International Journal of Engineering & Extended Technologies Research (IJEETR)

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802483

Wireless Electric Vehicle Charging System

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Publication History: Received: 25.02.2026; Revised: 20.03.2026; Accepted: 25.03. 2026; Published: 28.03.2026.

ABSTRACT: Wireless Electric Vehicle (EV) charging systems represent an innovative approach to energy transfer, eliminating the need for physical connectors between the power source and the vehicle. This technology is primarily based on the principle of electromagnetic induction, where electrical energy is transferred from a transmitter coil embedded in the ground to a receiver coil installed in the vehicle.

The system consists of a power supply unit, high-frequency inverter, transmitting coil, receiving coil, and rectifier circuit. When alternating current flows through the transmitter coil, it generates a magnetic field, inducing voltage in the receiver coil, which is then converted into usable electrical energy to charge the EV battery.

Wireless charging offers several advantages, including improved safety, convenience, reduced wear and tear, and suitability for automated and dynamic charging systems (charging while driving). However, challenges such as energy efficiency, alignment issues, cost, and electromagnetic interference must be addressed.

This project aims to design and demonstrate a prototype wireless charging system that is efficient, safe, and feasible for future smart transportation infrastructure.

KEYWORDS: Wireless Power Transfer (WPT), Electric Vehicle (EV) Charging, Electric Vehicle (EV) Charging, Inductive Charging, Electromagnetic Induction, Resonant Coupling, Transmitter Coil, Receiver Coil, Energy Efficiency, Battery Charging System, Power Electronics, Smart Transportation.

I. INTRODUCTION

The rapid growth of electric vehicles (EVs) has created a strong demand for efficient, reliable, and user-friendly charging solutions. Conventional charging methods rely on physical cables and connectors, which can be inconvenient, time-consuming, and prone to wear and safety issues. To overcome these limitations, wireless charging technology has emerged as a promising alternative.

Wireless EV charging systems operate on the principle of electromagnetic induction, enabling the transfer of electrical energy without direct physical contact. In this system, a transmitting coil embedded in a charging pad generates a magnetic field when supplied with alternating current. A receiving coil installed in the vehicle captures this energy and converts it into electrical power to charge the battery.

This technology offers significant advantages such as ease of use, improved safety by eliminating exposed conductive parts, reduced maintenance, and compatibility with automated systems. It also supports advanced concepts like dynamic charging, where vehicles can be charged while in motion, enhancing driving range and reducing dependency on large battery capacities.

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Despite its benefits, wireless charging faces challenges including energy losses, alignment sensitivity between coils, higher installation costs, and electromagnetic interference. Ongoing research focuses on improving efficiency, optimizing coil design, and developing standardized systems for widespread adoption.

This project aims to explore the design, working principle, and practical implementation of a wireless EV charging system, contributing to the development of smarter and more sustainable transportation technologies.

1.1 PROBLEM STATEMENT

The increasing adoption of electric vehicles (EVs) has highlighted several limitations in conventional wired charging systems. These systems require physical connectors, which can lead to inconvenience for users, especially in adverse weather conditions. Frequent plugging and unplugging also result in mechanical wear and tear, increasing maintenance costs and reducing system reliability.

Additionally, wired charging infrastructure poses safety risks such as electric shock, cable damage, and exposure to environmental factors like dust and moisture. The need for manual intervention limits the potential for automation in modern smart transportation systems. Furthermore, the growing demand for efficient and seamless charging solutions emphasizes the need for innovative technologies that can support dynamic and user-friendly charging methods.

Therefore, there is a need to develop a wireless charging system that can efficiently transfer power without physical connections, ensuring safety, convenience, reduced maintenance, and compatibility with future automated and smart mobility solutions.

1.2 OBJECTIVES

To design and develop a wireless power transfer system for charging electric vehicles without physical connectors.
To study and implement the principle of electromagnetic induction for efficient energy transfer.
To design transmitter and receiver coils for optimal power transmission.
To develop a circuit system including inverter and rectifier for effective power conversion.
To improve charging convenience, safety, and reliability compared to conventional wired systems.
To analyze system efficiency and identify power losses during wireless transmission.
To explore the feasibility of static and dynamic wireless charging methods.
To create a cost-effective and scalable prototype suitable for future smart transportation systems.

II. RELATED WORK

Wireless power transfer (WPT) technology has been widely studied and developed for electric vehicle charging in recent years. Early research focused on inductive coupling methods, where energy transfer efficiency was limited by coil alignment and distance. Later advancements introduced resonant inductive coupling, significantly improving efficiency and allowing greater spatial tolerance between transmitter and receiver coils.

Several organizations and researchers have contributed to the development of wireless EV charging systems. Companies like Qualcomm (Halo technology) and WiTricity have developed commercial solutions based on magnetic resonance coupling, achieving high efficiency and practical implementation for stationary charging. Automotive manufacturers such as BMW and Toyota have also experimented with wireless charging systems integrated into their vehicles.

Research studies have explored various aspects such as coil design optimization, compensation topologies (series-series, series-parallel), and power electronics control to enhance system performance. Dynamic wireless charging, where vehicles are charged while moving over embedded road coils, has also been investigated to reduce battery size and extend driving range.

