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Direct AC-AC Full Bridge Converter

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Abstract: *Induction heating are applied for several industrial and domestic application .Among these application it is mainly applied to domestic field as an induction cooker. In conventional induction heating application, efficiency and cost are compromised due to the conduction loss and increased components. The proposed topology with full bridge converter uses only two diodes reducing conduction loss and a direct ac-ac conversion is possible here. The IGBT is operated by a switching frequency of 150KHz.*

I. Introduction

Induction heating is emerging as the most important application in power electronics. .Due to its high temperature it is applicable to steel melting, brazing and surface hardening .Domestic induction heating has become very relevant due to its higher efficiency and the reduced heating time .Induction heating which is a non contact heating technique requires high-frequency current supply that will induce a high frequency eddy current in the working piece that will result in the heating effect. Power semiconductor switching devices, digital and analogue control devices, circuit components and high frequency soft switching inverters are used to bring out the unique advantages of induction heating into practical. Classical induction heating method is based on two stages: a rectifier and resonant inverter. A four-diode full bridge rectifier is used to rectify the main ac voltage and a small value dc-link capacitor to ensure input power factor close to 1.The resonant inverter supply the inductor pot system. The one switch topology is mostly used for low cost appliances and low output power levels, for medium output power half bridge inverter is used. Finally, the full bridge inverter is used for high output power levels. The proposed converter uses a half bridge boost rectifier and a full bridge inverter for obtaining high output power levels. As result converter efficiency is improved and low frequency ac current do not flow through IH load, thus reducing peak current and conduction losses. Full bridge topology has dual –IGBT(Insulated gate bipolar transistor) inverter modules to convert
AC sine wave so that the high frequency current waveform is complete, clear and stable and due to the high current allocation efficiency of full bridge topology it can electronically transfer high thermal efficiency and can load high inductive loads.

II. Direct Ac-Ac Converter

An ac-ac converter converts a fixed voltage, fixed frequency ac input supply to obtain a variable voltage ac output. In ac-ac converter sinusoidal input currents and bidirectional power flow can be achieved by coupling a pulse width modulation (PWM) rectifier and a PWM inverter to a dc link. The DC link quantity is an energy storage element which is a capacitor C for the voltage dc link and inductor for the current dc link.Here we propose a direct ac-ac converter for achieving high frequency application. In conventional design due to the input current harmonics, a low frequency power get across the load. So it take less heating time. The need of an additional filter requirement is eliminated in the proposed model. Due to the activation of more than one diode on each half cycle leads to high conduction loss in case of an conventional converter. Direct ac-ac converter is free from the conduction loss.

III. Block Diagram

The fig.1 Shows the block diagram of Direct AC-AC Full Bridge Converter. The input ac voltage is fed to AC-AC full bridge converter. Controller provides necessary gate signal for the driver circuit. Driver circuit fix duty ratio of these pulses and it is driven to the resonant converter. Thus a high frequency ac voltage is fed to the induction pan.

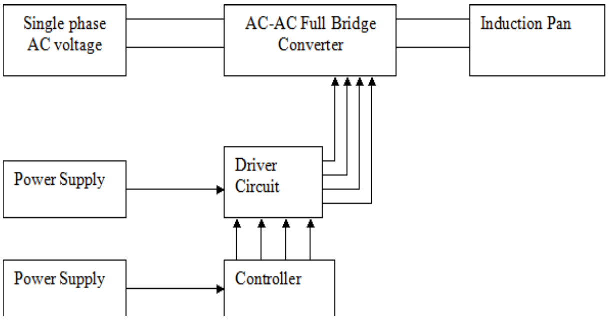

Fig. 1. Block diagram of direct ac-ac full bridge converter

IV. Circuit Diagram

The circuit diagram of direct ac-ac converter is shown in fig.2. We propose full bridge ac-ac converter here which is more efficient than half bridge converter.

