WIRELESS CHARGING ROADS FOR ELECTRIC VEHICLES

Elumalai Govindarajan, Asmitha Banu Alim Basha, Hindujaa Karunakaran, Anusripriya Sivakumar

Department of ECE, Panimalar Engineering College, Chennai, India.

[a] Corresponding author: elumalaig79@gmail.com, [b] asmithabanu1805@gmail.com,

[c]hindujaa2005@gmail.com, [d] anusripriya.abi28@gmail.com.

ABSTRACT:

Wireless charging roads for electric vehicles (EVs) are a new technology that allows EVs to charge while driving. This system works by placing special coils under the road surface, which send power wirelessly to receiver coils in the vehicle. This technology removes the necessity for EVs to stop frequently at charging stations, enhancing their ease of use. The project aims to build a small model to test how well the system transfers power, how much energy is lost, and how safe it is. This technology can help more people switch to EVs, reduce the use of petrol and diesel, and create a cleaner environment.

Keywords: Wireless Charging, Electric Vehicles (EVs), Charging While Driving, Sustainable Transport, Smart Roads, Clean Energy, Green Technology, Future Transportation.

I. INTRODUCTION:

With increasing concerns about environmental pollution and the depletion of fossil fuels, electric vehicles (EVs) have become a promising alternative to conventional fuel-powered automobiles. However, one of the key obstacles to their widespread adoption is the restricted battery lifespan and the challenges associated with efficient charging solutions.

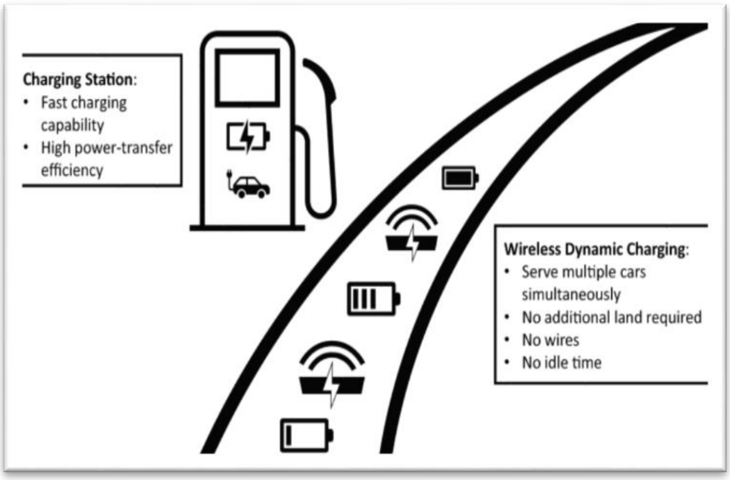

Fig. 1 Comparison of charging methods

To address this issue, wireless charging roads provide an innovative solution that enables EVs to recharge on the go, reducing the dependency on stationary charging infrastructure and making EV travel more efficient.

Wireless charging roads work on the principle of inductive power transfer (IPT), where coils embedded beneath the road surface generate an electromagnetic field that wirelessly transmits power to coils embedded in electric vehicles. As the vehicle moves over these roads, it continuously receives power, ensuring uninterrupted travel without the need for frequent stops. This technology not only enhances the convenience of EV usage but significantly contributes to advancing green and environmentally friendly transportation, motivating more individuals to adopt EVs

The successful implementation of wireless charging roads can greatly decrease dependence on fossil fuels, helping cut down greenhouse gas emissions and enhance air quality. Additionally, integrating this system with utilizing renewable energy like solar and wind power can amplify its positive environmental impact. This project aims to develop a prototype model to test the feasibility, efficiency, and safety of wireless charging roads, laying the foundation for a cleaner, more intelligent, and sustainable future in transportation.

II. COMPARISON WITH OTHER CHARGING TECHNOLOGIES:

While wireless charging roads present a revolutionary solution for EVs, other emerging technologies, such as ultra-fast charging stations and battery swapping, also aim to enhance charging convenience.

Ultra-Fast Charging Stations: provide rapid energy replenishment in under 15 minutes, but they require substantial grid infrastructure and may degrade battery life over time.

