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High Gain Direct AC-AC Resonant Converter Applied to Domestic Induction Heating Applications

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ABSTRACT: Domestic induction heating is currently used in domestic applications because of some benefits like fast heating time, efficiency and improved control. Conventional design causes several problems such as switching loss and conduction loss, component count and cost is comparatively high, need of additional dc link capacitor, need of electromagnetic compatibility filter requirement etc. The aim of this project is to design a new topology for domestic induction heating applications. It is a direct ac-ac half bridge boost converter. The equivalent operation of this converter can be modelled by superposition of a synchronous boost dc-dc converter and a half bridge series resonant inverter.

KEYWORDS: Induction heating (IH),Half Bridge Series Resonant Inverter(HBSRI),Insulated Gate Bipolar Transistor(IGBT)

I. INTRODUCTION

Domestic induction heating (IH) technology is becoming a standard option in the cooking market due to its benefits such as cleanliness, higher efficiency, and the reduced heating times. In order to implement such appliances, a wide bandwidth converter, typically from 20 to 100 kHz, and high output power up to 5kW,is required. Nowadays, the limited cooling capabilities and the high requirements in terms of consumed energy during the cooking process are pushing toward new efficient and cost effective solutions. Classical IH solutions are based on two separate stages: a rectifier plus a resonant inverter. First, a four-diode full bridge rectifier is commonly used to rectify the mains ac voltage. A small value dc-link capacitor is used to ensure an input power factor close to 1. Thus, a high-ripple dc-link voltage is used to supply an inverter stage. Consequently, the switching devices must withstand higher current levels, whereas the required filter stage is minimized.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 is introduced in this paper.

II. CONCEPT OF RESONANT CONVERTER

A resonant converter can be divided into four main block sets: the full/half bridge converter, a resonant tank, a rectifier, and a low-pass filter. Starting on the input side the full/half bridge converter is typically configured in complementary mode with a fixed duty cycle 50% and with some dead-time. The bridge converter is typically operated by adjusting the duty cycle but in the case of the resonant converter, the bridge converter is frequency controlled. This means that by changing the frequency of the converter we change the impedance of the resonant tank.The resonant tank is made up of reactive components (capacitors and inductors) and can have several different configurations. Depending on the tank configuration, the output will have either a sinusoidal current or voltage. The resonant tank will introduce a phase shift between the voltage and current and because of this we are able to achieve soft-switching. Combining the bridge converter and the resonant tank we create a resonant inverter and by adding a rectifier and low pass filter we create a resonant converter.

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III. DIRECT AC - AC RESONANAT BOOST CONVERTER

The proposed converter is shown in fig.2.The converter consist of two switches S_1 and S_2 , resonant capacitor C_r, dc link capacitor C_b, input inductor L_s ,diodes D_H and D_L and induction load which are supplied by the input voltage V_s.The input AC supply is rectified by the half bridge rectifier composed of two diodes D_H and D_L. The half bridge inverter circuit consist of two switches with an antiparallel diodes .The boost dc - dc conversion of the main AC voltage , and supplying high frequency current to the inductor load are performed by the two switches S_1 and S_2. The voltage boost is performed by means of input inductor L_s and dc link capacitor C_b . The series equivalent RL circuit composed of R_{eq} and L_{eq} is modelled as the IH load .In addition to this, the series RLC resonant tank is completed with a resonant capacitor Cr which is split into two capacitors having the same value $C_r/2$.These capacitors are connected to the positive and negative bus so as to reduce EMC filter requirement.

IV. 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 (stages I and II) whereas D_L conducts during the negative half cycle(stages 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 S_H and for the negative cycle ,its done by switch S_L. The required high frequency AC current i_o to supply the IH load is performed by the inverter branch composed of S_H and S_L, and the resonant capacitors. The voltage across the dc link capacitor is C_b higher.

