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AC-AC Resonant Boost Converter for Domestic Induction heating with Reduced Total Harmonic Distortion

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Abstract- **Domestic induction hobs have been becoming increasingly popular, due to its specific features of safety, cleanliness, quick warming and high efficiency. Some of these features derive of the fact that the heating is directly generated in the vessel, unlike the traditional contact heating methods. Specially, the later feature is attracting the attention of researchers devoted to highly efficient power electronic systems. Domestic induction heating technology requires specific features such as high output power levels in a reduced enclosure, large load variation, and reduced cost with high efficiency. Domestic induction appliances require power converters that feature high efficiency and accurate power control in a wide range of operating conditions. In order to achieve this aim, an ac–ac boost resonant converter is proposed in this paper. The main features of this proposal are the improved efficiency, reduced component count, proper output power control and reduced Total harmonic distortion (THD). With the addition of a passive filter circuit, input current total harmonic distortion can be decreased. Converter design procedure is also analyzed. And an experimental setup has been carried out.**

Keywords- Induction heating, efficiency improvement, resonant boost converters, Total Harmonic Distortion.

I. INTRODUCTION

Induction cookers constitute the domestic application of the induction heating phenomena. In such devices, the desired heating is produced in metallic vessels by a varying magnetic field, which in its turn is generated by a planar coil fed by a power electronics inverter. Basically, a domestic induction arrangement consists of a planar turn winding situated below a metallic vessel and supplied by a medium-frequency power source, normally operated between 20 kHz and 100 kHz[1].

For generating high frequency current, there are different types of topologies that can be used, basically, half and full bridge resonant converters and single switch resonant converters. The first two topologies have their own advantages and disadvantages [2].

Induction appliances take the energy from the mains voltage; this is rectified by a bridge of diodes. A bus filter is designed to allow a high voltage ripple, getting a resultant input power factor close to one. Then, an inverter topology supplies the alternating current (between 20 kHz to 100 kHz) to the induction coil. Nowadays, burners of domestic induction appliances are designed to deliver up to 5.5 kW. A schematic diagram of the power stage of a domestic induction apparatus is shown in Fig. 1.

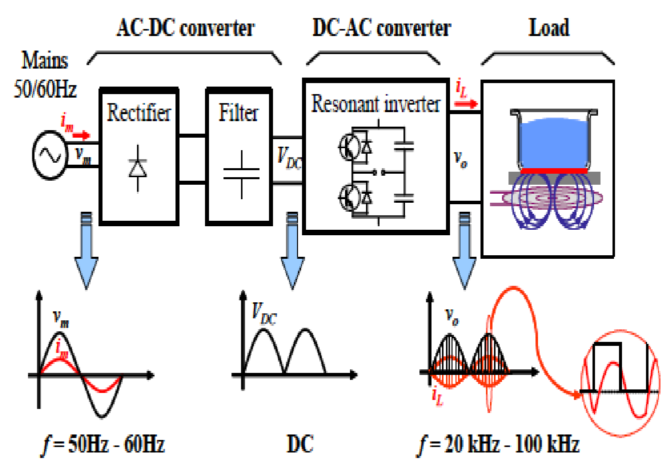

Fig. 1 Domestic induction heating appliance: power conversion scheme

The half-bridge series resonant inverter (HB-SRI) featuring insulated-gate bipolar transistors (IGBTs) are commonly used for the domestic IH applications. Its well-balanced device voltage stress, reduced control complexity, and cost make the HB-SRI the preferred option. In order to reduce component count and to increase efficiency, a high frequency direct ac–ac converter with reduced THD is proposed in this paper. Direct ac–ac converters have been widely used in many applications [3]–[4] due to the component count reduction .It reduces the intermediate dc-link storage requirements. The converter proposed in this paper is based on the half bridge boost rectifier.

The remainder of this paper is organized as follows. Section II describes the Literature survey. Section III performs the analysis of design. Section IV describes the proposed converter. Section V focuses on simulations performed on the system and the results. Section VI is the conclusions.

