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Design and Implementation of Wireless on-road Charging System for Electric Vehicle

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ABSTRACT: The rapid growth of electric vehicles (EVs) has created a strong demand for efficient and convenient charging solutions. Conventional charging methods require vehicles to stop for long durations, reducing usability and increasing travel time.

This limitation highlights the need for innovative approaches that can improve the practicality and adoption of EV technology.

This paper presents the design and implementation of a wireless on-road charging system that enables electric vehicles to charge dynamically while in motion. The system is based on electromagnetic induction, where transmitter coils embedded beneath the road generate a magnetic field, and receiver coils mounted on the vehicle capture this energy and convert it into electrical power.

The received power is rectified, regulated, and used to charge the vehicle battery efficiently. An embedded controller monitors and controls the charging process, while a display unit provides real-time system information. This approach reduces dependency on stationary charging stations, minimizes charging time, and improves driving range, thereby reducing range anxiety.

A prototype model is developed to validate the feasibility of wireless power transfer for moving vehicles. The system also considers proper coil alignment, safety, and reliability to enhance performance.

The results demonstrate that the proposed system supports continuous charging and contributes to the development of smart roads and sustainable transportation infrastructure, making it a promising solution for future electric mobility.

KEYWORDS: Wireless Power Transfer, Electric Vehicles, Embedded System, Inductive Charging, Microcontroller, Dynamic Charging, Power Transfer Efficiency, Coil Alignment, Real-Time Monitoring.

I. INTRODUCTION

The rapid growth of electric vehicles (EVs) has emerged as a promising solution to reduce greenhouse gas emissions and dependence on fossil fuels. Despite these advantages, EV adoption faces challenges due to limited battery capacity and frequent charging requirements. Conventional charging methods demand long stationary periods, increasing travel time and reducing convenience. These limitations highlight the need for more efficient and user-friendly charging solutions.

Wireless power transfer (WPT) technology has gained significant attention as an alternative to traditional wired charging systems. It enables energy transfer without physical connectors, eliminating the need for plug-in infrastructure. This approach enhances user convenience and reduces wear and tear associated with charging ports. As a result, WPT is considered a key advancement in modern EV charging systems.

Among various WPT techniques, electromagnetic induction-based wireless charging is widely preferred due to its simplicity and reliability. This method uses magnetic fields to transfer energy between coils, ensuring safe and efficient power delivery. It has already been implemented in several low-power applications. Its adaptability makes it suitable for scaling into larger systems like electric vehicles.

Dynamic wireless charging has recently emerged as an innovative solution to overcome EV range limitations. In this system, transmitter coils are embedded beneath road surfaces, while receiver coils are mounted on vehicles. As the vehicle moves over the energized road, power is transferred wirelessly, enabling continuous charging. This reduces dependency on stationary charging stations and enhances travel efficiency.

This project presents the design and implementation of a wireless on-road charging system for EVs. The system integrates transmitter and receiver modules along with control and monitoring units to ensure efficient operation. It aims to reduce range anxiety and improve the practicality of EV usage. The prototype demonstrates real-time wireless charging, contributing to sustainable and smart transportation infrastructure.

II. BACKGROUND

Electric vehicles (EVs) have emerged as a sustainable alternative to conventional internal combustion engine vehicles due to their reduced environmental impact and improved energy efficiency. However, one of the major challenges associated with EV adoption is the limitation of battery capacity and the need for frequent charging. Traditional charging methods require physical connections and stationary charging, which increases downtime and reduces convenience for users.

Wireless power transfer (WPT) technology offers a promising solution to overcome these limitations by enabling the transfer of electrical energy without direct physical contact. This technology is primarily based on the principle of Electromagnetic Induction, where a time-varying magnetic field induces voltage in a nearby conductor. In a typical WPT system, a transmitter coil generates a magnetic field when supplied with alternating current, and a receiver coil captures this magnetic field to produce electrical energy.

