Debabrata ROY[1], Pradip Kumar SADHU[2], Nitai PAL[2]

Batanagar institute of engineering management and science, Kolkata-141 (1),
Indian School of Mines (Under Mhrd, Govt. Of India), Dhanbad, Jharkhand-826004, India (2)

doi:10.15199/48.2015.04.27

Reduction of Harmonics Contained in the Input Power Supply - Dynamic Tool for Current Source Full-Bridge Inverter Based Induction Heater

***Abstract**. This paper highlights an approach to drastically minimize the injection of unwanted harmonics to the input power supply incorporating an LC low-pass filter (LPF) which is fitted in between the high frequency current source full bridge inverter used in induction heater and input power supply. This LPF protects the other consumers those are connected on the same power line from the spurious signals. Fast Fourier Transform (FFT) has been used to perceive between the fundamental and the unwanted harmonics. It is a better analytic tool for diagonising all spurious signals in the frequency domain. From the result of PSIM simulation, it has been established that the Total Harmonic Distortion (THD) get reduced drastically from 49.63% to below 4.768% by incorporating the LPF.*

***Streszczenie.** W artykule opisano metodę minimalizacji zawartości harmonicznych w wysokoczęstotliwościowym pełno-mostkowym przekształtniku stosowanym do nagrzewania indukcyjnego. Zastosowany filt dolnoprzepustowy chroni innych użytkowników sieci przed niepożądanymi zakłóceniami.* **Redukcja zawartości harmonicznych w prądowym zasilaczu prądowym stosowanym do nagrzewania indukcyjnego**

Keywords: Current Source Full Bridge Inverter, Harmonics, LPF, PSIM simulation, FFT, THD.
Słowa kluczowe: źródło prądowe, zawartość harmonicznych, nagrzewanie indukcyjne

Introduction

The DC-link high frequency current source full bridge inverter that used in induction heater produces an alternating current for contactless induction heating [1]-[4]. The several applications of such inverters are in the field of air-craft power supply, switching mode power supply (SMPS), grid isolation in case of grid connected solar photovoltaic power generation, HVDC link, high frequency induction heating and microwave heating. The output frequency of such inverters is controlled by gating signal of power semiconductor switches and output voltage is controlled by variable DC-link voltage [8]-[11]. Current source used as an input of high frequency inverter is more acceptable than voltage source in case of variable work load in induction heater [5]-[6]. Moreover this topology generates high frequency alternating current for the contact-less load of induction heater from the single phase or three phase low frequency (i.e. 50 Hz as per Indian Standard) power. The block diagram of total DC-link high frequency current source full bridge inverter fitted induction heater system is given in figure.1.

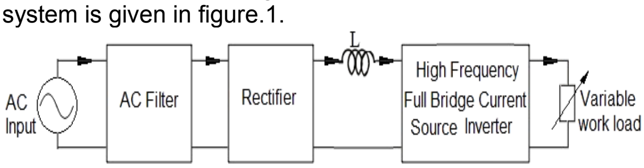

Fig. 1: Block Diagram of DC-link high frequency current source full bridge inverter fitted induction heater system

Different types of high frequency inverters

A. Single-phase high power and single-phase low power load resonant inverters

The circuit topologies of single phase load resonant inverter are usually selected on the basis of power delivering to the load. In general, single phase full bridge hybrid load resonant inverter circuit is very much suitable for high power application. Moreover the power delivery capacity of full bridge series load resonant inverter circuit is more appropriate for medium power application. On the other hand, modified half bridge inverter topology is used when the load power requirement is very low (less than 1KW).

B. Voltage source and current source inverters

In accordance with the circuit electromagnetic processes, voltage source inverters (VSI) and current source inverters (CSI) are distinguished. A VSI is the most commonly used for high frequency induction heating system. The output signal of such inverter is a function of voltage source. This inverter has low internal impedance. Generally, it has a capacitor of high capacity which is connected across the supply that keeps the voltage level constant. The another feature of VSI is that it has bi-directional input current. To provide this peculiarity, power semiconductor switches must be constructed with a freewheeling diodes. The output current of the VSI is generated according to the voltage value and the load impedance. There is usually provision for adjustment the output voltage of the inverter. Firstly by varying DC input voltage which is supplied to the inverter, the output voltage can be varied. Secondly the alternative way of ac voltage variation is within the inverter by a modulation technique which is not possible for high frequency inverter i.e If the high frequency range is from 10 kHz, the modulation technique is possible (For example PWM for the power control in induction heating systems). For high frequency VSI, the first method is adoptable.

