Half Bridge Series Resonant Converter For Domestic Induction Heating

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***Abstract*--The Domestic induction heating operation is based on a resonant inverter which supplies medium-frequency currents (20–100 kHz) to an inductor, which heats up the pan. This paper presents the analysis of an AC–AC resonant converter which is based on the half-bridge series resonant inverter applied to domestic induction heating. Only two diodes is used in this topology to rectify the mains voltage. The converter can operate with zero-voltage switching during both switch-on and switch-off transitions. Since half bridge topology is being employed, it doubles the output voltage, and therefore, the current in the load is reduced for the same output power. The simulation of this topology has been carried out in MATLAB/ SIMULINK at a switching frequency greater than the resonant frequency. A prototype has been implemented which works on three different frequencies. It has verified that the condition with minimum delay heats up faster. This topology also shows great improvement in efficiency (about 96%).**

Keywords — High frequency; induction heating, Resonant converter; zero-voltage switching (ZVS).

I. INTRODUCTION

Domestic induction technology has become more popular in recent years due to features such as efficiency, safety, and accurate output power control, which outperform other traditional domestic heating technologies. Domestic induction hobs are now becoming a standard option, especially in Asia and Europe. The high efficiency of the induction hobs is attracting the attention of researchers devoted to highly efficient power electronic systems. Induction heating is a non-contact heating process. It uses high frequency electricity to heat materials that are electrically conductive. Since it is non-contact, the heating process does not contaminate the material being heated. It is also very efficient since the heat is actually generated inside the work piece. This can be contrasted with other heating methods where heat is generated in a flame or heating element, which is then applied to the work piece. For these reasons Induction Heating lends itself to some unique applications in industry.

Induction cooker constitute a major domestic application of the induction-heating phenomena. In such devices, the desired heating is done in metallic vessels by varying the magnetic field, which in turn is generated by a planar coil fed by a power electronics inverter. Basically, a domestic induction arrangement consists of a planar multi-turn winding situated below a metallic vessel [2], [9] and supplied by a medium-frequency power source, normally operated between 20 and 100 kHz. The frequency is higher than 20 kHz is preferred to avoid the audible range and lower than 100 kHz to reduce switching losses. Increasing the frequency of operation of power converters is desirable, as it allows the size of circuit magnetics and capacitors to be reduced, leading to cheaper and more compact circuits. However, increasing the frequency of operation also increases switching losses and hence reduces system efficiency. One solution to this problem is to replace the "chopper" switch of a standard SMPS topology (Buck, Boost etc.) with a "resonant" switch [8], which uses the resonances of circuit capacitances and inductances to shape the waveform of either the current or the voltage across the switching element, such that when switching takes place, there is no current through or voltage across it, and hence no power dissipation.

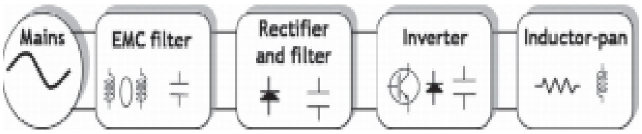


Fig.1.Induction cooking appliance block diagram

The most used device is the insulated gate bipolar transistor (IGBT) because of the operating frequency range and the output power range, up to 3 kW. The main blocks of an induction cooking appliance are outlined in Fig. 1 [3]. The energy taken from the mains is filtered by an EMC filter, which prevents the device from inserting interferences, and it provides immunity to voltage transients. Afterward, the voltage is rectified and filtered, generating a dc bus. A low value of filter capacitor is chosen to get a high PF, and, as a consequence, a high-ripple dc bus is obtained. Then, the resonant inverter supplies variable-frequency current to the induction coil. This current produces an alternating magnetic field, which causes eddy currents and magnetic hysteresis heating up the pan.

A topology giving efficient operation is discussed in this paper which utilizes the resonant inverter to heat up the pan. An experimental set up is also presented in this paper.

