Fuzzy Logic Control of Single Phase Matrix Converter Fed Induction Heating System

P. Umasankar [#1], Dr.S.Senthilkumar [*2]

[#] Research Scholar, Anna University
Department of Electrical & Electronics Engineering,
Chennai, TN, India

[*] Asst. Prof,
Department of Electrical & Electronics Engineering,
Govt. College of Engineering, Salem, TN, India

Abstract— This article represents the modeling and simulation of a Single Phase Matrix Converter (SPMC) fed Induction Heating (IH) system. The working principle and the control system using Fuzzy Logic Controller (FLC) are elucidated in detail. The performance of the system and their harmonic content analysis of Single Phase Matrix Converter are carried out in MATLAB/Simulink environment. Pulse Width Modulation (PWM) switching strategy by varying the duty cycle based on Fuzzy Logic Control is employed to obtain better performance for a constant voltage, constant frequency input supply for various output frequencies. The proposed control strategy results achieve low Total Harmonic Distortion (THD) for various operating frequencies without large reactive storage elements.

Keyword- Single Phase Matrix Converter, Fuzzy Logic Control, Induction Heating, Total Harmonic Distortion, Pulse Width Modulation

I. INTRODUCTION

Induction Heating (IH) systems have been deployed in various industrial applications such as melting, forging, hardening, tempering, annealing, brazing, bonding, welding, specialty heating, plastic injection molding, etc., and in domestic applications such as cooking, boiling, and super heating applications. A typical Induction Heating [1-4] system necessitates high frequency AC supply for which inverters or AC – AC converters or AC – DC – AC converters were being employed.

The AC – AC converters when compared to DC link converters possesses more advantage such as variable frequency, variable voltage output from a fixed frequency and fixed voltage input supply without any intermediary DC link, which is highly advantages for these type of converters over other conventional converter and the advancement of fast and efficient switching devices paved way for using these AC – AC converters in practice effectively.

The Matrix Converter [3-15] classified under AC – AC converters are bidirectional power flow converter. These converters utilize minimum energy storage elements whose performance over various operating frequencies can be controlled by varying the Pulse Width Modulation (PWM) signal applied to the switches of the converter. The Single Phase Matrix Converter (SPMC) [4], [7-8], [10] and Three Phase Matrix Converter (TPMC) [5-6], [9], [11-15] are used for various ranges of applications from domestic usage to industrial applications.

In this article a Single Phase Matrix Converter (SPMC) controlled by a Fuzzy Logic Controller (FLC) is employed to supply an Induction Heating (IH) system. The operation of FLC controlled SPMC and the performance of the system over different operating frequencies is revealed in the following sessions.

II. SPMC: MODES OF OPERATION

The Single Phase Matrix Converter (SPMC) block consisting of eight switches is designed in a matrix form of four switching blocks in a bidirectional switching pattern as shown in figure 1. Each switching block consists of two switches connected in anti-parallel direction as shown in figure 2 with a recovery diode for each switch. The output of the matrix converter is connected to the inductive heating system which is indicated by load as shown in figure 1.

The switching pattern of the Matrix Converter switches for a constant input supply frequency of 50 Hz is given in Table I for various output frequencies of the Matrix Converter fed Induction Heating system. Table I gives switching pattern for output frequencies 25 Hz, 50 Hz and 100 Hz whereas output frequencies 1 kHz, 10 kHz and 100 kHz switching pattern have 40, 400 and 4000 time intervals respectively for a single cycle of input waveform and hence not represented in the Table I.

There are basically four modes of operation, i.e., forward and reverse power flow for positive half cycle and forward and reverse power flow for negative half cycle as described below.

