FULL BRIDGE INVERTER FED MULTIPLE IH LOAD SYSTEM

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Abstract-*This paper presents and analyzes the asymmetrical voltage-cancellation(AVC)control, for power control of multiple induction heating (IH) load system. It is applied to the two output full-bridge series resonant inverter. The synthesized converter is considered as a multi-output extension of a full-bridge topology. The AVC control scheme allows the control of output power, simultaneously and independently, up to their rated values. The proposed control technique achieves better efficiency performances than the other control strategies, due to its wide range of switching operation. The control scheme is verified using MATLAB tool. Hardware prototype model is also implemented for verifying the proposed control scheme.*

Key words :*Asymmetrical voltage cancellation control, induction-heating, two output inverter, series-resonant inverters, zero voltage switching.*

Introduction

Multiple-output inverters are suitable for multiple Induction Heating (IH) loads. Conventional converters use several single-output inverters or a single-output inverter multiplexing the loads along the time periodically. Multiple-burner induction cooking appliances including two or four inductors are the most common solution [1]. In a multiple-burner induction cooker it is possible to use one inverter per burner as traditional approach. The most common technique uses a single-output inverter multiplexing the loads along the time periodically by means of electromechanical switches, causing a very low frequency switching with power and acoustic noise. Another approach is based on the use of several resonant capacitors connected with loads by activating electromechanical switches to cause the power division. In this approach, the operating frequency is not fixed; actually it depends on power distribution and load conditions [2]. The converter is configured to supply either both inductors or only one, depending on whether one or two inductors are operated. When only one of the inductors is active, all of the rated power of the converter can be applied to the load, obtaining a quick heating function. The use of multiple-output inverters has clear benefits for multiple-burner cookers: higher utilization ratio of electronics, higher maximum power. Finally, it is possible to share some components of the power converters [3].

The basic required specifications of a two-output series-resonant inverter are variable output power and a fixed-frequency control. The synthesized converter should allow the control of the two outputs, simultaneously and independently, up to their rated powers [4]. The fixed-frequency control has some additional advantages; reduced electromagnetic noise spectrum and avoiding the acoustic noise due to different operating frequencies which cause low-frequency interferences. Several modulation schemes are employed for power control of multi output inverter.

In Pulse Width Modulation (PWM) Technique, the output power is controlled by varying duty cycle D_{PWM}. For variation in D_{PWM}, T_{on} should be changed.It causes non- Zero Voltage Switching (ZVS) operation [5-7]. In Pulse Density Modulation (PDM) Technique, D_{PWM} is maintained constant and D_{PDM} is varied to vary the output power. It is possible to control the output power by varying the period of power injection without disturbing the switching frequency and D_{PWM}. The variation in PDM frequency will lead to acoustic noise problems and the output power is discontinuous [8].

Series Resonant for Multi induction heating system [9] is designed. While varying the pulse width output power of the inverter using conventional (PWM technique) the soft switching range is small. PDM control does not satisfy the continuous power requirement of IH load.This work presents fixed frequency AVC control of multiple output inverters for the multiple load IH system [10]. Latest advancements in the IH systems are discussed

[11-13]. In this technique where the control angle α is varied and simultaneous control of output voltage, current and power is obtained. The purpose of this work is to get a wide range of soft switching operation of switches during the power control of a two output full bridge series resonant inverter using AVC control.

Description of multi IH load system

A typical arrangement of the single two output full bridge resonant inverter based power conversion system is shown in Figure 1. This AC-AC power converter circuit converts low frequency AC into high frequency AC required by both the IH load. Multi output high frequency series resonance inverter composed of six power switching devices S_1, S_2, S_3, S_4, S_5 and S_6.

