Development of Embedded Based Power Control Scheme in Class D Inverter for Induction Heating System

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Abstract- This paper presents embedded controlled class D inverter based high frequency power conversion circuit suitable for induction melting. This power conversion circuit convert utility frequency ac into high frequency ac. Embedded based pulse width modulation based control strategy for class D inverter is presented to achieve good power control with lesser harmonic distortion and cost effective high power density solution. This embedded controlled high frequency AC power supply is more suitable and acceptable for medium and high power induction heating applications. The performed analysis includes the description of the operation and control strategy principle .The power converter is designed; open loop and closed loop studies have been performed for output power control through MATLAB simulation. Simulation results of the proposed controller for class D inverter are presented to prove the performance. Prototype model of embedded controlled high frequency ac power supply is implemented for induction heating. The obtained experimental waveforms validate the simulation results.

I. Introduction

High frequency induction heating is widely used in many industries for induction melting applications. Electromagnetic induction heating is a non-contact heating process. It uses high frequency electricity to heat materials that are electrically conductive. Since it is non-contact, the heating process does not contaminate the material being heated. Induction heating uses high-frequency AC supply, on the other hand, it will lead to increased switching losses, high switching stress which can harm the power devices. "High frequency AC (HFAC) power supply for IH equipment's have the advantages like energy saving, high reliability and low electromagnetic noise.3" These advantages are brought in accordance with the great progress of power semiconductor switching devices, different control methods and high frequency inverters.[10]The main desired feature of induction heating power supply is less cost and high efficiency[9].A large number of inverter topologies have been developed for different applications with power levels ranging from hundreds of watts to several megawatts for domestic and industrial applications. Most of the recent developments for induction heaters are using high frequency inverter. "Among them voltage-fed half bridge inverters are used in low and medium power applications[1-3].For power applications full bridge type inverter is most commonly used[4,5]. The different types of tank circuit are also be used to create resonance. The series resonant circuit is the most widely used in induction heating power supply system and it is also discussed in many of the literatures. 6, 8 . High quality heating depends on power control of load. Different power control and regulation strategies have been proposed such as pulse frequency modulation, pulse density modulation and phase shift control. The aim of the paper is to propose an embedded controlled class D resonant inverter fed induction heater for melting applications. In this paper power supply for induction heating (IH) system with single phase diode rectifier with input side T filter, a single phase class D inverter with IGBT as power switches, and series model of induction heating load is described. The use of diode bridge rectifier with the input side T filter causes lesser harmonic distortion. The class D inverter is considered since it is the mostly used topology due to its simplicity and less cost. "Induction coil and work piece is modelled as series connection of inductor (Leq) and resistor (Req), based on its analogy with respect to transformer. 8" Pulse width modulation [PWM] based control scheme is used to control the output power. Inverter operation at resonance is maintained in the proposed

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control scheme so that losses are less which improves output power compared to pulse frequency control technique. Embedded control of PWM is done using PIC16F877 for the power control of induction heater.

II. System Configuration and Circuit Description

Fig.1 shows the general block diagram of the induction heating power supply system, where it may be seen that the required input power is supplied by high frequency inverter which is of the voltage source load resonant type. Induction heater takes the energy from the supply mains which are rectified by diode bridge rectifier. Rectified DC is switched to high frequency AC through inverter. Induction heating arrangement consists of work coil and work piece to be heated. The inverter supplies high frequency current to the coil. A class-D inverter will be generally used to energize the induction coil to generate high-frequency magnetic induction between the work coil and the work piece, consequently, high-frequency eddy current, and finally, heat in work piece. The power circuit for high frequency ac-ac conversion circuit using class D inverter is shown in Fig.2. The single phase ac supply is given to the rectifier circuit. T filter is used in between AC supply and uncontrolled rectifier to reduce total harmonic distortion (THD). The rectifier converts ac supply into dc. After the rectifier, filter capacitor is connected in parallel to filter out the ripple contents available in dc. The dc voltage is converted again into a high-frequency ac voltage by the class-D inverter. Then, the inverter supplies a high-frequency current to the induction coil. The class-D inverter onsists of two switches *Q*1 and Q2 with antiparallel diodes *D*1 and *D*2, two resonant capacitors *Cr/*2, and an Induction coil. The dc input voltage is directly supplied into an inverter. Then, (Q1, *D*1), and (*Q*2, *D*2) are alternately used to administer a high-frequency current to the induction coil. In particular, two switches are operated at square wave with suitable dead time between the two driving commands.