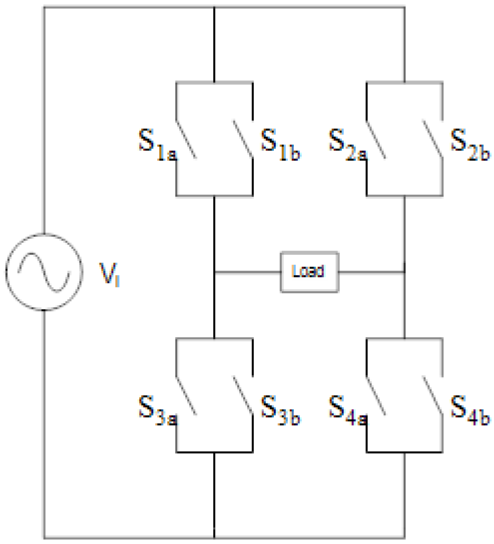

Fig. 1. Single phase matrix converter

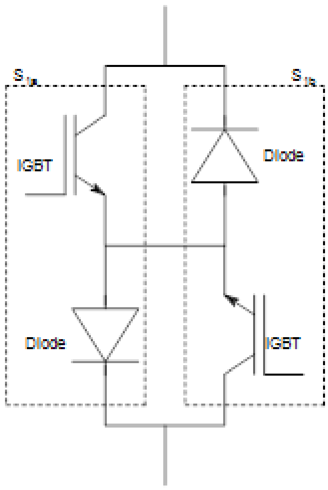

Fig. 2. Bidirectional Switch

TABLE I
Single Phase Matrix Converter Switching Sequence

Input Frequency	Output Frequency	Time Interval	Switching Mode
50 Hz	25 Hz	1	S_{1a} & S_{4a}
		2	S_{3b} & S_{2b}
		3	S_{2a} & S_{3a}
		4	S_{4b} & S_{1b}
	50 Hz	1	S_{1a} & S_{4a}
		2	S_{4b} & S_{1b}
	100 Hz	1	S_{1a} & S_{4a}
		2	S_{2a} & S_{3a}
		3	S_{3b} & S_{2b}
		4	S_{4b} & S_{1b}

A. *Mode I Operation*

In mode 1 operation as shown in figure 3 the switches S_{1a} and S_{4a} are triggered to conduct the positive half cycle of the input supply through the load in forward direction. These switches are controlled by the PWM signal generated through the controller.

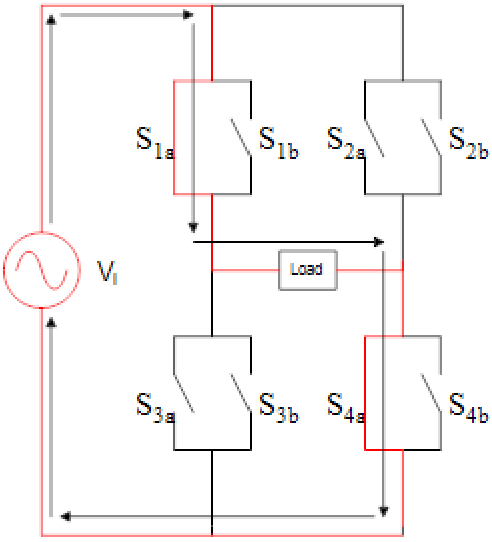

Fig. 3. Power flow in Mode 1 operation

B. *Mode II Operation*

In mode 2 operation as shown in figure 4 the switches S_{2a} and S_{3a} are triggered to conduct the positive half cycle of the input supply through the load in reverse direction. These switches are controlled by the PWM signal generated through the controller.

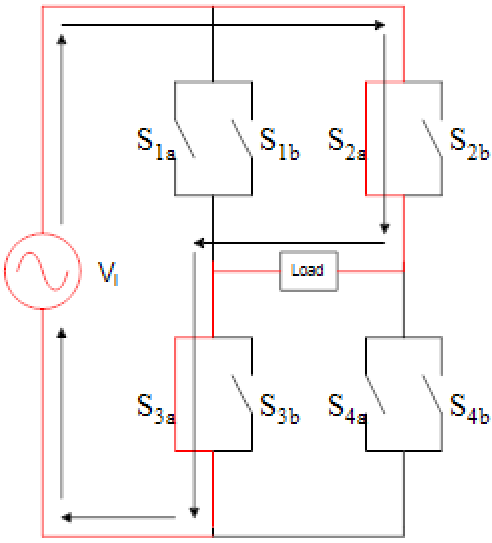

Fig. 4. Power flow in Mode 2 operation

C. *Mode III Operation*

In mode 3 operation as shown in figure 5 the switches S_{3b} and S_{2b} are triggered to conduct the negative half cycle of the input supply through the load in forward direction. These switches are controlled by the PWM signal generated through the controller.

