COMPARISON OF PARALLEL RESONANT INVERTER AND SERIES RESONANT INVERTER FOR INDUCTION HEATING

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Abstract: *AC/AC converters with resonant switching are composed of two kinds, which are series resonant and parallel resonant converter. The circuit configuration and topology, control strategy, principle characteristics, performance parameters of two-kinds of converters are comparatively investigated in this paper, and important conclusions are obtained .*

Key words: *Electronics, AC-AC Converter, Resonant switching, induction heater.*

1. 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 and machine-building industries, as well as for jewellery, smithy heating, domestic heating and 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 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. Three phase AC to DC converters with improved power quality is given by [7]. The above literatures does not deal with closed loop modeling and comparison of AC to AC converter fed induction heater. This paper presents, closed loop controlled AC to AC converters also compares the series resonant converter with the parallel resonant converter and important conclusions are obtained.

2. Circuit configuration and topology

The series resonant converter scheme is shown in Fig.1a. In this converter there are two main advantages: It is characterized by a high power factor and a sine wave input current, and on the other hand the inverter

circuit is constructed with a single controlled switch, which serves as a high-frequency generator for induction heating. The resonant circuit in the output produces high frequency output required by the load.
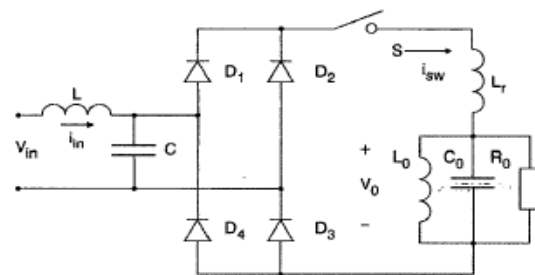
a. Series resonant converter
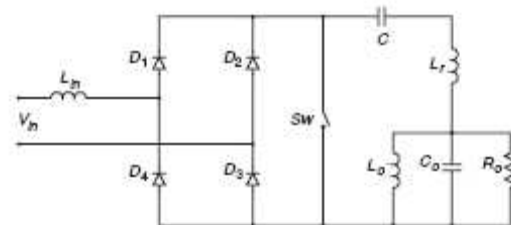
b. Parallel resonant converter

Fig. 1. Circuit diagram

The parallel resonant converter scheme is shown in Fig.1b. This converter scheme, maintains all the advantages of the series resonant type. The main feature of the circuit is that the capacitor is connected in series with the load. Such a connection completely eliminates the DC component in the load current in the steady-state regime. This allows us to use the matching transformer and to apply the same converter in installations to various required levels of a load voltage.

3. Principle of operation

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

waveforms 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 $v_{in}>0$.
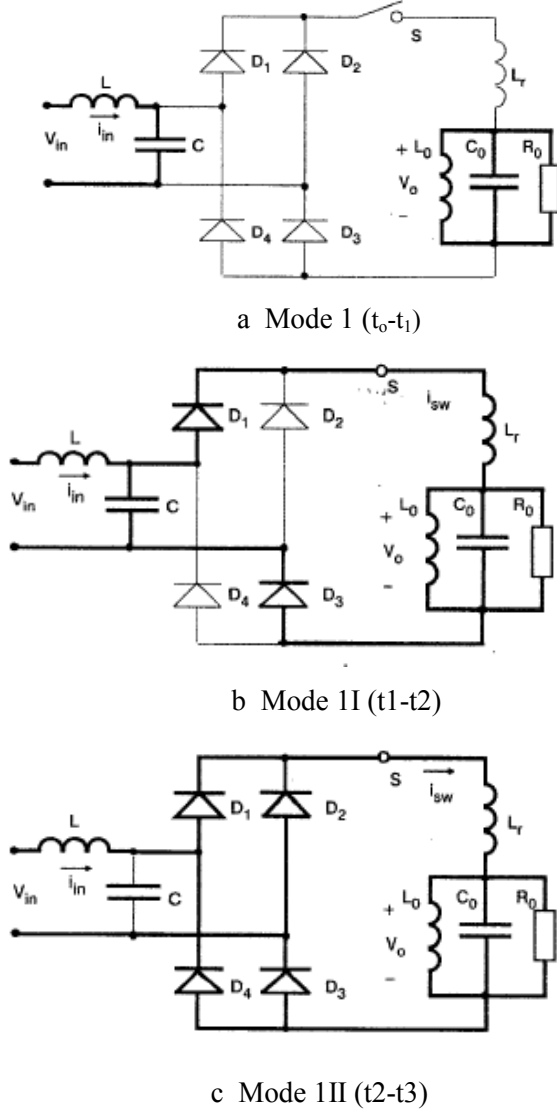

