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Abstract

A single-switch parallel resonant converter for induction heating is simulated and implemented. The circuit consists of input LC-filter, bridge rectifier and one controlled power switch. The switch operates in soft commutation mode and serves as a high frequency generator. Output power is controlled via switching frequency. Steady state analysis of the converter operation is presented.. A closed loop circuit model for AC to AC converted induction heating system is also proposed. Experimental results are compared with simulation results.

Introduction

Static frequency converters have been extensively applied in industry as a medium –frequency power supply for induction heating and melting installations. They are applied in all branches of the military, machine-building industries, jewellery, smithy heating, domestic heating cooking devices and other purposes.

The ordinary circuit of an AC-AC converter for induction heating typically includes a controlled rectifier and a frequency controlled current source or a voltage source inverter. It is a well known fact that the input rectifier does not ensure a sine wave input current, and is characterized by a low power [1-3]. Recently many studies of high power factor rectifiers with a single switch have been made [4-5]. These schemes are also characterized by a close to sine wave input current. In addition, in [6] the scheme of the AC-AC converter for induction heating is described. The input circuit of the converter is constructed similarly to the input circuit in [4, 5], which also ensures a high power factor. However the inverting circuit is constructed by traditional mode with four controlled switches. The above literature does not deal with closed loop modeling and embedded implementation of AC to AC converter fed induction heater. In the present work AC to AC converter is modeled and it is implemented using an atmel microcontroller. The present problem aims to minimize the cost of induction heater system by using an embedded controller.

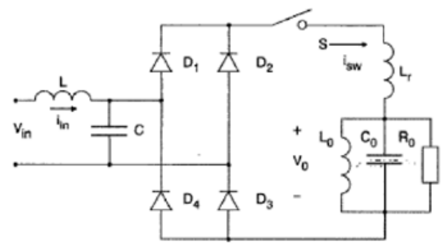

Fig.1 Circuit Diagram

In the scheme (Fig.1) of the AC-AC converter there are two main advantages: It is characterized by a high power factor and a sine wave input current. On the other hand the inverter circuit is constructed with a single controlled switch, which serves as a high-frequency generator for induction heating.

Principle Of Operation

The operating principles of the circuit are illustrated by Fig.2 and the theoretical waveforms

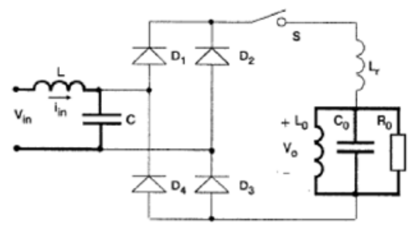

Fig.2a. Mode 1 (t_o-t_1)

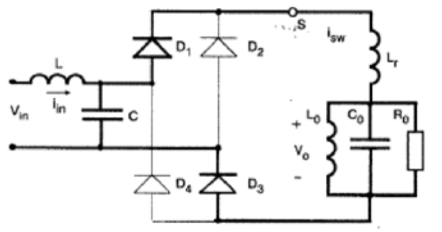

Fig.2b. Mode 1I (t_1-t_2)

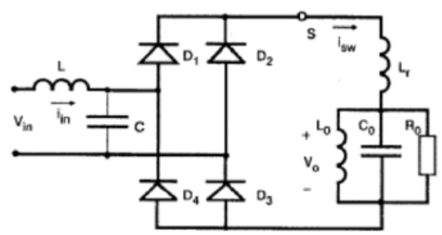

Fig.2c. Mode 1II (t_2-t_3)

Fig.2 Equivalent Circuits

are shown in Fig.3.We suppose the switching frequency is much higher than the input line frequency and in the analysis we arbitrarily chose the time interval where $v_{in}>0$

Interval 1: $t_0<t<t_1$
The equivalent circuit is shown in Fig.2a. Four diodes D_1-D_4 and the switch S are off. In this interval the capacitor C charges up practically linearly at a rate and a polarity corresponding to the instantaneous input voltage v_{in}.

Interval 2: $t_1<t<t_2$
The equivalent circuit is shown in Fig.2b. Two diodes D_1, D3 and the switch S are on. In this interval the capacitor C is discharging via the circuit C-D_1-S-L_r-load-D_3. This interval ends when the capacitor voltage reduces to zero.

Interval 3: $t_2<t<t_3$
The equivalent circuit is shown in Fig.2c. All the diodes and the switch S are on. In this interval the current through switch S flows via two parallel bridge branches. This interval ends when this switch current decreases to zero. At this moment the switch turns off and the process starts from the beginning.