Wireless charging systems for EVs can be broadly classified into static and dynamic charging methods. Static wireless charging is performed when the vehicle is stationary, such as in parking lots or charging stations. In contrast, dynamic wireless charging enables vehicles to charge while in motion, thereby reducing the need for large onboard batteries and minimizing range limitations.

In dynamic wireless charging systems, transmitter coils are embedded beneath the road surface, and receiver coils are installed in the vehicle chassis. As the vehicle moves over the energized road segments, electrical energy is transferred wirelessly from the infrastructure to the vehicle. This approach improves energy utilization, enhances driving range, and supports continuous vehicle operation.

Despite its advantages, wireless charging technology requires careful design considerations, including coil alignment, power transfer efficiency, system control, and safety measures. Efficient implementation of these factors is essential for achieving reliable and effective energy transfer in real-world applications.

III. RELATED WORKS

Wireless power transfer technology for electric vehicles has been widely studied to improve charging convenience and efficiency. Several research works and practical implementations have contributed to the development of both static and dynamic wireless charging systems.

1. Inductive power Transfer System:

The authors presented a wireless charging system based on inductive power transfer. Energy is transmitted from a ground-based transmitter coil to a vehicle-mounted receiver coil. The study focused on improving power transfer efficiency through proper coil design and alignment techniques.

2. Dynamic Wireless Charging Model:

A dynamic wireless charging model was proposed to enable electric vehicles to charge while in motion. The system utilized segmented transmitter coils embedded in the roadway. These coils were activated only when the vehicle passed over them, improving efficiency and reducing energy loss.

3. OLEV System- KAIST:

A significant contribution was made by Korea Advanced Institute of Science and Technology through the development of the Online Electric Vehicle (OLEV) system. This system demonstrated real-time wireless charging for public transportation. It uses embedded road infrastructure and optimized electromagnetic coupling.

4. WiTricity Technology:

Commercial advancements by WiTricity have introduced highly resonant wireless power transfer systems. These systems improve transmission distance and efficiency compared to conventional inductive methods. Their technology has been adopted in several prototype electric vehicles.

5. Elect Reon Dynamic Charging Road:

Electreon has implemented dynamic wireless charging roads. This enables continuous charging of electric vehicles while driving. Their pilot projects have demonstrated the feasibility of large-scale deployment of wireless charging infrastructure.

IV. PROPOSED SYSTEM

The proposed system focuses on the design and implementation of a wireless on-road charging mechanism for electric vehicles using inductive power transfer. The architecture consists of transmitter modules embedded in the road and receiver modules installed in the vehicle, along with control and power conditioning units.

1.System Overview

The overall system is designed to enable continuous charging of electric vehicles while in motion. It consists of two main sections:

the ground-side transmitter system and the vehicle- side receiver system. Electrical energy is wirelessly transferred through magnetic coupling between the coils, ensuring uninterrupted power supply to the vehicle battery.

2.Transmitter Unit Design

transmitter unit is embedded beneath the road surface and is responsible for generating a magnetic field. It includes a power supply, high-frequency inverter circuit, and a transmitter coil. When alternating current flows through the coil, it produces a time-varying magnetic field that serves as the medium for wireless energy transfer.

