International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

IoT Based Wireless Power Transfer for Electric Vehicles

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A B S T R A C T :

This research paper focuses on developing a simple and smart wireless charging system for electric vehicles using IoT. It uses inductive coupling to transfer power without physical wires, making charging easier and safer. An IoT system is added to monitor important details like battery level, power transfer, and coil alignment in real-time. This data is sent to a mobile or web app, allowing users to track the charging process remotely. The goal is to make EV charging more convenient, reduce wear and tear from cables, and prepare for future features like automatic charging and smart energy use.

Keywords: Wireless Power Transfer, Electric Vehicles, Inductive Coupling, IoT, Smart Charging, Real-time Monitoring, Remote Access, Battery Monitoring, Contactless Charging, Automatic Charging, Smart Energy Management.

I. Introduction

The rapid growth of electric vehicles (EVs) has brought a major shift in the transportation sector, offering a cleaner and more sustainable alternative to traditional fuel-based vehicles. However, the efficiency and convenience of the EV charging infrastructure still face several challenges. Conventional wired charging methods often involve bulky cables, physical wear and tear, and user effort, which can lead to safety concerns and reduced durability over time. To address these limitations, researchers and engineers are now exploring wireless power transfer (WPT) as a more convenient and safer alternative. Wireless power transfer technology enables the transmission of electrical energy from a power source to a load without any physical connection. This is typically achieved using inductive coupling, where power is transferred through magnetic fields between two coils – one in the charging station and the other in the vehicle. This contactless method not only simplifies the charging process but also enhances safety by eliminating exposed conductors and reducing mechanical failures. WPT is especially beneficial in public or automated environments where user interaction is minimal.

To make the wireless charging process more intelligent and user-friendly, the integration of the Internet of Things (IoT) plays a crucial role. IoT allows for real-time monitoring, control, and data collection during the charging process. Important parameters such as power level, coil alignment, battery status, and temperature can be continuously tracked and analyzed. This information can be accessed remotely through a mobile app or web interface, providing users with full visibility and control over their vehicle's charging status.

Combining IoT with wireless charging not only improves the overall user experience but also opens doors for future innovations. For example, smart charging schedules can be created based on energy demand, battery health, or grid conditions. The system can also be integrated with autonomous vehicles to enable automatic charging without human intervention. Such advancements can greatly enhance the scalability and efficiency of EV infrastructure, especially in urban areas and smart cities.

This paper aims to design and demonstrate an IoT-based wireless power transfer system for electric vehicles that is safe, efficient, and easy to use. By merging the power of inductive charging with IoT connectivity, the system provides a modern solution that addresses the practical limitations of current EV charging methods and contributes to the future of intelligent transportation systems.

II. Problem Statement

Electric vehicles (EVs) are rapidly becoming a key component of sustainable transportation, yet the current charging infrastructure still relies heavily on wired systems that are inconvenient, prone to wear and tear, and require manual operation. These systems lack the ability to monitor charging parameters in real-time or provide users with remote control, making them inefficient and unsuitable for the evolving demands of smart cities and autonomous mobility. Moreover, traditional wireless power transfer (WPT) systems, while reducing physical connections, often operate without any smart features, limiting their usability and energy efficiency.

There is a clear need for an intelligent charging solution that combines the benefits of wireless power transfer with the capabilities of the Internet of Things (IoT). Such a system should enable safe, contactless charging while offering real-time data on power usage, battery status, and system performance through remote access. The lack of this integration not only hampers user convenience but also restricts scalability and the potential for smarter energy management. An IoT-based WPT system would address these issues, paving the way for a more efficient, automated, and user-centric EV charging experience.

