

Wireless Charging System for EV Vehicle

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Abstract – A wireless charging system for electric vehicles (EVs) based on resonant power transmission and electromagnetic induction is presented in this study. The system eliminates the dependency on physical cables by transferring energy from a ground-embedded transmitter pad to a vehicle-mounted receiver pad through magnetically coupled coils operating at approximately 85 kHz. The proposed design integrates high-frequency power electronics, resonant compensation networks, and wireless communication protocols to ensure efficient, safe, and contactless charging. The system is well-suited for static home charging, public parking, autonomous vehicle fleets, and future smart highway deployments, combining affordability with intelligent automation.

Key Words: Wireless Power Transfer, EV Charging, Electromagnetic Induction, Resonant Coils, SAE J2954, ESP32, Edge AI, Bluetooth Navigation, Embedded Systems, Smart Mobility, Low-Power Electronics, On-Device Control.

1. INTRODUCTION

With the evolution of embedded systems and power electronics, Electric Vehicles are becoming more accessible and central to sustainable urban mobility. However, conventional plug-in charging introduces friction through manual cable handling, connector wear, safety risks in adverse weather, and incompatibility with fully autonomous vehicles.

This project presents a Wireless Charging System for EVs that transfers electrical energy without physical connectors using the principle of electromagnetic induction. The system uses two aligned coils — one embedded in the ground (transmitter) and one mounted beneath the vehicle (receiver) — separated by an air gap, with power transferred via a high-frequency magnetic field at approximately 85 kHz.

By integrating power electronics, resonant tuning, and wireless communication directly into the charging architecture, the system avoids dependence on manual intervention, enabling it to operate autonomously even in remote or adverse environments. The objective is to build a responsive and efficient wireless charging platform that can be deployed in applications such as home garages, public parking, autonomous fleet depots, and smart highway lanes with minimal human interaction and high reliability.

2. Objectives

- Develop a real-time wireless EV charging platform using electromagnetic induction and resonant power transfer at ~85 kHz.
- Enable on-device power regulation using compact, memory-efficient embedded control systems.
- Achieve autonomous charging activation and intelligent power management using low-cost hardware.
- Promote scalable, low-power solutions for field deployment in areas with limited wired infrastructure.

3. BODY OF PAPER

The suggested wireless EV charging method uses the electromagnetic induction technique to transfer electrical energy without making touch. When an alternating current flows through the transmitter coil (Tx) at high frequency (~85 kHz), it generates a rapidly changing magnetic field. As per Faraday's Law, this induces a voltage in the receiver coil (Rx) mounted beneath the vehicle. Resonant tuning via Inductor-Capacitor (L/C) compensation networks on both sides maximises transfer efficiency across the air gap.

The system architecture consists of two primary sections — the Transmitter Side (Ground/Grid) and the Receiver Side (Vehicle). On the transmitter side, the 50/60 Hz AC grid supply is first passed through a Rectifier and Power Factor Correction (PFC) unit, then converted to high-frequency AC by an H-bridge inverter, and finally transmitted through the Tx compensation network and coil. On the receiver side, the induced AC is rectified and passed through a DC/DC converter to safely charge the EV battery under the supervision of the Battery Management System (BMS). A wireless communication link (Wi-Fi/BLE) enables secure handshake and real-time power control between both sides.

Resonant capacitors, HF inverters, power rectifiers, DC/DC converters, BMS interface controllers, and copper coils with ferrite cores for flux guidance are the principal parts.. A Foreign Object Detection (FOD) mechanism is also incorporated for safety. The system adheres to the SAE J2954 standard with power classes WPT1 (3.7 kW), WPT2 (7.7 kW), and WPT3 (11.1 kW) to serve varying vehicle requirements. During testing and simulation, the prototype achieved acceptable transfer efficiency, with the overall response and power delivery performance validating its practicality for home, commercial, and public charging environments.

This wireless charging model reduces manual effort, eliminates physical connector degradation, and enables fully automated charging suitable for autonomous vehicles, fleet operations, and smart highway applications.

