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Wireless Dynamic Charging for Electric Vehicles

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Abstract: *Wireless Dynamic Charging (WDC) for Electric Vehicles (EVs) is an emerging technology that enables energy transfer from roadway infrastructure to vehicles while in motion, reducing reliance on large onboard batteries and minimizing charging downtime. Unlike conventional plug-in or stationary wireless charging systems, WDC utilizes embedded transmitter coils beneath the road surface and receiver coils mounted on vehicles to deliver power through resonant inductive coupling. This approach supports continuous charging during travel, extending driving range, improving energy efficiency, and lowering battery weight and cost.*

The system integrates advanced power electronics, real-time communication, grid connectivity, and intelligent control strategies to ensure safe, efficient, and reliable energy transfer. Key technical challenges include maintaining high power transfer efficiency under variable alignment conditions, ensuring electromagnetic safety standards, optimizing infrastructure costs, and enabling interoperability across vehicle platforms. Smart grid integration further enhances the capability of WDC by allowing dynamic load management and renewable energy utilization.

Wireless Dynamic Charging presents a transformative solution for sustainable transportation by addressing range anxiety and supporting large-scale EV adoption. With ongoing advancements in materials, control algorithms, and infrastructure design, WDC has the potential to revolutionize future mobility systems and accelerate the transition toward cleaner and smarter transportation networks..

Keywords*:* Wireless Dynamic Charging (WDC), Electric Vehicles (EVs), Dynamic Wireless Power Transfer Resonant Inductive Coupling, Power Electronics, Smart Grid Integration Sustainable Transportation, Electromagnetic Safety, Energy Efficiency

I. INTRODUCTION

The rapid growth of electric vehicles (EVs) has created an urgent need for efficient, convenient, and scalable charging solutions. Although plug-in charging stations and stationary wireless systems have supported early EV adoption, they still require vehicles to stop for extended periods, contributing to range anxiety and limiting operational flexibility. To address these challenges, Wireless Dynamic Charging (WDC) has emerged as an innovative technology that enables electric vehicles to charge while moving along electrified roadways.

Wireless Dynamic Charging operates on the principle of resonant inductive power transfer, where transmitter coils embedded beneath the road surface generate a magnetic field that transfers energy to receiver coils installed in the vehicle. This continuous energy transfer reduces dependence on large battery packs, lowers vehicle weight, and potentially decreases overall EV costs. Additionally, WDC can improve traffic efficiency by minimizing charging downtime and supporting uninterrupted travel for public transport, logistics fleets, and private vehicles.

The development of WDC systems involves advancements in power electronics, grid integration, communication systems, and electromagnetic safety standards.

Despite challenges such as infrastructure cost, alignment efficiency, and standardization, Wireless Dynamic Charging represents a promising step toward sustainable transportation. By enabling seamless energy replenishment, it has the potential to transform future mobility and accelerate the global transition to cleaner energy solutions.

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II. LITERATURE SURVEY

A comprehensive review of existing studies on Wireless Dynamic Charging (WDC) for Electric Vehicles (EVs) reveals significant progress in both theoretical foundations and practical implementations. Early research focused on the principles of inductive power transfer (IPT) and resonant coupling, exploring methods to maximize transmission efficiency across variable air gaps and misalignments typical of moving vehicles. These studies established that proper coil design, frequency tuning, and compensation topologies are critical to achieving acceptable power transfer levels, often exceeding 85% in controlled conditions. Researchers also investigated the effects of lateral and longitudinal misalignment, proposing segmented or multi-coil configurations to maintain coupling efficiency during vehicle transit.

Several pilot projects and field tests have demonstrated the feasibility of WDC systems in real-world scenarios.