II. LITERATURE SURVEY

A) Direct ac-ac full ZCS converter

ZCS and the ZVS operation modes are penalized by switching losses. Operation at the resonant frequency ensures both ZCS in the turn-on and the turn-off transition. This condition is only fulfilled at the resonant point, being impossible to control the output power. In spite of this, these converter achieves the same operation waveforms by using an unidirectional current device. As a result, the current is deactivated when it reaches zero. The full ZCS direct ac-ac converter embeds the rectifier stage within the inverter, reducing the component count[5].

In addition to this, this converter optimizes the switching conditions during both turn-on and turn-off transitions. Mains ac voltage V_{ac} is filtered by a small series inductance L_s and a small value capacitor C_s to ensure an input PF close to one and reduced harmonic content. Four fast switching diodes, $D_{H,A}$, $D_{L,A}$, $D_{H,B}$, and $D_{L,B}$, are used to rectify the mains and to provide a fast unidirectional path to naturally disable the load current when it reaches zero. After that, two complementary activated switching devices, S_H and S_L, provide the source voltage for the inductor–pot system. As a difference with classical implementations, resonant capacitors C_H and C_L are directly connected to the mains voltage. Consequently, load current cannot be recirculated through the switching devices, ensuring a unidirectional flow and reducing conduction losses It is important to note that, unlike dc-link inverters, there is no energy storage element in the dc bus and fast diodes are used and embedded within the ac–ac converter. Moreover, zero current switching (ZCS) is achieved during turn-on and turnoff transitions, and diode conduction is reduced, further increasing the converter efficiency.

B)High Efficiency AC–AC Converter

This topology, based on the half-bridge series resonant inverter. It uses only two diodes to rectify the mains voltage. This converter can operate with zero-voltage switching during both switch-on and switch-off transitions. Moreover, this topology doubles the output voltage, and therefore, the current in the load is reduced for the same output power. As a consequence, the converter efficiency is significantly improved[6].

This topology employs two bidirectional switches S_H and S_L composed of a transistor T_H or T_L , typically an IGBT, and an anti-parallel diode D_H or D_L , respectively. The mains voltage V_{ac} is rectified by two diodes D_{rH} and D_{rL}, 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. The topology is a series–parallel resonant converter. The inductor–pot system is modeled as an equivalent series resistance R_{eq} and inductance L_{eq}. This topology implements resonant capacitors Cr and may use a bus capacitor C_b. Due to the symmetry between positive and negative mains voltage, both resonant capacitors have the same value. An input inductor Ls is used to reduce the harmonic content to fulfill the electromagnetic compatibility regulations and negative mains voltage, both resonant capacitors have the same value. An input inductor Ls is used to reduce the harmonic content to fulfill the electromagnetic compatibility regulations.

III PROPOSED AC-AC BOOST RESONANT CONVERTER WITH REDUCED THD

The series-resonant half-bridge inverter is the most used inverter topology for domestic IH due to its well-balanced performance and cost[7]. Considering the classical half-bridge converter for induction heating, the maximum output power, $P_{o,max}$, is achieved at the resonant frequency. As a result, the converter current ratings are inversely proportional to the supply voltage level for a given maximum output power. Thus, a current reduction is possible by increasing the supply. [8]-[9].

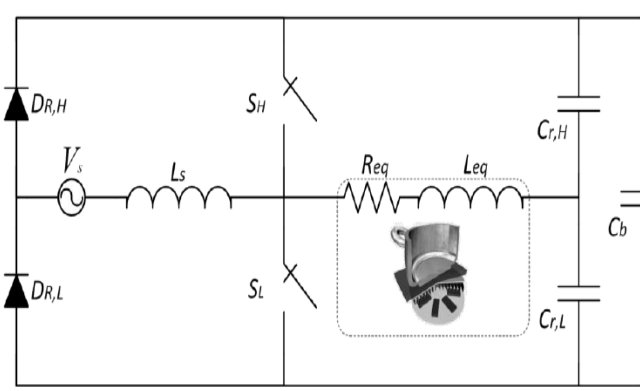

Fig.2 AC-AC boost resonant converter

Instead of using a cascade combination of a boost-rectifier and an inverter stage, the converter integrates both stages into a direct ac-ac converter, removing redundant components and achieving higher efficiency levels. The proposed converter works as follows: the ac power supply, Vs, is rectified by the half-wave rectifier branch composed of $D_{R,H}$