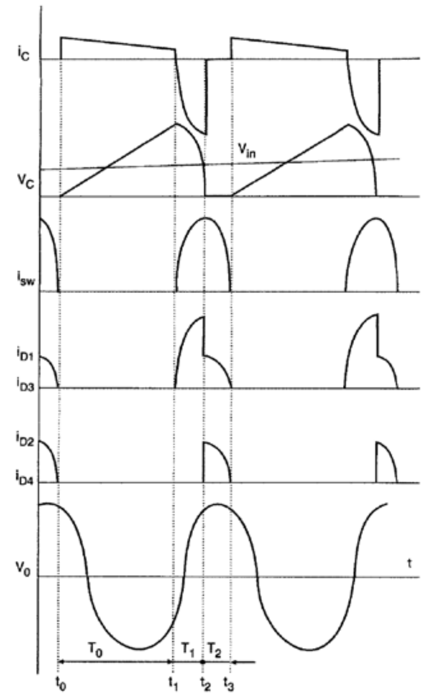

Fig.3 Ideal Switching Waveforms

Operation Analysis

Analysis of the circuit operation is based on the commonly accepted assumption that all circuit components are ideal. The approximate analytical calculations are based on two additional assumptions: the switch current can be approximated by a semi sinusoidal, and the load power is determined by the first harmonic of the load voltage. In this converter optimal range of normalized parameters was chosen. Maximum normalized value of switch voltage ($v^*_{swmax} = v_{swmax} / v_B = 4 - 5$). To provide these values it is necessary to choose the following ranges of the normalized circuit parameters:

$$L_1^* = \frac{L_r}{L_0} = 0.1 - 0.2;\quad \omega_r^* = \frac{1/\sqrt{L_r C}}{\omega_B} = \qquad (1)$$

$$3 - 5;\ \omega_s^* = 1.1 - 1.9$$

Evaluation of the relationship between input and output voltages $M_g = V_o/V_{in}$

$$A_1 = \frac{I_{sw.\max}}{i_{in}} = \frac{\pi}{D}\cdot\frac{(1-D+D_1)}{1-\cos(\pi\frac{D_1}{D})} \qquad (2)$$

$$A_2 = \frac{I_{sw1.\max}}{I_{sw.\max}} = \frac{2D}{\pi(1-4D^4)}.\cos(2\pi D) \qquad (3)$$

$$A_3 = \frac{I_{R1.\max}}{I_{sw.1.\max}} = \frac{1}{\sqrt{1+R_0^{*2}(\omega_s^* - 1/\omega_s^*)^2}} \qquad (4)$$

$$M_g = \frac{V_{o.r.m.s}}{V_{in.r.m.s}} = \frac{\sqrt{2}}{A_1.A_2.A_3} = \sqrt{2}\,\frac{\sqrt{1+R_o^{*2}(\omega_s^* - \frac{1}{\omega_s^*})^2}\,(1-\cos(\frac{\pi D_1}{D}))}{1.1\pi(1-D+D_1)} \qquad (5)$$

This relationship is represented in Fig. 3.a The values of duty cycles D1 and D may be calculated from the plot Fig.3.b.

Fig. 3.a Factor $M_g = V_o/V_{in}$ against parameters R_o^* & ω_s^*

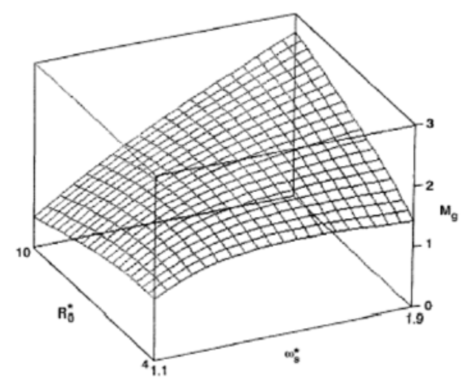

Fig.3.b Duty cycle against parameters L_r^*, ω_s^*

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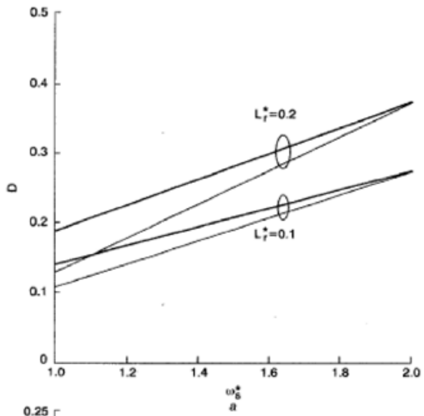