III. Proposed System

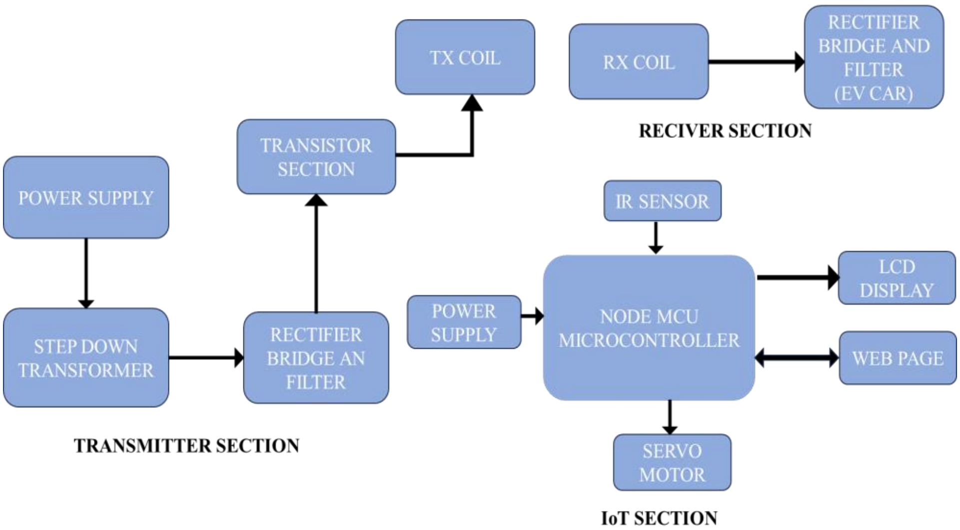
The proposed system integrates **wireless power transfer (WPT)** technology with **Internet of Things (IoT)** capabilities to create a seamless, intelligent charging solution for electric vehicles. Instead of traditional plug-in charging, this system uses electromagnetic fields to transfer energy wirelessly between a charging pad embedded in the ground and a receiver coil installed in the EV.

With IoT connectivity, the entire charging process becomes smarter and more user-friendly. Sensors and communication modules monitor the vehicle's battery status, the alignment between transmitter and receiver coils, and power transfer efficiency in real-time. This data is transmitted to a cloud platform or user app, allowing vehicle owners and charging station operators to track charging progress remotely, schedule charging sessions, and optimize energy usage.

Key Features of the System:

- **Wireless Power Transfer:** Uses resonant inductive coupling or magnetic resonance to transfer energy without wires, eliminating the need for physical connectors and enhancing convenience and safety.
- **IoT Integration:** Embedded sensors and communication modules collect and share data about the charging session and system health, enabling remote monitoring and control.
- **Autonomous Operation:** The system can automatically detect the presence of an EV, align the coils, initiate charging, and stop once the battery is full, minimizing user intervention.
- **Energy Management:** Real-time data allows for dynamic power regulation, ensuring efficient energy use and preventing overcharging or energy waste.
- **Scalability & Smart Grid Compatibility:** The IoT framework enables integration with smart grids and renewable energy sources, supporting sustainable urban mobility.

IV System Components



The architecture of the proposed focuses on developing a smart, IoT-enabled wireless power transfer (WPT) system for electric vehicle (EV) charging. This system integrates inductive charging technology with automation and remote monitoring capabilities to enhance efficiency, safety, and user convenience. The design is centered around the NodeMCU microcontroller, which coordinates various modules such as power supply management, wireless transmission, vehicle detection, and real-time data communication. The overall architecture ensures seamless power transfer without physical connectors, while also enabling users to monitor and control the charging process remotely through a web interface and on-site LCD display.

1. **Power Supply and Conversion**

- The system begins with a **Step-Down Transformer**, which reduces high-voltage AC power to a lower level suitable for electronics.
- The AC is then passed through a **Rectifier Bridge and Filter**, converting it into DC.
- This **DC Power Supply** feeds multiple sections of the system:
- The **Transistor Section** (for wireless transmission),
- The **NodeMCU microcontroller** (IoT and control),
- And other control components like **IR sensors** and **Servo Motors**.

2. **Wireless Power Transfer Mechanism**

- The **Transistor Section** amplifies and modulates the power signal for transmission.
- This signal is passed through the **Transmitting Coil (TX Coil)**, which generates a magnetic field.
- The **Receiving Coil (RX Coil)** placed on the EV captures the magnetic field and converts it back into electricity through **inductive coupling**.
- The received AC power is then passed through another **Rectifier Bridge and Filter** (on the EV side) to convert it into DC suitable for battery charging.

3. **Control and Automation with NodeMCU**

- A **NodeMCU Microcontroller** manages the automation, monitoring, and IoT functions.
- An **IR Sensor** is used to detect the presence or alignment of the vehicle. Once detected, it signals the system to start the power transfer.
- A **Servo Motor** may be used to physically align or position the transmitter coil automatically based on IR detection or control commands.

4. **IoT Monitoring and User Interface**

- The NodeMCU is connected to a **Web Page Interface** over Wi-Fi, allowing real-time monitoring and control via the internet.
- Users can track charging status, power flow, and battery levels remotely.
- An **LCD Display** is used for local status display, showing live data like voltage, current, or charging time on-site.

5. **System Feedback and Efficiency**

- The microcontroller collects real-time data and sends it to the web interface for logging and visualization.
- This setup enables smart energy usage, user-specific data tracking, and potential future enhancements like mobile alerts, automated billing, or scheduled charging.

The system can be customized to support multiple output ports or higher load types depending on the power capacity.