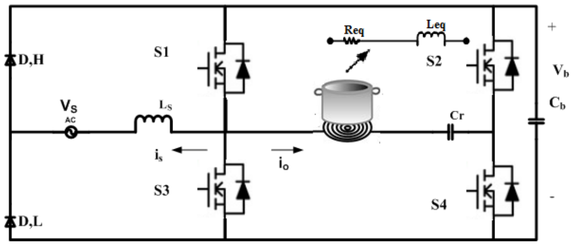

Fig. 2. Circuit diagram of direct ac-ac converter

The converter consists of input AC voltage Vs, four IGBT switches S1, S2, S3, and S4, dc-link capacitor C, input inductor Ls , diodes D,H D,L and IH load. The AC power supply is rectified by the half-wave rectifier branch composed of D,H and D,L.The full bridge inverter circuit consists of four switches with anti-parallel diodes S1, S2, S3 and S4. The switches S1and S2 is used both to perform a boost dc–dc conversion of the mains ac voltage and additionally, to supply the high frequency current to the inductor along with S3 and S4. The voltage boost is performed by means of the input inductor L_s and the dc-link capacitor Cb .The IH load is modelled as a series of equivalent RL circuit composed of Req and L_{eq}. The input inductor L_s and the dc-link capacitor Cb boost the voltage. The boost dc-dc conversion of mains AC voltage is done by switches S1 and S3. The wave form of the boost dc-dc circuit is shown in fig.3.

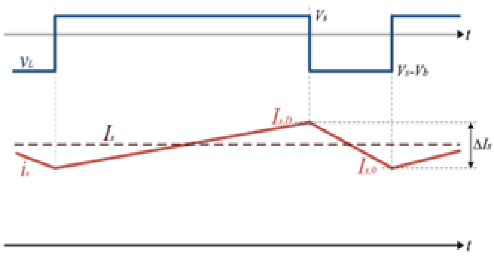

Fig. 3. Wave form of the boost dc-dc circuit

V. Ac-Ac Full Bridge Converter Analysis

The direct AC - AC converter operation can be analyzed through the four modes of operation through the equivalent circuit I to IV. During the positive half cycle of the main voltage D_H conducts that is in indicated by the two stages I and II. Where as D_L conducts during the negative half cycle that is indicated by the stage III and IV. This shows that only one rectifier is activated at a time,that will reduce conduction loss as it is compared to the conventional converter. The Zero voltage switching is guaranteed in it by providing time delay between the switching of each switch. The supply voltage is applied across the inductor during the modes I and III and the dc link capacitor is charged by the inductor current during mode II and IV. The rectification for positive supply voltage is done by switch S1 and for the negative cycle,its done by switch S2. The required high frequency AC current i_o to supply the IH load is performed by the inverter branch composed of S1, S2, S3 and S4. The equivalent full bridge inverter is supplied by the dc link capacitor voltage Vb. The total current in the device is expressed as the sum of the boost stage and the equivaent full bridge inverter stage. stage and the equivalent full bridge series resonant inverter. In mode1 S3 and S4 are turned on, D,H conducts during positive half cycle of current dc link capacitor is charged by the supply voltage and input inductor Ls . The high frequency current is applied across the load. Mode 1 is shown in figure .S1 and S4 are turned on during mode 2, supply voltage is applied to the input inductor Ls. In mode 3 S1 and S2 are turned on D,L conducts and supply voltage and charge stored in the input inductor charges the dc link capacitor Cb. S3 and S2 conducts during mode 4 and charges input inductor Ls. Modes 2, 3, 4 are shown in figures 5, 6, 7 respectively. There are many advantages of direct converter over conventional converter that the output frequency of direct AC - AC converter is higher because of the input current is free from harmonics.

