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Harmonics Suppression of AC Source Current of a Single Phase Source Fed Induction Heating System

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Abstract. Any high frequency Induction heating system while undergoing through very high frequency switching operations, produces Electromagnetic Interference (EMI) noises or very high frequency harmonics within the system. These high frequency EMI noises conductively propagate towards the input AC source and distort the sinusoidal input AC current and make it non-sinusoidal. The desired performance from the induction heating cannot be anticipated. As such, it is inevitable to eliminate such EMI noises from the input AC source current to get the desired performance. Here, a specially designed ring type LC low pass passive filter is proposed which can accomplish to suppress these high frequency EMI noises up to satisfactory level and can restore the sinusoidal shape in the input AC source current waveform and thus improves the power quality of the AC supply for the induction heating system. The impact of the induction heating system without and with incorporating the proposed filter will be compared in this study.

Keywords. Induction Heating, EMI noises, Resonant inverter, Switching frequency

1. Introduction

During recent years, Induction heating process is regarded as one of most significant heating process that can provide a very fast heating method [1]. Induction heating process is also regarded as one of the energy efficient controllable process. In various domestic, commercial and industrial applications it can be utilized [1]. In this process no toxic gasses are produced and thus it is gradually gaining popularity due to its eco-friendly nature and thus induction heating process does not cause any health hazards to the consumers.

Induction heating method can provide faster heating due to the generation of very high frequency electromagnetic field produced by a working coil. The working coil produces this high frequency magnetic field, whenever a very high frequency current is sent by a 'Resonant Inverter' [2] produces it. The resonant inverter works as a very high frequency ac current generator. So far, various resonant inverter topologies have been developed, which can be selected in accordance to various applications with distinct power ranges. The mostly cheap and frequently used resonant inverter topologies are single switch based quasi-resonant inverter topology, the half-bridge inverter topology [2, 3], full-bridge inverter topology, hybrid inverter topology etc [4]. Any induction heating system demands a

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utility frequency AC supply, which must provide a pure sinusoidal voltage and current at the input of the induction heating system. However, regarding the very high frequency switching operations of the resonant inverter and non-linear tendencies of the inductive load up to a certain level, very high frequency Electromagnetic interference (EMI) or high frequency noises within the resonant inverter [5]. These high frequency noises have a tendency to be conducted towards the input AC source and superimpose on the input AC source current, distorts it and makes it non-sinusoidal in nature. This will cause adverse results on the normal conventional operation of the induction heating system. As such, to accomplish normal operation of the induction heating system to get desired performance, these high frequency EMI noises must be blocked up to allowable level [5]. Suitably designed and passive filters are suggested in various electrical systems for harmonics suppression [5, 6]. In this paper, the performance of an LC type passive filter is analyzed, which can suppress high frequency conducted EMI noises in the input AC source current in a high frequency full-bridge series resonant inverter fitted induction heating system fed by Asymmetrical Voltage Cancellation (AVC) technique. It will be proved that the proposed filter can suppress high frequency EMI noises up to satisfactory level and improves the performance of the induction heating system to a great extent.

2. Operational Principle of the Proposed Induction Heating System

The following Figure 1 is depicting the proposed induction heating system fitted with the proposed low pass EMI filter.

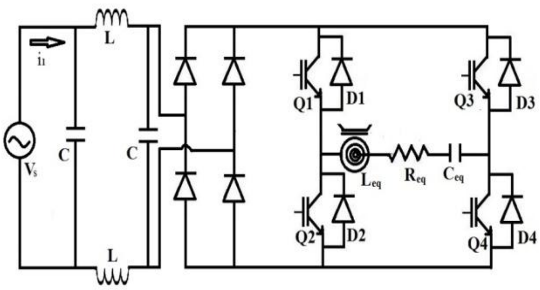

Figure 1. Proposed Induction Heating System fitted with Filter.