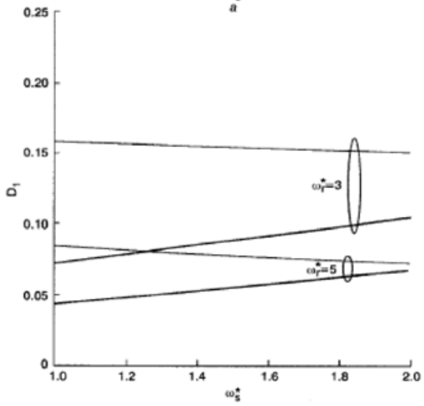

The values of duty cycles D_1 and D may also be found from the approximate polynomial expressions

$$D_1 \approx (325.8 - 36.7\omega_r^* - 33.4\omega_s^* - 25.4R_0^* + 2.2\omega_r^* R_0^* + 7.4R_o^*\omega_s^*)10^{-3} \tag{6}$$

$$D \approx (-88.3 - 445.5L_r^* - 15.5\omega_s^* + 175.1\omega_s^* + 19.3R_0^* + 725L_r^*\omega_s^* - 10.3R_0^*\omega_s^*)10^{-3}$$

Simulation Results

The AC to AC converter fed induction heater is simulated using matlab simulink and their results are presented here. The circuit model of AC-AC converter is shown in Fig.4a.. Scopes are connected to measure output voltage, driving pulses and capacitor voltage.

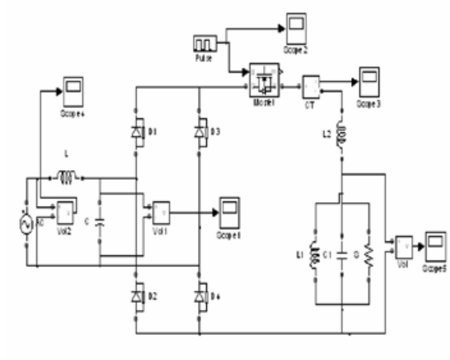

Fig.4a. open loop Circuit

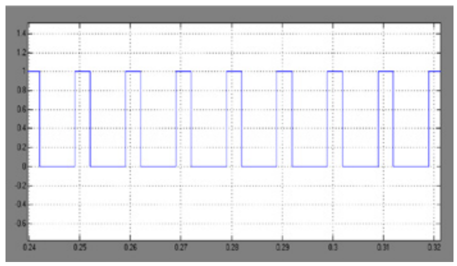

Fig.4b. Driving pulses

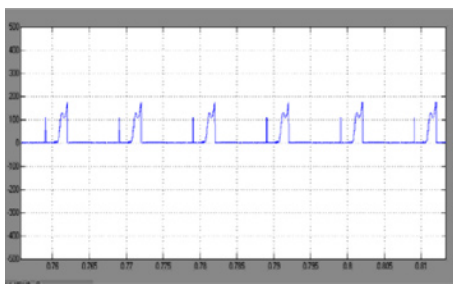

Fig.4c. Voltage across S_1 (V_{ds})

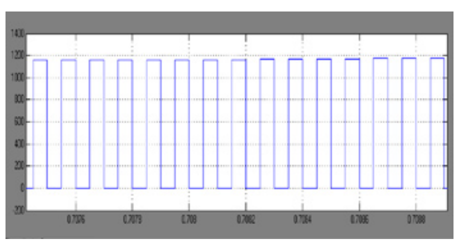

Fig.4d. Current through S_1

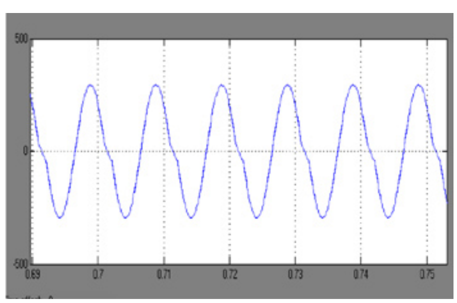

Fig.4e. AC Output Voltage

Switching pulses are shown in Fig 4b.Voltage and current waveforms of the switch are shown in Fig.4c & Fig 4d respectively. High frequency AC output of converter is shown in Fig. 4e.

The closed loop circuit model of AC-AC converter is shown in Fig.4_f. Scopes and displays are connected to measure the output voltage.

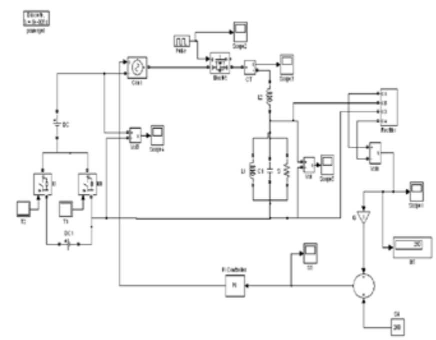

Fig.4f. Closed loop controlled AC-AC Converter

A disturbance is given at the input by using two switches. Output voltage is sensed and it is compared with the reference voltage. The error signal is given to the controller. The output of PI controller controls the dependent source. Response of open loop system is shown in fig 4g.