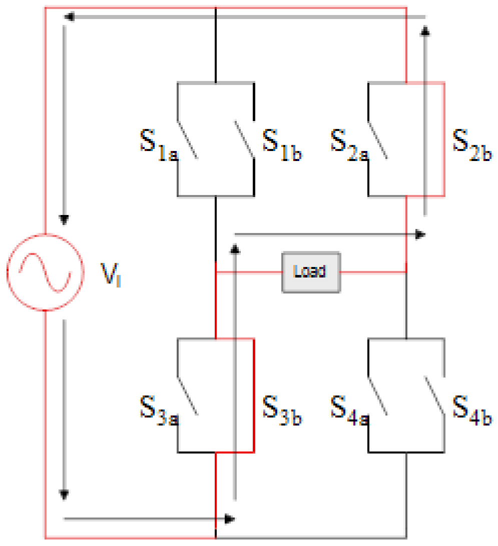

Fig. 5. Power flow in Mode 3 operation

D. Mode IV Operation

In mode 4 operation as shown in figure 6 the switches S_{1b} and S_{4b} are triggered to conduct the negative half cycle of the input supply through the load in reverse direction where these switches are controlled by the PWM control signal.

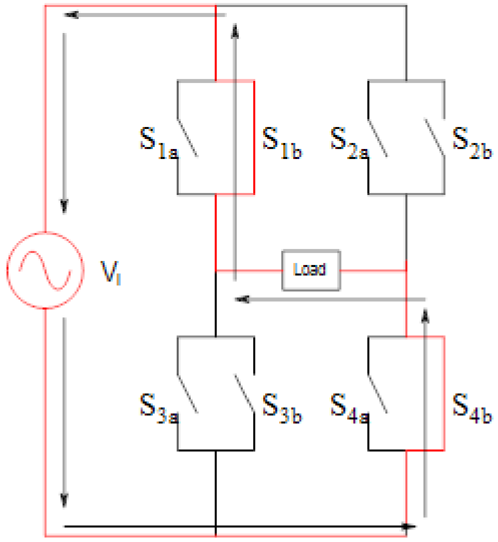

Fig. 6. Power flow in Mode 4.

III.FLC CONTROLLED SPMC FED IH SYSTEM

All The following figure 7 shows the Fuzzy Logic Controlled Single Phase Matrix Converter fed Induction Heating system block diagram, in which the output current is compared with reference current value and the error (e) signal and its derivative (ce) with respect to time is taken and both the signals are fed as input to the Fuzzy Logic Controller which produces a control signal (d) which is fed to PWM signal generator and this PWM signal is fed to the SPMC switches.

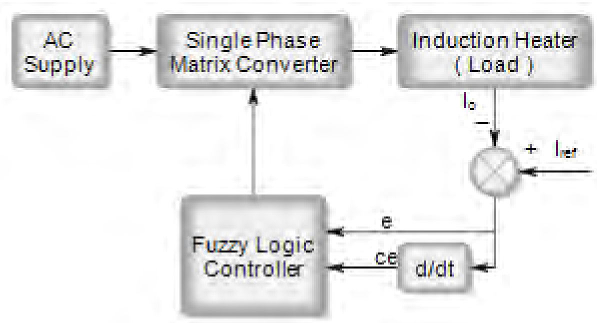

Fig. 7. Block diagram of FLC controlled SPMC fed IH system

The figure 8 indicates the Fuzzy logic input membership function error "e" pictorial view with the membership functions namely Negative Big (NB), Negative Medium (NM), Zero (ZE), Positive Medium (PM) and Positive Big (PB).

