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Dynamic Wireless Charging For E-Vehicles

[1]Krishnaveni.R, [2]Abinesh.A.J, [3]Abilash.S, [4]Balaji.M

[1,2,3,4]Department of Electronics and Communication Engineering, KIT-Kalaignar Karunanidhi Institute of Technology, Coimbatore, India

Authors E-mail: [1]k.veni.84@gmail.com, [2]kit.25.21bec0003@gmail.com, [3]kit.25.21bec002@gmail.com, [4]kit.25.21bec015@gmail.com

***Abstract* - Dynamic wireless charging for EVs enables continuous charging while in motion using induction coils embedded in roads. These coils generate a high-frequency magnetic field, captured by EV receiving coils to induce current for battery charging. A power conversion system with MOSFETs (e.g., IRFZ44N, URF840), ultrafast diodes (e.g., UF5408), and PWM controllers (e.g., SG3525, U3525) regulates AC-to-DC conversion. A BMS optimizes charging, while sensors and control algorithms adjust power transfer based on vehicle position. This technology enhances EV range, eliminates frequent stops, and supports sustainable urban mobility.**

Keywords: INDEP, 8-Bit Comparator, VLSI Circuit Design, Power Efficiency, Delay optimization, Cadence, CMOS vs INDEP.

I. INTRODUCTION

The growing adoption of EVs highlights their role in sustainable transportation, yet conventional plug-in charging limits efficiency due to prolonged idle times. Dynamic Wireless Charging (DWC) addresses this by enabling seamless energy transfer while vehicles are in motion, eliminating charging stops and enhancing range and convenience. This innovation supports the transition to electric mobility and a carbon-neutral future but requires overcoming infrastructure, efficiency, and cost challenges. Despite these hurdles, DWC represents a transformative step in modern transportation, aligning technology with sustainability goals.

II. LITERATURE REVIEW

This review explores the transformative role of Inductive Wireless Power Transfer (WPT) in enabling fully automated, efficient, and reliable charging for driverless electric vehicles (EVs). It highlights the advantages of Resonant Inductive WPT, including high efficiency, minimal maintenance, and operational flexibility. The study compares various wireless charging technologies, covering static and dynamic systems, compensation techniques, and power electronics. Additionally, it introduces an advanced alignment system using metal proximity sensors to enhance precision in autonomous EVs. Experimental evaluations confirm its effectiveness in improving safety and efficiency. The review underscores WPT's potential in shaping a sustainable and intelligent future for electric mobility.

III. METHODOLOGY

The transmitter circuit, a high-frequency inverter, enables efficient wireless power transfer using a 12V DC input. It employs a half-bridge inverter with IRFZ44N MOSFETs, driven by a U-3525 PWM controller at 65 kHz. A ferrite core transformer with a center-tapped primary winding converts DC to high-frequency AC, which is transmitted via a 40-turn copper coil. The receiver coil captures the electromagnetic waves, and a BA159-based bridge rectifier converts them into stable 12V DC for EV charging or motor operation, ensuring seamless energy transfer.

IV. SYSTEM DESIGN AND ARCHITECTURE

The dynamic wireless charging system enables continuous energy transfer to electric vehicles in motion through efficient interaction between the transmitter and receiver subsystems. The system eliminates the need for stationary charging stops by utilizing inductive power transfer at a high operating frequency of 65 kHz.

A. Transmitter Subsystem

The transmitter circuit is driven by the U-3525 PWM controller, responsible for generating two phase-shifted PWM signals that are 90° out of phase. These signals drive two IRFZ44N N-channel MOSFETs in a half-bridge inverter configuration. The alternating switching action of the MOSFETs directs the DC current through the upper and lower windings of a high-frequency ferrite core transformer, effectively generating a high-frequency AC output.

The transformer plays a crucial role in converting the DC input into high-frequency AC, with its primary winding center-tapped for efficient current flow. The high-frequency AC voltage is then supplied to the transmitter coil, which consists of 40 turns of copper wire. This coil generates an alternating electromagnetic field at the designed operating frequency, facilitating inductive power transfer to the receiver system.

B. Receiver Subsystem

On the receiving end, a dedicated receiver coil captures the electromagnetic waves emitted by the transmitter coil. The captured energy is then converted back into high-frequency AC voltage. This AC voltage is rectified using a high-frequency bridge rectifier, built with BA159 fast-switching diodes to efficiently handle the high-frequency signal without excessive losses.

