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Research Article

IMPLEMENTATION OF RESONANT INVERTER FOR INDUCTION HEATING USING ASYMMETRICAL METHOD

Latha R [1], Walter Raja Rajan B [2]
**Author for Correspondence: rlathima17@gmail.com*

ABSTRACT

This paper proposes a high efficiency LLC load configuration of full bridge resonant inverter for induction heating application. Induction heating is a well-known technique to produce very high temperature. A large number of topologies have been developed in this area such as voltage and current source inverter. Recent developments in switching schemes and control methods have made the voltage-source resonant inverters widely used in several applications that require output power control. The series-resonant inverter needs an output transformer for matching the output power to the load but it carry high current as a result additional real power loss is occur and overall efficiency is also reduced. The LLC load configuration is a combination of a series inductor and, parallel connected inductor and capacitor. The LLC resonant tank is designed without the use of output transformer. The output power is controlled using the asymmetrical voltage cancellation technique. This results in an increase of the net efficiency of the induction heating system. The circuit is simulated using MATLAB and results were verified.

Keywords: *Asymmetrical control, induction-heating, LLC load, resonant inverters, zero voltage switching (ZVS)*

INTRODUCTION

Nowadays induction heating is a well known technique to produce large temperature for some applications such as heating, melting, brazing and surface hardening. The skin effect and depth of penetration have to be defined for the work piece, which decides the operating frequency. This technology is similar to transformer operation; here the secondary was short circuited. Induction heating requires high frequency of current which induces high frequency of eddy current in the work piece.

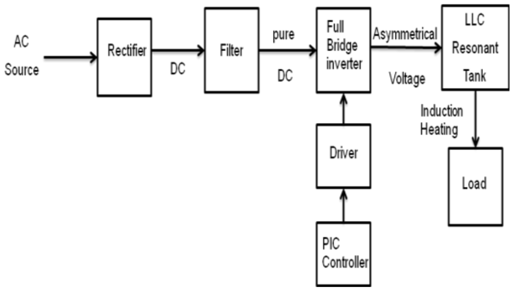

Figure 1: Block diagram

A large number of topologies have developed for this induction technique. In which current source resonant inverter and voltage source resonant inverter are most commonly used, where current fed inverters have short circuit protection capability and controlled only using phase controlled rectifier, and voltage fed inverters have various controls. Recent developments in switching scheme and control methods have made the voltage source resonant inverter for many applications that requires output power control. In pulse frequency modulation (PFM), the output power can be controlled by varying the switching frequency when the inverter operates under zero voltage switching (ZVS) scheme. The phase shift (PS) control varies the output power by shifting the phase of the conduction sequence of the switches in the inverter. The asymmetrical duty cycle (ADC) control produces an unequal duty cycle operation in theinverter. The asymmetrical voltage cancellation (AVC) has been proposed by for the voltage cancellation for fixed frequency control strategies. This AVC was implemented in full bridge series resonant inverter. The series resonant inverter (SRI) had a transformer for matching the output power to the load. Induction heating applications require accuracy in output control capability. In SRI transformer's secondary winding must carry high current and additional real power losses were introduced, thus the system overall efficiency is reduced. Therefore the transformer is later removed in the series parallel resonance inverter (LLC), which gives better performance than series resonant inverter and also provides short circuit protection.

In this paper LLC resonant inverter with AVC control technique for induction heating. The main aim is to produce high temperature using output power control for melting, brazing and hardening applications.The LLC resonant inverter has series inductor L and parallel LC resonant tank circuit. The major advantage of the paper is to provide short circuit protection for the induction coil.

FULL BRIDGE LLC RESONANT INVERTER

A. Functional Block Diagram

The fig. 1 shows the block diagram of LLC resonant source inverter for induction heating. It consists of several stages such as Ac source, rectifier, filter, full bridge inverter, LLC resonant tank and load. The first stage is the 230V/50Hz ac source. It provides the AC supply to the rectifier. An inductor is connected in the input side which issued to improve the power factor. The purpose of the rectifier is used to convert AC to DC supply. In general the output of the rectifier will not be pure DC, it would contain some ripples, these ripples might produce many losses, and hence they are filtered using the capacitor filters. Thus the pure DC was used as the supply to resonant inverter. This resonant inverter used to convert DC to AC voltage. The output of asymmetrical voltage is obtained by the zero voltage switching (ZVS) control. The controller voltage is not enough to trigger the switches hence the driver is used to amplify the output pulse from the controller. It uses optocoupler to provide isolation from the power circuit. This voltage is then fed to the LLC resonant tank circuit and thus the induction heating is performed.

