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Dynamic Bidirectional Wireless Power Transfer for Electric Vehicles with Reduced Switching Losses Under ZVS

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Abstract: Wireless Power Transfer Systems (WPTSs) have gained significant attention as an efficient and convenient method for charging electric vehicles (EVs). A major challenge in WPTSs is improving transfer efficiency while maintaining stable voltage and current regulation. Conventional impedance-matching control can enhance system efficiency but often requires additional DC–DC converters or results in hard switching, which increases power losses. To overcome these limitations, this work investigates a bidirectional dynamic wireless charging system for EVs operating under Zero Voltage Switching (ZVS) conditions. The proposed system employs a converter to generate high-frequency AC for wireless transmission. A feedback loop incorporating voltage and current signals is processed through a PI controller to generate optimised gating pulses for both primary and secondary converters, ensuring ZVS operation. The receiving side delivers power to a 48 V lead-acid battery, with charging and discharging characteristics that demonstrate bidirectional energy flow between the grid and the vehicle. Simulation results demonstrate the system's ability to operate in both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) modes. Furthermore, a comparative evaluation of instantaneous efficiency with and without ZVS confirms the reduction in switching losses and the enhancement of overall system performance.

Keywords: Wireless Power Transfer; Inductive Coupling; Zero Voltage Switching; Electric Vehicle; System Performance; Voltage and Current Regulation; Dynamic Wireless Charging.

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1. Introduction

The rapid growth of electric vehicles (EVs) has created an urgent need for efficient, convenient, and reliable charging technologies to support widespread adoption. Traditional plug-in charging methods, although widely used, face several challenges, including user inconvenience, safety concerns associated with exposed conductors, and limitations in integrating advanced functionalities such as bidirectional power flow. Wireless Power Transfer Systems (WPTSs) have been identified as a highly suitable option for contactless energy transfer between the vehicle and the grid. In the absence of physical connectors,

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WPTSs increase user convenience and security while reducing maintenance needs, making them highly desirable for future transportation systems [6]. Despite such benefits, efficiency limitations limit the practical application of WPTSs. The switching characteristics of the power converter primarily determine the efficiency of wireless charging. Traditional impedance-matching control methods have been proposed to efficiently control voltage and current. Still, they require additional DC–DC conversion stages or involve hard switching, leading to increased switching losses and decreased overall efficiency. To address this limitation, Zero Voltage Switching (ZVS) has attracted considerable attention as an effective means to reduce switching losses, lower power device stress, and improve system efficiency. Maintaining ZVS across all switches ensures energy transfer with minimal dissipation and enables WPTSs to operate at near-theoretical efficiencies. Bidirectional power transfer is another novel achievement in EV charging technology. While conventional charging focuses on Grid-to-Vehicle (G2V) power transfer, bidirectional charging enables power to be pumped back to the grid from vehicle battery stored energy, using the generic term Vehicle-to-Grid (V2G). This characteristic transforms EVs into distributed energy resources with the potential to provide grid stability, support demand-side management, and facilitate renewable energy integration.

The marriage of wireless power transmission with bidirectional ZVS operation will open new opportunities for both car users and utility companies, placing EVs at the heart of future smart grids [1]. This paper highlights the modelling and analysis of a bidirectional dynamic wireless EV charging system under ZVS conditions. The system is modelled using MATLAB/Simulink [11]. A typical 220 V, 50 Hz AC source is used to supply the system. The AC source is rectified and supplied to a high-frequency AC inverter subsystem optimised for ZVS operation. The voltage and current feedback signals are processed by a proportional–integral (PI) controller to generate accurate gating pulses for the converters. This ensures ZVS is maintained at all times, reducing switching losses and boosting system efficiency. On the receiving side, the secondary converter supplies power to a 48 V lead-acid battery, enabling continuous charging. Moreover, bidirectional functionality is confirmed by simulating a reverse power flow from the battery to the grid, which represents the V2G procedure. The significance of this work lies in its dual contribution: first, it demonstrates how ZVS can be effectively employed to enhance the performance of wireless charging systems; second, it highlights the practical benefits of bidirectional energy flow for future EV-grid integration. Comparative analysis of system performance with and without ZVS further confirms the effectiveness of the proposed method. As EV implementation continues to accelerate, such advanced wireless charging solutions will play a vital role in enabling sustainable, efficient, and intelligent energy ecosystems [2].

2. Literature Review

The body of research on wireless power transfer (WPT) for electric vehicles has steadily advanced along three intertwined lines: (i) hardware topologies and compensation networks for efficient power exchange, (ii) control methods for impedance matching and soft switching, and (iii) bidirectional operation enabling G2V/V2G energy flow. Early experimental validation on series–series (S–S) compensated links set the foundation for practical insights into coupling, tuning, and bidirectionality. De Lacerda et al. [3] proposed an experimental bidirectional S–S IPT system with low power, focusing on hardware feasibility and on the controller coordination for primary/secondary bridges. Although at modest power, the study confirmed symmetry of the S–S link during power reversal and reported issues with sustaining soft switching across modes and load changes. Transfer physics and dynamic charging are among the prominent avenues. Li et al. [4] investigated electric-field resonance WPT and its use in dynamic environments, moving beyond simple magnetic coupling. They were specifically concerned with regulation and safety issues in road scenarios involving gap and alignment changes, eliminating the need for tight regulation and soft-switching techniques under motion. In vehicle applications, Buja et al. [7] presented the design and testing of an electric city car WPT charger, with system-level verification of automotive-grade integration, including coil design and compensation, rectification, and the battery interface. With support from hardware analysis, Li et al. [8] proposed maximum efficiency point tracking (MEPT) for magnetically resonant systems and demonstrated that closed-loop tuning of operating points (not constant-current/voltage) could minimise losses due to parameter drift and misalignment [14].

