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ENHANCED LCC COMPENSATION TOPOLOGY WITH INTEGRATED DUO TRANSMITTER WINDING FOR EFFICIENT WIRELESS POWER TRANSMISSION IN EV

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ABSTRACT

The growing demand for Electric Vehicles (EVs) necessitates the advancement of efficient charging systems. While dynamic charging models exhibit superior efficiency in Wireless Power Transfer (WPT) systems compared to static charging, however, the inherent challenges impede the effective operation of EV charging. This research aims to effectively address the existing research gap causing coil misalignment and sub-optimal efficiency in wireless charging systems for EVs by proposing a circuit design integrating an enhanced LCC compensation topology specifically tailored for wireless charging systems. The key innovation lies in the inclusion of a dual transmitter winding which optimizes power transmission between receiver and transmitter coils while ensuring high efficiency. The duo transmitter winding is split into sub windings one connected to the inverter and the other left open which further enhances performance, enabling operation under higher misalignment conditions while maintaining elevated efficiency levels. The advantage of both open and closed inductance in the circuit configuration significantly improves performance, overcoming previous constraints and providing a more robust and reliable charging solution. The circuit design implements Zero Voltage Switching (ZVS) to minimize energy losses in the Snubber MOSFET capacitance, typically used as a switch. Additionally, a ZVS feedback mechanism is incorporated to dynamically adjust the series capacitor on the receiver side, suggesting the presence of a resonant circuit. This approach aims to optimize the switching characteristics of the MOSFET, reduce losses, and enhance the overall efficiency of the power electronic system, potentially for applications such as wireless power transfer or power supplies. By enhancing the effectiveness and reliability of wireless power transfer in EVs, this study contributes to advancing the ease and feasibility of charging electric vehicles, potentially revolutionizing the EV industry's charging infrastructure.

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1. INTRODUCTION

The primary cause of environmental pollution, which degrades the air quality and contributes to global warming pollution by excreting toxic pollutants (e.g, sulfur dioxide (SO2), nitrogen oxides (NOx), carbon monoxide (CO), and so forth), is the increasing number of vehicles, including motorbikes, cars, trucks, buses, and so forth, that are powered by fossil fuels (Liu, X., 2020, pp-42404-42421). In addition to endangering the ecology, hazardous pollutants also harm nearly every biological structure in the human body (Liu, S., Xin, D., Yang, L., & Wang, L., 2020, pp.198201-198213). Experts and governments have responded to the aforementioned environmental concerns by stressing the necessity of decarbonizing with healthy alternatives, which may be accomplished through electric vehicles (EVs) (Masood, A., Hu, J., Xin, A., Sayed, A. R., & Yang, G., 2020, pp.-31519-31529). EVs have progressively gained popularity during the past several decades as a result of their promising features, such as their lack of hazardous gases, and absence of releases of greenhouse gases, with great efficiency (Kim, Y., Kim, H., & Suh, K., 2021, pp.-128892). The latest research has revealed significant & advantageous improvements when it comes to using EVs, especially in terms of reducing higher fuel costs, increasing energy-saving capability, as well as fulfilling the prerequisites for green sources of transportation, all while improving overall fuel economy & reducing emissions (ElGhanam, E., Hassan, M., Osman, A., & Ahmed, I., 2021, pp-92). For example, since 2014, the market shares for battery-enabled electric vehicles (BEVs) have grown significantly. For these particular BEVs to operate efficiently and affordably, specific batteries and charging techniques must be used. Contrarily, to continue their levels of growth in the intervening decades, numerous businesses are performing greater extensive research into BEV charging systems (Simonazzi, M., Campanini, A., Sandrolini, L., & Rossi, C., 2021, pp-70).

When contrasted to plug-in charging systems, WPTs provide electrical and mechanical separation, minimize the usage & plugs, and also provide safe operation in challenging atmospheres. However, the low transfer efficiency of WPTs is a significant barrier to their widespread adoption (Adil, M., Ali, J., Ta, Q. T. H., Attique, M., & Chung, T. S., 2020, pp-187933-187947). Excellent electrical durations are still a problem for WPT, particularly in certain real situations like recharging for public transit systems (buses and electric locomotives). Long charge times can be eliminated with high-power charging (Majhi, R. C., Ranjitkar, P., Sheng, M., Covic, G. A., & Wilson, D. J., 2021, pp-432-455). As a consequence, there is a growing demand for high-power WPT. It is difficult to boost the power capabilities of WPT systems because of the current and voltage restrictions on power electronic components. Several business and research organizations have suggested high-power WPT devices with power levels of 50 kW or above, at the cost of employing wide-bandgap semiconductors like silicon carbide (SiC) (Sanguesa, J. A., Torres-Sanz, V., Garrido, P., Martinez, F. J., & Marquez-Barja, J. M., 2021, pp-372-404). However, any advancements in system power capabilities will be constrained by appliances.

