BRIDGE LESS Z SOURCE NETWORK FED SINGLE PHASE FIVE LEVEL INVERTER WITH DC-DC CONVERTER USING SOFT SWITCHING TECHNIQUES

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Abstract— In this project the bridge less Z-source converter is introduced to power factor correction (PFC) applications. The concept is demonstrated through a wireless charging, namely Z-source resonant converter (ZSRC). The ZVS and ZCS operation will reduce the switching losses. Due to the Z-source network (ZSN), the ZSRC inherently performs PFC and regulate the system output voltage simultaneously, without adding extra semiconductor devices and control circuitry to the conventional WPT system such as conventional PFC converters do. In other words, the ZSN can be categorized as a family of the single stage PFC converters. In addition, the ZSN is suitable for high power applications since it is immune to shoot-through states, which increases reliability and adds a boost feature to the system. Simulations, and experimental results based on a prototype are presented to validate the analysis, and demonstrate the effectiveness of the ZSN in the PFC of the WPT system. The single phase five level inverter ill reduce the THD. The hardware is implemented by using DSPIC30F2010 controller.

Keywords— THD, PFC, ZVS, ZCS, ZVRC, ZSN, Z Source network, DSPIC30F2010 controller.

I. INTRODUCTION

The switched mode DC-DC converters are some of the simplest power electronic circuits which convert one level of voltage into another level by switching action. These converters have received an increasing deal of interest in many areas. This is due to their wide range applications like power supplies for personal computers, office equipments, appliance control, telecommunication equipments, automotive, aircraft, etc. The literature survey for design, modelling and application of variety of converters is presented in this section. Herman Wiegman (1992) discussed the analysis and implementation of a resonant pulse gate drive based on a simple charge pulse circuit. The pulse charging and discharging instances are controlled by the user, hence their circuit is applicable to pulse width modulation schemes as well as resonant converters. Guichao Hua and Fred Lee (1995) proposed a number of soft switching techniques aiming at combining the desirable features of both the conventional PWM and resonant converters while avoiding their respective limitations. They reviewed three types of zero voltage soft switching PWM converters and two types of zero current soft switching PWM converters with their merits and limitations. Poon and Pong (1996) introduced a Zero Voltage Switching (ZVS) based DC-DC converter. Amplitude modulated square wave train is generated in their work and the output is controlled by the amplitude of this square wave train. Energy is directly transferred to the output and it results in simple configuration and inherent ZVS characteristics. Robert Watson, Fred Lee and Guichao Hua (1996) analyzed the behaviour of the ZVS active clamp fly back converter operating with unidirectional magnetizing current and presented the design equations. They concluded that fly back derived topologies are attractive because of their relative simplicity compared with the other topologies used in low power applications. Incorporation of the active clamp circuit, the fly back topology serves to recycle the transformer leakage energy while minimizing the switch voltage stress. Mariodi Bernardo et al (1998) analyzed the nonlinear phenomena in closed loop pulse width modulated DC-DC converters.
They obtained the analytical conditions for the occurrence of the periodic orbits and flip bifurcations and derived the necessary conditions for infinite local stretching on the phase plane. Rais Miftakhutdinov et al (1999) proposed a modification in the asymmetrical zero voltage switched half bridge DC-DC converter topology that substantially changes the static transfer function and the voltage stress distribution within the converter power mesh. This modification allows the converter circuit to be optimized for higher efficiency and power density.

They also postulated that the modification with its corresponding benefits can be utilized in other complementary driven topologies. Although the asymmetrical half bridge converter is inherently capable of ZVS switching, only the proper choice of parameters can ensure ZVS in all modes of operation. Marcelo Lobo Heldwein et al (2000) presented a simple clamping circuit for the ZVS PWM asymmetrical half bridge DC-DC converter. This clamping circuit reduces the oscillations caused by the reverse recovery of the output diodes and thus increasing the efficiency of the converter. Trevor Smith et al (2000) presented a control technique for DC-DC converters using an improved resonant switch model. The model recognizes that a converters power switch has a finite resistance in its ON state. If MOSFET is used, then this resistance will be variable. A switch that has a finite resistance has a voltage across it when the current passes through it. This voltage can be compared to a threshold voltage of an inverter which determines when the switch changes in its state. This method provides self oscillation and inherent overload protection for a converter. The variable resistance of a MOSFET can be utilized to change the time taken by the switch voltage to reach the inverter threshold voltage. This changes the ON time and provides a regulation mechanism for variable output power and input voltage. Xunwei Zhou Mauro Donati et al (2000) implemented a methodology that utilizes the duty cycle signal to improve light load efficiency. Since current sensors are not required, high density and high efficiency can be achieved. This makes the whole circuit suitable for integration. For low voltage high current applications synchronous rectifier technologies are widely used. It was suggested that in order to improve the performance at light load, the converters have to operate in discontinuous conduction mode to reduce its conduction loss and at lower switching frequency to reduce the gate drive loss.