Recent work focuses on improving efficiency, reducing electromagnetic interference, and developing standard protocols for interoperability. Despite significant progress, challenges such as high installation cost, alignment sensitivity, and infrastructure requirements remain key areas of ongoing research.

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III. EXISTING METHODOLOGY

The existing methodology for wireless EV charging is primarily based on inductive power transfer (IPT) and resonant inductive coupling techniques. In current systems, electrical energy from the power source is first converted into high-frequency alternating current using a power electronic inverter. This high-frequency AC is supplied to a transmitter coil placed in a charging pad, generating an alternating magnetic field.

A receiver coil mounted underneath the electric vehicle captures this magnetic field through electromagnetic induction. The induced AC voltage in the receiver coil is then converted into direct current (DC) using a rectifier circuit. This DC power is regulated and used to charge the EV battery.

Most existing systems follow either:
Static Wireless Charging: The vehicle is parked over a charging pad, and power is transferred when proper alignment between coils is achieved.

Dynamic Wireless Charging: Charging occurs while the vehicle is in motion over specially designed roads embedded with transmitter coils.

To improve efficiency and reduce power loss, compensation networks (such as series-series or series-parallel capacitors) are used to achieve resonance between transmitter and receiver coils. Modern systems also incorporate control units for monitoring voltage, current, and alignment to ensure safe and efficient operation.
Although existing methodologies provide a convenient and contactless charging solution, they still face limitations such as high infrastructure cost, sensitivity to coil misalignment, limited transfer distance, and efficiency losses under varying conditions.

IV. PROPOSED METHODOLOGY

The proposed wireless EV charging system consists of the following key components:
Power Supply Unit
Provides the required electrical energy (AC or DC source) to the system.
High-Frequency Inverter
Converts DC power into high-frequency AC, which is essential for efficient wireless power transfer.
Transmitter Coil (Primary Coil)
Placed in the charging pad, it generates an alternating magnetic field when energized.
Compensation Network (Capacitors)
Used to achieve resonance between transmitter and receiver coils, improving power transfer efficiency.
Receiver Coil (Secondary Coil)
Installed in the vehicle, it captures the magnetic field and converts it into electrical energy.
Rectifier Circuit
Converts the received AC power into DC power suitable for battery charging.
Voltage Regulator / DC-DC Converter
Ensures a stable and controlled output voltage for safe battery charging.
Battery Management System (BMS)
Monitors and protects the battery by controlling charging parameters like voltage, current, and temperature.
Electric Vehicle Battery
Stores the electrical energy for vehicle operation.
Control Unit (Microcontroller)
Manages system operation, alignment detection, safety mechanisms, and communication between transmitter and receiver.

4.1 System Architecture
The wireless EV charging system is divided into two main sections: the transmitter side (charging station) and the receiver side (vehicle unit). These two sections work together to transfer power wirelessly through electromagnetic coupling.

4.2 Transmitter Side (Charging Pad)
AC Power Source: Supplies electrical energy to the system.

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Rectifier & Filter (if AC input): Converts AC to DC for further processing.
High-Frequency Inverter: Converts DC into high-frequency AC to improve power transfer efficiency.
Compensation Network: Uses capacitors to create resonance with the transmitter coil.
Transmitter Coil: Generates an alternating magnetic field for wireless energy transfer.

2. Wireless Power Transfer Link
Energy is transferred through an air gap using electromagnetic induction or resonant coupling.
Proper alignment between transmitter and receiver coils ensures maximum efficiency.

3. Receiver Side (Vehicle Unit)
Receiver Coil: Captures the magnetic field and induces AC voltage.
Compensation Network: Maintains resonance for efficient power reception.
Rectifier Circuit: Converts induced AC into DC.
DC-DC Converter / Voltage Regulator: Stabilizes output voltage for safe charging.
Battery Management System (BMS): Controls and monitors charging conditions.
EV Battery: Stores the received electrical energy.

4. Control and Communication Unit
Ensures proper alignment detection between coils.
Monitors voltage, current, and temperature.
Provides safety features such as overvoltage and overcurrent protection.
Enables smart charging and possible communication between charger and vehicle.

4.3 Working of Wireless EV Charging System
The wireless EV charging system operates based on the principle of electromagnetic induction and resonant coupling. The overall working process is explained step by step below:
Power Supply Conversion

The system receives electrical energy from the main power source. If the input is AC, it is first converted into DC using a rectifier and filter circuit.

High-Frequency Inversion
The DC power is then converted into high-frequency AC using a high-frequency inverter. High frequency is used to improve the efficiency of wireless power transfer.
Magnetic Field Generation (Transmitter Side)
The high-frequency AC is supplied to the transmitter coil placed in the charging pad. This coil generates an alternating magnetic field around it.

Wireless Energy Transfer
When the electric vehicle is positioned above the charging pad, the receiver coil (mounted under the vehicle) comes within the magnetic field. Through electromagnetic induction, voltage is induced in the receiver coil without any physical contact.