3.Receiver Unit Design

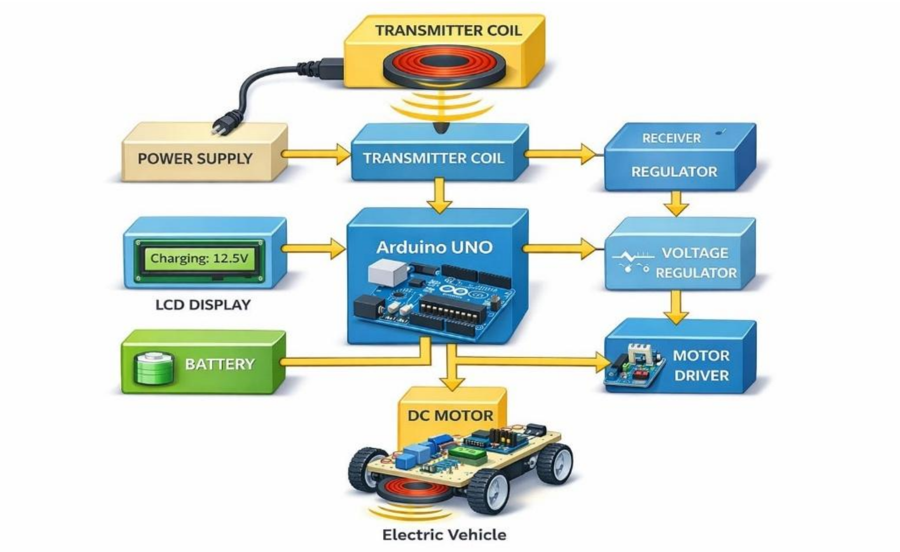
The receiver unit is mounted underneath the electric vehicle. It consists of a receiver coil, rectifier circuit, filter, and voltage regulator. The receiver coil captures the magnetic field generated by the transmitter and converts it into electrical energy. The rectifier converts AC to DC, which is then regulated and used to charge the battery.

4.Control and Monitoring System

A microcontroller-based control system (such as an Arduino platform) is used to monitor and regulate the charging process. It controls the activation of transmitter segments, manages voltage levels, and ensures safe operation.

5.System Architecture and Power Flow

The system architecture follows a structured flow of energy from the power source to the vehicle battery. Initially, electrical energy is supplied to the transmitter circuit, which generates a magnetic field. This energy is wirelessly transferred to the receiver coil, converted into usable DC power, and stored in the battery. Proper alignment between transmitter and receiver coils enhances efficiency and reduces power loss.



V. DATA COLLECTION

1.Input power data
Data is collected from the transmitter side to measure input voltage and current supplied to the system. This helps in analyzing the total power consumption and system efficiency.

2.Wireless Power Transfer Efficiency Data
Data is recorded to evaluate how efficiently power is transferred from the transmitter coil to the receiver coil. Measurements are taken at different distances and alignments.

3.Receiver Output Data
The output voltage and current at the receiver side are measured after rectification and regulation. This data helps determine the effectiveness of the charging process.

4.Coil Alignment and Distance Data
Data is collected by varying the distance and alignment between transmitter and receiver coils. This helps analyze its impact on power transfer efficiency.

5.Battery Charging Performance Data
Battery parameters such as charging voltage, charging time, and state of charge are recorded to evaluate the system's performance in real-time charging conditions.

6.Control System Data
Data from the microcontroller (Arduino) is collected, including switching signals, system status, and charging control parameters to ensure proper system operation.

7.Thermal and Safety Data
Temperature variations in coils and circuits are monitored to ensure safe operation and to prevent overheating during wireless power transfer.

VI. APPLICATION OF EMBEDDED SYSTEM DESIGN

Embedded system design plays a crucial role in the implementation and operation of the proposed wireless on- road charging system for electric vehicles. It ensures real- time control, monitoring, and efficient power management within the system.

1. System Control and Automation

The embedded system is responsible for controlling the overall operation of the wireless charging process. A microcontroller such as Arduino Uno is used to automate switching, regulate power flow, and manage system functions without human intervention.

2.Sensor Data Acquisition

Embedded systems collect real-time data from sensors such as voltage, current, and alignment sensors. This data is used to monitor system performance and ensure proper functioning of the charging mechanism.

3.Power Management and Regulation

The embedded controller regulates voltage and current levels to ensure safe and efficient power transfer. It helps prevent overcharging, power loss, and system instability during wireless energy transmission.

4.User Interface and Display System

An embedded system is used to interface with display modules such as LCD screens to show important parameters like charging status, voltage levels, and system conditions to the user.

5.Safety and Protection Mechanisms

The system incorporates safety features such as overvoltage protection, overheating detection, and fault monitoring. The embedded controller ensures immediate response to abnormal conditions to protect system components.

