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An Energy Efficient Circuit Topology of Z-Source Hybrid Resonant Inverter Fitted Induction Heating Equipment

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Abstract

This paper presents a new circuit topology for efficient induction heating in PSIM using an impedance source (abbreviated as Z-source) hybrid resonant inverter. Now a day, usage of induction heating technique is significantly increased for both domestic and industrial purposes for its high energy efficiency and controllability. In general, high frequency resonant inverters are incorporated in induction heating equipments to generate high frequency alternating magnetic field. Previously voltage source inverters were used in induction heating equipments. But they have certain kinds of limitations. So, in this paper, a new scheme of Z-source hybrid resonant inverter has been introduced which increases the energy efficiency and controllability and the same is validated by PSIM.

Keywords: *High Frequency, Z-source, Hybrid Resonant Inverter, PSIM, Induction Heating, Controllability.*

1. Introduction

Induction heating technique is becoming popular day by day because of its energy efficiency, controllability and cost effectiveness. In induction heating, a high frequency alternating current flows through an induction coil. Due to this, a high frequency alternating magnetic field is produced which cuts the nearby work piece and induces eddy currents in it [1-3,16]. These eddy currents when flow produces heat by Joule's effect due to inherent resistance of the work piece. High frequency resonant inverters are installed in the induction heating equipment to produce the rapidly alternating magnetic field. Previously voltage source inverters were widely used for this purpose. But certain kinds of limitations are there in case of voltage source inverters.

- First of all, the voltage source inverters are generally step down converters. The ac output voltage is always less than the dc input voltage.
- Shoot through state is not permissible i.e. the upper and lower switches of the same leg of the inverter cannot be switched on simultaneously.
- Reliability is not so good in case of EMI noise.

The impedance-source (Z-source) converter overcomes these limitations [9-11]. It employs a unique impedance network that couples the power circuit to the converter. In case of impedance-

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source hybrid resonant converter the shoot through state can be used to boost the output voltage of the inverter. So, efficiency and controllability is increased in case of Z-source hybrid resonant inverter fitted induction heating equipment.

2. The Developed Scheme and its operation

In the proposed scheme, at first the single phase ac supply is rectified to dc by an uncontrolled rectifier. After that a Z-source is connected which is basically a split inductor and two capacitors connected in X shape. After that a high frequency hybrid resonant inverter is connected comprising of four IGBT switches operating at 22 kHz frequency. The induction coil and the work piece to be heated serve as the load of the hybrid resonant inverter. The X shaped network creates an impedance source which couple the inverter to the dc source. As the inverter switches are operating at a high frequency, so a high frequency alternating current flows through the coil which results in induction heating of the work piece. But in normal voltage source inverters the shoot through condition is not permissible i.e. two switches of the same leg cannot be switched on at the same time. Whereas, in the present scheme of the z-source hybrid resonant inverter, the shoot-through condition can be used to boost up the load voltage [9-11]. The advantage of this scheme is that, a wide range of output voltage can be found irrespective of the input voltage. As the inverter is operating at high switching frequency, high frequency harmonics are produced in the load side which flow back towards the supply. To avoid this and to improve the input power quality, a low pass filter is incorporated at the input which prevents the high frequency harmonics to flow back to the supply side [28].

