Hardware Implementation of MOSFET Based High Frequency Inverter for Induction Heating

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ABSTRACT: High frequency three phase inverter circuit that can output at different frequency by Power Metal Oxide Semiconductor Field Effect Transistor (MOSFET) for induction heating. The induction heating is often used for the heat-treatment of a metal work-piece. In hardening of a gear, since the bottom or tips are heated at lower frequency or higher frequency respectively. The proposed circuit cannot realize with the IGBT to output the high frequency. The circuit uses the Power MOSFET instead of the IGBT. Otherwise, the device has the disadvantages of withstand voltage and current. However, this problem can be solved by the methods of connecting switching devices to series and using step down transformer. A simplified analysis and simulation results are experimentally verified in prototype module.

Keywords— MOSFETs , HF Inverter ,SIT,

1. INTRODUCTION

High frequency induction heating applies electromagnetic induction theory to the heating of work-pieces and the distribution of the power density inside the heated work-pieces is achieved conveniently by the selection of power supply frequency and the correct design of induction coils [1]. In the past, high frequency power supplies for induction heating application above 100kHz have based on vacuum tube oscillators, which made the equipments have some defects such as low efficiency, huge volume, short lifetime and preheating before use.

With the advances of the high-power semiconductor devices technology, the research on high-power solid-state high frequency power supply has achieved great progress. High frequency power supplies with various devices, such as static induction transistors (SIT), insulated gate bipolar transistor (IGBT) and power MOSFET have been reported in the literature [2]. The IGBT offers low on resistance and requires very little gate drive power, it is widely used in generators with frequencies up to 100 kHz, but the frequency about 400 kHz is hard to achieve for the state-of -the art IGBT. The SIT has the defects like high conduction loss compared to IGBT, complicated fabrication process, high cost and price that restrict it in its applications. MOSFET has the advantages like high switching speed, easy to be paralleled, so MOSFET is used in the range of high frequencies (in the range of 100-800 kHz) and high-power applications.

2: INDUCTION HEATING PRINCIPLE

Many practical work-pieces are cylindrical in form and are heated by being placed inside multi- or single-turn coils. The magnetic field, induced in the coil when energized, causes eddy currents to occur in the work-piece and these give rise to the heating effect. Theoretical analysis and practical experience a like show that most of the heat, generated by eddy currents in the work-piece, is concentrated in a peripheral layer of thickness δ given by,

$$\delta = \sqrt{\frac{\rho}{\pi \mu f}}$$

Where p and p are the magnetic permeability and electrical resistivity of the work-piece, respectively; f is the applied frequency.

The basic concepts are similar to the well known transformer theory, but modified to a single-turn short-circuited secondary winding.

The induction heating load (heating coil and work-piece) can be modeled by means of a series combination of its equivalent resistance RL and inductance LL. These parameters depend on several variables including the shape of the heating coil, the spacing between the work-piece and coil, their electrical conductivities and magnetic permeability, and the frequency [3].

3: SERIES RESONANT INVERTER

The Class-D inverter will be generally used to energize the induction coil to generate high-frequency magnetic induction between the coil and the cooking vessel, high-frequency eddy currents and finally heat in the vessel bottom area. Class-D inverters take the energy from the mains voltage. The DC voltage is converted again into a high-frequency AC voltage by a Class-D inverter. Then the inverter supplies the high-frequency current to the induction coil.