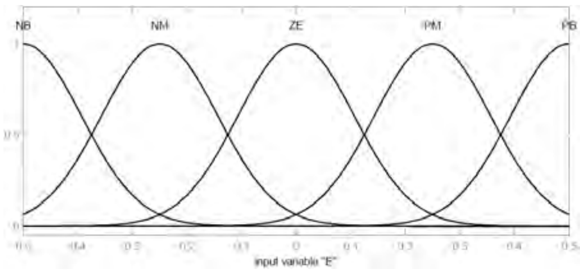

Fig. 8. View of Fuzzy membership function "e"

The following figure 9 indicates the Fuzzy logic input membership function change in error "ce" pictorial view.

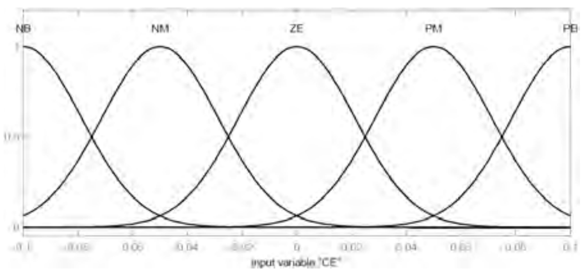

Fig. 9. View of Fuzzy membership function "ce"

The figure 10 indicates the Fuzzy logic output membership function duty cycle or control signal "d" pictorial view.

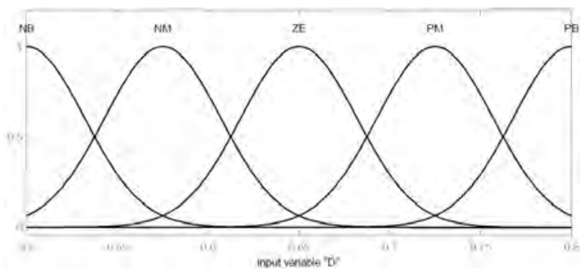

Fig. 10. View of Fuzzy membership function "d"

The following figure 11 indicates the Fuzzy logic controller rule base surface view for the input functions "e", "ce" and output function "d".

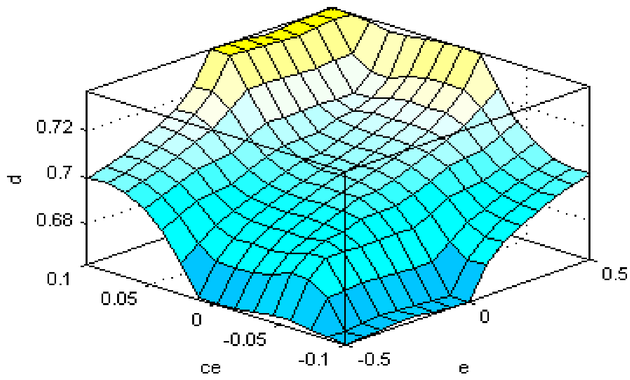

Fig. 11. FLC Rule base surface view

Table II indicates the Fuzzy Logic Controller rule base for the above said membership function classifications.

TABLE II
Fuzzy Rule Base

e\ce	NB	NM	ZE	PM	PB
NB	NB	NB	NB	NM	ZE
NM	NB	NB	NM	ZE	PM
ZE	NB	NM	ZE	PM	PB
PM	NM	ZE	PM	PB	PB
PB	ZE	PM	PB	PB	PB

IV. Results And Discussion

The results obtained from FLC controlled SPMC fed Induction Heating system for various operating frequencies from 25 Hz to 100 kHz is presented from figure 12 to figure 26.

Figure 12 shows the input voltage and output voltage for operating frequency of 25 Hz and figure 13 shows the corresponding output current fed to the single phase Induction Heating system load rated for 230 V, 2.25 A. Figure 14 depicts the THD measured for the corresponding operating frequency output. A THD of 7.25 is being measured for 25 Hz output frequency.