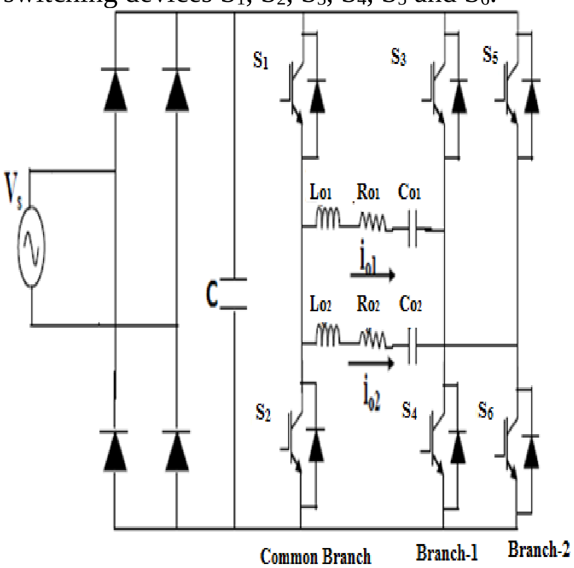

Figure 1. Circuit configuration of two output full bridge series resonant inverter fed IH system

Switches S_1 and S_2 are in the first (or) common branch. Switches S_3 and S_4 are in the second branch. Switches S_5 and S_6 are arranged in the third branch. The two loads are represented by their equivalent effective inductor (L_o) in series with equivalent effective resistance (R_o).Each load is in series with the resonant capacitor (C_o). First load (LOAD-1) is connected between common branch and first branch. Second load (LOAD-2) is connected between common branch and second branch.

Analysis of the two-output series resonant inverter

Basic specifications for the converter synthesis are given below. A two-output series-resonant inverter is operated under a fixed-frequency. Two IH loads are supplied, simultaneously and independently, up to their rated output powers. The energy state equation of a generic converter can be given as;

$$\begin{bmatrix} L_o & 0 \\ 0 & C_r \end{bmatrix} \begin{pmatrix} i_{L_o} \\ V_{c_o} \end{pmatrix} = \begin{bmatrix} -R_o & I \\ -\mathrm{I} & 0 \end{bmatrix} \begin{pmatrix} i_{L_o} \\ V_{c_o} \end{pmatrix} \begin{pmatrix} f_j \\ 0 \end{pmatrix} V \qquad (1)$$

Where

i_{Lo} and Vc_o are vectors of the currents through the inductive coils across the capacitors C_o respectively.

$$i_{Lo} = \begin{pmatrix} i_{L_{o1}} \\ i_{L_{o2}} \end{pmatrix}, \; V_{Co} = \begin{pmatrix} V_{c_{o1}} \\ V_{c_{o2}} \end{pmatrix} \qquad (2)$$

L_o, C_o and R_o are diagonal matrices whose diagonal elements are the inductances, capacitances and resistances, respectively.

$$L_o = \begin{bmatrix} L_{o1} & 0 \\ 0 & L_{o2} \end{bmatrix}, \; C_o = \begin{bmatrix} C_{o1} & 0 \\ 0 & C_{o2} \end{bmatrix},$$

$$R_o = \begin{bmatrix} R_{o1} & 0 \\ 0 & R_{o2} \end{bmatrix} \qquad (3)$$

f_j is the vector which describes the connections between the network components (both serial RLCbranches) and the input voltage V_o for each circuit configuration of the converter.

$$f_j = \begin{pmatrix} f_{1j} \\ f_{2j} \end{pmatrix} \qquad (4)$$

The possible values of the two elements of f_j are either 1 (forforward connection), 0 (forno connection), or -1 (forreversed connection).

From the equation 1

$$L\frac{di_{Lo}}{dt} = -R_o i_{Lo} + Vc_o + f_j V_o \qquad (5)$$

$$C\frac{dV_{Co}}{dt} = -i_{Lo} (6)$$

According to the equations (5) and (6), the unique function controlled by the switches in the converter is f_j . So it has to be the control function, representing the connection of the input voltage source to the two loads. From (5)

$$f_j = (L\frac{di_{Lo}}{dt} + R_o i_{Lo} - Vc_o)\frac{1}{V_o} \qquad (7)$$

As a consequence, assuming that $iL_o$and Vc_o are periodic functions, the control function f_j is also periodic. The possible values for the two elements of f_j are 1, 0, or -1. Only this range of values can be used to obtain periodic sequences to control the converter.

