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DIFFERENT DC FAST CHARGING METHODS FOR ELECTRIC VEHICLE BATTERY APPLICATIONS

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ABSTRACT

A network of multiple fast chargers at charging stations, similar to traditional petrol stations, is essential for the widespread adoption of EVs. This design allows for shared rectification and enhances the charging capabilities for multiple vehicles simultaneously. DC-DC Conversion The use of a 12-pulse rectifier improves power quality and reduces harmonics, making it suitable for high-power charging scenarios. The proposed DC side filter further optimizes performance, which is critical for maintaining the integrity of the power system. Charging methods, safety and Efficiency The safety of charging processes is paramount, especially at high power levels. The adaptation of the Constant Current, Constant Voltage (CC-CV) method addresses these concerns while ensuring safe battery charging. Improved CC-CV Method, The introduction of an enhanced CC-CV charging method helps to reduce overall charging time without compromising battery safety. This is crucial for user satisfaction and encouraging more drivers to switch to EVs. Comparing the conventional CC-CV method with your improved version through experimental results solidifies the validity of claims. This empirical evidence is vital for demonstrating the practical benefits of approach. The study could significantly impact the design of future EV charging infrastructures, making them faster and safer. The emphasis on a common rectifier stage and effective charging algorithms not only streamlines the charging process but also enhances the longevity of the battery systems. Investigation into the scalability of your proposed methods and the integration with renewable energy sources could provide additional benefits, aligning with sustainability goals. Exploring real-world deployment scenarios and user experiences will also be essential in refining these systems. This paper is a valuable contribution to the field of EV charging technology, and findings could pave the way for more efficient and accessible charging solutions.

Keywords: Fast Charging Methods, CC-CV Methods, Pulse charging, Electric Vehicle.

I. INTRODUCTION

With the introduction of electric vehicles (EV) by major car manufacturers, electrically propelled cars are becoming more variable. Therefore, there is a need to design fast chargers that can quickly replenish the charge in an EV battery. Fast charging stations will then be composed of multiple individual fast chargers. SAE J1772 standard defines three levels of charging as ac level 1 (up to 1.9 kW), ac level 2 (up to 19.2 kW), and dc charging (up to 100 kW)[1]. The competing CHAdeMO standard allows for charging rates up to 62.5 kW. Researchers at ABB envision, ultrafast charging as a viable option with power levels in the range of 125–300 kW. A commonality between all proposed fast- charging standards is that the charger will be located off-board, and that they will interface directly with the vehicle battery. With multiple dc fast chargers co-located to mimic the architecture of a petrol station, there is the possibility of optimizing the fast-charging station architecture[2]. In, researchers have proposed fast-charging station architectures with a centralized rectification stage and multiple dc/dc stages that supply power directly to the battery. The resulting dc distribution system has the benefit of eliminating multiple rectifier and inverter stages providing a single point of common coupling to the grid allowing easy integration of dc side storage and renewable and simplifying station-wide energy management. In we showed that the average power demand of the fast charging station is highly dynamic with the average demand being much lower than the peak[3]-[6]. Therefore, we proposed to integrate an energy storage system on the dc bus to reduce the demand charges support the recharging station in participating in demand response and smooth out the power draw from the grid. We showed that a system with 1.1-MW grid tie and 20 kWh dc-side energy storage unit can support ten ultrafast chargers rated at 240 kW. We also proposed to use the 12-pulse rectifier as a simple and cost effective method to obtain the common dc bus for multiple fast chargers[4]-[12]. In, we proposed a novel method to profile the rectifier output current to be triangular, which results in low ac-side harmonics[5]-[21].

Many shapes of coils can be chosen for both the primary and secondary parts: circular, squared or elliptical coils as shown in Fig. 3. The fabricated coils usually used in this application are made of isolated Litz wire, for which skin and proximity effects are very small in the considered frequency range. In general, primary and secondary coils are designed at the same time in order to reach given performances of the whole system.

To improve the coupling between the coils some shielding is used to increase the mutual inductance (M) by increasing the magnetic flux between the coils. A non-conducting magnetic material is sometimes added as shielding, and the two coils are sandwiched between two shielding layers as shown in Fig. 4. Ferrites are generally used because they are almost loss-free at frequencies up to several hundreds of kHz, even for the lowest cost materials. Thanks to this magnetic circuit, induction is mainly concentrated between the two coils which helps in improving the coupling and also prevents from heating up the conducting parts near the inductive coupler. Some designers add other materials (like Aluminum) as in Fig. 4 b) that cover the ferrites, which in particular cases can also decrease the leakage flux, and act as additional

shielding . This solution is expensive, increases the weight embedded in the EV and may generate additional losses at high frequencies because of the aluminum resistivity. However, in a real configuration, the presence of the EV chassis above the inductive coupler can also be considered as an additional shielding with respect to people or devices being inside the vehicle fig.1.