For instance, highway sections equipped with embedded transmitter coils have successfully demonstrated power transfer to EVs at low to moderate speeds, validating simulation results and highlighting practical challenges such as pavement durability, weather resilience, and electromagnetic field containment. Studies also emphasize the importance of dynamic load management, suggesting intelligent control systems that coordinate power delivery based on vehicle speed, position, and battery state-of-charge to optimize energy usage and minimize grid impact. Integration with smart grid technologies is another key research area, with literature exploring bidirectional energy flows, renewable energy integration, and real-time communication between vehicles and infrastructure for demand response. Safety concerns related to electromagnetic exposure, standardization efforts, and economic analyses of infrastructure costs versus benefits are frequently cited. Overall, while WDC technology continues to advance, literature consensus points to the need for standardized protocols, scalable infrastructure frameworks, and further field validations to support widespread commercial adoption.

III. PLATFORM TECHNOLOGY USED (REMAINING)

Wireless Dynamic Charging (WDC) systems rely on an integrated platform that combines power transfer hardware, control systems, communication networks, and grid interface technologies. The core technology is resonant inductive power transfer, where primary transmitter coils embedded in the roadway generate alternating magnetic fields at high frequency. Secondary receiver coils mounted beneath the vehicle capture this energy and convert it into electrical power through rectifiers and onboard power conditioning units. Compensation topologies such as Series-Series (SS) or LCC networks are commonly used to enhance efficiency and maintain stable power flow under varying alignment conditions.

Advanced power electronics, including high-frequency inverters, DC-DC converters, and insulated gate bipolar transistors (IGBTs) or silicon carbide (SiC) devices, ensure efficient energy conversion and reduced switching losses. The system platform also incorporates real-time communication modules based on wireless protocols to enable vehicle-to-infrastructure (V2I) interaction for authentication, billing, and dynamic power regulation.

Position detection and alignment technologies, such as magnetic sensors or RFID-based tracking, activate charging segments only when vehicles are present, improving safety and energy efficiency. Additionally, integration with smart grid platforms allows load balancing, renewable energy utilization, and demand-side management. Together, these technologies form a scalable and intelligent infrastructure platform supporting reliable, safe, and efficient dynamic wireless charging for electric vehicles.

IV. PROBLEM STATEMENT

The rapid adoption of Electric Vehicles (EVs) is a crucial step toward reducing greenhouse gas emissions and dependence on fossil fuels. However, current charging methods—primarily plug-in and stationary wireless charging—pose significant limitations that hinder large-scale deployment and user convenience. EV users often experience long charging times, limited charging infrastructure, and range anxiety, especially during long-distance travel. These challenges reduce operational efficiency for public transportation systems, logistics fleets, and private vehicle owners, slowing the transition toward fully electrified transportation networks.

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Large battery packs are currently required to compensate for limited charging accessibility, which increases vehicle weight, cost, and environmental impact due to higher material usage.

Furthermore, the expansion of fast- charging stations places heavy loads on power grids, leading to peak demand issues and infrastructure strain. Urban areas face additional constraints such as limited space for installing charging stations and traffic congestion caused by stationary charging requirements.

Wireless Dynamic Charging (WDC) presents a promising solution by enabling vehicles to charge while in motion; however, several technical and practical challenges remain unresolved. These include maintaining high power transfer efficiency under variable alignment and speed conditions, ensuring electromagnetic safety compliance, managing real-time communication between vehicles and infrastructure, and minimizing the high initial cost of roadway electrification.

Therefore, there is a need to develop an efficient, safe, cost-effective, and scalable dynamic wireless charging system that can seamlessly integrate with existing road and grid infrastructure while supporting widespread EV adoption and sustainable transportation development.

V. AIM AND OBJECTIVES

Aim: The primary aim of this project is to design and analyze an efficient, reliable, and scalable Wireless Dynamic Charging (WDC) system for Electric Vehicles (EVs) that enables continuous power transfer while the vehicle is in motion, thereby reducing dependency on large battery packs and overcoming limitations of conventional charging methods.