6.Real-Time Operation

Embedded systems enable real-time processing and quick response to changes in system conditions, such as vehicle movement or coil alignment, ensuring continuous and efficient charging.

7.System Integration

The embedded system integrates all hardware components including transmitter circuits, receiver modules, sensors, and actuators into a unified system for smooth operation.

VII. TRAINING FLOW CHART

1.Data Acquisition

Collect real-time data from sensors such as voltage current, coil alignment, and temperature.

2.Signal Conditioning

Filter and process raw sensor signals to remove noise and ensure accurate readings.

3.Data Processing

Microcontroller (Arduino/ESP32) processes sensor data and converts it into usable parameters.

4.Feature Extraction

Extract key features like power efficiency, alignment distance, and charging stability.

5.System Calibration

Adjust system parameters (coil position, frequency, voltage) for optimal performance.

6.Control Algorithm Execution

Embedded control logic regulates power transfer and charging conditions in real time.

7.Performance Monitoring

Continuously monitor system outputs such a efficiency, temperature, and power loss.

8.Feedback Adjustment

System automatically adjusts parameters based on feedback to improve efficiency.

9.System Optimization

Fine-tune embedded settings for stable and efficient wireless charging.

VIII.TESTING AND VALIDATION

Testing and Validation – Performance Analysis Testing and validation are essential stages in the development of the wireless on-road charging system for electric vehicles. These stages that the system operates efficiently and provides reliable wireless power transfer under real-time conditions.

1.System Testing

System testing is conducted to evaluate whether all hardware and embedded components of the system function correctly. The testing process includes verifying coil performance, power transfer efficiency, sensor operation, and system stability.

1.1 Hardware Testing

Hardware testing ensures that each physical component operates properly.

Microcontroller Testing

The microcontroller (Arduino/ESP32) is tested to confirm that it correctly processes sensor inputs and controls the wireless power transfer system.

Transmitter Coil Testing

The transmitter coil is tested to ensure stable magnetic field generation and efficient power transmission.

Receiver Coil Testing

The receiver coil is tested to verify proper power reception and conversion into usable electrical energy.

Power Circuit Testing

The power circuit is tested for voltage stability, current regulation, and safe operation.

2.Pre-Charging Measurement

before activating the wireless charging system, the input and output power levels are measured. Improper alignment and distance between coils result in reduced efficiency.

Example measurement:

Input Power = 1000 W
Output Power before alignment = 600 W

Post-Charging Measurement

After proper alignment and system adjustment, the output power is measured again.

Example measurement:

Output Power after alignment = 850 W

3.validation of the system

Validation ensures that they system performs reliable under different environment condition.

3.1Functional Validation

Functional validation checks whether the system performs all intended operations correctly.

- ✓ Detecting vehicle presence using sensors.
- ✓ Activating wireless power transfer system.
- ✓ Maintaining proper coil alignment during charging.
- ✓ Regulating power flow using embedded controller.
- ✓ Displaying system parameters on LCD/monitoring unit.

3.2Performance Validation

Performance validation evaluates how well the system operates in real-time conditions.

Key parameters analyzed include:

- ✓ Power transfer efficiency
- ✓ Charging time for the vehicle
- ✓ Alignment accuracy between transmitter and receiver coils
- ✓ Power losses during transmission
- ✓ System response time

3.3Reliability Validation

Reliability testing ensures that the system can operate continuously without failure. Multiple charging cycles are performed to confirm stable and consistent performance.

3.4Data Analysis Using Bar Chart

A bar chart is used to visually compare power output before and after proper coil alignment in the wireless charging system.

Parameters in the Bar Chart

X-axis: Charging Condition

Before Alignment
After Alignment

Y-axis: Power Output (Watts)
Example Data
Condition
Power Output (W)
Before Alignment 600 W
After Alignment 850 W

3.5Interpretation of Results

The analysis of experimental data shows that proper alignment of transmitter and receiver coils has a significant impact on wireless power transfer efficiency.