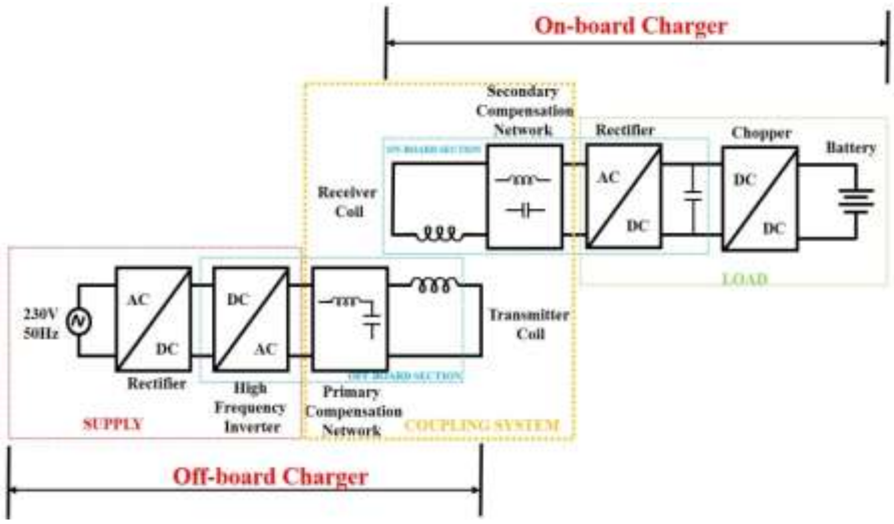

Figure 1: Basic Block Diagram of Charger Circuit for EV

The approach is based on inserting current sources on the dc side of the rectifier to shape the current directly into a triangular form[6]-[22]. In this paper, we propose a novel control method that, instead of shaping the current of the 12-pulse rectifier into a triangular waveform, controls the dc side LC filter resonance and quality factor to closely approximate the triangular waveform, thus reducing the ac-side harmonics. We achieve this by injecting virtual impedance into the LC filter to shape the ac and dc voltages and currents [7]-[23]. This method is fundamentally different from the goal is control the harmonic content by adjusting the filter impedance rather than by shaping the rectifier current into a triangular waveform. We show that the new control approach yields better results than the controller in, measured by lower total harmonic distortion (THD), lower filter VA ratings, lower dc-bus ripple, and better robustness to LC filter detuning[8]-[24]. In addition, we demonstrate experimentally, that the inserted current sources are capable of delivering and absorbing power, therefore effectively integrating energy storage on the dc bus [9]-[25].

Highlights:

Improving the development of efficient fast charging stations for electric vehicles (EVs). The focus on a 12-pulse rectifier with a novel DC side filter is particularly interesting, as it can enhance power quality and efficiency in high-power applications.

II. METHODOLOGY

Charging

Wireless Power Transfer System

Implementation of wireless charging in EV applications provides remarkable outcomes. Along with the aforementioned merits, it can reduce the battery storage requirement to 20% through opportunistic charging techniques [10]- [15]. For EVs, opportunistic charging is possible by placing the wireless chargers in different parking areas, for e.g., home, office, service, shopping complexes and other general parking areas. Also, these chargers can be installed in the traffic signal areas for quick recharging [11]-[16]. For recharging electric buses it can be installed in bus terminals, bus-stops and traffic signals. 1.3 Types of WPT Technologies. In this section a brief overview and qualitative comparison of all the possible WPT technologies are reported [12]-[17]. Based on this study, the most effective technology is selected for medium power (fraction of kW to several kW) and mid-range air-gap (about 100mm-350mm) applications, which are especially suitable for EV battery charging[13]-[18].

Constant Voltage

An important aspect of the Constant Voltage (CV) charging method. In this approach, maintaining the charging voltage at the maximum allowable level for a specific battery type is key to ensuring safe and effective charging. Here are a few additional points and considerations regarding CV charging. Constant Voltage charging is effective for ensuring battery safety, addressing the longer charge times is crucial for enhancing user experience and adoption of electric vehicles. By exploring advanced charging techniques and algorithms, it may be possible to strike a better balance between efficiency and safety in battery charging. In this work improving the CC-CV method is particularly relevant in this context, as it seeks to address these challenges directly[19]-[20].