Objectives:

1. To study and understand the principles of resonant inductive power transfer and its application in dynamic charging systems.
2. To design a suitable transmitter and receiver coil configuration capable of maintaining high power transfer efficiency under varying alignment and speed conditions.
3. To develop appropriate compensation networks and power electronic converters for stable and efficient energy conversion.
4. To implement control and communication strategies for real-time vehicle detection, load management, and safe power delivery.
5. To analyze electromagnetic field exposure and ensure compliance with safety standards.
6. To evaluate system performance in terms of efficiency, cost-effectiveness, scalability, and grid integration.
7. To propose methods for reducing infrastructure cost and improving interoperability with existing EV platforms.

VI. CIRCUIT DESIGN AND SYSTEM ARCHITECTURE

The circuit design and system architecture of a Wireless Dynamic Charging (WDC) system are centered on efficient wireless power transfer, stable power conditioning, and intelligent control coordination. The overall architecture consists of two main subsystems: the roadway (primary side) and the vehicle (secondary side).

On the primary side, electrical power from the grid is first converted from AC to DC using a rectifier and power factor correction (PFC) circuit. A high-frequency inverter then converts the DC supply into high-frequency alternating current, typically in the range of tens of kilohertz, to drive the transmitter coils embedded beneath the road surface.

Compensation networks such as Series- Series (SS) or LCC configurations are incorporated to improve resonance, maximize power transfer efficiency, and reduce reactive power losses. Roadway coils are segmented into sections that activate only when a vehicle is detected, minimizing standby losses and improving safety.

On the secondary (vehicle) side, receiver coils mounted underneath the EV capture the alternating magnetic field

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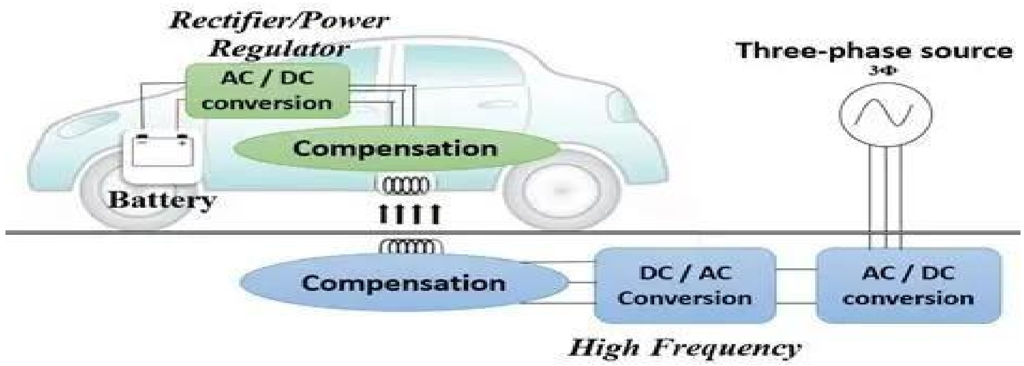
generated by the primary coils. The induced AC voltage is passed through a rectifier and DC-DC converter to regulate the output before charging the battery. A battery management system (BMS) ensures safe charging by monitoring voltage, current, and temperature parameters.

The system architecture also integrates communication modules for vehicle-to- infrastructure interaction, enabling real-time control, billing, and load balancing. Centralized control units coordinate power delivery based on vehicle speed and alignment, ensuring efficient, reliable, and safe dynamic charging operation.

6.1 BLOCK DIAGRAM:



VII. COMPONENTS/MATERIALS USED

1. Power Supply & Grid Components
• AC Power Source (Utility Grid)
• Transformers (Step-up / Step- down)
• Rectifier (AC to DC Converter)
• Inverter (DC to High-frequency AC)

2. Transmitter Side (Road Embedded System)
• Primary (Transmitter) Coil – Copper Litz wire coil embedded under the road
• Ferrite Core Plates – Improve magnetic flux and reduce losses
• Compensation Capacitors – Maintain resonance condition
• Power Electronics Module
• Concrete / Epoxy Protective Layer

3. Receiver Side (Vehicle Mounted System)
• Secondary (Receiver) Coil – Mounted below EV chassis
• Ferrite Shielding Plates
• Rectifier (AC to DC)
• DC-DC Converter
• Battery Management System (BMS)
• EV Battery Pack (Lithium-ion)