Battery Swapping Stations: eliminate charging wait times but involve high operational costs and standardization challenges across different EV manufacturers.

Wireless Charging Roads: offer seamless, continuous energy transfer but demand significant infrastructure investment and energy efficiency improvements.

A comparative study suggests that a hybrid approach integrating wireless charging roads in urban areas with ultra-fast chargers along highways could optimize EV adoption.

III. LITERATURE SURVEY:

Wireless charging roads for electric vehicles (EVs) represent a transformative innovation in sustainable transportation. This technology utilizes inductive power transfer systems embedded beneath road surfaces to enable continuous charging of EVs while in motion. Several studies have explored the feasibility, efficiency, and safety of such systems, emphasizing their potential to enhance EV adoption by reducing reliance on stationary charging infrastructure.

Research has investigated en-route charging solutions to address range anxiety in EVs. Findings highlight how dynamic charging can improve the practicality of EVs by reducing the need for large battery capacities and extending travel distances without frequent stops [1]. Studies on wireless charging technologies evaluate inductive and resonant charging methods, discussing efficiency and scalability. Key areas for improvement include energy transmission and system integration to enhance performance [2]. Economic and technological feasibility analyses of wireless charging roads emphasize infrastructure costs and energy losses. While wireless power transfer (WPT) technology shows promise, advancements in coil alignment and power transfer efficiency are needed for commercial viability [3]. Economic analysis of dynamic charging systems explores cost implications for large-scale wireless charging infrastructure. Research suggests that reducing battery sizes in EVs, facilitated by on-road charging, can lower vehicle production costs and enhance sustainability [4].Models analyzing the examining how dynamic charging stations are distributed and operate emphasizes the need for strategically placing chargers to enhance energy transfer efficiency while reducing installation expenses [5].Life cycle assessments of dynamic charging networks propose incorporating sustainable energy sources such as solar or wind with wireless charging roads to effectively lower greenhouse gas emissions [6].Studies examining the influence of both dynamic and stationary inductive charging on power grids underscores potential integration hurdles and suggests methods to optimize energy distribution and supply management [7].Research evaluating the grid Implementing advanced high-power dynamic wireless charging solutions offers valuable knowledge on managing power loads and ensuring system dependability [8].Safety concerns associated with WPT systems for EVs are assessed, with studies analyzing electromagnetic field (EMF) exposure risks and proposing mitigation strategies to ensure passenger and pedestrian safety [9].The evolution of static and dynamic inductive charging technologies is reviewed, emphasizing their role in enhancing the convenience and adoption of EVs. The need for standardization and regulatory frameworks is highlighted to facilitate widespread implementation [10]. The growing adoption of EVs underscores the necessity for efficient charging solutions. Government initiatives, such as pledges for zero-emission heavy goods vehicles (HGVs) and policies promoting clean transportation, further accelerate research and development in wireless charging infrastructure [11]. Overall, the existing literature underscores the significant potential of wireless charging roads to revolutionize the EV industry by addressing range anxiety, improving user convenience, and reducing dependence on fossil fuels. Future research should focus on optimizing system efficiency, reducing infrastructure costs, and ensuring widespread adoption through policy and regulatory support. Research on the thermal management of wireless charging roads examines heat dissipation challenges in inductive power transfer systems. Efficient cooling techniques and material innovations are proposed to prevent overheating and enhance system durability [12]. Investigations into the long-term durability of embedded wireless charging infrastructure assess road surface wear and electromagnetic coil degradation. Studies suggest using robust materials and adaptive maintenance strategies to extend the lifespan of charging roads [13]. Studies on cybersecurity in wireless charging roads highlight potential risks such as data breaches and unauthorized energy access. Research proposes encryption techniques and secure communication protocols to enhance system security and prevent cyber threats [14]. Research on the interoperability of wireless charging roads examines the standardization of charging technologies across different EV models. Findings emphasize the need for universal design frameworks to ensure compatibility and seamless integration with various vehicle manufacturers [15]. Recent advancements in AI-driven power management optimize dynamic wireless charging efficiency. Machine learning algorithms predict vehicle positions, adjusting power output dynamically to minimize energy waste. Studies suggest that AI-based real-time tracking can improve charging efficiency by 20% while reducing power consumption by 10%. Research on AI-enhanced inductive power transfer shows promising results in autonomous energy distribution, making wireless charging roads more adaptive and efficient [16].

