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A Voltage-Fed Full Bridge AC-AC Series Resonant Converter for High Power Induction Heating Applications

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ABSTRACT: Domestic induction heating appliances have become popular due to their advantages such as efficiency, fast heating, cleanliness and safety. This paper presents a voltage-fed soft switching PWM utility frequency AC to high frequency (HF) full bridge series load resonant boost for induction heating appliances. The benefits of higher switching frequency are reduced component size, higher flux density around the surface of the heating objects and reduced size of the converter for same power rating. The main features of the proposal are reduced component count; high efficiency. Its operating principles and mode of operation are explained. The control scheme used in the inverter is asymmetrical duty cycle pulse width modulation. Simulations were obtained by MATLAB/SIMULINK.

KEYWORDS: Induction Heating (IH), pulse width modulated (PWM) control scheme

I.INTRODUCTION

Among various emerging applications of power electronics induction heating plays a great role in industry and home appliances. It is a well-known technique to produce very high temperature for applications like steel melting, brazing, and surface hardening. In each application, an appropriate frequency must be used depending on the work piece geometry and skin-depth requirements. In general, the induction-heating technique requires high-frequency current supply that is capable of inducing high-frequency eddy current in the work piece that results in the heating effect. With tremendous advances of power semiconductor switching devices, the electromagnetic induction current based direct heat energy processing products and applications using high frequency power conversion circuits; inverters, cyclo-inverters and cyclo-converters have attracted special interest. Recently, cost effective induction heating (IH) appliances using high frequency inverters have been rapidly developed for utility frequency AC to high-frequency AC power conversion system for consumer power and energy applications. The IH equipments using high frequency inverter topologies have the practical advantages of safety, cost effectiveness, energy saving, clean environment, high thermal conversion efficiency, rapid and direct focusing heating process, high power density, high reliability, environment non-acoustic and low electromagnetic noise . These unique advantages are practically brought in accordance with great progress of power semiconductor switching devices, digital and analogue control devices, circuit components and high frequency soft switching inverters. Classical IH solutions are based on two separated 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. The resonant inverters used to supply the inductor-pot system can be classified as a function of the number of active devices, which is directly related to the final cost. For low-cost appliances and low output power levels, the one-switch topology is the most used. The half-bridge inverter is used for medium output power. Finally, for high output power levels, the full-bridge inverter is used.

The proposed converter uses a half bridge boost rectifier and a full bridge inverter for achieving high output power levels. By using half bridge boost rectifier achieves high reduction in the current levels can be achieved in the power converter and inductor acting as IH load. As a consequence, the converter efficiency is significantly improved and the low-frequency ac current do not flow through the IH load, reducing peak current and conduction losses. Full-bridge topology is a dual-drive technology; there are dual-MOSFET inverter modules to undertake the conversion on the AC sine wave so the high-frequency current waveform is complete, clear and stable. Due to the high current allocation efficiency of full bridge topology it can load high inductive loads, electronically transfer high thermal efficiency. In

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addition, ZVS soft-switching conditions are guaranteed reducing both conducted and radiated EMC issues, and increasing efficiency. Thus the new converter circuit offers high efficiency, reduced component count and cost than previous full bridge converter topologies for industrial induction heating applications.

II. LITERATURE SURVEY

Present research papers for inductive heating most focus on full-bridge or half-bridge and the driving signals were used Pulse Width Modulation (PWM), and Sinusoid Pulse Width Modulation (SPWM). The driving types can be divided into Symmetric and Non-symmetric. The switching methods are Zero-voltage and Zero-current. The switching frequency are Fixed-frequency switching and Variable-frequency to adjust output power. As to the power control are PWM with fixed-frequency control and SPWM technique in which the switching ON timing was adjustable to control power output. The other one is Pulse Frequency Modulation (PFM) that is varying the switching frequency according to load variety, and in this way, switching frequency would automatically correspond to the change of resonated frequency to get the maximal power output.

