SINGLE PHASE HIGH FREQUENCY AC CONVERTER FOR INDUCTION HEATING APPLICATION

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Abstract:

The proposed topology reduces the total harmonic distortion (THD) of a high frequency AC/AC Converter well below the acceptable limit. This paper deals with a novel single phase AC/DC/AC soft switching utility frequency AC to high frequency AC converter. In this paper a single phase full bridge inverter with Vienna rectifier as front end is used instead of conventional diode bridge rectifier to provide continuous sinusoidal input current with nearly unity power factor at the source side with extremely low distortion.. This power converter is more suitable and acceptable for cost effective high frequency (HF) consumer induction heating applications.

Key words: Vienna rectifier; zero voltage Switching; Sinusoidal pulse width modulation (ZVS–SPWM);Total harmonic distortion(THD).

1. Introduction

With tremendous advances of power semiconductor switching devices, the electromagnetic induction eddy current based direct heat energy processing products and applications using high frequency power conversion circuits such as inverters, cyclo-inverters and cyclo-converters have attracted special interest for consumer food cooking and processing appliances [1]–[6]. In recent years, the high frequency soft switching power conversion circuits namely high frequency inverters, high frequency AC-AC converters technologies contribute for effective home and industrial power applications. The power quality improvement, energy saving and downsizing for the domestic electric power appliances have been preceded with great advances of power semiconductor devices and passive circuit components. Electromagnetic induction heating applied technologies in home and business usages have been spotlighted in attractive induction heating appliances such as metal working process, heat treatment, dissolution process, induction heating soldering, and induction fusion of polyethylene pipe, induction heating (IH) rice cooker, IH boiler, and IH hot-water supplier. The developments on the modern electric kitchen systems with advantages as simple, reliability, safety, maintenance free, efficiency improvement of the food cooking and processing work, and reduction in total running cost have attracted special interest in modern society.

From these viewpoints, the development of high frequency AC/AC converters for kitchen equipments is the need of the hour. The development of the new high frequency induction heating cooker, boiler and super heated steamer, that is high-performance, high power density and high-efficiency compared with the conventional gas cooking equipment are much more attractive for home and business uses. By such technological background, high-frequency soft switching power supply for the electromagnetic induction heating with the control schemes has been developed in this paper

In this paper, a novel single stage high frequency zero voltage soft-switching full bridge PWM inverter topology with Vienna rectifier at the front is proposed. This converts the utility frequency ac power into high frequency ac power at nearly unity power factor with very less THD than paper [7]. This single stage high frequency inverter which is composed of single phase Vienna rectifier, non- smoothing filter, sinusoidal soft switching PWM high frequency inverter, and induction heated load with planar type litz wire working coil assembly. The modeling and simulation result satisfies the IEEE standards IEEE 519-92, IEC-555.

2. Equivalent Circuit Modeling of Induction Heating Load

The equivalent circuit modeling [8] of the electromagnetic induction heating load discussed below is shown in Fig.1 (a) and (b).

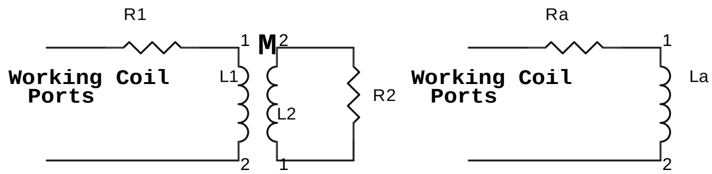

Fig. 1(a) Transformer type Fig. 1(b) Reduced model

Fig.1 Equivalent circuit modeling of electromagnetic induction eddy current based joule's heating load

