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Advanced Wireless Charging for Electric Vehicles

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Abstract: The rapid adoption of electric vehicles (EVs) has intensified the demand for efficient, safe, and user-friendly charging technologies. Conventional plug-in charging methods introduce limitations such as long charging times, physical connector wear, and range anxiety. This paper presents an advanced dynamic wireless charging system for electric vehicles based on inductive power transfer principles. The proposed system enables contactless energy transfer between road-embedded transmitter coils and vehicle-mounted receiver coils while the vehicle is stationary or in motion. The system integrates power electronics, resonant coupling, sensing units, microcontroller-based control, and IoT monitoring to enhance charging efficiency and automation. Experimental evaluation demonstrates reliable wireless power transfer, effective vehicle detection, and real-time system monitoring. The proposed approach supports the development of sustainable and intelligent transportation infrastructure.

Keywords: Electric vehicles, wireless power transfer, inductive charging, dynamic charging, IoT-based monitoring

I. INTRODUCTION

The transportation sector contributes significantly to global energy consumption and greenhouse gas emissions, accounting for a major share of fossil fuel usage worldwide. With increasing concerns regarding climate change, air pollution, and depletion of natural resources, electric vehicles (EVs) have emerged as a sustainable and environmentally friendly alternative to conventional internal combustion engine vehicles. EVs offer advantages such as zero tailpipe emissions, reduced operating costs, and compatibility with renewable energy sources.

Despite these benefits, the widespread adoption of EVs is constrained by several challenges related to charging infrastructure. Conventional plug-in charging methods require vehicles to remain stationary for extended periods, leading to increased charging downtime and inconvenience for users. Additionally, frequent use of physical connectors results in mechanical wear, safety concerns in harsh environments, and higher maintenance costs. These limitations contribute to range anxiety, which remains a significant barrier to large-scale EV adoption.

Wireless power transfer (WPT) technology provides a promising solution by enabling contactless energy transfer through electromagnetic fields. By eliminating physical connectors, wireless charging systems enhance safety, reduce maintenance, and improve user convenience. Advanced wireless charging systems can be deployed in parking areas, residential garages, and public infrastructure without the need for manual cable handling.

Dynamic wireless charging further extends these advantages by allowing electric vehicles to charge while in motion. In such systems, transmitting coils embedded beneath road surfaces generate alternating magnetic fields that transfer power to receiver coils mounted on vehicles. This approach reduces dependence on large battery packs, minimizes charging downtime, and supports continuous vehicle operation. The work presented in this paper focuses on the design and implementation of an advanced wireless charging system for electric vehicles, emphasizing efficiency, automation, and real-time monitoring to support future intelligent transportation systems.

II. LITERATURE SURVEY

[1] Kavitha M.S developed a wireless power transmission system for electric vehicles with optimized hardware integration. The system achieved reduced voltage and current ripple using low DC-link and filter capacitance values.

[2] Mou, Xiaolin, studied inductively coupled wireless power transmission for electric automobiles. The work highlights the applicability of wireless charging for different EV categories based on Tesla's wireless power concept.

[3] Aziz, Muhammad, and Donateo, T. discussed an advanced wireless charging system for automobiles. The study emphasizes reduced battery size, lower environmental impact, and improved vehicle autonomy through wireless charging.

[4] Lukic, Srdjan, and Pantic Zeljko proposed a static wireless charging station using inductive power transfer. The system improves safety and convenience compared to conventional plug-in charging methods.

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[5] Shanmugam, Yuvaraja presented a systematic review of static and dynamic wireless charging systems. The paper compared technologies, benefits, and challenges such as efficiency, alignment, and infrastructure cost.

[6] Yang, Yuanwang proposed an adaptive control strategy for dynamic wireless charging systems. The method balances user satisfaction, power cost, and system stability under varying road and vehicle conditions.

[7] Zhang, Xian analyzed coil design and efficiency for dynamic wireless charging. The study demonstrated improved coupling and efficiency under vehicle misalignment conditions.

[8] Bianchi, Tommaso introduced QEVSEC, a secure and lightweight authentication protocol for dynamic wireless charging. The protocol ensures secure billing and privacy with minimal computational overhead.