It consists of a series resonant load carrying an equivalent resistance R_{eq}, equivalent inductance L_{eq} and resonant capacitance C_{eq} respectively. Four IGBTs (Q1-Q4) are the main power semi-conductor high frequency switches which conduct the main load current. The four anti-parallel diodes (D1-D4) provide the path for the load current during the reverse conduction in the freewheeling period. Each IGBT can undergo the zero voltage switching (ZVS) condition during the turning process ensured by each freewheeling diode.. The utility frequency AC voltage (50 Hz) is at first rectified by uncontrolled rectifier unit, the rectified DC voltage is held constant by a DC link incorporating a large capacitor. Such DC voltage is converted to very high frequency AC voltage by the proposed full-bridge series resonant inverter, which sends a very high frequency AC current through the working coil that results a very high frequency electromagnetic field and it will cause the generation of heat in the work-piece. The high frequency AC current produced by the resonant inverter is continuously controlled by the by the asymmetrical voltage cancellation soft-switching techniques. But, regarding high frequency switching operations of all the IGBTs and due to non-linear behavior the series resonant load, very high frequency harmonics are generated which will superimpose on the main sinusoidal AC waveform and will distort it and will force it to be non-sinusoidal. Such high frequency harmonic current is known as Electromagnetic Interference (EMI). A suitably designed LC filter has the capability to suppress this high frequency harmonic current and can maintain the input AC source current sinusoidal.

3. Asymmetrical Voltage Cancellation (AVC) Technique

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Among various fixed frequency soft-switching techniques, AVC technique is considered as one of the effective and reliable fixed frequency control technique and can be used to regulate output power over wide range ensuring the ZVS (Zero Voltage Switching) condition throughout both on and off state conditions. This control technique possesses higher flexibility regarding the existence of three basic control parameters, which are α_+, α_- and β respectively as shown in Figure 2 in the typical output voltage waveform.

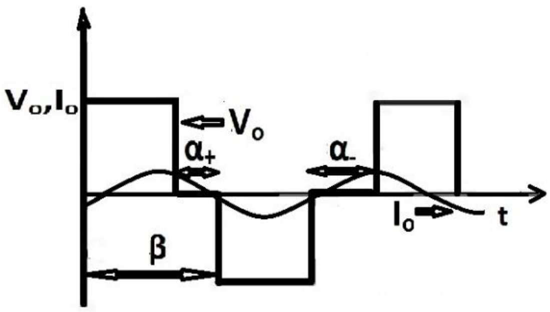

Figure 2. Typical Output Voltage and Current Waveforms under AVC Control Scheme.

The output power under AVC control scheme can be expressed as follows

$$P_o = \frac{V_{o1}^2}{2R_{eq}\left[1+Q_l^2\left(\omega_n - \frac{1}{\omega_n}\right)^2\right]} \tag{1}$$

Where, V_{o1} is the fundamental output voltage, R_{eq} is the equivalent resistance of the system including both working coil and work-piece and Q_l is the load quality factor.

$$Q_l = \frac{\omega_o L_{eq}}{R_{eq}} = \frac{1}{\omega_o R_{eq} C_{eq}} \tag{2}$$

and the expression of the normalized switching frequency is as follows

$$\omega_n = \frac{\omega_s}{\omega_o} \tag{3}$$

Where, ω_s is the switching frequency and ω_o is the resonant angular frequency and can be expressed as

$$\omega_o = \frac{1}{\sqrt{L_{eq}C_{eq}}} \tag{4}$$

Where, L_{eq} and C_{eq} are equivalent inductance and capacitance of the series resonant load.

4. EMI Filter Design for Harmonics Suppression in AC Source Current

An ideal low pass filter is a network, which passes signals within a certain specific frequency band, and blocks the signal higher than that frequency band. The following Figure 3 depicts the proposed low pass filter.

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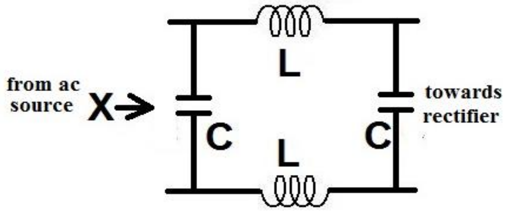

Figure 3. Proposed LC type Passive Low Pass Filter.