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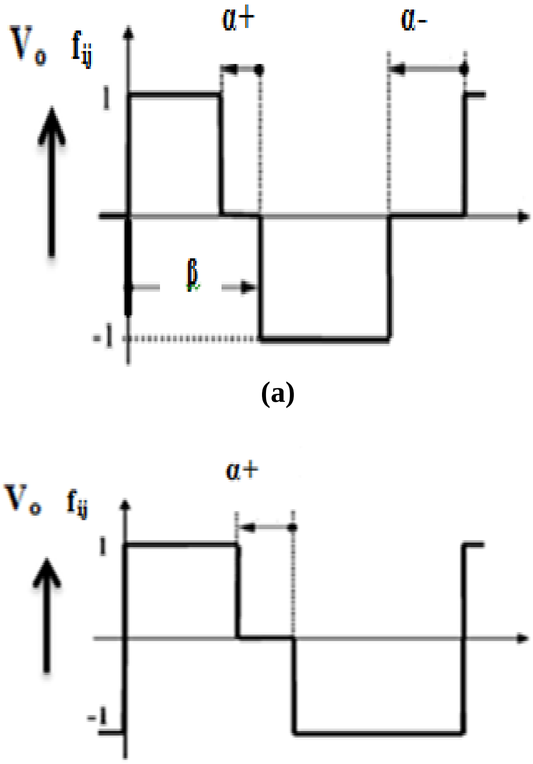


(a)

(b)

Figure 2. Possible periodic sequence of values for each element fij of fj : (a) Waveforms for fixed frequency control and (b) Theoretical waveforms for AVC control

In fixed frequency control, each element $f_{ij}$of the vector f_j to satisfy (7) will produce a quasi-square waveform shown in Figure 2(a). The parameters α+, α- and β are control variables. The theoretical waveforms for AVC control are shown in Figure 2(b). It can be observed that there is an unequal positive and negative half cycle in the output voltage. In AVC control, β is assumed as 180° and it is constant and only the control parameters α= α+ = α- are varied to reduce the output voltage and power. When the control angle αis varied, simultaneous control of output power of the two output inverter is obtained.

Simulation results

Simulation of the proposed system has been performed to verify the power control of multiple IH load system using AVC method

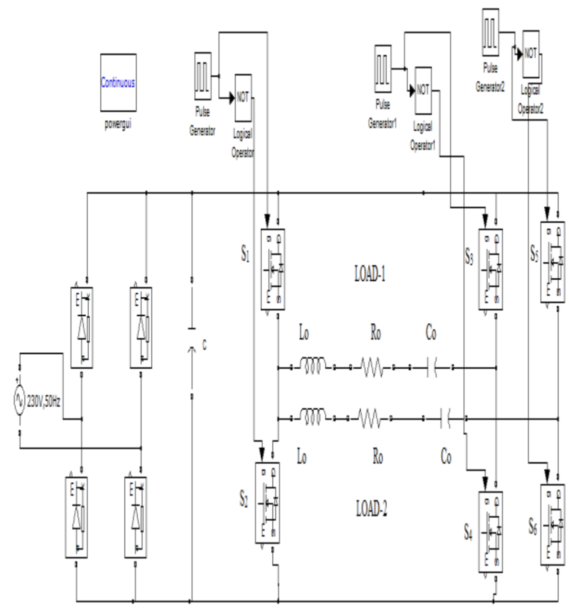


Figure 3. Simulink model of multiple output inverter fed IH load system

Figure 3 shows the Simulink model of multiple output inverter fed IH system. The design specifications and circuit parameters of multi load IH system are given in Table 1. The switches in the common branch are operated at 50% pulse width such that α_1=0°. Switches S_3 and S_4 are operated using constant frequency AVC based gate pulses. Switches S_5 and S_6 present in the second branch are also operated using constant frequency AVC based gate pulses. The control variables for the switches in the second branch and the third branch are α_2 and α_3. By varying the control variables α_2 and $\alpha_3$from 0° to 180°, the power fed to the multiple IH loads can be controlled. Figure 4 shows the gate pulses to the switches S_1, S_2, S_3, S_4, S_5 and S_6 for the control angles α_2=150° and α_3=150°. Figures 5(a) and (b) shows the voltage across load (Vo_1) and current through LOAD-1 (Io_1) at α_2=150° and α_3=150°. Figure 6(a) and (b) shows the voltage across load (Vo_2) and current through LOAD-2 (Io_2) at α_2=150° and α_3=150°.