a Mode 1 (t_o-t_1)

b Mode 1I (t1-t2)

c Mode 1II (t2-t3)

Fig.2 Equivalent Circuits

3.1 Interval 1: $t_0<t<t_1$

The equivalent circuit is shown in Fig.2a. Four diodes D1-D4 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 vin.

3.2 Interval 2: $t_1<t<t_2$

The equivalent circuit is shown in Fig.2b. Two diodes D_1, D_3 and the switch S are on. In this interval the capacitor C is discharging via the circuit C-D_1-S-

Lr-load-D_3. This interval ends when the capacitor voltage reduces to zero.

3.3 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 switch 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.
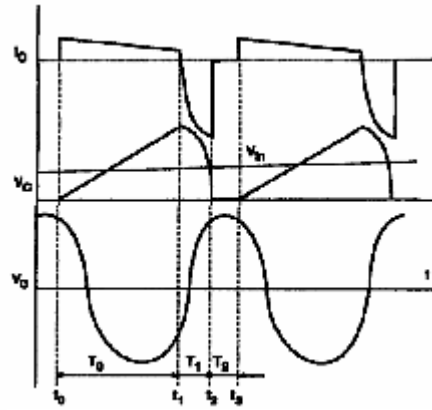

Fig.3 Ideal Switching Waveforms

The commutation process of the parallel resonant inverter, which consists of three time intervals, is shown in Fig. 4. The idealised waveforms of the input current Iin, capacitor current I_C, capacitor voltage V_C, switch current Isw, the currents via the bridge diodes I_{Dl}, I_{D2} and output voltage Vo are shown in Fig. 5. We suppose that the switching frequency is much higher than the input line frequency, and in the analysis we arbitrarily chose the time interval where $v_{in}>0$.

3.4 Interval 1: t0<t<t1

The equivalent circuit is shown in Fig. 4a. The switch Sw is off. The capacitor C charges up practically linearly via the circuit Lin- D_1-C-Lr-load-D_3. The charge rate is determined by the instantaneous input voltage vin.

3.5 Interval 2: t1<t<t2

The equivalent circuit is shown in Fig. 4b. The switch Sw is on. The capacitor discharges oscillatory via the circuit Sw-C-Lr-load. The discharging current IC varies harmonically and at the moment when the IC reaches zero the second interval ends.

3.6 Interval 3: t2<t<t3

The equivalent circuit is shown in Fig. 4c. Switch Sw is not in the conducting mode and the oscillatory discharging process continues via the circuit C-Lr-load-all the bridge diodes.
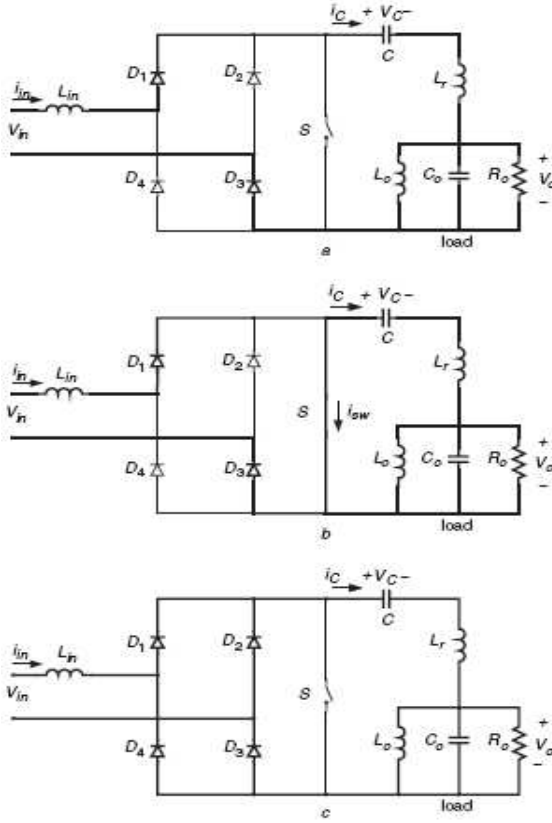

