

COMPARISON OF SIMULATION AND EXPERIMENTAL RESULTS OF CLASS - D INVERTER FED INDUCTION HEATER

Suresh A.¹, Dr. Rama Reddy S.²

¹Research Scholar, Sathyabama University, Chennai, INDIA

²Jerusalem College of Engg, Chennai, INDIA.

Email: ¹asuresz@yahoo.com, ²sreddy@vit.in

Abstract

This paper deals with simulation and experimentation of closed loop controlled class-D inverter fed induction heater system. This converter has reduced switching losses, stress and increased power density. The inverter system is designed and the simulation is done using Matlab. The results of simulation and experimentation are presented.

Keywords: Class-D inverter, induction heating (IH), closed loop control, zero voltage switching

I. INTRODUCTION

Induction heating is a well-known technique to produce very high temperature such as in steel melting, brazing and surface hardening. In this paper, a class *D* inverter is used to control the fluctuation in the input and prevent it from affecting the working of heater. A large number of topologies have been developed in this area. Current-source and voltage-source inverters are among the most commonly used types. The advantages of this inverter are high switching speed, short-circuiting protection capability, superior no-load performance because of its current-limiting *DC* link characteristic and low component count compared to a voltage-fed inverter topology. Common topologies of class *D* inverter in induction heating applications are full-bridge and half-bridge inverter in low power application such as cooking and small forging systems. The half-bridge inverter is preferable due to less number of switches required. However the half-bridge inverter suffers losses at the two high frequency inductors and a risk of saturation on both inductors. The controller of class *D* inverter needs to maintain the operating frequency at little higher than the resonant frequency for *IH* system.

The requirements for the *IH* system are given as follows:

1. High-frequency switching
2. High power factor
3. Wide load range
4. High efficiency
5. Low cost
6. Reliability

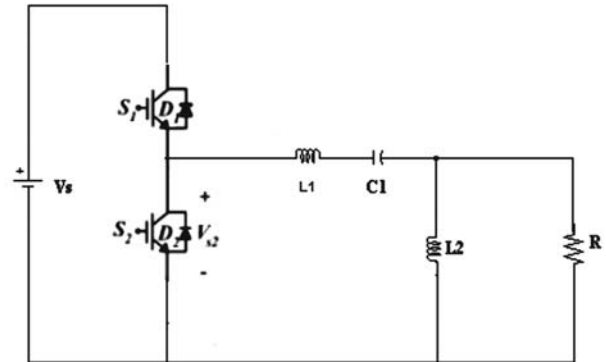


Fig. 1 Class D inverter system for IH

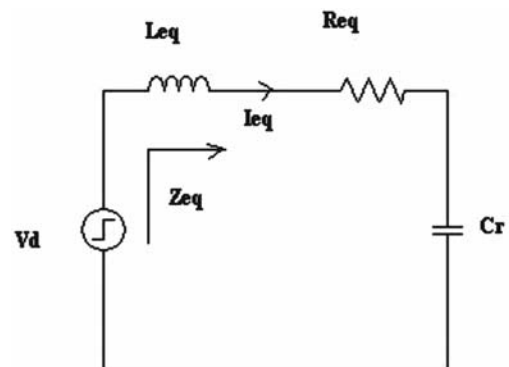


Fig. 2 Equivalent Circuit

A high-frequency class-D inverter has become very popular and is more and more widely used in various applications. It must be effectively selected under a high-frequency switching operation due to load specifications. In addition, one of the main advantages of the class-D inverter is low voltage across the switch, which is equal to the supply voltage. Thus, compared with other topologies (class-E quasi-resonant inverter, etc) for *IH* applications, the class-D inverter is suited