In CSI inverter the current source is used as input power supply of an inverter. The switches of the inverter periodically change the output current direction. The load of the inverter has the properties of the voltage source with almost zero reactance at resonant condition. Since the reflected work path resistance values of induction heater is 1Ω to 5Ω only. CSI is the only inverter topology which can support the varying secondary load. Overall CSI is more acceptable over VSI for variable load induction heater.

The harmonic content

The input waveforms of an ideal inverter should be sinusoidal. But, in practice, the waveforms are non-sinusoidal then it contain harmonics. The existence of harmonics can be visualized either in the time-domain or in frequency domain. The availability of high speed power semiconductor devices has enabled to reduce the harmonic contents in the input voltage significantly by switching techniques. Total Harmonic Distortion (THD) is a measure of the closeness of a waveform with its fundamental component. The task of the power electronics engineer is to reduce THD – it is accomplished by a passive LC Low Pass filter, appended at the input terminal which provides low harmonic content. Now a days, researchers are more interested to implement the active filters but the active filters are not possible for fundamental high frequency current of 22 kHz; of CSI. Because the generation of corrective signal of second order or fourth order harmonic content of 22 kHz; is very much difficult.

Current source full bridge inverter based induction heater

The full bridge CSI circuit is normally used for high power variable load. Figure. 2 represents the circuit diagram of DC-link high frequency current source full bridge inverter fitted induction heater system. In this circuit diagram four power transistors are used and two switches are triggered simultaneously. The diodes D1, D2, D3 and D4 are connected in series with power transistors for increasing number of junctions. Due to change of load and transient voltage arrises across the power transistors created high rate of change of voltage (dv/dt) across two transistors during turn ON and turn OFF, which try to fails the inverter operation due to thermal runway of the junctions of semiconductor switches. So to reduce this rate of change of voltage (dv/dt) in each junction the additional diodes are connected in series with the power transistors in each limb of full bridge circuit.

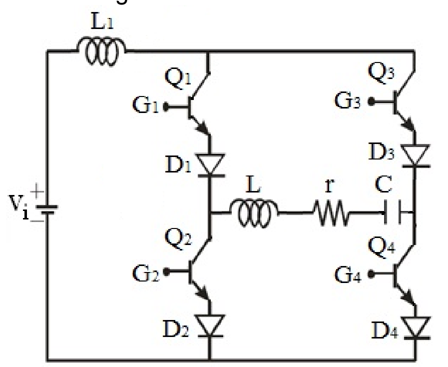

Fig. 2. Circuit diagram of DC-link high frequency current source full bridge inverter fitted induction heater system

The circuit is ON when switches Q1 and Q4 are triggered simultaneously. The current flows for a Full cycle of the resonant frequency and become zero when both switches Q1 and Q4 are turned off. When Q1 and Q4 stop conducting and switch Q2 and Q3 are turned ON, the power transistor which are connected with the respective switches. Finally the high frequency output will be produced in the working coil.

Commonly, in inverter the large inductor connected in series to the DC supply source, which keeps the current constant. CSI requires a DC current source at the input. Here large value inductor L is connected in series with DC link which can convert DC voltage source to current source at the input of such inverter. CSI can be used for such electrical equipment that needs the control of the current value likely variable load induction heating etc.

Analytical tools

The quality of the inverter can be obtained by THD and Fast Fourier Transform (FFT), analysis. It is a powerful mathematical tool which separates out the fundamental and the harmonic contents. FFT analysis is an essential digonesis tool for the AC passive LC filter design and practical implementation.

A. Total harmonic distortion (THD)

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

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

It is the ratio of the RMS value of all non-fundamental frequency components to the RMS value of the fundamental. For a rectangular wave the value of THD is very large. In quasi-rectangular form, the value is relatively less.

T.H.D Calculation of DC-link high frequency current source full bridge inverter fitted induction heater system without filter. Figure. 4 associated with the simulated wave shape of input current for the Current Source Full Bridge Inverter without Filter. From this simulated waveform the RMS value of input current can be obtained i.e R.M.S value of input current,I_2=31.17A

Figure.5 represents the FFT for Current Source Full Bridge Inverter without filter. From the FFT spectrum the THD cab be obtained which is as follows,

(2) $$T.H.D = \frac{\sqrt{\sum_{n=2,3,...}^{n} I_{r.m.s}^2}}{I_{1r.m.s}} = \frac{\sqrt{(15.39)^2 + (1.59)^2}}{31.17} A$$

$$= \frac{\sqrt{239.38}}{31.17} \times 100\% = 49.63\%$$

T.H.D Calculation of DC-link high frequency current source full bridge inverter fitted induction heater system with filter. From figure.7 it can be depicts that the R.M.S Value of Input Current incorporating the filter circuit at the supply side. i.e R.M.S value of input current, I_2=41.06A