Impedance matching and phase-shift coordination have become the most prevalent means of efficiency preservation across varied conditions. Jiang et al. [5] provided a complete suite of techniques. Their 2018–2020 research shifts from system design to the development of accurate control laws: optimal-frequency band selection for charging EVs, accurate ZVS-angle control of high-power WPT, PLL-aided chained-trigger schemes for impedance matching, double-side phase-shift (DSPS) regulation, and variable-angle phase shift of S systems [15]. Together, these papers illustrate that traditional single-sided phase control is typically not appropriate in the presence of load, coupling, or dc-link level variations; soft switching can be preserved, power controlled, and the converter kept close to its efficiency sweet spot with orchestrated primary–secondary control [9]. Their APEC paper also improves ZVS-angle selection for constant-current charging, directly relating soft-switching margins to battery-charging profiles and component stresses [10]; [17]. These form the basis for high-power EV applications, where switching losses and device stress determine reliability and thermal design. On the converter side, cutting-edge modulation technology has been implemented to expand the ZVS range. Li et al. [16] introduced a full-range, low-subharmonic, high-speed pulse-density modulation (PDM) technique for full-bridge ZVS operation to overcome the inherent limitation: traditional phase-shifted modulation loses ZVS at light load or during transients. By controlling pulse density instead of phase only, they expand the operating window for soft-switching and remove acoustic/subharmonic artefacts, thus enhancing dynamic response, a feature particularly applicable to dynamic charging and bidirectional operation where load steps and reversal of direction recur with frequency. Synthesizing these threads, the literature establishes that (a) S–S compensation is appealing for bidirectional EV charging because of its symmetric transfer behaviour; (b) in the generation and sustenance of ZVS in wide operating ranges, coordinated, preferably dual-sided control with direct angle/frequency scheduling is essential; and (c) efficiency-oriented control (MEPT/PDM) needs to be implemented in misalignment, parameter drift, and load fluctuation [12]; [13].

There are still large gaps, though. First, most studies guarantee ZVS in some areas, but comparatively fewer offer a system-level, detailed analysis of power loss, separating the advantage of ZVS at the individual switch leg from the overall system dynamics in both G2V and V2G directions. Second, bidirectional demonstrations at low power exist, and high-power ZVS control is well-developed, but integrated evaluations that simultaneously (i) enforce ZVS for all active devices, (ii) quantify instantaneous efficiency with/without ZVS, and (iii) validate seamless reversal between charging and discharging under grid-connected constraints are less common. Third, dynamic scenarios—motion, coil offset, and time-varying load from battery charging stages—are often addressed separately from bidirectionality, leaving a practical need for unified controllers that guarantee soft switching while managing battery profiles and grid codes. Your current work addresses these gaps by combining a bidirectional S-S-SWPT link with PI-driven ZVS enforcement and explicitly comparing instantaneous efficiency in ZVS versus non-ZVS operation while charting energy flow in both G2V and V2G modes. In doing so, it extends the control-centric literature with a loss-distribution perspective across all switches and bridges, and it complements the experimental bidirectional foundation and vehicle-level implementations with a focused, system-level evaluation directly relevant to EV–grid integration. This positions the paper as a practical step toward high-efficiency, bidirectional, dynamic wireless charging suitable for future smart-grid participation.

3. Methodology

The block diagram in Figure 1 represents the wireless power transfer system used to charge the battery of an electric vehicle. The process begins with an AC source that supplies input power.

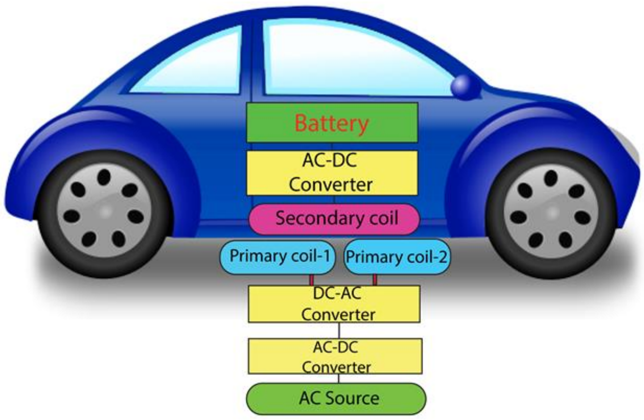

Figure 1: Block diagram of the proposed system

This alternating current is first rectified through an AC–DC converter, ensuring a stable DC supply. The DC power is then inverted back into high-frequency AC using a DC–AC converter, as high-frequency signals are more suitable for efficient inductive power transfer. The generated AC is fed into the primary coils, which create an alternating magnetic field. This is then followed by the secondary coil positioned within the vehicle. The secondary coil, via electromagnetic induction, senses the magnetic flux and converts it back into electrical energy. The induced AC voltage is converted by the onboard AC–DC converter into a stable DC voltage. Lastly, this regulated DC is stored in the vehicle's battery for later use. The wireless nature of the charging system eliminates the need for physical connectors, reduces wear and tear, and improves safety. In addition, the use of dual primary coils enhances alignment tolerance, ensuring efficient power transfer even if the vehicle is not perfectly aligned. The technique generally points toward a compact, efficient, and reliable contactless charging solution for electric vehicles.

