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Selection of Power Semiconductor Switches in M.H.B.R.I. Fitted Induction Heater for Less Harmonic Injection in Power Line

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ABSTRACT

This paper presents an approach to minimize the harmonics contained in input current of single phase Modified Half Bridge Resonant Inverter (M.H.B.R.I.) fitted induction heating equipment. A switch like IGBT, GTO and MOSFET are used for this purpose. It is analyzed the harmonics or noise content in the sinusoidal input current of this inverter. Fourier Transform has been used to distinguish between the fundamental and the harmonics, as it is a better investigative tool for an unknown signal in the frequency domain. An extensive method for the selection of different power semiconductor switches for Modified Half Bridge Resonant inverter fed induction heater is presented. Heating coil of the induction heater is made of litz wire which reduces the skin effect and proximity effect at high operating frequency. With the calculated optimum values of input current of the system at a particular operating frequency, the modified half bridge resonant inverter topology has been simulated using P-SIM software. From this proposed analysis the selection of suitable power semiconductor switches like IGBT, GTO and MOSFET are made. Waveforms have been shown to justify the feasibility for real implementation of single phase Modified Half Bridge Resonant inverter fed induction heater in domestic applications as well as industrial applications.

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1. INTRODUCTION

Induction heater for industrial applications [2] operates at a high frequency [4], [7] range from 1 kHz to 100 kHz. In the application of low frequency induction heating the temperature distribution can be controlled by slowly varying magnetic fields below a frequency [6] as low as 300 Hz. For medium frequency application, an auxiliary voltage-fed inverter is operated in parallel with the main current-fed inverter, since the current- fed parallel inverters [3] alone, when used for induction heating, fail to start. A high frequency modified half bridge inverters [1], [5] for induction heating and melting applications are self-started. For self-commutation, a resonant circuit is essential for SCR fitted inverter[8]-[9], [11]. It is assumed that the circuit is under damped; a mandatory condition for the circuit. The capacitor required for under damping can be connected in series or in parallel with the load [3] in the modern times, IGBTs [1], [8], GTOs and MOSFETs are preferred to SCRs mainly because they offer convenient turn OFF characteristics. Some auxiliary circuits and equipment are required to minimize switching losses occurring at high frequencies [2]. With the same designed parameters of the said inverter circuit, various switches such as IGBT, GTO and MOSFET have been used [10].

The requirements of induction heater are as follows:

a) Switching in high frequency range
b) High efficiency
c) Power factor close to unity
d) Wide power range and
e) Reliability

Induction heaters are usually designed to operate with a vessel made from a specific material, mainly cast iron or ferro-magnetic stainless steel. The following is therefore desire characteristics for the inverter,

a) No reactive components other than the heating coil and the non-smooth filter inductor,
b) No input or matching transformer,
c) 50% duty ratio, simplifying the control and gate circuits,
d) Clamped switch voltage and or current,
e) The use of uncontrolled voltage source.

Here the complete inverter configuration has been simulated using P-SIM. In this present paper, response of harmonic injection in input power line of modified half bridge resonant inverter is tested & verified with different power switches and finally appropriateness of the switches is confirmed.

2. ANALYSIS OF PROPOSED MODIFIED HALF BRIDGE RESONANT INVERTER

Proposed modified half bridge circuit is normally used for higher power output. Basic circuit is shown in the Figure 1. Four solid state switches are used and two switches are triggered simultaneously. Anti-parallel diodes are connected with the switch that allows the current to flow when the main switch is turned OFF. According to Figure 1, when there is no signal at Q_1 and Q_2, capacitors C_1 and C_2 are charged to a voltage of V_i /2 each. The Gate pulse appears at the gate of Q1 to turn IGBT ON. Capacitor C_1 discharges through the path NOPTN. At the same time capacitor C_2 charges through the path MNOPTSYM. The discharging current of C_1 and the charging current of C_2 simultaneously flow from P to T. In the next slit of the gate pulse, Q_1 and Q_2 remain OFF and the capacitors charge to a voltage V_i /2 each again. The Gate pulse appears at the gate of $Q_{2,}$ so turning on Q_2. The capacitor C_2 discharges through the path TPQST and the charging path for capacitor C_1 is MNTPQSYM. The discharging current of C_2 and the charging current of C_1 simultaneously flow from T to P.