A.Boost Sub-circuit

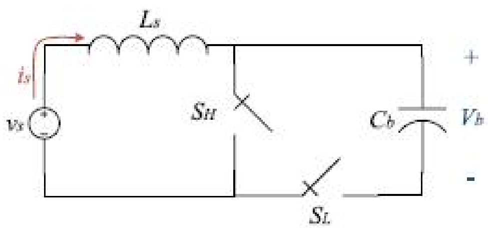

Fig 1.Boost Subcircuit

The input voltage is boosted by the input inductor L_s and dc link capacitor C_b. The switch S_H and S_L perform the boost dc to dc conversion,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.

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

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

$$\frac{V_b}{V_s} = \frac{1}{1 - D} \tag{2}$$

The input current of the temporal waveform can be calculated using the input current ripple ΔI_s,

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

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

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

The condition of CCM is satisfied as , $CCM \Rightarrow I_{S,0} > 0 \Rightarrow I_S > \dfrac{\Delta I_S}{2}$ (5)

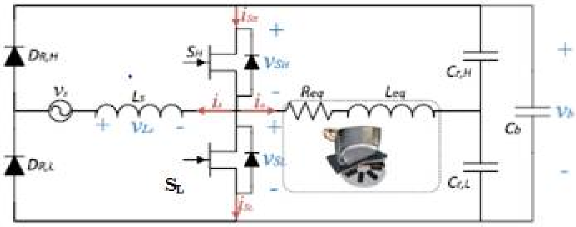

Fig.2. Circuit diagram of direct ac-ac resonant converter

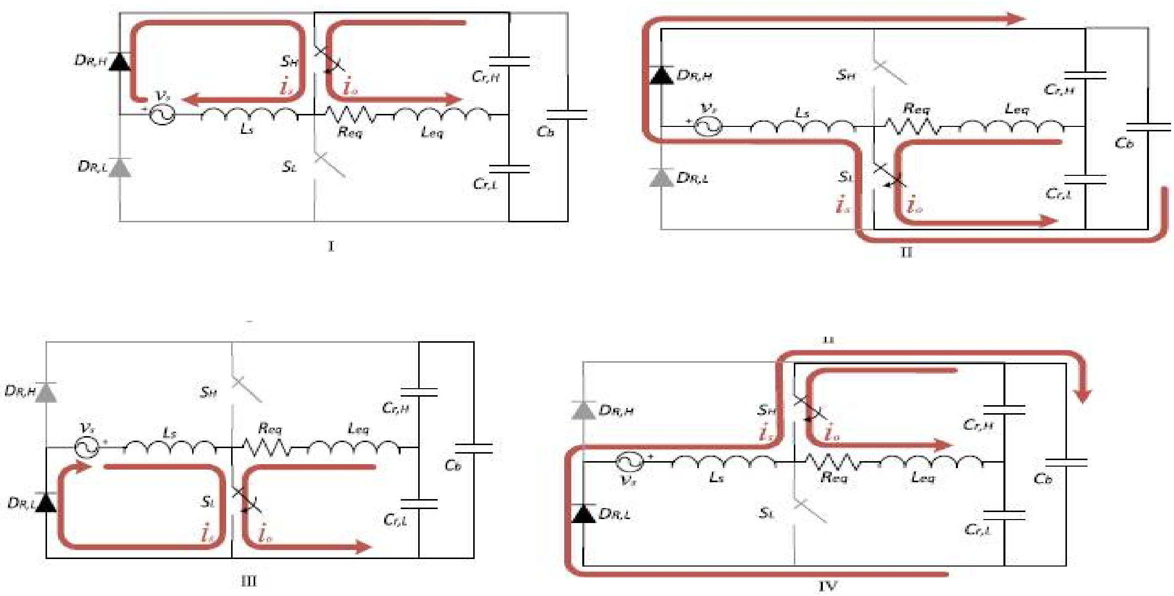

Fig.3.Modes of operation

The input power Pin 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, $P_{in} > \dfrac{V_S^{\,2}}{2L_S}DT_{SW}$ (7)

So there is a tradeoff between the input power, the input inductor value, and modulation parameters for a given supply

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voltage level to ensure CCM.