Peng Xu et al (2001) proposed a family of DC-DC converters which employs an innovative interleaving concept by using series primary windings and interleaved parallel secondary sides. The advantages of their converters include reduced filter size, improved transient response and increased efficiency. Pit Leong Wong et al (2001) proposed integrated coupling inductors in multichannel interleaving voltage regulator modules. Coupling inductors have different equivalent inductances for steady state and transient responses. With a proper design, the inverse coupling inductors reduce the steady state current ripple while maintaining the same transient response. The conduction losses in the MOSFET can thus be reduced. The air gap in the centre leg more evenly distributes the flux, which can reduce the core loss of the center leg. They concluded that the coupling inductor core structures make the manufacture of the cores easier and improve the mechanical stability of the cores. To Min Chen and Chern Lin Chen (2002) proposed the converter, which is attractive because of its simple capacitive output filter when compared with the other converters used in the multiple output and cost sensitive applications. They analyzed the detailed circuit behavior of the asymmetrical half bridge fly back converter. Several practical issues including the specific relationships between the duty cycle and the different types of energy in the energy storage elements and the zero voltage switching conditions of the power switches were examined. Jianhong Zeng et al (2002) presented the analysis, design and optimization of a DC-DC converter used for battery input applications. Joe Liu et al (2002) proved that the current driven synchronous rectifier with current sensing energy recovery are suitable for high frequency switching topologies. The synchronous rectifier can be driven ON and OFF automatically according to the current direction. It can be taken as an active diode with very low power dissipation. Khalid Rustom et al (2002) described a single stage power factor correction converter with direct energy transfer feature. They used an asymmetric half bridge topology as a DC-DC cell for its inherent ZVS capability. Direct energy transfer power factor correction cell is introduced to improve the conversion efficiency. Alou et al (2002) designed a
low power DC-DC converter with wide input voltage range. They analyzed several topologies and selected the flyback with active clamp converter circuit because it presents a good trade off between simplicity and efficiency. Their topology provides a wide regulation capability even at no load, ZVS capability and soft turn OFF in the rectifier diode. Masakazu Takagi et al (2002) considered the theoretical limitations in the efficiency of DC-DC converters used in telecom applications. They compared the theoretical limitations of the efficiency in single stage topology with two stage topology. They concluded that buck half bridge topology is suitable for high output current and low output voltage DC-DC converters.

Vitor Fernao Pires and Jose Fernando Silva (2002) illustrated a method to obtain nonlinear switched mode state space model of power converters suited for simulation and control design. They simulated the state space models of the electronic power converters with its associations and electromechanical devices with various types of control systems. They concluded that the MATLAB software provides the powerful simulation and control tool for power converters. Jose Eduardo Baggio et al (2003) presented an isolated DC-DC zero voltage switching converter composed of two half bridge converters operating at constant frequency. It can be seen as an alternative to the ZVS phase shift full bridge DC-DC converter for high voltage applications. They proposed a command strategy named interleaved phase shift which allows equalization of the input capacitor voltage where each capacitor shares one quarter of the total input voltage. Qing Du et al (2012) proposed a high power input, parallel output series half bridge converter. The circuit achieves complete decoupling from the input so that the mutual effects between modules are eliminated and thus oscillations are avoided. They analyzed the circuit structure, operating principles and basic relations. The inconformity of the transfer functions and the discontinuity caused by the switching time delay and the disturbance of input voltage are also analyzed. They described the combinational control strategy and the compensation methods in order to achieve effective control at steady state, smooth transition at mode change and reduction of the adverse effect caused by the disturbance of input voltage. Zhe Zhang et al (2012) proposed the converter that consists of push pull forward half bridge circuit and a high frequency transformer.

This structure minimizes the number of the switching transistors and their associate gate driver components. With phase shift control strategy, all the switches are operated under zero voltage switching condition. In order to optimize the converter performance and increase the efficiency, they investigated the optimal design methods and criteria including coupled inductors design, power flow analysis, harmonics analysis and ZVS range extension.