3.1. Bidirectional DC to AC Converter

A bidirectional DC-to-AC converter used in this paper is an essential component of power electronics, particularly for electric vehicles. In contrast to the traditional converter, which supplies power in a single direction, the bidirectional configuration can supply power from the DC side to the AC side and vice versa, making the direction of energy management flexible. It is basically an inverter and a rectifier, depending on the system requirements. While operating in inverter mode, the device converts DC power to high-frequency AC power for high-frequency AC charging. While operating in the rectifier mode, it receives high-frequency AC power from the battery through a multi-winding transformer and converts it back to DC. This two-way capability is one possible solution for applications such as energy storage and vehicle-to-grid. The primary approach uses high-frequency switching devices, such as MOSFETs, driven by pulse-width modulation (PWM). In inverter operation, the DC bus voltage is chopped and filtered to produce a sinusoidal AC output. In rectifier mode, synchronised switching efficiently converts AC to high-power-factor DC.

The system also needed control strategies that provide a smooth transition between the two operating modes without causing power disturbances. The use of this system in EV battery energy storage applications is one of its significant benefits. The bi-directional converter controls charging during periods of excess production and discharging during peak demand to optimise the utilisation of renewable energy sources. The converter in electric cars enables charging the traction battery from the grid and allows vehicle-to-grid mode, where excess energy can be returned to the grid when demand is high. Not only does this stabilise the grid, but EV owners also receive economic incentives for it. Reliability and efficiency are yet another key characteristic. Because power can flow in both directions, the converter design should minimise losses by using the best semiconductor materials, soft-switching techniques, and optimised thermal management. In addition, digital controllers execute adaptive algorithms that control voltage, frequency, and current harmonics in accordance with grid codes and safety standards.

3.2. Multi-Winding Transformer for EV Charging Applications

A multi-winding transformer is one of the most important devices used in contemporary electric vehicle charging stations due to its ability to provide isolation, efficient power transmission, and convenience across multiple operating modes. In contrast to a typical two-winding transformer, which has just one primary and one secondary, a multi-winding transformer has additional windings that may perform different functions simultaneously. This makes it suitable for EV applications that require quick charging, supplementary supply, and bidirectional energy transmission. The given specifications show three windings and mutual parameters: Winding 1 has a resistance of 0.01 ohm and an inductance of 0.08793 mH; Winding two also has a resistance of 0.01 ohm and an inductance of 0.08793 mH; and Winding 3 has a resistance of 0.01 ohm and an inductance of 0.1261 mH. In contrast, the mutual impedance is 0.1 ohms with 0.02106 mH of inductance. These parameters define the electrical conditions within the transformer and determine how it would behave during EV charging. The principle of operation is based on Faraday's law of electromagnetic induction. When alternating current flows through the primary winding, a time-varying magnetic field is created in the core. This flux links with the other windings, inducing voltages according to the number of turns and the rate of change of flux. In a multi-winding transformer, several secondaries can be designed to provide different voltage and current levels to meet requirements.

In EV charging stations, this is crucial because batteries require specific charging voltages and currents that vary with the state of charge, battery type, and charging profile. By connecting each winding to a different power electronic converter, the transformer enables the system to deliver safe, efficient charging power. The resistance values in the given design are very low at 0.01 ohms per winding, which is beneficial because it reduces copper losses and minimises heat generation. In high-power EV charging, where currents can be very large, even small resistances can cause significant energy loss, so low-resistance windings directly improve efficiency. The inductance values determine each winding's leakage reactance. Winding 1 and Winding 2 have equal inductance values, suggesting they are intended for similar operating conditions or balanced loads. Winding 3 has a slightly higher inductance, which may be designed to handle a different voltage ratio or auxiliary operation. The mutual impedance value shows how well the windings are magnetically coupled. While not ideal, the coupling is strong enough to ensure efficient transfer while still providing the necessary isolation. In a practical EV charging scenario, the transformer performs multiple roles. During grid-to-vehicle operation, high-voltage alternating current from the utility grid is stepped down by the primary winding. This reduced voltage is then rectified and processed by DC-DC converters to match the requirements of the EV battery. Galvanic isolation prevents disturbances or faults on the grid side from propagating into the vehicle, protecting sensitive electronics and enhancing safety.

The transformer also supports vehicle-to-grid (V2G) operation, in which the EV battery supplies energy back to the grid during peak demand. In this case, DC energy from the battery is first inverted to AC and then stepped up or stepped down by the transformer to synchronise with the grid voltage and frequency. By employing multiple windings, the transformer can supply multiple charging ports or ancillary loads simultaneously, reducing the number of single transformers. For instance, two rapid-charging ports can be supplied by Winding one and Winding 2, and Winding three can power ancillary systems such as metering, communication modules, or renewable integration. The transformer's efficiency is highly dependent on the electrical values provided. Low resistance minimises conduction losses, thereby increasing overall charging efficiency. The leakage inductance results in a low voltage drop and provides an inherent short-circuit current-limiting characteristic, which helps with protection. Combined with power electronic converters, the leakage reactance can also be used to shape current waveforms, suppress harmonic distortion, and thereby enhance power quality. EV chargers must adhere to very strict grid codes, which is useful. In addition, at high-power fast-charging stations, efficiency gains of only a few per cent can yield substantial cost and energy savings. Another critical field of transformer application is thermal management. The device is continually loaded, even with low resistance, and charging patterns constantly shift, so heat buildup needs to be carefully controlled. Overheating reduces lifespan and damages insulation, so loss management is critical.