for high-voltage application [1]. Generally, almost all IH applications use a variable-frequency scheme, pulse-frequency-modulation (PFM), and pulse-amplitude modulation (PAM) to control the output power [5], [6]. Between them, frequency-modulation control is the basic method that is applied against the variation of load or line frequency. However, frequency-modulation control causes many problems since the switching frequency has to be varied over a wide range to accommodate the worst combinations of load and line. Additionally, in case of operation below resonance, filter components are large because they have to be designed for the low- frequency range. In addition, it is apt to audible noise when two or more inverters are operated at the same time with different switching frequencies. Besides, the soft- switching operating area of the zero voltage switching (ZVS)-PFM high-frequency inverter is relatively narrow under a PFM strategy. Keeping the constant switching frequency and controlling the output power by pulse width modulation (PWM) are obvious ways to solve the problems of variable- frequency control. Therefore, class-D-inverter topologies using a PWM chopper at the input, phase-shifted PWM control, PWM technique, pulse width modulation- frequency modulation (PWM-FM) technique, current-mode control, and a variable resonant inductor or capacitor have been proposed [7]-[10]. The constant-switching- frequency operation supposes that each inverter in the applications is operating at the same frequency, making it necessary to control power without frequency variations, and this is highly desired for the optimum design of the output smoothing and noise filters. However, these control requirements and operating characteristics have considerable complexity due to the fixed switching frequency, which limits their performance. In addition, if the system is operated with phase-shifted PWM control, the ZVS is not achieved at light load. To simplify output-power control, a full-bridge zero-current switching (ZCS)-pulse-density modulation (PDM) class-D inverter is proposed. The output power of the ZCS-PDM class-D inverter can be controlled by adjusting the pulse density of the square-wave voltage. When the class-D inverter operates at a fixed switching frequency that is higher than its resonant frequency, it can maintain ZVS operation in the whole load range. Thus, the switching losses and electromagnetic interference (EMI) are decreased. In addition, by adjusting the duty cycle of fixed low frequency, the

output power is simply controlled in a wide load and line range. The advantages of a new power-control scheme are simple configuration and wide power-regulation range. It is easy to control the output power for wide load variation. In addition, the switches always guarantee ZVS from light to full loads, and a filter is easy to design by using the constant switching frequency. The power-control scheme and principles of the class-D inverter are explained in detail. The above literature does not deal with simulation of closed loop controlled class D inverter. This paper presents simulation of closed loop class D inverter fed Induction Heater.

The steady-state analysis of the class-D inverter is based on the following assumptions.

1. All components are ideal.
2. The DC input voltage is constant in one switching cycle.
3. The effects of the parasitic capacitances of the switch are neglected.
4. The load current is nearly sinusoidal because loaded quality factor Q_L is high enough.

The currents in positive and negative half cycles are as follows:

$$i_1 = (V_s + V_c/\omega_r) e^{-at} \sin \omega_r t$$

$$i_2 = (V_c/\omega_r) e^{-at} \sin \omega_r t$$

II. SIMULATION RESULTS

For induction heating class D inverter is used. This inverter converts DC input power into AC output power. This conversion is achieved by turning on and off alternately switches 1 and 2.

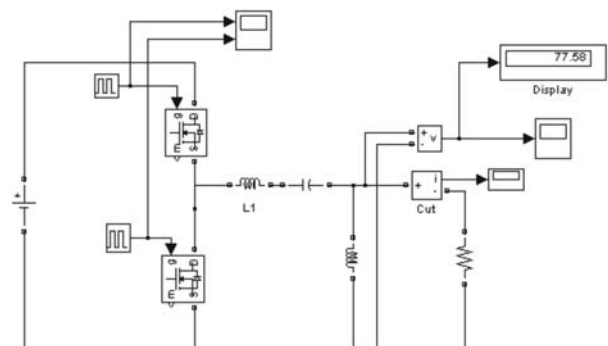


Fig. 3a Circuit Diagram

The voltage across the load is measured with the help of voltage measurement block and the output current is measured with the help of current measurement block and they are observed using a scope. Driving pulses given to the MOSFET are shown in Fig 3b. Output voltage and current are shown in Fig 3c. Both are sinusoidal due to the presence of L and C . The variation of output with the variation in the input is shown in Fig 3d.