Table 1. Design specifications and circuit parameters

Description of parameters	Symbol	Value
Rated power	P_o	100W
Switching frequency	f_s	22kHz
Filter capacitor	C_r	300mF
Resonant capacitor	C_o	1.26µF
Effective resistance component of IH load(LOAD- 1, LOAD- 2)	R_{o1}, R_{o2}	5
Effective inductive component of IH load(LOAD- 1, LOAD- 2)	L_{o1}, L_{o2}	0.05mH

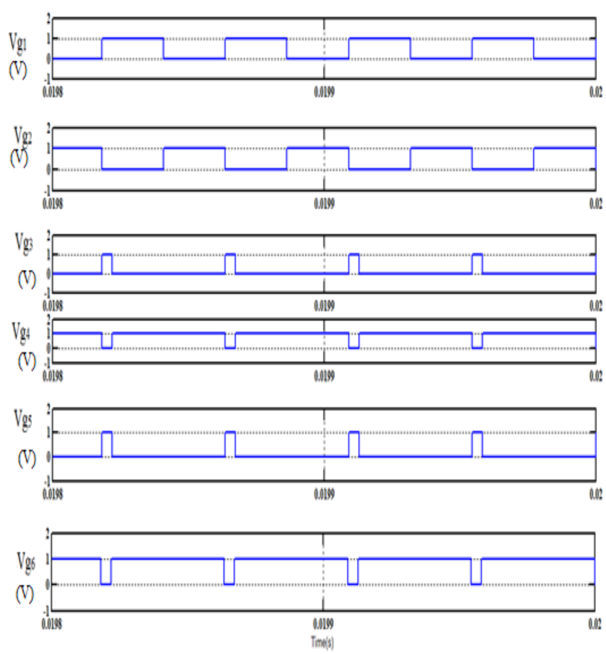
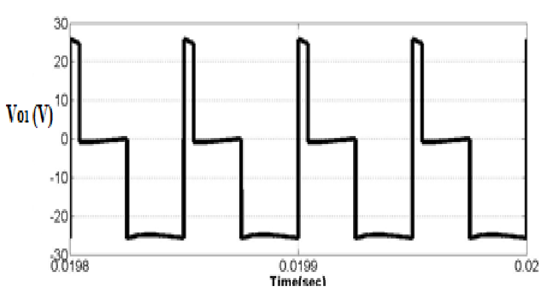


Figure 4. Gate pulses to the switches S1, S2, S3, S4, S5 and S6 at α2=150° and α3=150°



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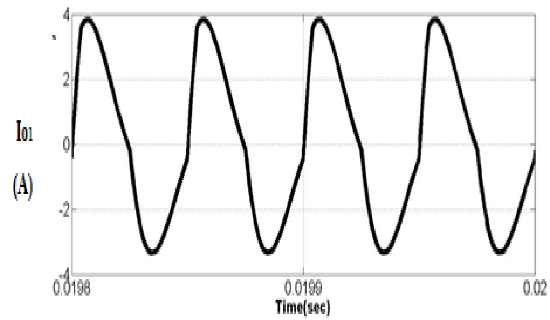

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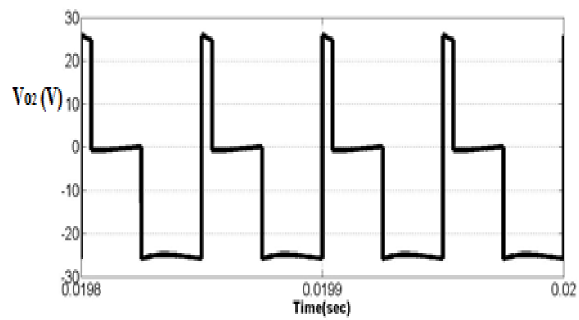
Figures5. (a) Voltage across LOAD -1 (Vo1)at α2=150° and (b) Current through LOAD-1 (Io1)at α2=150°