The values assigned here indicate a very effective design with lower copper losses, facilitating safe operating temperatures. Safety is also another extremely crucial factor. Since EV batteries operate at high voltages, galvanic isolation provided by the transformer is essential to prevent electric shock and to prevent the propagation of grid faults into the vehicle. The presence of three windings also allows designers to include monitoring and protection circuits that can detect abnormal conditions and respond quickly. To visualise the role of this transformer, consider a charging station serving multiple EVs. The utility grid delivers AC power at high voltage, which is connected to the primary. Winding one and Winding two, then feed two separate rectifier-converter chains that charge two different vehicles simultaneously. Each chain regulates the DC voltage and current according to the specific battery type. Meanwhile, winding three powers auxiliary loads, such as lighting, communication with the grid operator, or renewable integration. During off-peak times, power flows from the grid to the vehicles, while during peak times, it can flow in the opposite direction, from the vehicles to the grid. This bidirectional capability makes the charging station not just a consumer but also a contributor to grid stability. These features enable it to meet the demands of modern EV charging infrastructure, including fast charging and auxiliary supply, as well as integration with the grid for vehicle-to-grid operation. By ensuring high efficiency, safety, and reliability, the transformer plays a central role in the development of sustainable transportation systems.

3.3. Battery for EV Application

A lead-acid battery is one of the oldest and most widely used forms of rechargeable storage. Despite the growth of lithium-ion technology, it remains widely used in electric vehicles, particularly in cost-sensitive or low-power designs. The given specification highlights a nominal voltage of 48 volts, a rated capacity of 5 ampere-hours, and an initial state of charge of 50%. These values provide insight into how the battery behaves when integrated into an EV system, particularly during charging and discharging via wireless power transfer. With a nominal voltage of 48 volts, the battery is composed of multiple cells connected in series to achieve the desired voltage, since each lead-acid cell provides about 2 volts. The rated capacity of five ampere-hours indicates the amount of charge the battery can store and supply under standard conditions. In practical EV use, this capacity translates into the vehicle's range, which will be modest given its relatively small value, pointing toward light-duty vehicles or experimental setups rather than full-scale electric cars. Still, in such applications, the battery provides a useful energy buffer, supplying power to the motor during discharge and accepting energy during charging cycles. The initial state of charge of 50% suggests that the battery is neither fully charged nor depleted at the beginning of the cycle, which is an appropriate point for analysing charging and discharging performance.

Operating at mid-state of charge reduces stress on the plates and electrolyte, improves cycle life, and represents a realistic scenario in daily vehicle operation where batteries are rarely allowed to go fully empty. When considering charging through a wireless system, the lead-acid battery benefits from the galvanic isolation and flexibility that wireless power transfer offers. Energy is transmitted across an air gap using magnetic coupling between coils, and the induced AC is rectified and controlled before reaching the battery terminals. In the case of a 48-volt battery, the charging circuit must carefully regulate voltage and current to avoid overcharging. Lead-acid chemistry is sensitive to overvoltage, which can cause gassing, water loss, and plate degradation. Typically, charging involves a bulk phase in which current is supplied steadily until the voltage reaches a threshold, followed by an absorption phase in which the voltage is held constant and the current tapers off, and finally a float phase that maintains the battery at a safe level. In wireless charging systems, these stages are achieved by controlling the inverter and compensation network to ensure that the rectified DC matches the required charging profile. Since the initial state of charge is 50%, the battery can accept charging current efficiently without the immediate risk of overcharging, making it an ideal point for demonstrating wireless charging. During discharging, the battery provides DC power to the vehicle's motor and auxiliaries.

In a wireless bidirectional system, it can also discharge back through the same wireless link for vehicle-to-grid or vehicle-to-load applications. The discharge characteristics depend on the battery's internal resistance, the load current, and the depth of discharge. A 5AH battery will not sustain high currents for long durations, but in lightweight EVs or testbeds, it can deliver sufficient energy for practical operation. At 50% state of charge, the available capacity is about half the nominal capacity, so approximately 2.5 ampere-hours remain usable before reaching a critical low level. Wireless discharging requires efficient power electronics to invert the DC from the battery into high-frequency AC for transmission across the coupling coils, after which it is rectified back to usable form on the receiving side. This process must be managed carefully to avoid deep discharge, as deep cycling significantly shortens the life of lead-acid batteries. Efficiency is an important factor in both charging and discharging. Wireless transfer introduces additional losses compared to wired systems due to coil resistance, leakage flux, and misalignment between transmitter and receiver. Since the battery capacity is relatively small, maximising transfer efficiency is crucial to make the best use of the stored energy. Proper coil design, resonant compensation, and alignment control all contribute to achieving efficiencies that make wireless charging viable. The transformer-like coupling provides electrical isolation, enhancing safety, especially in outdoor environments where direct wired connections may be inconvenient or exposed.

4. Simulation Results and Discussion

The proposed bidirectional wireless charging system for electric vehicles was developed and analysed using a MATLAB/Simulink environment to ensure accurate modelling of both the power electronics and control subsystems, as shown in Figure 2. The methodology is structured to capture the essential stages of energy conversion from the grid to the vehicle battery and, conversely, from the vehicle back to the grid.

