Design and Implementation of Z Source Resonant Converter for EV Wire Less Charging Application

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Abstract — Wireless Power Transfer (WPT) technology is an emerging research area due to its safety and convenience. A Conventional WPT system has Front End PFC and DC-DC Boost Converter which makes the system bulkier. The Z Source Inverter (ZSI) was introduced into WPT systems to improve the system performance. The ZSI regulates the input voltage in WPT systems without Front End Converters and makes the inverter bridge immune to Shoot Through (ST) states. The results are through simulations and Finally, the designed system is implemented experimentally.

I. INTRODUCTION

WPT technology delivers power through an electromagnetic field without any physical connection between the transmitter and receiver [1]-[3]. Recent advancements in this field have led to more stringent design requirements being proposed and studied by researchers, such as efficiency improvement [4]-[8], coupling variation [9], [10], foreign object detection [11], [12], and output regulation [13]-[15]. Electronic technology plays a crucial role in these research studies and spurs WPT technology development. The voltage source inverter (VSI) is an essential part of a WPT system that generates high-technology development. The voltage source inverter (VSI) is a crucial component in the design of WPT systems and is used to regulate the output voltage of the system. The VSI is implemented experimentally.

Guidelines to design Z-source network based on steady state parameters were presented in [19]. Since the network is connected to a three-phase VSI, the output current of the network is regarded as a constant current. Meanwhile, the current in the network of WPT system is approximately sinusoidal over part of one switching period due to a sinusoidal resonant current. The mathematical analysis in [19] is modified when applied to a WPT system. In [20], the benefits of a ZSI in resonant converters are analyzed. These benefits include improved robustness and reliability, buck/boost function, and high efficiency over wide input and load ranges.

The ZSN in the proposed ZSRI provides the unique feature of inherent power factor correction (PFC) without adding extra switching devices. It is possible because it adds the unique features of immunity to the H-bridge inverter during shoot-through states. This characteristic makes the input current as a sinusoidal waveform and in phase with the ac input voltage. This variable also provides a boost factor to the system. However, to regulate the output voltage, the proposed ZSN-based inverter uses the active state duty cycle, which is a common control variable used in series resonant inverters. Both control variables are used in the series resonant H-bridge inverter and the ZSRI does not require additional control circuitry to provide power factor correction. In other words, because of the ZSN, the ZSRI can perform power factor correction as well as dc/ac conversion in single stage.

II. OPERATION OF Z SOURCE RESONANT CONVERTER

The ZSRC has more states in one switching cycle compared with other DC-AC systems. It is important to clarify all these states to understand the ZSRC. The boost ratio of ZSN is still related to the total shoot-through state duty cycle among these states. The operation principle of the ZSRC is described here with an example of the phase-shift control method. Assuming that the ZSN is symmetrical (C1 = C2 = C, and L1 = L2 = L) therefore, Vc1 = Vc2 = Vc, and Vc1 = Vc2 = Vc. Also, the resonant frequency of L and C in ZSN is at least ten times smaller than the switching frequency. Hence, the ZSN inductor current and the ZSN capacitor voltage are considered to be constant in one switching cycle. Fig. 2 shows the conducting devices in different states—active state, shoot through state, and zero state.
1. **Active State**: During the two active states time interval [see Fig. 6(c) and (g)], the diagonal switches are on, and the input side diode D1 is conducting. The resonant network draws current from both the ZSN inductor and capacitor. The difference between load current and ZSN inductor current is provided by a series connection of the two ZSN capacitor and dc source. The current going through the switches are only load current. The ZSN inductor voltage for this time interval is given as

\[ V_L = V_{DC} - V_C \]

2. **Shoot-Through State**: Three of the switches are ON. The two horizontal switches are carrying the load current and the switches in one-phase leg are carrying the ZSN inductor current. Hence, there is one switch carrying the sum of the two currents. Since the flow of ZSN inductor current is always in one direction and the load current would be bipolar, these two currents either subtract from each other or add together, contributing to the sum with their absolute value. Fortunately, phase-shift control only allows different polarity currents going through the same switch in shoot-through state. Here, the ZSN capacitors will charge ZSN inductors (this is how the ZSRC can boost the voltage). The ZSN inductor voltage for this time interval is given as

\[ V_L = V_C \]