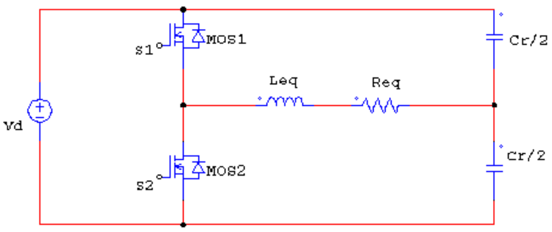

Fig. 1(a) : Inverter system

Fig. 1(a) shows a Class-D inverter system for an induction heating jar. The Class-D inverter consists of two switches S1, S2 using MOSFET, two resonant capacitors Cr/2 and an induction coil that consists of a series combination of resistance Req and inductance Leq. One of the main advantages of the half-bridge inverter is low voltage across the switch that is equal to the supply voltage. Thus, compared with other topologies (Class-E, Quasi-resonant inverter etc.) for induction heating applications, it is suited for high-voltage applications[1].Comparison between MOSFET and IGBT is described in table: I

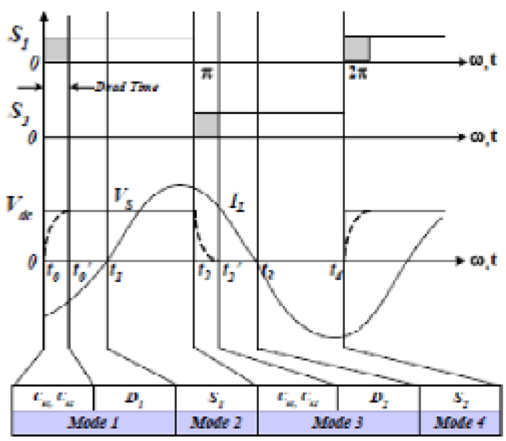

Fig. 1(b): Theoretical waveform of inverter

Fig. 1(b) described the operation mode including switching Signals and inverter output voltage Vs and current IL waveforms. As shown in Fig. 1(c), if the switches are operated above resonant frequency, the series resonant circuit represents an inductive load and the load current IL lags behind the output voltage Vs, Therefore, load current IL flows in the order of Cs1,Cs2→D1→S1→Cs1,Cs2→D2→S2. At this time, the switching losses do not occur at turn-on because the switches are turned on at zero voltage. The Class-D inverter with the PWM control scheme is explained in detail when it is applied to the IH-jar. Fig.1(b) and Fig.1(c) illustrates the steady-state theoretical waveforms and operation modes of the Class-D inverter. The steady-state analysis of the Class-D inverter is based on the following assumptions.

TABLE I
COMPARISON OF MOSFET AND IGBT

MOSFET	IGBT
MOSFET=Metal Oxide Semiconductor Field Effect Transistor	IGBT=Insulated Gate Bipolar Transistor
It is made of three terminals known as Gate, Source, Drain.	It is made of three terminals known as Emitter ,Collector ,Gate.
MOSFET are better at low voltages and higher frequency.	IGBT are better at high voltages and lower frequency.
Compared to IGBTs ,MOSFET switch faster.	Compared to MOSFET, IGBT switch Slower.
MOSFETs are preferred for Long duty cycles, Low-voltage ,Wide line or load variations, Higher frequency.	IGBT s are preferred for Low duty cycle, High-voltage ,Small line or load variations, Lower frequency.
MOSFET application include: Induction heating, SMPS(>200KHz),Battery charging	IGBT application include: Motor Control(<20KHz),UPS ,Low power lighting.

- All components are ideal.
- Input voltage of the DC link is constant in one switching cycle.

- Effects of the parasitic capacitances of the switch are neglected.
- Load current is nearly sinusoidal because the large load quality factor (Q) is high enough.

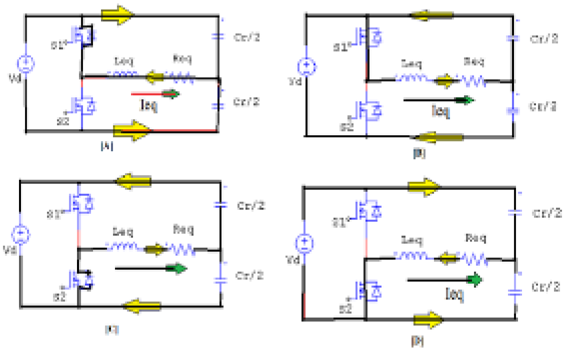

Fig 1(c): Operation modes of inverter

Mode Operation of Inverter: As shown in Fig.1(c), four operation modes exist within one switching cycle.