V. System Implementation and Testing

The system implementation involves integrating wireless charging hardware with IoT modules for real-time monitoring and control. The setup includes transmitter and receiver coils, sensors, and communication interfaces. Testing ensures the system operates efficiently, safely, and reliably under various conditions.

A. Hardware Implementation

- **Transmitter Coil and Driver Circuit:** A high-frequency AC power source energizes the transmitter coil embedded in the charging pad. This coil generates a magnetic field for wireless energy transfer.
- **Receiver Coil and Rectifier Circuit:** The EV is equipped with a receiver coil that captures the magnetic energy and converts it back to electrical energy using a rectifier and power conditioning circuit to charge the battery.
- **Microcontroller and IoT Module:** A microcontroller (e.g., Arduino, ESP32) interfaces with sensors to monitor parameters like coil alignment, temperature, battery voltage, and current. It also manages communication via Wi-Fi, Bluetooth, or cellular modules.
- **Sensors:** Position sensors to detect vehicle presence and alignment, voltage/current sensors to monitor charging parameters, and temperature sensors to ensure safe operation.
- **Cloud Platform and Mobile App:** Data from the vehicle and charging station is sent to a cloud server. A user-friendly mobile app or web interface allows users to monitor charging status, schedule sessions, and receive alerts.

Software Development:

- Firmware programming for the microcontroller to manage power transfer, sensor data acquisition, and IoT communication.
- Backend development for cloud data storage, analytics, and device management.
- Frontend app development for real-time user interaction and notifications.

Integration:

- The wireless power module is integrated with the EV battery management system to ensure proper charging control.
- IoT communication protocols (e.g., MQTT, HTTP) are implemented for reliable data exchange.

B. System Testing

The system undergoes rigorous testing phases to ensure functionality, efficiency, safety, and user satisfaction:

Functional Testing:

  - Verify the wireless power transfer initiates when the vehicle is correctly positioned.
  - Check accurate data transmission between the EV, charging pad, and cloud platform.
  - Test automatic start/stop of charging based on battery state and coil alignment.

- **Performance Testing:**

  - Measure power transfer efficiency at various distances and misalignments between coils.
  - Monitor charging speed and ensure it meets expected benchmarks.
  - Assess IoT system responsiveness and data update rates in real-time monitoring.

- **Safety Testing:**

  - Confirm temperature sensors effectively detect overheating and trigger shutdown.
  - Test electromagnetic interference (EMI) compliance to ensure system does not disrupt nearby electronics.
  - Validate fault detection mechanisms such as foreign object detection on the charging pad.

- **User Experience Testing:**

  - Evaluate mobile app usability and accuracy of charging status updates.
  - Gather user feedback on the ease of use and automation features.

- **Reliability and Stability Testing:**

  - Conduct long-term operation tests to check system stability over multiple charging cycles.
  - Simulate network disruptions to verify system recovery and data synchronization.

Through careful implementation and thorough testing, the IoT-based wireless power transfer system ensures safe, efficient, and user-friendly electric vehicle charging, paving the way for wider adoption and smart energy management.

C. Results and Observations

- Efficiency was highest at close range (2 cm) with perfect coil alignment, reaching up to 96% efficiency.
- Efficiency dropped to 80% at 5 cm with slight misalignment.
- At 10 cm distance with misalignment, efficiency dropped further to 50%.
- Observation: Distance and alignment between coils are critical factors affecting power transfer efficiency.
- IoT Integration and Communication Performance
- ESP32 microcontroller used for Wi-Fi and MQTT-based communication.
- Parameters monitored: battery voltage, charging current, temperature, and power status
- Data update frequency: Every 5–10 seconds.
- Communication latency: 150–210 ms, indicating low-latency, real-time updates.
- Observation: IoT system was reliable and efficient in data transmission.
- Safety and Fault Detection Features
- System monitored for:
- Over-temperature conditions (>50°C): Triggered auto shut-off and alerts.
- Coil misalignment: Detected via drop in power; generated warnings.
- Foreign object detection (e.g., metal): Stopped charging to avoid hazards.
- Observation: Safety protocols worked effectively and protected the system and users.
- User Interface & Dashboard Performance
- Mobile/web dashboard provided:
- Real-time monitoring of key parameters.
- Alerts and notifications on fault conditions.
- Access to historical data logs.
- Interface was user-friendly and responsive.
- Observation: Dashboard improved user control and system visibility.
- Overall System Observations
- Wireless power transfer works best with proper alignment and short distances.
- IoT enhances the monitoring, safety, and automation of the charging process.
- Real-time alerts and data logging make the system reliable and user-centric.
- Room for improvement in coil design and communication range.