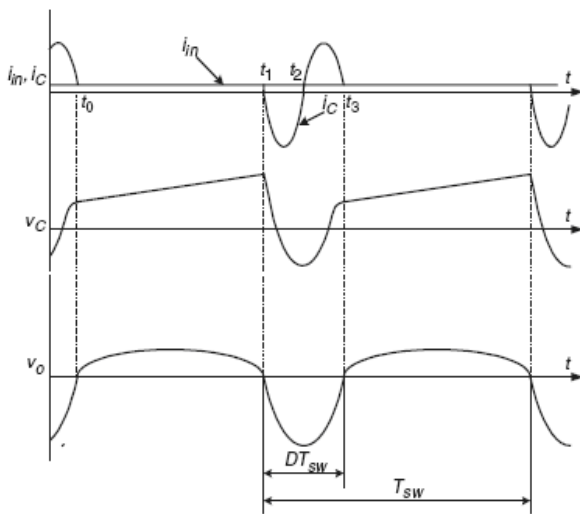Fig. 4. Equivalent circuits corresponding to each time interval.

Fig..5. Ideal switching waveforms

4.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) . Comparison of the relationship between input and output voltages Mg = Vo/V_{in} is given in table 1.

Table 1: comparison of operational parameters

Parameters	Series resonant inverter	Parallel resonant inverter
A1	$\dfrac{\pi}{D} \cdot \dfrac{(1 - D + D_1)}{1 - \cos\left(\pi\dfrac{D_1}{D}\right)}$	$\dfrac{\pi(1 - D)}{(1 - k)D}$
A2	$\dfrac{2D}{\pi(1 - 4D^4)}$	$\dfrac{2D}{\pi(1 - (nD)^2)}$
A3	$\dfrac{1}{\sqrt{1 + R_o^{*2}\left(\omega_s^* - \dfrac{1}{\omega_s^*}\right)^2}}$	$\dfrac{1}{\sqrt{1 + R_o^{*2}\left(n\omega_{sw}^* - \dfrac{1}{n\omega_{sw}^*}\right)^2}}$
Mg	$\dfrac{\sqrt{2}}{A_1 A_2 A_3}$	$\dfrac{\sqrt{2}}{A_1\sqrt{\sum\limits_{n=1}^{\infty}(A_{2,n}A_{3,n})^2}}$