II. PROPOSED SYSTEM

The input AC voltage is given to the bridgeless Z source network. This will convert the AC voltage into DC voltage with very less harmonics. This DC voltage is fed to the Single phase five level inverter. To reduce the switching losses resonant converters are proposed. The figure shows the proposed system circuit diagram. The features of resonant converters are zero current switching (ZCS), zero voltage switching (ZVS), and efficiency is high, size will be small and there are no EMI problems. Resonant converters are successfully applied to AC power supplies for improving the power factor and heating, DC power supplies for domestic and industrial applications. There are two types of basic resonant converters series and parallel RC. The series RC has better part load efficiency and lack of DC blocking voltage of the transformer due to the series connected capacitor in RC. But, its load regulation is poor and output voltage regulation is not possible in the no-load condition. But, the PRC offers good no-load regulation and load efficiency is poor and lack of DC blocking of the transformer the AC L-C-L resonant network formed with the components $L_1, C_1$ and $L_2$, along with the planar transformer connected at output stage and it provide isolation. The values of inductances and capacitance are chosen for the AC L-C-L resonant network are resonance at the output frequency of MLI. $V_x = V_1 + V_2$ From above equation voltage across $L_1$ will be $V_2$ and the voltage across $L_2$ will be $V_1$. 

\[ V_x = V_1 + V_2 \]
Figure 1. Proposed system circuit diagram

The output current of AC L-C-L resonant network, $I_2$, can be controlled by controlling the multilevel-inverter output voltage $V_1$. For electroplating process require the power supply low voltage DC and high current DC, but multilevel inverter output voltage is very high. So by using L-C-L resonant converter the output voltage can be reduces. Furthermore, the multilevel inverter output voltage $V_1$ is more compare to L-C-L network output voltage $V_2$. But the, merit of L-C-L resonant converter is to maintain the constant current source, that means current through $L_1$ is equal to the current through $L_2$, i.e. $I_1 = I_2$. Further, the output of AC L-C-L resonant converter connected to primary winding of planar transformers. In order to increase the current levels the planar transformer connected in the shown in fig above. That means there are eight transformers connected in primary side series and secondary side parallel with center tapped for isolation purpose. Primary windings are connecting in series the high voltage can be distributed each of primary winding with an equal voltage distribution assured by connecting the secondary side windings in parallel. Similarly, the parallel connection the high current to be distributed each of secondary winding with an equal current assured by connecting the primary in series.

From the above connection use planar transformer so many advantages like coupling improve, leakage inductance reduces, stray capacitance can be minimized, and skin effect and the losses in the secondary side can be also reduced. In the primary winding series and each transformer is center tapped with 1:1+1 turns ratio employed, which give the total number of turns ratio 8:1 shown fig above. Rectifiers are connected secondary winding of each transformer to allow smoothing the output current ripple to achieve using a DC L-C-L filter. To increase the load resistance, the voltage $V_2$ across $L_1$ will be increase. Thus, cause current drawn from MLI is increase. Due to the inductance $L_2$ and transformers the current supplied from the load will decreases. Decreasing load current causes due to division of current through transformers and higher load resistance. Therefore, a limit exist the size of the output load that can be used with AC resonant converter and the transformers. Further, electroplating process require load is 12 V DC and 500 A DC and 20 mΩ. And load decrease a very low value the current levels are increase high value. This load can be influences determine the value of $C_1$ in AC L-C-L resonant network. The value of $C_1$, AC L-C-L resonant converter operate at resonant frequency must high relative to reflected the load impedance.

If, take the capacitance value is low it reduce its effectiveness. The output stage of these we provide DC L-C-L filter with a components of $L_3$, $C_2$ and $L_4$. The AC L-C-L resonant converter connected to the transformer primary winding. In which transformer has some winding capacitance, due to transformer internal winding capacitance severe degradation in the output current regulation that means there is a reduction in the output current? The presence of transformer internal winding capacitance in the circuit, the third order L-C-L converter changes to the fourth order LC-LC structure. The fourth order LC-LC topology also maintain current source is constant. Thus, the transformer winding capacitance and leakage reactance are effectively utilized part of AC L-C-L resonant converter, thereby improving output characteristics. full-bridge AC L-C-L resonant
A resonant converter along with full bridge rectifier. Components of the resonant converter are $L_1, L_2, C$ and the full-bridge inverter switches are $S_1, S_2, S_3$ and $S_4$. The inverter drives the input to the resonant converter with large frequency square wave voltage $V_{in}$ with amplitude of $\pm V_{dc}$. Output of the AC L-C-L filter fed to the diode rectifier and filter capacitance convert AC to DC.