and $D_{R,L}$. An inverter branch composed of S_H, S_L, is used both to perform a boost dc-dc conversion of the mains ac and, additionally, to supply the high frequency current to the inductor. The voltage boost is performed by means of the input inductor Ls, and the dc-link capacitor C_b. As a result, the dc-link voltage applied to the induction heating load is controlled by the duty cycle, D, whereas the output power in the IH load is defined by the switching frequency, f_{sw}.

Direct ac–ac converters have been widely used in many applications due to the component count reduction, reducing the intermediate dc-link storage requirements. These converters are based on the HB-SRI featuring a four-quadrant equivalent switching device, composed of two anti series IGBTs. The converter proposed here is based on the half bridge boost rectifier, achieving a high reduction in the current levels in the power converter. As a consequence, the converter efficiency is significantly improved. Moreover, the proposed solution is in full agreement with recent developments in high-voltage and high-frequency switching. devices, such as the embedded-diode field-stop 1200-V PT IGBTs.

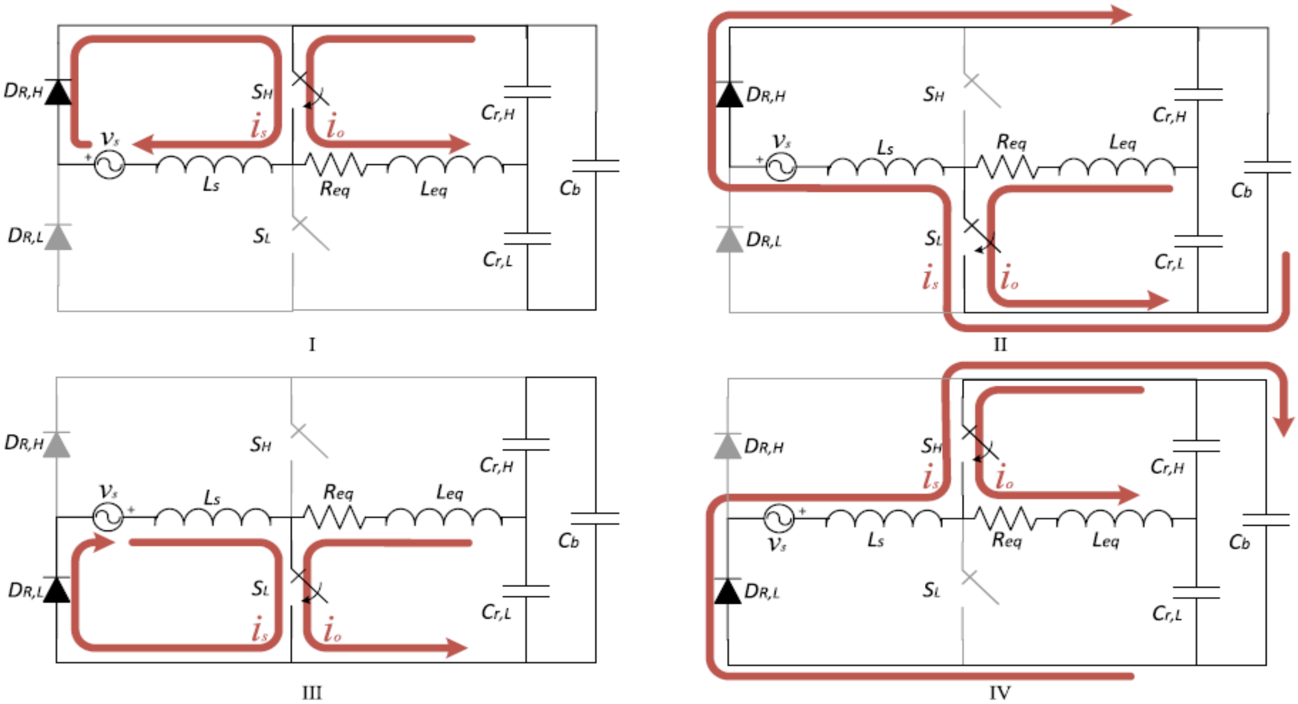

Fig.3 Modes of operation of Resonant boost converter

By adding a passive filter circuit at the input side input current total harmonic distortion (I_{inTHD}) can be reduced. And also efficiency of the system can be improved. The filter circuit consists of a resistor, capacitor and an inductance.

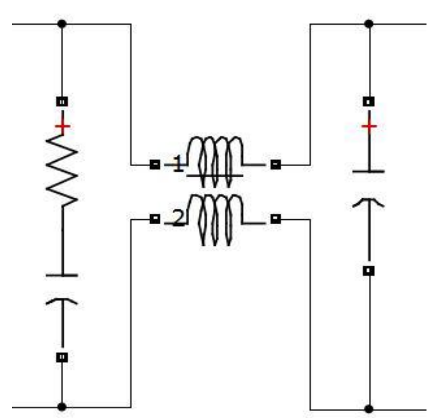