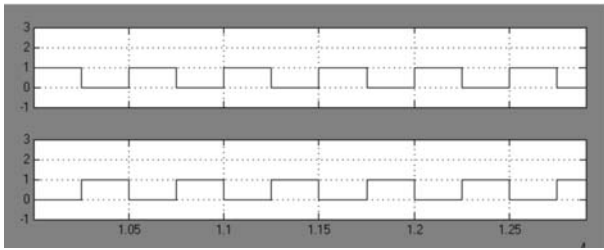


Fig. 3b Driving pulses

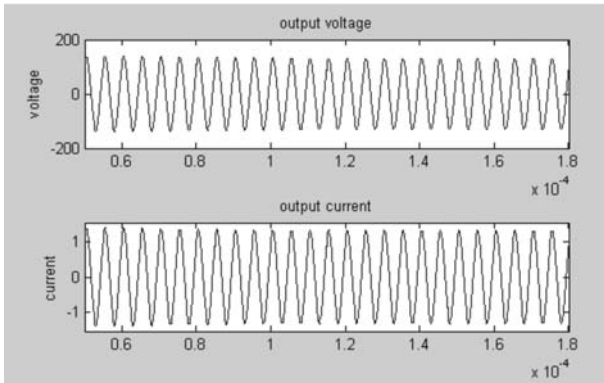


Fig. 3c Output voltage and current

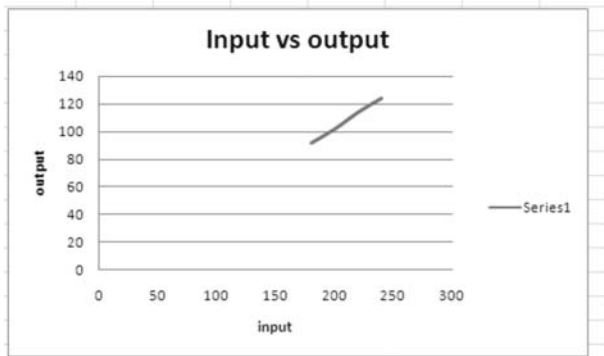


Fig. 3d Variation of Output

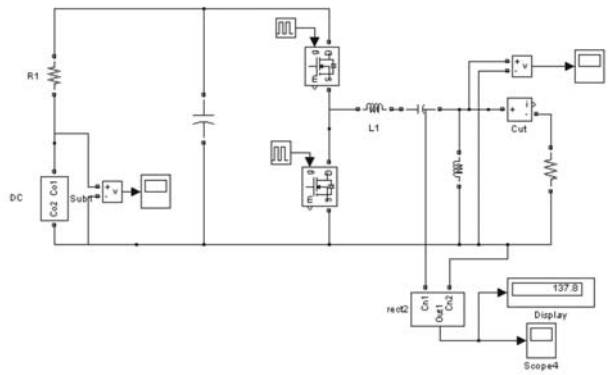


Fig. 4a Circuit Diagram of open loop system

The circuit of open loop system is shown in Fig4a. The rectifier output voltage increases due to the step rise in input. The output voltage of the inverter is measured with the help of voltmeter and it is observed using a scope. Similarly the current through the load is measured with the help of ammeter and it is observed using a scope. Input voltage and output voltage with a disturbance are shown in Figs 4b and 4c respectively. The voltage across the rectifier is shown in Fig. 4d.

