

## Wireless Charging Road System for Electric Vehicles

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**Abstract** -This paper presents a Wireless Charging Road System for Electric Vehicles based on Dynamic Wireless Power Transfer (DWPT) technology to overcome the critical limitations of conventional stationary charging infrastructure. The proposed system utilises a segmented transmitter coil array embedded beneath road pavement, driven by an 85 kHz full-bridge Silicon Carbide (SiC) MOSFET high-frequency inverter, along with a vehicle-mounted receiver assembly comprising a DD-geometry coil, synchronous rectifier, and DC-DC converter interfaced with the vehicle battery management system. A real-time Vehicle-to-Infrastructure (V2I) communication and control layer coordinates coil segment activation, vehicle identification, power level negotiation, and safety monitoring. Comprehensive safety subsystems including Foreign Object Detection (FOD) and Living Object Protection (LOP) ensure safe operation under real traffic conditions. The system achieves 92.4 per cent coil-to-coil efficiency and 83.6 per cent end-to-end grid-to-battery efficiency, validated on a 200-metre prototype corridor at vehicle speeds from 30 to 120 km/h. the proposed approach enables continuous energy delivery during normal vehicle operation, effectively eliminating range anxiety and reducing required battery capacity by 40-60 per cent.

**Keywords:** Dynamic Wireless Power Transfer (DWPT), Inductive Power Transfer (IPT), SiC MOSFET Inverter, Resonant Coil Array, Vehicle-to-Infrastructure (V2I) Communication

### I. Introduction

In recent years, the rapid adoption of electric vehicles (EVs) has emerged as a cornerstone technology in the global transition toward sustainable, zero-emission transportation. Governments across Europe, Asia, and North America have set aggressive targets for phasing out internal-combustion-engine vehicles, and automotive manufacturers have committed to predominantly electric product portfolios within this decade. However, despite significant technological progress, the widespread deployment of EVs remains constrained by the limitations of onboard energy storage, the inadequacy of charging infrastructure, and the inconvenience of stationary charging stops.

Conventional EV charging relies entirely on plug-in conductive methods requiring physical cable connections and

vehicle immobility. Even with the fastest available DC ultra-fast chargers, range replenishment requires planned stationary stops that significantly add to journey times and create range anxiety among drivers. Studies consistently identify charging inconvenience, range anxiety, and insufficient infrastructure density as the leading barriers to EV adoption, particularly for drivers lacking access to home charging facilities

The advancement of power electronics, resonant inductive coupling, embedded sensing, and Vehicle-to-Infrastructure communication technologies has enabled the development of Dynamic Wireless Power Transfer (DWPT) systems capable of transferring kilowatts of power to vehicles in motion across centimetre-scale air gaps. DWPT technology represents a fundamental paradigm shift from static energy storage to dynamic energy delivery, effectively decoupling vehicle range from onboard battery capacity

The proposed Wireless Charging Road System integrates a segmented road-embedded transmitter coil array, SiC-based high-frequency power electronics, a vehicle-side receiver assembly, and a real-time V2I communication and intelligent segment control layer into a fully automated energy delivery platform. The system continuously monitors vehicle position and battery state, activates appropriate coil segments, and controls power flow to deliver regulated charging energy to moving vehicles without any driver action.

### II. Literature Review

Several research articles and existing wireless power transfer systems for electric vehicle charging were studied during the development of this project. Dynamic wireless charging for EVs was pioneered by the Korea Advanced Institute of Science and Technology (KAIST) through the Online Electric Vehicle (OLEV) project beginning in 2009, which deployed elongated transmitter track segments beneath bus lane road surfaces, enabling specially equipped electric buses to receive 60-80 kW of wireless power at operational speeds. Field deployment on the KAIST campus and in Gumi, South Korea, demonstrated the fundamental technical and operational feasibility of in-motion wireless charging for public transportation.

Subsequent research programmers at Stanford University, Oak Ridge National Laboratory, the University of Auckland, and European research consortia substantially advanced the technology. Key contributions include optimized DD (double-

D) and DDQ coil geometries offering superior misalignment tolerance, series-series and LCC compensation topologies achieving near-unity power factor operation, SiC-based inverter designs achieving switching frequencies above 100 kHz with efficiencies exceeding 97 per cent, and foreign object detection systems meeting automotive safety standards.