[9] Nguyen, Dinh Hoa proposed an optimization model for planning dynamic wireless charging infrastructure. The model reduces deployment cost and improves reliability through optimal charger placement and renewable energy integration.

[10] Chevinly, Javad presented a GaN-based high-power inverter for wireless EV charging. The inverter achieves high efficiency and low harmonic distortion at high switching frequencies.

III. SYSTEM ARCHITECTURE

The proposed advanced wireless charging system is designed to support both stationary and dynamic electric vehicle charging using inductive power transfer principles. The system architecture comprises a power supply unit, transmitter section, receiver section, sensing module, control unit, and IoT communication interface.

The power supply unit converts the available AC mains voltage into a regulated DC voltage suitable for high-frequency power conversion. The transmitter section includes a transistor-based inverter and a transmitting coil that generates an alternating magnetic field. The receiver section consists of a receiving coil mounted beneath the electric vehicle, followed by rectification and filtering stages to provide DC power for battery charging.

A microcontroller-based control unit coordinates system operation by processing sensor inputs, controlling power flow, updating display information, and managing communication with the IoT module. The sensing module, implemented using infrared sensors, detects vehicle presence and ensures that charging is activated only when a vehicle is correctly positioned. The IoT interface enables real-time monitoring and future integration with smart grid and billing systems.

A. Block Diagram Description

Fig. 1 illustrates the block diagram of the dynamic wireless charging system. The main power supply is stepped down and rectified to provide DC power. A transistor-based inverter converts DC to high-frequency AC to drive the transmitter coil. The receiver coil captures the magnetic flux and converts it back into electrical energy for charging the EV battery. A microcontroller manages sensing, control, display, and IoT communication.

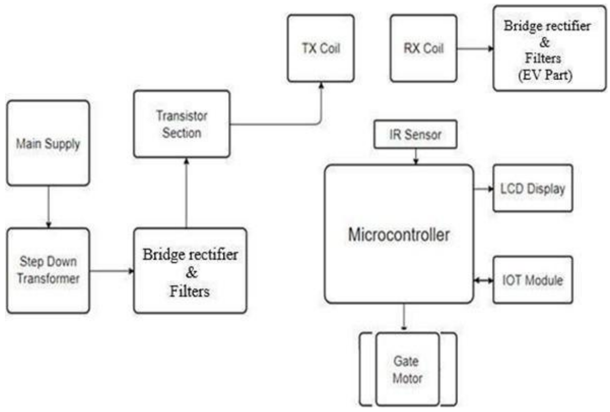

Fig. 1. Block diagram of the wireless charging system

IV. METHODOLOGY

The operation of the proposed wireless charging system follows a structured methodology to ensure safe, efficient, and automated charging of electric vehicles. The process begins with stepping down the AC mains voltage using a transformer to a lower and safer voltage level. This AC voltage is then converted into DC using a bridge rectifier and filter capacitors to obtain a stable and ripple-free DC supply.

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The regulated DC voltage is fed into a transistor-based switching circuit that generates high-frequency AC required for inductive power transfer. Operating at high frequency improves magnetic coupling efficiency between the coils. The transmitter coil, energized by this high-frequency AC, produces an alternating magnetic field in its vicinity.

When an electric vehicle is positioned above the transmitter coil, the receiver coil mounted beneath the vehicle captures the magnetic flux through electromagnetic induction. The induced AC voltage at the receiver side is rectified and filtered to obtain DC power suitable for charging the vehicle battery or powering the onboard load.

An infrared sensor continuously monitors the presence and position of the vehicle within the charging zone. Upon detection, the microcontroller activates the charging circuit and ensures controlled power transfer. The microcontroller also manages system logic, monitors charging status, and updates system information on the LCD display for user awareness.

To enhance system intelligence and accessibility, an IoT module is integrated for remote monitoring and data logging. This enables real-time observation of charging activity, system status, and fault conditions. The IoT interface also supports future expansion toward automated billing, smart grid integration, and centralized monitoring in smart transportation infrastructure.