Direct ac–ac converters have been widely used in many applications due to the component count reduction achieved, reducing the intermediate dc-link storage requirements. In the case of matrix converters, such direct ac–ac converter implementations reduce or eliminate the required dc-link capacitor, enabling high power density implementations with improved operational life. Besides, in the case of wireless power transfer applications, direct ac–ac converter have demonstrated to enable the use of advanced modulations that reduce switching losses. Currently, direct ac–ac conversion has been also applied to IH applications. Moreover, considering multicoil IH systems, a series resonant multi-inverter featuring four-quadrants switching devices, and enabling the direct ac–ac conversion, has been successfully introduced , reducing electromagnetic compatibility (EMC) filter requirements. In addition to this, a current-source and voltage source direct ac–ac converter was proposed, enabling a component count reduction with higher efficiency levels. Here a voltage fed full bridge converter is introduced for high power industrial heating applications. A full bridge converter supplies more power than a half bridge converter. It can load high loads so more uniform layering can be done sequentially decreasing flame simulation results. The burdens of each component are reduced. So it offers high life expectancy than a half bridge converter where the burdens of components are higher.

III. INDUCTION HEATING COOKING APPLIANCES

Figure 1 demonstrates schematic configuration of a home and industry use IH cooking and processing appliance. The high frequency inverter circuit delivers a high frequency power to the planer-working coil with mutual coupling secondary circuit of electromagnetic eddy current based heating materials. These electromagnetic induction eddy currents directly flow through the pan or vessel. In accordance with Faraday's electromagnetic induction law, a high thermal heating is produced with high conversion efficiency. In case of multi-burner type high frequency IH equipments, the output AC power of each burner has to be controlled under the same constant frequency, because of beat sound caused from different frequencies of operating inverters. In order to alleviate power dissipation of working coil, it is necessary to block dc current components that are not effective for induction heating principle. In particular, the power dissipation reduction due to lower frequency coil current components and an improved soft-switching high frequency inverter operating under a condition of constant frequency pulse modulation should be developed and considered by boosting -dc link voltage.

Fig.1.Schematic configuration of IH cooking appliances

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IV.FULL BRIDGE RESONANT CONVERTER

The proposed converter is shown in Fig. 2. The converter consists of input AC voltage Vs, four MOSFET switches S1, S2, S3, and S4, resonant capacitor C_r, dc-link capacitor C_b , input inductor L_s , 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 antiparallel 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 $C_{b.}$ The IH load is modelled as a series equivalent RL circuit composed of R_{eq} and L_{eq}. In addition to this, the series RLC resonant tank is completed with a resonant capacitor C_r.

The input inductor Ls and the dc-link capacitor C_b boost the voltage. The boost dc-dc conversion of mains AC voltage is done by switches S1 and S3.The main waveforms of the dc–dc boost circuit are shown in Fig. 3, where I_s is the steady-state average input current.. In this circuit, continuous current mode (CCM) is assumed in order to minir current ripple and to avoid high-frequency currents through the rectifier diodes. In steady state, the average vo the inductor is zero and, thus