A) Mode 1 (t0-t1), When S2 is turned off at t = t0, antiparallel diodeD1 of S1 is conducted by negative load current ILeq. Then, the ZVS condition of S1 is obtained.

B) Mode 2 (t1-t2), At t = t1, as soon as antiparallel diode D1 of S1 is turned off, S2 is conducted and ZVS is achieved. During this mode, positive load current ILeq flows.

C) Mode 3 (t2-t3), At t = t2, S1 is turned off, similar to that in Mode 1, and antiparallel diode D2 of S2 is conducted. During this mode, the ZVS condition of S2 is obtained.

D) Mode 4 (t3-t0), At t = t3, when antiparallel diode D2 of S2 is turned off, S2 is conducted! and ZVS is achieved. During this mode, negative load current ILeq flows. Therefore, the one-cycle operation of the class-D inverter is finished, and then, the class-D inverter continues to repeat from Modes 1 to 4.

4: BASIC BLOCK DIAGRAM

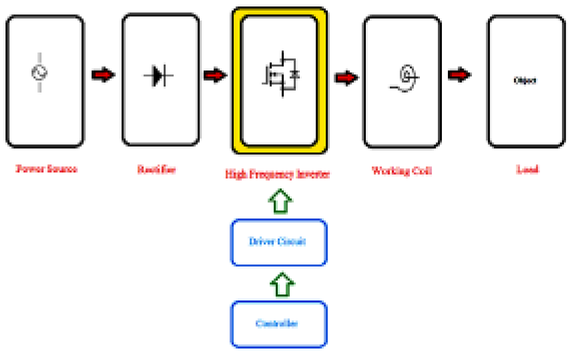

Fig. 2: Basic block diagram of inverter

The concept of induction heating employed in the application of an IH rice cooker. This concept can be simplified as follows. First, convert the AC current coming from the power source to DC using a rectifier. Then, connect this DC current to a high frequency switching circuit to administer high frequency current to the heating coil. According to Ampere's Law, a high frequency magnetic field is created around the heated coil. If a conductive object, e.g. the container of a rice cooker is put inside the magnetic field, then induced voltage and an eddy current are created on the skin depth of the container as a result of the skin effect and Faraday's Law. This generates heat energy on the surface of the container. Rice is cooked by using this heat energy.

5: CONTROL CIRCUIT

By executing powerful instruction in a single clock cycle, the ATmega16 achieves throughputs approaching 1MIPS per MHz allowing the system designer to optimized power consumption versus processing speed .Using this controller properly PWM pulses generated. This controller 8 bit timer/counters with separate prescalers and compares modes.

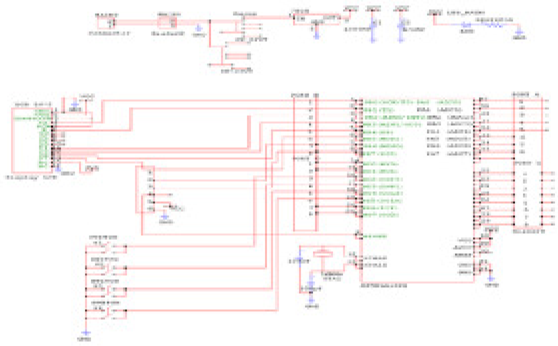

Fig.3 (a): Circuit diagram of control card

Using ATmega16 microcontroller PWM pulses are generated which logic is mention in Fig.3(b).

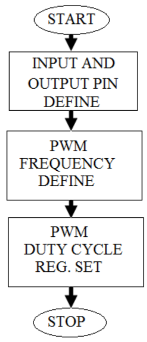

Fig. 3(b): Flow chart of PWM logic

6: SIMULATION RESULTS

Half bridge Inverter system is simulated in PSIM 6.0 and the satisfactory results are presented in open loop.

