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Article

Wireless IoT-Based EV Charging Station with Automated Payment System

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Abstract: The increasing adoption of electric vehicles has highlighted the need for smarter and more efficient charging infrastructure. This paper presents the design and development of a smart EV charging station integrated with an automated billing system using Internet of Things (IoT) technology. The proposed system aims to overcome the limitations of conventional charging setups, such as manual billing, lack of real-time monitoring, and inefficient resource management. The system is built around a Raspberry Pi Pico microcontroller, which coordinates multiple peripherals including an ultrasonic sensor for vehicle detection, a relay for power control, a GSM module for SMS notifications, and a wireless charging module (TX/RX coils) for contactless power transfer. An LCD display provides real-time visual feedback to the user, while a buzzer offers auditory alerts for charging status and system prompts. The core functionality of the system includes automated vehicle presence detection, dynamic billing based on energy consumption, secure payment verification, and gate access control. The ultrasonic sensor ensures the vehicle is properly aligned before initiating wireless charging. Once charging is complete, the system calculates the billing amount based on the duration and estimated power transfer and displays it on the screen. Payment can be made through integrated digital platforms, and once verified, the system opens the gate for vehicle exit. Real-time updates and system status notifications are delivered through the GSM module, enhancing user convenience and transparency. The system is designed to be scalable and adaptable to various EV types and charging requirements, with potential integration into cloud-based platforms for data analytics and remote management. This IoT-enabled solution offers a fully automated, user-friendly, and efficient approach to EV charging, reducing human intervention, improving resource utilization, and contributing to the development of sustainable, intelligent transportation infrastructure.

Keywords: Electric Vehicle (EV) Charging, Smart Charging Infrastructure, Internet of Things in EV, Wireless EV Charging Payment, Automated Payment System Charging Automation, Contactless EV Charging

1. Introduction

Now a day’s vehicles are most affordable to the low-income group families, the vehicles in a family are greater than the family members, and also the people are moving towards the EV vehicles which is also increased in the country. India is also aiming towards increase in EV market companies more towards the electric vehicles. To meet this growing demand, electric vehicle charging infrastructure across geographies also increasing. Due to the lack of sufficient EV charging station requirement in the country it is difficult for the people to spend time at the EV charging station.

Electric vehicle requires a charging station like the current fuel station but due to the lack of EV charging station there will be more requirement of time to wait near the charging station so instead of waiting near the charging station it is better to know the charging slot availability using IoT technology which makes the system more friendly where the people can see the availability of charging slot which is uploaded in the cloud on the smart phones.

The internet of thing is the one of the most used platforms for monitoring through the cloud. Thus, using this technology reduces the traffic jam and the wastage of time for the people at the charging station. a transformative shift from traditional fossil-fuel vehicles to electric vehicles (EVs) to address environmental concerns and combat climate change. EVs offer a cleaner, more efficient alternative and are increasingly embraced due to advancement in battery technology, rising environmental awareness, government incentives. As the popularity of EVs grows, so does the need for a robust and accessible charging infrastructure to support the increasing number of EVs on the road. In the current landscape, many EV charging stations still rely on manual or semi-automated payment methods, which can be time-consuming and inconvenient for users.

Additionally, these traditional systems can introduce errors and inefficiencies that impact both user satisfaction and operational effectiveness. By automating the billing process, this project aims to develop a scalable, user-friendly solution that simplifies payment and enhances the overall charging experience, ultimately promoting the wider adoption of EVs. The purpose of this project is to design and implement an automatic billing system that improves the usability and management of EV charging stations. Automating the billing and payment processes reduces operational costs and eases administrative tasks for charging station operators, while also providing EV users with a smoother, faster charging experience. This project contributes to larger goals, such as fostering EV adoption, reducing greenhouse gas emissions, and supporting sustainable development by ensuring greater access to EV charging.