B.HB-SRI

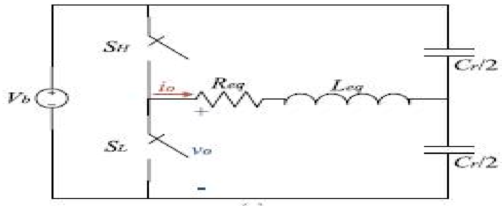

Fig 4. Half Bridge Series Resonant Inverter Subcircuit

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, Z_o is the impedance of the series RLC resonant tank, and V_o 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, $a_h = \sin(2\pi hD), b_h = 1 - \cos(2\pi hD)$

By manipulating the expressions of output power and using the boost output voltage,the output results

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

V. SIMULATION OF DIRECT AC - AC RESONANT BOOST CONVERTER

Design parameters and simulation circuit for the Direct AC - AC resonant boost converter are shown in the table 1 and fig 6 respectively.

Parameters	**Values**
Input Voltage	325.2V
Switching Frequency,f_s	150KHz
Equivalent Load Resistance,R_{eq}	25Ω
Equivalent Load Inductance,L_{eq}	150μH
Input Inductor,L_s	500μH
DC Link Capacitor,C_b	470pF
Resonant Capacior	8.50nF

Table 1.Design Values for Direct ac-ac resonant boost converter

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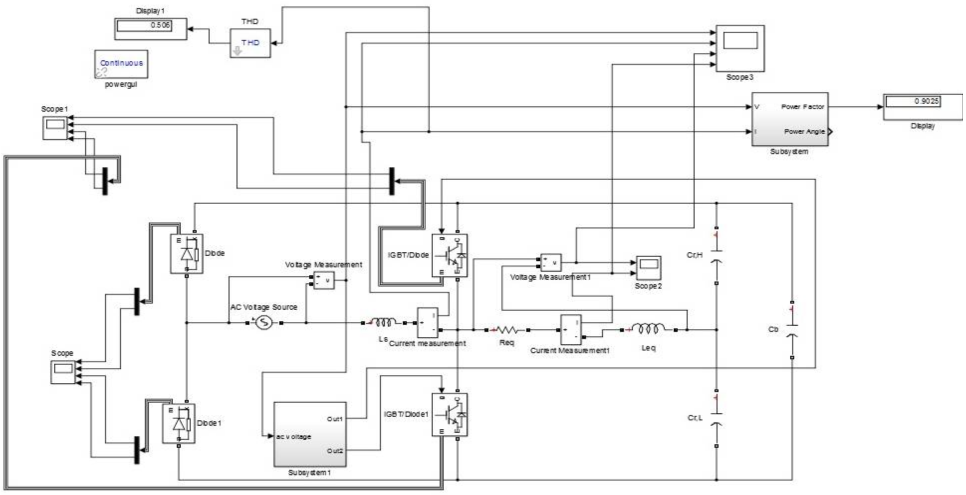

Fig.5 Simulation Of Direct AC-AC Resonant Converter using MATLAB

VI. SIMULATION RESULTS

Simulation results for positive and negative supply voltages are shown in fig.6 and fig .7