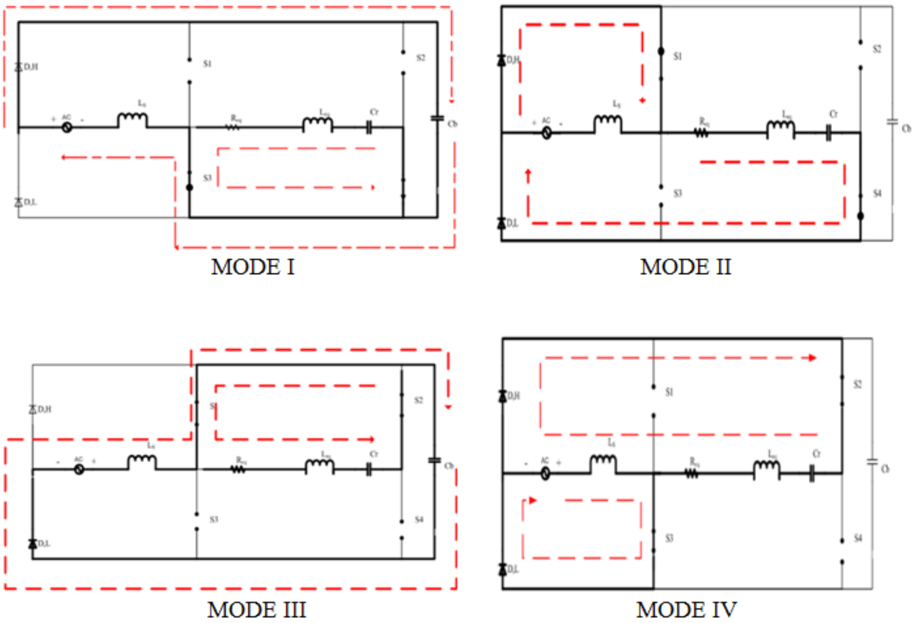

Fig. 4. Modes of operation

VI. Design Of Full Bridge Converter

The input voltage is boosted by the input inductor L_s and dc link capacitor C_b. The switch S1 and S3 perform the boost dc to dc conversion. The dc–dc boost circuit waveform are shown in Fig.7,where the steady state average input current is $I_{s.}$ In order to avoid the current ripples and high frequency current through the rectifier diode, a continuous current mode is assumed. In steady state average voltage across inductor is zero.

$$V_s DT_{sw} + (V_s - V_b)(1 - D)T_{sw} = 0 \qquad (1)$$

The ratio of voltage conversion is same as the boost converter.

$$\frac{V_b}{V_s} = \frac{1}{1 - D} \qquad (2)$$

The input current of the temporal waveform can be calculated using the input current rippl $\Delta I_{s,}$

$$\Delta I_S = I_{S,D} - I_{S,0} = \frac{V_S}{L_S} DT_{SW} \qquad (3)$$

Where the minimum and maximum input current values during a switching period is Is,0 and I s,D respectively. Consequently, the input current of the temporal waveform i_s results

$$I_s(t) = \begin{cases} \left\{ \left(I_s - \frac{I_S}{2} \right) + \frac{\Delta I_s}{DT_{SW}} t, (0 \le t < DT_{SW}) \right. \\ \left(I_S + \frac{\Delta I_S}{2} \right) - \frac{\Delta I_S}{DT_{SW}} (t - DT_{SW}), (DT_{SW} \le t < T_{SW}) \end{cases} \qquad (4)$$

The condition of CCM is satisfied as ,

$$CCM \Rightarrow I_{S,0} > 0 \Rightarrow I_S > \frac{\Delta I_S}{2} \tag{5}$$

The input power P_{in} for an unity power factor is assumed

$$I_S > \frac{\Delta I_S}{2} \Leftrightarrow \frac{P_{in}}{V_s} > \frac{V_S}{2L_S} DT_{SW} \tag{6}$$

that will lead to,

$$P_{in} > \frac{V_S^2}{2L_S} DT_{SW} \tag{7}$$

So there is a trade off between the input power, the input inductor value, and modulation parameters for a given supply voltage level to ensure CCM. The full bridge series resonant inverter consists of four switches S1, S2, S3 and S4. It is supplied by the output voltage of the boost stage Vb. By using the Fourier harmonic analysis, the output power Po results

$$P_o = \sum_{h=0}^{\infty} R_{eq} \frac{V_{0,h,rms}^2}{Z_{o,h}^2} = \sum_{h=0}^{\infty} R_{eq} \frac{\frac{1}{2} V_{o,h}^2}{Z_{o,h}^2}$$
$$= \sum_{h=0}^{\infty} \frac{R_{eq}}{2} \frac{V_{o,h}^2}{R_{eq}^2 + \left(2\pi f_{SW} h L_{eq} - \frac{1}{2\pi f_{SW} h C_r}\right)^2} \tag{8}$$

where h is the harmonic number, Zo is the impedance of the series RLC resonant tank, and Vo is the output voltage of the inverter. Its sinusoidal peak voltage results

$$\hat{V}_{0,h} = \frac{V_b}{h\pi} \sqrt{a_h^2 + b_h^2} \tag{9}$$

Where coefficients of fourier series are,

$$a_h = \sin(2\pi h D), b_h = 1 - \cos(2\pi h D)$$

The output power results,

$$P_0 = \sum_{h=0}^{\infty} \frac{(1 - \cos(2\pi h D))}{(h\pi(1-D))^2} \frac{R_{eq} V_S^2}{R_{eq}^2 + \left(2\pi f_{SW} h L_{eq} - \frac{1}{2\pi f_{SW} h C_r}\right)^2} \tag{10}$$