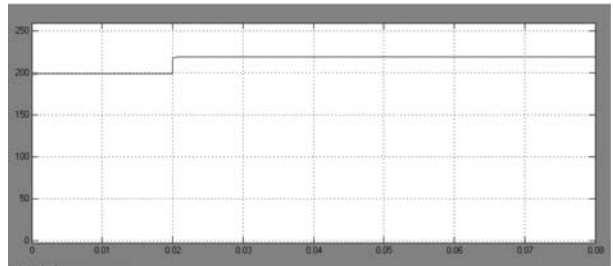


Fig. 4b Input voltage with disturbance

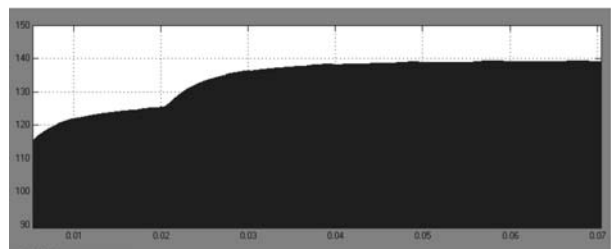


Fig. 4c Output voltage with disturbance

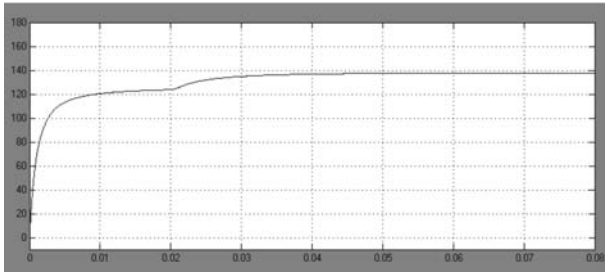


Fig. 4d Rectifier Output voltage

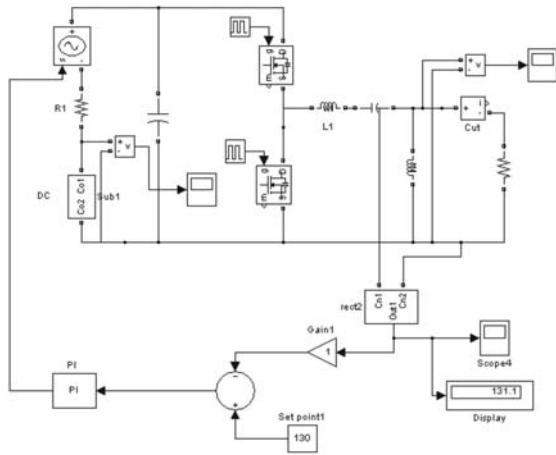


Fig. 5 Circuit Diagram of closed loop system

In open loop system the rectifier output voltage increases and it is undesirable. This is prevented by using closed loop system.

In closed loop system, output voltage is given to the rectifier and output of rectifier is given as input to the comparator. The comparator output is given to PI controller. The output of PI controller controls two pulses given to the two switches. In closed loop system the rectifier output voltage reaches steady state value. Output voltage of closed loop system is shown in Fig5c.

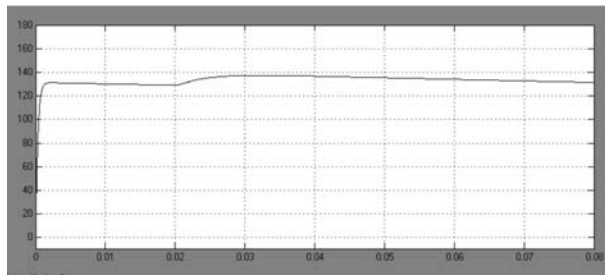


Fig. 5b Rectifier output voltage

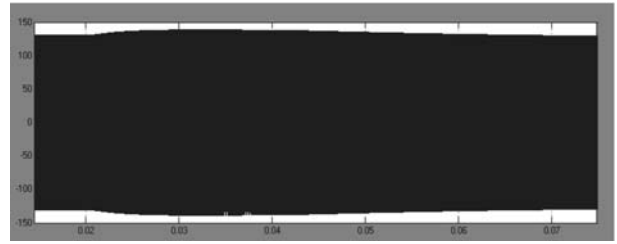


Fig. 5c Output voltage

III. EXPERIMENTAL RESULTS

The hardware is fabricated and tested in the laboratory. Top view of the hardware is shown in Fig6a. The DC input voltage is shown in Fig6b. Driving pulses given to the MOSFET are shown in Fig6c. The output of the class D inverter is shown in Fig6d. The control circuit used for generating the pulses are shown in Fig6e. The microcontroller 89C2051 generates the pulses. The pulses are amplified using the driver IC 2110.