Voltage stress as well as resonant component insulation are further obstacles to the deployment of high-power wireless charging due to the constrained internal capacity of EVs in real-world applications (Chen, X., Xing, K., Ni, F., Wu, Y., & Xia, Y., 2021, pp-175-194). Weak coupling results from the leaking magnetic flux having a lower reluctance route due to the enormous air gap among the main and secondary coils. In general, the size of the loosely coupled transformer is inversely proportional to the coupling coefficient at a fixed air gap (Zhang, Y., Li, J., Zhang, F., Chen, Z., Kong, Y., & Huang, N., 2022, pp-1218). However, the secondary coil installed on an electric vehicle's chassis is made to be as small and light as feasible. The primary (transmitting) coil's size and weight are also not important factors because they are hidden beneath the parking lot's surface or in the garage (ElGhanam, E., Hassan, M., & Osman, A., 2021, pp-885).

This task begins with optimizing the primary coil circuit to get the greatest coupling coefficient. The goal is to create a WPT system that is highly efficient while minimizing the coil circuit. The following is how this paper is organized:

- The research proposes an innovative circuit design that integrates an enhanced LCC compensation topology, specifically tailored for wireless charging systems. The key innovation involves the inclusion of a dual transmitter winding, which optimizes power transmission between receiver and transmitter coils.
- A ZVS feedback mechanism is introduced to dynamically adjust the series capacitor on the receiver side, suggesting the presence of a resonant circuit. This approach aims to optimize MOSFET switching characteristics, reduce losses, and enhance the overall efficiency of the power electronic system.
- This contribution aligns with the broader goals of analyzing the charging experience for electric vehicles by optimizing the Q value and k value, our research aims to offer an efficient and reliable charging infrastructure, addressing concerns related to the practicality and widespread adoption of electric vehicles.

By enhancing the effectiveness and reliability of wireless power transfer in EVs, the study contributes to advancing the ease and feasibility of charging electric vehicles. This has the potential to revolutionize the charging infrastructure in the EV industry. The flow of the proposed technology is as follows: The literature is explained in section 2, and a thorough explanation of the proposed technique is provided in section 3. The comparison results are presented in Section 4, and the article is wrapped up in Section 5.

2. LITERATURE REVIEW

(Badwey, M. A., Abbasy, N. H., & Eldallal, G. M., 2022, pp-6565-6580) suggested a brand-new dual inductive & capacitive wireless power transmission technology. In a bid to boost magnetic coupling capability, the inductive component was made using a circular spiral coil coupled with a helical coil and supported by cross-shaped ferrite bars. The capacitive element was constructed from four square cylindrically evacuated plates that matched the size of the inductive section to aid in the combination process. Using the Maxwell-3D simulation program, the system structure was first built. The designing & modeling of a 10.1 kW hybrid energy system was then done using MATLAB/Simulink and ANSYS/Simplorer. A high consequent efficiency of 99.37 percent is achieved at a resonance frequency of 1 MHz by excluding the internal losses of the inverter and rectifier and just taking into account the AC losses of the coils as indicated in its parasitic resistance.

(Mohamed, N., Aymen, F., Alqarni, M., Turky, R. A., Alamri, B., Ali, Z. M., & Aleem, S. H. A., 2022, pp-101569) proposed a unique work that includes the creation of an innovative kind of WPT device to guarantee high-efficiency EV charging time as well as to improve the operation of the dynamic wireless recharge system. The designed scheme now includes receiver coils to boost charging power. With the use of such coils, a dynamic theoretical formalism may be created to specify & monitor source-to-vehicle power transfer while the car is in motion. All of the physical variables associated with the model are included in the proposed mathematical formula. The outcomes demonstrated the viability of the recommended methodology. By putting two coil receivers beneath the automobile, the modeling findings were produced, and the experimental testing additionally validated their correctness.

As per (Tan, L., Zhao, W., Liu, H., Li, J., & Huang, X., 2020, pp-74595-74604), the ground-side power transmission coil parameter design technique, the length of the transmitting coil is adjusted depending on the EV's driving speed, energy use per kilometer, coil energy loss, and system charging effectiveness. The process utilizes the LCC-S resonance correction topology, a long-track transmission coil, as well as a rectangular receiving coil. The charging power and energy transfer efficiency are first calculated. Secondly, the lowest value of the receiving coil current is determined using the peak value of charging power along with the proper compensatory inductance and transmitting coil wire diameter. Finally, the link between transmitting coil length, load resistance, and system efficiency is established.

(Zhang, M., Tan, L., Li, J., & Huang, X, 2020, pp-127993-128004) examine charge management & performance enhancement methods for the WPT system with dynamic loads. Investigations are made into the full-bridge controlled rectifier circuit's functionality. The WPT system was developed using a controlled rectifier circuit on the secondary side along with a double-sided LCC compensating design. The result properties of the WPT system are then examined. The article proposes CC and CV charging solutions based on phase shift control of a controllable rectifier circuit as well as an efficiency optimization strategy that utilizes dynamic equivalent impedance matching in a bid to enhance the transmission efficiency of the WPT system while installing CC and CV charging.

For the three-coil WPT system with load-independent output voltage, (Darvish, P., Mekhilef, S., & Illias, H. A. B., 2020, pp-1341-1355) devised a unique series-series-LCLCC (S-S-LCLCC) compensation architecture that could still actualize ZPA characteristics all through the charging period. In regards to energy efficiency, resilience over load variation, misalignment, flexibility to maximize system efficiency, reduction of voltage stress, and enhancement of power supply to load, the innovative topology significantly outperforms the standard one. The experimental method demonstrates that the recommended design's improved performance trend is greater than the standard design's as the load lowers.