II. HALF BRIDGE SERIES RESONANT INVERTER

The power converter generally implemented in domestic IH appliances is a resonant inverter due to its improved efficiency and lower size. The main power circuit employs a half-bridge series converter switching at a high frequency. The half-bridge series resonant inverter is the most employed topology due to its simplicity, its cost-effectiveness, and the electrical requirements of its components [7]. The simplest half bridge inverter topology is shown in Fig 2. The switching circuit consists of an IGBT. Zero voltage/current turn-on switching is enabled by turning on the IGBT while the diode is in turn on period. The resonant circuit comprises of resonant inductance (L_r) and resonant capacitance (C_r) [10]. The capacitors, C_1 and C_2, are the lossless turn-off snubbers for the switches, S_1 and S_2. The resonant frequency f_r of the converter is mainly determined by the inductance L_r and the capacitance C_r of the series capacitor.

$$fr = \frac{1}{2\pi\sqrt{L_r C_r}}$$

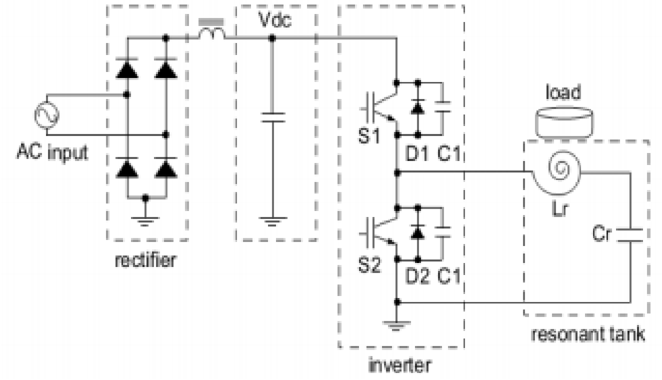


Fig. 2 Half bridge series resonant inverter

Induction-coil-and-pan coupling is modelled as a series connection of an inductor and a resistor, based on the analogy of a transformer, and it is defined by the values of L_{eq} and $R_{eq.}$ [4] The switching frequency of the system is set higher than the resonance frequency, in order to avoid noise generated within the audio frequency band. The resonant load consists of the pan, the induction coil and the resonant capacitor. By connecting the IGBT switching circuit, S_1 and S_2 in parallel to diodes D_1 and D_2, current loss is minimized. When S_1 is turned-off, D_2 helps S_2 stay on zero voltage/current before being turned on, thereby substantially reducing current loss (the same is the case with S_1). There is no reverse-recovery problem as the voltage on both sides remains zero after the diode is turned off. However, as the switching circuit is turned off at around the upper limit of voltage and current, some switching loss results on turn-off. The capacitors C_1 and C_2, acting as turn-off snubbers connected in parallel to S_1 and S_2, keep this loss to a minimum. Upon turn-on the switching circuit starts from zero voltage/current, so these turn-off snubbers operate as lossless turn-off snubbers.

III. AC-AC POWER CONVERTER

This topology (see Fig. 3) consists of two bidirectional switches composed of IGBT's T1 and T2, and antiparallel diodes D1 and D2, respectively. Only two diodes is used in this topology to rectify the mains voltage Vac, shown as D_H and D_L, but only one of them is activated at the same time. This operation increases efficiency with regard to classical topologies based on a full-bridge diode rectifier plus a dc-link inverter. This topology is a series–parallel resonant converter. The inductor–pot system is modelled as an equivalent series resistance R_{eq} and inductance L_{eq}, as shown in Fig. 3.

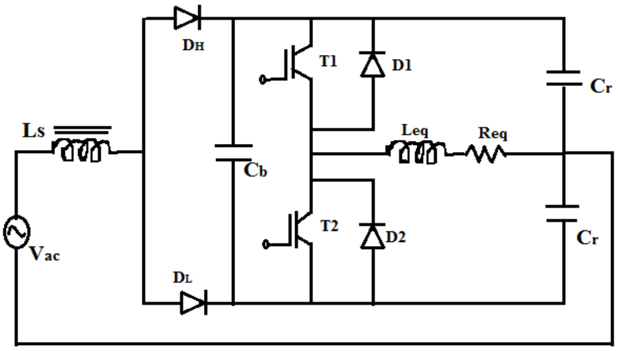


Fig.3 Ac-Ac power converter applied to domestic induction heating

IV. ANALYSIS

Since the converter is having symmetry between positive and negative ac voltage supply, simplified analysis is possible. The circuit can been drawn for one of the half cycles since it is applicable to the other cycle too. The equivalent circuit for positive half cycle is as shown in Fig. Based on series resonance normalised equations can be written [1], [7].