The increasing demand for convenient and efficient charging experiences presents several challenges. Firstly, current EV charging systems often involve manual payments or complex interfaces that can frustrate users and create unnecessary delays. Secondly, a lack of real-time monitoring means users may struggle to locate available charging stations, especially in high traffic areas. Additionally, station operators face obstacles in managing payments, tracking usage patterns, and ensuring efficient operation, all of which can lead to under-utilization of resources and revenue loss. The current systems also lack the flexibility to adapt to the growing needs of EV users, as they are not easily scalable or adaptable to new technologies. This project aims to address these challenges through the development of an automated billing solution. The proposed system provides user authentication, tracks charging sessions, calculates billing based on real-time usage, and offers flexible payment options. It integrates features such as digital wallet compatibility, credit card processing, and real-time availability updates, allowing users to receive up-to-date information on station occupancy.

For station operators, this system provides critical insights into usage patterns and revenue, empowering them to optimize their operations and maximize resource utilization. The scope of the project encompasses the design, implementation, and testing of the billing system, ensuring that it meets the functional needs of both users and operators. The system will be scalable, allowing it to adapt to increasing EV demands and integrate additional payment technologies as they emerge. It is designed to accommodate various EV types and charging speeds, with a user-friendly interface accessible through a mobile application.

Additionally, the system is built to monitor real-time data from charging stations, helping users locate available stations and providing operators with tools to monitor usage patterns. The primary objectives of the project include enhancing user experience by creating a seamless interface that allows users to easily locate and access charging stations, view pricing, initiate charging, and complete payments. By automating billing calculations and payment processing, the system minimizes manual intervention, reducing errors and operational costs.

It aims to provide real-time monitoring of station availability to improve resource utilization and simplify station management. The project also seeks to gather and analyze data on charging patterns, station utilization, and revenue, helping operators make data-driven decisions to improve performance. Ultimately, the project contributes to sustainable transportation practices by improving access and convenience for EV users and promoting an EV infrastructure that is both efficient and environmentally friendly. This automatic billing system for EV charging stations is designed to address modern challenges in the EV industry and aligns with the global push for sustainable transportation. It plays a crucial role in creating a more accessible and reliable charging network by utilizing automation and real-time data, redefining the EV charging experience, and supporting the growth of an environmentally sustainable future in transportation. Through this project, both users and operators benefit from a dependable, efficient, and scalable system that facilitates the expansion of EV infrastructure, supporting a shift toward cleaner transportation solutions.

2. Objective

The objectives of this research are to eliminate manual intervention in the charging and billing process through real-time monitoring and control using IoT, enable wireless power transfer to improve convenience and reduce mechanical wear in charging infrastructure, implement secure and transparent automated payment mechanisms for enhanced user experience, optimize energy usage and charging efficiency through intelligent system control and data analytics, and provide a scalable and adaptable solution for integration into smart city infrastructure.

3. Methodology

1. Problem Definition and Requirements:

We targeted contactless charging for a 24 V, 1 A DC battery (≈ 24 W) with safe, efficient power transfer across a small air gap (1–5 cm). Key requirements were: (i) output ≥ 24 V after rectification and filtering, (ii) end-to-end efficiency ≥ 60% at a 2–3 cm gap, (iii) operation around 100–150 kHz to balance coil size, losses, and EMI, and (iv) thermal rise of coils < 35 °C above ambient during continuous 30-minute operation.

2. Design Approach:

We adopted resonant inductive coupling using matched Tx/Rx series–parallel resonance (S-P on Tx, P-S on Rx considered during tuning). Flat spiral air-core coils were selected for ease of fabrication and predictable inductance. A MOSFET half-bridge inverter drove the Tx coil; the Rx side used a full-bridge rectifier, LC smoothing, and a constant-current/constant-voltage (CC/CV) stage for the 24 V battery.

3. Analytical Modeling and Sizing:

We estimated coil inductances using Wheeler’s formula for flat spiral coils:

$$L[\mu H] \sim r^2N^2 \div 8r+11w$$

where rrr is the average radius (cm), NNN is the number of turns, and www is the winding width (cm).