The calculation results of the dependency of Mg by R*o and ω^*_{sw} are shown in Fig. 6 (all the harmonics higher than 5th order have been neglected)
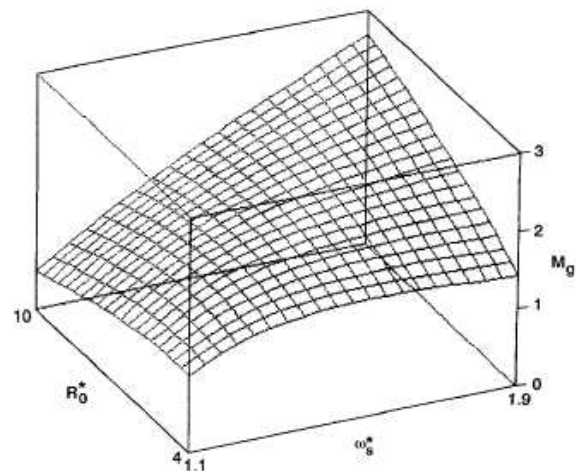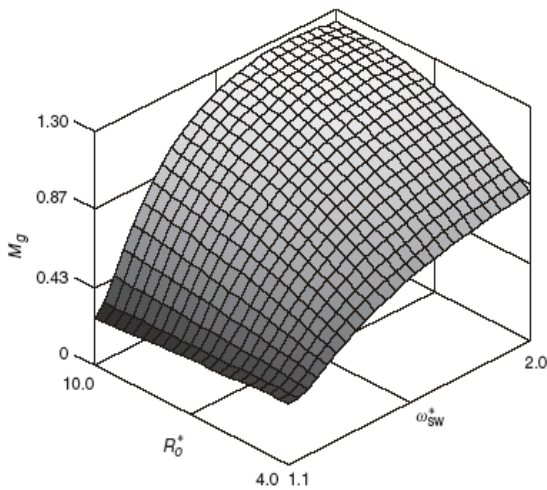

Fig. a Series resonant inverter

Fig. b Parallel resonant inverter
Fig. 6. Factor Mg=Vo/Vin plotted against Ro * and
ω*s

As can be seen, comparatively in parallel resonant inverter the change of the load Ro* hardly influences Mg at all. At the same time since the A coefficients include the duty cycle D and frequency ω, the change of the switching frequency in the range $1:1 < \omega_{sw}^* < 2$ enlarges Mg, (as well as the output voltage) 3–4 times. These results indicate the positive feature of the converter, i.e. the change of a load hardly influences the output voltage and only with the change of frequency can one regulate the output voltage.

5. Simulation Results

The closed loop circuit model of AC-AC converter is shown in Fig.7. Scopes are connected to measure output voltage.
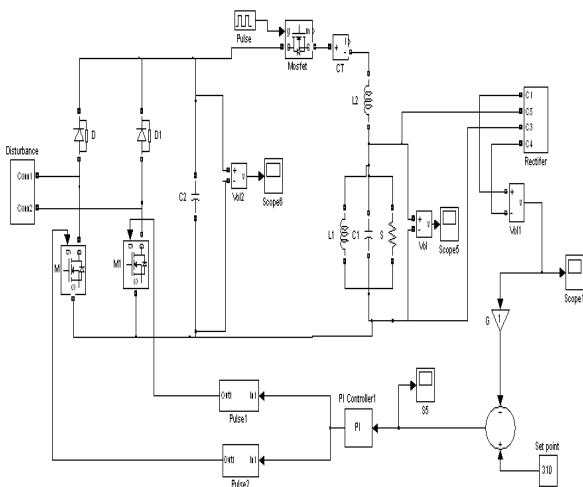

