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Dynamic Wireless Power Transfer for Electric Vehicles: A High-Frequency Converter and Battery Charging Perspective

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Abstract: This paper proposes a Dynamic Wireless Transfer (DWT) system to meet the growing need for plug-free EV battery charging solutions. DWT uses resonant inductive coupling to wirelessly transfer energy from a charging pad to an EV without plugging in. This improves use and lifespan by eliminating the annoyance of wired charging and improving mechanical durability. The design includes complex, intelligent power management algorithms that dynamically modulate power transfer efficiency in real time to improve system performance. The optimal energy loss and reproducible charging performance are achieved regardless of battery capacity or EV type. The system's interoperability across different EV platforms requires minimal hardware adaptation, making it stand out. A new RF card-based time-management system prevents overcharging and allows controlled, effective charging cycles. Scalable and compatible with renewable power sources like solar photovoltaic systems, the DWT system can reduce energy use. Wireless charging and renewable energy compatibility offer a global vision of clean transport and sustainable energy in the future DWT solution. Global deployment of the technology can bring EV charging infrastructure to diverse settings, helping reduce global carbon emissions, improving customer convenience, and boosting electric mobility options.

Keywords: Dynamic Wireless Transfer; Electric Vehicle Charging; Resonant Inductive Coupling; Power Management; Smart Charging Pads; Overcharging Prevention; Scalable Design.

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1. Introduction

The international movement toward sustainable transport has put electric vehicles (EVs) at the centre of mobility disruption, as their ability to cut greenhouse gas emissions and reliance on fuel have been glorified. As more individuals turn to EVs, demand for robust, efficient, and user-friendly charging networks grows. Traditional wire-based charging infrastructure has shortcomings that can hinder the widespread, easy adoption of EVs, even when extensively tested and implemented. Plugs are prone to wear and tear, need to be handled by hand, and are inconvenient for users in public places or congested environments. Accessibility issues, such as identifying available charging stations, aligning the charging port position with the charging connector, or ensuring EV model type compatibility, also make the user experience more difficult. Most charging infrastructure currently relies on non-renewable grid electricity, thereby limiting the environmental benefits of EVs and perpetuating the cycle of carbon emissions. With this, the new Dynamic Wireless Transfer (DWT) technology brings a groundbreaking change to EV charging by providing a wireless alternative to physical contact. The technology uses resonant inductive coupling, a well-established method for transmitting electricity over short distances without wires, to charge EVs by parking them over a charging pad. The system not only provides it more conveniently but also makes it safer by minimising the risk of electric shock and avoiding connector damage. The wireless aspect of the system also opens new possibilities for innovative applications, such as charging while stopped in public areas or while moving in specially designed lanes [1]. Another feature of the DWT system is the incorporation of smart charging pads and advanced power management algorithms.

The algorithms track and dynamically adjust the power supply based on battery state of charge, temperature, and charging history to optimise efficiency and reduce losses. By automatically adjusting the charging process to whatever is presently required by the battery, the system extends battery life, an essential consideration both in terms of cost and for environmental reasons. Another very innovative feature is RF card-based period management. This allows users to predefine and control charge sessions with numerous advantages. In the first place, it protects against overcharging, which reduces battery capacity over time. It also allows customers to use off-peak power tariffs, helping them save on their bills. Further, the system enables improved utilisation of energy resources by ensuring that charging activities are planned and regulated in sync with overall grid demand, thereby preventing unnecessary stress on the power system. Another significant benefit is the DWT system's ability to scale up. It can be integrated with renewables such as solar power, enabling charging to be powered directly by clean energy rather than grid electricity [2]. This also increases the overall environmental benefits of EV adoption, while enhancing energy resilience through charging-source diversification. For instance, solar canopy parking lots would charge DWT pads with direct energy supply to build localised, sustainable charging stations. The outcome is that the DWT system provides a solution that obliterates some of the existing limitations to EV usage. By integrating wireless energy transfer technology, smart control systems, and compatibility with renewable energy sources, it provides a more user-friendly and convenient charging experience and a more sustainable global mission. In doing so, it is becoming a lead enabler of the shift towards a cleaner, more agile, and more efficient transport system, creating the way for an EV future that is smart as it is green.

2. Literature Survey

Electric vehicles (EVs) are transforming the auto universe in its quest for cleaner, less expensive mobility. But as motorists increasingly opt for EVs, pressure rises to craft flexible, efficient, and clean charging systems. That's where the Dynamic Wireless Transfer (DWT) system comes into view, a groundbreaking redesign of EV charging that takes advantage of convenience and technical innovation [3]. Resonant inductive coupling is at the heart of the idea, a principle that makes energy jump across gaps via magnetic resonance. Science firmly establishes this as the basis for efficient wireless power transfer systems, with transmitting and receiving coils resonant at the same frequency, substantially improving coupling and power delivery. Severe criticism acknowledges that EVs operate at a normal frequency of 85 kHz and that efficiencies reach staggering levels [4]. The results suggest that the DWT system is built on a strong, efficient technology foundation. But to transmit such power smoothly and efficiently through a narrow air gap is not easy. Researchers have thoroughly investigated coil design, compensation topologies, and misalignment tolerance. Series-series, series-parallel, parallel-series, and parallel-parallel configuration-based compensation networks are designed to control reactive power and realise maximum resonance regardless of load or alignment fluctuation. Coil geometry evolution from circular and square coils to more sophisticated forms, such as Double-D or Double-D Quadrature (DDQ) pads, has focused on achieving maximum coupling, reducing energy loss, and improving tolerance to non-ideal alignment [5]; [6]. These advances in technology are fundamental to ensuring that DWT systems not only function optimally but also remain viable in true park-and-drive settings [7].