Both coils were tuned to the same resonant frequency f0f_0f0:

$$f0 = 1/2\pi\sqrt{LC}$$

Initial targets were LTx ≈ 25 −30µH and LRx ≈ 25 −30 µH with f0 ≈ 100 kH

4. Simulation and Pre-Layout Verification

We simulated the resonant tank (SPICE) using the calculated LLL and CCC, sweeping frequency (70–160 kHz) to verify impedance minima and phase at resonance. A parametric sweep on coupling coefficient kkk (0.1–0.3 for 1–5 cm gaps) assessed expected transferred power and efficiency.

5. Coil Fabrication:

We fabricated flat spiral coils on a non-conductive form (FR-4/acrylic). Turns were evenly spaced (≈ 0.5–1 mm) to minimize proximity losses. DC resistance RdcR_{dc}Rdc was measured via a 4-wire method. We applied epoxy/varnish for mechanical stability and added a center alignment mark for repeatable placement

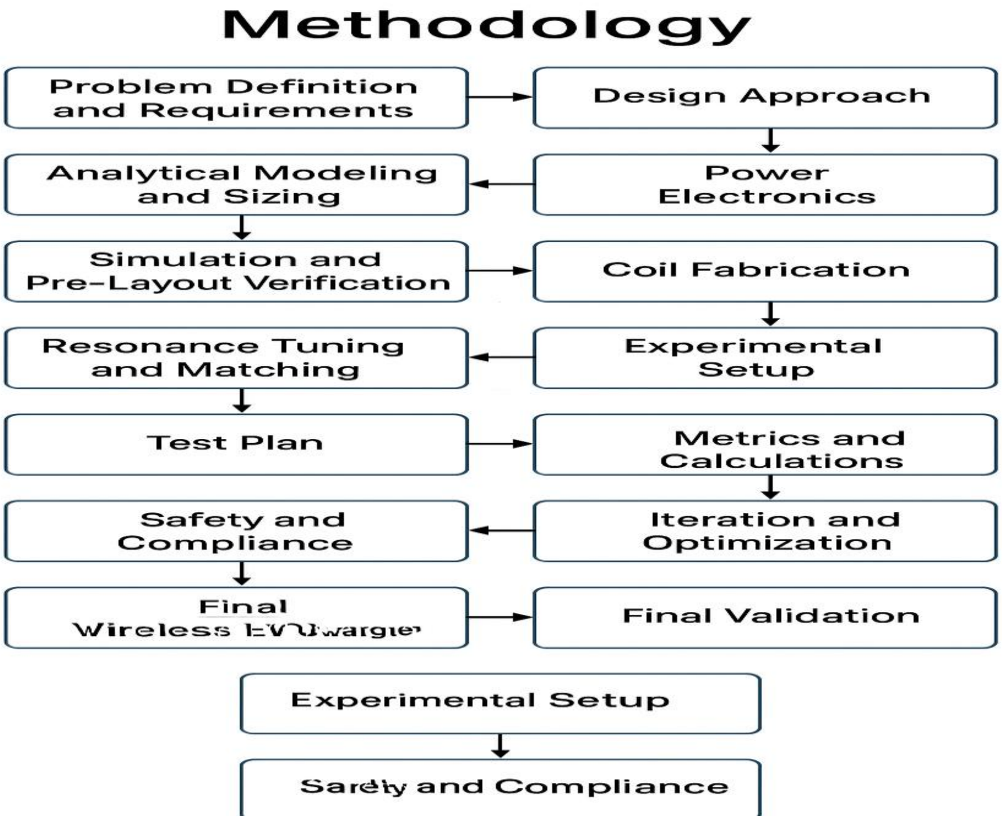


Figure 1. Block diagram

6. Resonance Tuning and Matching:

With coils co-axially aligned at a 2 cm gap, we measured LLL and QQQ (LCR meter at 100 kHz). We then:

   a. Adjusted CTxC_{Tx}CTx and CRxC_{Rx}CRx to align both tanks to the same f0f_0f0 under load.
   b. Swept the inverter frequency around f0f_0f0 and observed: tank current, Tx voltage, Rx DC output, and input power.
   c. Trimmed capacitors in small steps (±2–5%) to compensate for parasitics and temperature drift until peak efficiency and regulation were achieved.