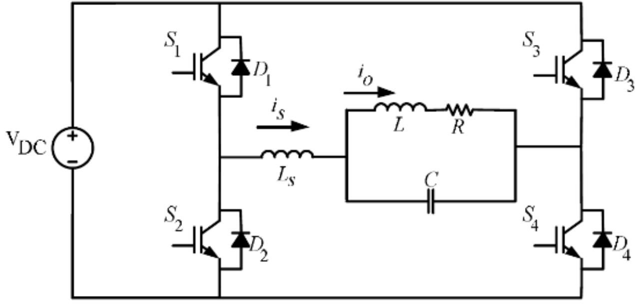

Figure 2: Full Bridge series parallel resonant inverter

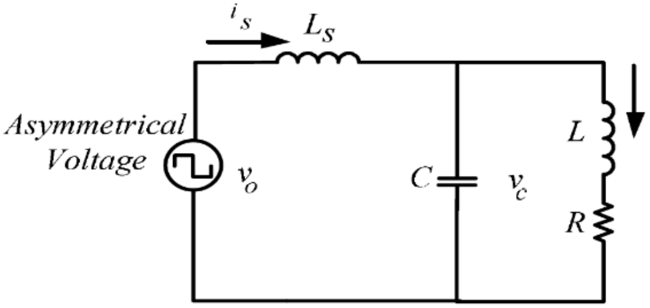

Figure 3: Equivalent circuit

B. Circuit Description

The fig. 2 shows the power circuit of LLC resonant inverter for induction heating applications. The inverter consists of four antiparallel diodes, a matching inductor, a resonant capacitor and an induction coil which is a series combination of resistor and inductor. The equivalent circuit of the LLC inverter system is shown in the fig. 3 where the input voltage can be viewed as asymmetrical AC voltage supplied to the system.In the equivalent circuit the total impedance of the asymmetrical voltage source is denoted as Z_{TOTAL}. The current i_s and i_o are input and output current, respectively.

C. Modes of Operation

The operation of the LLC resonant inverter is similar to that of the normal inverter. The switches S1 and S4 are triggered first and next follows the S2 and S3, thereby the cycle continues. As asymmetrical voltage control is being used the switching sequence was altered.

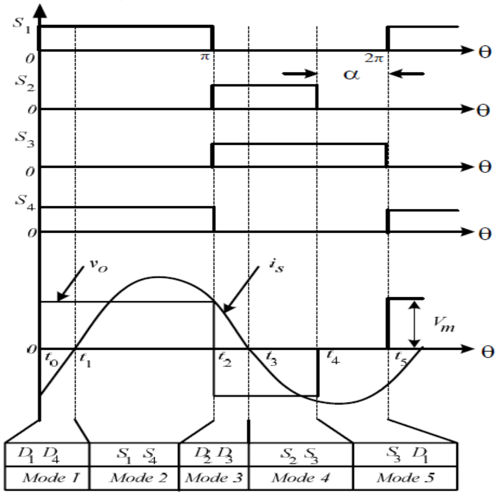

Figure4: Gate signals, output voltage and current

Hence five modes of operation exist within one cycle as shown in fig. 4.The modes of operation are illustrated with its corresponding circuit diagram:

1) *Mode 1[$t_0 – t_1$]*While switches S_2 and S_3 are off, at t = t_0, switches S_1 and S_4 receive positive gating signals. The negative input current(i_s) flows through diodes D_1 and D_4.

2) *Mode 2[$t_1 – t_2$]*At t = t_1, as soon as the antiparallel diodes D_1 and D_4 are turned off, switches S_1 and S_4 are conducted and ZVS operation is achieved. During this mode, the positive input current (i_s) flows.

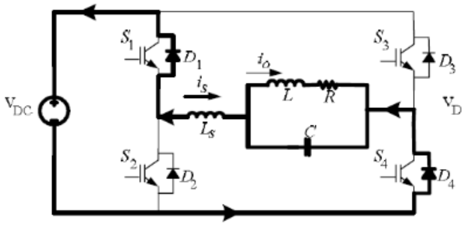

Figure 5: Mode 1 (t_0–t_1)

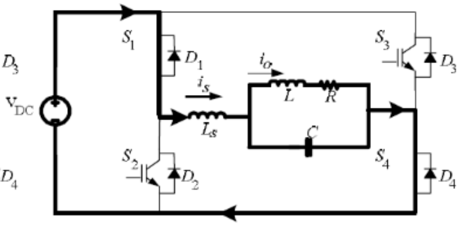

Figure6: Mode 2 (t_1−t_2)

3) *Mode 3[$t_2 – t_3$]* At $t = t_2$, the switches S_1 and S_4 are turned off, similar to that in Mode 1, and the antiparallel diode D_2 and D_3 conduct by the positive input current *(is)*.

4) *Mode 4[$t_3 – t_4$]* At $t = t_3$, when the antiparallel diode D_2 and D_3 are turned off, the switches S_2 and S_3 conduct and the ZVS condition is achieved. During this mode, the negative input current *(is)* flows.