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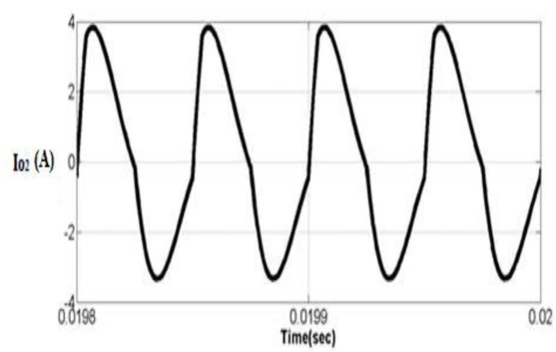
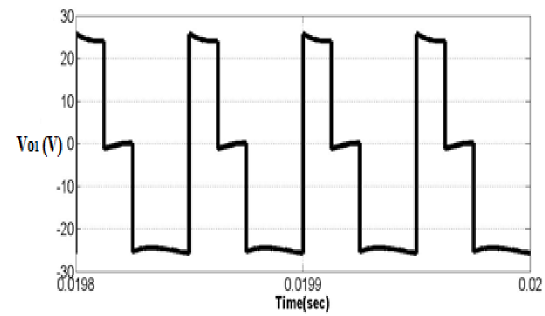


(b)

Figures6. (a) Voltage across LOAD -2(Vo2)at α3=150°and(b) Current through LOAD-2 (Io2)at α3=150°

Figures 7 (a) and (b) shows the voltage across load and current through LOAD-1 at α_2=90° and α_3=150°. Figures 8 (a) and (b)shows the voltage across load and current through LOAD-2 at α_2=90° and α_3=150°.



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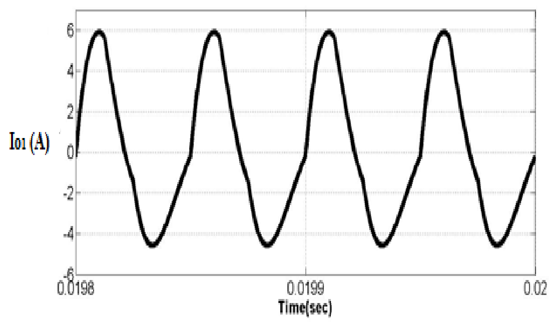

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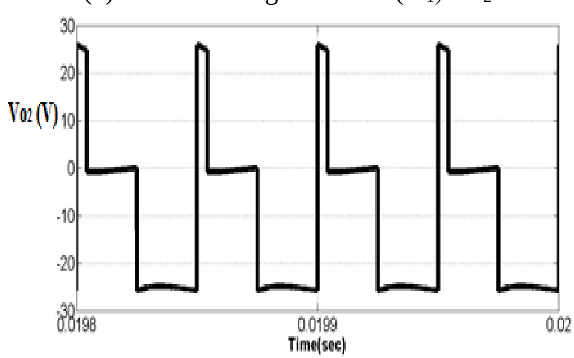
Figures7. (a) Voltage across LOAD -1(V_{o1})at α_2=90° and (b) Current through LOAD-1(I_{o1})at α_2=90°



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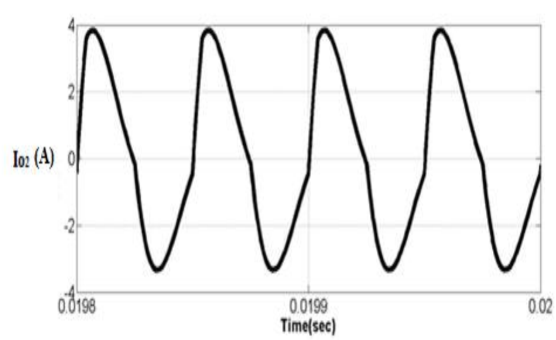
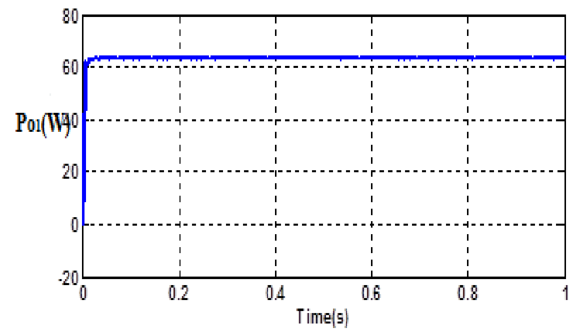


(b)

