A Single Stage soft switching-PWM Inverter with CF to HF AC Power Applications

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Abstract : A Single phase half bridge inverter is used to provide continuous sinusoidal input current with nearly unity power factor at the source side with extremely low distortion. In this paper a single phase AC/DC/AC soft switching utility frequency AC to high frequency AC converter. The proposed 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.The working of the high frequency inverter using the latest MOSFETs are illustrated, which includes high frequency AC power regulation ranges based on zero voltage soft switching (ZVS) operation ranges are compared with those of the previously developed high frequency inverter.

IndexTerms: Softswitching (ZVS),CF(Commercial Frequency), HF (High Frequency), Induction heating(IH), Sinusoidal pulse width modulation(SPWM), Utilityfrequency, powerconversion, Boost active clamp bridge single stage, ZVS-PWM mode

I. INTRODUCTION

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, and high reliability[3]-[7].

Internal resistance to electrical current is used to generate heat for parts that are heated by resistance or induction heating. Because the internal resistance can vary significantly from part to part it is essential to measure the part temperature during the heating process in order to assure a consistent temperature value. Simple process variables such as surrounding air currents can have a dramatic impact on the temperature of the heated parts in controlled by electrical power rather than temperature. The typical arrangement of an induction-heating is as shown in the Fig.1.

The 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.

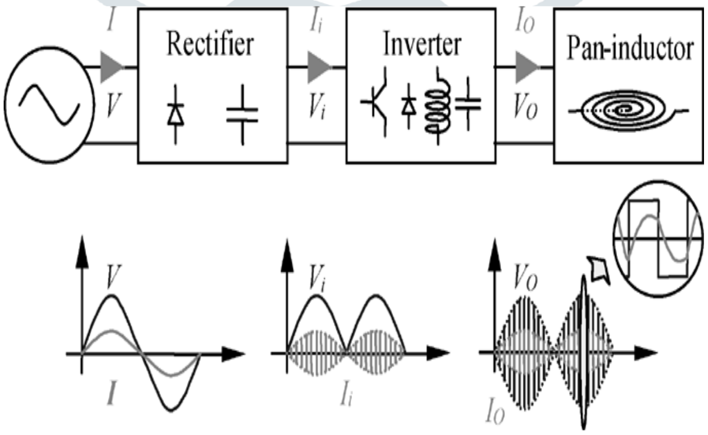


Fig . 1. Typical arrangement of an induction-heating

Under the aforementioned technological situations, high frequency soft switching inverter topologies are indispensable for consumer IH appliances. These high frequency soft switching inverters must have the advantages of simple configuration, high efficiency, low cost and wide soft commutation operating ranges for high frequency operation. The voltage source type soft-switching high frequency inverter using the latest IGBTs and its modifications match the practical operating requirements mentioned previously. A single circuit integration one stage configuration of high frequency power conversion can be established by combining both boost converter and active clamped bridge inverter [8].

In this paper, a novel prototype of a boost-active clamp bridge one-stage high frequency zero voltage soft-switching PWM inverter, which converts the utility frequency AC power into high frequency AC power with voltage boosting. This one-stage high frequency inverter which is composed of single phase diode bridge rectifier, non-smoothing filter, boost-active clamp bridge type zero voltage soft switching PWM high frequency inverter, and induction heated load with planar type litz wire working coil assembly. Also we discussed in this paper in order to extend the soft switching operation ranges and to improve the power conversion efficiency.

The heat is generated at the bottom of the pan due to eddy currents and hysteresis losses. These induced currents are caused by an alternating magnetic field generated by a medium frequency (20–100 kHz) current through the coil.

Pan-inductor coupling is usually modelled as the series connection of an inductor and a resistor based on the transformer analogy. The values of the equivalent inductance and resistance depend on the operating frequency and the required maximum power.

A bus filter is designed to allow a big voltage ripple getting a resultant input power factor close to one. Then the inverter topology supplies the high-frequency current to the induction coil. Due to this ripple all components have to be designed for the voltage and current peak values.

II. INDUCTION HEATING APPLICATIONS

Induction heating is used for an ever-widening range of industrial and scientific applications: material joining processes such as brazing, soldering and curing. The material processing applications including in hardening, forging, annealing and melting and the component assembly applications such as epoxy bonding and heat staking metal into plastic. Our engineers have also applied the technology for catheter tipping, hot heading and other component manufacturing processes.

Induction heating is used in plastic injection molding machines. Induction heating improves energy efficiency for injection and extrusion processes. Heat is directly generated in the barrel of the machine, reducing warm up time and energy consumption. The induction coil can be placed outside thermal insulation, so it operates at low temperature and has a long life. The frequency used ranges from 30 kHz down to 5 kHz, decreasing from thicker barrels. The reduction in cost of inverter equipment has made induction heating increasingly popular. Induction heating can also be applied to molds, offering even mold temperature and improved product quality.