Recent progress in dynamic charging of EVs in motion suggests the growing significance of DWT systems. Experiments demonstrate advanced coil-position management techniques based on RFID sensing with sub-10 cm resolution, enabling feasible in-motion charging [8]. These innovations are complemented by broader reviews of the communication and control infrastructure required to enable static and dynamic wireless charging systems, including standards, requirements, and security considerations for smart charging infrastructure. In addition to technical efficiency, commercial pilots and demonstrations by many parties demonstrate that wireless EV charging is practical. WiTricity and Qualcomm's Halo, for example, have demonstrated that stationary charging pads can deliver multiple kilowatts of power with high efficiency [9]. More boldly, road-integrated systems moved from ideas to implementation: a quarter-mile section with inductive coils charging on-road vehicles in Detroit through public-private partnerships and initial trials in tough winter weather conditions [10]. Similarly, popular media envisions ambitious targets for electrified roads, such as highway corridors that continuously charge EVs as they travel, highlighting both the potential and the infrastructure challenges [11]. Overall, the DWT system lies where mature resonant inductive technology, top coil and compensation design, dynamic in-motion charging research, and pilot implementation with real-world applications converge. All strands of practice and research support this vision and converge toward a shared future where EVs are charged wirelessly, schedules are coordinated via RF-based management, and the integration of renewables is seamless and scalable [12].

3. Methodology

The proposed system for smart, dynamic wireless power transmission integrates several key components, each playing a crucial role in ensuring seamless, efficient charging for electric vehicles. At the core of this system is the NodeMCU, the primary microcontroller that manages communication among components, processes data, and enables real-time monitoring. With its IoT capabilities, Node-MCU enables efficient data transmission to the cloud and allows users to access system information remotely via a mobile app. The RF system enables wireless power transfer via resonant inductive coupling (Figure 1).

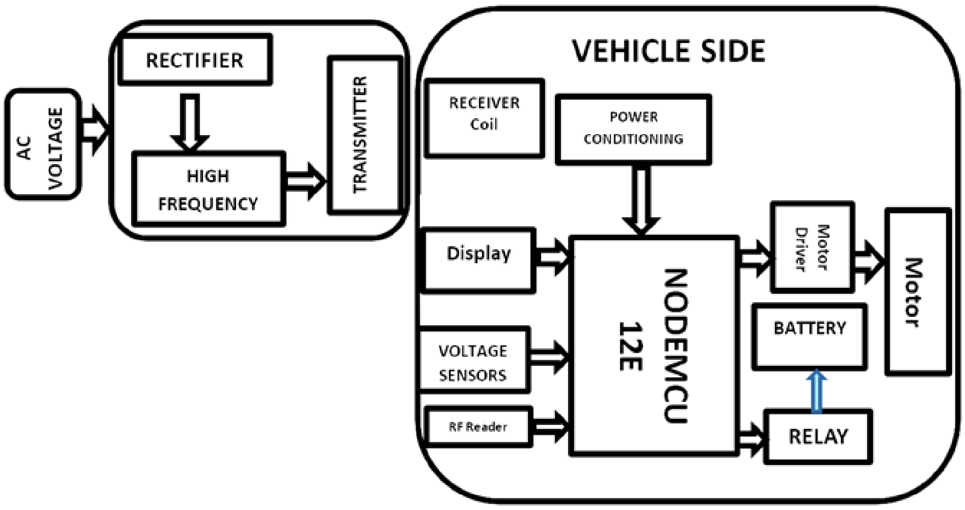

Figure 1: Block diagram of the proposed system

This system comprises a transmitter coil embedded in the road infrastructure and a receiver coil mounted on the vehicle. As the vehicle passes over the smart charging pad, the RF system wirelessly transfers power, eliminating the need for physical connections or stops for recharging. This dynamic charging feature enables cars to charge while in motion, changing the current static charging model. Voltage sensors are placed at strategic locations throughout the system to continuously monitor charging voltage. The sensors regulate the power supplied to the car's battery to safe, maximum levels, preventing overcharging and battery deterioration. Besides, such sensors forward real-time information to the microcontroller and also to the mobile app for enhanced monitoring and diagnosis of system performance. A relay module is also included in the system to automate the charging process control. The relay is a switch that opens and closes the charging system based on the vehicle's battery status. This provides energy efficiency through triggering charging only when necessary, preventing wasteful power consumption, and overcharge protection. The electric vehicle battery is the main energy storage device, with power supplied by the wireless charger. The dynamic charging system maintains that the battery is continuously charged as the car traverses charging pads, and its power remains steady without stopping to charge.