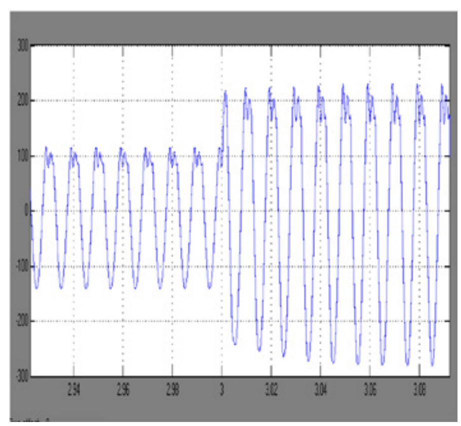

Fig 4g. Output voltage of open loop system

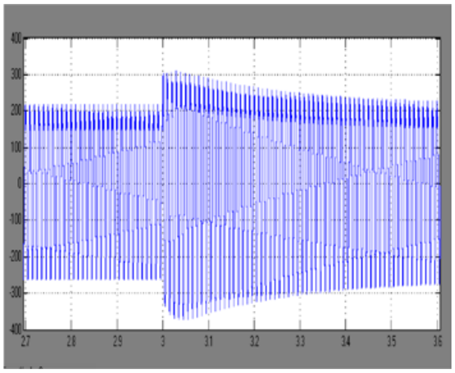

Fig 4h. Output voltage of closed loop system

The output voltage of closed loop system is shown in Fig 4h. The disturbance is applied at 3.0 secs. The control circuit takes proper action to reduce the amplitude to the set value and settles after 0.5 secs. Thus the closed loop system reduces the steady state error.

Experimental Verification

The single-switch AC-AC converter was built and tested at 230V. Experimental setup of AC to AC converter is shown in Fig. 5.

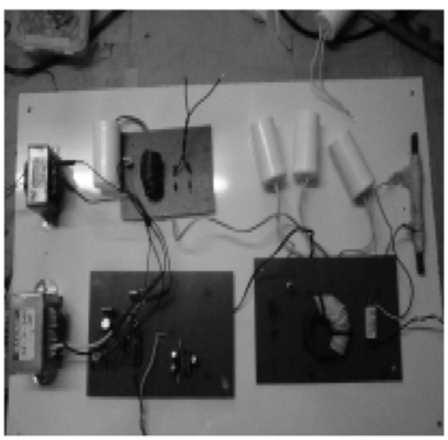

Fig. 5. Hardware layout

The circuit parameters are R_0=60Ω; L_0=150μH; C_0=2.35μF; L_r=22μH; L_i=8.0mH; C_{in}=0.94μF and the switching frequency ω_S= (62-113) x10^3 s^{-1}. The experimental waveform of output voltage is shown in Fig.6.

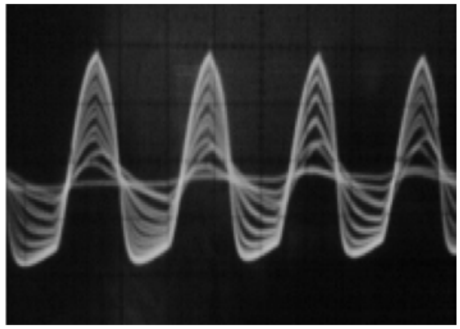

Fig.6 Oscillogram of output voltage

The output power control was also checked and its dependency by switching frequency is shown in Fig.7. The output power increases with the increase in switching frequency.

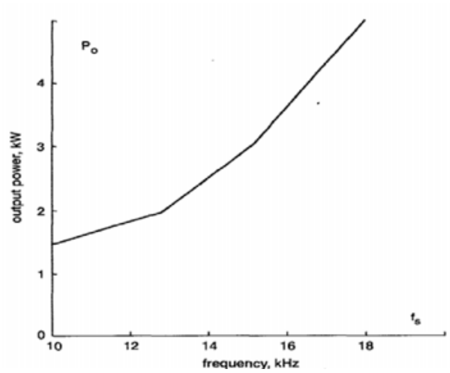

Fig.7 Output power v/s switching frequency

Conclusion

An AC-AC converter circuit for induction heating has been simulated and tested. The converter input current is practically sinusoidal and its power factor is close to unity. The circuit topology is very simple since includes only one power switch. This switch operates in a soft commutation mode. The converter provides a wide-range power control. This converter has advantages like reduced hardware, reduced stresses and high power density. Closed loop circuit model is developed and it is successfully used for simulation studies. The limitation of this converter is presence of DC component in the output current and operating frequency is limited to 11MHz. Simulation and experimental results demonstrate the actual converter capability to control the heat. The experimental results closely agree with the simulation results.

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