III. BOOST-ACTIVE CLAMP HIGH FREQUENCY INVERTER

A. Circuit Description

The basic circuit configuration of the proposed one stage soft switching PWM power converter incorporating two switches only for boost chopper and active clamp bridge zero voltage soft switching (ZVS) high frequency PWM inverter are as shown in Fig.2 and modified topologies respectively[2].

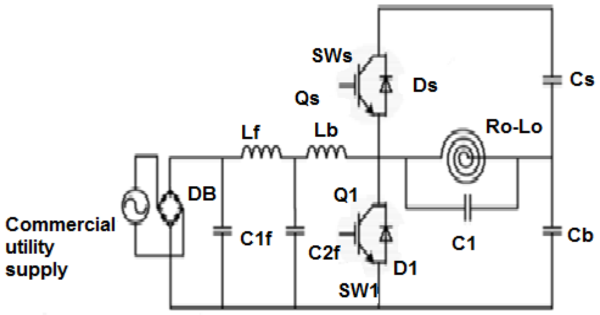


Fig .2. Proposed single stage soft-switching PWM HF inverter topologies

The boost-active clamp bridge one stage high frequency inverter circuit topology includes two active power switch blocks Q_1 (SW_1/D_l), Q_s (SW/D_s), divided series capacitors C and C_b and lossless snubbing capacitor C_1 in parallel to the IH working coil L_o.

In addition, the divided series capacitors C and C_b are used to block the lower frequency current components flowing through the IH working coil is assembled from the planar type litz wire.

In addition to that, the voltage boosted block composed of the boost inductor L_b and active power switch Q_1 (SW1/D1) from the circuit configuration of proposed topology, the switching block Q_1 (SW_1/D_1) shares and performs the operation of both single-phase boost chopper converter and ZVS-PWM high frequency inverter[1].This is resulted from adding additional circuit components as the boost chopper inductor L_b. On the other hand, for high power this is resulted from adding additional circuit components as the boost chopper inductor L_b.

B. High Frequency AC Power Control Scheme

The high frequency AC output power of the proposed inverter circuit, which is delivered to the Induction heating load as IH cooking heater can be continuously regulated by a constant frequency asymmetrical PWM control scheme under a condition ZVS. The gate voltage pulse timing signal sequences for Q_l and Q_s are shown schematically in Fig. 3.Switch Q_1 is firstly switched on during a period T_{onl} and before Q_l is turned off by a time of T_o. Then, Q_s is turned on after turning off Q_l by a dead time of T_{d1}. Q_l is again switched on after a dead time T_{d2} as another period starts as depicted in Fig.3. In this the inverter has equal dead time control scheme. By adjusting the constant frequency asymmetrical PWM control duty cycle, which is defined as the sum of the conduction time T_{0n1} of Q_l and total switching period T.

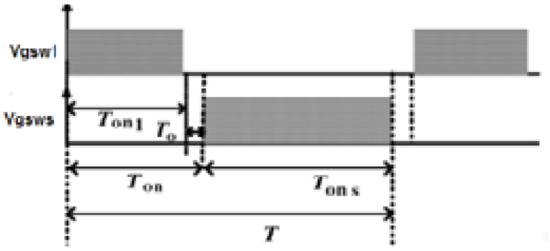


Fig. 3. Schematic PWM gate pulse timing sequences pattern

By varying the duty cycle D as a control variable, the high- frequency AC output power of this soft-switching inverter can be regulated continuously.

IV. EQUIVALENT CIRCUITS AND SWITCHING MODES OF OPERATION

Mode 1 (SW_1: on, D_1: off, SW_s:off, and D_s:off)

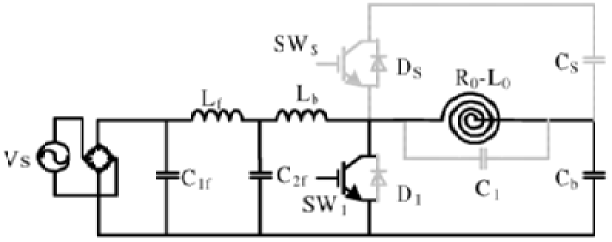


Fig .4(a) Mode 1

This switching mode equivalent circuit of mode 1 is as shown in Fig. 4(a).In this operating mode, two current loops in the equivalent circuit are formed. The magnetic energy is stored into the boost inductor L_b through the loop of C_{2f} - L_b-Q_1- C_{2f} , and the input power is delivered to the induction-heated load through C_b-L_o-Q_1-C_b.