The rectified voltage is passed through a filtering capacitor to smooth out ripples and stabilize the DC output. The resultant 12V DC serves as a reliable power source, either for directly powering the vehicle's motor or for charging its battery, ensuring an uninterrupted energy supply while the vehicle remains in motion.

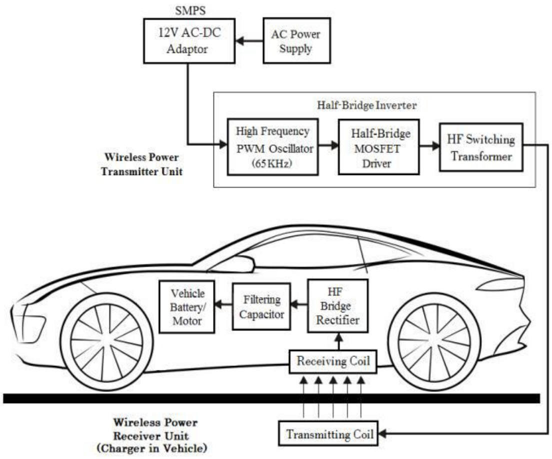

Figure 1: Block Diagram of Proposed System

Key Components and Functionalities:

a) **AC Power Supply:** Provides 220V AC to power the wireless transmitter.

b) **AC-DC Adapter (SMPS):** Converts 220V AC to a stable 12V DC for circuit operation.

c) **High-Frequency PWM Oscillator:** Uses a KA3525 IC to generate 65 kHz switching pulses, phase-shifted by 90°, to control MOSFETs.

d) **Driver MOSFETs:** Alternately switch to drive the high-frequency transformer, creating an AC square wave.

e) **High-Frequency Transformer:** Converts DC to high-frequency AC using a ferrite core for minimal losses.

f) **Half-Bridge Inverter:** Integrates MOSFETs and transformer to generate high-frequency AC for transmission.

g) **Transmitting Coil:** Converts AC into electromagnetic waves for inductive power transfer.

h) **Receiving Coil:** Captures electromagnetic waves and converts them into high-frequency AC.

i) **HF Bridge Rectifier:** Uses fast-switching diodes to convert AC to DC.

j) **Filtering Capacitor:** Smoothens the rectified DC for stable power delivery to the EV battery or motor.

V. CIRCUIT IMPLEMENTATION AND PCB DESIGN

The transmitter circuit is designed as a high-frequency inverter system operating at 65 kHz with a 12V DC input from an AC-to-DC adapter or SMPS. It employs a half bridge inverter with two IRFZ44N MOSFETs controlled by a U-3525 PWM generator, which alternately switches the current through the ferrite core transformer's center-tapped primary winding, producing high-frequency AC. The transmitter coil (40-turn copper air-core inductor) converts this AC into electromagnetic waves for wireless power transfer. A voltage feedback loop via a fast bridge rectifier ensures stable voltage regulation.

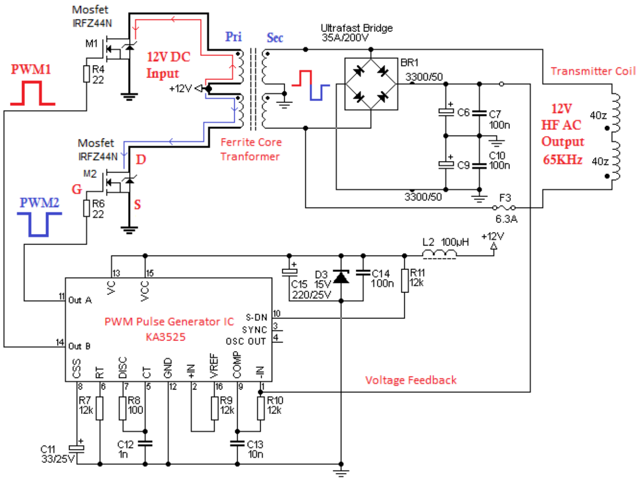

Figure 2: Transmitter Circuit Diagram

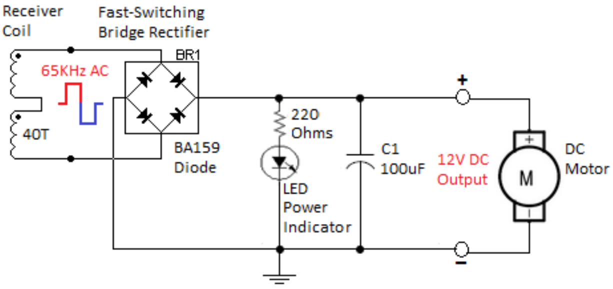

Figure 3: Receiver Circuit Diagram

The receiver coil captures electromagnetic waves and converts them into high-frequency AC, which is rectified by BA159 diodes into 12V DC. A filtering capacitor smooths the output for battery charging or motor operation.