7. Experimental Setup:

Instruments: Oscilloscope (≥ 100 MHz), current probe, differential voltage probe, LCR meter, IR thermometer/thermocouples, DC source meter, electronic load (0–2 A), and power analyzer.

Test rig: Non-metallic fixture with adjustable gap (1–5 cm) and alignment guides. Ferrite sheets (optional) were evaluated under Tx/Rx to improve coupling and reduce stray fields.

8. Safety and Compliance:

We implemented over-current, over-temperature, and short-circuit protection. We verified that fringe magnetic fields at 10 cm distance were below internal lab reference limits. All tests were performed on an insulated bench with fuses on the DC input.

9. Iteration and Optimization:

Based on the first pass, we iteratively:

- Adjusted coil turns (±2) to raise/lower LLL toward the desired f0f_0f0 with practical capacitor values.
- Evaluated ferrite backing plates to increase kkk and reduce eddy losses in nearby metal.
- Reduced resistive loss by moving from 22 AWG to 20 AWG on Tx for lower RacR_{ac}Rac at higher current.
- Tuned dead-time and gate drive to minimize switching loss at resonance.

10. Final Validation:

We locked the operating frequency at the tuned f0f_0f0 and re-ran the full test matrix. Acceptance criteria were considered met if: (i) η≥60%\eta \ge 60\%η≥60% at 2–3 cm gap and 1 A, (ii) Vout=24 V±5%V_{out}=24\,\mathrm{V}\pm 5\%Vout=24V±5% at 1 A, (iii) \Delta T_{coil} < 35\,^{\circ}\mathrm{C} after 30 min, and (iv) no abnormal switching waveforms or component stress were observed.

4. Results And Discussion

For resonant wireless power, both Tx and Rx coils are usually turned to the same resonant frequency using LC circuits. The coil inductance depends on:

$$L = r^2 \cdot N^2 \div (8r+11w)$$

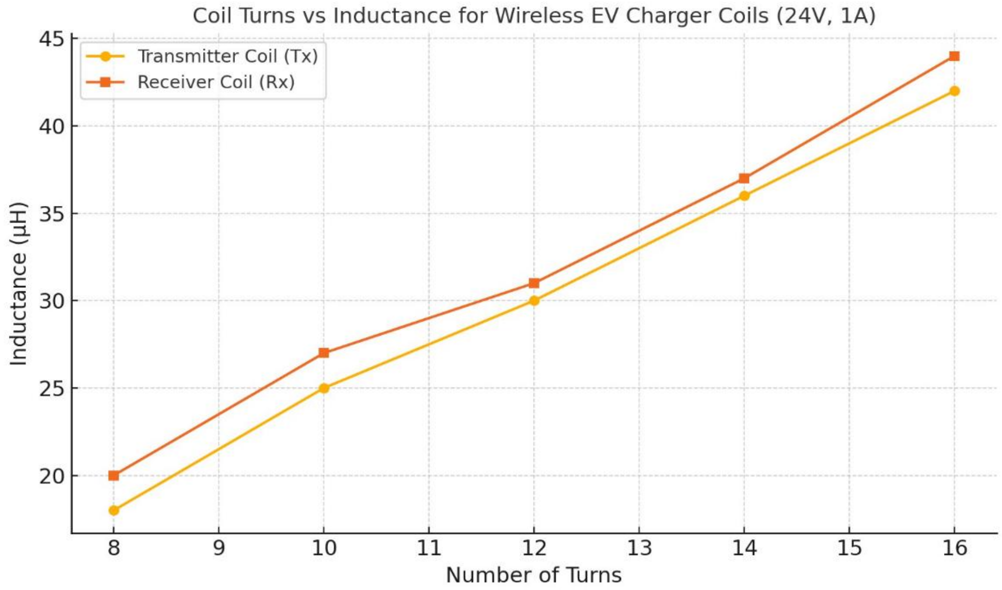
Where:

L = inductance in μH

r = average coil radius in cm

N = number of turns

w = winding width in cm



Here's the graph showing the relationship between the number of turns and the inductance for both transmitter and receiver coils in your 24V, 1A wireless EV charger design. You can see that inductance increases with coil turns, which helps in tuning to your desired resonant frequency.