A. Equivalent model of IH load

IH load consists of work coil and work piece. The resonant tank of the proposed inverter is a series RLC composed of the equivalent resistor *Req* and inductance *Leq* of the inductor-work piece system. The induction heating load is actually transformer representation of the electromagnetic induction between the primary work coil and secondary work piece. It is difficult practically to measure the transformer model parameters. Therefore IH load is represented using a simple model such that its parameters can be measured at any operating frequency. The equivalent model is useful for design purposes. The series equivalent model of the IH load is shown in Fig.3.L1 refers the self-inductance of the IH work coil and it is due to high frequency inverter supply current.L2 is the self-inductance of the secondary load and M is the mutual inductance of the transformer.R2 is the IH load resistance and its value depends on the operating frequency.

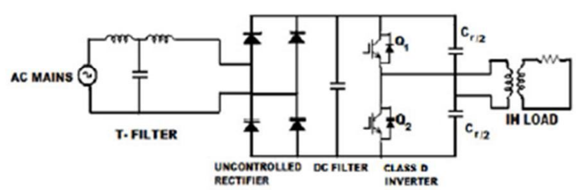

Fig.1. Block diagram of HFAC power conversion system for induction heater. Fig.2. Power circuit topology

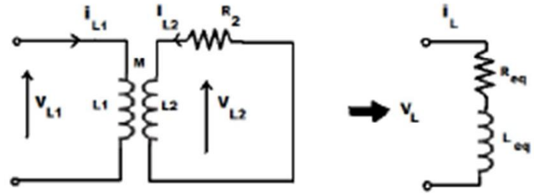

Fig.3. Equivalent circuit of Induction heating load.

The load parameters are $R_{eq} = \dfrac{\omega_S^2 M^2 R_2}{R_2^2 + \omega_S^2 L_2^2}$; $L_{eq} = L_1 - \dfrac{\omega_S^2 L_2 R_{eq}}{R_2 \omega_S^2}$

III. Control Strategy

Power regulation is the important goal to be achieved in an induction melting load to maintain the required temperature. The power input to the working coil of IH load has to be controlled to control the heating of the work piece. It is achieved by control of class D inverter using pulse width modulation (PWM) technique in this paper. In PWM the output power is controlled through PWM duty cycle (DPWM) which is the ratio between the turn on time (TON) of the power switch to the total switching period (T) as shown in Fig.4. The duty cycle DPWM is the control variable for continuous power regulation. During the requirement of high power the conduction interval of the switch TON is increased. On the other side, low power is supplied by decreasing the conduction interval. The gating pulses of the switches are interchanged in accordance with the utility supply.