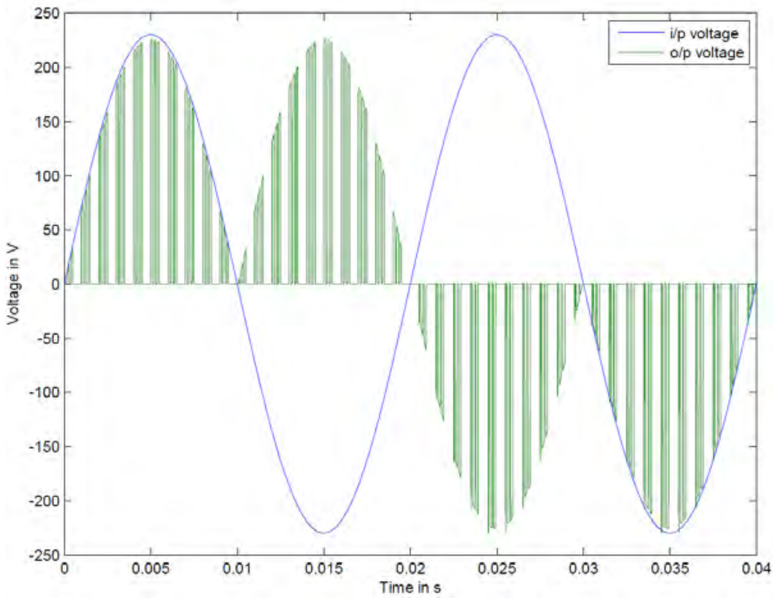

Fig. 12. Input and Output Voltage waveform for f_o = 25 Hz

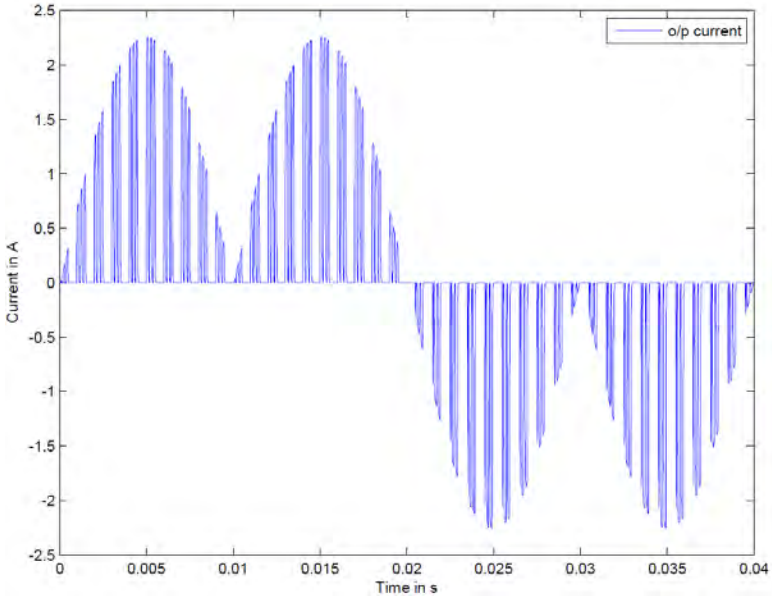

Fig. 13. Output Current waveform for f_o = 25 Hz

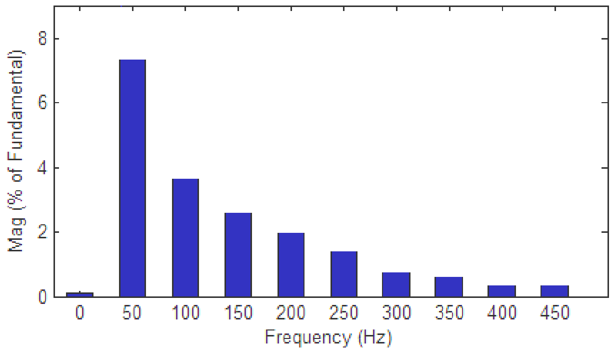

Fig. 14. THD for f_o = 25 Hz

Figure 15 shows the input voltage and output voltage for operating frequency of 50 Hz and figure 16 shows the corresponding output current fed to the single phase Induction Heating system load. Figure 17 depicts the THD measured for the corresponding operating frequency output. A THD of 6.78 is being measured for 50 Hz output frequency. Also the current and voltage waveforms are in phase which shows the unity power factor.