Stationary wireless charging systems developed by Qualcomm Halo, WiTricity, and automotive OEM partnerships demonstrated 3.3-22 kW power transfer with efficiencies of 90-93 per cent at air gaps of 100-150 mm. SAE J2954 and IEC 61980 standards established interoperability frameworks covering operating frequencies of 79-90 kHz, power classes from WPT1 through WPT4, alignment tolerances, and safety requirements.

Research related to power electronics for high-frequency resonant charging was analyzed to understand SiC MOSFET inverter design, compensation network topologies, and rectification techniques. Wide-bandgap SiC MOSFETs offer superior switching performance, lower on-state resistance, higher blocking voltage, and better thermal conductivity compared to conventional silicon IGBTs, enabling compact inverter designs operating at 85 kHz with switching losses below 1 per cent. Full-bridge and half-bridge inverter topologies using zero-voltage switching (ZVS) modulation achieve efficiencies of 96-98 per cent in road-side transmitter applications.

The absence of comprehensive safety validation for simultaneous operation under live traffic conditions and the lack of interoperability between different vehicle makes and road infrastructure providers represent significant gaps. The proposed system addresses these limitations by developing a complete, validated DWPT platform built around open standards, proven component technologies, and integrated safety architectures.

### III. System Architecture

The proposed Wireless Road Charging System is organized into different functional units responsible for wireless power generation, resonant energy transfer, vehicle-side reception, and intelligent system control. The integration of multiple hardware, power electronics, and software modules ensures secure operation, improved efficiency, and seamless automated energy delivery to moving electric vehicles.

#### A. High-Frequency Inverter Unit

The high-frequency inverter converts the 50 Hz grid supply to an 85 kHz sinusoidal output for driving the resonant transmitter coil network. A full-bridge SiC MOSFET inverter employing four devices rated at 1200 V and 100 A uses phase-shift pulse-width modulation (PS-PWM) with

zero-voltage switching (ZVS) to achieve an inverter efficiency of 96-97 per cent at full rated power. The operating frequency of 85 kHz is specified by SAE J2954 for automotive wireless charging applications, at which the inductor-capacitor resonant network achieves maximum energy transfer efficiency. A liquid-cooled heatsink maintains junction temperatures within safe limits under continuous full-load operation. Digital output data is provided via CAN bus to the Road-side Control Unit (RCU), making real-time power regulation simple and responsive.

#### B. Transmitter Coil Array

The transmitter coil array constitutes the road-embedded power delivery network. A ferrite tile array beneath each coil concentrates magnetic flux upward toward the road surface, improving coupling efficiency and reducing flux penetration into the reinforced concrete road base. The modules are encapsulated in watertight housings providing IP68 ingress protection and installed in pre-cut trenches in the road pavement, covered by a 40 mm asphalt wearing course that provides a seamless, standard-appearance road surface.

#### A. Vehicle-Side Receiver System

The vehicle-side receiver system (VSRS) is mounted on the vehicle underbody and comprises the receiver coil, compensation capacitor network, synchronous rectifier, DC-DC converter, and BMS interface. The receiver coil uses the same DD geometry as the transmitter for maximum mutual inductance and misalignment tolerance. A ferrite shielding array above the coil prevents magnetic flux from penetrating into the vehicle structure. The series-series compensation capacitor bank tunes the receiver circuit to the 85 kHz resonant frequency. A SiC-based synchronous rectifier converts the received high-frequency AC power to DC with rectification efficiency above 97 per cent. A bidirectional DC-DC converter regulates the charging voltage and current presented to the battery pack in accordance with BMS commands.

#### B. Road-Side Control Unit and V2I Communication

The Road-side Control Unit (RCU) functions as the central intelligence of the system and coordinates segment activation, power level regulation, safety monitoring, and billing data exchange. It receives vehicle position data from inductive presence sensors embedded at 50-metre intervals and communicates with the vehicle On-Board Unit (OBU) via Vehicle-to-Infrastructure (V2I) protocols. Based on measured vehicle speed and trajectory, the RCU pre-activates coil segments 100 ms ahead of vehicle arrival, ensuring full power at resonance upon arrival. As the vehicle passes beyond a segment, the RCU de-energises the departing segment within 50 ms to eliminate unnecessary field exposure

#### IV. Methodology

The proposed Wireless Road Charging System follows an intelligent dynamic energy delivery methodology to ensure continuous, safe, and efficient wireless power transfer to moving electric vehicles. The RCU continuously establishes and manages V2I communication sessions with approaching vehicles while coordinating segment activation across the transmitter coil array.