IV. Results and Discussion

To verify the validity of the class-D inverter system with the proposed control scheme, a simulation and an experiment were equally performed. Schematic of the voltage fed class D resonant inverter with series load model is developed for time domain simulation using Mat lab simulation tool. The evaluations and discussions in simulation prove the validity of the proposed control of class D inverter circuit treated here. Simulation is carried out for an IH load of 3.7KW with an input voltage of 230V. The design specifications and the circuit parameters of the proposed high-frequency conversion circuit using commercial IGBT and diode modules are listed in Table I. Time domain simulation results performed with Simulink using the calculated series load parameters is discussed here. These results show the voltage, current and power through the IH system working at the switching frequency of 20 kHz, with the inverter switches applied by pulse modulated gate pulses. The simulation and experiment results of the class-D inverter using the proposed scheme are performed when the system is operated on the variation of input power. The gate signals for the switches Q1& Q2 are shown in Fig 5.a. Simulation is carried out for an IH load of 3.7KW with an input voltage of 230V. Voltage across the power switch Q1 (VQ1) and current through the switch (IQ1) are shown in Fig.5. (b) proves the soft switching operation of the proposed modulation topology. Zero voltage switching (ZVS) is taking place during turning off the switches. This soft switching operating condition in maintained at wide values of power variation with the variation in DPWM, since the switching operation takes place at the constant frequency of 20 kHz. The utility side input voltage of 50 Hz frequency and DC link voltage are shown in Fig.6. (a). Output voltage, output current of the inverter at the switching frequency of 20kHz is shown in Figure.6.(b),(c) respectively.

Table.1. Design specifications and Circuit Parameters

Quantity	Symbol	Values
Supply voltage	V	230volts
Power(load)	P	3.7kw
Switching frequency	F_s	20kHz
Equivalent inductance	L_{eq}	$29.6e^{-6}$H
Equivalent resistance	R_{eq}	2.89ohms
Resonant capacitor	C_r	$2.14e^{-6}$F

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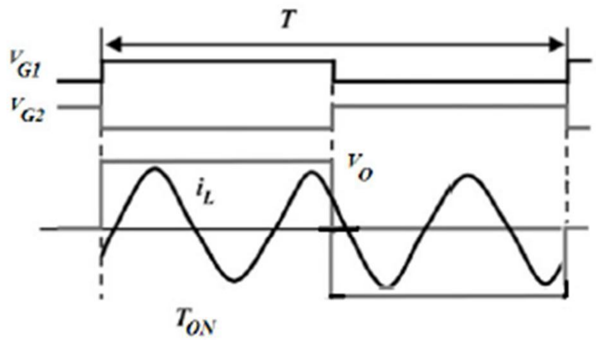
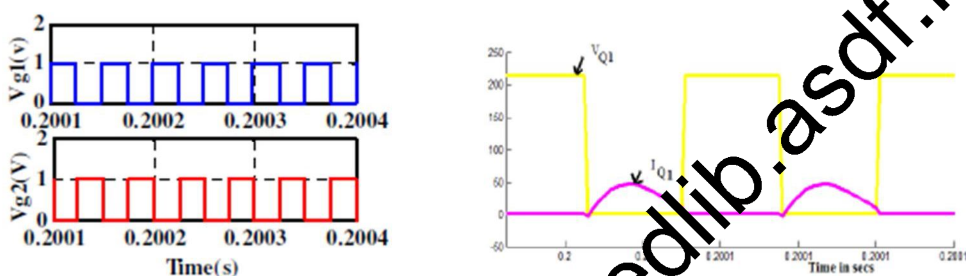