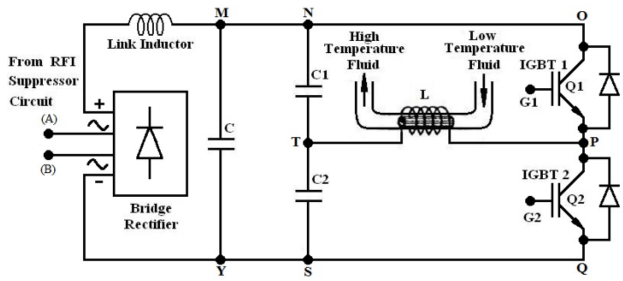

Figure 1. Proposed modified half bridge resonant inverter

Figure 2 indicates a specially designed eddy current heated metallic package which is tightly integrated into then on- metallic vessel or tank in the pipe line. The mechanically processed thin stainless-steel layer package with many spots and fluid channels for cylindrical induction-heated assembly is demonstrated in Figure 3.

When the fluid flows through the inherent package in the vessel or tank having a working coil connected to pipeline, the turbulent fluid is heated abruptly by eddy current losses generated inside the stainless-steel package. Internal structure of this metallic package to be heated by eddy current losses is indicated in Figure 3.

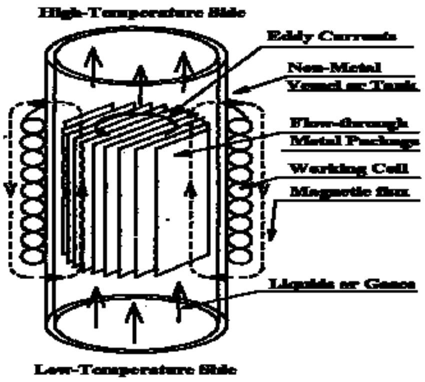

Figure 2. Heating package in the vessel and tank

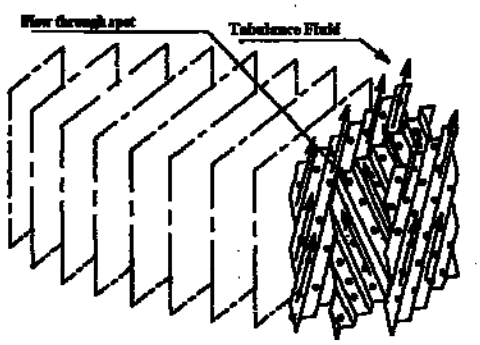

Figure 3. Internal structure of fluid through metal layer packing to generate turbulence flow

3. CIRCUIT EQUATIONS

3.1. Instantaneous Current i_0

With inductive load the equation of instantaneous current i_0 can be obtained as:

$$i_0(t) = \sum_{n=1,3,5,...}^{\infty} \frac{2V_i}{n\pi\sqrt{R^2 + (n\omega L)^2}} \sin(n\omega t - \theta_n)$$

Here, $Z_n = \sqrt{R^2 + (n\omega L)^2}$ is the impedance offered by the load to the n^{th} harmonic component, $\frac{2V_i}{n\pi}$ is the peak amplitude of n^{th} harmonic voltage, and:

$$\theta_n = \tan^{-1}\left(\frac{n\omega L}{R}\right)$$

3.2. Output Power

The output power at fundamental frequency (n=1) is given by:

$$P_{1_{rms}} = E_{1_{rms}}.I_{1_{rms}}.\cos\theta_1 = I_{1_{rms}}{}^2.R$$

Where, $E_{1_{rms}}$ =RMS value of fundamental output voltage.

$I_{1_{rms}}$ =RMS value of fundamental output current.

$$\theta_1 = \tan^{-1}\left(\frac{\omega L}{R}\right)$$

But,

$$I_{1_{rms}} = \frac{2V_i}{\sqrt{2}.\pi.\sqrt{R^2 + (\omega L)^2}}$$

$$P_{1_{rms}} = I_{1_{rms}}{}^2.R = \left[\frac{2V_i}{\pi.\sqrt{2}.\sqrt{R^2 + (\omega L)^2}}\right]^2.R$$

$$= \left[\frac{4V_i^2.R}{2\pi^2(R^2 + \omega^2 L^2)}\right] = \left[\frac{2V_i^2.R}{\pi^2(R^2 + \omega^2 L^2)}\right]$$

In high frequency heating application the fundamental power is more important, the output power due to fundamental current is generally the useful power and the power due to harmonic current is dissipated as heat.