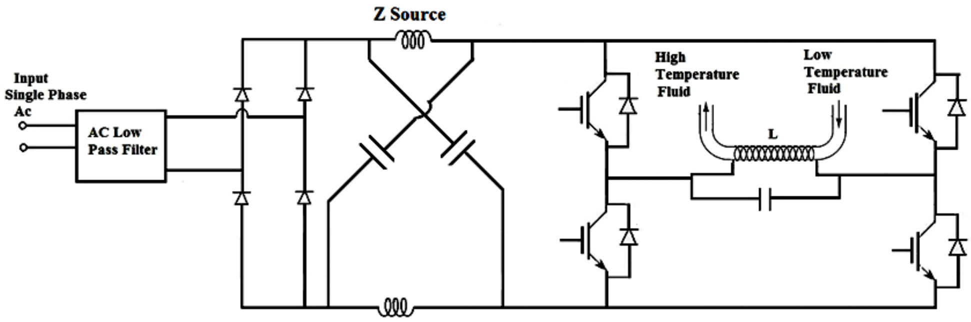

Figure 1: Developed scheme of high frequency Z-source hybrid resonant inverter

3. Analysis of Z-Source Hybrid Resonant Inverter

Fig. 1 depicts the scheme of Z- source hybrid resonant inverter fitted induction heating equipment. Here an induction coil wound non-metallic pipe serves as the load. To heat the fluid passing through the non-metallic pipe, metallic packages are employed inside it [4-7, 17]. The simplified equivalent circuit of the scheme is shown in fig. 2. Here L_R, R_L and C_R are the equivalent impedance of the induction coil and its secondary object reflected in primary [8, 12-15, 24-27]. The parameters of the circuit are chosen such that the circuit becomes under damped. To minimize the switching loss, soft switching technique (ZCS) is implemented in the circuit [18-24]. Here both series and parallel resonant circuits are used. Here at first a single phase ac supply is rectified to dc through an uncontrolled full bridge rectifier. This dc voltage serves as the input of the Z-source high frequency inverter. At first S_1, S_4 is turned on and a resonant current flows through the load. In this period C_R is charged. The current through the load becomes sinusoidal as the circuit is under damped. Then at some zero current crossover point, S_1 and S_4 are switched off. Now the capacitor (C_R) starts discharging itself and the current flows through L_R and R_L. So due to Joule's effect heat is produced. In the next half cycle S_2 and S_3 are switched on and the same process is continued. At some instants, both the switches of the same leg are made on to boost up the output voltage.

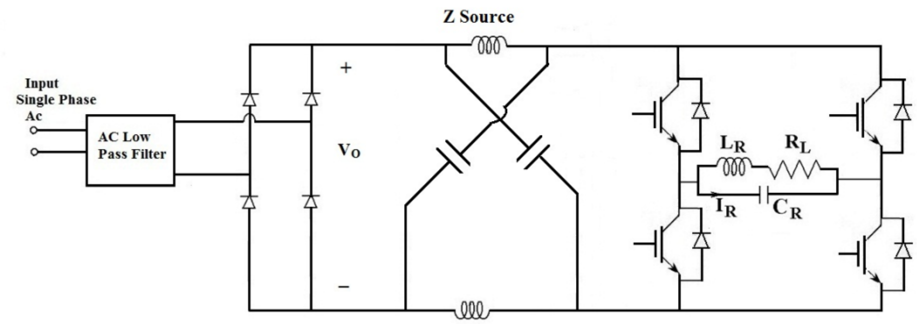

Figure 2: Equivalent circuit diagram of Z-source hybrid resonant inverter fitted induction heating equipment

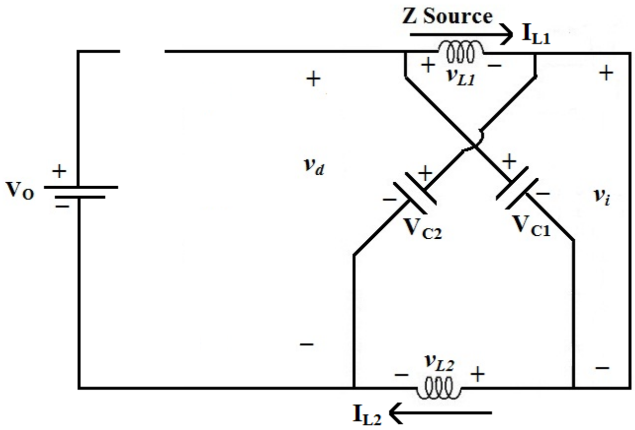

Figure 3: Equivalent circuit of the Z-source inverter (viewed from the output of the rectifier) when the inverter bridge is in the shoot-through state

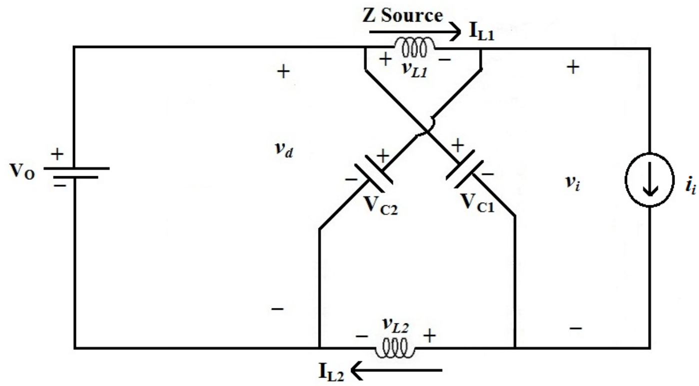

Figure 4: Equivalent circuit of the Z-source inverter (viewed from the output of the rectifier) when the inverter bridge is in one of the eight nonshoot-through switching states