Figure.5 represents the FFT for Current Source Full Bridge Inverter with filter. From the FFT spectrum the THD cab be obtained which is as follows,

(3) $$T.H.D = \frac{\sqrt{\sum_{n=2,3,...}^{n} I_{r.m.s}^2}}{I_{1r.m.s}} = \frac{\sqrt{(1.62)^2 + (1.10)^2}}{41.06} A$$

$$= \frac{\sqrt{3.8344}}{41.06} \times 100\% = 4.768\%$$

Table 1. THD values for variable path resistances (from 1Ω to 5Ω)

Serial No	Value of Resistance	T.H.D Without Filter	T.H.D With Filter
1	1ohm	49.63%	4.768%
2	2ohm	43.33%	4.44%
3	3ohm	40.28%	4.25%
4	4ohm	38.50%	3.82%
5	5ohm	37.25%	3.74%

B. Fast fourier transform (FFT) analysis

It is a linear algorithm that can transform a time domain signal into its frequency domain equivalent and back. A better understanding of an unknown signal is obtained in the frequency domain.

C. Lc-low pass filter

An LC-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.

Simulation and results

Figure. 3 gives the simulated circuital configuration of a current source full-bridge inverter without filter. The portion to the left of the rectifier-bridge (shown as a block) is at power frequency. In the portion to the right of the rectifier-bridge, there is the current source full-bridge inverter, operating at high frequency (i.e.22kHz); and feeding the load. The frequency can be varied by varying the pulse rate of the logic train. The load is represented as a series combination of resistance, inductance and capacitance. Both these parameters vary along with temperature rise. An inductance is placed in series with the rectifier output to smooth out the ripples as far as possible so as to realize a current source.

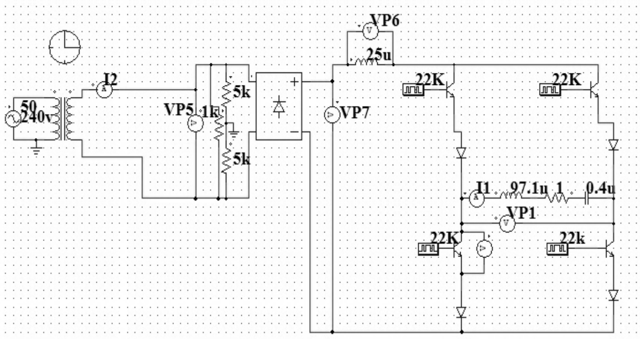

Fig. 3. Current Source Full Bridge inverter without filter

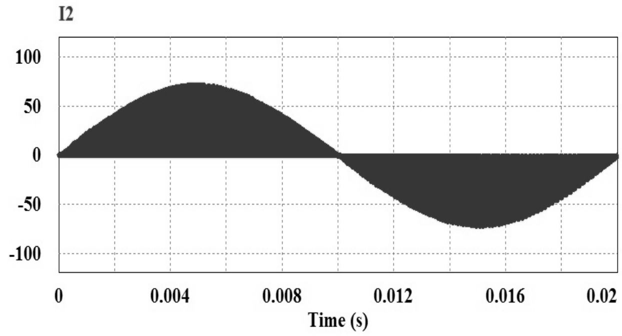

Fig. 4. Wave shape of input current for the Current Source Full Bridge Inverter without Filter

Figure. 4 shows the wave-form of the input current of the rectifier section for the current source full-bridge without filter. Figure. 5 shows the FFT for the same. It may be noted that the 3rd and 5th harmonics are dominant. To reduce the level of harmonics, LC LPF is incorporated at the input side.

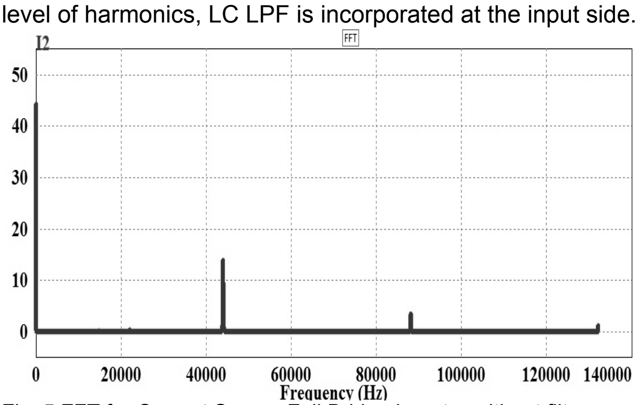

Fig. 5 FFT for Current Source Full Bridge Inverter without filter

Figure. 6 shows the circuit configuration for the current source full-bridge inverter with LC filter. Figure. 7 shows the wave-shape of the input current and Figure. 8 shows the FFT of input current.