Figures 8. (a) Voltage across LOAD -2 at (Vo2)α3=150° and (b) Current through LOAD-2(Io2)at α3=150°



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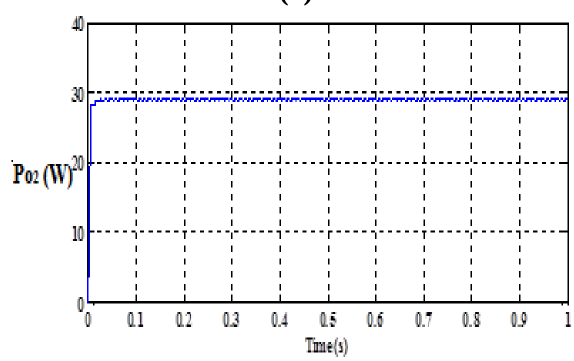


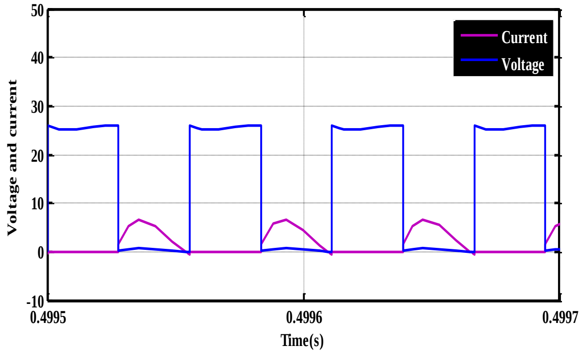
(b)

Figures 9. (a) Output power across LOAD-1 (Po1)at α2=90° and (b) Output power across LOAD-2(Po2)at α3=150°

Figures 9 (a) and (b) shows the variation of output power with respect to control angle and it is observed that the output voltage, current and power increases as the control angle decreases.

Table 2. Switching table

	I	II	III	IV	V	VI	VII	VIII
S_1	1	1	1	1	0	0	0	0
S_2	0	0	0	0	1	1	1	1
S_3	0	0	1	1	0	0	1	1
S_4	1	1	0	0	1	1	0	0
S_5	0	1	1	1	0	1	1	1
S_6	1	0	0	0	1	0	0	0



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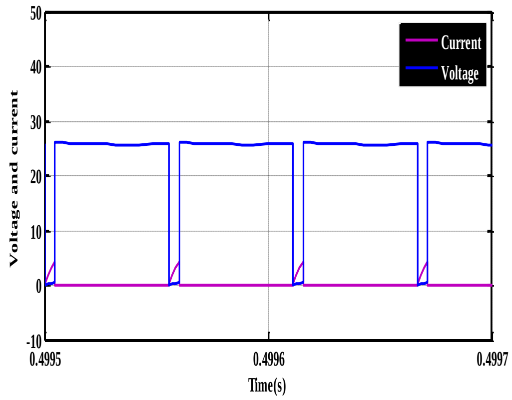

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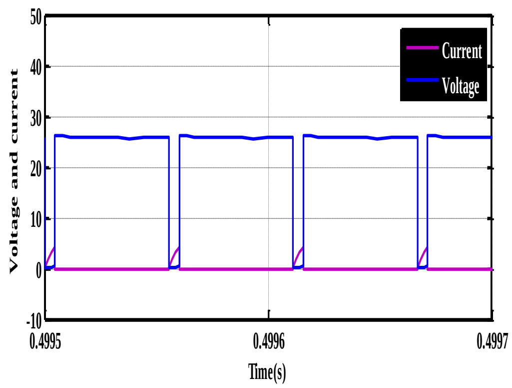


(c)

Figures10. (a) Voltage across the switch S1 (Vs1) and Current through the switch S1 (Is1) (b) Voltage across the switch S3 (Vs3) and Current through the switch S3 (Is3) (c) Voltage across the switch S5(Vs5) and Current through the switch S5 (Is5)

Figures 10 shows the ZVS switching which is achieved using the proposed control strategy. The switching operation occurs when the voltage across the switch becomes zero. Hence the switching power loss is reduced.