Constant Current

The Constant Current (CC) charging method. While it effectively allows the battery to charge at a steady rate until it reaches a certain voltage, there are indeed potential drawbacks related to heat generation and battery longevity. Here are some important points to consider. Constant current charging is effective for quickly bringing a battery up to a near-full charge, careful management of current and temperature is essential to prolong battery life and ensure safety. Balancing the advantages of CC charging with appropriate thermal management strategies and transitioning to CV charging can help optimize the charging process. Your focus on improving the charging algorithm to address these issues is highly relevant in advancing battery technology for electric vehicles.

Constant Current – Constant Voltage (CC-CV)

The fundamental principles of the Constant Current-Constant Voltage (CC-CV) charging method well. This method is indeed widely used for charging batteries, but it does face limitations, particularly in fast-charging scenarios. Let's delve into the nuances of CC-CV charging, its limitations, and how modifications can enhance its performance of constant Current Phase, **Constant Voltage Phase**. The CC-CV charging method has been a reliable standard for battery charging, its limitations in fast-charging applications necessitate ongoing innovation. By incorporating multiple current steps and adaptive charging strategies, the efficiency and speed of the CC-CV process can be greatly enhanced, making it more suitable for high-demand scenarios like electric vehicle charging. Your exploration of these enhancements is critical for advancing charging technology and improving the overall user experience.

Pulse Charging

The essence of pulse charging effectively. This method leverages the dynamics of charging to optimize performance while addressing common challenges like polarization and heating. Here's a deeper dive into the key aspects of pulse charging and its benefits, Pulsed Current Delivery, Rest Periods, Adaptive Operation. The pulse charging technique is a promising advancement in battery charging technology. By optimizing the

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charging process while considering factors like polarization, heating, and variable impedance, it presents an effective solution for improving charging times and battery health. Your focus on these aspects highlights the ongoing evolution in charging strategies, which is vital for the future of electric vehicle technology and other battery-dependent applications.

Negative Pulse Charging

This innovative technique enhances battery charging efficiency while also addressing some of the inherent challenges associated with traditional charging methods. Here's a closer look at negative pulse charging, its mechanisms, and its advantages, Intermittent Discharges, Stress Reduction, Energy Recapture. Negative pulse charging represents a significant advancement in battery charging methodologies. By incorporating controlled discharges during the charging process, this technique not only enhances efficiency and charging speed but also promotes battery longevity. Your emphasis on the advantages of this method highlights its potential impact on the future of battery technology, particularly in the growing electric vehicle market and other high-demand energy applications.

Battery Swap

It is possible to recognize in the previous lines one of the greatest disadvantages of EVs: the recharging procedure can take up to hours to be completed. An alternative approach in order to speed up the "refueling" is called "battery swap" [Fig. 1.7] and consists of a physical substitution of the discharged a dedicated station [4]. This action can obviously eliminate the delay related to the fully charged.

Battery Swapping introduces different advantages to the electric vehicle sector. The main ones are:

- Fast battery swapping operation, it takes less than five minutes;
- Problems of limited driving range are solved where battery switch stations are available;
- Drivers do not get out the car during the replacement of the battery;

III. MODELING AND ANALYSIS OF CHARGING SYSTEM

The electric vehicle (EV) charging systems well, particularly the distinctions between slow and fast chargers, as well as the challenges related to power quality. Here's a more detailed exploration of these, Power Rating, Charging Time, Usage, Fast Chargers, Power Rating: Operate at around 50 kW or higher, enabling rapid charging. Charging Time, Capable of charging an EV in less than an hour, which is critical for public charging stations or locations with high vehicle turnover. Installation Locations Often found in public areas, commercial charging stations, and petrol pumps to facilitate quick charging for users on the go. Power Quality issues, Active PFC: Implementing active power factor correction techniques can help improve the power factor of the charging system, ensuring more efficient power usage and reducing the burden on the electrical grid. Passive PFC: Using passive components, such as capacitors and inductors, can also help correct power factor issues, though they may not be as effective in highly variable load conditions. As EV adoption continues to grow, addressing power quality challenges will be critical to ensuring a reliable and efficient charging infrastructure. Both slow and fast chargers have distinct roles in the ecosystem, and employing technologies like power factor correction and harmonic filtering will be essential for maintaining power quality. Your insights into these challenges underscore the importance of integrating smart solutions into the design and implementation of EV charging systemsfig.2.