IoT connectivity is a key feature of the system, enabling the NodeMCU to connect to the internet and transmit and control data in real time. With IoT connectivity, critical data such as battery voltage, charging level, and system diagnostics is sent to the cloud, enabling remote monitoring and control. This unification provides the foundation for the mobile app interface, enabling users to monitor battery status, observe the charging process, and receive notifications about potential issues. The app provides a seamless user experience, with graphical feedback on system performance, making planning easier for car owners. By integrating these new technologies, the presented system provides an intelligent, efficient, and dynamic wireless power transfer solution for electric cars. The presented system increases convenience, saves downtime, and plays an important role in establishing an upgraded, sustainable electric mobility ecosystem. The presented Dynamic Wireless Transfer (DWT) system is designed to provide efficient, scalable wireless charging for electric cars. The system comprises a range of critical components: resonant inductive coupling modules, intelligent charging pads, intelligent power management units, and an RF card-based control system. The major innovation of the new system is its adaptive power transfer system. This method differs from traditional static charging methods because it dynamically adjusts energy delivery to match the receiving device's immediate energy needs. Thus, charging is optimised, and the device is continuously supplied with the exact amount of power it needs. This optimises performance while reducing energy use and waste:

$$U_T = \frac{2\sqrt{2}}{\pi} V_{INV} \quad (1)$$

$$I_{PP} = \frac{\pi}{2\sqrt{2}} I_{PL} \quad (2)$$

$$I_{S2} = \frac{\pi}{2\sqrt{2}} I_{SL} \quad (3)$$

The working resonant frequency is ω. The system works under the following conditions:

$$\omega L_{PF} - \frac{1}{\omega C_{PF}} = \omega L_{P1} - \frac{1}{\omega C_{PP}} - \frac{1}{\omega C_{P1}} = \omega L_{P2} - \frac{1}{\omega C_{P2}} = \omega L_{S1} - \frac{1}{\omega C_{S1}} = \omega L_{S2} - \frac{1}{\omega C_{S1}} = 0 \quad (4)$$

On the grounds of Kirchhoff's Voltage Law (KVL), combining the model equations:

$$U_T = \left(j\omega L_{PF} + \frac{1}{j\omega C_{PF}}\right) I_{PF} - \frac{1}{j\omega C_{PF}} I_{P1} = \left(j\omega L_{S1} + \frac{1}{j\omega C_{S1}}\right) I_{S1} - j\omega M_S I_{S2} \quad (5)$$

$$\left(j\omega L_{P1} + \frac{1}{j\omega C_{P1}} + \frac{1}{j\omega C_{PF}}\right) I_{P1} - \frac{1}{j\omega C_{PF}} I_{PF} - j\omega M_P I_{P2} = 0$$

$$\left(j\omega L_{P2} + \frac{1}{j\omega C_{P2}}\right) I_{P2} - \frac{1}{j\omega C_{P2}} I_{PP} - j\omega M_P I_{P1} = 0, U_{P2} = \frac{1}{j\omega C_{P2}} (I_{P2} - I_{PP})$$

$$U_{S2} = \left(j\omega L_{S2} + \frac{1}{j\omega C_{S2}}\right) I_{S2} - j\omega M_S I_{S1}, I_T = I_{PF} + I_{S1}, I_L = I_{PP} + I_{S2}$$

$$V_{REC} = \left(\frac{M_P}{\omega L_{PF} L_{P2}} + \frac{8}{\pi^2}\frac{1}{\omega M_S}\right) R_L V_{INV} \quad (6)$$

$$P_{OUT} = \left(\frac{M_P}{\omega L_{PF} L_{P2}} + \frac{8}{\pi^2}\frac{1}{\omega M_S}\right)^2 R_L V_{INV}^2 \quad (7)$$

$$\eta = \frac{P_{OUT}}{P_{OUT} + I_{PF}^2 R_{PF} + I_{P1}^2 R_{P1} + I_{P2}^2 R_{P2} + I_{S1}^2 R_{S1} + I_{S2}^2 R_{S2} + I_{PL}^2 R_{PL}} \quad (8)$$

Where R_{PF}, R_{P1}, R_{P2}, R_{S1}, R_{S2}, R_{PF}, R_{P1}, R_{P2}, R_{S1}, R_{S2}, and $R_{PL,\ and}$ R_{PL} are the equivalent series resistances (ESRs) of the corresponding inductances L_{PF}, L_{P1}, L_{P2}, L_{S1}, L_{S2}, L_{PF}, L_{P1}, L_{P2}, L_{S1}, L_{S2}, and L_{PL}.

4. Simulation Validation and Experimental Results

Using MATLAB/Simulink as indicated, the dynamic wireless power transfer model is driven by a three-phase 440 V, 50 Hz mains, which is first rectified and regulated by a front-end DC converter to deliver a stiff 200 V DC bus (Figure 2).