Experimental results

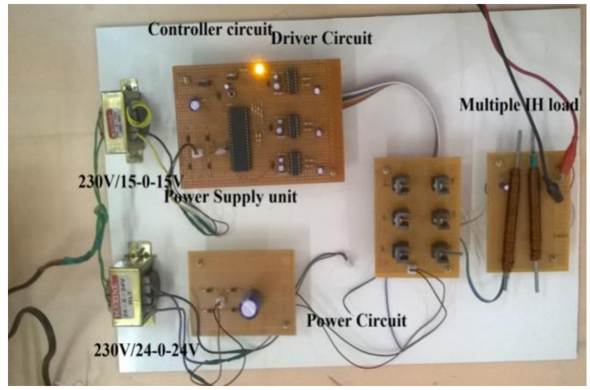
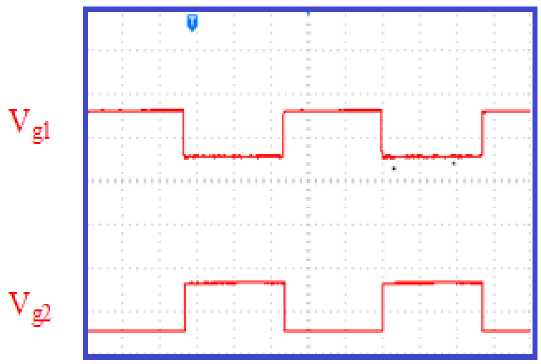


Figure 11. Photograph of the Hardware layout of the multiple IH load system

Induction heating requires High frequency AC supply .The AC voltage of 230V, 50Hz is given to the primary side of the transformer from the source. The transformer is used to step- down the voltage from an AC voltage of 230V to 50V which is given to the power supply circuit.Diode bridge rectifier is used to convert the 50V, 50 Hz AC supply into pulsating DC. By using the capacitor filter the pulsating DC is then converted into pure DC. Then it is converted into high frequency AC using two output inverter.The DC voltage obtained from the rectifier is applied to the AVC controlled full bridge series resonant inverter of multi IH load system. IRF 840 is used as the power switches. Two work coils are connected to the inverter. Each work coil has 152 turns with the winding inductance of 0.04mH. Isolation is provided between the work coil and work piece and the iron rod is taken as work piece of length 15cm. The value of the each resonant capacitor is 1.3μF. The coil has the winding resistance of 5 Ω.

The main control part of the hardware circuit is the PIC controller. In this work, PIC16F877A is used as the controller. Implementation of AVC controlled full bridge inverter needs six gate pulses to drive the switches. The AVC based driving pulses required for the MOSFET is obtained from this controller. A bridge rectifier, capacitor and regulator IC's (7805 and 7812) are used to obtain +5V and +12V auxiliary power supply.These voltages are applied to driver circuit and microcontroller circuit. A suitable program is written in the controller to generate

AVC pulses for the gate. In port B pin number 33 to 38 are used to obtain AVC pulses. The magnitude of the gate pulses obtained from PIC controller is very low i.e., 5V which could not be able to drive the MOSFET switches. Driver is used to amplify the pulses from 5V to 12V which is most enough to drive the switches in the power circuit. The output pulses from the driver are given to the gate terminal of the MOSFETs. The complete hardware circuit diagram is shown in Figure 11.



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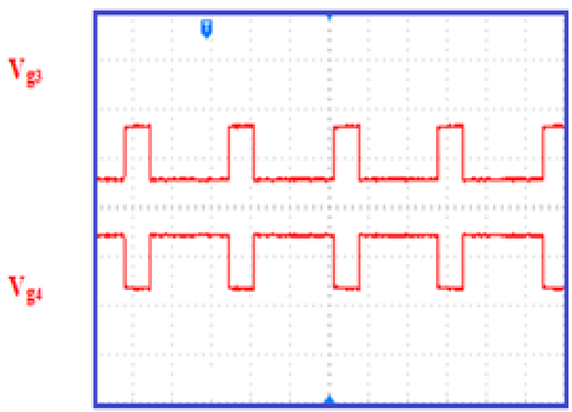