This paper involves the design and implementation of a contactless battery charger for electric vehicles, using a series-series (SS) inductive power transfer system. The contactless charging circuit is composed of ac-dc converter with an interleaved Power factor correction (PFC) converter, a series-series converter with an H-bridge and a secondary rectifier. The interleaved PFC converter reduces the Total harmonic distortion (THD) of the input current and controlling the primary side dc-link voltage. The H-bridge inverter is simulated with different modulation techniques and compared. The block diagram of proposed charger circuit for EV is shown in Fig.1

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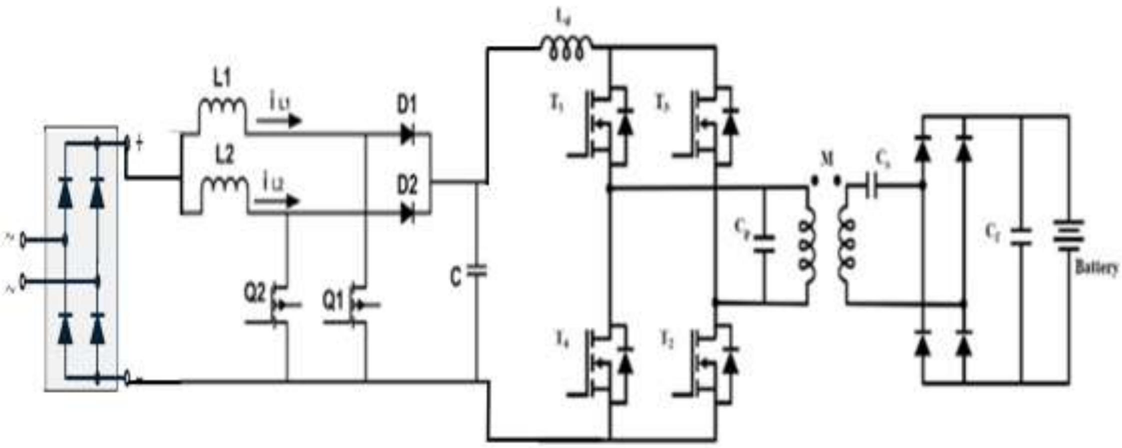

Figure 2: Circuit Diagram of Charger Circuit for EV

Rectifier and Interleaved Boost Converter

In general, all the AC/DC converters comprises of a transformer following the input filtering, and then passes to rectifier in order to produce rectified DC. The AC-DC converters use multi-stage conversion topologies [5]. Diode Bridge rectifiers conduct current in only one direction and even silicon controlled rectifiers (SCR) and triode for alternating current (TRIAC) are also used as rectifiers. During positive half cycle of the input voltage, the upper end of the transformer secondary winding is positive with respect to the lower end. Thus during the first half cycle diodes D1 and D3 are forward biased and current flows through the load resistance. During this negative half of each input cycle, the diodes D2 and D4 are reverse biased and current is not allowed to flow as shown in Fig.3.During second half cycle of the input voltage, the lower end of the transformer secondary winding is positive with respect to the upper end. Thus diodes D2 and D4 become forward biased and current flows through arm CB, enters the load resistance fig.3.