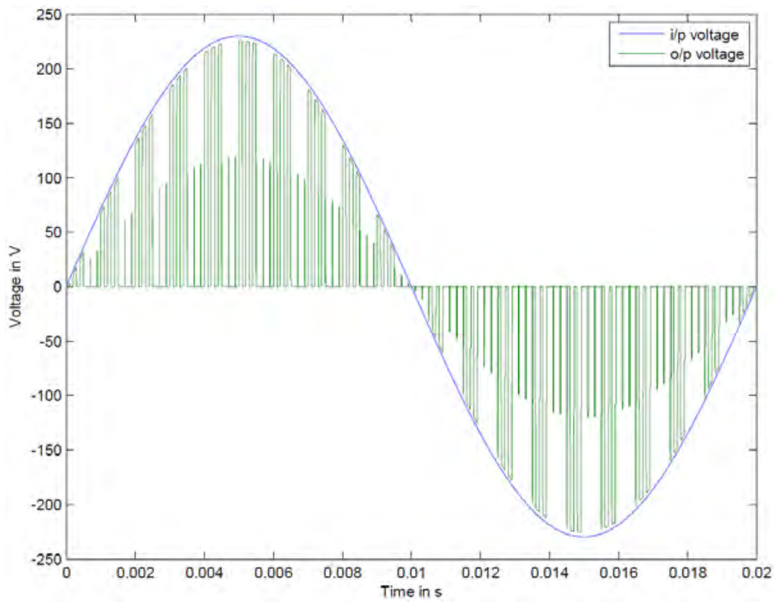

Fig. 15. Input and Output Voltage waveform for f_o = 50 Hz

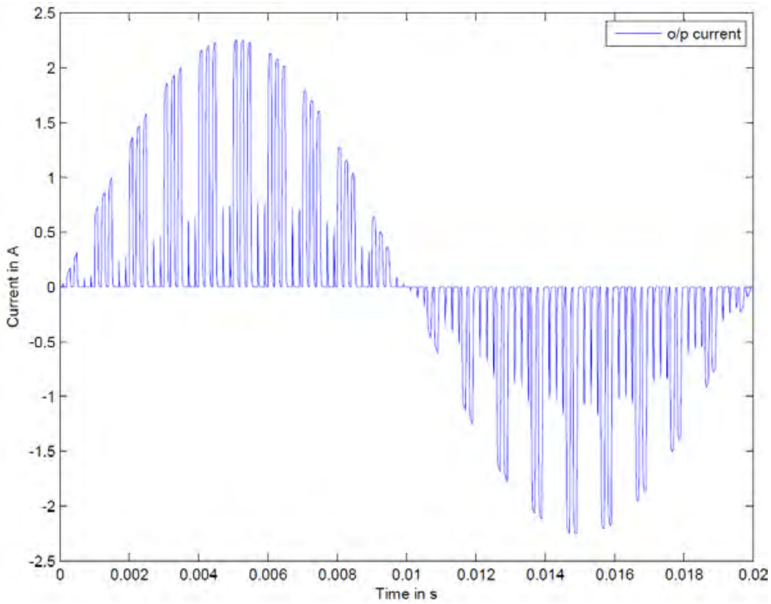

Fig. 16. Output Current waveform for f_o = 50 Hz

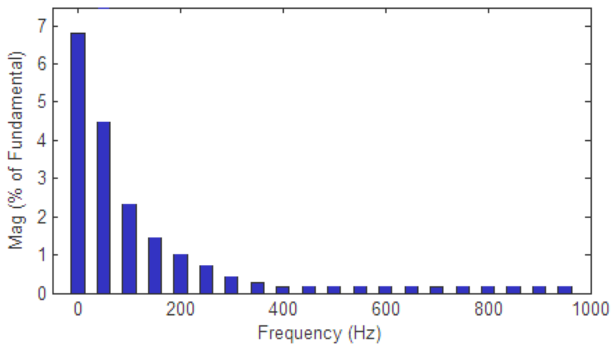

Fig. 17. THD for f_o = 50 Hz

Figure 18 shows the input voltage and output voltage for operating frequency of 100 Hz and figure 19 shows the corresponding output current fed to the single phase Induction Heating system load. Figure 20 depicts the THD measured for the corresponding operating frequency output. A THD of 6.62 is being measured for 100 Hz output frequency.