(El-Shahat, A., & Ayisire, E., 2021, pp-2842) suggested a 3d view of the coils for the transmitter and receiver for magnetic resonance wireless transmission EV charging. In addition to increasing the power, this idea was implemented into the physical layout of the magnetic resonance connection employing ANSYS Simplorer. A closed-loop three-level cascaded PI controller was constructed and utilized to wirelessly charge an EV battery to avoid voltage variation brought on by variations in the space among coils. Solar-powered wireless power transmission with a tracking device for maximum power points was employed to simulate wireless charging for electric cars. Fuzzy logic & neuro-fuzzy controllers were used to provide a better dependable performance level, but they resulted in excellent outcomes. The next part explains the specifics of the proposed scheme.

3. PROPOSED METHODOLOGY

A novel circuit with an Enhanced LCC compensation topology for electric vehicles employing a wireless charging system with integrated duo transmitter winding is designed to achieve high efficiency with a sizable separation distance of the coils. Initially, integrated conductors are combined with the primary coils in an LCC topology to increase the transmission capacity between the coils. By using smaller additional inductances of the compensation topology, this structure may transfer the same amount of power while using less space for the new inductive coil. By examining the movement of the coils, the proposed WPT controller system may switch between four switching modes (anti, positive, negative, and panoramic) in response to an increase in the input voltage. As a result, the circuit can function with greater coil misalignment. Furthermore, ZVS is used, where the body diode conducts before the Snubber MOSFET does, to reduce energy losses in Snubber MOSFET capacitance. By turning on Snubber MOSFET with a negative current, this can be accomplished. To adjust the receiver side compensation and mitigate the energy loss, ZVS feedback is introduced. To boost the power of transmission and produce more coupling, the integrated duo transmitter winding is split into two sub-windings, one of which is linked to the inverter and the other of which is in an open circuit. The charging current & charging voltage might well be identified by determining the induced current of the first sub-winding as well as the induced voltage of the second sub-winding, respectively. Therefore, with a simple circuit configuration, the layout can operate with a bigger misalignment condition and a wider air gap with high efficiency. Figure 1 demonstrates the proposed model. The compensation topology has a design on both the transmitter's (primary) which consists of one inductor, two capacitors, as well as the primary circuit.

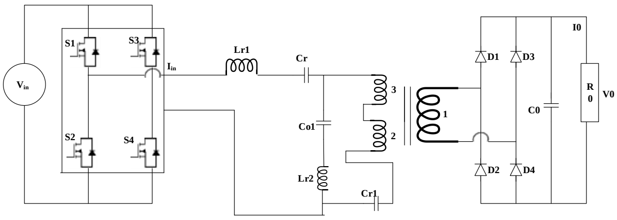

Figure 1. Schematic circuit of the proposed wireless charging system

This LCC compensation network makes up the compensatory resonant circuit as well as a high-frequency inverter. The whole bridge of the inverter is made up of four power Snubber MOSFETs (S_1–S_4). This inverter is utilized to convert the AC power supply to DC for running the motor in the electric vehicle. A 3-coil topology is introduced which is one of the common configurations for strongly coupled magnetic resonance. Two coils are in the power source (transmitter coil) and one in the load (receivers side). The power source has a dual LCC compensation network consisting of the nodes Lr_1, Co_1, and Cr for coil 3 and Lr_2, Co_1, and Cr_1 for coil 2. The extra coil and double inductance are necessary to incorporate lumped reactive components to ensure that the power transfer will take place under proper resonant conditions. This work proposes a control approach for the WPT system with a structure of single-sided LCC compensation topology and a double transmitting coil is incorporated to realize CC and CV charging and efficiency optimization.

The system can operate in several stages in a switching cycle depending on the components in the circuit, the coupled coefficient of the main coils, the electronic component, and the load used by the components. When the operating frequency is fixed at the resonance frequency (85kHz as per SAE J2954). Due to symmetry, only half of the transition circle needs to be analyzed. The diodes on the receiver side as shown in fig. 1, only conduct when the voltage across the output of coil 1 (i.e. a & b). There are four possible stages as explained below. The formulas representing the phases include boundary value problems that are common to normal differential equations (Li, W., Zhao, H., Li, S., Deng, J., Kan, T., & Mi, C. C., 2014, pp-4215-4225):

A) Anti-mode: During anti-mode, all of the diodes of the rectifier are off and the current from the load side to terminal a is zero. The coil 1 (load side) does not join the resonance with other circuit components, and neither does the battery, but as mentioned before, the system still has the same resonant frequency as other stages. During Anti-mode, the voltage between nodes a and b is lower than the battery voltage V_0 and does not include any power transfer to the battery. The differential equation can be expressed as shown in equation 1 (Li et al., 2014) with the boundary condition $x(0) = -x(\frac{T}{2})$. This condition fits all the operating modes.

$$\dot{x} = C_1 x + D_1 u \tag{1}$$

B) Negative mode: In the first half cycle of negative mode, which comes after anti-mode, the voltage between the two terminals of coil 1 is negative and higher than the battery voltage, diodes $D_1$and D_4 are off, while $D_2$and D_3 are operational, and the battery will be connected to the circuit in reverse. For this case, the system passes through Anti-mode, Negative and Anti-mode successfully (Anti-Negative-Anti). The equations justifying the above conditions is:

$$\begin{cases} \dot{x} = C_1 x + D_1 u, & 0 \leq t \leq t_1 \\ \dot{x} = C_2 x + D_2 u, & t_1 \leq t \leq t_2 \\ \dot{x} = C_1 x + D_1 u, & t_2 \leq t \leq T/2 \end{cases} \tag{2}$$

The WPT system's operating mode switches from positive to negative when the input voltage rises.