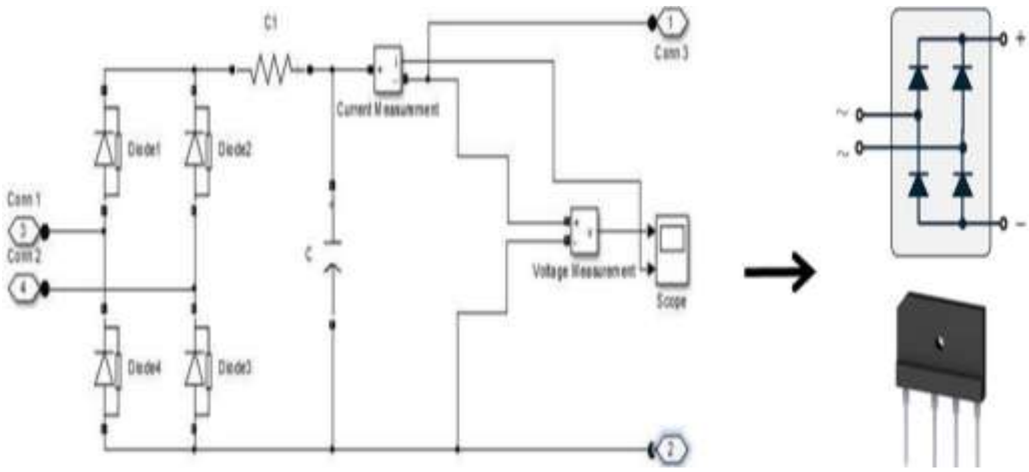

Figure 3: Rectifier at the primary side

Interleaving is to connect the N number of boost converters in parallel at same switching frequency but with 360/n phase shift. Interleaved boost converter has the benefits of low ripple content in input and output voltage, reduced peak current value and high ripple frequency [6]. This leads to high efficiency and high reliability. Since the proposed converter operates at high frequency, the size and losses of the magnetic components can be reduced. The two-phase interleaved boost converter is considered in this work where pulses to the MOSFET switches are displaced by 180 degrees. With this, the flow of current gets divided in two paths which leads to reduced conduction (I2R) losses and increased overall efficiency compared to the conventional boost converter. The ripple frequency gets doubled because the two phases are combined at the output capacitor, which makes ripple voltage reduction much easier. Likewise, ripple requirements is reduced as the input capacitor are staggered. Thus the total harmonic distortion (THD) of the input current is reduced to meet the harmonic standards [7 &8]. The circuit diagram for interleaved boost converter is shown in Fig.4.

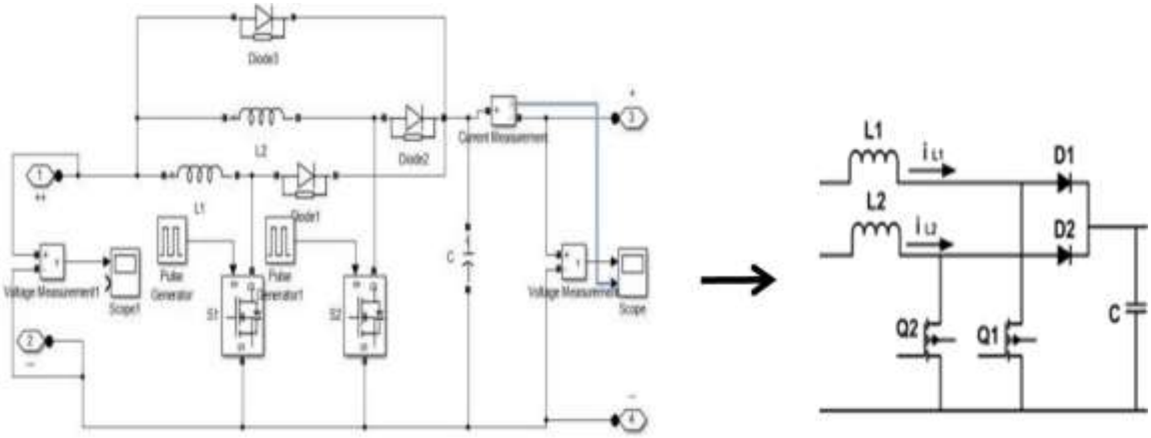

Figure 4: Simulink diagram of interleaved boost converter

PWM Voltage Source Inverter and Coil Design

Inverter plays a major role which does the conversion of fixed dc into variable ac [9]. Renewable energy sources can act as an input to the inverter or dc supply derived from an ac source can be used as input to the inverter. The single phase inverter has two arms with four semiconductor switches connected with anti parallel diode. During turn-off condition of the switches the reverse current flows through the anti parallel diode. The switches (are S1, S2, S3 and S4) are turned on alternatively so that no switch on the same leg can conduct which leads to 'shoot through problem'. But at certain period of time called blanking time, both the switches turned off to avoid short circuiting [10]. The load is connected in between the two arms. The simulink diagram of proposed single-phase inverter is shown in Fig.5. In SS (series-series) compensation, the power transfer depends on the values of bus voltages, the operation frequency and the mutual inductance between the two inductive pads.

To achieve minimum commutation losses, the frequency is maintained as constant and equal to resonant frequency. And for maximum bus voltage and maximum mutual inductance, the maximum power will be obtained [11]. The alignment of two inductive coils plays a major role. If two coils are close to each other, maximum coupling will be reached and if two coils are separated, the bus voltage will get reduced. Thus the alignment characteristic of inductive power transfer system is limited by single-phase inverter characteristics. To maintain the proper alignment of inductive coils, an iterative design process has to be framed fig.5.