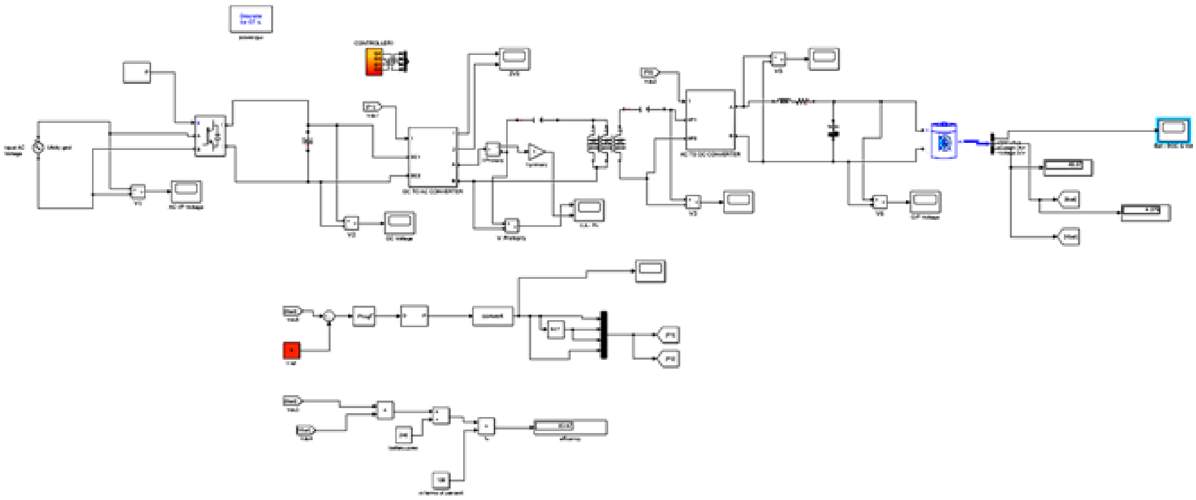

Figure 2: Simulation of open-loop high-gain single ZQR DC-DC converter system

Each subsystem was designed to maintain Zero Voltage Switching (ZVS) conditions, which minimise switching losses and enhance efficiency during both charging and discharging.

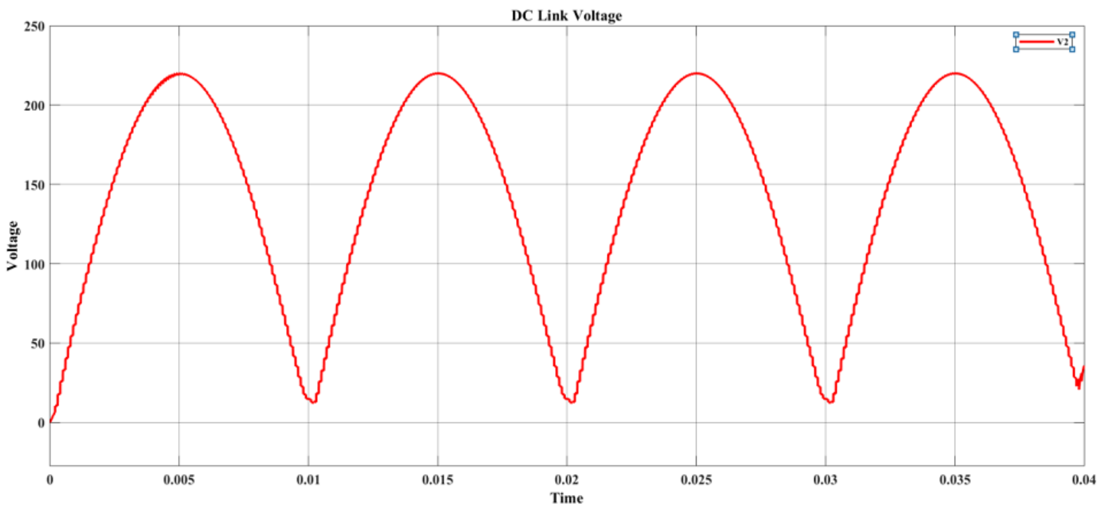

Figure 3: DC link voltage

The system begins with a 230 V, 50 Hz single-phase AC input, which represents a typical grid supply. This input is rectified using a universal bridge model, configured to generate a stable DC link voltage of 220V as indicated in Figure 3. The rectification stage was designed with appropriate gating signals derived from four single-phase controlled pulses, ensuring smooth conversion and a regulated DC supply to the subsequent stages. Following rectification, the DC voltage is inverted into a high-frequency AC signal Figure 4 using a dedicated inverter subsystem. A high-frequency operation of 20 kHz is critical for efficient inductive power transfer, as it reduces the size of passive components and enhances magnetic coupling between the transmitter and receiver coils. Table 1 presents the specifications of the multi-winding transformer used in the simulation.

Table 1: Multi-winding transformer specification

Type	Unit	Value
Winding 1	R1 (Ohm), L1(H)	0.01 Ω, 0.08793 mH
Winding 2	R2 (Ohm), L2(H)	0.01 Ω, 0.08793 mH
Winding 3	R3 (Ohm), L3(H)	0.01 Ω, 0.1261 mH
Mutual impedance	R_m (Ohm), L_m(H)	0.1 Ω, 0.02106 mH

To realise ZVS operation, a closed-loop control strategy was implemented. The system's output voltage and current are continuously monitored and fed back to a proportional–integral (PI) controller. The PI controller processes these feedback signals to generate optimised gating pulses for the primary- and secondary-side converters. The values of P and I are set to 0.005 and 10, respectively, for the simulation. These pulses, denoted P1 and P2, ensure that switching transitions occur under zero-voltage conditions, thereby minimising switching losses, reducing electromagnetic interference, and extending converter lifespan.