VII. Simulation Of Full Bridge Converter

The simulation of full bridge converter is obtained in MATLAB.Simulation diagram is shown in fig.5. The high frequency output voltage across the load is shown in fig.6

Table I: Design Parameters

Parameters	**Values**
Input voltage	325.2V
Switching frequency, f_s	150KHz
Equivalent load resistance, R_{eq}	98.9Ω
Equivalent load inductance, L_{eq}	155µH
Input inductor , L_s	900µH
DC link capacitor C_b	470pF
Resonant capacitor	8.56nF

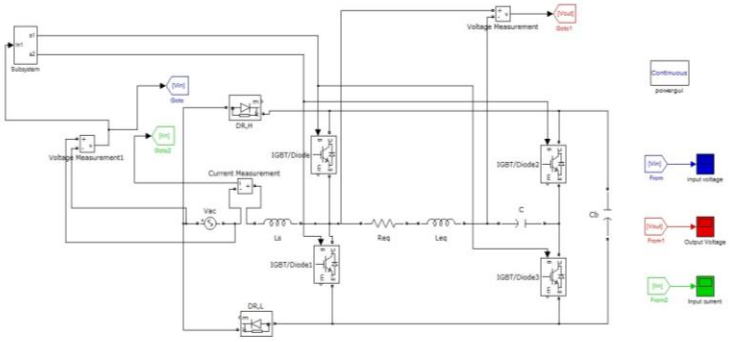

Fig. 5. Simulation of full bridge converter

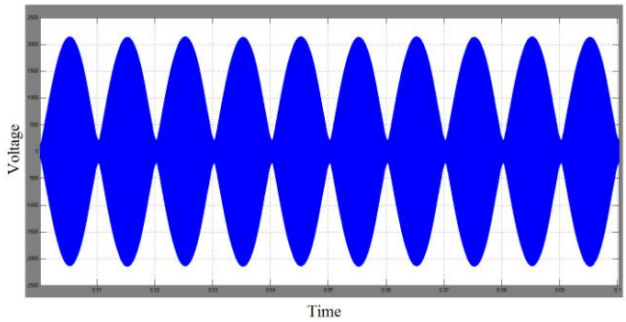

Fig. 6. Output Voltage waveform

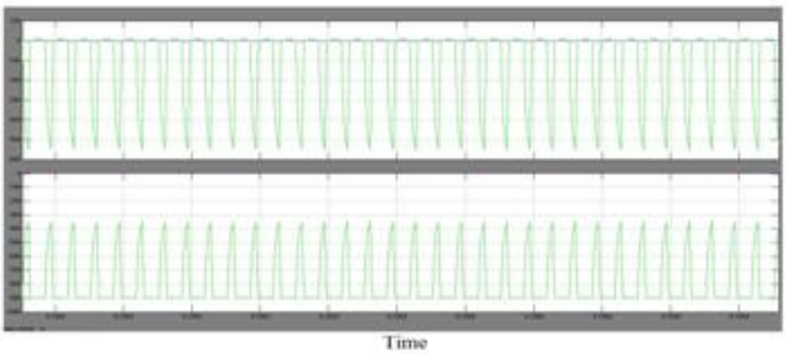

Fig. 7. Voltage & current across Diode

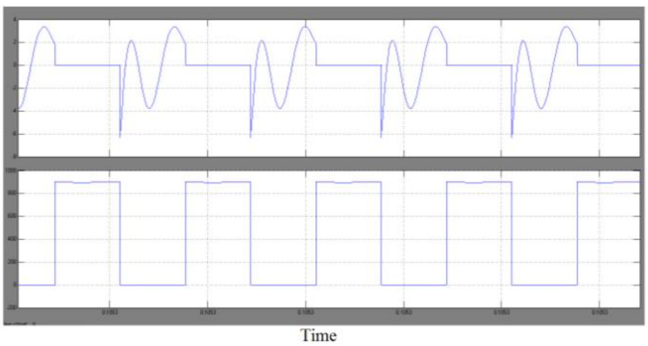

Fig. 8. Voltage & current across IGBT

The voltage and current across Diode is shown in Fig.7. There is only one diode is activated at a time so it will reduce conduction loss.Due to the reduction of non-linear load in the input, input current is free from harmonics.The Voltage and current across IGBT are shown in fig.8. S1 and S3 conducts 50 percent during positive half cycle .S2 and S4 conducts 50percent during negative half cycle.