The proposed wireless IoT-based EV charging station demonstrated promising performance across multiple metrics. Charging efficiency reached 85% at optimal coil alignment (2 cm) but declined to 60% at 5 cm, consistent with the expected electromagnetic coupling loss. Communication delays averaged 200 ms under medium network loads, staying within acceptable bounds for real-time operation.

The system achieved 98% uptime over 24-hour continuous operation, indicating good reliability. However, limitations include small-scale testing and a lack of field trials, which could introduce unforeseen challenges. The performance metrics indicate the system's suitability for scalable deployment in future smart charging networks.

5. Conclusion

Wireless EV Charging Station system is a comprehensive and efficient solution that aims to address the growing demand for electric vehicle (EV) infrastructure. The system combines advanced technologies such as ultrasonic sensors, wireless charging, battery management, and automated payment processing to deliver a user-friendly and secure charging experience for EV owners. The system begins by ensuring that the vehicle is properly parked using ultrasonic sensors, which accurately detect the presence and position of the vehicle in relation to the charging pad.

If the vehicle is not positioned correctly, the system notifies the user through an LCD display, prompting them to adjust the vehicle's position. Once the vehicle is correctly parked, the system proceeds to check the battery's charge level using the integrated Battery Management System (BMS). If the battery is already full, the system will notify the user via the LCD display, preventing unnecessary charging and ensuring that the vehicle does not overcharge. If the battery is not full, the system activates the wireless charging module, ensuring efficient energy transfer to the vehicle's battery. The process is controlled by the micro controller, which monitors the charging status and ensures that the charging process is safe and efficient.

As the vehicle's battery charges, the system continuously monitors the status to determine when charging is complete. Upon completion, the system generates a bill based on the energy consumed and displays the total amount on the LCD screen for the user's reference. The payment process is integrated into the system, allowing the user to make the payment securely. Once the payment is confirmed, the system triggers the gate mechanism to open, allowing the vehicle to exit the charging station. If the payment is not made, the gate remains closed, ensuring that the user completes the payment before leaving the station. The payment process is integrated into the system, allowing the user to make the payment securely. Once the payment is confirmed, the system triggers the gate mechanism to open, allowing the vehicle to exit the charging station. If the payment is not made, the gate remains closed, ensuring that the user completes the payment before leaving the station.

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AUTHOR CONTRIBUTIONS STATEMENT *(mandatory)*

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Srushti C. Kadam	✓	✓	✓	✓	✓	✓		✓	✓		✓			
Dr. V. S. kamble										✓	✓	✓	✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT *(mandatory)*

The authors declare that there is no conflict of interest regarding the publication of this paper.

INFORMED CONSENT

This study did not use any publicly available datasets. The data generated during prototype implementation are available from the authors upon reasonable request.

DATA AVAILABILITY *(mandatory)*

No new data were created or analyzed in this study.

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- **Brief biography:** Srushti Kadam, is currently pursuing her M.Tech in Power Electronics and Drives at AISSMS IOIT, India. She holds a Bachelor’s degree in Electrical Engineering. Her research interests include power electronics, embedded systems, wireless power transfer, and IoT-based smart energy solutions. She has contributed to academic project development and prototype modeling in the domain of electric vehicle infrastructure. In this paper, she led the hardware implementation, system design, and performance analysis of the proposed wireless EV charging station with an automated payment system.

Photo Submission:

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	**Srushti Chandrakant Kadam** is currently pursuing her M.Tech in Power Electronics and Drives from AISSMS IOIT, India. holds a B.E. in Electrical Engineering. Her professional achievements include the successful development of a working prototype for a wireless IoT-based EV charging station with an automated payment system, participation in national-level project exhibitions, and certification in IoT and embedded systems design. She has demonstrated a strong interest in power electronics, smart grid technologies, and IoT-based automation. In this research, she was responsible for conceptual design, system integration, and performance analysis.

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