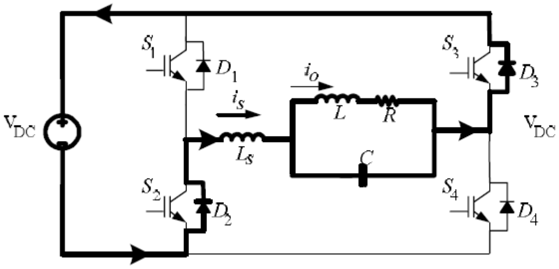

Figure 7: Mode 3 (t_2–t_3)

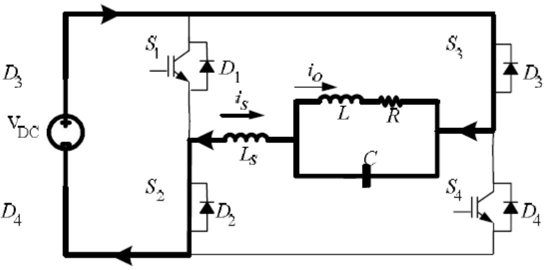

Figure 8: Mode 4 (t_3–t_4)

5) *Mode 5[$t_4 - t_5$]* At $t = t_4$, When the switch S_3 conducts, the switch S_2 is turned off and the antiparallel diode D_1 of S_1conducts. During this mode, the ZVS condition of S_2 is obtained.

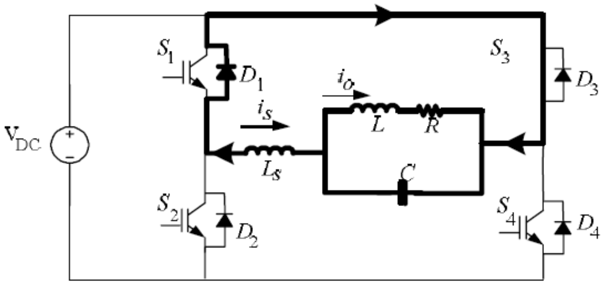

Figure 9: Mode 5 (t_4–t_5)

I. CIRCUIT ANALYSIS

A. Analysis of output power

From the equivalent circuit, the relation between the load voltage and the inverter output voltage can be calculated.

$Vc/Vo=(R+j\omega L)/ ((j\omega Ls\times j\omega C)(R+j\omega L)+(j\omega Ls+R+j\omega L))$ (1)

The inverter is designed to operate such that the switching frequency is higher than that of the resonant frequency for maximum output power. The resonant frequency of the system in fig gives, $\omega_o=\sqrt{}\ (L+L\ s) / (L\cdot L\ \cdot Cs)$(2)

To take only the fundamental component of the inverter output voltage accounts the load voltage is given by, $V_c= \{(-L/Ls)-((L^2/RLs)\omega_o)\}$ (3)

Fundamental voltage can be represented by Fourier series as follows,

$b_n=(Vm/n\pi)\times[2-(-1)^n- \cos n(Vm/n\pi)]$ (4)

$a_n=(Vm/n\pi)\times[-\sin n(Vm/n\pi)]$ (5)

where α is shifted angle of the switch S2, as shown in fig. The amplitude of the fundamental voltage is given,

$V\hat{}1= (V_m/\pi)\times\sqrt{}\sin^2(180-\alpha)+(3- \cos (180-\alpha))^{2}$ (6)

And the average out put power P is,

$P=Vo^2Re\{Z_{coil}\ (j\omega_o)^{-1}\}$ (7)

That is,

$P=(V_m{}^2/2R\pi^2)\times(\sin^2(180-\alpha)+(3-\cos(180-\alpha))^2\times(L/L_s)^2$ (8)

Since the output power depends on the shifting angle (α), therefore output power can be controlled though adjustment of α.

B. Design Algorithm

The starting data are:

1) Voltage V_{dc} applied to the resonant (V_{dc}).
2) Frequency of max power (f_0).
3) Maximum power (Pmax).

4) Equivalent estimated resistance of the load(R)
5) Maximum current allowed through the switches (I_S max)
6) Maximum voltage allowed in the capacitor (V_C max).
STEP 1: Calculate the amplitude of the first harmonic of the input voltage.
$V1=4.V_{dc}/\pi$ (9)
STEP 2: Check the following inequality.
I_S max>2 Pmax/V_1(10)
STEP 3: Calculate the ratio α between the parallel and series inductance.
$\alpha= L / L_S =\sqrt{2}Pmax .R/ V_1$ (11)