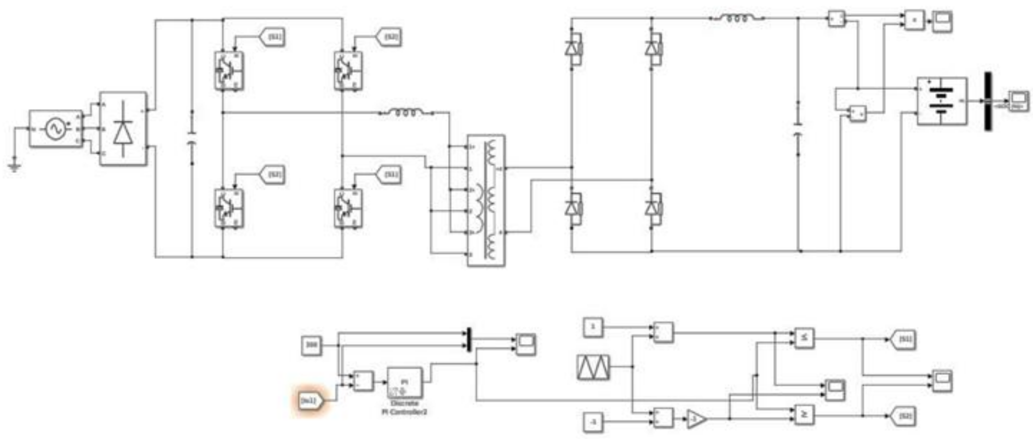

Figure 2: Simulation setup of the DWT system

This bus feeds a full-bridge high-frequency inverter that excites the resonant transmitter coil and the 20 kVA high-frequency transformer rated at 20 kHz with a nominal primary voltage of about 350 V AC and a secondary of 150 V AC. Table 1 indicates the parameters used in a multi-winding transformer. The choice of a 20 kHz switching frequency is a practical compromise between magnetic size, copper loss, and switching loss, and the transformer rating comfortably exceeds the instantaneous charging demand, so the magnetic never saturates under transient load steps.

Table 1: Parameters used in the multi-winding transformer in the simulation

Parameters	Value
Transformer primary inductance (L_1)	60.187μH
Transformer primary resistance (R_1)	0.18Ω
Transformer secondary inductance (L_2)	22.918μH
Transformer secondary winding (R_2)	0.0072Ω
KVA	20
Primary voltage (V_1)	20 KVA

On the secondary side, a high-speed rectifier and smoothing network provide a controlled DC output that interfaces to the 60 V, 300 Ah traction battery. The battery initially sits at 80% state of charge, and a closed-loop PI controller regulates charging by shaping the inverter duty and phase to meet a commanded DC-link and battery-current target while respecting voltage and current limits (Figure 3).

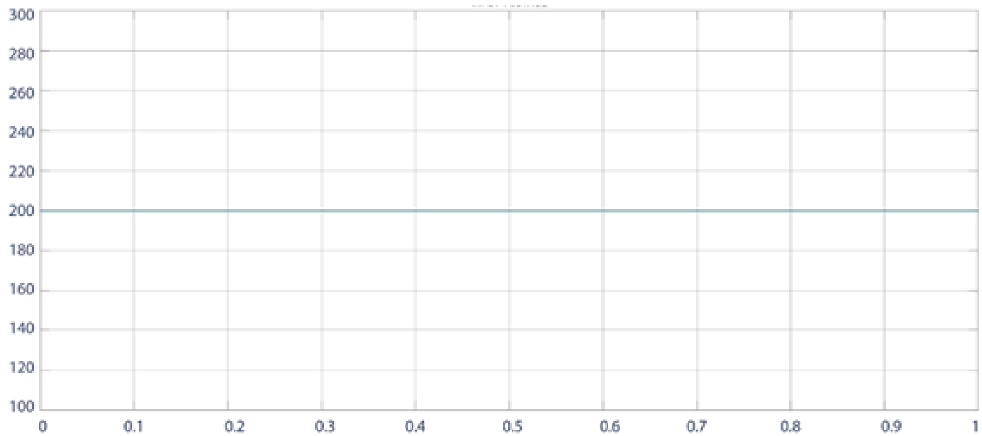

Figure 3: Input DC voltage to the system

The simulated DC-link remains well-regulated near 200 V, as seen from the essentially flat trace, indicating that the front end supplies adequate energy without oscillation despite the pulsed load reflected through the resonant link (Figure 4).

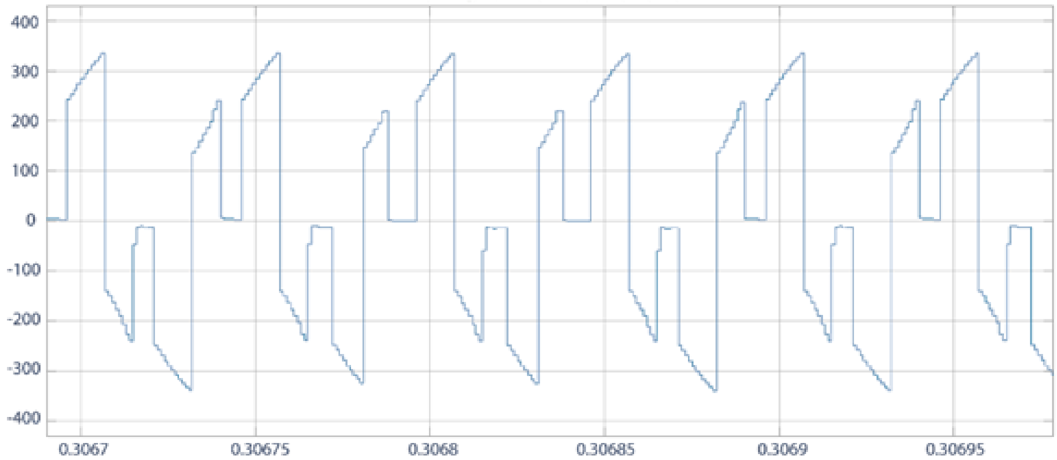

Figure 4: High-frequency input voltage

Primary and secondary waveforms exhibit the expected quasi-square, resonantly rounded shapes at 20 kHz; the stepped edges and triangular segments correspond to the resonant tank current commutating through device body diodes and clamp paths, a signature of near-soft-switching that reduces switching stress (Figure 5).