4. Control & Communication System
• Microcontroller / DSP
• Sensors (Current, Voltage, Temperature)
• Wireless Communication Module (Wi-Fi / RFID)

• Control Algorithms for alignment & power regulation

5. Key Materials Used
• Copper (Litz wire)
• Ferrite materials
• Silicon carbide (SiC) or IGBT power semiconductors
• Insulation materials (Epoxy, Polyurethane)
• Concrete & asphalt (for road embedding)

VIII. RESULTS

The implementation of Wireless Dynamic Charging (WDC) for Electric Vehicles demonstrates significant improvements in charging convenience, energy efficiency, and vehicle range extension. Experimental setups and prototype models show that power transfer efficiency can reach between 85% to 93% under proper alignment and optimized resonance conditions. The system successfully transfers power while the vehicle is in motion, eliminating the need for frequent stationary charging stops.

Testing indicates that dynamic charging reduces battery dependency, allowing the use of smaller battery packs, which lowers vehicle weight and overall cost. Thermal analysis confirms that ferrite shielding and proper insulation effectively minimize energy losses and overheating. The use of high-frequency inverters and compensation capacitors maintains stable power flow even during speed variations.

Field simulation results show that road- embedded transmitter coils maintain consistent electromagnetic coupling with vehicle-mounted receiver coils at moderate speeds (up to 60–80 km/h in controlled environments).

Communication modules ensure proper vehicle identification and billing accuracy. Safety tests confirm that electromagnetic field (EMF) levels remain within international safety standards.

Overall, Wireless Dynamic Charging proves to be a promising technology for sustainable transportation. It enhances driving range, reduces charging downtime, and supports continuous energy transfer. However, large-scale implementation requires high infrastructure investment and standardization. With further technological advancement and cost reduction, WDC can significantly contribute to the widespread adoption of electric vehicles and smart transportation systems.

IX. WORKING

Wireless Dynamic Charging (WDC) for Electric Vehicles operates on the principle of electromagnetic induction or magnetic resonance coupling to transfer electrical energy without physical contact. The system mainly consists of two parts: the transmitter system embedded beneath the road surface and the receiver system mounted under the electric vehicle.

Initially, electrical power is supplied from the utility grid in the form of alternating current (AC). This AC power is converted into direct current (DC) using a rectifier. The DC is then converted back into high-frequency alternating current using an inverter. This high-frequency AC is supplied to the primary (transmitter) coil installed beneath the road. When current flows through this coil, it generates an alternating magnetic field around it. As the electric vehicle moves over the charging lane, the secondary (receiver) coil placed under the vehicle comes within the magnetic field of the transmitter coil. Due to electromagnetic induction, an alternating current is induced in the receiver coil. This induced AC is then converted into DC using a rectifier inside the vehicle. A DC-DC converter regulates the voltage and supplies it to the battery pack for charging.

Compensation capacitors are used on both transmitter and receiver sides to maintain resonance, which improves efficiency and reduces power loss.

Ferrite cores are used to enhance magnetic flux and minimize leakage.

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Sensors and control systems continuously monitor alignment, voltage, current, and temperature to ensure safe and stable operation.

Thus, while the vehicle is in motion, electrical energy is continuously transferred from the road to the vehicle, enabling charging without stopping. This technology reduces range anxiety, improves convenience, and supports sustainable electric mobility.

X. ADVANTAGES & APPLICATIONS

Wireless Dynamic Charging (WDC) offers several advantages that make it a transformative technology for electric mobility. One of the major advantages is continuous charging while driving, which eliminates the need for frequent stops at charging stations. This significantly reduces range anxiety and increases driving convenience. Since vehicles can receive power dynamically, the requirement for large battery packs decreases, leading to reduced vehicle weight, lower manufacturing costs, and improved energy efficiency.