C) Positive mode: The system will go through a special mode throughout this process which sits on the borderline between positive and negative and can be classified as either of the two. When the voltage between terminals of coil 1 (a and b) is positive and higher than the battery voltage, diodes $D_1$and D_4 are turned ON, while $D_2$and D_3 will be turned off and the input voltage increases to a level beyond negative mode, battery is directly connected to the resonant circuit. The equations are for positive mode, which happens when the input voltage increases above positive mode.

$$\begin{cases} \dot{x} = C_2x + D_2u,\ 0 \le t \le t_1 \\ \dot{x} = C_1x + D_1u,\ 0 \le t \le t_2 \\ \dot{x} = C_2x + D_3u,\ t_2 \le t \le T/2 \end{cases} \tag{3}$$

D) Panoramic: When the input voltage is higher, all the diodes of the rectifier at receiver side will always be ON. The circuit's statuses will alternate between the negative clamped stage with the positive clamped stage. During the first half of the resonant cycle, the system will successively pass over the elements negative mode and Positive mode. These equations are displayed:

$$\begin{cases} \dot{x} = C_2x + D_2u,\ 0 \le t \le t_1 \\ \dot{x} = C_2x + D_3u,\ t_1 \le t \le T/2 \end{cases} \tag{4}$$

By using the numerical method for tackling the preceding formulas, the quantities of any states at any period may be determined, which has been proved by (Li, W., et al., 2014, pp-4215-4225). The study mentioned above makes calculating the output power and efficiency simple as

$$P_{out} = \frac{2}{T}\int_0^{T/2}\big(u_{cd}(t)\cdot i_0(t)\big)dt \tag{5}$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{\int_0^{T/2}\big(u_{cd}(t)\cdot i_0(t)\big)dt}{\int_0^{T/2}\big(u_{CD}(t)\cdot\ i_{Lr}(t)\big)dt} \tag{6}$$

Where u_{CD} and $u_{cd}$are the rms values of the input voltage & output voltage, P_{out} is the active output power. It is known that the WPT system's output power & efficiency are correlated with the mode of operation. In positive mode, the efficiency will rise fast with rising input voltage, but as the system switches to negative mode, the rate of rise will be slower. The efficiency will stabilize at its maximum efficiency after the conclusion of both the negative mode and the complete panoramic mode by utilizing the proposed compensation.

3.1 Optimized Switching Controller

In this study, Snubber MOSFETs are used as the entire bridge converter's switching components. Since the Snubber MOSFET's parasitic parallel output capacitance can keep the voltage almost at zero throughout the turnoff transition, the turnoff switching loss is relatively low. Nevertheless, two significant switching losses occur during the Snubber MOSFET turn-on process: The energy held in the Snubber MOSFET output capacitance is lost, and the loss caused by the diode reverse recovery operation is the other. If the Snubber MOSFETs are turned on under the ZVS condition, both of them can be mitigated. To produce ZVS, the body diode may conduct before the Snubber MOSFET. This means that a negative current should be used to switch on the Snubber MOSFET. The analysis above predicts that S_1 and S_4 will be turned off at the end of the first half cycle, while S_2 and S_3 will be switched on, and that the opposite will occur at the end of the cycle. As a result, the current on L_r should be positive after the first half cycle. The turnoff current must be sufficient to drain the junction capacitors within the dead time to achieve Snubber MOSFET ZVS turn-on in the three primary operating modes (positive, negative, and panoramic), which can be written as (7) given in (Lu, B., Liu, W., Liang, Y., Lee, F. C., & Van Wyk, J. D., 2006, pp-6).

$$I_{OFF} > \frac{2C_{OSS}U_{CD,max}}{t_{dead}} \tag{7}$$

Here, C_{occ} is the Snubber MOSFET junction capacitance, $U_{CD,\,max}$ is the maximum input voltage, and t_{dead} is the dead time. Finding a reliable method to ensure that the Snubber MOSFETs are turned on at ZVS condition is crucial since switching losses during the Snubber MOSFET turn-on transition cannot be disregarded. The fixed resonance frequency of the system is advantageous, and it can be managed by adjusting the input voltage. As a result, tuning the switching frequency to achieve Snubber MOSFET ZVS turn-on while the system is running is not allowed. Another technique to make the input impedance of the resonant circuit inductive is to slightly alter the circuit's characteristics. Raising the secondary series capacitor is an easy way to achieve ZVS.