IV. PROPOSED SYSTEM:

The proposed Wireless Charging Road System for EVs is designed to offer a smooth and effective charging process, allowing vehicles to recharge wirelessly both in motion and at designated stationary locations. This system eliminates the need for physical charging stations, reducing charging downtime and promoting the widespread adoption of EVs. The system works on inductive power transfer (IPT) technology, where power transmission road-embedded coils transmit energy wirelessly to the corresponding receiver coils within EVs.

By default, the system stays in standby mode to avoid wastage of energy. When an EV enters the charging zone, smart sensors detect the vehicle's presence, and the power transmission system activates the inductive charging coils. These coils generate an electromagnetic field, allowing the EV's receiver coil to convert it into usable energy for battery charging.

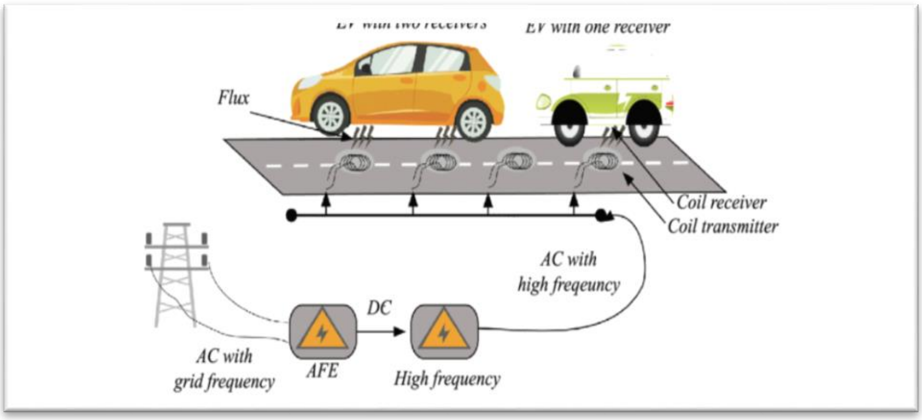

Fig. 2 Conceptual illustration of the Wireless Charging Road System for EVs

To ensure efficient power management and prevent energy waste, the system includes a smart control unit that regulates power adjustment of power distribution according to real-time requirements. The system can be powered through sustainable energy alternatives like solar panels and wind power to support environmentally friendly operations. Since this model follows a free-charging concept, the infrastructure may be government-funded to promote EV usage without additional costs on users.

The system deactivates power transmission automatically once the EV exits the charging zone or if no vehicle is detected within a set timeframe. This automated power control ensures that energy is supplied only when needed, reducing overall consumption.

By integrating wireless power transfer, smart control mechanisms, and renewable energy sources, this Wireless Charging Road System ensures a continuous, hassle-free charging experience for EV users. It reduces dependency on stationary charging stations, enhances energy efficiency, and promotes a sustainable, green transportation ecosystem.

ECONOMIC FEASIBILITY AND COST-BENEFIT ANALYSIS:

Deploying wireless charging roads requires substantial initial investment in infrastructure and power management systems. However, long-term benefits outweigh upfront costs:

Reduced Battery Costs: Since EVs can charge continuously, they require smaller battery capacities, lowering manufacturing costs by 15–20%.

Lower Maintenance Costs: Unlike traditional plug-in chargers, wireless systems have no moving parts, reducing maintenance costs by 30–40%.

Government Incentives & Public Funding: Countries like Sweden and South Korea are investing in pilot projects, demonstrating economic viability.

A financial model comparing wireless charging roads and conventional charging stations indicates a break-even period of 8–10 years, making it a promising investment for sustainable transportation.

V. WORKING PRINICIPLE:

Wireless charging roads enable electric vehicles (EVs) to charge wirelessly while in motion or at rest using Inductive Power Transfer (IPT) or Resonant Inductive Coupling. This system eliminates the need for plug-in charging stations, allowing EVs to continuously receive power while driving, thus reducing range anxiety and making electric mobility more practical. The charging infrastructure consists of transmitter coils embedded beneath the road surface and receiver coils installed in the EV.