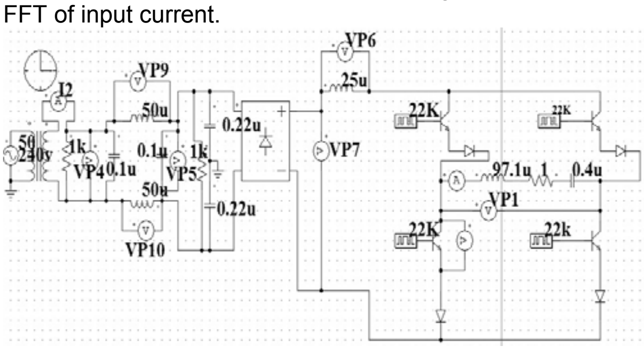

Fig. 6 Current source full bridge inverter with filter

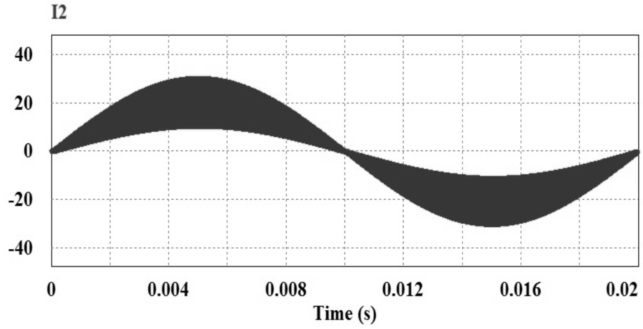

Fig. 7. Wave-shape of the input current to the current source full bridge inverter with filter

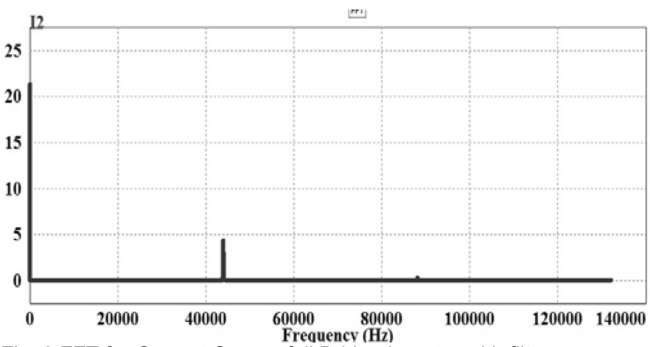

Fig. 8 FFT for Current Source full Bridge Inverter with filter

It is observed from the wave-shapes that the noise in the input current is much less after incorporating LC filter. It is revealed from the FFT that the harmonic contents are almost absent.

Conclusion

High frequency CSI inverters are fed from power frequency supply through transformer, rectifier bank and associated equipment. Harmonic distortions and penetration of noise occur invariably in them due to high frequency switching. The high frequency components in the input current are again processed through the rectifier and fed to the inverter, thus giving rise to a recurrent action. An input with reduced harmonic distortion and noise is highly desirable. This objective can be fulfilled by inserting a passive LC filter in cascade with the input section. The LC low pass filter is to be designed properly so as to suppress the unwanted harmonics. This objective has been fulfilled by the use of a properly chosen LPF. The paper has described the design and analysis of DC-link high frequency current source full bridge inverter fitted induction heater system. Achieving low distortion in this process ensures high quality of power at the supply end. A well-designed filter can attenuate the harmonics which is generated due to power semiconductor switching. The injection of harmonics into the power supply is to be limited as per specified standards. The proposed scheme employs passive LC filters to meet the standards on utility distortion limits imposed by regulatory authorities. It limits the injection of current harmonics and improves power quality at the supply end.

Acknowledgment

Authors are thankful to the UNIVERSITY GRANTS COMMISSION, Bahadurshah Zafar Marg, New Delhi, India for granting financial support under Major Research Project entitled "Simulation of high-frequency mirror inverter for energy efficient induction heated cooking oven" and also grateful to the Under Secretary and Joint Secretary of UGC, India for their active co-operation. is to be limited as per specified standards. The proposed scheme employs passive LC filters to meet the standards on utility distortion limits imposed by regulatory authorities. It limits the injection of current harmonics and improves power quality at the supply end.

REFERENCES

[1] Alireza Namadmalan and Javad Shokrollahi Moghani *"Self-Oscillating Switching Technique for Current Source Parallel Resonant Induction Heating Systems"* Journal of Power Electronics, vol. 12, no. 6, November 2012.