STEP 4: Determination of the boundaries of Q.
I_S is monotoniously decreasing with Q so it take a
Q higher than the i_s max called Qmin,
$Qmin= 1/\alpha \sqrt{} (I_S max .v_1 V_1/2Pmax)^2-1$ (12)
Vc is monotoniously increasing function of Q must take a
Q lowers than the corressponding to V_c max called Qmax,
$Qmax=V_c max/ V_1.\alpha.(1+\alpha)$ (13)
STEP 5: Selection of Q.
Q should be close to Qmax if it decrease the current stress in the switches.
Q should be close to Qmin if itincrease the voltage stress in thecapacitor.
STEP 6: Calculation of C, L, L_S.
$C =1/Q.R.2\pi. f_0$(14)
$L =Q.(\alpha+1).R/2\pi. f_0$ (15)
$L_s=L/\alpha$ (16)

RESULTS

A. Simulation results

Simulation has become a very powerful tool on the industry application as well as in academic nowadays. The Computer simulation is performed for a full bridge LLC resonant inverter circuit with asymmetrical voltage cancellation control technique. The simulation circuit is shown in Fig. 10. The following are the parameters used V_{dc}=140V, L=0.9μH, R=0.02Ω and L_s=1.3μH. It is noted that the inductor L_s is wound on air core to avoid saturation.The current and the voltage waveforms are noted for different α values. Here α is used to control the output power.

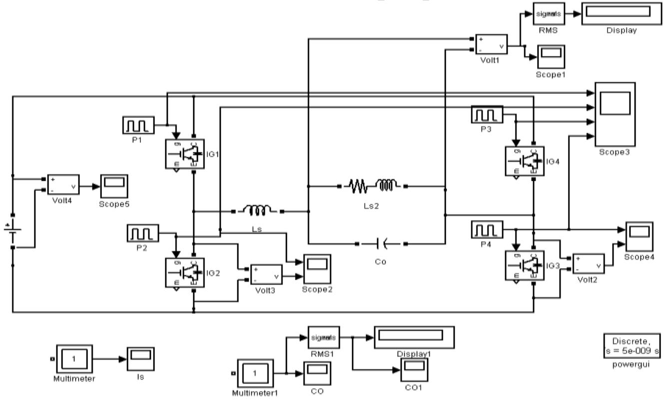

Figure 10: Simulation circuit

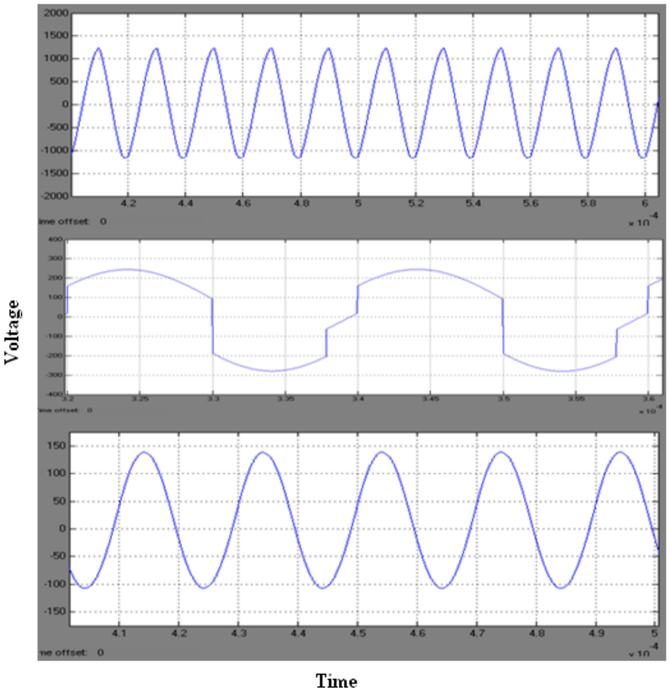

Figure 11: Output current, asymmetrical voltage and output voltage

B. Experimental Results

To verify the proposed method, a hardware setup is prepared with the same set of parameters as provided in the simulation study.The load is a 30-grams aluminum workpiece.Here PIC16F84A is used to drive the inverter circuit. The LLC resonant inverter has IGBT25N120 as the operating switch, which operates at a very high frequency of about 87 kHz. The input power to the inverter is 240 W. As asymmetrical voltage is also employed the efficiency is 92%. Hence the output power from the tank circuit to the induction coil is 226W. It varies according to the shifting angle.

CONLUSION

The full-bridge LLC resonant inverter topology for induction heating application has been proposed. The asymmetrical control can be used to control the output power of the induction coil in the series parallelresonance tank. The proposed asymmetrical technique is the combination of the asymmetrical control technique is performed through simulation and the corresponding waveform is obtained.The proposed control scheme ensuresthe maximum power transfer to the load throughout the heating cycle with minimal loss. Thereby the LLC resonant inverter circuit has to be designed using the simulation values and the real time outputs are compared with the theoretical values obtained.

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