The system's parameters are initially designed roughly based on the analysis, and when the couplings of the main coils and extra coils are taken into account, they are modified using the finite-element approach. During the anti-mode, the turnoff current rises linearly as the input voltage rises, changing to a high-order polynomial once the positive-negative modes are entered. In conclusion, the turnoff current in panoramic mode is roughly linear with the input voltage. We need to pay attention to the turnoff currents in positive, negative, and panoramic modes which may suppress the voltage and reduce the power. It is clear that while the system is in the negative mode, the turnoff current is at its lowest. In this case, the approximation of the fundamental element is inappropriate. The research is significant as it directly addresses the challenges prevalent in current wireless charging systems for EVs, thereby offering a more efficient, reliable, and practical solution. Its applicability extends to real-world scenarios by contributing to the advancement of EV charging infrastructure, potentially fostering widespread adoption of electric vehicles by improving charging convenience and reliability. The results and analysis of our proposed method are provided in the next section in detail.

4. RESULTS AND DISCUSSION

The proposed system is established in MATLAB 21a to simulate the proposed method. Figure 2 shows the simulated model of the proposed model. The proposed method uses dual transmitter coil named as coil 2 and coil 3, each with LCC compensation topology which means it that each coil contains one inductor and two capacitances. C_{01} serves as a common capacitance for the LCC topology of coil 2 and coil 3. The LCC topology for coil 2 consists of L_{r1}, C_r, and C_{01}, while the LCC topology for coil 3 is made up of L_{r2}, C_{r1}, and C_{01}. The output side termed as receiver coil consists of one coil named as coil 1. At the transmitter side, the integrated LCC comes together to create a power output. The resonance frequency of the system is fixed at 85kHz as per SAE J2954. The simulation results are discussed in the following sections.

A MOSFET is a type of transistor that uses an electric field to regulate current flow in a semiconductor. MOSFET voltage and current of proposed methods is illustrated in Figure 3. When the MOSFET is switching, varying voltages are applied across its terminals. While the MOSFET is in the on-state (conducting), the voltage across it is rather low, but when it is in the off-state (non-conducting), it can be significantly higher. The MOSFET conducts current from the input source to the output load when it is in the on-state and very little or none while it is in the off-state, which is another effect of the switching process. It is crucial to keep in mind that switching losses and transients in the MOSFET's voltage and current might affect the overall efficacy and efficiency of the LCC compensation system. MOSFET switching losses are reduced due to ZVS ability to create smooth switching transitions. The voltage across the MOSFET is almost zero during turn-on or turn-off because the switching process is timed to coincide with the zero voltage point of the input waveform. As a result, power dissipation is decreased, and total efficiency is raised.

The proposed enhance LCC compensation topology to achieve high efficiency constant current and constant voltage mode is designed for the parameters shown in Table-I and simulation model shown in Fig. 2. The maximum power of the proposed model is selected almost 7.2 kW for coupling coefficient as k=0.14, k=0.23 and k=0.3 at operating frequency $f = 85kHz$. The charging voltage and current are calculated as $V_o =$ 280V in constant voltage mode and $I_o =$ 25.5A in constant current mode respectively. The equivalent resistant of the approximately 10Ω.

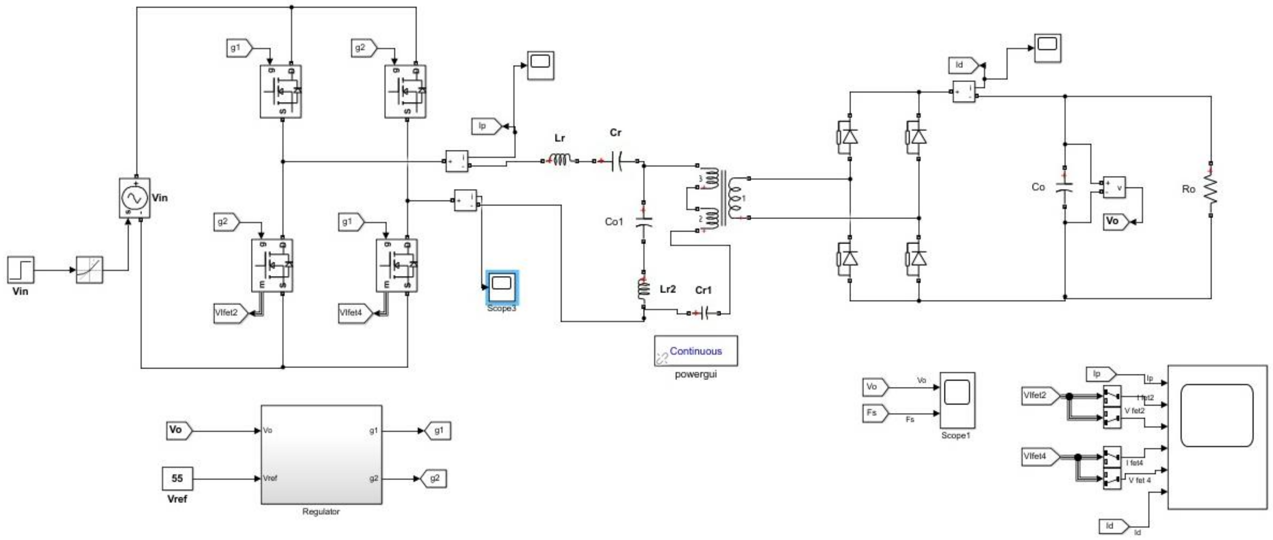

Figure 2. Simulation model of Enhanced LCC based proposed wireless charger

Table 1. Simulation parameters for the proposed wireless charging system

Parameters	Value
Max. Power	7.2kW
Input voltage	325V
V_o (constant voltage mode)	280V
I_o(constant current mode)	25.5A
f (operating frequency)	85kHz
L_{r1}, L_{r2}	215μH, 45.5μH
C_r, C_{r1}	78.59 nF, 20.7 nF
C_{01}	18.79 nF