4. THE HARMONIC CONTENT

The input current waveforms of an ideal inverter should be sinusoidal. But, in practice, the input current waveforms are non-sinusoidal. It contains harmonics. The existence of harmonics is visualized either in the time-domain or in the frequency domain easily. The availability of high speed power semiconductor devices has enabled us to reduce the harmonic contents in the input voltage significantly by switching techniques [6]. Total Harmonic Distortion (THD) is a measure of the closeness of a waveform with its fundamental component. The task of the design engineer is to reduce THD. It is accomplished by an LC Low Pass filter (LPF) as well as using most suitable high frequency semiconductor switch. LPF append at the input power supply terminal of Modified Half Bridge Resonant Inverter for induction heating equipment. It provides low harmonic impedance to ground.

4.1. Analytical Tools

The quality of input current of a Modified Half Bridge Resonant Inverter is obtained by Fast Fourier's analysis. It is a powerful mathematical tool which separates out the fundamental and the harmonics. Fourier's transforms allows us to peep into the frequency domain representation of the waveform.

4.1.1. Total Harmonic Distortion (THD)

It is a measure of distortion of a waveform. It is given by the following expression:

$$T.H.D = \frac{\sqrt{\sum_{n=2,3}^{\alpha} I_{nr.m.s}{}^2}}{I_{1r.m.s}} \tag{1}$$

It is the ratio of the RMS value of all non-fundamental frequency components to the RMS value of the fundamental. Our aim is to reduce to a minimum. For a rectangular wave: The value is very large. In quasi-rectangular form, the value is relatively less.

T.H.D Calculation from Software Simulation:

a) T.H.D Calculation of Modified Half Bridge Resonant Inverter using MOSFET. The R.M.S Value of Input Current, $I_4 = 2.21A$.

$$T.H.D = \frac{\sqrt{\sum_{n=2,3}^{\alpha} I_{nr.m.s}{}^2}}{I_{1r.m.s}}$$
$$= \frac{\sqrt{(1.16\times10^{-2})^2 + (1.07\times10^{-2})^2 + (4.63\times10^{-2})^2 + (1.06\times10^{-1})^2}}{3.13} A$$
$$= 3.73\%$$

T.H.D Calculation of Modified Half Bridge Resonant Inverter using GTO. The R.M.S Value of Input Current, $I_4 = 4.08A$.

$$T.H.D = \frac{\sqrt{\sum_{n=2,3}^{\alpha} I_{nr.m.s}{}^2}}{I_{1r.m.s}}$$
$$= \frac{\sqrt{(8.95\times10^{-2})^2 + (2.56\times10^{-2})^2 + (5.95\times10^{-2})^2}}{4.08} A$$
$$= 2.7\%$$

T.H.D Calculation of Modified Half Bridge Series Resonant Inverter using IGBT. The R.M.S Value of Input Current, $I_4 = 4.097A$.

$$T.H.D = \frac{\sqrt{\sum_{n=2,3}^{\alpha} I_{nr.m.s}{}^2}}{I_{1r.m.s}}$$

$$= \frac{\sqrt{(2.38\times10^{-2})^2 + (2.81\times10^{-2})^2 + (7.57\times10^{-3})^2 + (7.76\times10^{-2})^2}}{4.097} A$$

$$= 2.1\%$$

4.1.2. Fast Fourier Transform (FFT) Analysis:

A Fast Fourier Transform (FFT) is an algorithm to compute the discrete Fourier transform (DFT) and it's inverse. It is a linear algorithm that can transform a time domain signal into its frequency domain equivalent and back. An FFT is a way to compute the same result more quickly. FFTs are of great importance to a wide variety of applications, from digital signal processing and solving partial differential equations to algorithms for quick multiplication of large integers. A better understanding of an unknown signal is obtained in the frequency domain. Peak noise in the input current of Modified Half Bridge Resonant Inverter using MOSFET, GTO and IGBT with LPF filter is determined by FFT analysis. The magnitudes of peak noises are given in the following Table 1.