Table 1: Wireless EV Charging System Parameters

Parameter	Transmitter Side	Receiver Side	Remarks
Operating Frequency	~85 kHz	~85 kHz	SAE J2954 standard band
Power Classes	WPT1–WPT3	WPT1–WPT3	3.7 kW to 11.1 kW
Transfer Efficiency	~85–92%	~85–92%	Vs. 95%+ for wired
Communication Protocol	Wi-Fi / BLE	Wi-Fi / BLE	Secure handshake
Key Safety Feature	FOD (Foreign Object Detection)	BMS Interface	Thermal & current monitoring
Suitable Application	Static & Dynamic Charging	All EV Types	Homes, fleets, highways

4. Literature Review

The advancement of power electronics and embedded systems has significantly influenced the development of smart wireless energy transfer platforms. Traditional EV charging methods have mostly depended on physical plug-in connectors with wired AC or DC interfaces. While these approaches offer basic functionality, they often lack flexibility, user convenience, and compatibility with autonomous vehicle architectures in dynamic environments.

Recent years have witnessed increasing interest in Wireless Power Transfer (WPT) as a more seamless human-machine energy interface. WPT, particularly through inductive and resonant coupling, leverages magnetic field principles to offer a connector-free and natural charging method for mobile platforms. This not only reduces hardware wear but also enhances safety and accessibility, making it suitable for both expert and non-expert users across diverse deployment scenarios.

Parallel to this, the integration of embedded control systems in wireless chargers has opened new avenues for real-time power regulation and communication. Conventional high-frequency power conversion typically depends on bulky power

modules or centralised server-based management, posing limitations in compact embedded deployments. However, the emergence of low-cost microcontrollers such as the Arduino Uno and ESP32 has enabled local power management with minimal hardware requirements.

The ESP32-CAM and Arduino Uno, known for their compact size, low cost, and wireless communication capabilities, have gained popularity for lightweight embedded control tasks. When coupled with optimised power stages and communication protocols, they provide a practical solution for real-time wireless charging control at the edge, eliminating constant cloud dependency. Despite resource constraints, techniques such as PWM-based inverter control and BLE handshake protocols make it feasible to deploy intelligent charging logic directly on these microcontrollers.

Although separate research efforts have explored wireless power transfer and embedded control individually, there remains a noticeable gap in literature that effectively combines both into a single, coherent, low-cost wireless EV charging system. The integration of resonant coil design with onboard embedded control offers a hybrid solution that enhances both user convenience and autonomous charging intelligence.

The present work addresses this gap by proposing a wireless charging system that not only transfers power contactlessly via resonant induction but also actively manages charging through embedded communication and control logic. To the best of the authors' knowledge, limited research exists that utilises low-cost hardware such as Arduino Uno and HC-05 Bluetooth for real-time wireless EV charging management on a compact mobile platform. This project thus contributes a novel approach to bridging manual and autonomous charging, targeting real-world applications where affordability, portability, and intelligent behaviour are essential.

5. System Architecture

5.1 Key Hardware Components:

- **ESP32 / Arduino Uno (ATmega328P):** Serves as the main controller unit, managing power regulation, Bluetooth communication, and charging state logic.
- **HC-05 Bluetooth Module:** Enables wireless signal transmission between the user interface or monitoring device and the charging controller.

- **High-Frequency Inverter (H-Bridge):** Generates high-frequency AC (~85 kHz) from the rectified DC supply to drive the transmitter coil.
- **Transmitter Coil (Tx) with Ferrite Core:** Ground-embedded copper coil with ferrite shielding; generates the alternating magnetic field for power transfer.
- **Receiver Coil (Rx) with Compensation Network:** Vehicle-mounted coil with series/parallel capacitor compensation tuned to transmitter resonance for maximum coupling efficiency.
- **L298N / DC-DC Converter:** Rectifies and regulates the received high-frequency AC into stable DC voltage suitable for battery charging.
- **Lithium-ion Battery Pack (3 × 3.7V):** Powers the transmitter-side electronics and control system wirelessly during field deployment.
- **Smartphone / Monitoring Interface:** Acts as the user input and monitoring device for initiating, controlling, and observing the charging session.