The output voltage of our proposed method as shown in Figure 4. The voltage produced by the proposed device, a voltage regulator or generator, is referred to as the output voltage. Voltage regulators keep voltage levels steady. The dynamic response of a system defines how, in reaction to a particular input, the output voltage alters over time. The time domain reaction, frequency domain response, and stability are some of the important factors considered while analyzing the dynamic response. Using our proposed simulation method, the waveforms in the proposed technique are continuous and steady.

The rate at which the voltage is switched on and off during the pulse width modulation procedure is referred to as the switching frequency. The switching frequency is 85kHz for the presented approach as per the SAE J2954 standard.

By analyzing the power losses and comparing them to the output power, one may determine the efficiency of proposed architecture. The ratio of output power to input power stated as a percentage, is the standard definition of a power electronic system's efficiency.

$$\text{Efficiency}=\frac{Output\ power-power\ losses}{Input\ power}\times 100 \quad (8)$$

The variation in resistance of switch 2 (S_2 and S_3) is demonstrated in figure 5. The efficiency varies with the change in resistance value. The below graph is drawn using resistance R1 of transmitter coil and resistance of receiver coil and the efficiency. It is analyzed that as the Resistance R1 increases it results in increase in the efficiency whereas R2 is inversely propositional to the

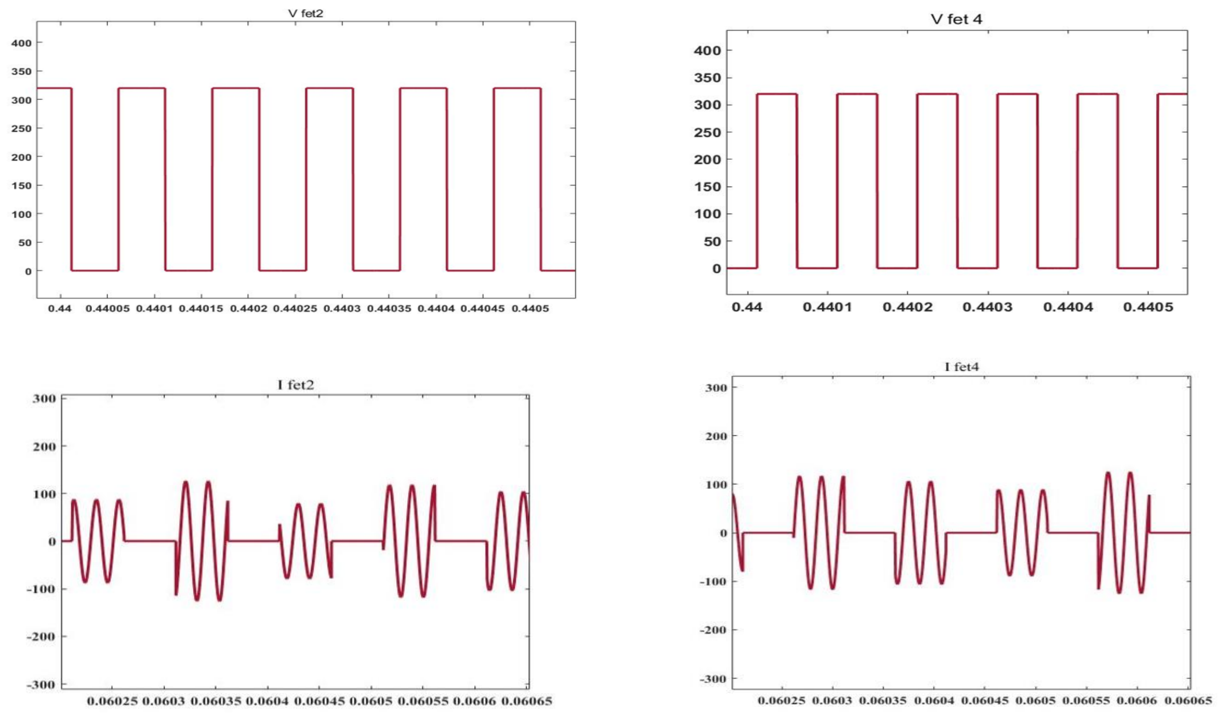

Figure 3. Simulation MOSFET switching characteristics (Voltage and Current)