Let, the inductors L_1 and L_2 of the Z-source possess the inductance L and the capacitors C_1 and C_2 possess the capacitance C [9]. So, from the equivalent circuits, it can be found that,

$$V_{C1} = V_{C2} = V_C \text{ And } v_{L1} = v_{L2} = v_L \tag{1}$$

Let us assume that, the inverter is in the shoot through state for an interval of T_0 in a switching cycle T. From the equivalent circuit as shown in fig. 3 it can be concluded that

$$v_L = V_C, v_d = 2V_C, v_i = 0. \tag{2}$$

Let us consider again that the inverter is now in one of the non shoot-through states for an interval of T_1. It can be deduced from fig. 4 that

$$v_L = V_O - V_C, v_d = V_{O,} v_i = V_C - v_L = 2V_C - V_O \tag{3}$$

Here $T = T_0 + T_1$.

As the inductors are reactive elements, so in a complete cycle (T) at steady state the average voltage across the inductors will be zero. So,

$$V_L = \overline{v_L} = \frac{T_0 \times V_C + T_1(\mathrm{V}_0 - \mathrm{V}_C)}{T} = 0$$

$$or, \frac{V_C}{V_0} = \frac{T_1}{T_1 - T_0}$$

The average voltage across the inverter can be found similarly.

$$V_i = \overline{v_i} = \frac{T_0 \times 0 + T_1 \times (2\,\mathrm{V}_C - \mathrm{V}_0)}{T} = \frac{T_1}{T_1 - T_0} \times V_0 = V_C$$

The peak voltage across the inverter bridge can be represented as,

$$\hat{v}_i = V_C - v_L = 2V_C - V_0 = \frac{T}{T_1 - T_0} \times V_0$$

Where this [T/(T_1-T_0)] is called the boost factor.

As the inverter bridge has no energy storage elements, so the instantaneous input power must be equal to the instantaneous output power.

$$V_d(\mathrm{t})\,\mathrm{I}_d(\mathrm{t})(1 - \mathrm{d}_s) = \mathrm{MV}_d(\mathrm{t}) \sin \omega \mathrm{t} \times M \frac{V_d(\mathrm{t})}{|Z|} \sin(\omega \mathrm{t} - \phi)$$

Where V_d(t) and I_d(t) represent the rectifier output voltage and current, d_s stands for the shoot through duty ratio, M for modulation index, Z and Φ for load impedance and power factor, ω for inverter output angular frequency. The effects of switching frequency components are neglected.

4. Simulation Diagram and Results :

The equivalent circuit of the proposed topology of high frequency z-source hybrid resonant inverter fitted induction heating equipment has been developed and then simulated in PSIM. Figures below depict the simulated circuit diagrams and the obtained waveforms. Fig. 4 depicts the circuit diagram of the developed scheme as simulated in PSIM. Here the switching frequency of the Inverter is chosen as 22 kHz. Fig. 5 shows the waveform of the output voltage (VP5) when simulated in PSIM. The RMS value of the output voltage (VP5) which is 384.96 volt is depicted in Fig. 6. Fig. 7 shows the waveform and RMS value of rectifier output voltage (VP6) for the developed scheme. The RMS value of rectifier output voltage is 454.225 volt as shown in figure. The gate voltage waveforms for the developed scheme of high frequency Z-source hybrid resonant inverter is shown in figure. It can be seen from the figure that there are some instances when both the IGBTs of the same leg are switched on. This is not possible in normal voltage source inverter, but in z-source inverter this switching state can be implemented to boost the output voltage.