A transformer with 1:n turns ratio is connected to the output of AC L-C-L resonant network and produces output current $I_0$, output voltage $V_0$ with an input of $V_{dc}$. The transformer has leakage inductance $L_t$ and winding capacitance $C_{wc}$ shown in fig above. The winding capacitance can be transferred to primary with turns ratio of 1:n is $C_{wc} = n^2C_{wc}$. The AC L-C-L resonant converter behaves as constant current source and transformer inductance is observed with a total inductance $L_t = L_2 + L_1$ and $L_1$. The circuit can be operated at the resonant frequency of $\omega_0 = 1/\sqrt{L_1C}$. This half-bridge and resonant converter can be replaced by a constant current source $i_{L}$ and it can be divided into $i_{cw}$ and $i_{dp}$. In this the average output current of resonant converter decrease with increase in transformer winding capacitance. Similarly due to the transformer internal winding capacitance the output current also reduces. In this constant current $I_L$ can flows through capacitor and transformer primary winding. Due to transformer winding capacitance primary winding current reduces. The winding capacitance can be observed by AC L-C-L resonant converter. So, due to winding internal capacitance output current also reduces. The isolation transformer output voltage is given to the synchronous rectifier. It will convert the AC voltage into DC voltage. This voltage is fed to the load.

III. Z SOURCE DESIGN

ZSI of two inductor and two capacitors. This inverter is a energy storage element and also a filtering element. ZSI is more helpful to reduce the voltage and current ripples so that torque ripples can be reduced. Additional advantage provided by Z Source network requires less capacitance and smaller size compared to traditional voltage source inverter and current source inverter. As per reference paper [1], the peak dc link voltage can be expressed as,

$$V_{py} = B V_0$$

Where $V_0$ is Input Dc voltage and $B$ is Boost factor determined by shoot through duty ratio. The Z source network capacitor voltage is determined by

$$V_{cl} = V_{c1} = V_c = \frac{1 - D_c}{1 - 2D_c} V_0$$

Here $D_c$ is less than 1, this representing a high Z source capacitor voltage stress. The z source network inductor current equals the average input current. The z source inductor current increases and the current decreases.

IV. OPERATION OF FIVE LEVEL INVERTER

Fig. 2 shows a configuration of the proposed single-phase five-level PWM inverter. One switching element and four diodes added in the conventional full-bridge inverter are connected to the center-tap of dc power supply. Proper switching control of the auxiliary switch can generate half level of dc supply voltage. The operation of proposed inverter can be divided into 10 switching states. divided into 10 switching states as illustrated in Fig. 3. Operational states of the conventional inverter are shown in figure.(b), (e), (f), (i), and (j) in sequence, and additional states in the proposed inverter synthesizing half level of dc bus voltage are shown in Fig. (c), (d), (g), and (h). The additional switch must be properly switched considering the direction of load current. The switching patterns adopted in the proposed inverter are illustrated in Fig, and the output voltage levels according to the switch on off conditions. Basic principle of the proposed switching strategy is to generate gate signals by comparing the reference signal with the two carrier waves having same frequency and in phase, but different offset voltages.
Largely, there are two switching methods according to the output voltage levels. If the required output voltage for a certain load can be produced using only the half of dc bus voltage, only the lower carrier wave is compared with the reference signal the lower dc bus voltage is used to generate the output voltage. Namely, the modulation index is equal or less than 0.5, the behavior of proposed inverter is similar to the conventional full-bridge three-level PWM inverter, and the distribution of harmonic components in output voltage is similar to that of the conventional inverter having the values two times the modulation index.
Figure 3. Operational states according to the switch on_off conditions and the direction of load current.

The mentioned above is the first operational mode. On the other hand, if the required output voltage is increased beyond the modulation index 0.5, it comes into the second mode using the upper bank of capacitor. In this case, the switching function produced by upper carrier wave is prior to that of the lower. According to the amplitude of the voltage reference, the operational interval of each mode varies within a certain period.

Figure 4 Switching patterns of the proposed single-phase five-level PWM inverter.
V. SIMULATION & EXPERIMENTAL RESULTS

Figure 5. Simulink diagram

Figure 6. Five level inverter output voltage

Figure 7. Isolation transformer output voltage
VI. CONCLUSION

An auxiliary resonant circuit ensuring Soft switching bridgeless Z source based five level inverter along with the synchronous rectifier has been discussed in this project. The simulation results ensure the soft switching of both the switches, thus eliminating switching losses, conduction losses, electric stresses & EMI. Proper design of inductor must be taken for appropriate soft switching as the inductor plays a very vital role in the design of Boost converter. A proper difference can be perceived in the effectiveness of Hard Switching & Soft Switching converters. This method of soft switching can be used for low power DC equipment mainly in telecom services. This soft switching method not only eliminates the losses but also increase the overall efficiency of systems thus making the overall system to cost-effective & reliable to use.
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