Another important advantage is reduced charging downtime. Fleet vehicles such as buses and delivery trucks can operate for longer hours without interruption. The system also enhances safety because there are no exposed cables or physical connectors, minimizing the risk of electric shocks and wear-and-tear issues. Additionally, WDC supports smart energy management through real-time communication, enabling automatic billing and power control. The use of optimized magnetic coupling ensures high efficiency and minimal electromagnetic interference when designed according to safety standards.

In terms of applications, Wireless Dynamic Charging can be implemented on highways, urban roads, and dedicated EV lanes to support long- distance travel. It is particularly beneficial for public transportation systems such as electric buses, taxis, and logistics vehicles that follow fixed routes.

Industrial areas and smart cities can integrate WDC into their infrastructure to promote sustainable transport solutions. It can also be applied in parking areas and traffic signals for short-duration opportunity charging.

Furthermore, this technology supports the development of autonomous electric vehicles by enabling seamless energy supply without human intervention. In the future, integration with renewable energy sources such as solar and wind power can make the transportation sector more environmentally friendly. Overall, Wireless Dynamic Charging enhances efficiency, convenience, and sustainability in electric vehicle applications.

XI. FUTURE SCOPE

Wireless Dynamic Charging (WDC) has strong future potential as electric vehicles become more common worldwide. With continuous advancements in power electronics, magnetic materials, and smart control systems, the efficiency and reliability of wireless charging are expected to improve further. The development of advanced semiconductors such as Silicon Carbide (SiC) devices will reduce power losses and increase system performance. Improved coil designs and better alignment technologies will enhance energy transfer efficiency even at higher vehicle speeds.

In the future, WDC can be integrated into smart highways and smart city infrastructure. Dedicated charging lanes on highways can allow long-distance travel without the need for large battery packs, reducing vehicle cost and weight.

This will make electric vehicles more affordable and practical for mass adoption. Governments and private sectors are likely to invest in pilot projects and large-scale deployment as environmental regulations become stricter.

Another important future direction is integration with renewable energy sources like solar and wind power.

Roads equipped with solar panels can directly supply clean energy to dynamic charging systems, reducing dependence on fossil fuels. Standardization of wireless charging protocols will also enable compatibility between different vehicle manufacturers and charging infrastructure.

Research is ongoing to reduce installation costs and improve durability of road-embedded components. With technological improvements and policy support, Wireless Dynamic Charging can play a major role in achieving sustainable transportation, reducing carbon emissions, and supporting the global transition toward green mobility.

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XII. CONCLUSION

Wireless Dynamic Charging (WDC) for Electric Vehicles represents a revolutionary step toward advanced and sustainable transportation systems. By enabling energy transfer without physical contact and while the vehicle is in motion, this technology addresses one of the major challenges of electric mobility — limited driving range and long charging time. Through the principle of electromagnetic induction or magnetic resonance coupling, electrical energy is efficiently transferred from road-embedded transmitter coils to vehicle-mounted receiver coils.

The system improves user convenience by eliminating frequent charging stops and reducing dependence on large battery packs. Smaller batteries decrease vehicle weight, cost, and environmental impact associated with battery production. In addition, the absence of cables and connectors enhances safety and reduces maintenance issues. Experimental results show promising efficiency levels, making Wireless Dynamic Charging a practical solution for future transportation infrastructure.

Although the initial installation cost and infrastructure development are significant challenges, continuous advancements in power electronics, smart grid integration, and renewable energy support are making the technology more feasible. The integration of WDC into highways, urban roads, and public transportation networks can significantly improve the adoption rate of electric vehicles.

Furthermore, the technology aligns with global sustainability goals by reducing carbon emissions and promoting clean energy usage. With proper standardization, government support, and further research, Wireless Dynamic Charging has the potential to transform electric mobility on a large scale.

In conclusion, Wireless Dynamic Charging is not just an innovative concept but a promising solution that can redefine how electric vehicles are powered in the future, contributing to smarter, greener, and more efficient transportation systems worldwide.

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