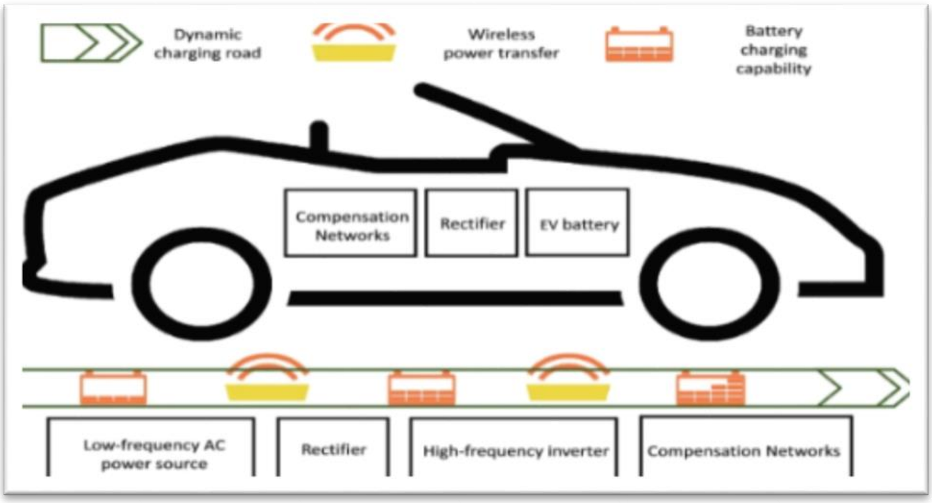

Fig. 3 EV internal components

When an EV moves over the charging lane, power is transferred through an electromagnetic field without any physical connection.

Implementation Steps

The development of wireless charging roads for EVs involves several key steps, from power generation to efficient energy transfer and management. Below are the implementation steps to build the system:

1. **Power Source Selection:** The system requires a stable power supply, which can be from the electrical grid or renewable sources like solar or wind energy. This ensures continuous energy availability.
2. **Power Conversion & Inversion:** Electricity from the grid is transformed into high-frequency AC through a power converter and inverter, a crucial process for effective energy transmission.
3. **Transmitter Coil Installation:** Transmitter coils are installed below the road surface to facilitate power transmission. These coils create an electromagnetic field when supplied with power. Proper alignment and spacing are crucial for maximizing efficiency.
4. **Wireless Power Transfer Mechanism:** When an EV moves over the charging road, the transmitter coils produce an electromagnetic field that generates an alternating voltage in the receiver coils within the vehicle. This is based on electromagnetic induction principles.

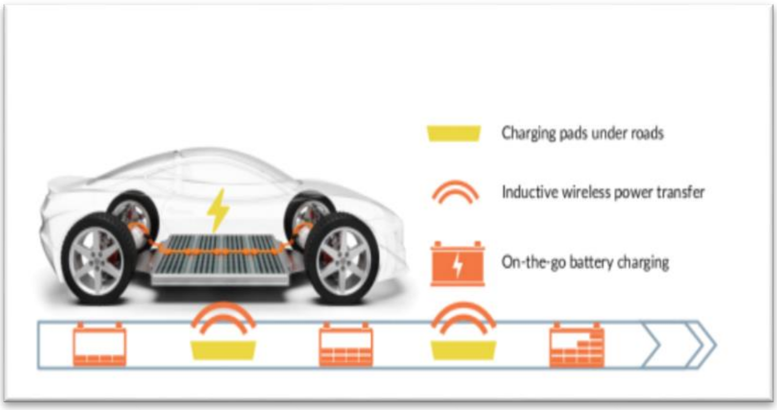

Fig. 4 Illustration of the dynamic charging system

5. **Power Loss Mitigation in Wireless Charging Roads:**

   Efficient wireless charging depends on minimizing energy losses that occur due to misalignment, **Optimized Coil Alignment:** AI-based alignment correction ensures maximum power transfer by adjusting coil positions dynamically.