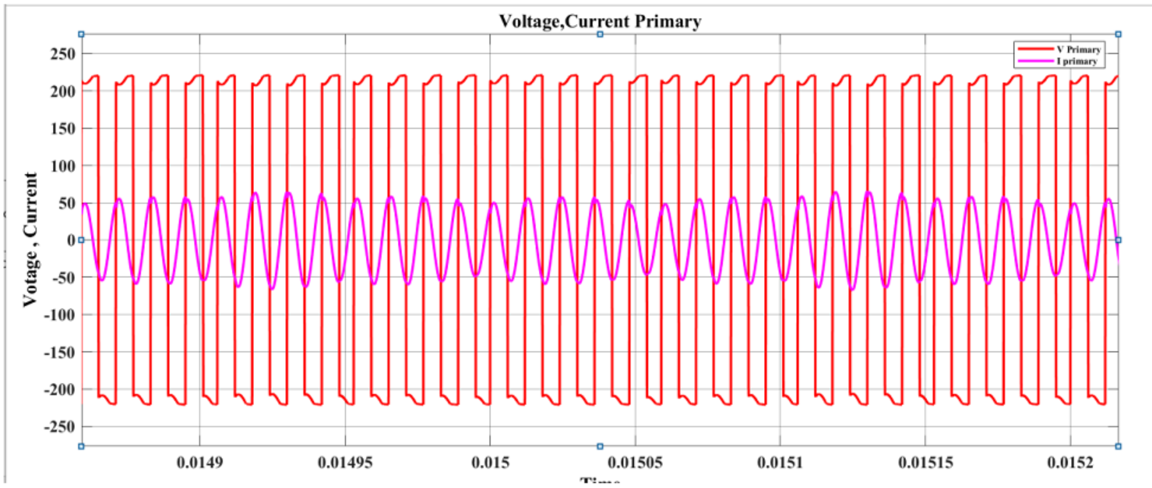

Figure 4: Primary voltage and current

The PI controller was carefully tuned to balance fast dynamic response with system stability, ensuring ZVS is consistently achieved across varying load conditions. On the receiving side, the secondary converter rectifies the high-frequency AC back into DC, which is then delivered to a 48 V lead-acid battery, as indicated in Figure 5. Table 2 presents the specifications of the lead-acid battery used in the simulation. This stage replicates the charging behaviour of a typical EV battery pack. The charge cycle was simulated to track battery voltage, current, and state of charge over time, validating the system's ability to deliver regulated power during Grid-to-Vehicle (G2V) operation, as shown in Figure 6. Correspondingly, to evaluate Vehicle-to-Grid (V2G) functionality, the system was simulated in reverse mode, with the battery's stored energy discharged back into the grid, as shown in Figure 7. The discharging process was modelled to demonstrate seamless power reversal while maintaining ZVS across all active switches. This bidirectional power flow confirms the system's dual capability and its potential for integration with smart grids and renewable energy networks.

Table 2: Lead-acid battery specification

Parameter	Value
Nominal voltage (V)	48
Rated capacity (Ah)	5
Initial state-of-charge (%)	50

A key element of the methodology is the evaluation of instantaneous system efficiency. To this end, simulations were performed under two conditions: with ZVS enforced and without ZVS. Comparative analysis yielded a comprehensive representation of switching losses, conduction losses, and system efficiency. Loss allocation was tracked across converters and switch components to determine the optimal range that prevents power loss. ZVS-friendly topology preserved enhanced efficiency and minimised heat stress on components during over-hard-switching operation, attesting to the efficacy of the adopted control strategy. The method also applied dynamic analysis to address pragmatic applications, such as mode switching and load fluctuations between the V2G and G2V modes. Simulations were developed to mimic actual operating environments, i.e., fluctuating battery charge requests and grid interactions. The robustness of the control strategy was ensured by the system's ability to operate in ZVS under these conditions without compromising efficiency or stability.

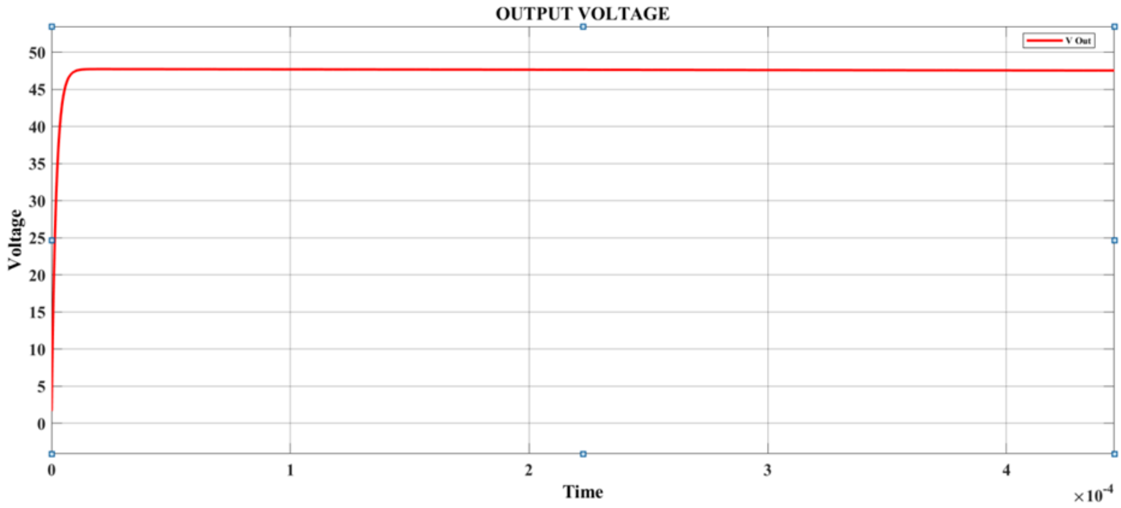

Figure 5: Battery output voltage

Generally speaking, the approach integrates realistic power-electronic modelling with aggressive simulation analysis. By incorporating hardware-focused converter modelling and software-based feedback control, the system demonstrates technical feasibility and performance benefits.