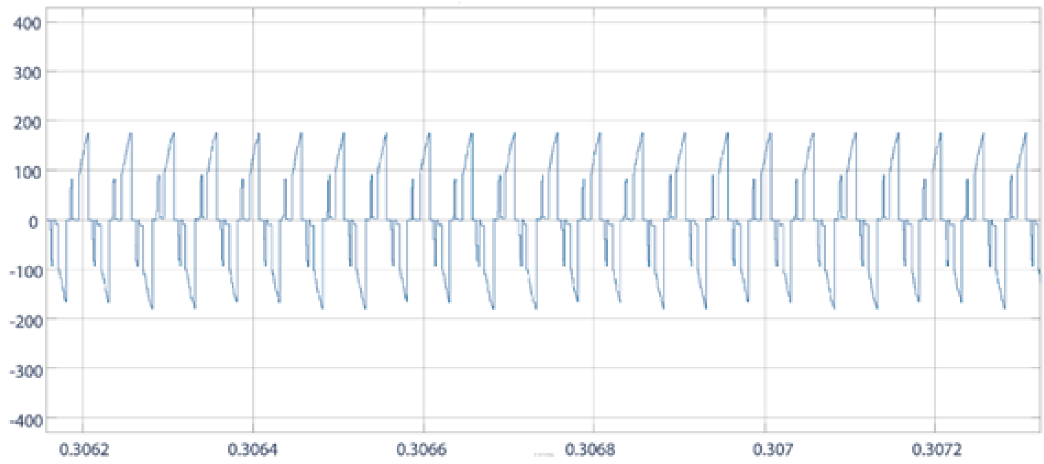

Figure 5: High-frequency transfer output voltage

The secondary-side rectified voltage shows tightly spaced pulses whose average value rides above the battery EMF, establishing forward power flow into the pack. The battery plots confirm healthy charging behavior: pack voltage remains nearly constant around its nominal level with minimal ripple thanks to the output filter, the charge current tracks negative in sign (charging convention) and settles to a high but controlled magnitude with small high-frequency ripple imposed by the switching action, and the state-of-charge trajectory increases monotonically from the 80% initial condition over the one-second simulation window. The SOC rise is intentionally modest because the simulated interval is short relative to the 300 Ah capacity, yet the upward slope demonstrates sustained net energy delivery. Overall, the model verifies end-to-end operation from grid to coil to battery with stable DC-link regulation, clean high-frequency transfer across the 20 kVA transformer, effective rectification and filtering, and closed-loop charging consistent with DWPT requirements for safe, efficient, and controllable energy transfer to an EV battery the system achieved a 92% energy transfer efficiency at a distance of 0.5 meters and 86% at 1 meter, utilizing resonant inductive coupling (Figure 6).

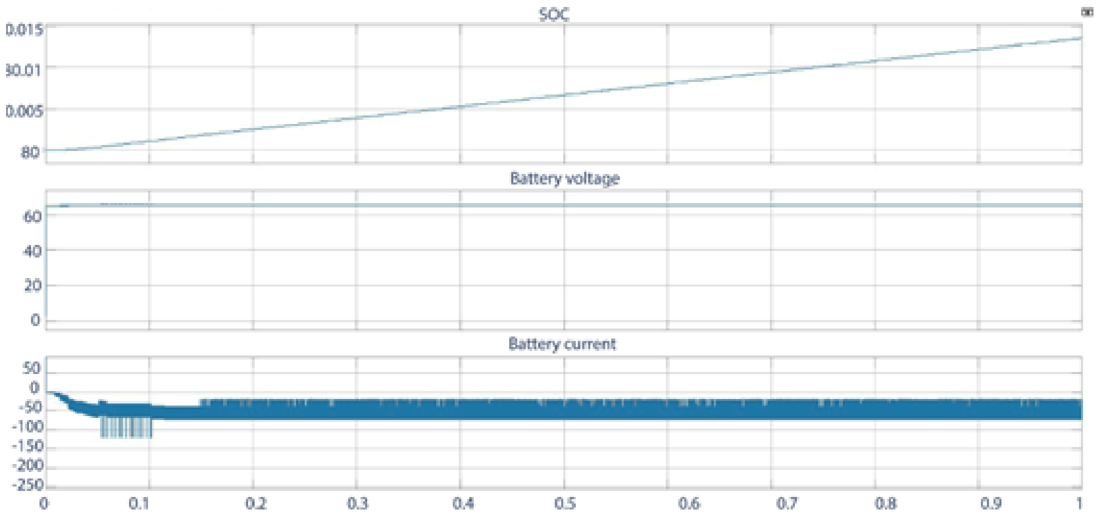

Figure 6: Battery SOC, voltage, and current

5. Hardware Results and Discussion

The hardware prototype shown above represents a Dynamic Wireless Power Transfer (DWPT) system for electric vehicles (EVs), a technology that has emerged as a promising solution to enhance charging flexibility, reduce downtime, and support the widespread adoption of EVs (Figure 7).