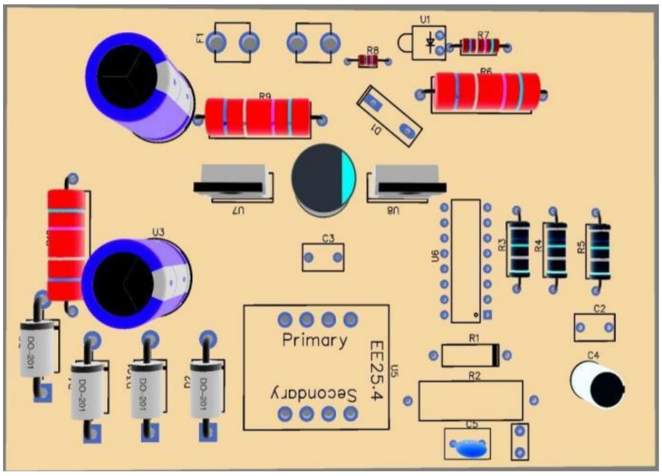

Figure 4: PCB Design of the Proposed System

The PCB design, created in EasyEDA, optimizes signal integrity, thermal management, and EMI reduction. Component placement and routing were carefully planned to support high-frequency switching while ensuring safety, efficiency, and reliable performance in real-world dynamic wireless charging applications.

VI. HARDWARE DEVELOPMENT

The development of the dynamic wireless charging system followed a structured approach to ensure seamless power transfer and efficient operation. The process began with selecting a suitable power supply, where a 220V AC input was converted into a stable 12V DC output using a Switching Mode Power Supply (SMPS). This conversion provided a consistent power source for the transmitter circuit. At the core of the transmitter circuit, a high-frequency half-bridge inverter was implemented using IRFZ44N N-channel MOSFETs. These MOSFETs played a crucial role in generating a high-frequency AC output at 65 kHz. The switching operation was managed by a KA3525 Pulse Width Modulation (PWM) controller, which produced phase-shifted PWM signals (90° out of phase) to drive the MOSFETs alternately. This controlled switching ensured smooth operation of the inverter. A ferrite core transformer was integrated to efficiently handle high-frequency power conversion. The transformer's center-tapped primary winding facilitated controlled DC current flow, while its secondary winding generated the high-frequency AC voltage required for wireless transmission. This AC signal was fed into the transmitter coil—comprising 40 turns of copper wire—which converted the electrical energy into electromagnetic waves for inductive power transfer. On the receiver side, the receiver coil was responsible for capturing the electromagnetic waves and converting them back into high-frequency AC voltage. To transform this AC into a usable DC form, a high-frequency bridge rectifier was employed, using fast-switching BA159 diodes that efficiently processed the high-frequency signals. Capacitors were used to filter out ripples, ensuring a stable 12V DC output. This output could be used to charge an electric vehicle's battery or directly power its motor, providing continuous energy delivery. During the hardware development process, key considerations included thermal management of MOSFETs to prevent overheating and incorporating noise suppression techniques to improve system reliability. Proper grounding and shielding were also implemented to enhance safety and reduce electromagnetic interference. Multiple testing and refinement stages ensured that all components functioned cohesively, minimizing power losses and optimizing efficiency. By effectively integrating these components, the system demonstrated a reliable solution for dynamic wireless charging of electric vehicles. This innovation contributes to the advancement of sustainable charging infrastructure, offering a convenient and efficient alternative to traditional charging methods.

VII. POWER ELECTRONICS & CONTROL SYSTEMS

In this dynamic wireless charging system for electric vehicles, the power electronics and control systems are designed with a focus on high-speed switching and precise voltage regulation to ensure efficient power transfer. The core of the transmitter circuit relies on N-channel MOSFETs, chosen for their superior switching characteristics, particularly their fast switching capabilities. N-channel MOSFETs are ideal for this application due to their low on-resistance and high current handling capacity, which allow them to switch on and off rapidly, thereby minimizing switching losses and improving the overall efficiency of the system. These MOSFETs are driven by a KA3525 PWM controller, which generates precise pulse-width modulation signals at a frequency of 65 kHz to control the gate of each MOSFET in a complementary manner. The KA3525 ensures that the MOSFETs are switched alternately, with each MOSFET operating 90 degrees out of phase with the other, thereby creating a high-frequency AC output at the transformer's primary winding.