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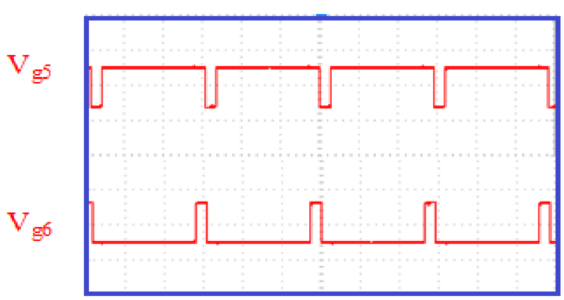
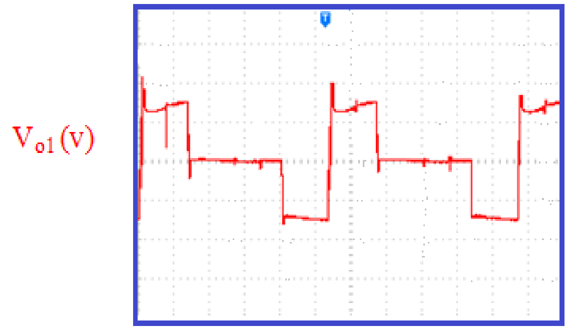


(c)

Figure 12. Gate pulses to the switches (X axis 1cm=25μs, Y axis 1 cm= 10V)

The output voltage across Load-1(Vo_1) at α_2=90° and Load-2(Vo_2) atα_3=150° are shown in Figures 13(a) and (b) respectively.



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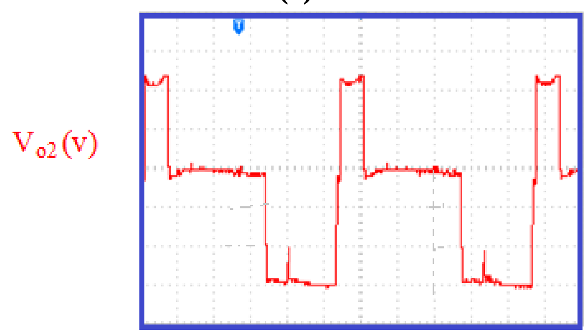

(b)

Figures 13 (a) Voltage across LOAD -1(Vo_1)at α_2=90° (X axis 1cm=25μs, Y axis 1 cm= 20V) and (b) Voltage across LOAD -2 (Vo_2)at α_3=150° (X axis 1cm=25μs, Y axis 1 cm= 10V)

Table 3. Control angle Vs Output power for equal value of α_2 and α_3

Table 4. Control angle Vs Output power for different value of α_2 and α_3

α_1 =0°	α_2	α_3	P_{01}	P_{02}
Constant	30°	30°	98	98
Constant	90°	90°	65	65
Constant	150°	150°	29	29

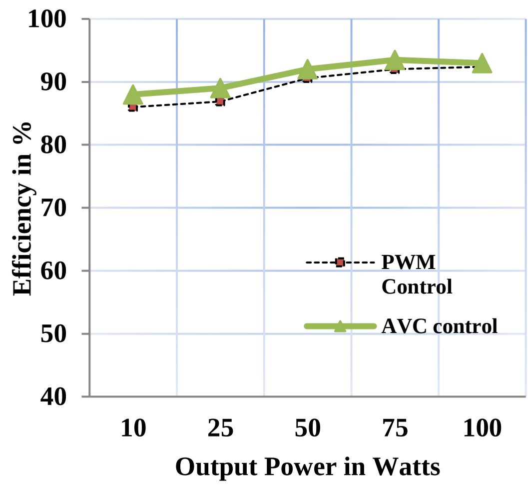

Figure 14. Efficiency Vs Output power

Conclusion

In this paper, AVC controlled twooutput series-resonant inverter has been designed, simulated and implemented. The synthesized converter allows supplying two inductive loads up to their rated values simultaneously and independently with onlyone converter, By varying control angle (α), the output power is controlled.When the control angle alpha increases the output power decreases. During the control of alpha from 0° to 180° the ZVS turn ON and OFF are achieved.The validity of the proposed AVC control scheme is verified through simulation and experimental results. It can be concluded that the presented control technique, the output voltage is cancelled asymmetrically and it is used to control the output power to the induction coil without losing the soft switching condition.It maintains soft switching for wide range variation of output power. The performance of the AVC control techniques was better than the other control strategies.

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