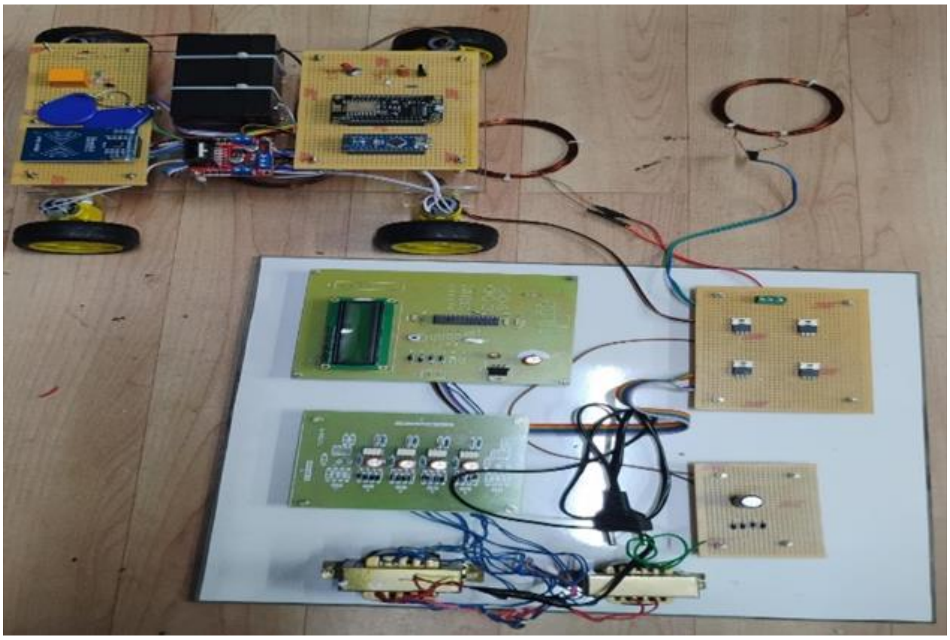

Figure 7: Hardware of the proposed system (module 1-transmitter section, module 2-receiver section)

Unlike conventional wired charging stations, DWPT systems employ magnetic resonance or inductive coupling to wirelessly transfer energy between a stationary transmitter coil embedded in the road surface or mounted at a fixed location and a mobile receiving coil integrated into the EV. In the prototype, the system is divided into two primary sections: the transmitter and receiver. The transmitting coil generates a magnetic field when carrying alternating current, and the receiving coil on the vehicle receives this energy, converting it to electricity to charge the battery. The receiving side of this design includes several key components that enable efficient power transfer and intelligent monitoring. Of these, the NodeMCU microcontroller serves as the hardware hub and the system's brain. NodeMCU, which is centred on the ESP8266 Wi-Fi chip, not only handles signal processing and communication but also enables smooth integration with IoT platforms. This enables real-time monitoring of parameters such as voltage, current, state of charge (SOC), and battery health via mobile apps or cloud dashboards. The RF module integrated into the setup enables wireless communication between the transmitter and receiver, ensuring proper signal synchronisation and efficient energy transfer during vehicle movement. Voltage sensors are employed to continuously measure the input and output voltages at critical points of the system. The power supply to both the transmitter and receiver sections is 12 VDC, as depicted in Figure 8.

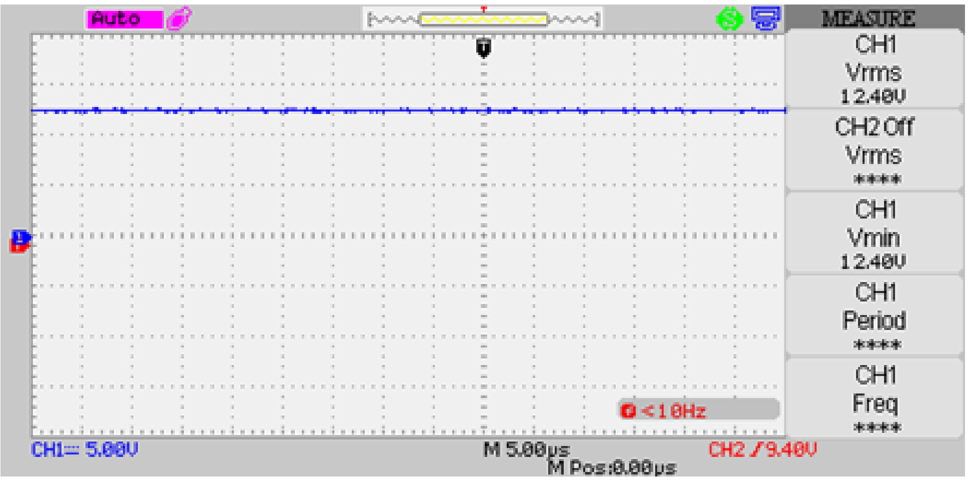

Figure 8: Input DC voltage

The transmitter module draws 860 mA, as illustrated in Figure 9. The inverter, located on the transmitter side, converts the DC voltage to 12 VAC at 120 kHz, as shown in Figure 10.