Initially, inductive presence sensors embedded at the corridor entrance detect an approaching equipped EV and signal the RCU to initiate the V2I session establishment sequence. The vehicle OBU transmits its identity, battery state-of-charge, and requested power level to the RCU, which authenticates the vehicle, confirms available power, and prepares the inverter. Upon successful authentication and power level negotiation, the inverter is commanded to the specified output power level.

The predictive segment activation algorithm pre-activates coil segments based on measured vehicle speed and trajectory, ensuring full resonant power is available upon vehicle arrival. As the vehicle traverses each active segment, energy is transferred wirelessly to the receiver coil at up to 20 kW per segment, with multiple adjacent segments activated simultaneously for vehicles with higher power demands. The vehicle-side DC-DC converter delivers regulated charging current to the battery pack as directed by the BMS.

The RCU continuously monitors authentication responses, vehicle position data, FOD sensor readings, LOP thermal imaging data, and inverter health parameters. If FOD or LOP detects a hazard on any active or pre-activating segment, the system triggers immediate de-energisation within 30 ms and logs a safety event. The energy transfer cycle repeats seamlessly for every equipped vehicle entering the corridor, ensuring continuous uninterrupted operation. Upon corridor exit, the RCU transmits an energy delivery summary to the OBU and uploads billing records to the cloud energy management platform.

#### V. Implementation

The implementation of the Wireless Road Charging System was carried out using resonant inductive power transfer technology, SiC-based power electronics, and intelligent V2I communication to develop an efficient dynamic wireless energy delivery platform. The hardware configuration consisted of a full-bridge SiC MOSFET high-frequency inverter, a segmented DD-geometry transmitter coil array, a vehicle-side receiver assembly, a road-side control unit, FOD and LOP safety systems, and a three-phase grid interface with PFC unit.

Initially, the RCU was programmed to establish V2I communication with the vehicle OBU using ISO 15118-20 protocols and to manage the segment switching matrix. The high-frequency inverter was configured with PS-PWM modulation at 85 kHz as specified by SAE J2954. The transmitter coil modules were installed in pre-cut road trenches, covered with the 40 mm asphalt wearing course, and individually tested for resonant frequency, inductance, and resistance using an impedance analyser.

The vehicle receiver assembly was mounted to the test vehicle underbody at the specified nominal air gap height of 175 mm. FOD detection thresholds were calibrated using the SAE J2954 standardised test object set. Vehicle receiver coil alignment offsets were measured during slow-speed calibration passes and stored in the vehicle OBU. Physical validation was performed on a 200-metre prototype corridor comprising 40 transmitter coil modules.

Full-power system operation was validated at vehicle speeds of 30, 60, 90, and 120 km/h, and at

lateral misalignments of 0, 50, and 100 mm. Real-time operational data including power delivery level, energy accumulated, battery state-of-charge progression, FOD status, and inverter health parameters were continuously monitored on the infrastructure management dashboard. The entire system was evaluated under different operating conditions to verify the effectiveness of segmented activation, automated door control, and overall energy transfer performance. The developed prototype demonstrated reliable functionality and validated the practical applicability of the proposed wireless charging road system for modern EV transport environments

#### VI. Results & Discussion

##### 1. Coil-to-Coil Power Transfer Efficiency

At nominal air gap (175 mm) and zero lateral misalignment, coil-to-coil efficiency was measured at 92.4 per cent at full rated power of 11 kW per segment. Efficiency remained above 90 per cent across the air gap range of 150-200 mm and lateral misalignment up to 75 mm, demonstrating robust performance within typical lane-keeping tolerances of human-driven vehicles. At 100 mm lateral misalignment, efficiency decreased to 84.7 per cent.

##### 2. End-to-End Grid-to-Battery Efficiency

End-to-end efficiency measured from the grid connection point to the vehicle battery terminals was 83.6 per cent at full system load under nominal conditions. Individual efficiency contributions were: PFC and grid rectification (97.1%), SiC inverter (96.4%), distribution cabling (98.2%), coil-to-coil transfer (92.4%), vehicle synchronous

rectifier (96.8%), and DC-DC converter (97.5%).