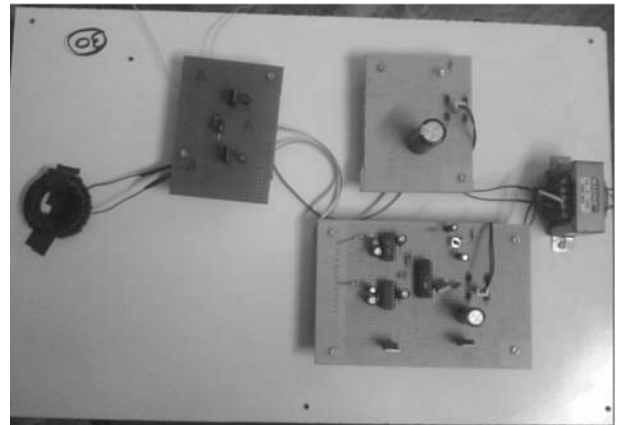


Fig. 6a. Hardware Circuit

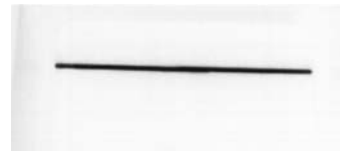


Fig. 6b. DC Input Voltage

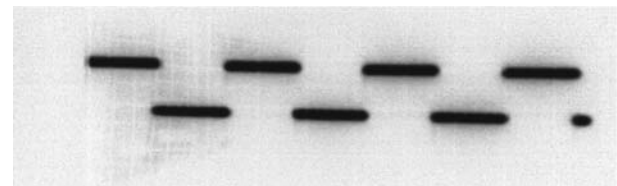


Fig. 6c. Driving Pulses

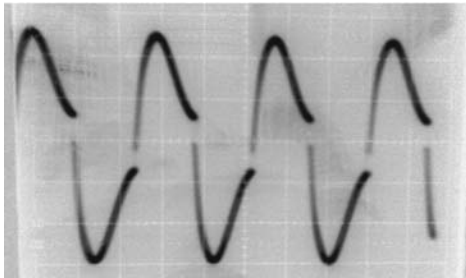


Fig. 6d. Output of class D inverter

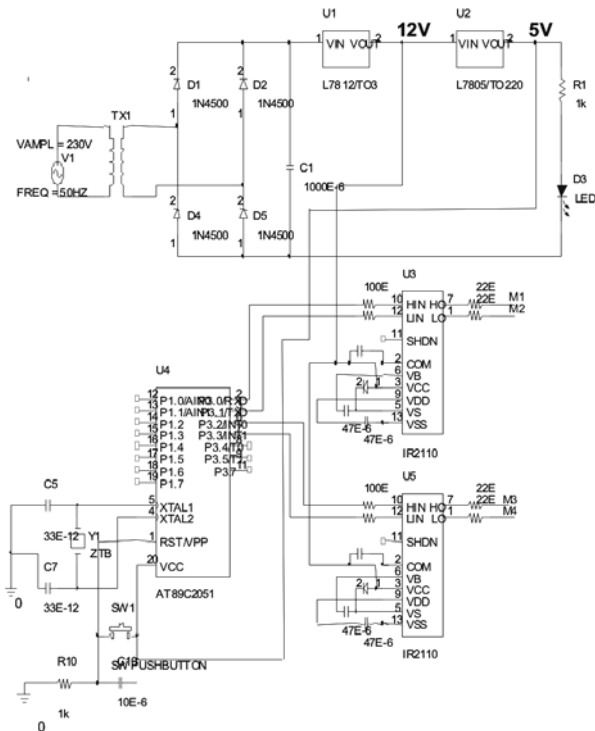


Fig. 6e. Control Circuit

IV. CONCLUSION

The class D inverter fed induction heater system is simulated and implemented. This system operates at high efficiency due to soft switching. The simulation and experimental results are presented. It is observed that the experimental results are similar to the simulation results.