V. HARDWARE AND SOFTWARE IMPLEMENTATION

The hardware implementation of the proposed system consists of several key components working together to achieve efficient wireless charging. A step-down transformer reduces the mains voltage, while a bridge rectifier and filter capacitors provide a stable DC supply. The BD139 transistor is used in the switching stage to generate high-frequency AC for driving the transmitter coil. Copper coils are employed for both transmission and reception of power.

A NodeMCU microcontroller serves as the central control unit, interfacing with the infrared sensor, LCD display, gate motor, and IoT module. The infrared sensor detects vehicle presence, while the LCD provides real-time system feedback. The gate motor demonstrates automation and controlled access within the prototype setup.

The software is developed using the Arduino IDE, which provides an efficient environment for writing, compiling, and uploading control programs. The firmware handles sensor data acquisition, control logic execution, display updates, and IoT communication, ensuring coordinated system operation.

VI. RESULTS AND DISCUSSION

An electric vehicle in a dynamic wireless charging system involves the transfer of electrical energy from a charging source (embedded in the road) to the electric vehicle while it is in motion. This system typically uses magnetic induction. Coils are placed in the road and in the vehicle. When the vehicle passes over the charging coils, an alternating current flows through the road coils, creating a magnetic field. This field induces a current in the vehicle's coils, which then charges the battery. The efficiency of this system depends on several factors, including the distance between the coils, the alignment of the coils, and the speed of the vehicle. The primary result is the continuous charging of the electric vehicle's battery while driving, which extends the vehicle's range and reduces the need for frequent stops at charging station for electric vehicles contribute to its operation and efficiency. The system’s design must consider the power transfer rate, which is influenced by the frequency of the alternating current, the strength of the magnetic field and the size and the configuration of the coils. The alignment of the coils is crucial; precise positioning ensures optimal energy transfer, and any misalignment can significantly reduce efficiency.

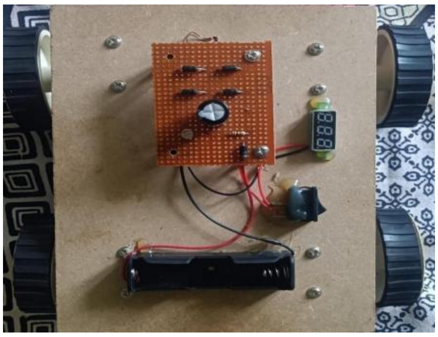

Fig. 2. Electric Vehicle

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charging status and system operation, enhancing user interaction. IoT-based monitoring enabled remote observation of charging activity, indicating readiness for integration with smart infrastructure.

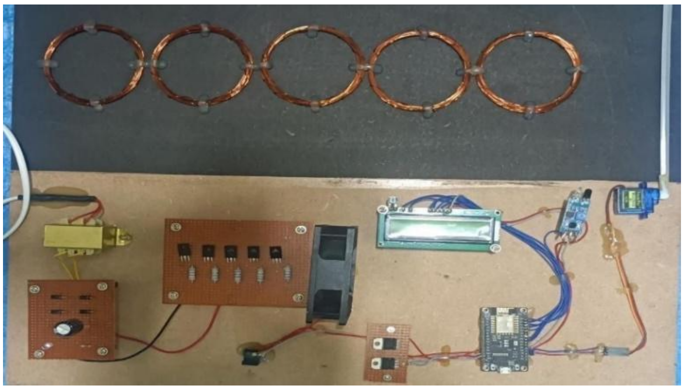

Fig. 3. Charging Lane

The charging lane model explains how the electric vehicle receives power while moving through a dedicated lane embedded with dynamic wireless charging coils. The charging lane contains a series of transmitting coils embedded beneath the road surface.

Overall, the experimental results validate the feasibility of the proposed wireless charging system for electric vehicle applications and demonstrate its potential for further enhancement and large-scale deployment.