Fig.4 Passive filter circuit

IV. DESIGN PROCEDURE

Considering a fixed mains voltage $V_{ac,rms}$ = 230 V and assuming a maximum output power $P_{o,\max}$ = 3 kW, the maximum IH heating equivalent series resistor calculated at the resonant point is 25 Ω. So R_{eq} = 25 Ω. The IH quality factor Q_{IH} depends on the inductor design, i.e., external diameter, internal diameter, and turns number. For the selected IH load, Q_{IH} = 1.32, the series inductance obtained is Leq = 150μH. The maximum output power is achieved at the resonant load natural frequency, which will be the maximum switching frequency. In order to reduce the magnetic component size, $f_{sw,\max}$ = 100 kHz has been selected, and as a consequence, the resonant capacitor is Cr 15 nF[10].

$$PF = \frac{\mathrm{R}_{eq}}{\sqrt{\mathrm{R}_{eq} + \left(L_{eq}.2.\pi.f_{sw}\right)^2}} \tag{1}$$

$$\mathrm{R}_{eq} < \frac{(1-\cos(2\pi D_{\max}))}{(\pi(1-D_{\max}))^2}\frac{V_s^2}{P_{o,\max}} \tag{2}$$

$$L_{eq} = \frac{Q_{IH} R_{eq}}{2\pi f_{sw,\max}} \tag{3}$$

$$C_r = \frac{1}{L_{eq}\left[\left(\frac{R_{eq}}{2L_{eq}}\right)^2 + \left(2\pi f_{sw,\max}\right)^2\right]} \tag{4}$$

$$L_s > \left(\frac{\Delta I_s}{I_s}\right)\frac{V_s^2}{P_{in}}\frac{D}{f_{sw}} \tag{5}$$

$$P_0 = \sum_{h=0}^{\infty}\left(\frac{1-Cos(2\pi hD)}{(h\pi(1-D))^2}\right)\frac{R_{eq}V_s^2}{R_{eq}^2 + [2\pi f_{sw} h L_{eq} - \frac{1}{2\pi f_{sw} h C_r}]^2} \tag{6}$$

The input inductor L_s is designed according to the maximum input ripple specifications.Here it is selected as 500 μH.