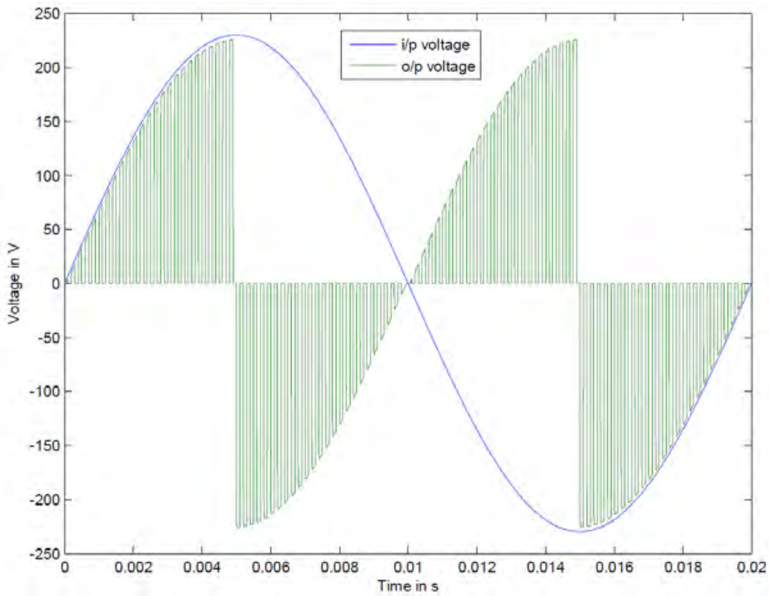

Fig. 18. Input and Output Voltage waveform for f_o = 100 Hz

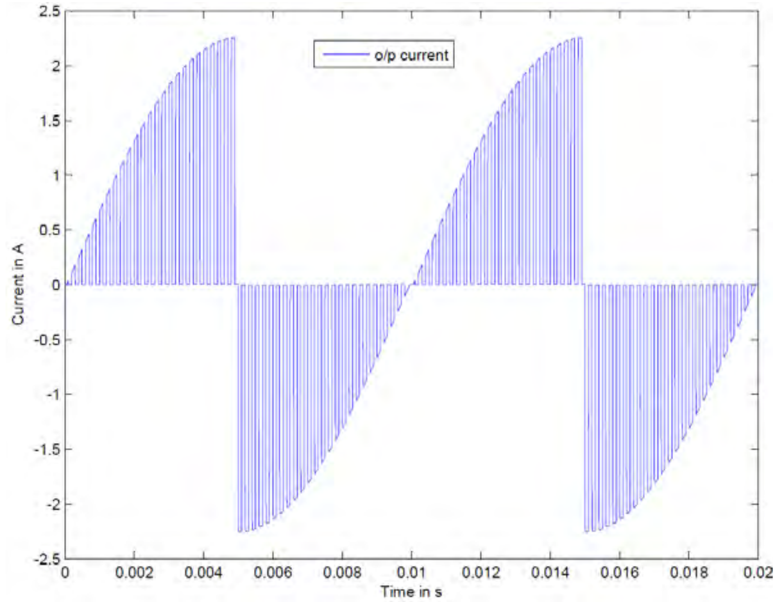

Fig. 19. Output Current waveform for f_o = 100 Hz

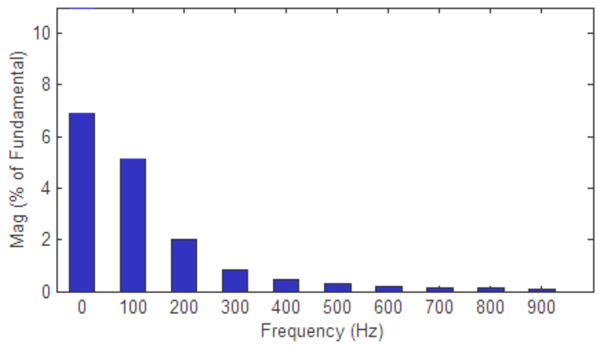

Fig. 20. THD for f_o = 100 Hz

Figure 21 shows the input voltage and output voltage for operating frequency of 1 kHz and figure 22 shows the corresponding output current fed to the single phase Induction Heating system load. The THD for the corresponding operating frequency output is being measured as 6.23.