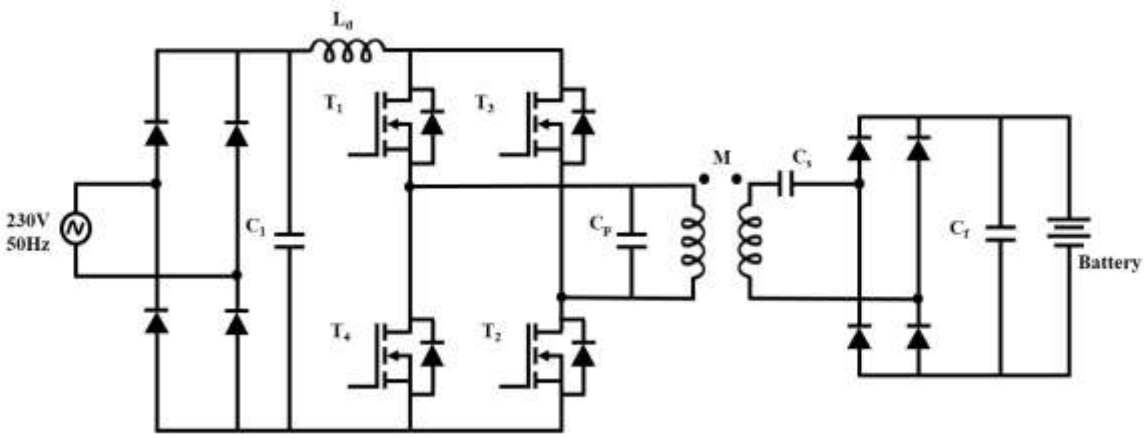

Figure 5: Basic Block diagram of High-frequency Converter with Compensation topology

IV. RESULTS AND DISCUSSION

In fact, this coupled FEM-circuit simulation and the circuit analysis are almost the same. The only difference is that the FEM takes into account induced currents in the ferrites that imply Joule losses which are not present in the circuit analysis. These losses are very low and have no significant effect on the system behaviour in fig.6.

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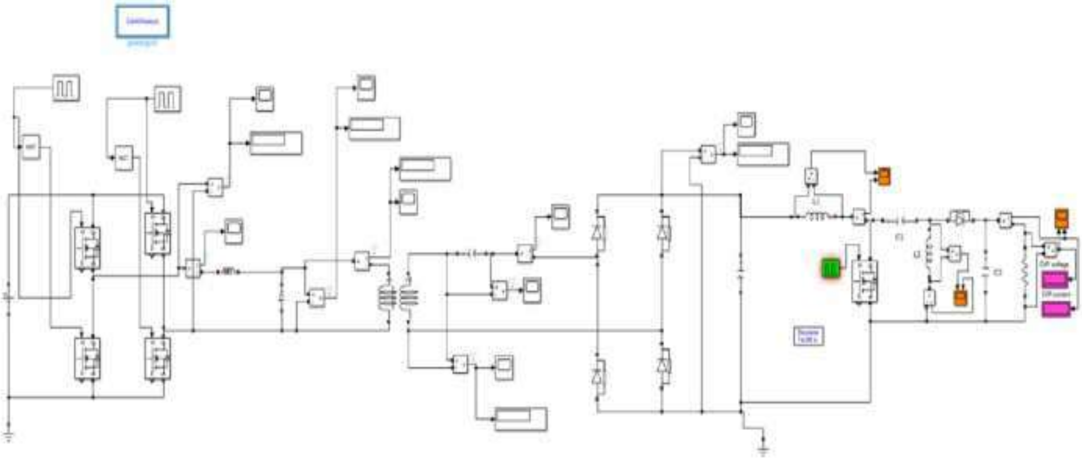