REFERENCES

[1] Apisak polsprim, Saicol chudjarjeen, Anawach Sangswang, Piyasawat Navaratana Na Ayudhya and Chayant Koumpai , PEDS2009 "A soft switching class -D current source inverter for induction heating with ferromagnetic load".

[2] Kirubakaran Dhandapani,Ramareddy sathi,2009 "Improved modification of the closed loop controlled

ac-ac resonant converter for induction heating," ETRI journal, vol31, no 3.

[3] Nam-Ju Park, Dong-Yun Lee and Dong-Seok Hyan, June 2007 "A power control scheme with constant switching frequency in class- D inverter for induction heating jar application,"IEEE Tran.Ind Appl,vol54,no 3 pp1252-1260.

[4] Jung D.Y. and Park J.Y, "Electronic ballast with constant power output controller for 250W MH lamp ,2006 "J. Electr. Engg. Technol.Vol 1, no3,pp 332-327

[5] Matysik J.T."A new method of integration control with instantaneous current monitoring for class D series resonant converter, Oct, 2006." IEEE Tran.Ind Appl, vol53, no 5 pp1564-1576.

[6] Sugimura H., Muraoka, Ahmed T., Chandhaket S., Horaki E., Nakanoda M. and Lee H.W., Jul 2004 " Dual mode phase shifted ZVS-PWM series load resonant high frequency inverter for induction heating super heated steamer", J.Power Electron, vol 4, no 3, pp 138-151.

[7] Bayindir N.S., Kukrer O. and Yakup M., May 2003 "DSP based PLL controlled 50-100 khz 20 kw High Frequency Induction System for surface Hardening and Welding Applications,"IEEE proc-Electr. Power Appl., Vol 150 no.3, pp 365-371.

[8] Kifune H., Hatanaka Y. and Nakaoka M., Jan 2004, "Cost Effective Phase Shifted Pulse Modulation Soft Switching High Frequency Inverter for Induction Heating Applications", IEEE proc-Electr.Power Appl.,Vol 151 no.1,pp 19-25.

[9] Saha B. et al, Sep 2007 "Selective Dual Duty Cycle Controlled High Frequency Inverter Using a Resonant Capacitor in Parallel with an Auxiliary Reverse Blocking Switch,"J.Power Electron, vol 7, no.2, pp 118-123.

[10] Singh B. et al, Oct 2003 "A Review of single phase Improved Power Quality AC-DC Converter," IEEE Trans-Ind. Electron,Vol 51 no.3,pp 962-981.

[11] Tebb D.W."An induction heating power supply using high voltage, "in Proc.PIC,pp 236-244.

[12] Tudbury C.A., 1960, " Basics of Induction Heating" Newyork: Rider.

[13] Koertzen H.W., VanWyk J.D., and Ferreria A., "Design of the half bridge series resonant converter for induction cooking, 1995"inProc.IEEE Power Electron Spec. Conf., pp729-735.

[14] Kazimierczuk M.K., Nanda kumar T., Wang, Jan.1992 "Analysis of series-parallel resonant converter,"IEEETrans. Aerosp. Electron. Syst. vol29, no1, pp88-97.

[15] Izaki K., Hirota Y., Yamashita H., Kamli M., Omori H., and Nakaoka M., 1995 "New constant-frequency

variable powered quasi-resonant inverter topology using soft switched type IGBTs for induction-heated cooking appliance with active power filter,” in Proc. Eur. Power Electron.Conf,pp.129-134.



A. Suresh is a research scholar at sathyabama university, Chennai. His area of interest is Induction Heating. He has a decade of teaching experience in engineering college. He is a life member of ISTE.



Dr.S.Rama Reddy has obtained his ME degree from Anna University, Tamil Nadu, India, in 1989. He has pursued research in the area of resonant converters in 1995. He has 2 years of industrial experience and 18 years of teaching experience. He is a life member of IE, IETE, ISTE, SSI, and SPE. He has authored text books on Power Electronics and Electronic Circuits. He has published 20 papers in the area of Power Electronics and FACTS.