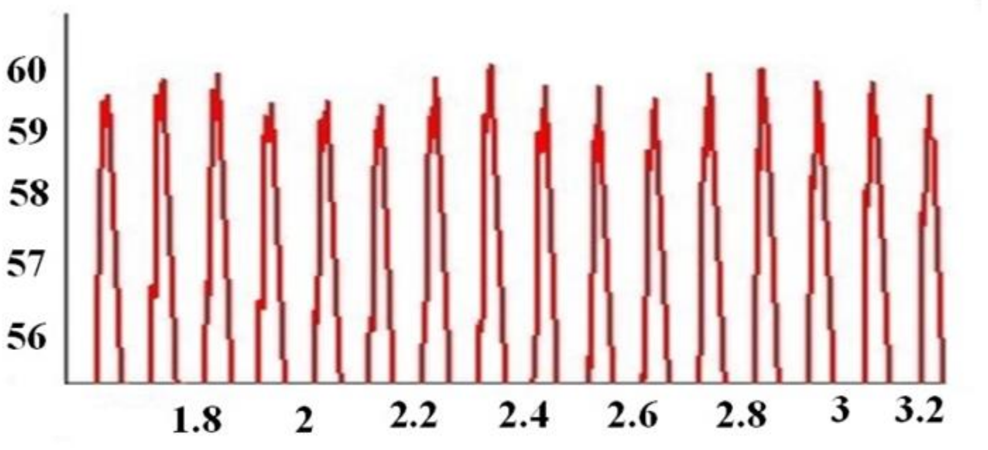

Figure 4. Output voltage of proposed

The Capacitance in Resistance for the proposed technique is shown in Figure 5. To obtain the output, we adjust the resistance values for each difference in efficiency. For our proposed approach, we got the constant efficiency value (i.e., 81.64) during simulation while changing at panoramic mode. The varying inductance for switch 1 (S_1 and S_4).. The gained efficiency varies depending on the varying inductance value in switch 1. The Inductance for switch1 for the proposed approach is shown in Figure 6. Switch 2 inductance efficiency may change as the inductance value is changed. By altering the inductance value, we can get different efficiency rates. The greatest efficiency value for switch 2 inductance is 82.24.

The inductance value ranges from 100 to 200, and the efficiency values may vary depending on the inductance value. We simulate load inductance in MATLAB and increase the load inductance value to obtain better efficiency for load inductance. The Load Inductance of our proposed methodology is shown in Figure 8. Our approach efficiency will fluctuate depending on changes in load inductance. the efficiency values may vary depending on the resistance value. The efficiency value for load resistance cannot be changed by altering the load resistance.

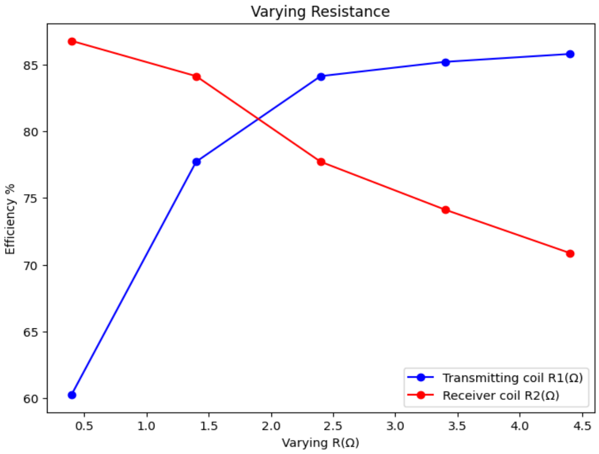

Figure 5. Effect of varying resistance vs efficiency

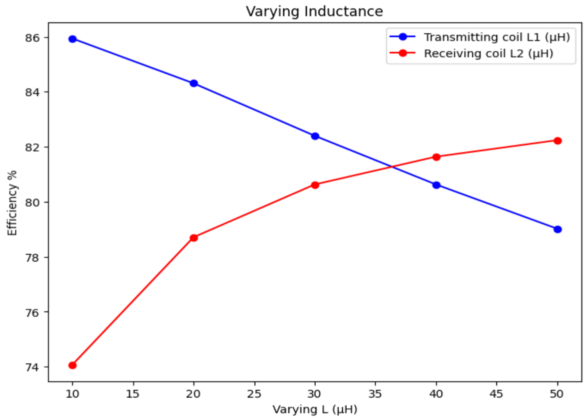

Figure 6. Effect of varying inductance vs efficiency

The control loop of the LCC compensation topology is essential in both situations of fluctuating load inductance and varying load resistance. To maintain the proper output voltage regulation, it should continually monitor the output voltage and alter system parameters such as switching frequency, duty cycle, or control signals. The comparative outcomes of our proposed approach are described in this part. When compared to the current methodologies, the proposed solution performs better.

The graphs are performed in MATLAB version 21a. Fig. 8 displays the efficiency graph for the proposed technique. It shows that effectively input energy is transformed into usable output energy or work is represented by efficiency. The simulation model is running for the procedure using output power and efficiency. The improved efficiency of the proposed work is 95.2% at k=0.30, At k=0.23, the proposed method experienced 94.9% efficiency, while at k=0.14, the proposed method gained 94.2% efficiency. At k=0.30, the greatest efficiency is 95.2% as represented in fig. 8.