V SIMULATIONS AND RESULTS

Direct ac-ac boost converter system with reduced THD has been modeled and simulated using the Matlab/ Simulink/ Sim Power Systems environment. Value obtained from design procedure are used in the simulation

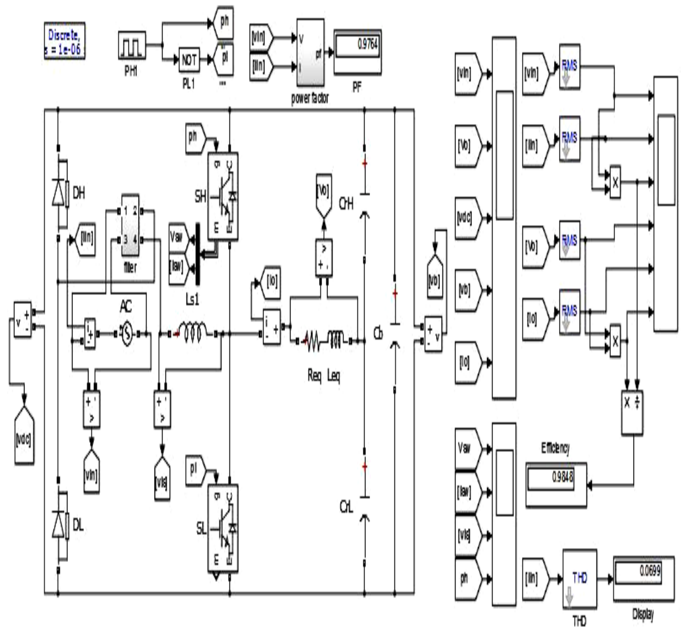

Fig 5 MATLAB Simulation of AC-AC resonant boost converter

Simulation Results of direct ac-ac boost converter are shown in fig 7. Input voltage, Output voltage, rectified voltage, Voltage across capacitor C_b, output current respectively are shown in the graph below.

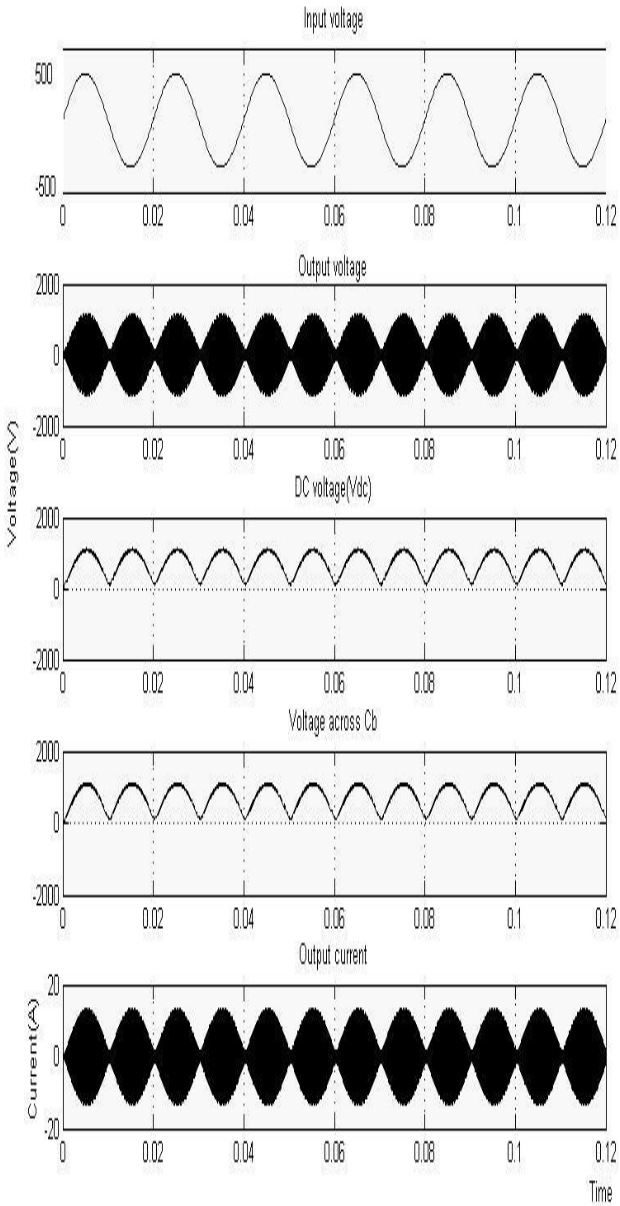

Fig.6 Input voltage, Output voltage, rectified voltage, voltage across capacitor C_b, Output current of AC-AC resonant boost converter