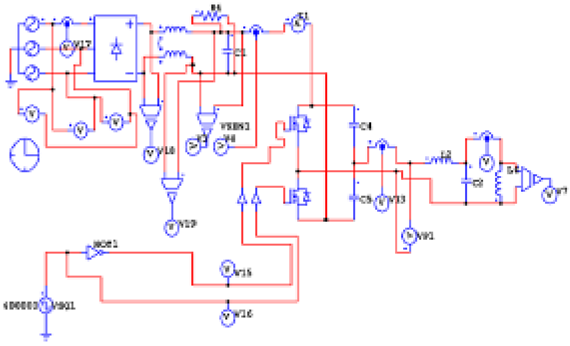

Fig.4(a): Schematic diagram of HF inverter

Schematic diagram is shown in Fig.4(a) PWM pulses are shown in Fig:4(b) Scope is connected to measure switch voltages and load voltage. Output load current is shown in Fig:4(c) .Open loop system is completely worked on high frequency , Output voltage waveform is shown in Fig.4(d).

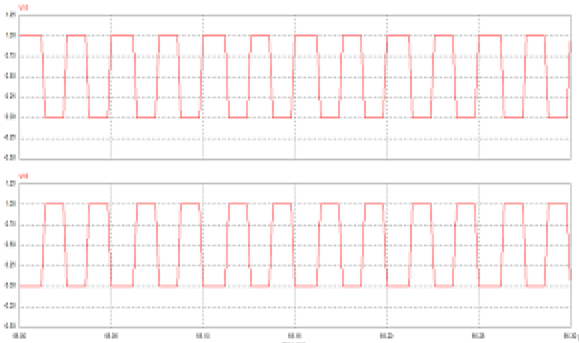

Fig 4(b): Gating pulse of M1 and M2

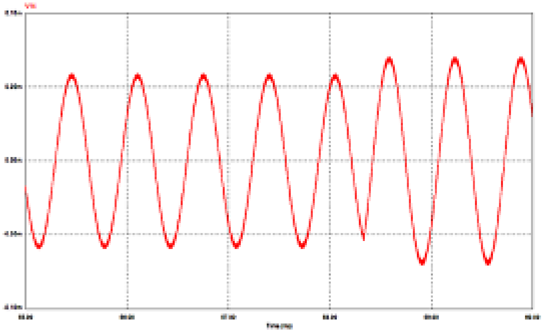

Fig4(c): Output waveform of load current

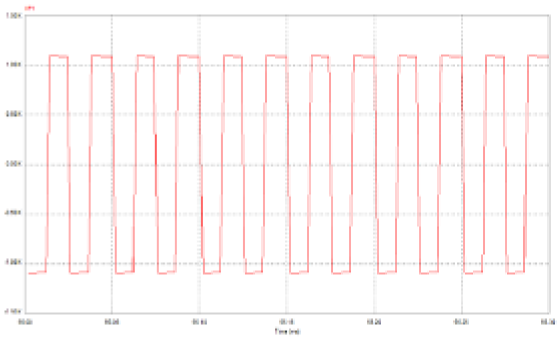

Fig 4(d): Output voltage waveform

7: EXPERIMENTAL RESULTS

In this prototype, three phase uncontrolled rectifier is used. As a switching, MOSFET SPW47nC3 is used. For the filter circuit capacitor is used. Completely prototype is tested on 150Vdc, 200Vdc,according to that satisfactory results are discuss as below. Driver IC TC4422 is used for the MOSFET firing and driver IC controlled circuit and power circuit are electrically isolated. In our prototype module output of controlled circuit is 5V, driver circuit operates on 15V dc .so magnitude of PWM pulse is increased. Experimental and hardware result are mentioned in Fig.5(a).Completely prototype setup is shown in Fig.5(b). Load current waveform is shown in Fig.5(c).As per early discussion, H-bridge inverter worked on ATmega16 controller, So that this prototype tested on sequential frequency from lower to higher. At 40KHz switching frequency H-bridge inverter worked satisfactory on Induction Heating principle and output waveform of voltage shown in Fig.5(d).