Mode 2 (SW_1: off, D_1: off, SW_s:off and D_s:off)

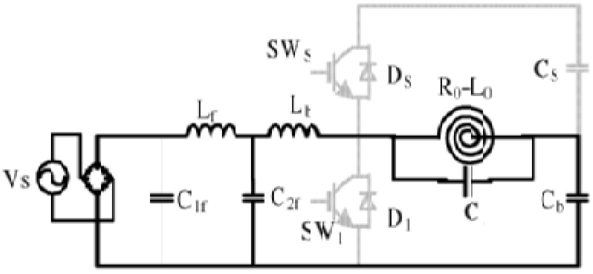


Fig .4(b) Mode 2

The equivalent circuit of mode 2 is depicted in Fig. 4(b). In mode 2 the resonant energy is stored into C1 through the two loops composed of L_b-C_1-C_b-C_{2f} -L; and L_0-C_1-L_0.

Mode 3 (SW_1:off , D_1: off, SW_s:off and D_s: on)

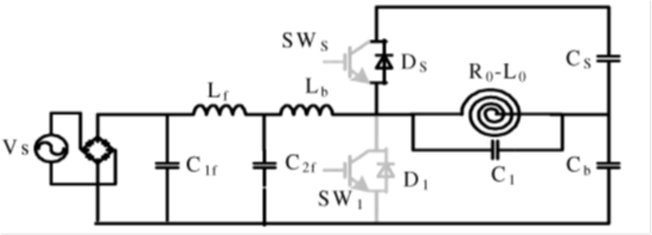


Fig .4(c) Mode 3

The energy is stored into *C*, through the loop formed by L_b-C_S-C_b-C_{2f} –L_b and the energy is delivered to the IH load through the loop composed of D_s-C_s-C_{2f} -L*;* The equivalent circuit of mode 3 is shown in Fig.4(c)

Mode 4 (SW_1: off, D_1: off, SW_s: on and D_s: off)

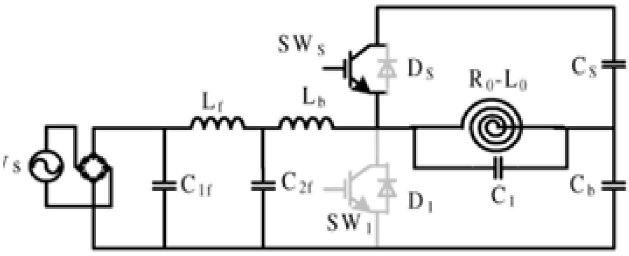


Fig .4(d) Mode 4

Mode 4 operation is as shown in the Fig. 4(d).In that the energy is delivered to the induction heating load through the loop composed of C_s-Q_s-L_o-C_s and the energy is stored into capacitor C_b through the loop composed of L_b-L_o-C_b-C_{2f}.

Mode 5 (SW_1: off , D_1 : off, SW_s: off and D_s: off)

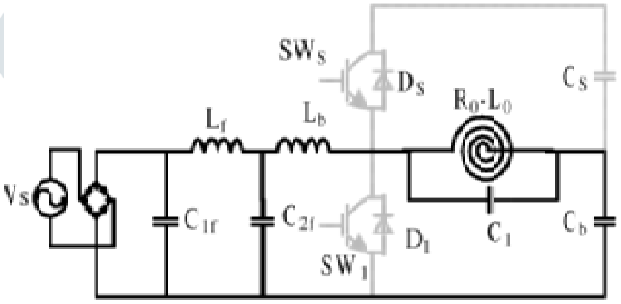
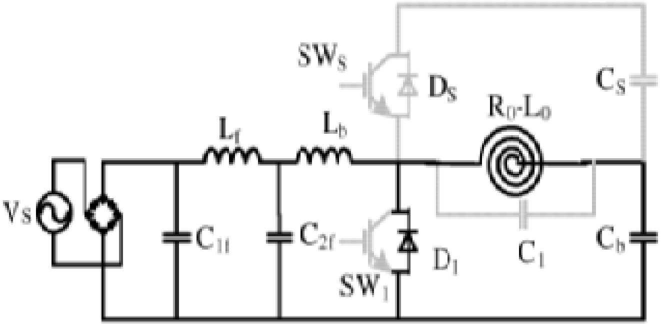


Fig .4(e) Mode 5

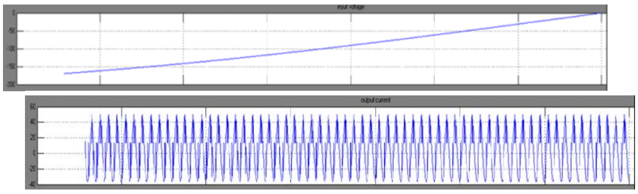
The equivalent circuit of Mode 5 is as shown in the Fig.4(e). During this operating mode, the energy is transferred to the IH load-working coil L_o through the loop composed of L_o-C_1-L_O and the energy is stored into capacitor C_b through the loop composed of L_b-L_O-C_b-C_{2f} as in mode 4.