VIII. Hardware Platform

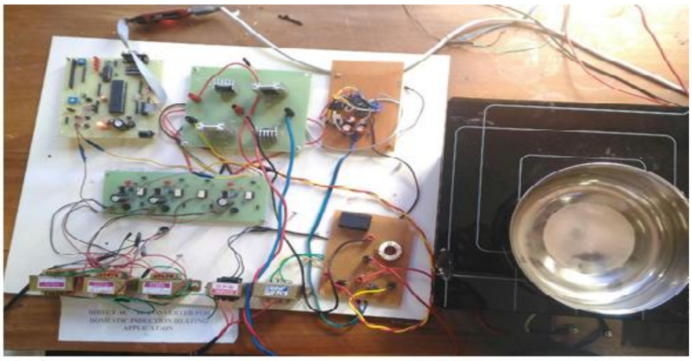

Fig.9. Haedware setup

Table II: Hardware Requirement

Components	Specification
IGBT	IRF540
Driver IC	TLP 250
Capacitor	470nF
Diodes	IN4007
Inductor	155µH
Microcontroller	ATMEGA 16

In hardware section consist of a Rectifier section inverter section (H-Bridge inverter), driver circuit,Microcontroller for giving pulse, and an induction coil. The Switching pulse for to switch corresponding IGBT are obtained in DSO are shown in fig.10

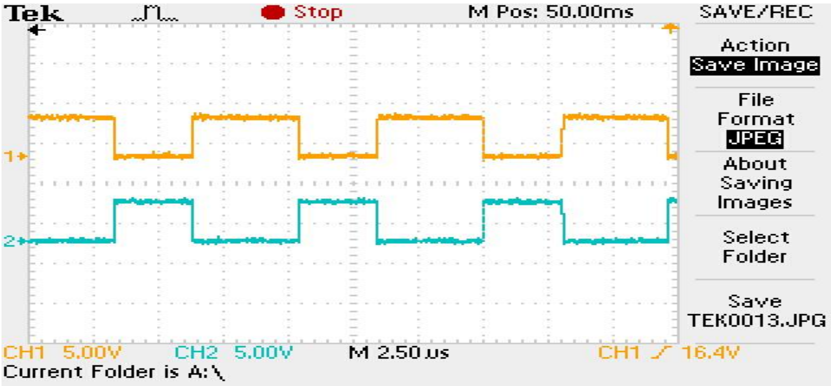

Fig. 10. Switching pulse

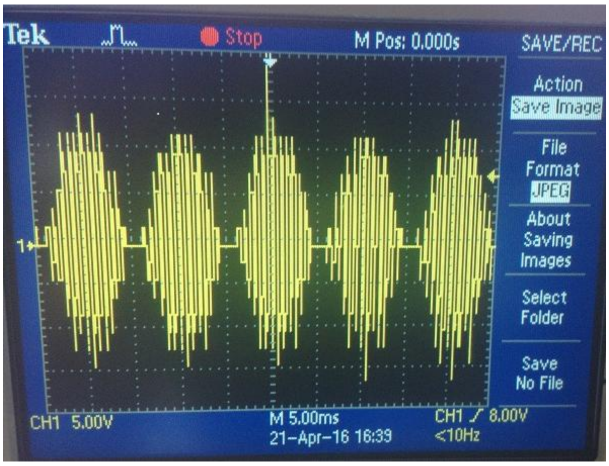

Fig. 11. Output Voltage

IX. Conclusion

A full bridge AC-AC resonant converter for induction heating application is proposed here. The key features of the proposed converter are reduced component count and high efficiency. The converter can operate with zero voltage switching. As a result power converter is improved in whole operating range. The hardware is presented using AVR microcontroller as a prototype model.

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