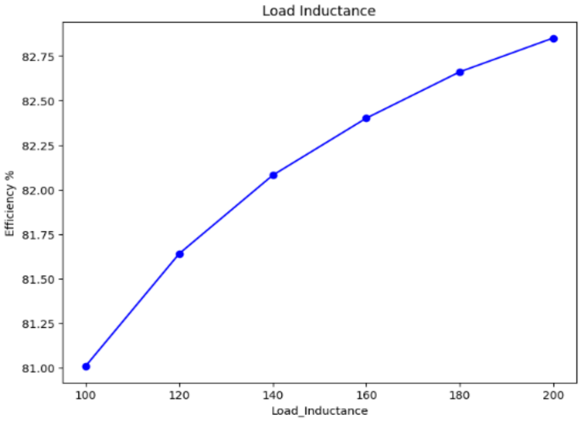

Figure 7. Load inductance vs efficiency

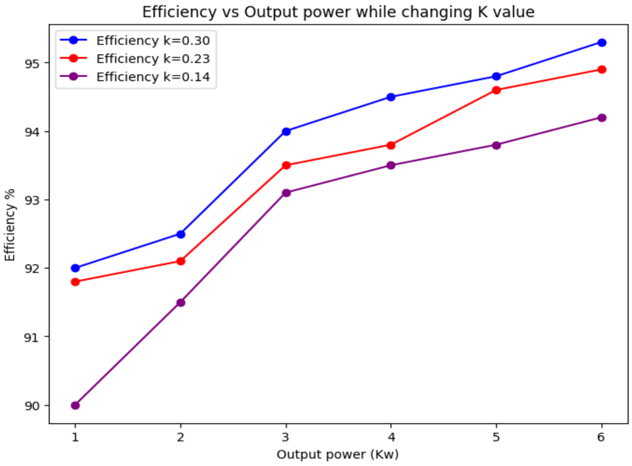

Figure 8. Effect of varying coupling factor (k=0.14, 0.23 and 0.30) on output power vs efficiency

This analysis helps evaluate the effectiveness of the LCC compensation scheme in controlling the inductive behavior and its impact on the coil's phase relationships at operating frequency. This information is crucial for fine-tuning the coil design to achieve better performance and efficiency in wireless power transfer systems, contributing to the practical implementation of high-performance charging solutions for Electric Vehicles.

The Q value is a dimensionless parameter that represents the quality or efficiency of a resonant circuit. It indicates the ratio of energy stored in the circuit to the energy dissipated as losses during each cycle of oscillation. A higher Q value indicates lower energy losses and better efficiency in the resonant circuit. It is crucial for achieving efficient power transfer in wireless systems.

$$Q = \frac{E_{SC}}{E_{DL}} \tag{9}$$

Where,

E_{SC}= Energy stored in the circuit.
E_{DL} =Energy dissipated as losses per cycle.

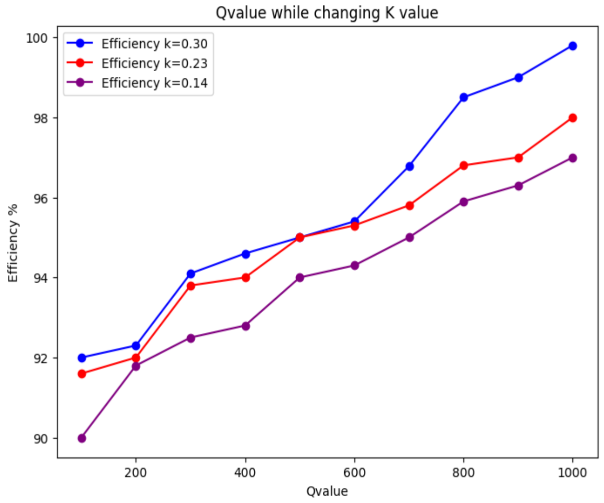

Figure 9. Effect of varying coupling factor (k=0.14, 0.23 and 0.30) on Q-value vs efficiency

The k value, or coupling coefficient, is a measure of the magnetic coupling between the transmitter and receiver coils in a wireless power transfer system. It quantifies the extent to which the magnetic field generated by the transmitter coil couples with and induces a voltage in the receiver coil. The k value typically ranges from 0 to 1, where 0 represents no coupling, and 1 represents perfect coupling. A higher k value indicates a stronger coupling between the coils, which is desirable for efficient power transfer. It is a critical factor in determining the overall efficiency of a WPT system. Fig. 9 displays the efficiency Vs Q-value graph for the proposed technique. Efficiency measures how effectively input energy is transformed into usable output energy or work. The simulation model of the proposed method is running under the procedure using Q-value and efficiency. The improved efficiency is 99.8% at k=0.30. At k=0.23,

the proposed method experienced 98.2% efficiency, while at k=0.14, we gained 97% efficiency. At k=0.30, the greatest efficiency is 99.8%.

5. CONCLUSION

This paper develops an enhanced LCC compensation scheme for electric vehicles employing WPT with a dual transmitter. As a switching partner with ZVS functions, we utilized a Snubber MOSFET. For the simulation component, four different switches schemes are used. The increased efficiencies were then determined using MATLAB version 21a to replicate our model. Therefore, with a simple circuit configuration, the layout can operate with a bigger misalignment condition with high efficiency. The gained greatest efficiency is 99.8% at k=0.30 in accordance with the Q-value and the improved efficiency of the proposed work is 95.2% at k=0.30 in accordance with output power. An LCC-modified design for electric cars utilizing a wireless charging system with integrated dual transmitter winding is developed since the receiver side of WPT vehicles retains more power. Finally, the proposed model is built for charging using WPT and finds that the proposed approach works effectively. As a future direction, the WPT coil modeling can be made in a magnetic program (Maxwell, j-mag, comsol, etc.) then these coils can be used by simulating MATLAB.

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