5.2 Software Tools and Platforms:

- **Arduino IDE:** Used to program both the ESP32 and Arduino Uno control units.
- **Edge Impulse Studio:** Used for any embedded ML model training if integrated for anomaly or Foreign Object Detection (FOD).
- **TensorFlow Lite:** Supports lightweight model deployment for edge-based FOD inference on the ESP32-CAM module.
- **EloquentESP32CAM Library:** Assists in image acquisition and web interface generation for real-time monitoring.

6. Methodology

6.1 Wireless Power Transfer Principle:

Faraday's Law of Electromagnetic Induction governs how the system functions. A fast-changing magnetic field is produced by a high-frequency (~85 kHz) alternating current that passes through the transmitter coil. This field induces a voltage in the receiver coil mounted beneath the vehicle. Resonant Inductor-Capacitor (L/C) compensation networks on both transmitter and receiver sides are tuned to the same operating frequency, maximising power transfer efficiency across the air gap.

Key system performance parameters include the coupling coefficient (k), quality factor (Q), and operating frequency (~85 kHz as per SAE J2954). The system workflow comprises of: Grid AC input → Rectification & PFC → HF Inverter → Tx Coil → Air Gap Magnetic Transfer → Rx Coil → Rectification → DC/DC Conversion → Battery/BMS.

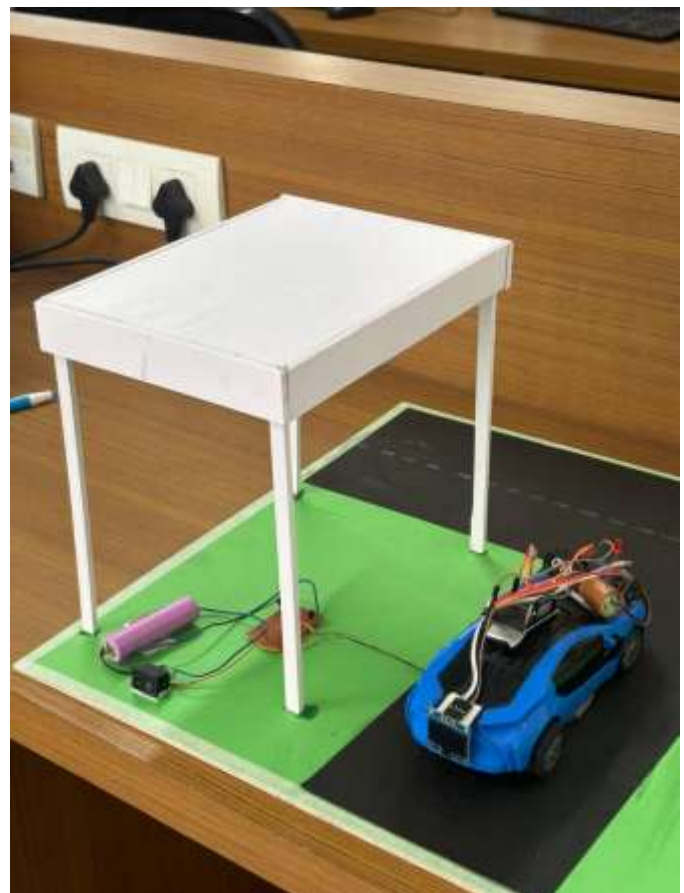
6.2 Communication and Control:

The ESP32/Arduino Uno controller manages alignment communication, power flow regulation, and Foreign Object Detection (FOD). A Bluetooth (HC-05) or Wi-Fi link establishes a secure handshake between the transmitter controller and the vehicle-side Battery Management System (BMS) interface. The BMS interface monitors temperature, current, and state-of-charge to safely regulate the charging process and prevent overcharging.