$$L_s = \beta L_{eq}, \beta \geq 1$$

$$C_b = \alpha C_r, \alpha \geq 0$$

$$\omega_0 = \frac{1}{\sqrt{L_{eq} C_r}}$$

$$\omega_n = \frac{\omega_{sw}}{\omega_0}$$

$$Z_0 = \frac{L_{eq}}{C_r}$$

$$R_{eq} = \frac{\omega_0 L_{eq}}{Q_{eq}} = \frac{Z_0}{Q_{eq}}$$

Where β is the ratio between the input choke and the equivalent inductance of the inductor pot system and α is the ratio between the dc-link and the resonant capacitors and. ω_0, ω_{sw}, ω_n are respectively the angular resonant frequency, the angular switching frequency, and the normalized angular switching frequency. Z_0 is the equivalent impedance of the resonant circuit. And Q_{eq} is the quality factor at the resonant frequency of the equivalent inductor-pot system. The pulses given to the switches are given as in Fig 4.[2]

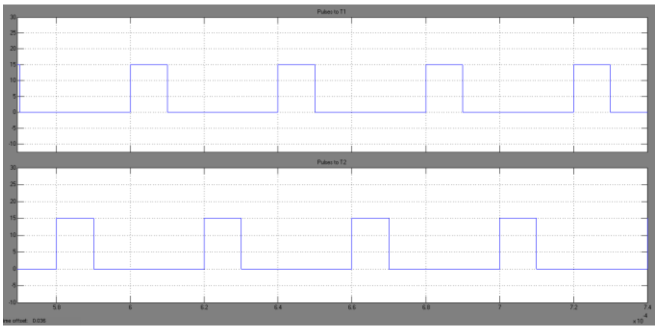
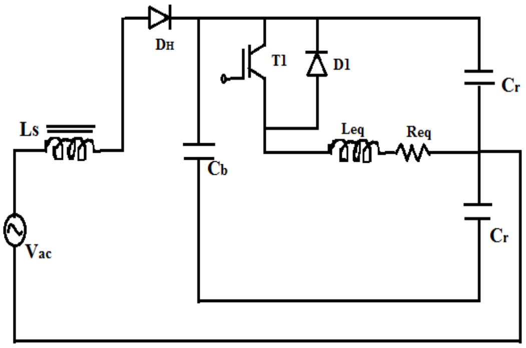


Fig.4. Pulses to both switches

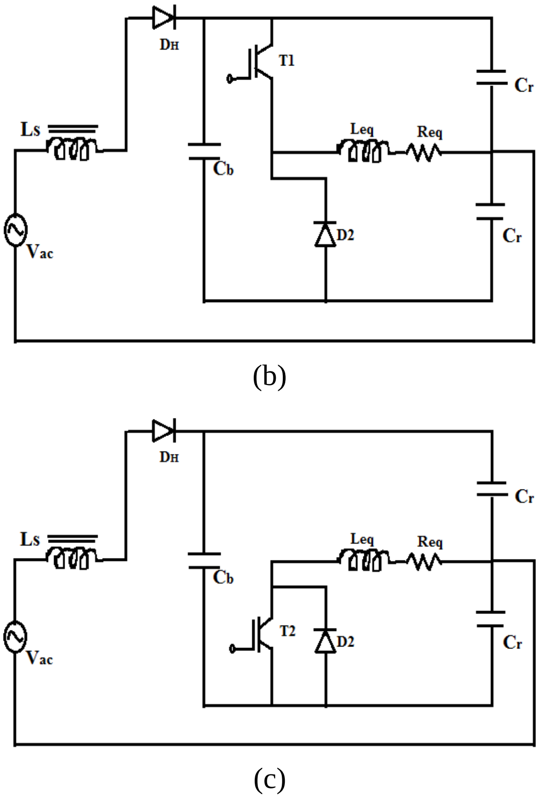
For zero voltage transitions three different states could be presented here based on turn-on and turn-off of both the switches. The equivalent circuit representing the 3 states are shown in Fig 5 (a, b, c). The first state begins when the lower switch is triggered OFF. In this moment, the antiparallel diode D1 conducts and T1 can be triggered ON ensuring ZVS switching-on conditions. The parallel resonant circuit is set by an equivalent capacitor Ceq, obtained from Cr and Cb and the load parameters Req and Leq.

$$C_{eq} = C_r \left(\frac{1 + 2\alpha}{1 + \alpha}\right)$$

In the second state both switching devices conducts, although only the upper switch is triggered ON. The parallel resonant circuit is set by the load parameters in parallel with both resonant capacitors. The third state starts when the upper switch is triggered OFF. Then D2 starts conducting and T2 can be triggered ON achieving ZVS switch-on conditions. This state ends when the lower switch is deactivated. The resonant circuit is set by C_r in parallel with the series connection of Cb and the parallel connection of the load and the other one C_r.