Table 1. Noise response of different power semiconductor switches

Noise Signal	Magnitude of Peak Noise Current of Modified Half Bridge Resonant Inverter		
	MOSFET	GTO	IGBT
1st Noise	1.16×10^{-2}	8.95×10^{-2}	2.38×10^{-2}
2nd Noise	1.07×10^{-2}	2.56×10^{-2}	2.81×10^{-2}
3rd Noise	4.63×10^{-2}	5.95×10^{-2}	7.57×10^{-3}
4th Noise	1.06×10^{-1}	—	7.76×10^{-2}

4.1.3. LC-Low Pass Filter

An L-C low pass filter (LPF) allows waves of lower frequency to pass out more easily compared to the waves of higher frequency. While cascaded with an inverter, it is designed for such a cut-off frequency that the higher harmonics face more impedance and get reduced in magnitude.

5. SIMULATION AND RESULTS

In this paper, the proposed modified half bridge resonant inverter has been simulated using P-SIM with the help of equivalent parameters connected at the input of the induction heated system. Here from this topology the waveforms have been obtained using P-SIM software using different power semiconductor switches using IGBT, GTO and MOSFET from modified half bridge resonant inverter circuit and harmonics can be obtained. Figure 4 shows the simulation diagram of modified half bridge resonant inverter circuit using MOSFET with Low pass filter. Figure 5 shows the Power simulated wave-form of the input current of the modified half bridge resonant inverter using MOSFET Switch. Figure 6 shows the FFT waveform of input current using MOSFET switch. It may be noted that the harmonics are dominant using MOSFET switch. Figure 7 shows the circuit configuration for the modified half bridge resonant inverter using GTO. Figure 8 shows the wave-form of the input current for the modified half bridge resonant inverter with GTO Switch. Figure 9 shows the FFT for the same. It may be noted that here also the harmonics are dominant. Figure 10 shows the circuit configuration for the modified half bridge resonant inverter using IGBT. Figure 11 shows the wave-form of the input current for the proposed inverter using IGBT Switches. Figure 12 shows the FFT for the same. Here also the harmonics are dominant.

It is observed that from the power simulated wave-shapes and mathematical analysis the noise in the input current is much less after using the IGBT switches from the proposed topology. It is exposed from the FFT that the harmonic contents are almost absent in IGBT switch using P-SIM software apart from other power semiconductor switches.

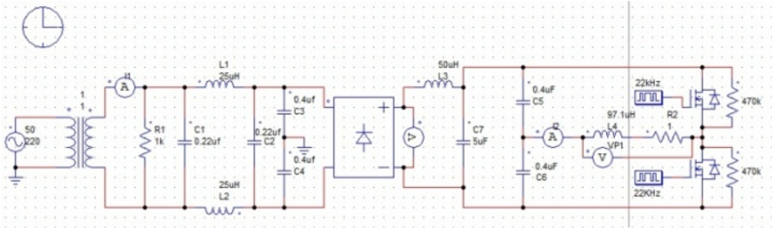

Figure 4. Modified Half Bridge Resonant Inverter circuit using MOSFET with LPF filter

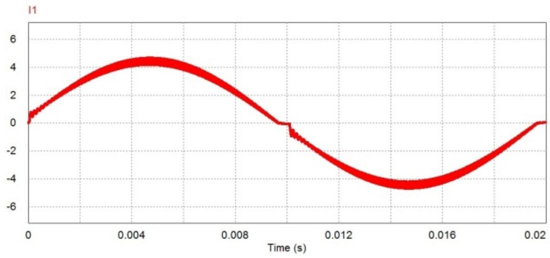

Figure 5. Input current waveform of Modified Half Bridge Resonant Inverter using MOSFET with LPF filter

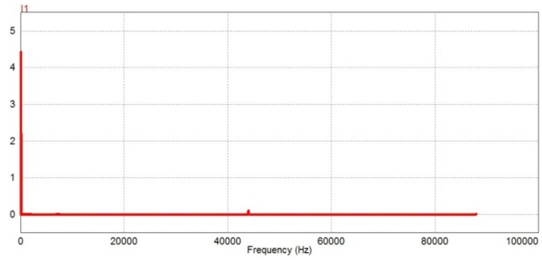

Figure 6. FFT of input current of the Modified Half Bridge Resonant Inverter using MOSFET with LPF filter