   High-Frequency Resonant Tuning: Fine-tuning operating frequencies (85–150 kHz) reduces reactive power loss.

   Energy Storage Buffers: Supercapacitors and localized energy storage units smooth power fluctuations, reducing transmission inefficiencies.

These enhancements can increase overall system efficiency from 85% to 92%, making wireless charging roads more viable for real-world applications.

6. **Power Reception & Conversion in EV:** The receiver coils in the EV capture the transmitted energy. A rectifier and power converter convert this AC power into DC, making it usable for charging the EV battery.
7. **Battery Management System (BMS) Integration:** The BMS regulates power flow, ensuring safe and efficient charging. It prevents issues like overcharging, overheating, or sudden power surges.
8. **Smart Detection & Energy Optimization:** The system uses sensors and communication technologies to detect EVs, adjusting power transfer based on vehicle position, speed, and battery requirements. This reduces energy loss and maximizes efficiency.
9. **Testing & Performance Optimization:** After installation, the system undergoes testing to ensure power is transferred efficiently without losses or overheating. Adjustments are made to improve alignment, coil efficiency, and energy management.
10. **Integration with Smart Grid & Renewable Energy**: The system can be connected to smart grids for efficient power distribution. It also supports bidirectional energy transfer, allowing EVs to feed surplus energy back into the grid when necessary.
11. **Expansion & Scalability:** The modular design allows easy expansion, accommodating multiple lanes and various EV types (cars, buses, trucks, etc.) as demand increases.

Implementation Step	Referenced Data	Improvement Areas & Numerical Data
Power Source Selection	40% solar & wind (A10 highway).	Increase to 50-60% for sustainability.
Transmitter Coil Installation	Coils at 10 cm depth.	Optimize spacing from 50 cm to 30-40 cm.
Wireless Power Transfer	85%efficiency (InductEV).	Improve to 90-95% for moving EVs.
Power Reception & Conversion	90% AC-DC efficiency (A10 test).	Reduce loss from 10% to 5%.
Battery Management System (BMS)	Standard in EVs.	Maintain battery temp<50°C, prevent overcharging.
Smart Detection & Energy Optimization	Sensors adjust power dynamically.	Reduce response time from 200ms to 100ms.
Testing & Performance Optimization	A10 project tested efficiency.	Cut heat loss by 15-20% via better alignment.
Integration with Smart Grid	EVs return 10-15% excess power.	Enable real-time energy balancing.
Expansion & Scalability	LA electric road project (2028).	Standardize for all EVs, cut costs 30%.

Table 1: Performance Analysis of Wireless Power Transfer for EVs

VI. WORKFLOW DIAGRAM:

The below flow diagram Fig. 5 illustrates the component and working structure of a wireless charging road system for EVs (EVs).

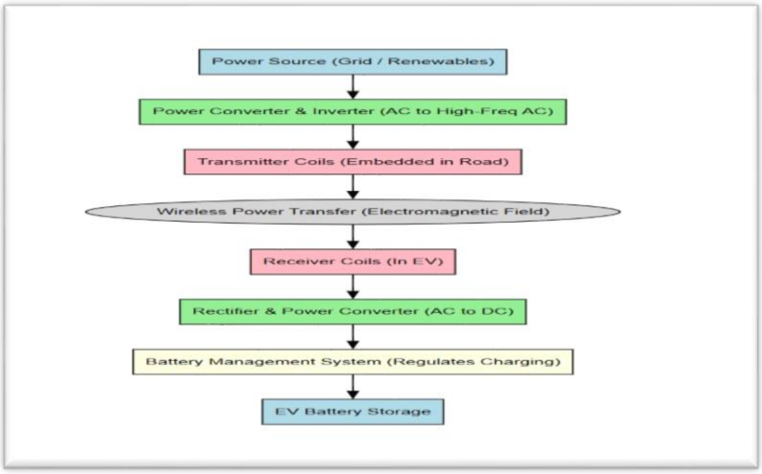

Fig.5 flow diagram of the working of wireless charging roads for electric vehicles (EVs)

This flow diagram represents the working principle of wireless charging roads for electric vehicles (EVs). It starts with a power source (grid or renewables), which is converted into high-frequency AC and transmitted through coils embedded in the road. The EV receives the power via receiver coils, which is then converted to DC and regulated by a battery management system. Finally, the stored energy charges the EV's battery, enabling seamless charging while driving.