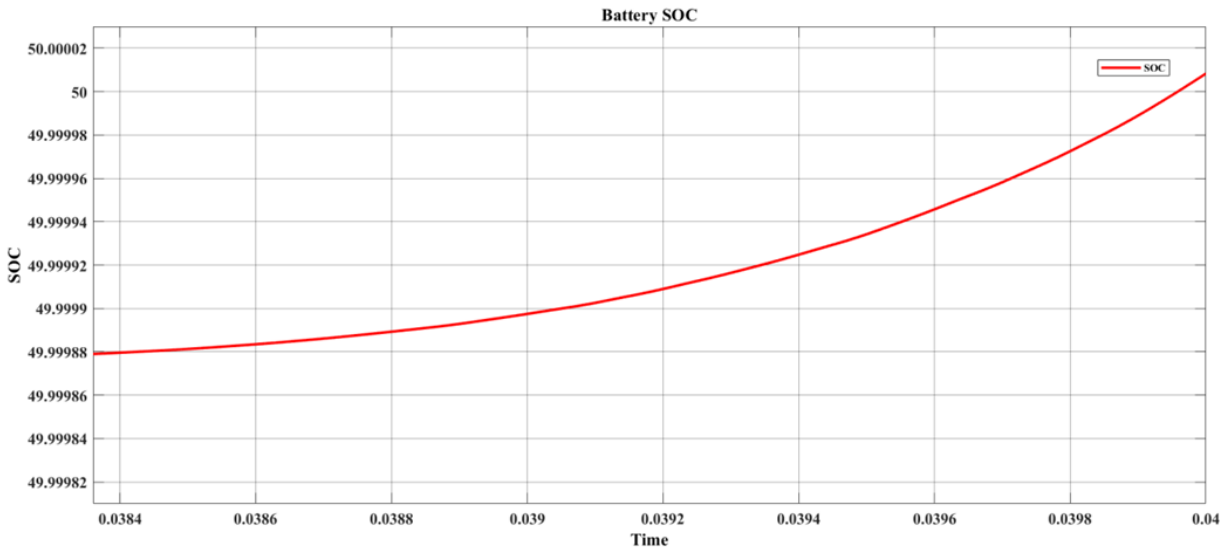

Figure 6: Battery charging graph

The method not only validates the advantages of ZVS in bidirectional wireless charging but also highlights its significance in enabling stable energy communication between EVs and the grid. The method provides a rigorous framework for future experimental verification and implementation of bidirectional dynamic wireless charging systems.

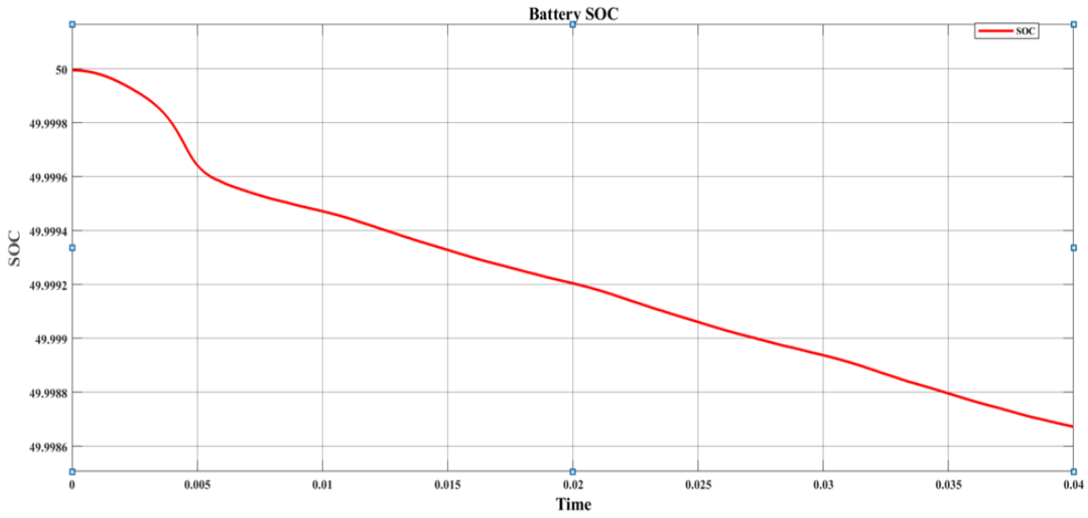

Figure 7: Battery discharging graph

5. Hardware Implementation and Discussion

The hardware shown in Figure 8 represents the practical implementation of a wireless power transfer system designed for charging the battery of an electric vehicle. At one end, a rechargeable battery is placed, which serves as the system's storage element. The circuit begins with a rectifier and converter stage, where the AC input supply is first converted to DC using an AC–DC converter (230 VAC/12 VDC).

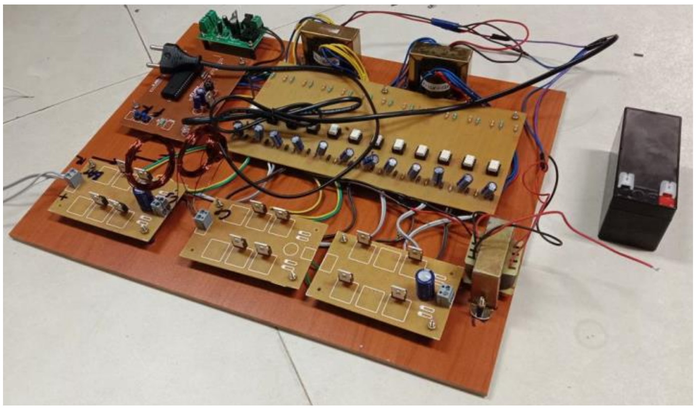

Figure 8: Proposed hardware model

This DC power is further processed by a DC–AC inverter section, which generates a high-frequency alternating current (20 kHz) required for inductive coupling, as indicated in Figure 9.