Output power variation in the classical stage is symmetric, and the maximum output power is achieved for D = 0.5.But in direct boost converter, the output power is the combination of the boost circuit operation and the resonant inverter. Since the supply voltage for the equivalent HB-SRI V_b is increased by the boost sub circuit as the duty cycle increases, the output power is also increased as the duty cycle increases.

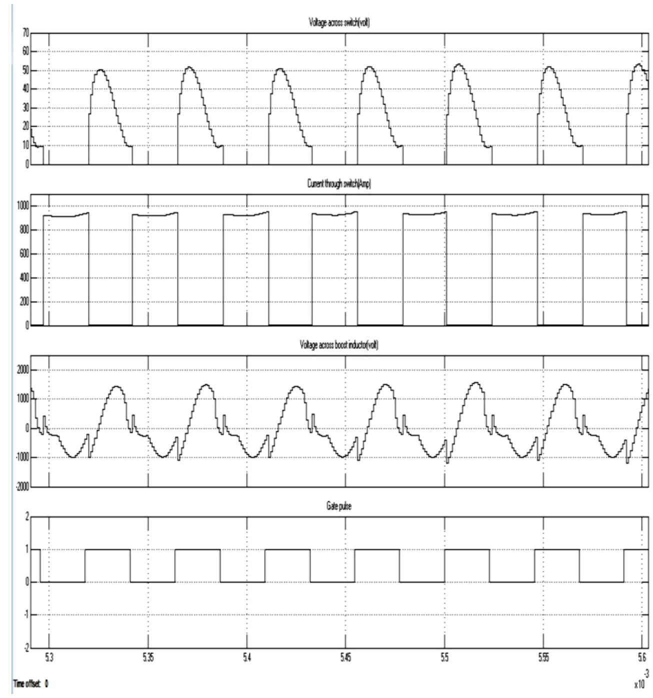

Fig.7 Voltage across switch,Current through switch,Voltage across boost inductor,Gate pulses

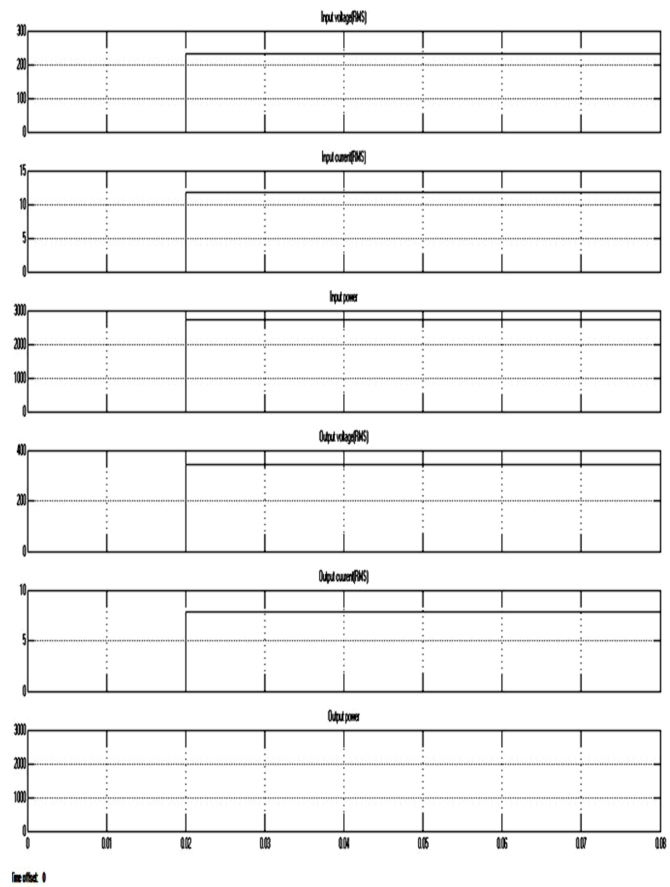

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Fig 8 RMS values of input voltage, input current, input power, output voltage ,output current, output power(2500W)