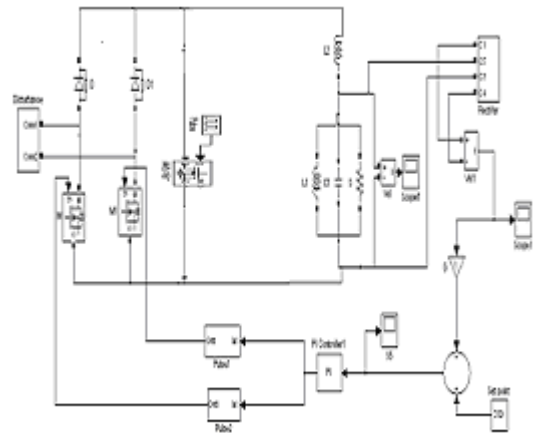Fig. a. Series resonant Converter

Fig. b. parallel resonant converter
Fig. 7. closed loop circuit

A disturbance is given at the input by using two switches. The output voltage is sensed and it is compared with the reference voltage. The error signal is given to the controller. The output of the PI controller controls the dependent source. The response is shown in Fig .8a & Fig.8b.
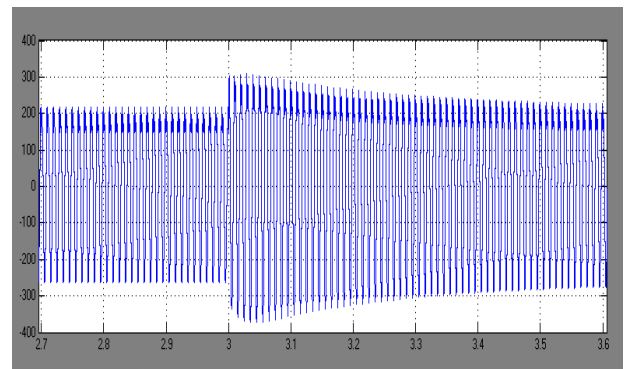

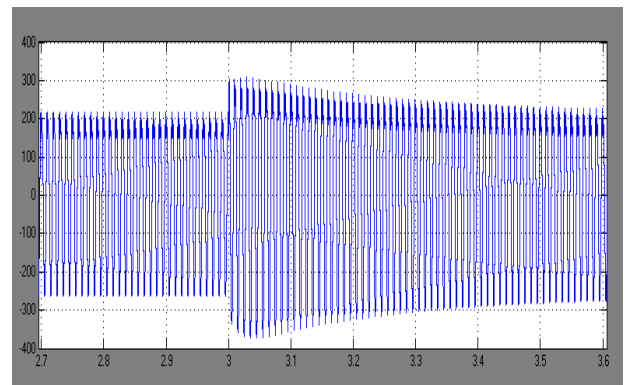Fig. a. Series resonant converter

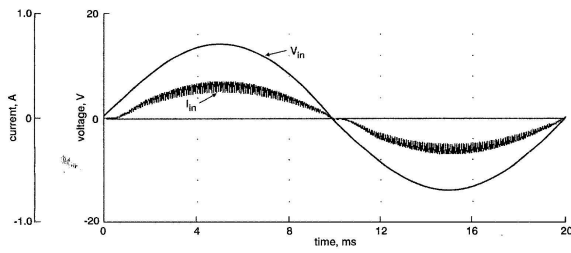

Fig. b. Parallel resonant converter
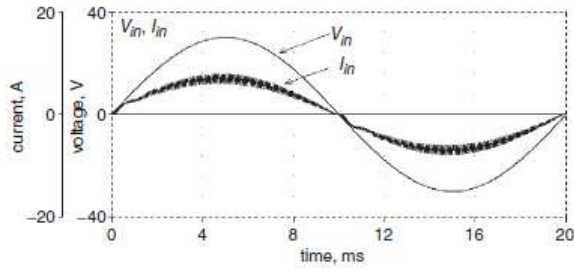
Fig. c. Series resonant inverter

Fig. d. Parallel resonant inverter

Fig. 8. Simulation results

Comparatively the series resonant converter closed loop system reduces the steady state error. Fig. 8c & Fig. 8d demonstrates the simulation input voltage and current. Comparatively the parallel resonant converter has better power factor near to unity.