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

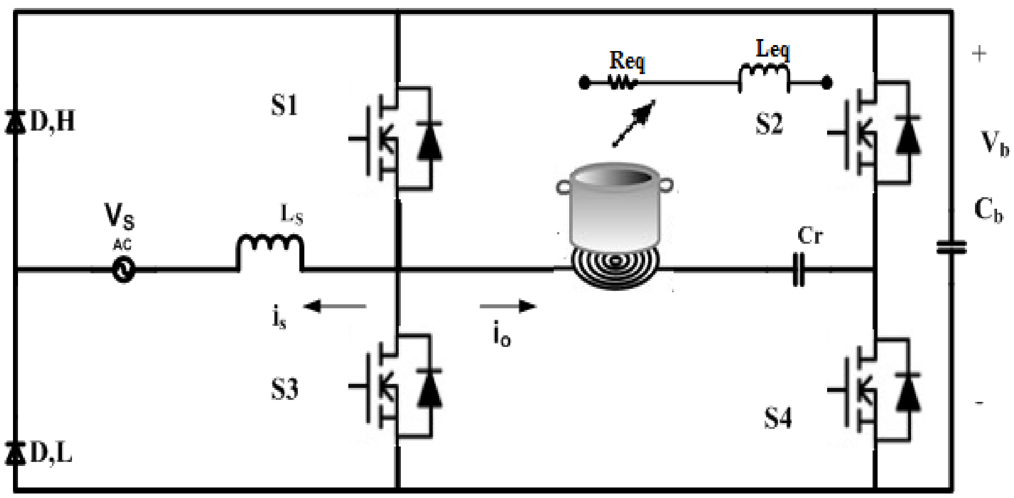

Fig.2.Proposed Converter Circuit

Consequently, the voltage conversion ratio is the same as in a boost converter

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

The temporal waveforms of the input current can be calculated by 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 $I_{s,0}$ and $I_{s,D}$ are the minimum and maximum input current values during a switching period, respectively. Consequently, the input current temporal waveform i_s results

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$$i_s(t) = (I_S - \frac{\Delta I_s}{2}) + \frac{\Delta I_S}{DT_{SW}} t, (0 \le t < DTsw)$$

$$= (Is + \frac{\Delta Is}{2}) - \frac{\Delta Is}{DT_{sw}}(t - DT_{sw}), (DT_{sw} \le t < T_{sw}) \quad (4)$$

Thus, the CCM condition to be satisfied is

$$CCM \Rightarrow I_{S,0} > 0 \Rightarrow I_s > \frac{\Delta I_s}{2} \quad (5)$$

By assuming a unity input power factor, this condition can be related to the input power P_{in} resulting

$$I_S > \frac{\Delta I_S}{2} \Leftrightarrow \frac{P_{in}}{V_S} > \frac{V_S}{2L_S} DT_{sw} \quad (6)$$

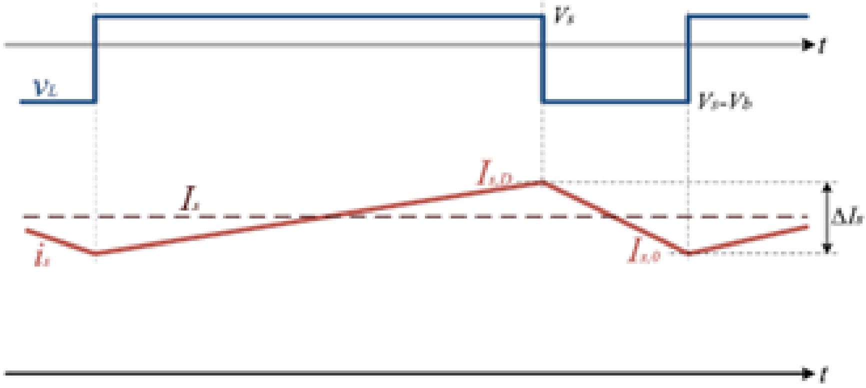

Fig.3. Waveforms of boost circuit

leading to

$$P_{in} > \frac{V_S^2}{2L_s} DT_{SW} \quad (7)$$

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 V_b. By using the Fourier harmonic analysis, the output power P_o results

$$P_0 = \sum_{h=0}^{\infty} R_{eq} \frac{V_{O,h,rms}^2}{Z_{o,h}^2} = \sum_{h=0}^{\infty} R_{eq} \frac{\frac{1}{2} V_{O,h}^2}{Z_{o,h}^2} = \sum_{h=0}^{\infty} \frac{R_{eq}}{2} \frac{V_{0,h}^2}{R_{eq}^2 + (2\pi f_{sw} h L_{eq} - \frac{1}{2\pi f_{sw} h C_r})^2} \quad (8)$$

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

$$\hat{V}_{o,h} = \frac{V_b}{h\pi} \sqrt{a_h^2 + b_h^2} \quad (9)$$

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The output power results

$$P_O = \sum_{h=0}^{\infty} \frac{(1-\cos(2\pi hD))R_{eq}V_S^2}{(h\pi(1-D))^2 R_{eq}^2 + (2\pi f_{SW}L_{eq} - \frac{1}{2\pi f_{sw}hC_r})^2} \qquad (10)$$