The high-frequency AC voltage generated at the transmitter coil is then transmitted wirelessly through electromagnetic waves to the receiver coil. On the receiver side, an ultra-fast recovery diode is employed in the bridge rectifier to handle the rapid transitions of the high-frequency AC signal. These diodes are specifically selected for their ability to recover quickly from reverse bias, thereby ensuring minimal reverse recovery time and reducing the risk of voltage spikes that could potentially damage the circuit. The fast-switching diodes efficiently rectify the AC signal, converting it into DC voltage, which is then filtered by a capacitor to remove any ripple and provide a smooth, stable DC output.

Design Considerations and Optimization:

a) Thermal Management: Proper heat dissipation measures, including heat sinks and optimized PCB layout, were implemented to ensure stable MOSFET operation.
b) Electromagnetic Compatibility: Shielding and proper grounding techniques were applied to minimize interference and enhance overall system reliability.
c) Compact PCB Layout: The circuit board design prioritized minimal footprint, efficient trace routing, and robust component placement to enhance performance and durability.

Voltage feedback is a critical element in maintaining the stability and regulation of the charging system. The voltage feedback mechanism is designed to monitor the rectified DC voltage and relay this information back to the PWM controller. By using the voltage feedback, the U-3525 adjusts the PWM duty cycle to ensure a constant output voltage, compensating for variations in load or vehicle position. This closed-loop control system maximizes power efficiency and ensures that the wireless charging process remains reliable, delivering optimal power to the electric vehicle's battery or motor without the risk of overcharging or power loss. Together, the combination of N-channel MOSFETs for fast switching and ultra-fast recovery diodes for rectification plays a fundamental role in the high-performance operation of the dynamic wireless charging system, contributing to the system's overall effectiveness in delivering continuous, efficient power to the electric vehicle.

VIII. SYSTEM INTEGRATION AND REAL-WORLD APPLICATIONS

The integration of dynamic wireless charging systems for electric vehicles (EVs) into real-world applications offers immense potential for transforming the electric mobility landscape, while leveraging cost-effective, readily available technologies. The fundamental components of the system, including the high-frequency inverter, N-channel MOSFETs, ultra-fast recovery diodes, and PWM controllers, are already well-established in the power electronics field, with widespread use in consumer electronics, renewable energy systems, and industrial applications. By utilizing these off-the-shelf components, the cost of implementing dynamic wireless charging systems can be significantly reduced without compromising performance or reliability. The integration of the system into urban infrastructure can be achieved using the same principles employed in existing electric grid systems, such as inductive charging coils embedded within roads or highways, which can be seamlessly incorporated during road construction or retrofitting existing roads.

To reduce costs further, advanced manufacturing techniques like automated pick-and-place machines, surface-mount technology (SMT), and PCB assembly can be utilized to produce the power electronics circuitry at scale. For the wireless power transfer (WPT) technology, ferrite core transformers and air-core inductors, which are widely used in other applications such as wireless charging pads and telecommunications, can be adapted and optimized for high-frequency operation. These components, which are both inexpensive and effective at higher frequencies, will ensure reliable power transfer while keeping manufacturing costs low.

The system can also be implemented with low-cost, yet precise control systems for power management, utilizing microcontrollers or digital signal processors (DSPs) that are capable of handling PWM generation, feedback control, and sensor integration. These processors, which have become more affordable in recent years, can ensure that the charging process is efficient and responsive to changes in the vehicle's position, speed, and load, all in real time. Additionally, using cost-effective wireless communication technologies such as Bluetooth or Zigbee for vehicle-to-infrastructure communication can enable real-time data exchange between the vehicle and charging road, improving system intelligence and operational efficiency.

Furthermore, the scalability of the technology allows for gradual implementation in urban areas, starting with key locations such as bus routes, taxi fleets, or dedicated EV lanes, before expanding to broader applications. By leveraging existing infrastructure, such as public transportation corridors or commercial parking lots, and adapting current road technologies, the system can be gradually deployed without the need for major new investments. Moreover, the combination of smart grid technology with vehicle-to-grid (V2G) capabilities can allow for two-way energy transfer, enabling vehicles to not only charge while in motion but also contribute back to the grid during off-peak hours, further enhancing the economic feasibility of the system.

