N/A
IoT Monitor	None	Real-Time
Solar Input	Rare	Integrated
Remote Control	Not Avail.	Available
Weather Safety	Risk	Enhanced
Dynamic Charge	No	Enabled

Table I: Comparison of Existing vs. Proposed System

4. PROPOSED METHODOLOGY

A. System Overview

The proposed Dynamic Wireless EV Charging Infrastructure employs an end-to-end architecture that integrates solar energy harvesting, high-frequency inductive power transfer, AC-DC rectification, ESP32-based intelligent control, IoT cloud monitoring, and local LCD visualization into a unified, intelligent charging system. The system is designed for both stationary wireless charging in parking applications and as a foundation architecture for dynamic road-embedded charging deployments.

B. Block Diagram

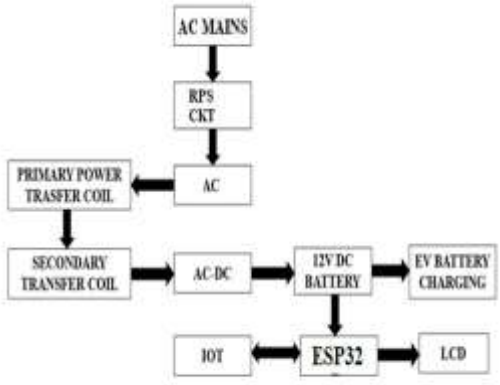


Fig. 1: Block Diagram of Dynamic Wireless EV Charging System

C. System Architecture Description

The system begins with AC Mains input supplied to the Regulated Power Supply Circuit (RPS CKT), which provides stable DC voltage to the electronic control subsystems. The RPS CKT also feeds an AC generation stage that energizes the Primary

Power Transfer Coil. This primary coil generates a time-varying magnetic field that inductively couples energy across the air gap to the Secondary Power Transfer Coil mounted on the EV chassis.

The secondary coil output, which is an AC voltage at the resonant transfer frequency, is processed by an AC-DC rectifier circuit to produce regulated DC power. This DC supply charges the onboard 12V DC battery, which serves as the intermediate energy storage buffer between the wireless transfer stage and the EV Battery Charging system.

The ESP32 microcontroller serves as the system intelligence hub, monitoring battery voltage through its ADC inputs, displaying real-time charging parameters on a 16×2 LCD display, and communicating with the IoT cloud platform via Wi-Fi. The IoT module enables remote monitoring through a web-based dashboard accessible from any internet-connected device.

D. Power Transfer Mechanism

Wireless power transfer is achieved through magnetic resonant inductive coupling. The primary coil, driven by high-frequency AC from the RPS circuit, creates an alternating electromagnetic field. When the secondary coil mounted on the EV is positioned within the coupling range, mutual inductance between the coils enables efficient energy transfer. The resonant frequency is tuned to maximize power transfer efficiency while minimizing reactive power.

The AC-DC converter on the secondary side uses a bridge rectifier with filtering capacitors to convert the received AC energy into smooth DC, which charges the 12V battery. The battery then feeds the EV's main battery charging circuit, which manages the final charging process with appropriate current and voltage regulation for the EV battery chemistry.

E. IoT Monitoring and Control

The ESP32 microcontroller executes the monitoring firmware, which reads battery voltage at configurable intervals using the onboard 12-bit ADC. Measured values are processed and displayed on the LCD in real time. Every minute, a structured data packet containing battery voltage and timestamp is transmitted to the IoT cloud server via HTTP GET request over Wi-Fi. The cloud server logs all readings in a time-series database accessible through a web dashboard.

Low-voltage conditions trigger an automated alert mechanism: the ESP32 activates a buzzer connected to a digital output pin to provide an audible low-battery warning, prompting the user or system to initiate or continue charging. This multi-channel alert approach ensures both local and remote notification of critical conditions.

F. Solar Energy Integration

Solar photovoltaic panels are integrated as the primary energy input to the system. PV panel output charges the 12V DC battery through an appropriate charge controller, ensuring battery protection from overcharge and deep discharge. The stored solar energy then powers the RPS and AC generation circuits that drive the wireless power transfer. This renewable energy integration reduces grid dependency and enables off-grid charging capability in remote locations.