IV.CONVERTER ANALYSIS

The operation of the proposed direct ac–ac converter can be analysed through the four modes shown below D,H conducts during the positive mains voltage period (modes 1 and 2), whereas D,L is activated during negative main voltage period (modes 3 and 4). As a result, only one rectifier diode is activated simultaneously, reducing conduction losses when compared with classical solutions

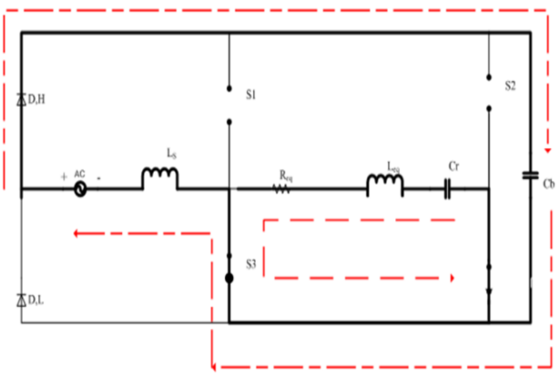

Fig.3.Mode 1

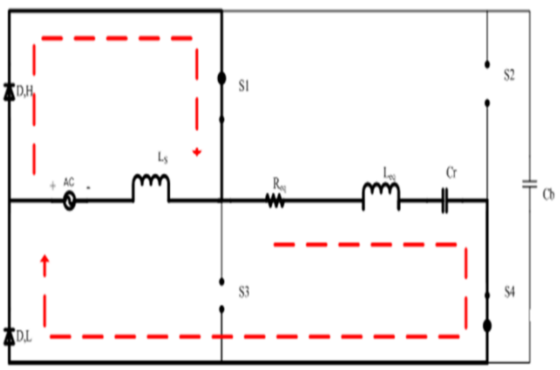

Fig.4.Mode 2

During modes 1 and 3, the supply voltage is applied to the input inductor Ls, whereas in modes2 and 4, the dc-link capacitor C_b is charged by the inductor current. Thus, the converter is operated as a classical boost converter, performing S1 the rectification for positive supply voltage levels, and S2 in the case of negative ones. On the other hand, an equivalent full bridge series resonant converter composed of S1,S2,S3 and S4 and the IH load (R_{eq}, L_{eq}), and the resonant capacitors C_r is used to generate the required high-frequency ac current to supply the IH load. This equivalent full bridge series resonant is supplied by the dc link capacitor voltage V_b corresponding to the aforementioned boost stage. Thus, device currents can be expressed as the sum of the contributions of both the boost stage and the equivalent full bridge series resonant inverter. In mode 1S3 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 L_s. The high frequency current is applied across the load. Mode 1 is shown in figure 3.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 C_b.S3 and S2 conducts during mode 4 and charges input inductor L_s. Modes 2,3,4 are shown in figures 4,5,6 respectively.

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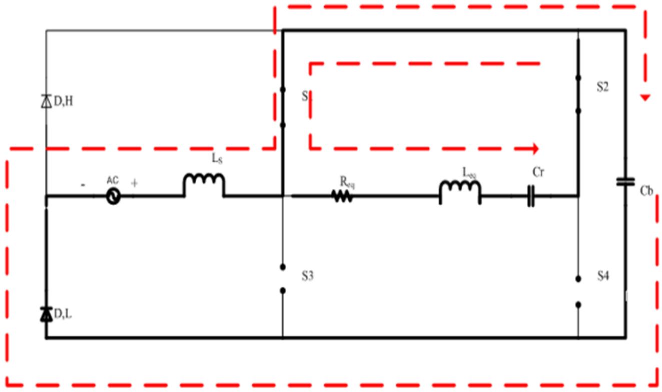