This low pass filter can be fitted with a line impedance stabilizing network (LISN) to suppress the unwanted high frequency harmonics in the input source current.

The following expression gives the equivalent reactance of the filter network from the AC supply

$$X = \frac{\frac{2L}{C} - \frac{1}{\omega^2}}{2j\left(\omega L - \frac{1}{\omega C}\right)} \tag{5}$$

At resonant frequency, X will be very high which is

$$\omega = \omega_1 = \frac{1}{\sqrt{LC}} \tag{6}$$

Here, L= 200 μH and C= 0.1 μF and as such the cut-off frequency regarding the filter is f_1= 35.6 kHz and the filter can block the high frequency current waveform with fundamental frequency of 40 kHz which is also the fundamental frequency regarding load current.

5. Simulation Results

The overall analysis is realized through Power System Simulator (PSIM) software. At first the performance of the proposed induction heating system is analyzed and thereafter, the performance of both the low pass filter and the induction heating system is investigated. The following Figure 4 is representing the PSIM simulated circuit diagram of the induction heating system without the incorporation of the filter. The selected switching frequency is 40 kHZ, whereas, the selected equivalent load parameter values are $R_{eq} = 1\Omega$, $L_{eq} = 50\mu H$ and $C_{eq} = 0.6\mu F$ respectively.

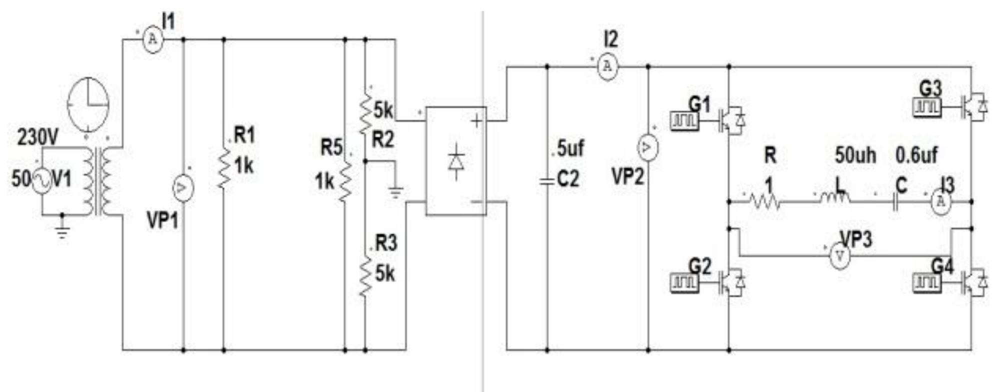

Figure 4. PSIM Simulated Circuit Diagram of the Induction Heating System without Filter.

The following Figure 5 is depicting the input AC source current waveform following the PSIM simulation of the proposed induction heating system without using filter.

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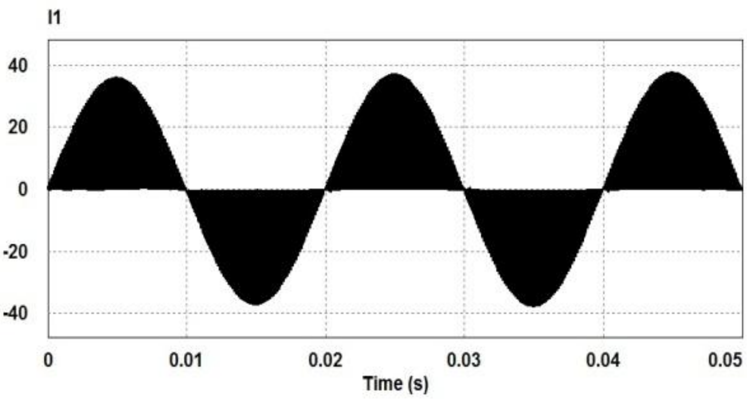

Figure 5. Input AC Source Current Waveform for $\alpha = 30^{o}$ without incorporating the Filter.