[2] A.J. Onah, *"Harmonics: Generation and Suppression in AC System Networks"*, Nigerian Journal ofTechnology, Vol. 31, No. 3, November, 2012, pp. 293-299.

[3] A. Suresh and S. Rama Reddy *"Series and Parallel Resonant Inverter Fed Ferromagnetic Load-A Comparative Analysis"* International Conference on Emerging Trends in Computer and Image Processing (ICETCIP'2011) Bangkok December, 2011.

[4] B. Singh, K. Al-Haddad, and A. Chandra, *"A Review of Active Filters for Power Quality Improvement", IEEE Transactions on Industrial Electronics*, Vol. 46. No. 5, 1999, pp .960-971. Simulation Using MATLAB 7.5

[5] Dahono P.A., Purwadi A., Qamaruzzaman: *An LC filter design method for single-phase PWM inverters. Power Electronics and Drive Systems*, Proceedings 1995, Vol.2, pp.571–576.

[6] D.E. Steeper and R.P. Stratford, *"Reactive Compensation and Harmonic Suppression for Industrial Power Systems Using Thyristor Converters"*, IEEE Transactions on Industry Applications, Vol. 12, 1976, pp 232-254.

[7] Diego Puyal, Carlos Bernal, Student Member, IEEE, José M. Burdío, Member, IEEE, Jesús Acero, Member, IEEE, and Ignacio Millán,Versatile High-Frequency Inverter Module for Large-Signal Inductive Loads Characterization Up to 1.5 MHz and 7 kW *IEEE TRANSACTIONS ON POWER ELECTRONICS*, VOL. 23, NO. 1, JANUARY 2008 PP75-86

[8] Dr. S. P. Chowdhury A new generation fluid heating using BJT and IGBT-by– Published in *"Journal of the institution of engineers"* volume-82 March, 2002, P. P 273 -280.

[9] Iran Azim, Habibur, Rahman. *Analysis & Simulationof Total Harmonic Distortion in Hysteresis Inverter.International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)* Vol.2, Issue.3, March, 2013, pp.574-578.

[10] Imran Azim, Habibur Rahman. *Harmonics Reduction of a Single Phase Half Bridge Inverter, Global Journal of Research in Engineering*,Vol.13 Issue 4,Version 1, 2013, pp.9-12.

[11] J. Kim, J. Choi, H. Hong, *"Output LC filter design of voltage source inverter considering the performance of controller"*, Power System Technology, Proceedings 2000,Vol. 3, pp.1659–1664.

[12] Jose M. Burdio, Fernando Monterde, Jose R. Garcia, Luis A. Barragan, and Abelardo Martinez, *A two-output series-resonant inverter for induction-heating cooking appliances, IEEE Trans. Power Electron.*, Vol. 20, No. 4, , July 2005, pp. 815-822.

[13] Kazuki Saso, Takahiro Ito, Yusuke Ishimaru, Kouki Matsuse and Masayoshi Tsukahara *"Adjustable High Frequency Quasi-Resonant Inverter for Induction Heating"* Journal of International Council on Electrical Engineering vol. 1, no. 1, pp. 104-109, 2011.

[14] M.A Inayathullaah, Dr. R. Anita, *"Single Phase High Frequency Ac Converter For Induction Heating Application"*, International Journal of Engineering Science and Technology, vol.. 2 no.12,pp. 7191-7197, 2010.

[15] Omar El-Nakeeb, Mostafa I. Marei, Ahmed A. El-Sattar *"A High Frequency modular Resonant Converter for the Induction Heating"* International Journal of Emerging Technology and Advanced Engineering Website: www.ijetae.com ,ISSN 2250-2459, ISO 9001:2008 Certified Journal, vol. 3, Issue 2, February 2013.

[16] P.A. Dahono, A. Purwadi, Q. Amaruzzaman, *"An LC filter design method for single-phase PWM inverters"*. Power Electronics and Drive Systems, Proceedings 1995, Vol.2, pp.571–576.

***Authors**: asst. prof. Debabrata Roy, Batanagar institute of engineering management and science, kolkata-141, E-mail: debabrataroy1985@gmail.com; prof. dr.Pradip Kumar Sadhu, Head of the department of electrical engineering, Indian school of mines (under mhrd, govt. Of india), dhanbad, jharkhand 826004, india, E-mail: pradip_sadhu@yahoo.co.in; assoc. prof. dr. Nitai Pal, Indian school of mines (under mhrd, govt. Of india), dhanbad, jharkhand 826004, India, E-mail: nitai_pal@rediffmail.com.*