Fig.1 is an approximate linear equivalent model of the induction heated load circuit represented by equivalent effective inductance L_a in series with equivalent effective resistance R_a with reference to the input side of working coil terminals of the generic induction heater. R_a and L_a of the IH load are respectively determined by the self-inductance L_1 and internal resistance R_1 of the working coil, self-inductance L_2 of eddy current heated device in electromagnetic induction transformer secondary side and mutual inductance M between L_1 and L_2. It is actually considered that these circuit parameters in spite of output power regulation delivered to the high frequency IH load is approximately kept constant, when high frequency AC power is regulated for a constant frequency PWM. The high frequency dependent resistance R_2, recognized and estimated by the skin effect resistance and is kept constant under the principle of a fixed frequency Sinusoidal PWM scheme. High frequency AC voltage is provided to the IH load via ceramic spacer and working coil excited by high frequency inverter. The effective AC value V_{rms} of HF AC voltage and effective value I_{rms} of HFAC current with electrical angular frequency ($\omega=2\Pi f$), power factor $\cos\theta$ ($\cos\theta$: difference in angle between output voltage and output current) are directly measured for high frequency IH load with working coil driven by HFAC power supply. Equation (1) is simply obtained on the basis of the sine wave AC circuit theory.

$$\frac{V_{rms}}{I_{rms}} = Z_{rms} = \sqrt{R_a{}^2 + (\omega L_a)^2}$$

$$\cos\theta = \frac{R_a}{\sqrt{R_a{}^2 + (\omega L_a)^2}}, \sin\theta = \frac{\omega L_a}{\sqrt{R_a{}^2 + (\omega L_a)^2}} --$$

The impedance Z_{rms} of the high frequency induction heating load for the angular frequency ω of output voltage and output current from high frequency inverter is calculated using the equation (1). By using measured fundamental power factor, the equivalent circuit parameters R_a and L_a of the high frequency IH load with pan, kettle and utensil or vessel placed exactly on pancake type working coil are estimated. In the case of considering internal resistance R_1 of the planar working coil itself, the equivalent effective resistance value becomes $R_a + R_1$.

3. Conventional ZVS-PWM Boost Active Clamp Inverter Topology with Diode Bridge Frontend

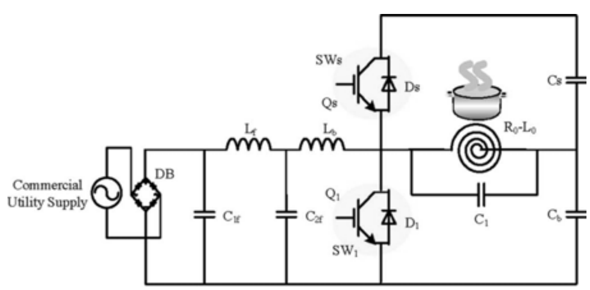

Fig.2. Single stage soft-switching PWM boost active clamp inverter topology with diode bridge rectifier at the front end

Fig. 2 represents the basic circuit configuration of single stage soft switching PWM power converter incorporating two switches for boost chopper and active clamp bridge zero voltage soft switching (ZVS) high frequency PWM inverter. The boost-active clamp bridge single stage high frequency inverter circuit topology includes two active power switch blocks Q_1 (SW1/D1), Q_S (SWS/DS) divided series capacitors C_S and C_b and lossless snubbing capacitor C_1 in parallel to the IH working coil R_0-L_0. In addition, the voltage boosted block composed of the boost inductor L_b and active power switch Q_1 from the circuit configuration of proposed topology, the switching block Q_1 shares and performs the operation of both single-phase boost chopper converter and ZVS-PWM high frequency inverter. This diode bridge front end boost-active clamp conventional ZVS–PWM high frequency inverter topology produces the THD greater than 5% as specified by IEEE standards IEEE 519-92, IEC-555 and European EN 61000-3-2 standards for allowable harmonic contents of mains.