(a)



(b)

(c)

Fig.5 Equivalent circuits at different states during positive half cycle. (a)State 1 (b) State 2 (c) State 3

V. SIMULATION RESULTS

The AC to AC converter fed domestic induction heater is simulated using MATLAB/SIMULINK and their results are presented here. The SIMULINK model of AC-AC converter is shown in Fig.6 and its corresponding waveforms is also shown.

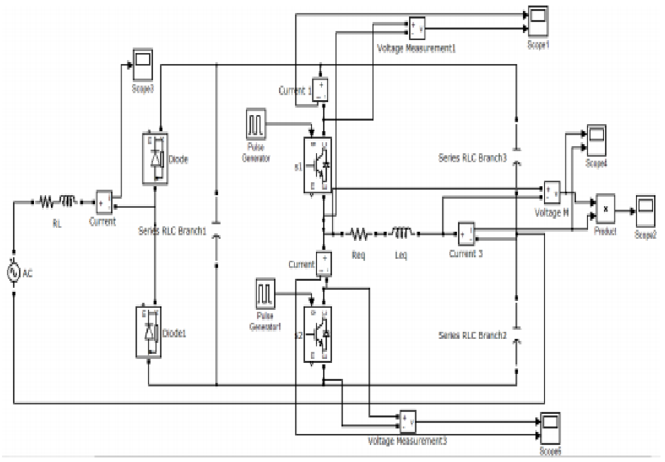


Fig.6 Simulink model of ac - ac converter

The simulation has been carried out with the parameters as shown in table 1.

Table1: Parameter values

Parameters	Values
Equivalent resistance, Req	7Ω
equivalent inductance, Leq	70µH
Supply source voltage, Vac	230V
resonant capacitor, Cr	450nF
DC link capacitor, Cb	450nF
input inductance, Ls	1.6mH
equivalent series resistance, Rs	80m Ω
switching frequency	25kHz.

The simulation was done with a duty cycle of 25% and is assumed to have a switching frequency of 25 kHz. The input voltage waveform is as seen in Fig 7. The input current through the inductor is obtained with amplitude of approximately 5A. The voltage and current waveforms through the upper and lower switches are shown in fig 5.3 and 5.4 respectively.