Resonance Enhancement
Both transmitter and receiver coils are tuned using compensation capacitors to operate at the same resonant frequency. This increases the efficiency and allows better power transfer even with slight misalignment.

Power Conversion (Receiver Side)
The induced AC voltage in the receiver coil is converted into DC using a rectifier circuit.
Voltage Regulation
The DC output is regulated using a DC-DC converter to provide a stable voltage suitable for charging the EV battery.

Battery Charging
The regulated DC power is supplied to the battery through a Battery Management System (BMS), which ensures safe charging by controlling voltage, current, and temperature.
Control and Safety

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A control unit monitors the entire process, ensuring proper alignment, preventing overcharging, and providing protection against faults.

4.4 performance enhancement techniques in wireless
EV Charging System

Improving the performance of a Wireless EV Charging System mainly focuses on increasing efficiency, reducing power loss, improving alignment tolerance, and enabling faster, safer charging. Here are the key performance enhancement techniques explained clearly:

Performance Enhancement Techniques in Wireless EV Charging
1. Resonant Inductive Coupling Optimization
Uses tuned resonance between transmitter and receiver coils
Increases power transfer efficiency over larger air gaps
Reduces energy loss compared to basic inductive coupling
Based on Resonant Inductive Coupling
Key idea: Both coils operate at the same resonant frequency
2. Coil Design Optimization
Use of circular, rectangular, or Double-D (DD) coil shapes
Litz wire reduces skin effect losses
Improves magnetic field strength and uniformity
Better coil design = higher efficiency + less heat
3. Alignment Improvement Techniques
Misalignment reduces efficiency significantly
Solutions:
Position detection sensors
Automatic parking assistance
Multi-coil or coil array systems
4. Compensation Networks
Capacitors added to coils to maintain resonance
Common topologies: Series-Series (SS), Series-Parallel (SP)
Helps stabilize voltage and improve efficiency
5. Power Electronics Optimization
High-frequency inverters improve energy transfer
Use of soft-switching techniques like:
Zero Voltage Switching (ZVS)
Zero Current Switching (ZCS)
Reduces switching losses and heat
6. Frequency Control & Tuning
Dynamic adjustment of frequency based on load conditions
Maintains optimal performance even with distance variations
7. Thermal Management
Cooling systems (air/liquid cooling)
Heat-resistant materials
Prevents efficiency drop due to overheating
8. Smart Control Systems
Use of microcontrollers or AI-based control
Real-time monitoring of:
Voltage
Current
Temperature
Enables adaptive charging and improves safety
9. Magnetic Shielding
Ferrite materials used to guide magnetic flux
Reduces leakage and electromagnetic interference (EMI)
10. Dynamic Wireless Charging
Charging while the vehicle is moving
Embedded coils in roads

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Advanced concept for continuous energy supply
11. Battery Management System (BMS) Integration
Ensures optimal charging cycles
Prevents overcharging and improves battery life
12. Efficiency Enhancement Formula
Efficiency depends on coupling and quality factor:
�
Where:
� = coupling coefficient
� = quality factors of coils
Higher values = better efficiency
Conclusion
Performance of wireless EV charging can be significantly improved using:
Better coil design
Smart control systems
Advanced power electronics
Proper alignment and shielding
These enhancements make wireless charging more practical, efficient, and ready for future smart transportation systems.

4.5 Future Trends & Challenges
1. Dynamic (In-Motion) Charging
EVs can charge while driving using coils embedded in roads
Reduces battery size and charging downtime
Pilot projects in Sweden and South Korea
2. High-Power Fast Wireless Charging
Development of 50 kW–100 kW wireless systems
Comparable to fast wired charging
Advanced work by WiTricity
3. Autonomous & Hands-Free Charging
Self-driving cars automatically align and charge
No human intervention needed
4. Smart Grid Integration
Charging connected to intelligent power grids
Load balancing and efficient energy usage
Supports renewable energy sources
5. IoT & AI-Based Optimization
Real-time monitoring of charging parameters
AI improves efficiency, safety, and scheduling
6. Vehicle-to-Grid (V2G) Technology
EVs can send power back to the grid
Helps in energy storage and grid stability
7. Standardization
Universal charging standards for compatibility
Driven by organizations like SAE International
8. Smart City Integration
Wireless charging in:
Parking areas
Roads
Public transport systems

VI. CONCLUSION

Wireless EV charging is a promising and innovative technology that enables safe, convenient, and cable-free energy transfer for electric vehicles. By using principles like electromagnetic induction and resonant coupling, it simplifies the charging process and supports automation in modern transportation systems.

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The technology shows strong potential with advancements such as dynamic charging, smart grid integration, AI-based control, and high-power wireless systems, making it suitable for future smart cities and autonomous vehicles.
However, challenges like high cost, lower efficiency, alignment issues, and infrastructure limitations still need to be addressed. Continuous research and standardization efforts by organizations like SAE International are helping to improve performance and compatibility. Overall, wireless EV charging is expected to play a key role in the future of sustainable transportation, offering a more user-friendly and intelligent charging solution as technology continues to evolve.

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