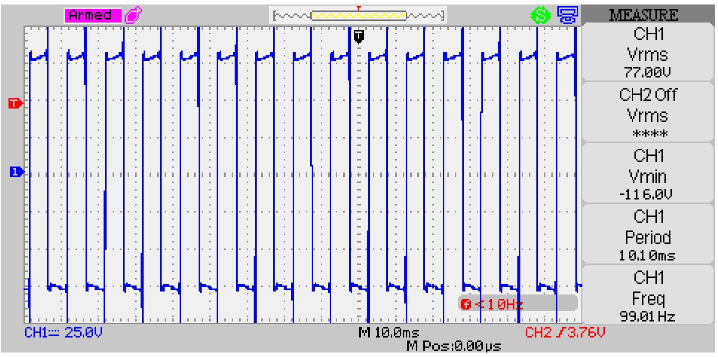

Figure 9: Transformer high-frequency 20KHz output

The three smaller circuit boards at the front contain the primary coil-driving circuits. These boards include switching devices, capacitors, and control circuitry that help in producing a resonant high-frequency signal. The generated alternating current energises the primary coils, which are designed to induce a magnetic field. The secondary coil, placed within the receiving side and connected to the battery section, captures this magnetic flux. Once power is received, it is rectified again by an AC–DC converter, providing a stable DC output that is directed to the battery for charging (12.8 VDC), as shown in Figure 10.

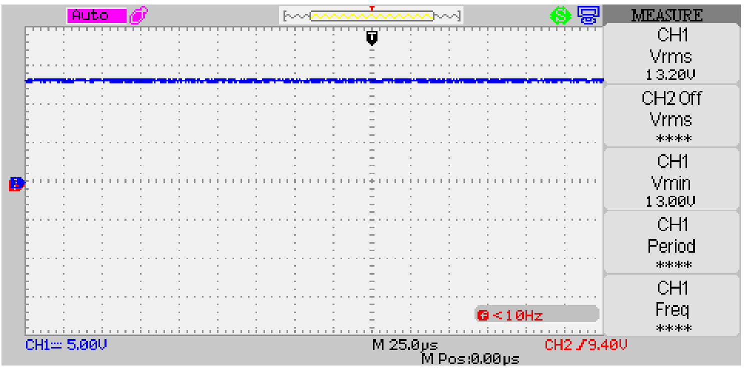

Figure 10: Battery charging voltage

The gate pulses generated by the dsPIC30F2010 are indicated in Figure 11. The larger central board hosts the control and driver circuits, including multiple switching devices, indicators, and regulating components, which help maintain synchronisation between the transmitting and receiving sides. Proper filtering and regulation circuits are also included to ensure smooth DC charging current without fluctuations. The arrangement of multiple primary coil driver boards highlights the possibility of using a dual- or multi-coil configuration to improve efficiency and alignment tolerance. This allows the vehicle to receive power even if it is not perfectly aligned with the transmitter. The wiring interconnections demonstrate how different modules are integrated into one complete system, while the separate battery connection shows the final stage of energy storage.

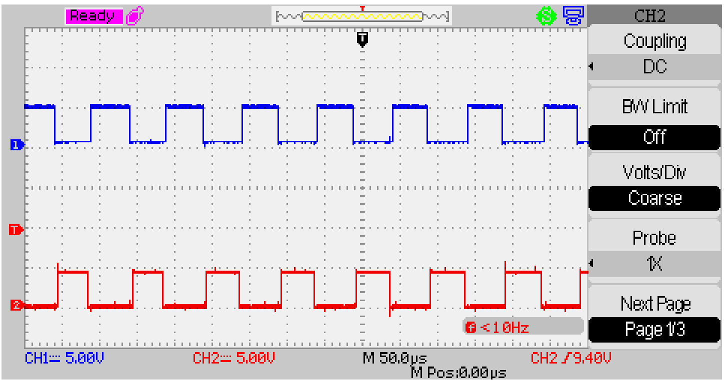

Figure 11: Gate pulse

6. Conclusion

This work outlines the design, modelling, and performance evaluation of a bidirectional wireless power transfer (WPT) system for electric vehicle (EV) applications functioning under Zero Voltage Switching (ZVS) conditions. The suggested method uses inductive power transmission as a safe and effective way to transfer energy without physical contact. This enables both Grid-to-Vehicle (G2V) charging and Vehicle-to-Grid (V2G) discharging. The bidirectional architecture enables smooth power transfer between the EV battery and the utility grid while maintaining high conversion efficiency and operational stability. A major benefit of this work is that it eliminates extra DC–DC converter stages, simplifying the system structure, reducing the number of parts needed, and lowering power losses. By properly controlling the resonant inverter, stable voltage and current regulation are achieved, enabling effective power transmission even when the load and coupling conditions change. By enabling all switching devices to operate in ZVS mode, the system reduces switching losses, electromagnetic stress, and thermal impacts. This makes the system more efficient, reliable, and long-lasting. Extensive simulation experiments are conducted to validate the proposed design and control technique. The results show that the EV battery and the grid can transfer energy back and forth with very little power loss, and that switching between G2V and V2G operating modes is smooth. A comparative performance analysis between ZVS-enabled operation and typical hard-switching settings shows a significant increase in efficiency and a pronounced reduction in overall power losses when ZVS is used. The study also identifies the optimal operating ranges for switching frequency and load conditions that result in the least power loss. These results show that the suggested ZVS-based control approach is quite robust and can maintain high efficiency even as conditions change. The results show that ZVS greatly improves the performance of bidirectional wireless EV charging systems. This makes the proposed solution a good fit for next-generation smart grid and EV infrastructure applications.

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