As a result:

- ✓ Power transfer efficiency increases
- ✓ Energy losses are reduced
- ✓ System performance improves
- ✓ Reliability of charging system is enhanced

3.6Real-Time Impact of the System

- ✓ The real-time implementation of the wireless charging system offers several advantages:
- ✓ Enables dynamic charging of electric vehicles
- ✓ Reduces dependency on stationary charging stations

Minimizes energy loss during transmission Improves overall efficiency of electric vehicle operation

Testing Process

Pre-Charging Test
Measure and record power transfer output before proper coil alignment.
Post-Charging Test
Measure and record power output after aligning transmitter and receiver coils.
System Validation
Compare expected wireless power transfer efficiency with actual system performance.
Data Collection
Collect data on voltage, current, coil distance, alignment, and power output during operation.

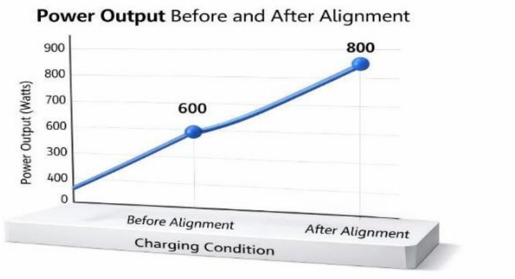
CONDITION	POWER OUTPUT (W)
Before Alignment	600 W
After Alignment	850 W

Result Analysis

The bar chart clearly shows that power output increases significantly after proper alignment of transmitter and receiver coils.

Interpretation of Results

The analysis of experimental data demonstrates that coil alignment plays a crucial role in wireless power transfer efficiency. With proper alignment, energy transfer becomes more effective and power losses are reduced.



IX. CONCLUSION

The proposed wireless on-road charging system using an embedded system provides an efficient and innovative solution for electric vehicle charging. The system successfully demonstrates contactless power transfer through inductive coupling between transmitter and receiver coils. The integration of a microcontroller ensures proper control, monitoring, and regulation of power flow during operation

.

Experimental results show that proper alignment of coils significantly improves power transfer efficiency and reduces energy losses. The system operates reliably under different conditions and provides stable performance in real-time applications. Additionally, the embedded system design enhances system safety, flexibility, and ease of implementation.

Overall, the proposed system reduces the dependency on conventional charging methods and supports the advancement of sustainable transportation. It offers a promising approach for future smart transportation systems and large-scale deployment of wireless charging infrastructure.

X. FUTURE WORK

The proposed wireless on-road charging system can be further enhanced by integrating advanced technologies and improving system efficiency. Future developments can focus on the following areas:

1.**Dynamic Charging Implementation**: The system can be extended to support dynamic wireless charging, allowing electric vehicles to charge while in motion, thereby reducing dependency on large battery storage.
2.**Improved Power Transfer Efficiency:** Future work can focus on optimizing coil design, alignment techniques, and power electronics to enhance energy transfer efficiency and reduce transmission losses.
3.**Integration with Smart Grid:** The system can be integrated with smart grid technology to enable efficient energy distribution, real-time monitoring, and better load management.
4.**IoT-Based Monitoring and Control:** Incorporating IoT technology can enable remote monitoring, fault detection, and real-time control of the charging system through cloud-based platforms.
5.**Automatic Alignment Mechanism:** Future systems can include automatic alignment techniques using sensors and actuators to improve power transfer efficiency without manual adjustment.
6.**Renewable Energy Integration:**
The system can be powered using renewable energy sources such as solar or wind energy to make the charging process more sustainable and environmentally friendly.
7. **Scalability for Public Infrastructure:** The proposed system can be scaled for large-scale deployment in highways, parking areas, and urban roads to support widespread adoption of electric vehicles.
8.**Enhanced Safety Mechanisms:** Future improvements can include advanced safety features such as foreign object detection, thermal protection, and electromagnetic field shielding.

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