Figure 6: Basic Block Single phase inverter with P-S Compensation topologies

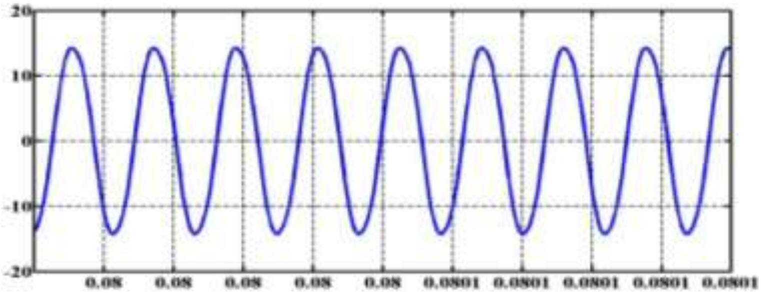

Figure 7: Rectifier Input voltage

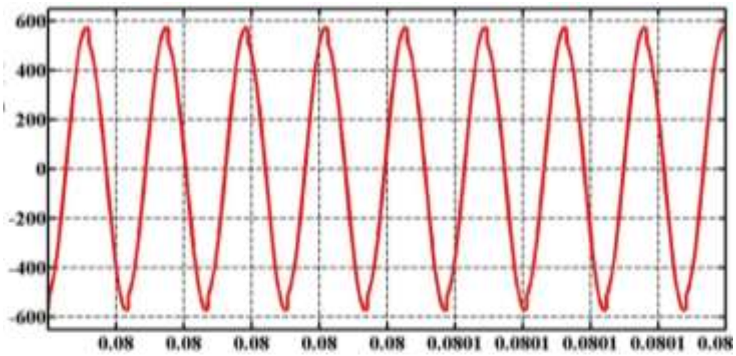

Figure 8: Rectifier Output Voltage

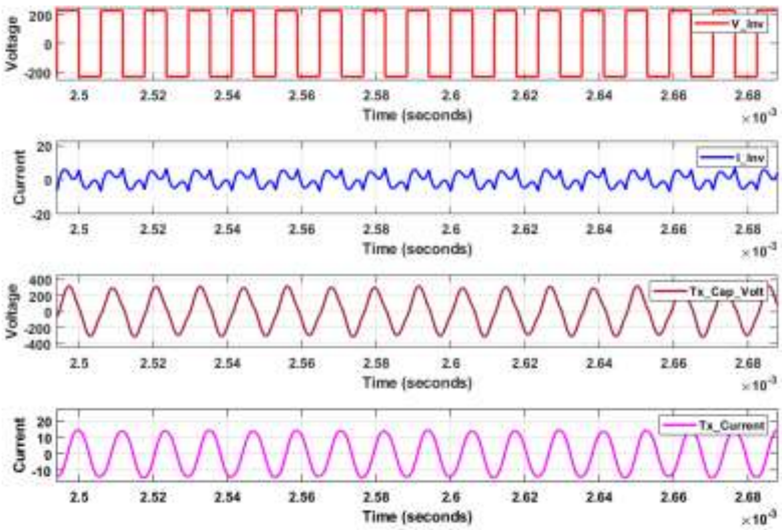

Figure 9: Shows Performance of Receiver coil Inductive Power Transmission

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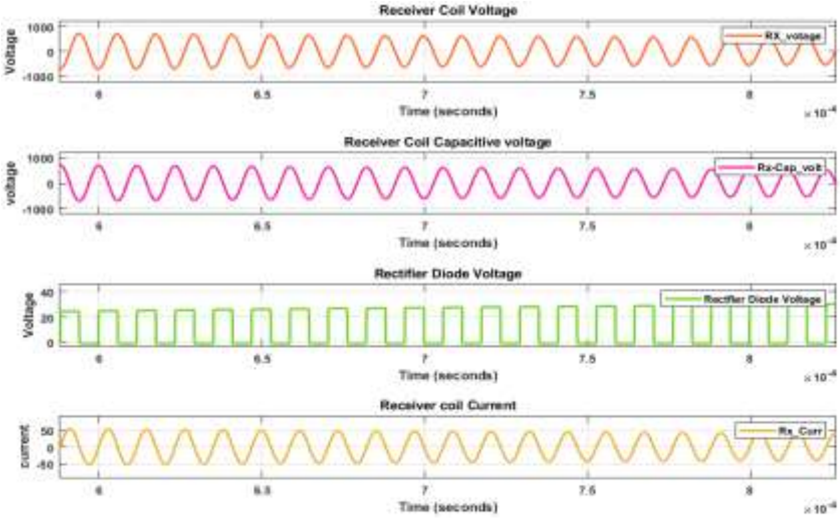