3. **Zero State**: During the zero state’s time interval, two horizontal switches are ON. The ZSN is isolated from the load. The load current is freewheeling and the ZSN inductors charge the ZSN capacitors. The ZSN inductors voltage for this time interval is given as

\[ V_L = V_{DC} - V_C \]

These three states are all the possible states in ZSRC. Different allocation of these three states along one switching period would generate different load regulation characteristic.
III. SIMULATION OF WPT SYSTEM WITH ZSI

Simulation of Z Source Resonant Converter for EV Wireless Charging is done using MATLAB/Simulink 2016

1. Simulation Parameters
Simulation parameters are shown in table 1.

| Parameter            | Value     |
|----------------------|-----------|
| Input Voltage        | 33 V      |
| Resonant Frequency   | 20 kHz    |
| Transformer Turns Ratio | 20 : 15 |
| ZSN Capacitors       | 4.7 mF    |
| ZSN Inductor         | 1 mH      |
| Output Filter Capactor | 1 mF    |
| Primary Side Leakage Inductance | 0.415 mH |
| Secondary Side Leakage Inductance | 1.07 mH |
| Primary Side Leakage Capacitance | 180 nF |
| Secondary Side Leakage Capacitance | 65.80 nF |

The input voltage of the ZSRC is $V_s=33V$ and the output voltage and current is $V_o=88V$ and $I_o=2.28A$ with the resonant frequency of $20kHz$. Assuming that the ZSN is symmetrical ($C_1=C_2=C$, and $L_1=L_2=L$) therefore, $V_{C1}=V_{C2}=V_C$, and $V_{L1}=V_{L2}=V_L$. Also, the resonant frequency of $L$ and $C$ in ZSN is at least ten times smaller than the switching frequency. Hence, the ZSN inductor current and the ZSN capacitor voltage are constant in one switching cycle.

The significant part of the design is choosing the inductor and capacitor values and operating frequency. On the contrary, use of the low frequency leads to increases both on the size and also the cost of inductors and capacitors. Thus, there is a trade-off between the size and efficiency in determining the operating frequency of the converter. The frequency is selected as 20kHz.

2. Simulation Result
The complete model of the developed WPT is shown in Fig.4

Simulation has been performed and the results are presented for each converter stage. The circuit consists of a high frequency (HF) Z Source Resonant Converter. High frequency switching is implemented using MOSFET switches. This is the high frequency link. A HF transformer provides voltage transformation and isolation between the DC source and the load. At the output side, a full bridge rectifier is connected to load. For analytical study, a resistive load is selected. The closed loop is controlled for constant output.
IV. HARDWARE IMPLEMENTATION

The main circuit diagram consists of four sections, converter section, control section, driver section and power circuit. The converter section consists of four IRFP460N MOSFETs. Even if there is any fluctuations in the input the output will be maintained constant by the program stored in the microcontroller. Microcontroller sends the corresponding signals which will be too feeble to drive the MOSFET switches, so a driver circuit consisting of TLP250 Driver are used which boosts the amplitude of the signals enough to drive the switches.

V. CONCLUSION

A new circuit topology for high power WPT applications using a full bridge Z-source resonant inverter has been developed and simulated. The control methods in the system with the insertion of shoot-through modes of the Z-source inverter have been investigated. In simulation, ideal MOSFETs and diodes were used. The output voltage of 27 V and output current of 0.9 A, i.e output of 23.5 W is obtained for the coupling coefficient k of 0.2. In the experiment, an output current of 0.9 A, and output voltage of 16 V was obtained. The slight difference between the simulation and experimental results is due to the following reasons: Core losses, simulation-ideal diode and MOSFET switches were used. Nevertheless, in both the simulation and experiment, the results obtained are very close to the analytical design value. This, in turn, validates the designed parameters.

VI. REFERENCES

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