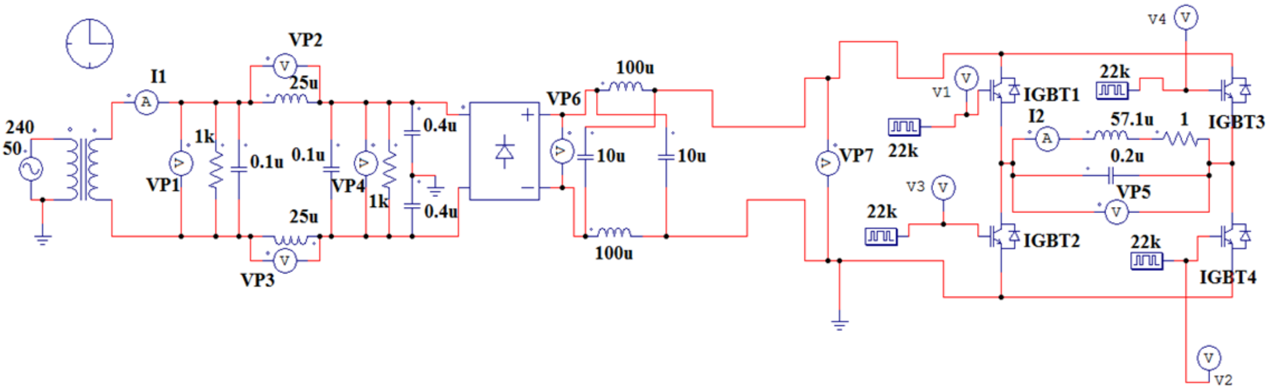

Figure5: Simulated circuit diagram for the developed scheme of high frequency Z-source hybrid resonant inverter fitted induction heating equipment on PSIM software

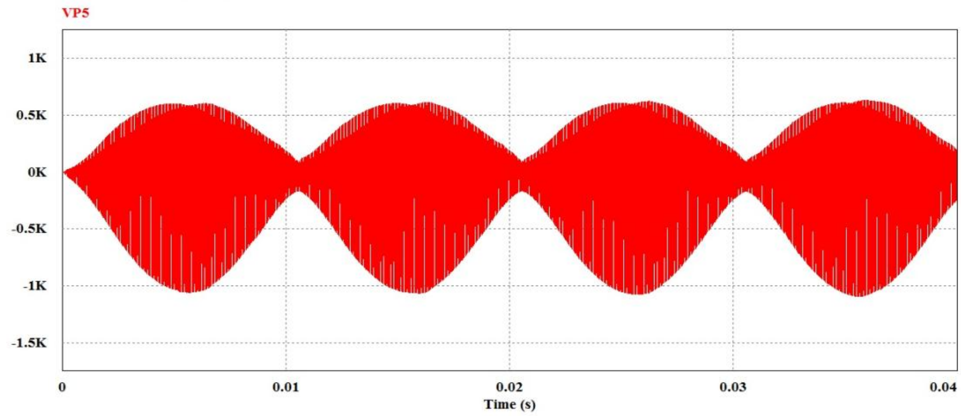

Figure 6: Waveform of load voltage (VP5) for the developed scheme of high frequency Z-source hybrid resonant inverter fitted induction heating equipment on PSIM software

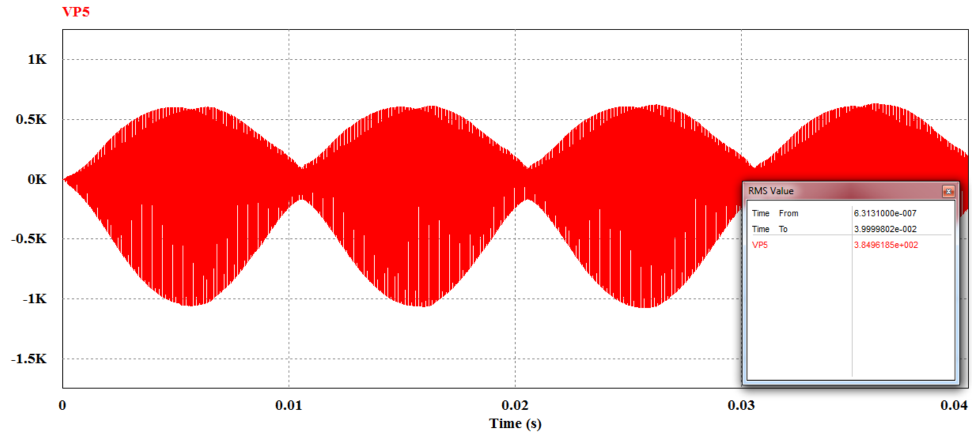

Figure 7: RMS value of load voltage (VP5) for the developed scheme of high frequency Z-source hybrid resonant inverter fitted induction heating equipment on PSIM software