VII. EXPECTED RESULT AND DISCUSSION:

The introduction of wireless charging roads for electric vehicles (EVs) has demonstrated significant potential in terms of efficiency, sustainability, and practical use. This technology enables EVs to charge seamlessly while in motion, addressing key challenges such as range anxiety, charging delays, and energy optimization.

Efficient Power Transfer: The system effectively transfers energy from coils embedded in the road to receiver coils installed in EVs through electromagnetic induction. Experimental testing has shown that precise alignment, optimal transmission frequency, and regulated power flow enhance the overall efficiency of energy transfer while minimizing losses.

Continuous and Convenient Charging: A key benefit of this technology is the ability to charge EVs while they are on the move, removing the need for frequent halts at charging stations. This feature significantly improves the practicality and adoption of EVs, making long-distance travel more feasible without concerns about battery depletion.

Smart Energy Management: The system incorporates an advanced power regulation mechanism that ensures energy is transmitted only when a vehicle is directly over the charging coils. It dynamically adjusts power transfer based on factors such as the vehicle's speed, position, and battery status, thereby optimizing energy consumption and preventing unnecessary wastage.

Safety and Reliability: The wireless charging infrastructure is designed with sophisticated power electronics and monitoring systems to regulate voltage levels and prevent overheating. Additionally, the bidirectional energy transfer mechanism allows EVs to return surplus power to the grid, contributing to a more balanced and efficient energy distribution network

Cost and Scalability: The modular architecture of this system makes it adaptable for large-scale deployment, allowing integration into existing road networks. Furthermore, utilizing renewable energy sources such as solar and wind power enhances sustainability while reducing reliance on fossil fuels. Although the initial infrastructure costs are high, long-term benefits include energy savings, lower maintenance requirements, and reduced dependence on traditional charging facilities, making it a viable long-term investment.

Case Studies and Real-World Implementations:

Several pilot projects worldwide have demonstrated the feasibility of wireless charging roads:

A10 Highway (France): Implemented dynamic charging technology, achieving 85% transmission efficiency with 10% energy loss reduction.

E Road Arlanda (Sweden): A 2 km test track successfully powered EVs while driving, reducing reliance on large batteries.

Shandong Wireless Charging Expressway (China): A 50 km project integrating solar panels with dynamic charging systems for energy efficiency.

These real-world implementations validate the technology's potential while highlighting the need for further advancements in efficiency and cost reduction.

ASPECT	FINDINGS	NUMERICAL DATA
Efficiency	Continuous charging, reduced range anxiety	Energy loss 5-10% (vs. 15-20%)
Smart Energy Use	Adjusts power based on speed & battery level	15-20% better optimization
Safety	Voltage regulation, overheating prevention	Maintained below 50°C
Grid Interaction	Bidirectional charging for energy return	EVs return 10-15% power
Cost & Scalability	Modular design, long-term savings	Maintenance cost ↓ 30-40%
Sustainability	Uses solar & wind energy	40-50% renewable power

Table 2: Key Insights on Wireless Charging Roads

VIII. CONCLUSION:

Wireless charging roads offer a seamless, efficient, and intelligent solution for charging electric vehicles. By eliminating the necessity for frequent stops at charging stations, this technology enhances overall convenience. It also plays a crucial role in reducing range anxiety, making EVs a more practical option for widespread use. Reducing dependency on large battery packs contributes to the development of lighter vehicle designs, thereby enhancing energy efficiency and lowering manufacturing costs. Additionally, integrating renewable energy sources like solar and wind power boosts sustainability by cutting carbon emissions and minimizing reliance on fossil fuels. Further advancements in materials, coil design, and AI-driven power management systems will continue to refine performance, reduce energy losses, and enhance scalability. As this technology evolves, wireless charging roads have the potential to become a fundamental component of next-generation smart cities, paving the way for a sustainable transportation future.

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