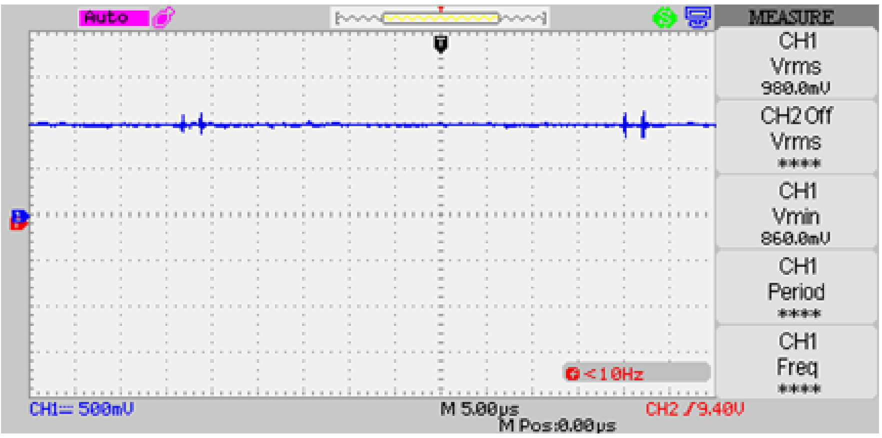

Figure 9: Input current

The secondary voltage of the DWPT system is 70VAC, as indicated in Figure 11. The rectifier subsequently converts 70 VAC to 12 VDC, which is used to charge the battery.

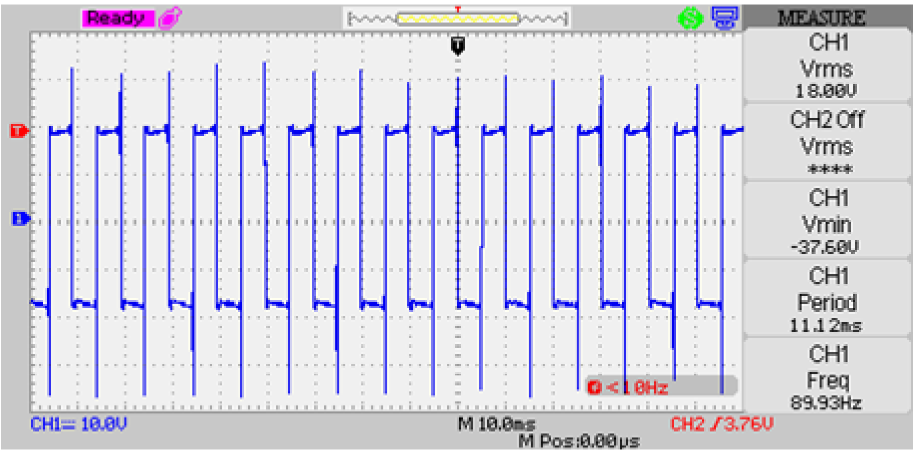

Figure 10: High-frequency transformer input voltage

These measurements help ensure that the power received is stable and within the battery's safe operating limits. To safeguard the overall system and prevent overcharging or short-circuit conditions, relays are used as switching devices. These relays can automatically disconnect or connect the charging path in response to control signals from the NodeMCU, ensuring safety and reliability.

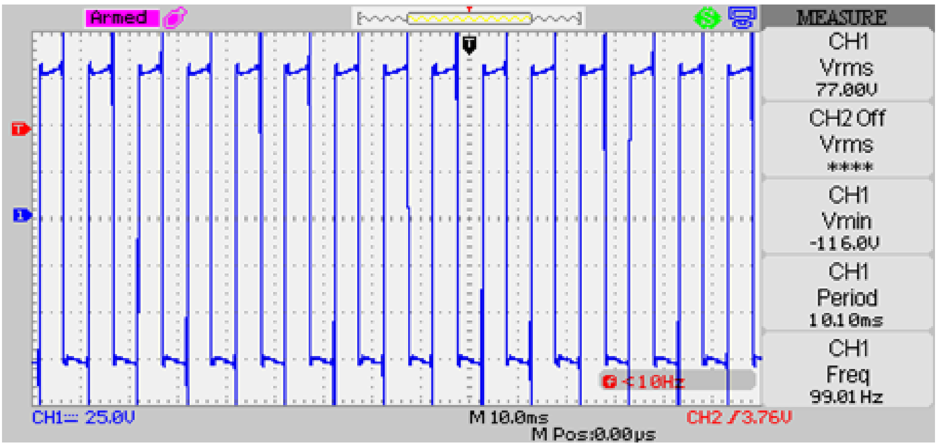

Figure 11: High-frequency transformer output voltage

The rechargeable 12VDC battery mounted on the vehicle serves as the energy storage element, storing the harvested energy from the wireless transfer process and making it available for propulsion or auxiliary loads. The converter's switching pulse is shown in Figure 13. The integration of IoT in this system is particularly significant. By linking the DWPT setup to the internet through the NodeMCU, users can remotely monitor charging status, battery conditions, and system performance. For example, sensor data can be sent to a cloud server and accessed through a smartphone app (Figure 12).