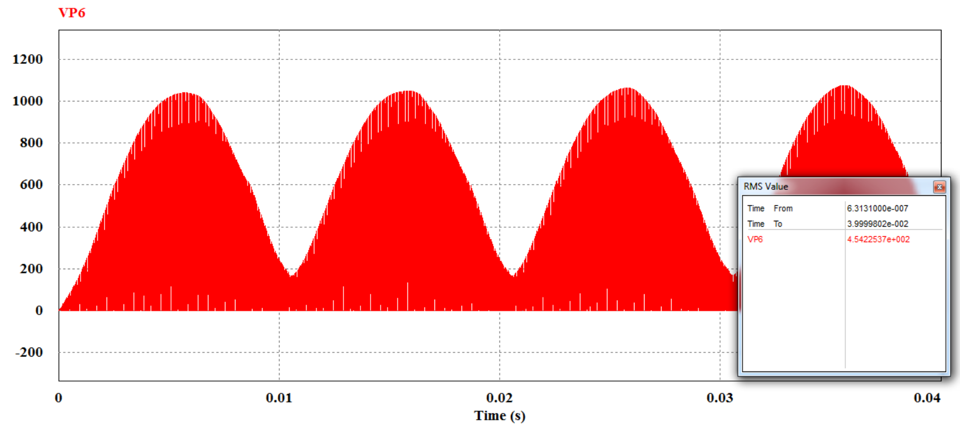

Figure 8: Waveform and RMS value of rectifier output voltage (VP6) for the developed scheme of high frequency Z-source hybrid resonant inverter fitted induction heating equipment on PSIM software

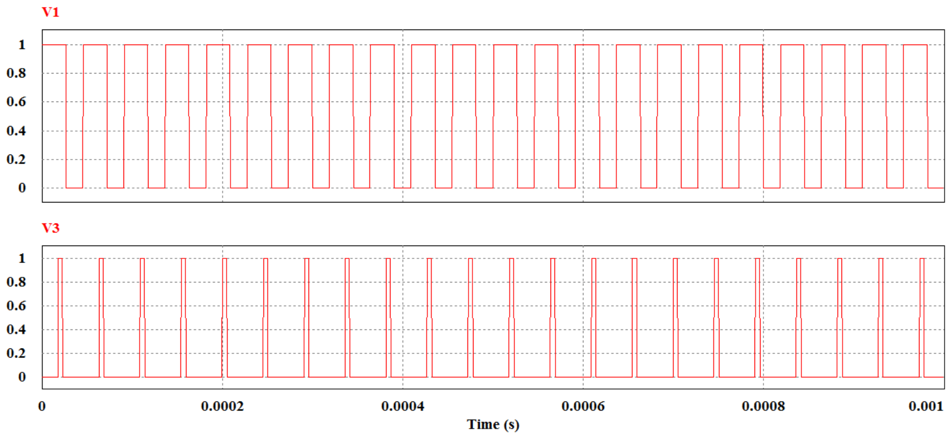

Figure 9: Gate voltage waveforms for the developed scheme of high frequency Z-source hybrid resonant inverter fitted induction heating equipment on PSIM software

Conclusion

In this paper, a new topology of impedance source hybrid resonant inverter fitted induction heating equipment is designed which is suitable both for domestic and industrial applications. The impedance source hybrid resonant inverter is operating at very high switching frequency (22 kHz). The output waveforms are shown in figures when the simulation is done using PSIM. In this scheme, an impedance network couples the power circuit to the high frequency inverter circuit. So, it overcomes the limitations which are faced by conventional voltage source inverters. This topology allows the user to implement the Shoot through state to boost the output voltage. So, a wide range of output voltage can be generated using this scheme which results in a wide range of heating. Considering all factors, it can be concluded that this novel topology of high frequency impedance source (Z-source) hybrid resonant inverter fitted induction heating equipment is highly energy efficient and controllable.

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