Now, Figure 6 is depicting the PSIM simulated circuit diagram of the proposed induction heating system incorporating the proposed low pass filter.

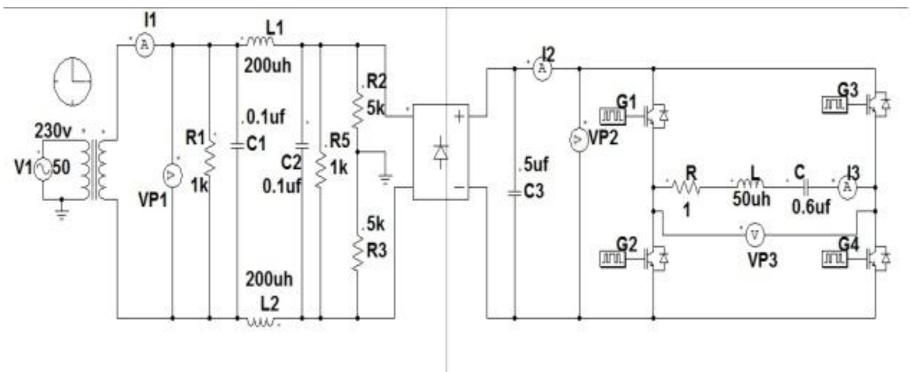

Figure 6. PSIM Simulated Circuit Diagram of the Induction Heating System with incorporating Filter.

The following Figure 7 is depicting the input AC source current waveform following the PSIM simulation of the proposed induction heating system incorporating the filter.

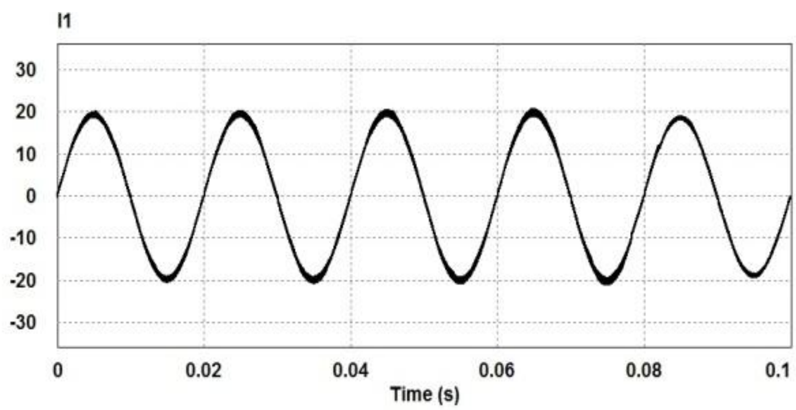

Figure 7. Input AC Source Current Waveform for $\alpha = 30^{o}$ with incorporating the Filter.

6. Results and Discussions

From the software simulations as obtained from Figure 5 and Figure 7, two different results are achieved. In the first case, as obtained from the simulation of the circuit depicted in Figure 4, the input

AC source current waveform is non-sinusoidal containing a large amount of very high frequency EMI noises, which are produced due to very high frequency switching operations. A suitably designed low pass filter can suppress all these high frequency EMI noises, which is incorporated in the induction heating system as shown in the PSIM diagram in Figure 6. Following the simulation of that circuit, the input AC source current obtained in this case as shown in Figure 7 is almost sinusoidal, which indicates that the low pass filter suppresses the high frequency noises up to a satisfactory level.

7. Conclusions

Due to high frequency switching operations and due to the presence of non-linear load, high frequency EMI noises are produced in the induction heating system, which is conducted towards the input AC supply and superimposes on the main sinusoidal AC waveform of line frequency. This causes distortion in the input AC source current waveform and converts to be a non-sinusoidal waveform. After the incorporation of the proposed LC ring type low pass filter, the conducted EMI high frequency noises are suppressed up to a satisfactory level and the input AC source current waveform becomes almost sinusoidal and improves the power quality of the single phase AC supply.

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