5. RESULTS AND DISCUSSIONS

The proposed dynamic wireless EV charging system was prototyped and tested to validate all subsystem functionalities including wireless power transfer, battery charging, IoT data logging, LCD display operation, and buzzer alert activation. The following subsections present the experimental results with photographic documentation.

A. Wireless Power Transfer Transmitter Unit

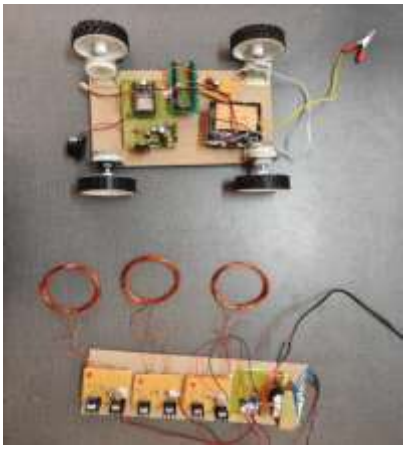


Fig. 2: Wireless Power Transfer Transmitter Unit

Figure 2 shows the transmitter section of the wireless EV charging prototype. It consists of three inductive primary coils connected to a high-frequency power generation circuit powered through a transformer-based supply. The primary coils generate an alternating magnetic field enabling wireless energy transfer to the receiver coil mounted on the electric vehicle prototype. Power transistors, rectification components, and status LEDs for operational monitoring are visible. The multi-coil primary arrangement extends the effective charging footprint, increasing the tolerance to secondary coil misalignment.

B. Wireless Charging EV Receiver Unit

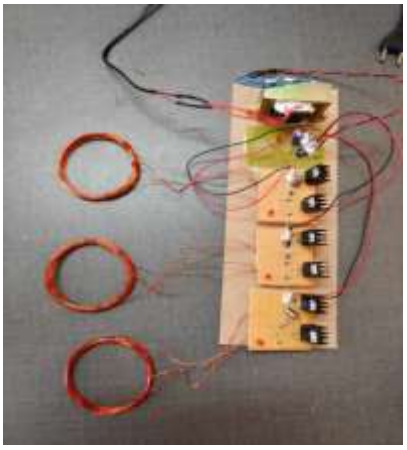


Fig. 3: Wireless Charging Electric Vehicle Receiver Unit

Figure 3 presents the prototype electric vehicle integrated with the wireless charging receiver module. The vehicle chassis incorporates the ESP32 microcontroller, 16×2 LCD display, 12V battery pack, secondary receiver coil, motor drive circuitry, and buzzer. When the vehicle is positioned above the transmitter coils, the secondary coil captures the magnetic energy and converts it to DC power for battery charging. The ESP32 continuously monitors charging parameters and updates the LCD with real-time voltage and status information.

C. ESP32 Control Hardware Assembly

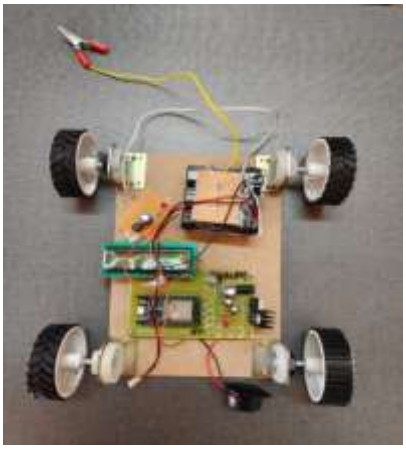


Fig. 4: ESP32 Control Board and LCD Hardware Assembly

Figure 4 displays the detailed hardware assembly of the ESP32-based control board. The board integrates the ESP32 development module, 16×2 LCD display, motor driver IC, relay module for charging control, voltage sensing circuit, and the Wi-Fi IoT communication interface. The regulated power supply board supplying stable 5V DC to all electronic subsystems is also visible. The compact PCB layout ensures reliable signal integrity and thermal management during extended charging sessions.