Fig.5.Mode3

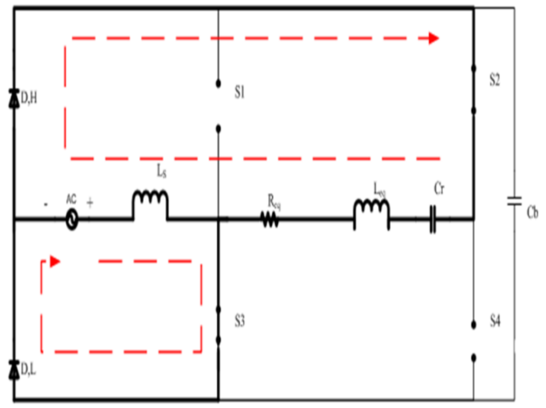

Fig.6.Mode4

VI. SIMULATION RESULTS

The converter fed induction heater is simulated using matlab /simulink and their results are presented here. The circuit model of converter is shown in Fig.6. For the power supply voltage of 230V AC the inductor resistance is 98ohm,coil inductance is 90uH.The simulation parameters are listed in table I.

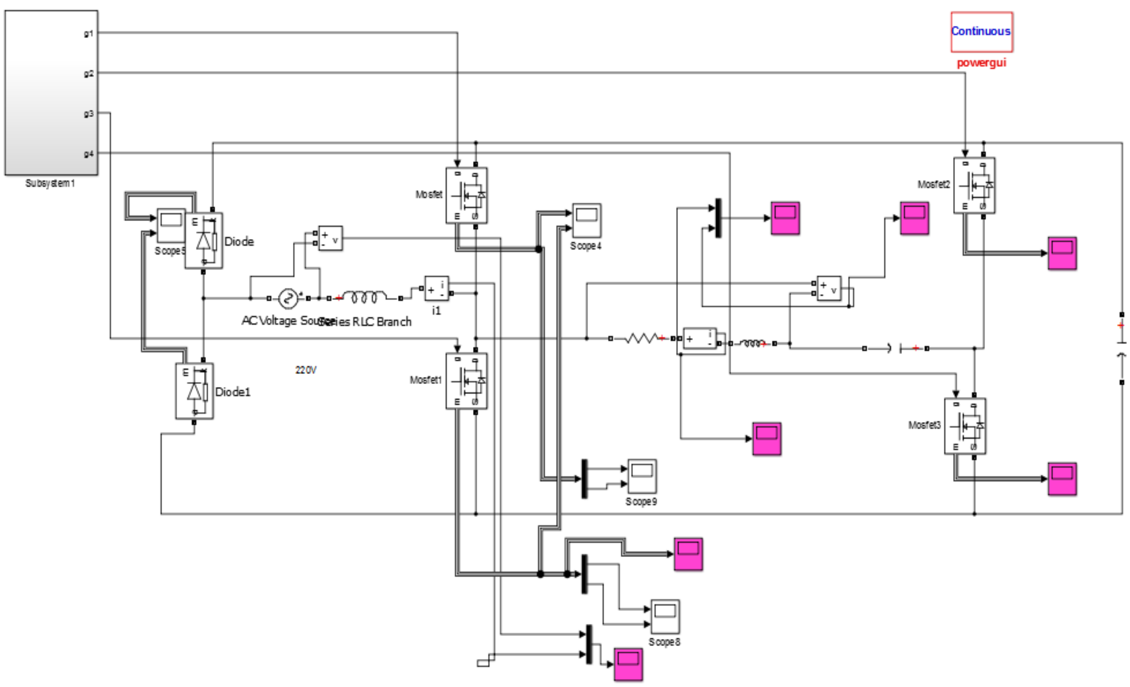

Fig.7.Simulation Diagram of full bridge converter

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The lower switching frequency was set to 455 kHz and the maximum frequency can be 500 kHz. Single phase 230V, 50 Hz AC supply is applied to the input of diode rectifier. Four MOSFETS are used as switching devices. Series RL branch is the representation of equivalent inductance and resistance of inductor pot system.