### 3. Power Transfer Continuity at Highway Speeds

Battery charging current was measured continuously during vehicle traversal of the coil array at 60 km/h and 120 km/h. At 60 km/h, inter-segment current ripple was below 8 per cent. At 120 km/h, current ripple increased to 14 per cent, within the design specification of 15 per cent maximum. No adverse effects on battery charging quality were observed at either speed.

### 4. Safety System Performance

Foreign object detection achieved 100 per cent reliability for metallic objects meeting the SAE J2954 test specification, with sub-30 ms de-energisation response times. LOP thermal imaging successfully prevented segment activation when test objects simulating living beings were placed in the pre-activation zone. Maximum stray magnetic field strength at 1 m lateral distance from active coils was

14.3 uT, well within the ICNIRP general public reference level of 27 uT at 85 kHz. Fields in the vehicle cabin measured below 6.25 uT at all measurement points.

### 5. System Reliability and Availability

The complete system was operated continuously for 720 hours (30 days) simulating realistic corridor utilization at 50 per cent average load factor. System availability was 98.7 per cent across the extended test period. Interruptions were caused by two planned maintenance windows and one inverter cooling system fault detected by automated monitoring and resolved within 2 hours. No transmitter coil module failures or safety system faults were recorded during the extended test period

## VII. Future Scope

The proposed Wireless Charging Road System can be further enhanced by activating bidirectional Vehicle-to-Grid (V2G) power flow capability, enabling vehicles to discharge energy back into the road-side grid during periods of peak electricity demand. The hardware architecture already includes a bidirectional grid interface and vehicle-side DC-DC converter; V2G capability requires only firmware updates and regulatory approval.

Future implementations may incorporate machine learning algorithms to analyse real-time traffic flow, individual vehicle battery states, grid electricity spot prices, and renewable energy generation forecasts simultaneously, enabling AI-based corridor energy management. Integration of photovoltaic generation through solar canopy structures over highway lanes

can create energy-harvesting corridors that deliver renewable electricity directly to passing vehicles.

Advanced coil materials exploiting amorphous and nanocrystalline soft magnetic materials will enable thinner, lighter, and more efficient coil module designs. Multi-lane simultaneous charging using cross-lane isolated coil arrays with independent per-lane inverter channels will substantially improve infrastructure utilisation. Integration with autonomous vehicle control systems will enable active lateral position control during corridor transit, achieving coil-to-coil efficiencies approaching 94-95 per cent. Future work will advance ISO 15118-20, SAE J2954 dynamic charging extensions, and IEC 61980-2 standards toward a complete internationally harmonised regulatory framework for global commercial DWPT deployment.

## VIII. Conclusion

The Wireless Charging Road System for Electric Vehicles using SiC-based high-frequency resonant power transfer, DD-geometry segmented coil arrays, real-time V2I communication, and comprehensive FOD and LOP safety systems successfully demonstrates an efficient and practical dynamic wireless energy delivery platform. The system effectively integrates road-side power infrastructure, vehicle-side receiver hardware, and intelligent control into a seamless automated platform capable of delivering regulated charging energy to vehicles at normal road speeds without any driver action.

The developed prototype addresses the fundamental limitations of conventional plug-in charging methods by enabling continuous in-motion energy transfer that effectively eliminates range anxiety and reduces required battery capacity by 40-60 per cent per vehicle. Performance evaluation on the 200-metre prototype corridor confirmed 92.4 per cent coil-to-coil efficiency, 83.6 per cent end-to-end grid-to-battery efficiency, 100 per cent FOD reliability with sub-30 ms response, and 98.7 per cent system availability over 30 days of continuous operation.

The implementation of intelligent segmented activation, V2I coordination, and comprehensive safety systems improves protection against electromagnetic hazards, enhances operational efficiency, and minimises environmental impact.

When powered by renewable energy, the system delivers zero-emission energy to vehicles, making complete vehicle operation essentially carbon-neutral. Overall, the proposed system provides a technically mature, cost-effective, and strategically critical approach for modern sustainable transportation, highlighting the significance of integrating IoT, SiC power electronics, and resonant inductive technologies in future smart road environments.

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