4. Proposed ZVS-PWM Full Bridge Inverter Topology with Vienna Rectifier Frontend

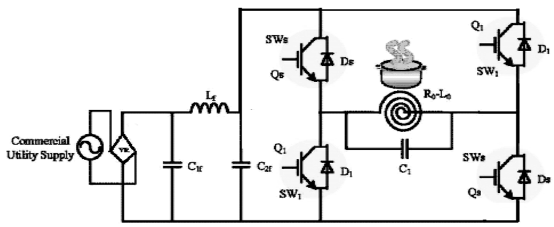

Fig.3 Single stage soft-switching PWM HF inverter topology with Vienna rectifier at the front end

Fig. 3 represents the basic circuit configuration of single stage soft switching PWM power converter incorporating four switches for inverter operation and a Vienna rectifier for sinusoidal current consumption. This topology includes two pair of four active power switch blocks Q_1 (SW1/D1), Q_S (SWS/DS) and lossless snubbing capacitor C_1 in parallel to the IH working coil R_0-L_0. The inverter is fired by an unsymmetrical zero voltage switching, Sinusoidal pulse width modulation.

Traditional diode rectifiers and thyristor rectifiers draw pulsed current from the ac main, causing significant current harmonics pollution. The international standards presented in IEEE Std. 519 and IEEE Monitoring Electric Power Quality Std 1159-1995 imposed harmonic restrictions to modern rectifiers, which stimulated a focused research effort on the topic of unity power factor rectifiers. Vienna rectifier is an excellent choice now a days since By using a Vienna rectifier sinusoidal input currents with Power Factor equal to 0.997, THD less than 5% and overall efficiency greater than 97% are obtainable with continuous sinusoidal input current and unidirectional power flow moreover any malfunction in control circuit does not manifest itself in short circuit of output or PFC front end [8-10].

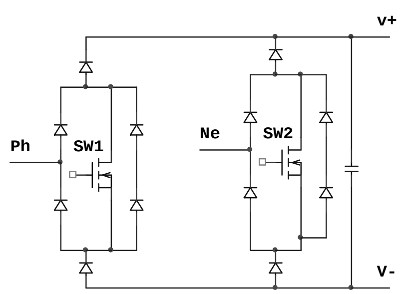

Fig.4. Vienna Rectifier Configuration

Fig. 4 represents Vienna rectifier configuration for a single phase source. A simple carrier based PWM is used at supply frequency to provide the switching instance for the Vienna rectifier. The switches SW1 and SW2 are complementary to each other.

5. Unsymmetrical ZVS Switching Schemes

The high frequency AC output power of the proposed inverter circuit, which is delivered to the IH load as IH cooking heater, can be continuously regulated by a constant frequency asymmetrical SPWM control scheme under a condition ZVS.

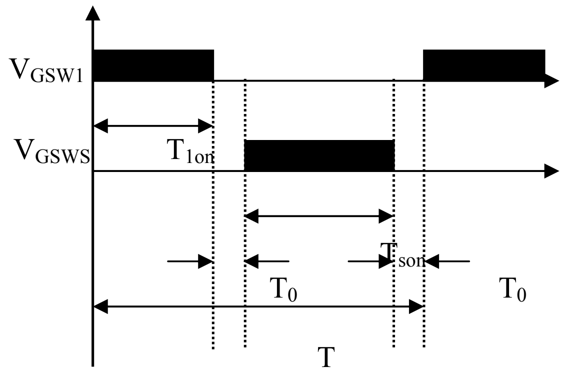

Fig. 5 Schematic SPWM gate pulse timing sequences pattern.

The gate voltage pulse timing signal sequences for Q1 and Qs are shown schematically in Fig. 5 as VGSW1 and VGSWs. Q1 is first switched on during a period T1on and Q1 is turned off before a time of T0. Then, Qs is turned on after turning off Q1 by a dead time of T0. Q1 is again switched on after a dead time as another period starts as depicted in Fig. 5. This high frequency inverter has equal dead time control scheme. The constant frequency asymmetrical SPWM duty cycle is the ratio of conduction time T1on of Q1 to total switching period T . As a control variable, the duty cycle is defined as

$$D = \frac{T_{1on} + T_0}{T} ------(2)$$

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

6. Simulation Results and Discussion

To show the effectiveness of the proposed topology the simulation model of the proposed ZVS-PWM Full Bridge Inverter Topology with Vienna Rectifier Front-end is setup using Matlab/Simulink software. The parameters taken from [7] is used to validate this topology as given in Table 1:

TABLE: 1 Simulation details

ITEM	SYMBOL	VALUE
Supply Voltage	V_S	200V
Switching Frequency	F_S	20kH$_Z$
Iron Pan With Working Coil Effective Resistance And Inductance	R_0 L_0	2.5 Ω 58µH
Charge Up Boost Inductor	L_b	500µH
Non Smoothing Filter Inductor	L_f	200µH
Non Smoothing Filter Capacitor	C_f	2µF

The matlab simulink diagram of the proposed ZVS-PWM Full Bridge Inverter Topology with Vienna Rectifier Front-end is shown below in the Fig. 6.

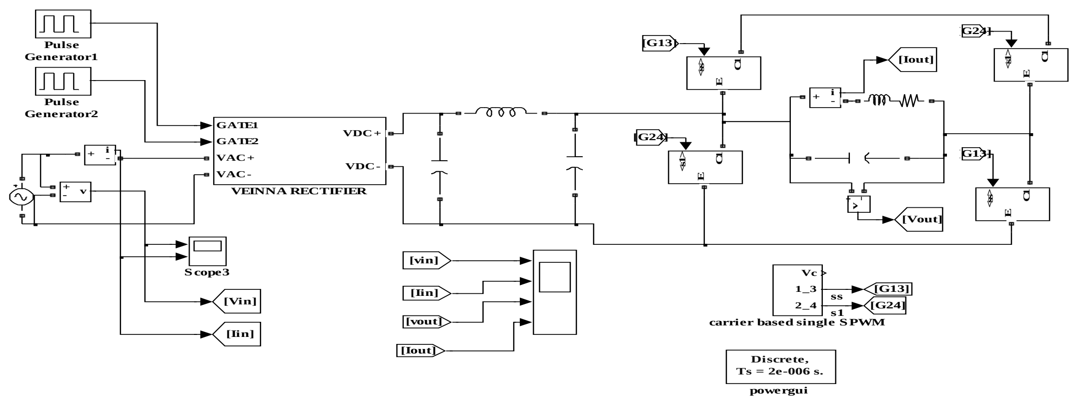

Fig.6. Matlab schematic of the proposed topology

The waveforms of input voltage, input current, output voltage and output current of ZVS-PWM inverter topology with diode bridge front end is shown in fig 7(a). The corresponding waveforms for the proposed ZVS-PWM full bridge inverter topology with Vienna rectifier front end is shown in fig 7(b).

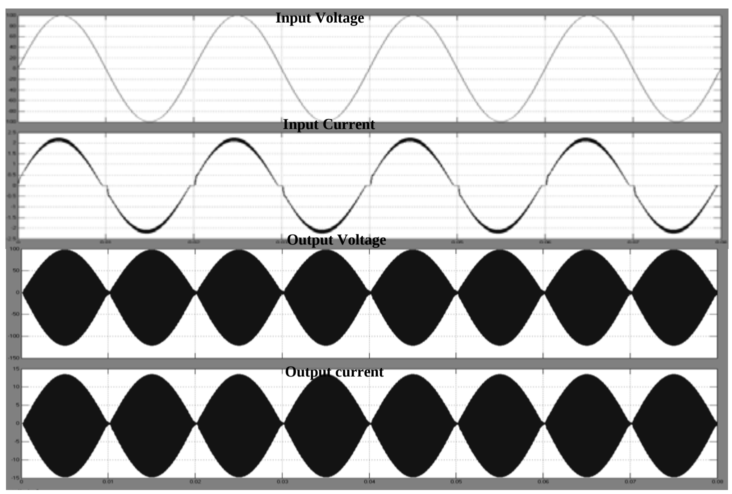

Fig.7 (a) Waveforms of input and output voltage and current for the conventional topology.