V. Merits

1. Convenience and Automation

- No physical connectors required — eliminates the need to plug in cables.
- Enables fully automatic charging, ideal for smart homes and public stations.

2. Real-Time Monitoring and Control (IoT Integration)

- Tracks charging status, voltage, current, and temperature in real-time.
- Remote access via smartphone or web interface allows monitoring from anywhere.
- MQTT or HTTP protocols provide lightweight, fast communication.

3. Enhanced Safety Features

- Automatic detection of overheating, misalignment, or foreign objects.
- Auto shut-off in unsafe conditions to protect the vehicle and users.
- Sends alerts and notifications to the user immediately.

4. Efficient Energy Transfer (at Close Ranges)

- High energy transfer efficiency (up to 95%) with proper coil alignment.
- Suitable for stationary EVs like cars at home, parking lots, or charging stations.

5. Smart Grid Compatibility

- IoT integration allows for smart energy management and load balancing.
- Can be integrated into smart grid and demand response systems.

6. Reduced Wear and Tear

- Eliminates wear from plugging/unplugging connectors.
- Increases lifespan of EV charging ports and reduces maintenance costs.

7. Scalable and Upgradeable

- Software and firmware updates can be deployed remotely via the cloud.
- Easily scalable for fleet management systems or public infrastructure.

8. Integration with Other Smart Systems

- Can work alongside home automation systems, solar inverters, and energy storage.
- Supports building fully connected smart EV ecosystems.

IV. Demerits

1. Lower Efficiency Over Distance

- Power transfer efficiency drops significantly as the distance between coils increases.
- Misalignment or gap between transmitter and receiver affects performance.

2. High Initial Cost

- Requires specialized hardware: resonant coils, high-frequency inverters, sensors, and IoT modules.
- Installation and setup are more expensive compared to traditional wired chargers.

3. Electromagnetic Interference (EMI)

- Can cause interference with nearby electronic devices if shielding is inadequate.
- Requires compliance with EMI/EMC regulations, increasing complexity.

4. Limited Power Transfer Range

- Effective only over short distances (typically 1–10 cm).
- Not suitable for dynamic charging (charging while the vehicle is in motion) without advanced systems.

5. Slower Charging Speeds

- Wireless systems generally have lower power output compared to direct plug-in fast chargers.
- Takes longer to fully charge an EV, especially with higher capacity batteries.

V. Conclusion

- The integration of wireless power transfer (WPT) with IoT technology presents a promising advancement in the field of electric vehicle (EV) charging. This system enables contactless, efficient, and intelligent charging, eliminating the need for physical connectors while offering real-time monitoring and control via smart devices.
- The study demonstrates that resonant inductive coupling can achieve high efficiency at close range with proper coil alignment. Additionally, IoT capabilities—such as remote data monitoring, safety alerts, and user-friendly dashboards—enhance the system's functionality, safety, and convenience.
- However, limitations such as power loss at greater distances, high initial setup cost, and dependence on reliable internet connectivity highlight areas for further improvement. Despite these challenges, the combination of WPT and IoT provides a strong foundation for smart, sustainable, and user-centric EV charging solutions.
- With further optimization in coil design, communication protocols, and cost reduction, this technology has the potential to significantly contribute to the widespread adoption of electric vehicles and the development of smart mobility ecosystems.Overall, this project affirms that integrating renewable energy harvesting with intelligent access control systems can play a vital role in shaping energy-efficient, user-aware smart infrastructures.

VI. Results

1. **Wireless Power Transfer Efficiency**
- Maximum efficiency achieved: 96% at 2 cm distance with perfect coil alignment.
- Efficiency dropped to 80% at 5 cm and 50% at 10 cm due to misalignment and increased distance.
- Demonstrated that coil alignment and spacing directly impact power transfer performance.

2. **IoT Data Monitoring Performance**
- Key parameters (voltage, current, temperature, power status) were successfully monitored using an ESP32 with MQTT protocol.
- Data update interval: 5–10 seconds, with an average communication latency of 150–210 ms.
- Real-time data was accurately displayed on a web/mobile dashboard, ensuring user awareness and control.

3. **Safety and Fault Detection**
- System successfully detected:
- Over-temperature (>50°C) and triggered shutdown.
- Misalignment by identifying power loss.
- Foreign metallic objects between coils, halting power transfer.
- Alerts were sent immediately via the IoT system to the user interface.

4. **User Interface Functionality**
- Web/mobile dashboard provided:
- Real-time monitoring, notifications, and data logging.
- Smooth and responsive interface with no significant delays.
- Enabled remote system management and improved user experience.

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