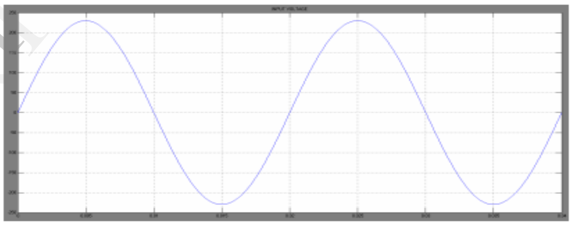


Fig.7 Input voltage waveform

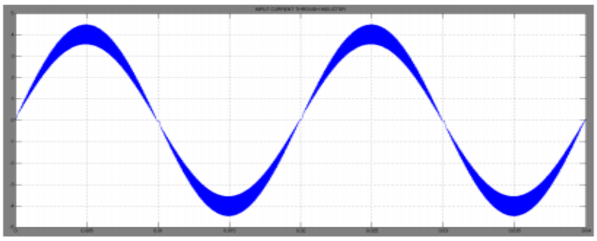


Fig.8 Input current through the inductor

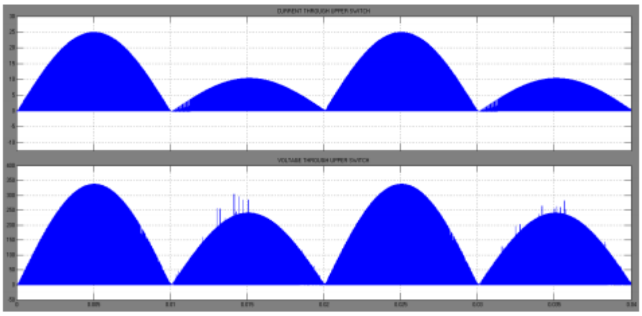


Fig. 9: The voltage and current waveforms through the upper switch

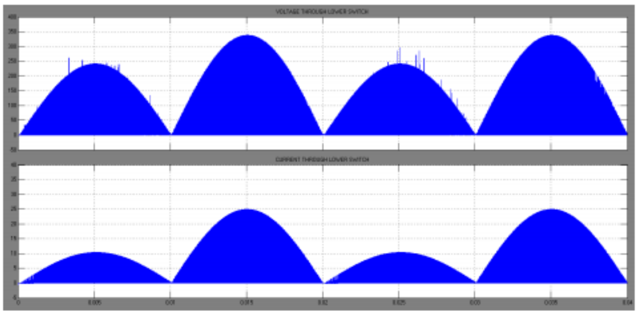


Fig.10 : The voltage and current waveforms through the lower switch

And the voltage and current obtained through the load R_{eq} and L_{eq} is shown in fig. 11

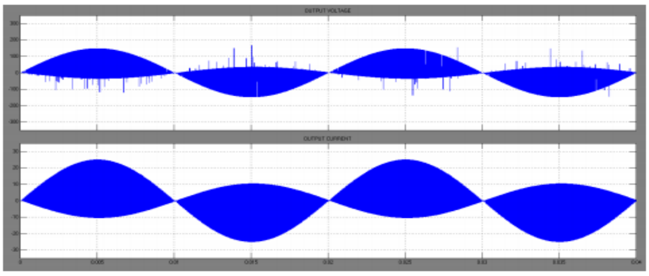


Fig.11 voltage and current obtained through the load

Thus with these following conditions and assumptions an output power of 3.6 kW is obtained. The waveform of power is also shown in Fig. 12.

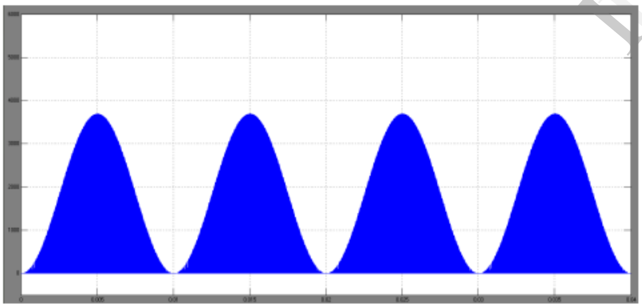


Fig.12: Output power waveform

A prototype has been built with the same circuit parameters [6]. It is implemented so as to work at 3 different frequencies. This is done by giving different delays between the two switches, 100s, 500s and 10ms respectively. The control is given using microcontroller (PIC16F877A). Since there are two switches two driver circuit is also needed. One part in the prototype is this driver circuit. The other part contains the main ac – ac power converter circuit. The coil is heated at all the three switching conditions representing three different frequencies. It has been observed that the coil heats up faster when the delay between both the switches (upper and lower) is low. A model representing the above discussed converter is implemented. The block diagram of the model is as in Fig 13.

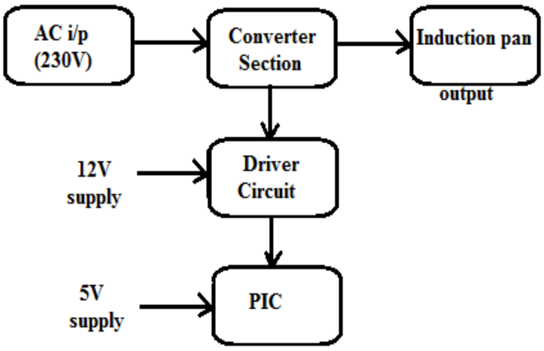


Fig.13: Block Diagram representing the setup

Here the supply 230V from the ac mains is step downed to 12V using a transformer for feeding the driver circuit, which mainly comprises of optocoupler, buffer IC and transistors. The pulses thus generated are given to the switches. The experimental setup is shown in Fig. 14.

Fig.14 Experimental set-up of the ac-ac power converter

VI. CONCLUSION

This paper presents an ac - ac converter applied to domestic induction heating. An analytical analysis has been done the equivalent circuit during the positive half cycle. The three states have been discussed based on switching of the two switches. The converter can operate with zero-voltage switching during both turn-on and turn-off commutations. Besides, the output voltage is doubled compared to the classical half-bridge, reducing the current through the switching devices. As a consequence, the power converter efficiency is improved in the whole operating range. A prototype has been implemented in order to validate the analytical results. Since it is not designed for a particular power, it could be shown as heating at fast rate with 3 different frequencies with fast heating at low time delay. This validates the feasibility of the power converter discussed above.

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