Table I

Parameter	Values
AC input voltage	230V
Switching frequency, f_s	455kHz
Equivalent load resistance, R_{eq}	98 Ω
Equivalent load inductance, L_{eq}	90uH
Resonant capacitor, C_s	1360uF
Input inductor, L_s	100uH
DC link capacitor, C_b	470uH

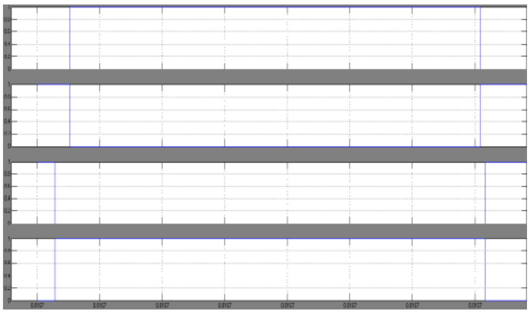

Fig.8.Gate Pulses

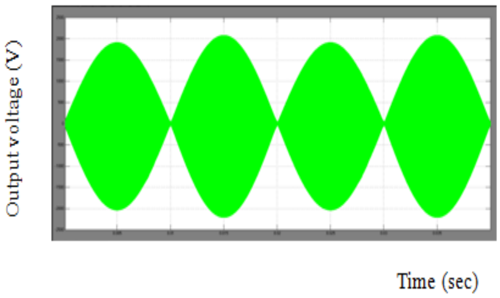

Fig.9.Output Voltage

The output voltage across the series RL branch is measured using voltage measurement block and the output current is measured using the current measurement block and scope is used for observing the output voltage and current waveform. Gate pulses are also observed using scopes. Gate pulses for four IGBT switches are shown in fig.8. Output voltage and Current across the load is shown in figure 9 and 10 respectively. We obtained high frequency AC wave. Voltage and current across the S1 is shown in the fig.11.softswitching of switches is achieved. The maximum output power achieved is 3.6kW.The waveform of output voltage and current is of high frequency. on symmetric PWM signal generates the gate pulses for four switches.ZVS soft switching is guaranteed by providing a time delay between the switching of switches. Soft switching reduces the losses due to high voltage and high current present in switch during transitions and losses due to shorting device capacitances.

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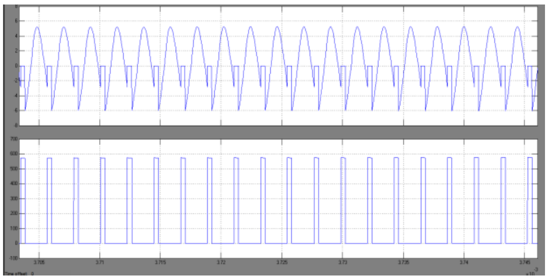

Fig.11.Voltage and Current across s1

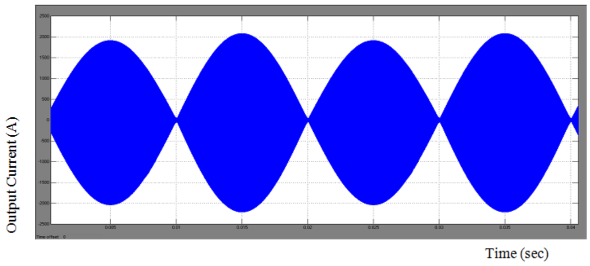

Fig.10.Output Current

VII.CONCLUSION

A voltage-fed full bridge AC-AC resonant boost converter is introduced. The converter supplies more power than half bridge converter .It reduces voltage stress and current stress across switches.It is based upon half bridge diode rectifier and a full bridge inverter characterised by compact size and low cost converter The analysis of the converter operation can be simplified taking into account that the operation in modes 1 and 3 and modes 2 and 4, is equivalent for the positive and negative mains voltage cycles, respectively. The equivalent operation of the proposed direct ac–ac converter can be modelled by superposition of a synchronous boost dc–dc converter and a FB-SRI .The simulation of the converter is done using MATLAB/SIMULINK

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