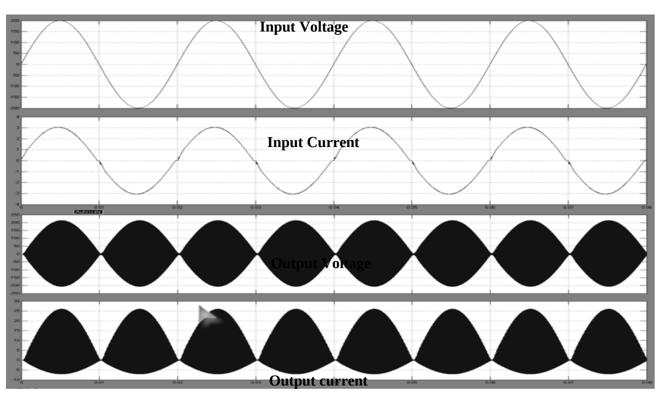

Fig. 7(b) Waveforms of input and output voltage and currents for the proposed topology

The FFT analysis of the conventional ZVS-PWM boost active clamp inverter topology with diode bridge front end and the proposed ZVS-PWM full bridge inverter topology with Vienna rectifier front end were shown in the Fig. 8 and 9

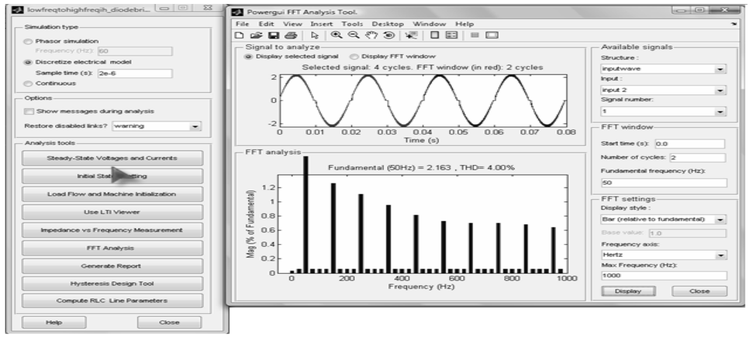

Fig.8 FFT analysis of ZVS-PWM boost active clamp inverter topology with diode bridge front end

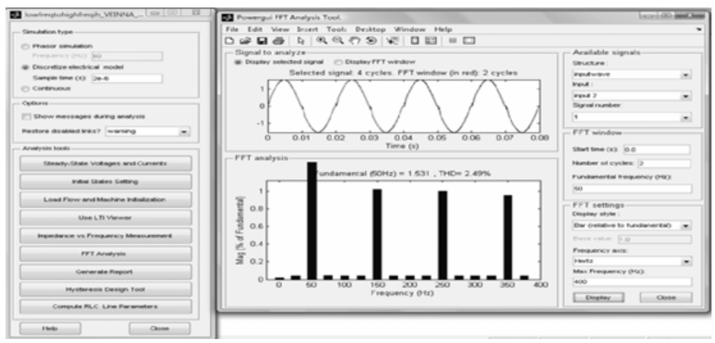

Fig.9 FFT analysis ZVS-PWM full bridge inverter topology with Vienna rectifier front end

According to Fig. 8, ZVS-PWM boost active clamp inverter topology with diode bridge front end draws the input peak current of 2.2A with the total harmonic distortion (THD) of input current being 4.00%. Compared to this as shown in Fig. 9 the proposed ZVS-PWM full bridge inverter topology with Vienna rectifier front end draws the input peak current of 3A with the total harmonic distortion (THD) of input current of just 2.49%. This results suggests that the proposed topology draws only little harmonic component compared with conventional topology.

7. Conclusion

In this paper a novel ZVS-PWM full bridge inverter topology with Vienna rectifier front end has been proposed. The simulation result shows that the compared ZVS-PWM boost active clamp inverter topology with diode bridge front end this novel ZVS-PWM full bridge inverter topology with Vienna rectifier front end draws source current with very less THD taking PF to nearly unity.

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