TABLE I. Comparison Table

	Without filter	With filter
Efficiency	85 %	98%
Input current THD	75%	6%

From Table I it is found that by adding a filter circuit at the input side, Efficiency is improved to around 98%. And input current THD is reduced to 6%.

Experimental setup of the system was developed. Gate signals to the IGBT switches are produced by using Piccolo C2000 IC Kit with a frequency of 22KHz .

Fig 9 Gate pulse generating circuit

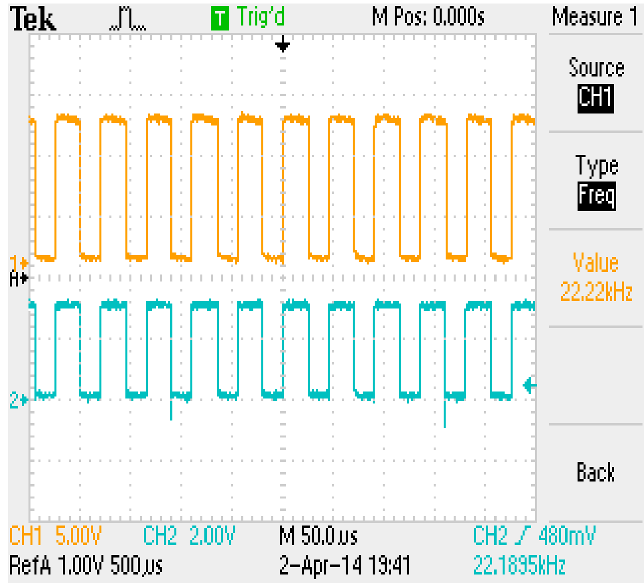

Fig 10 Gate pulses

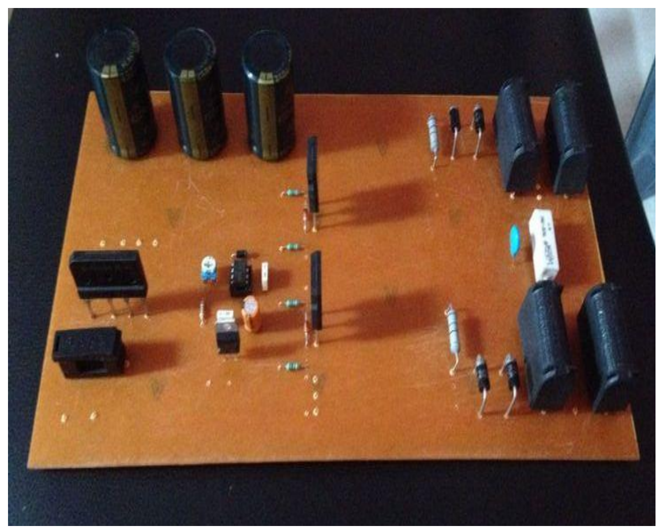

Fig 11 Power circuit

VI CONCLUSIONS

In this paper, a new high efficiency AC-AC resonant boost converter for domestic induction heating applications has been explained. By the increase of equivalent operating voltage, direct ac-ac boost converter reduces the required current levels; achieving higher efficiency. The performance of the system was analyzed by using asymmetrical duty cycle control. The main features of the proposed converter are reduced component count, high efficiency due to the reduced current levels and ZVS operation, and proper output power control. And a passive filter circuit is connected at the input side of the system. Thereby input current total harmonic distortion (I_{inTHD}) is reduced and there is an increase in the system efficiency. Experimental prototype of the system was developed.

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