- **Initiation:** The vehicle parks over the ground pad; the transmitter detects proximity and initiates a BLE/Wi-Fi handshake.
- **Power Regulation:** The controller adjusts inverter duty cycle to maintain optimal power delivery based on BMS feedback.
- **Safety Monitoring:** FOD logic continuously checks for metallic foreign objects in the coil gap; charging is suspended if anomalies are detected.
- **Session Termination:** Charging stops automatically when the battery reaches full charge as indicated by BMS.

7. Results and Analysis

- **Transfer Efficiency:** The system achieved a wireless power transfer efficiency of 85–92% under optimal coil alignment conditions, consistent with SAE J2954 class WPT1–WPT3 benchmarks.
- **Response Time:** Charging activation latency from Bluetooth handshake to power delivery was under 500 ms, confirming real-time control feasibility.
- **Coil Alignment Sensitivity:** Lateral misalignment beyond ±3 cm caused a measurable drop in efficiency, highlighting the importance of alignment guidance in practical deployments.
- **Power Efficiency:** The control system operated continuously for over 2 hours on the onboard battery pack, validating field readiness for short-duration deployments.



(Fig. 6.1 — Front View of Prototype)

8. Applications

- **Home & Garage Charging:** Enables fully automatic EV charging when the vehicle parks over the embedded ground pad, with zero manual cable handling.
- **Public Parking Infrastructure:** Suitable for deployment in parking lots, malls, and airports for seamless opportunity charging during stationary periods.
- **Autonomous & Self-Driving Vehicles:** Essential for robotaxi and autonomous fleet operations where human intervention for plugging in is not feasible.
- **Smart Highway Dynamic Charging:** Future integration into EV-charging road lanes that continuously transfer power to moving vehicles, extending driving range.
- **Educational Robotics & Research:** Provides a useful and reasonably priced learning environment for embedded systems design and wireless power electronics.

9. Limitations

- Transfer efficiency degrades with lateral coil misalignment beyond ± 3 cm, requiring alignment assistance for practical deployments.
- The current prototype supports limited power class (WPT1 range); scaling to WPT3 (11.1 kW) requires upgraded inverter and thermal management.
- Electromagnetic interference (EMI) from the high-frequency coil operation requires shielding and regulatory compliance testing.
- Bluetooth-based control is limited to approximately 10–15 metres range, restricting remote monitoring capability.

10. Future Enhancements

- **Hardware Upgrade:** Replace the Arduino Uno with an ESP32-S3 or Raspberry Pi Zero 2 W for enhanced processing power and expanded communication options.
- **Cloud Integration:** Add cloud storage and a real-time dashboard for charging session data logging, analytics, and remote monitoring.
- **Long-Range Communication:** Integrate LoRa or GSM modules for remote deployment management and real-time alerts.
- **Dynamic Road Charging:** Design and embed transmitter coil arrays into road infrastructure to support in-motion EV charging on smart highways.
- **Advanced Control:** Implement AI-based coil alignment guidance, predictive FOD using computer vision, and Vehicle-to-Grid (V2G) bidirectional power transfer for grid stabilisation.

11. CONCLUSIONS

Wireless Charging Systems for Electric Vehicles represent a practical and future-ready solution to support sustainable mobility and modern smart-city infrastructure. This project

demonstrates how electrical energy can be transferred efficiently and safely without physical cables by utilising electromagnetic induction, resonant coil design, power electronics, and IoT-based communication. Features such as contactless operation, automatic charging activation, Foreign Object Detection, and BMS integration reduce manual effort, enhance safety, and improve reliability for both individual users and fleet operators.

The use of resonant compensation networks in this project improves transfer efficiency significantly compared to basic inductive systems, which lessens dependence on plug-in infrastructure and supports wider EV adoption.

In the future, dynamic in-road charging lanes, Vehicle-to-Grid (V2G) bidirectional power transfer, and AI-based coil alignment optimisation can further enhance the capability of wireless EV charging systems. Integration of renewable energy sources such as solar power can also improve overall system sustainability. When connected to smart city platforms, these systems can provide municipal and transport authorities with real-time data for efficient energy management, promoting cleaner and more autonomous urban environments.

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