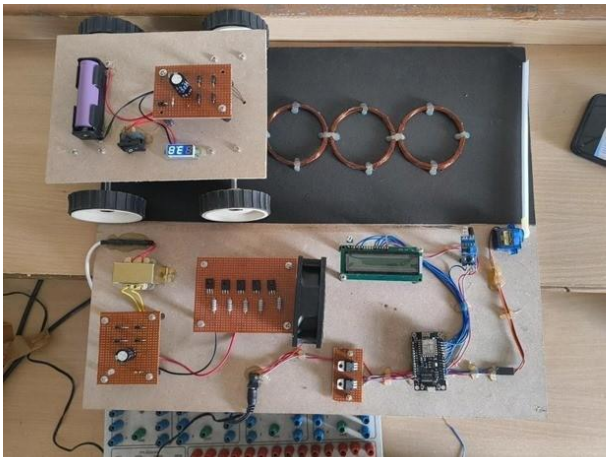

Fig. 4. Experimental setup of the wireless charging system

The prototype shows stable power transfer between the transmitting coils on the road and the receiving coils in the vehicles, proving the concept's feasibility. It helped reduce dependency on static charging stations and minimized charging time, while ensuring continuous energy supply. The results indicate that this system can improve driving range, reduce battery size requirements, and enhance the practicality and convenience of electric vehicles. With further development, it has strong potential to be integrated into future smart transportation infrastructure.

VII. APPLICATIONS

The proposed wireless charging system can be applied in smart highways, public transportation systems, electric parking facilities, autonomous vehicle charging lanes, and smart city infrastructure. Dynamic wireless charging enables electric vehicles to charge while in motion, significantly reducing range anxiety and charging downtime.
Public transportation systems such as electric buses can utilize wireless charging at stops and terminals for opportunity charging, improving operational efficiency. In parking facilities, wireless charging pads provide convenient and automatic charging without physical connectors. The system is also suitable for autonomous and shared mobility vehicles, where contactless charging supports seamless operation. Integration with IoT platforms further enables smart energy management and monitoring in future smart cities.

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VIII. LIMITATIONS

Despite its advantages, the system faces several challenges. The high initial infrastructure cost associated with embedding transmitter coils and power electronics can limit large-scale deployment. Power transfer efficiency is sensitive to coil alignment and air gap variations, especially in dynamic charging scenarios.

Electromagnetic interference and compliance with safety standards require careful system design and shielding. Additionally, scalability to high-power charging levels remains a challenge, as inductive charging is currently more suitable for low-to-medium power applications. Lack of standardization across different vehicle platforms may also affect widespread adoption.

IX. CONCLUSION AND FUTURE SCOPE

The evolution of electric vehicles and their supporting infrastructure. By eliminating physical connectors, wireless charging offers a safer, more convenient, and user-friendly method of power transfer. Recent progress in resonant inductive coupling, magnetic alignment, and dynamic wireless charging techniques has enabled faster charging, higher energy transfer efficiency, and the possibility of charging vehicles while in motion.

Furthermore, integrating wireless charging systems with smart grids enables efficient energy management through load balancing and reduced dependence on fossil fuels. Although challenges such as high implementation cost, infrastructure development, safety concerns, and standardization remain, continuous research and strong collaboration between academia and industry are driving the technology forward. Overall, wireless charging especially dynamic wireless charging has the potential to revolutionize the EV ecosystem by reducing range anxiety, lowering battery size requirements, and supporting cleaner, energy-efficient transportation systems.

Future research in wireless charging for electric vehicles will primarily focus on the large-scale deployment of dynamic wireless charging systems, allowing vehicles to charge continuously while traveling on specially equipped roads. This approach can significantly reduce charging downtime and improve driving range. Advances in coil design, magnetic materials, power electronics, and control strategies are expected to further improve energy transfer efficiency, misalignment tolerance, and operational safety.

In addition, integration with smart grids, renewable energy sources, and IoT-based monitoring systems will enhance sustainability and enable real-time diagnostics, automated billing, and efficient energy management. Standardization of wireless charging protocols across manufacturers will be crucial for interoperability and widespread adoption. In the long term, wireless charging technology will extend beyond passenger vehicles to support public transportation, commercial fleets, and autonomous vehicles, playing a key role in the development of smart cities and sustainable mobility.

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