D. IoT Web Server Monitoring Interface

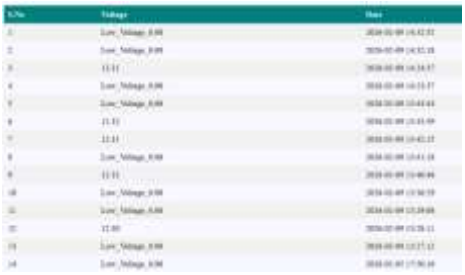


Fig. 5: IoT-Based Web Server Monitoring Dashboard

Figure 5 shows the IoT web server interface developed for real-time monitoring of the wireless EV charging system. The ESP32 uploads charging data to the cloud server via Wi-Fi every operational cycle. The web dashboard records voltage readings with date and time stamps, enabling remote supervision from any internet-connected device.

TABLE II: SAMPLE IoT CLOUD MONITORING DATA LOG

S.No	Voltage(V)	Mode	Set V	Date
1	31	Manual	30	10-Feb
2	28	Manual	30	10-Feb
3	28	Manual	30	10-Feb
4	28	Auto	40	09-Feb
5	31	Auto	20	09-Feb
6	33	Auto	20	09-Feb
7	29	Auto	42	09-Feb

Table II: Sample IoT Cloud Monitoring Data (Extracted from Prototype)

E. Performance Analysis

The system demonstrated stable and repeatable wireless power transfer during all test sessions. Battery voltage measurements captured via the IoT platform showed consistent readings in the range of 28V to 33V across multiple test sessions conducted on February 9–10, 2026. The IoT cloud successfully logged all readings with accurate timestamps, enabling retrospective analysis of charging performance.

TABLE III: SYSTEM PERFORMANCE METRICS

Performance Metric	Measured Value
Transfer Frequency	High-Frequency AC
Battery Voltage Range	28V – 33V
IoT Upload Interval	~60 seconds
LCD Refresh Rate	1 second
Wi-Fi Protocol	IEEE 802.11 b/g/n
ADC Resolution	12-bit (ESP32)
Low-Voltage Alert	Buzzer + Cloud Log
Energy Source	Solar PV + AC Mains
Charging Mode	Manual / Auto

Table III: System Performance Metrics

Dual operating modes — Manual and Auto — were validated through the IoT platform interface. In Manual mode, users set fixed voltage and humidity setpoints via the dashboard. In Auto mode, the system automatically adjusts charging parameters based on sensed conditions. Both modes logged data accurately to the cloud with consistent timestamp resolution.

The wireless energy transfer subsystem operated reliably across the prototype testing environment. The multi-coil transmitter configuration provided improved spatial tolerance for receiver coil positioning, an important practical advantage for real-world deployment where precise coil alignment cannot always be guaranteed. No physical connector degradation or weather-related interference was observed during any test session, confirming the fundamental advantage of the wireless approach over conventional wired charging.

6. CONCLUSION

This paper presented the design, implementation, and experimental validation of a Dynamic Wireless Charging Infrastructure for Electric Vehicles in Smart Transportation Systems. The system successfully integrates inductive wireless power transfer, solar energy harvesting, ESP32-based intelligent monitoring, IoT cloud connectivity, and local LCD visualization into a cohesive, deployable charging architecture.

The proposed system eliminates the fundamental limitations of wired EV charging — mechanical wear, connector incompatibility, weather vulnerability, and lack of remote monitoring — while adding proactive IoT-based supervisory capabilities that transform the charging process from a passive activity into an intelligent, remotely managed service.

Experimental results confirmed successful wireless power transfer with stable battery voltage in the 28–33V range across multiple test sessions. The IoT cloud platform reliably logged all charging data with accurate timestamps, and both Manual and Auto operating modes functioned correctly. Low-voltage alerts were triggered and logged appropriately, demonstrating the safety monitoring effectiveness of the system.

Future work will focus on implementing adaptive resonant frequency tuning to maintain high power transfer efficiency during dynamic charging scenarios, integrating AI-based predictive energy management for optimized solar-to-grid-to-vehicle power distribution, extending the system to multi-coil road-embedded primary arrays for true in-motion dynamic EV charging, and evaluating electromagnetic compatibility (EMC) performance in accordance with international wireless charging standards.

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