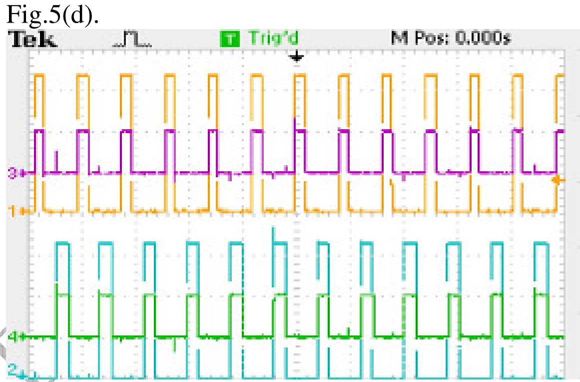

Fig. 3(a): Input-output waveform of control and driver Circuit

Fig 5(b): Hardware prototype

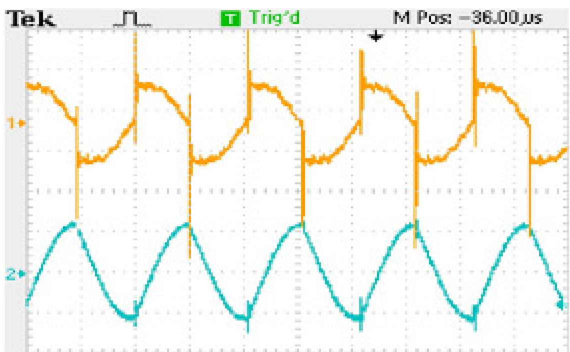

Fig 5(c): Load current Waveform

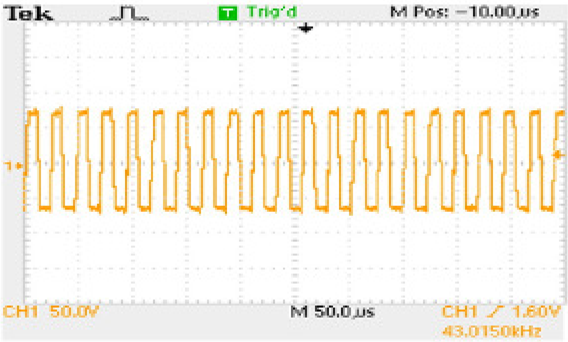

Fig 5(d): Inverter output voltage waveform

8: CONCLUSION

In this paper, an effective control scheme incorporated in the voltage-fed half-bridge series resonant inverter for induction heating applications has been proposed. Besides, the operation principle of the inverter system with the proposed control scheme has been demonstrated and its performance characteristics in the steady-state have been verified by the simulation and experimental results for a prototype induction heating system. The main advantages of this inverter system are characterized as follows; The reduction in size and weight,Wide power regulation range.

9:REFRENCES

[1] Arbab Waleed Ahmad. College of E&ME NUST, Fanrukh Kamran CARE (Pvt) Ltd. "TANDEM-H Bridge" A New Approach towards Low Switching Loss at High Switching Frequencies, International Conference on Emerging Technologies IEEE 2005.

[2] S. Zinn, S. L. Sem "Elements of Induction Heating: Design Control and Applications" ASM International 25-73 pages.

[3] M.H.Rashid "Power Electronics Circuits, Devices and Application" 3rd edition, Printice Hall of India, chapter 14, pp 601-637.

[4] Mokhtar Kamli, Member, ZEEE, Shigehiro Yamamoto, and Minoru Abe "A 50-150 kHz Half-Bridge Inverter for Induction Heating Applications" IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 43, NO. 1 PP163-173, FEBRUARY 1996.

[5] Robert W.Erickson "Power converters" An article in Wiley Encyclopedia of Electrical and Electronics Engineering.

[6] Valery I Rudnev, D "Handbook of Induction Heating" Publisher: CRC l pp 100-160 l 2002.