In conclusion, the integration of dynamic wireless charging systems into the real world can be realized through strategic use of low-cost, readily available technologies. By combining mass production methods, existing infrastructure, and scalable system design, dynamic wireless charging can offer a sustainable and affordable solution to the growing demand for electric vehicle charging, providing convenience for EV owners while contributing to the development of smart, energy-efficient cities.

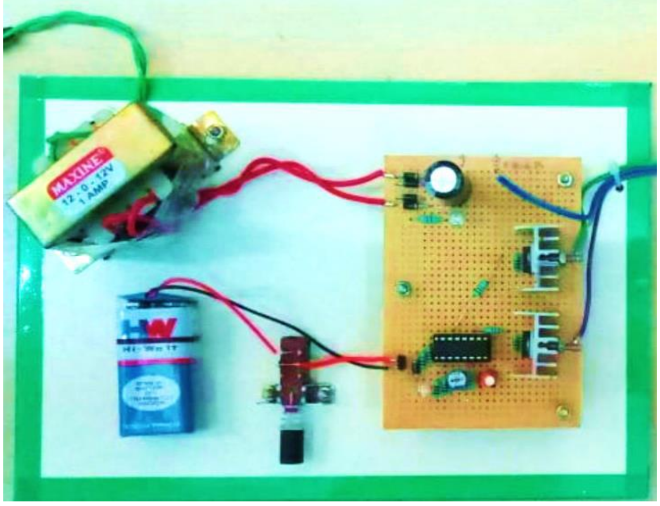

Figure 5: Existing Model

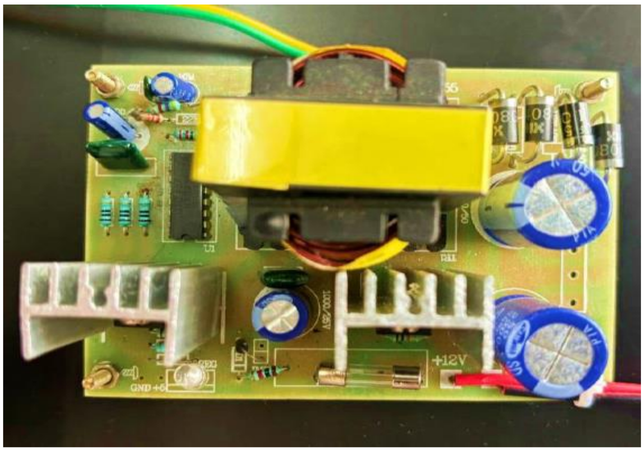

Figure 6: Fabricated Model

IX. CONCLUSION

In conclusion, the dynamic wireless charging system for electric vehicles (EVs) represents a revolutionary advancement in the realm of sustainable transportation. By leveraging high-frequency power electronics, advanced inductive charging technology, and efficient control systems, this project demonstrates the potential to significantly enhance the convenience, accessibility, and efficiency of EV charging. The integration of cost-effective components, coupled with the scalability and adaptability of the system, offers a promising solution to address the growing demand for EV infrastructure while reducing dependence on traditional charging methods. This system, when implemented in urban environments, has the capability to transform transportation networks, enabling seamless, continuous energy transfer to vehicles in motion, thereby enhancing the range and practicality of EVs.

However, while the system showcases substantial promise, there are several recommendations for further optimization and widespread deployment. First, the efficiency of energy transfer should be continuously evaluated and improved through further research and refinement of the power electronics, particularly with respect to the alignment and positioning of the transmitting and receiving coils. Additionally, the cost-effectiveness of the system could be enhanced by focusing on material innovations and reducing the complexity of the power conversion components. Furthermore, for widespread adoption, it is crucial to ensure that regulatory frameworks and safety standards are established to guarantee safe and efficient operation in diverse real-world environments. Collaboration between industry stakeholders, government bodies, and urban planners is essential to ensure seamless integration into existing infrastructure, with a focus on minimizing installation costs and maximizing public accessibility. Lastly, ongoing research into the integration of vehicle-to-grid (V2G) systems could enable bi-directional energy transfer, allowing EVs to not only receive power while in motion but also contribute to the grid during periods of low demand, further enhancing the system's utility and sustainability.

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