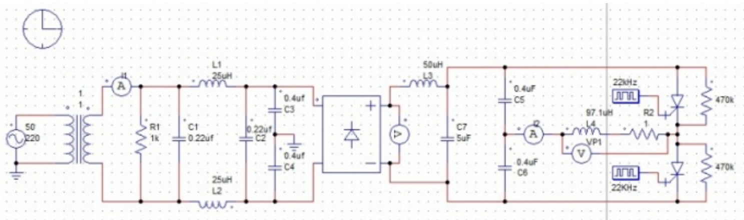

Figure 7. Modified Half Bridge Resonant Inverter circuit using GTO with LPF filter

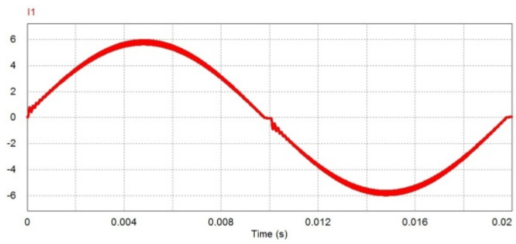

Figure 8. Input current waveform of Modified Half Bridge Resonant Inverter using GTO with LPF filter

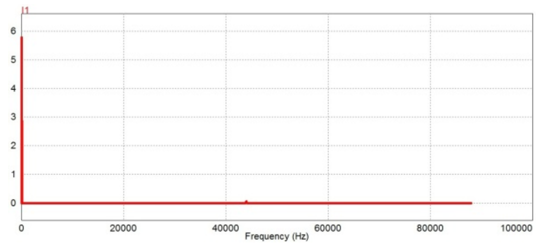

Figure 9. FFT of input current of the Modified Half Bridge Resonant Inverter using GTO with LPF filter

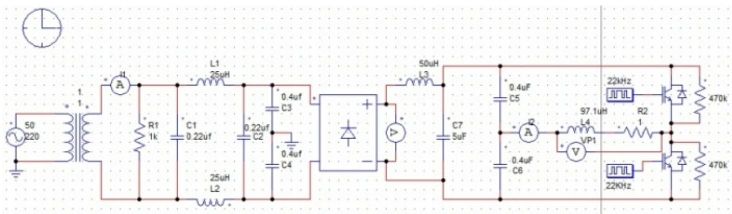

Figure 10. Modified Half Bridge Resonant Inverter circuit using IGBT with LPF filter

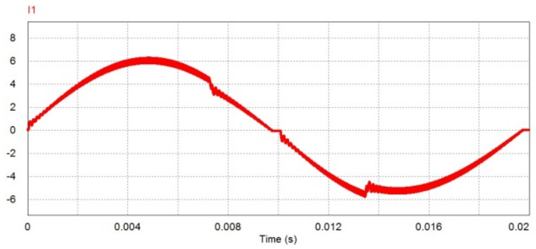

Figure 11. Input current waveform of Modified Half Bridge Resonant Inverter using IGBT with LPF filter

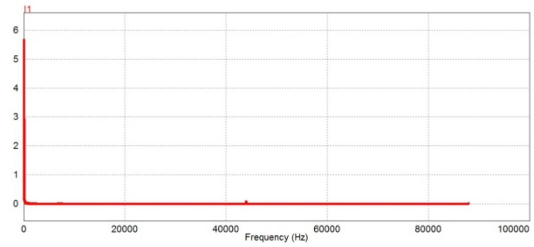

Figure 12. FFT of input current of the Modified Half Bridge Resonant Inverter using IGBT with LPF filter

6. LABORATORY TEST BENCH

Figure 13. Photograph of Experimental Set-up

7. CONCLUSION

Hence from the proposed topology it can be conclude that the different families of power semiconductor switches like GTO, IGBT and MOSFET are tested in modified half bridge resonant inverter fitted induction heater. To get minimum harmonics injection in the supply and to improve the efficiency of the inverter the proposed scheme can be employed in high frequency induction heating system. After comparing the wave-forms analysis of PSIM simulation, it is quite obvious that the selection of power semiconductor likely IGBT will be more suitable power semiconductor switch in high frequency modified half bridge resonant inverter. It has advantageous for reduced harmonic injection in power supply of induction heater. Again THD analysis is proven that selection of IGBT semiconductor switch is the best for induction heating applications.

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