5. Experimental Verification

The hardware circuit and are shown in Fig.9. The single-switch AC-AC converter was built and it is tested at 24V.
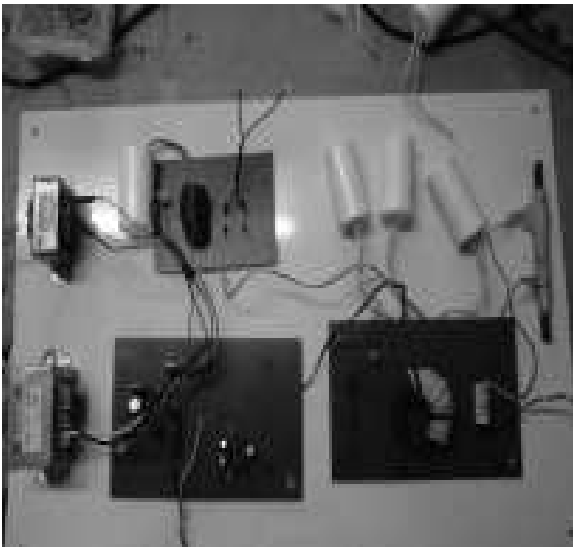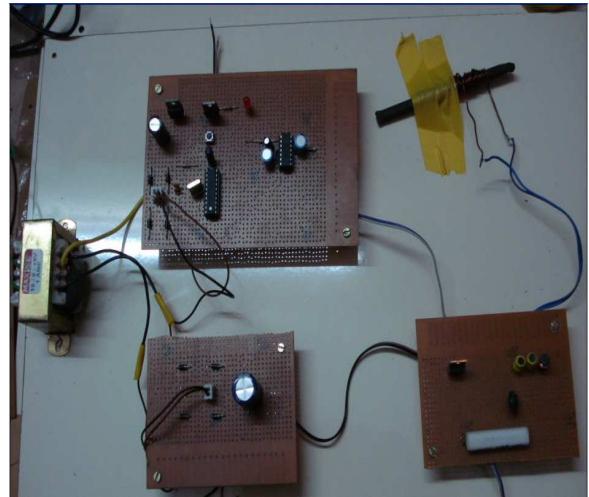

Fig. a. Series resonant inverter

Fig. b. Parallel resonant inverter
Fig. 9. Hardware layout

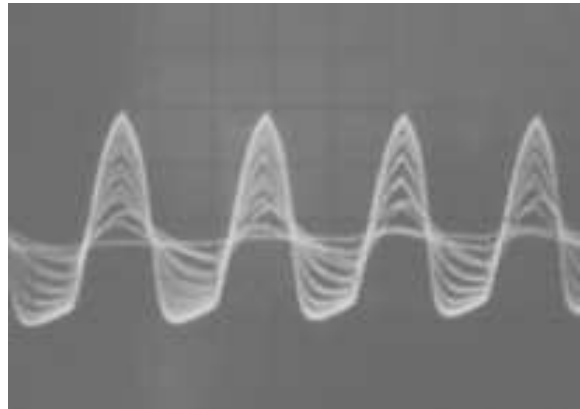The experimental waveform of output voltage is shown in Fig. 10.
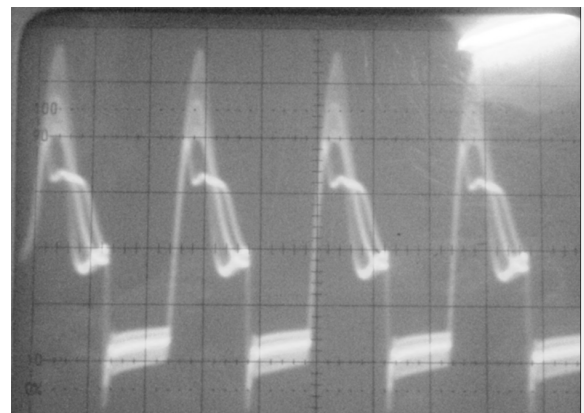

Fig. a. series resonant inverter

Fig. b. Parallel resonant converter
Fig. 10 Experimental output voltage

The comparison on the performance of converters is presented in Table 2. The results confirm that the parallel resonant converter delivers the better performance in achieving the better efficiency.

Table 2. Performance comparison

Input voltage in volts	Output voltage in volts		Efficiency in %	
	Series resonant converter	Parallel Resonant converter	Series resonant converter	Parallel resonant converter
180	149.6	153.4	81.6	84.7
200	164.1	171.2	82	85.1
220	179.2	188.4	82	85.2
240	193	205.5	82.1	85.8

6. Conclusion

This paper has compared the series resonant and parallel resonant AC-AC converter circuits for induction heating. Comparison between converters have confirmed that parallel resonant converter has advantages such as high efficiency, better power factor, eliminates dc component in load current and less change in Mg with respect to load resistance. The series resonant converter has advantages like reduced hardware, reduced stresses and high power density and reduces steady state error at closed loop mode of operation.

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