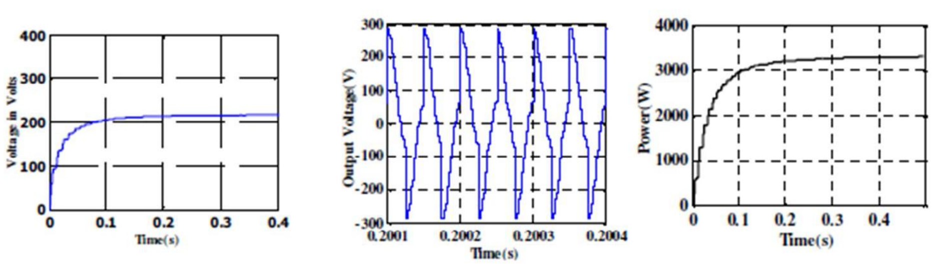
Fig.4. Theoretical waveforms



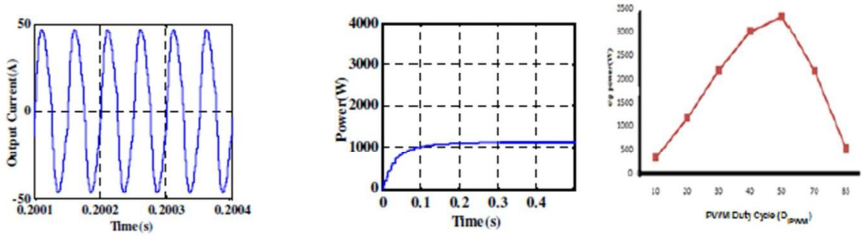
(a) (b)

Figure 5(a) Schematic diagram Open loop system used for time domain simulation. (b)Gating signals for Q1&Q2. (c)Voltage across the switch Q1 (VQ1), Current through the switch Q1(IQ1).

Fig 6(d), (e) show the output power of the inverter at duty cycle DPWM of 50% and 20% respectively. The output power POUT is the RMS power during the switching period TS. Output power variation with the variation in switching frequency is shown in Figure 6(f).Frequency variation causes more power losses during switching operation .But high output power is achieved during resonant condition at the frequency of 20 kHz. In this paper frequency is fixed, thus the variation in DPWM varies the output power smoothly and higher output power for DPWM lesser than 50%. This PWM control strategy for HFAC power converter provides a wide-range power control. The designed embedded controlled class D inverter based high frequency ac power supply has advantages like reduced hardware, high power density, improved output power due with reduction in switching losses, reduced switching stresses and low total harmonic distortion and it is successfully verified in simulation studies. Closed loop circuit model is developed for output power control and it is successfully used for simulation studies. Embedded controller based on PWM technique for class D inverter is implemented for prototype of IH load using PICS16F877. The performance of the controller is tested experimentally. Simulation and experimental results demonstrate the actual converter capability to control the output with the power disturbance. The cost of the system is also reduced by using low cost PIC16F877. The experimental results closely agree with the simulation results.

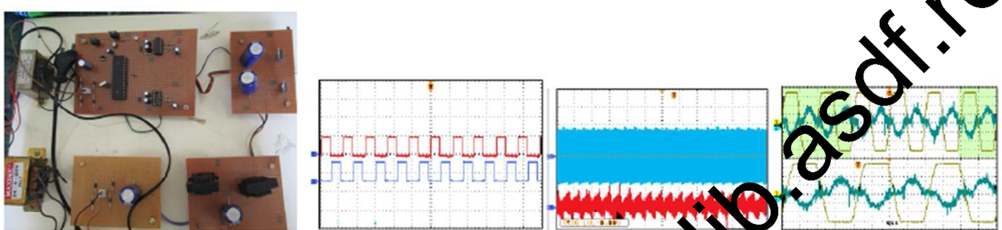


(a) (b) (c)



(d) (e) (f)

Figure 6(aDC link voltage.). (b) Inverter output voltage. (c) Inverter output current. (d) Output power at 50% DPWM. (e) Output power at 20% DPWM. (f) Output power vs. DPWM



(a) (b) (c) (d)

Fig.7. (a) Hardware layout.(b)Gate Pulses (c) Output voltage and current, Scale: X axis 1 unit=50usec/div;Y axis 1 unit=100V/div (d) Output voltage and current, Scale: X axis 1 unit=25usec/div, Y axis 1 unit=2A/div

V. Experimental Results

The single phase HFAC converter was built and tested at 230V. Hardware is implemented for a prototype model of IH load .Hardware experimental setup embedded controlled class D inverter fed IH load is shown in Fig.10 (a). Series resonant inverter has been implemented using IGBT transistors. The inverter switches are operated with 20 KHz for the output power of 100W. The control circuit has been implemented using PIC16F877 micro controller. The high frequency output voltage and current is measured using oscilloscope. The output voltage waveform is shown in Fig. 10(b) and the current waveform is shown in Fig.10.(c).

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