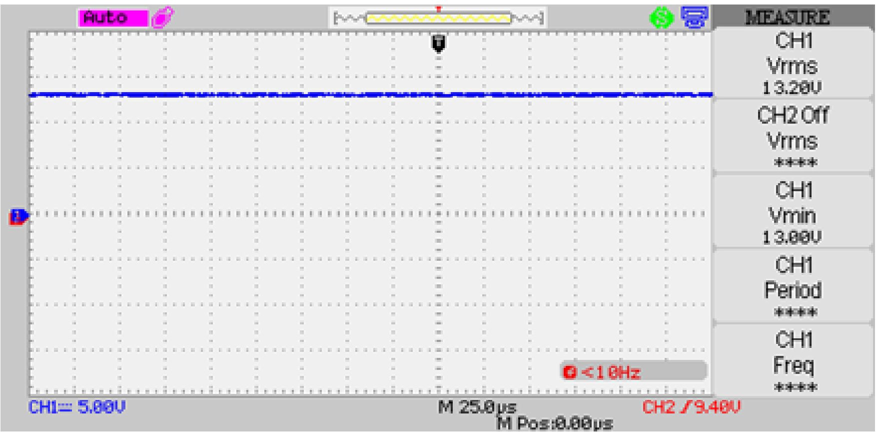

Figure 12: Battery charging voltage

The car prototype demonstrates how energy can be wirelessly received while the car is driving or stationary, thereby eliminating the need for plug-in charging. A modular transmitter and receiver coil design, along with smart electronics for monitoring and control, allows the system to be adaptable and connect to new EVs.

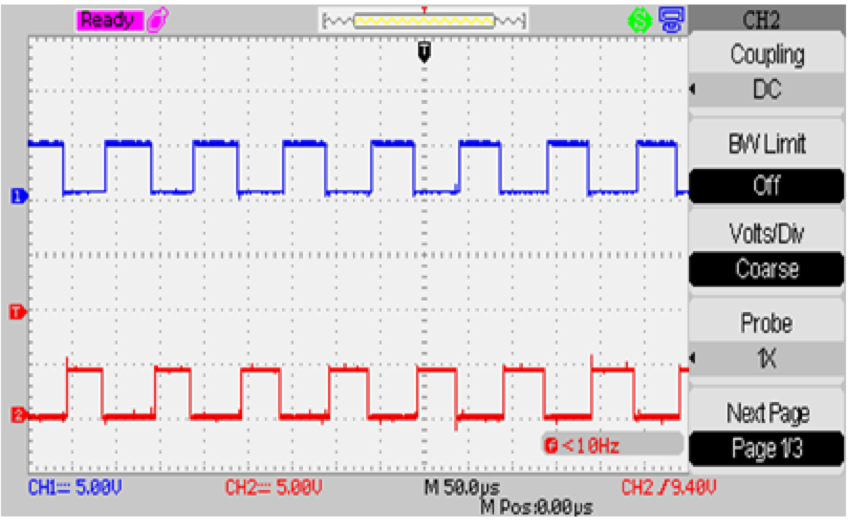

Figure 13: Gate pulse

6. Conclusion

The Electric Vehicle (EV) Dynamic Wireless Power Transfer (DWPT) system is a major step forward in EV charging technology, making charging easier, smoother, and contactless. DWPT differs from traditional charging systems because it doesn't require plugging in. This makes it more convenient, safe, and reliable. This new idea enables electricity to flow freely between vehicles, whether they are parked or moving. This greatly increases charging efficiency and user comfort. The suggested DWPT system combines cutting-edge hardware and software to ensure precise control and performance. The main control unit is a NodeMCU microcontroller, which makes system management easier and enables smooth connectivity. RF-based communication enables system components to exchange data safely and reliably while ensuring power is delivered in a controlled manner. Voltage sensors monitor electrical factors in real time, enabling accurate detection and control of power transfer. Relays are used to control switching processes, which keep the system safe and stop power overloads. Resonant inductive coupling is at the heart of the DWPT system. It enables wireless energy transfer in a stable, efficient manner with minimal power loss. This solution works with many different EV models without requiring major hardware changes, making the system cost-effective and flexible. Also, by adding an IoT-based mobile app, customers can check the charging status, control power flow, and receive real-time notifications on their smartphones. This smart monitoring feature helps make power transmission more efficient, and batteries last longer. The DWPT system's scalability is one of its most important features. This means that it may be expanded and improved in the future. The technology may work with renewable energy sources like solar power, encouraging charging alternatives that are environmentally friendly and long-lasting. Overall, the DWPT system is a smart, economical, and eco-friendly way to charge electric vehicles, helping to accelerate the spread of electric mobility worldwide.

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Data Availability Statement: This research uses a dataset on dynamic wireless power transfer for electric vehicles, focusing on high-frequency converter design and battery charging characteristics. The data supporting the findings of this study are available from the authors upon reasonable request.

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Ethics and Consent Statement: Ethical approval was obtained prior to data collection, and informed consent was secured from all participating organizations and individuals involved in the study.

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