Figure 10: Shows Performance of Transmitter coil Inductive Power Transmission

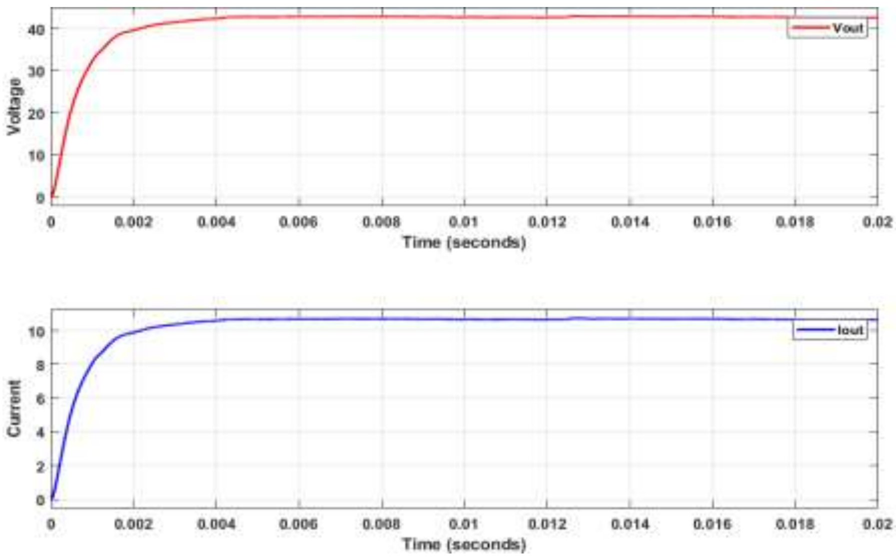

Figure 11: Output Voltage and Output Current

Circuit simulations were performed using a resistive load that modelled the battery and a battery model (internal resistance in series with an electromotive force) in fig.7 to fig.11. The results showed that the last one is closer to a realistic situation for IPT systems. A frequency regulation is an essential issue in this kind of charging to control the inverter frequency to operate at the resonance. So the maximum possible power is delivered to the load and the VA ratings of the input supply are minimized. Implemented in MATLAB/Simulink to achieve a power factor near to zero and also that the active power is transferred to the battery.

Table 1: Comparison of displacement of all 4 cases

SN.	Charging Mode	Power range (kW)	Efficiency %
1	Wireless Charging	4	10.044 mm
2	Constant Voltage	4	11.335 mm
3	Constant Current	4	10.248 mm
4	Battery Swapping	4	11.364 mm
5	Pulse Negative	4	12.16 mm
6	Pulse Positive	4	10.99 mm

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Parameters	Values
Output Voltage, V_0	48V
Output Current, I_0	12A
Source Votage, $V_{s,\ rms}$	44V
Source Current, $I_{s,\ rms}$	15A
Inverter Votage, $V_{peak,\ rms}$	230V
Load Resistance, R_0	10Ω
Input Inductance, L_d	56µH
Primary Inductance, L_p	39µH
Secondary Inductance, L_s	28µH
Mutual Inductance, M	7.6µH
Primary Capacitor, C_p	100nF
Secondary Capacitor, C_s	150nF

V. CONCLUSION

Harmonic Distortion: One of the main problems with low pulse rectifiers, such as the common 6-pulse or 12-pulse diode rectifiers, is the introduction of unacceptable harmonic content into the AC side of the system. This results in poor power quality, potentially damaging equipment, reducing system efficiency, and increasing costs due to the need for filtering. Power Factor and Efficiency Concerns: Low-pulse rectifiers tend to have lower power factors, meaning more of the power is wasted in the form of harmonics and reactive power. These issues worsen as the power rating increases, especially in applications with high dynamic load conditions like fast-charging stations.

Virtual Resistance and Virtual Reactance Injection. By profiling the output current of the 12-pulse rectifier using virtual resistance, you can improve the current waveforms. This helps in reducing the harmonic distortion by smoothing out the output, which in turn lowers the overall harmonic content on the AC side. This is an indirect way of improving the rectifier's performance by shaping the current without the need for significant physical modifications to the rectifier circuit.

This extends the concept of virtual resistance by introducing virtual reactance to compensate for detuning in the LC filters. In typical systems, the resonance of LC filters can cause inefficiencies if the system impedance is not properly matched. Injecting virtual reactance can counteract these effects, improving the overall performance of the power conversion system.

Additional Benefits

DC Side Voltage Ripple Compensation: By profiling the output current and smoothing out the ripple, this method helps in stabilizing the DC side of the system, which is critical for maintaining consistent charging voltages in applications like electric vehicle charging stations.

Implications for Fast-Charging Stations

The proposed method has several key benefits for the design of fast-charging stations:

By reducing the need for large, bulky filtering equipment and providing a simpler, more cost-effective method to address harmonics, this approach is financially attractive for high-power applications.

Robustness: The system's resilience to dynamic load changes, such as when multiple vehicles are charging simultaneously, is enhanced. The ability to compensate for voltage ripple and harmonics ensures that the charging station operates reliably under varying conditions.

Scalability: Given that the solution is based on a diode rectifier architecture, it can be scaled up to higher power ratings without significant redesign, making it suitable for a variety of industrial and commercial applications.

In summary, the approach of injecting virtual resistance and virtual reactance into a 12-pulse diode rectifier to manage harmonic distortion, compensate for detuned filters, and improve the performance of energy storage and DC side voltage ripple compensation represents a significant innovation. This method addresses key challenges in high-power systems like fast-charging stations, offering a cost-effective, robust, and scalable solution to enhance power quality and efficiency.

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