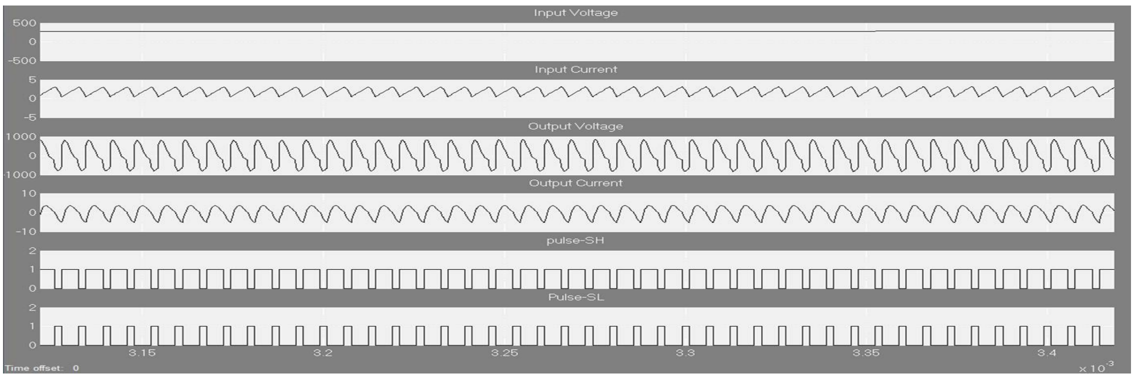

Fig.6 Simulated waveforms for positive supply voltage

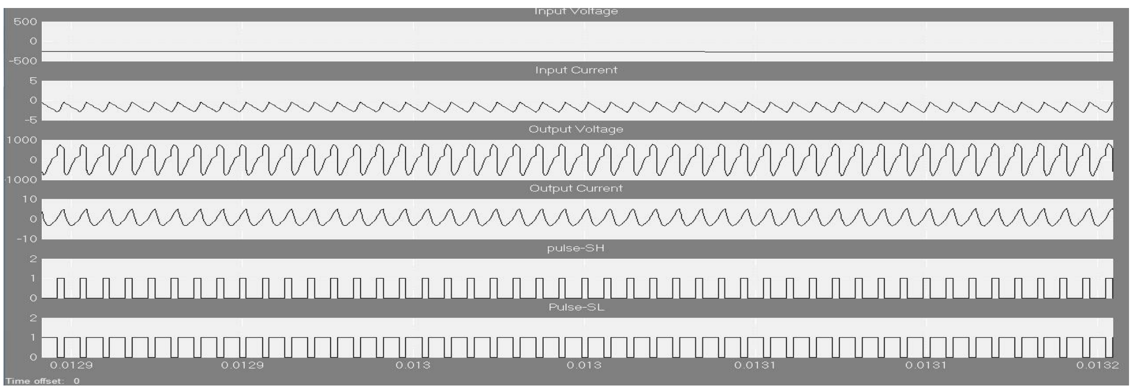

Fig.7. Simulated waveforms for negative supply voltage

The voltage and current across switch S_H and S_L is shown below.The switch S_H conducts 70 percent during positive half cycle and 30 percent during negative half cycle.The switch S_L is in the reverse manner

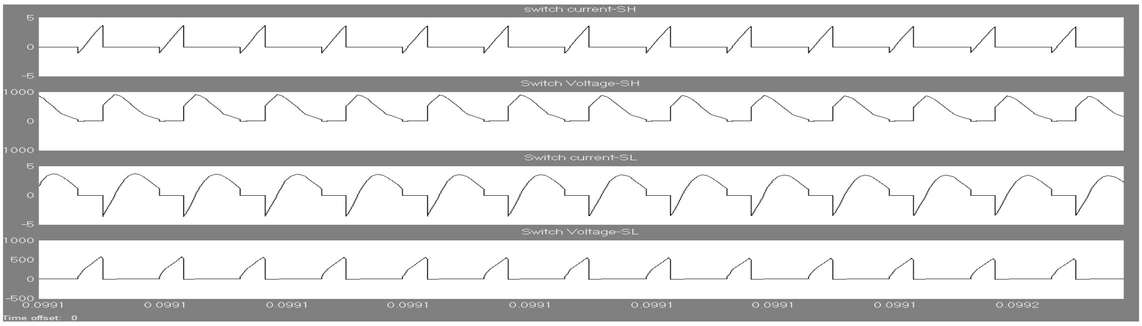

Fig.8.Voltage and current across S_H & S_L

VII. CONCLUSION

In this paper, a direct ac-ac boost resonant converter applied to domestic IH application was introduced. The main features of the converter include a reduced component count, high efficiency due to the reduced current levels and ZVS operation, and proper output power control. A detailed analytical model was presented, obtaining steady state closed-form expressions for the relevant converter magnitudes, including the efficiency. Using these results, a design procedure has been proposed taking into account all the design constraints. As a conclusion, the direct ac-ac boost resonant converter not only reduces the component count, but also exhibits higher efficiency levels, making it appropriate for the domestic IH application.

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