Mode 6 (SW_1: off, D1: on, SW_s: off and D_s: off)



The energy stored in the IH working coil L_o is transferred into the capacitor C_b through the loop composed of L_o-C_b-L_O and the energy is stored into capacitor C_b through the loop composed of L_b-L_o-C_b-C_{2f}

V. SIMULATION RESULTS AND DISCUSSIONS



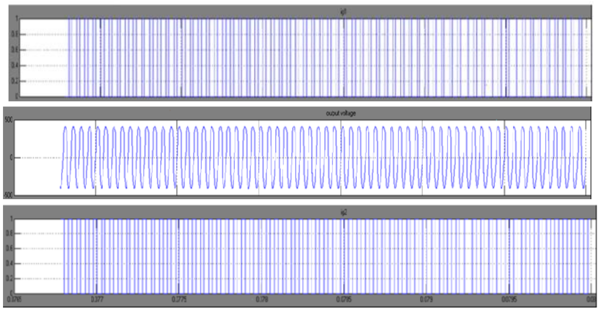


Fig .5. Simulated voltage and current waveforms of the inverter circuit

The simulated operating waveforms of the proposed boost active clamp PWM high frequency inverter are shown in Fig.5. The switching frequency of the inverter is designed for 20 KHz and input rms voltage 200V.

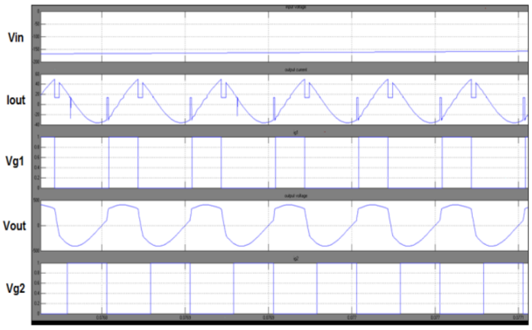


Fig .6. Waveform of input voltage, output voltage and output current

The modelling of this converter is done using MATLAB software and the modelling diagram is shown in the Fig .7. The output voltage and current of the converter are depicted. According to the switching signals of the converter, the duty cycle D is varied, a PWM technique is used for switches S_1, and S_2. The duty ratio D is defined by (1)

$$D = \frac{Ton + Toff}{T} \quad (1)$$

where T_{On} is the on-time interval of the switches and T_S is the switching period. The converter model is simulated for the following:

Input Voltage = 200V AC Voltage
Output Voltage ≈ 400V AC Voltage

The simulated waveforms are shown in the Fig .5 and Fig .6.

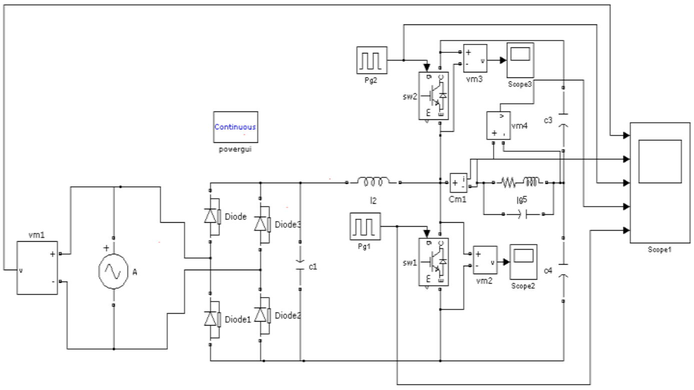


Fig.7.Simulated Model of the Induction Heating

VI. CONCLUSION

In this paper, a circuit topology of commercial frequency AC to high frequency AC power converter employing boost active-clamped single stage ZVS-PWM high frequency inverter has been proposed for consumer induction heating appliances such as IH heater, IH polymer heater, IH superheated steamer, IH fixing roller and IH far-infrared griddle. A single stage high frequency IH inverter using boosted voltage function can eliminate the dc and low frequency components of the working coil current and reduce the power dissipation of the circuit components and switching devices. The operating principle of this high frequency inverter and its unique features have been presented and discussed on the basis of simulation results. The steady state operating performances have been illustrated as compared with previously developed high frequency power converters which include high frequency AC power regulation characteristics and power conversion efficiency based on the power loss analysis.

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