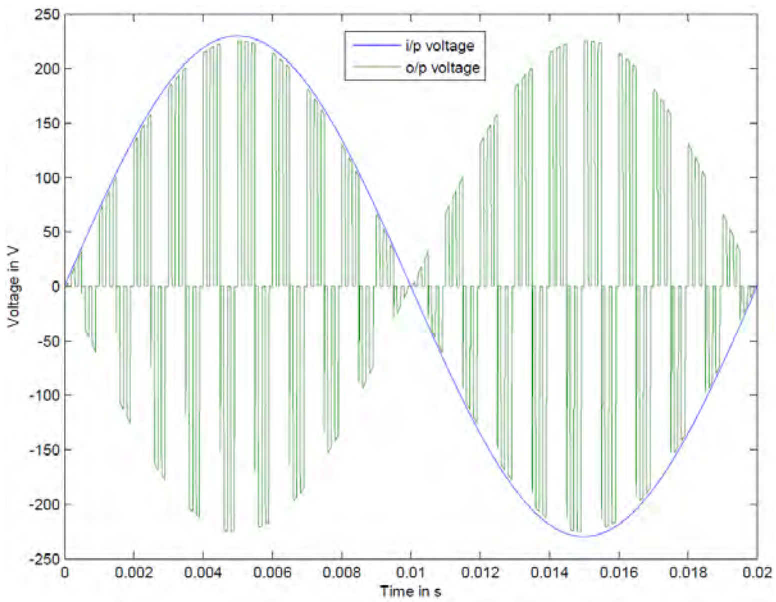

Fig. 21. Input and Output Voltage waveform for f_o = 1 kHz

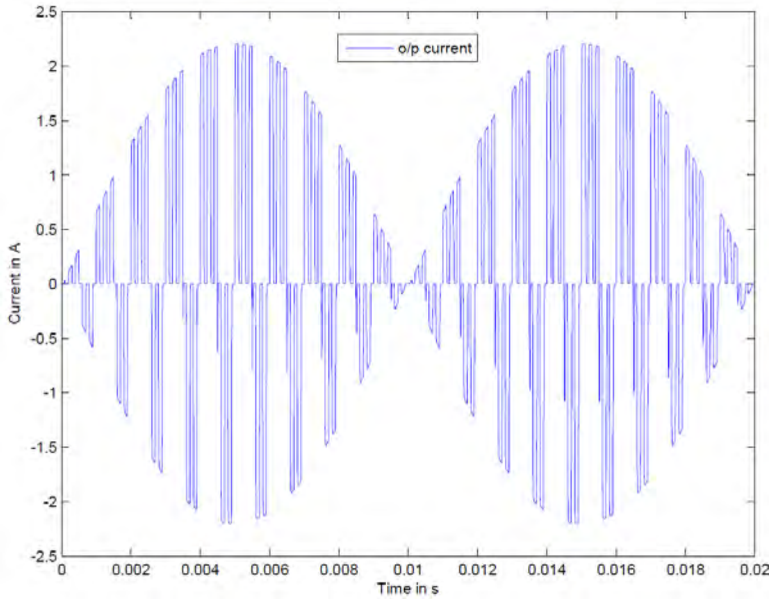

Fig. 22. Output Current waveform for f_o = 1 kHz

Figure 23 shows the input voltage and output voltage for operating frequency of 10 kHz and figure 24 shows the corresponding output current fed to the single phase Induction Heating system load. The THD measured for the corresponding operating frequency output is being 5.02.

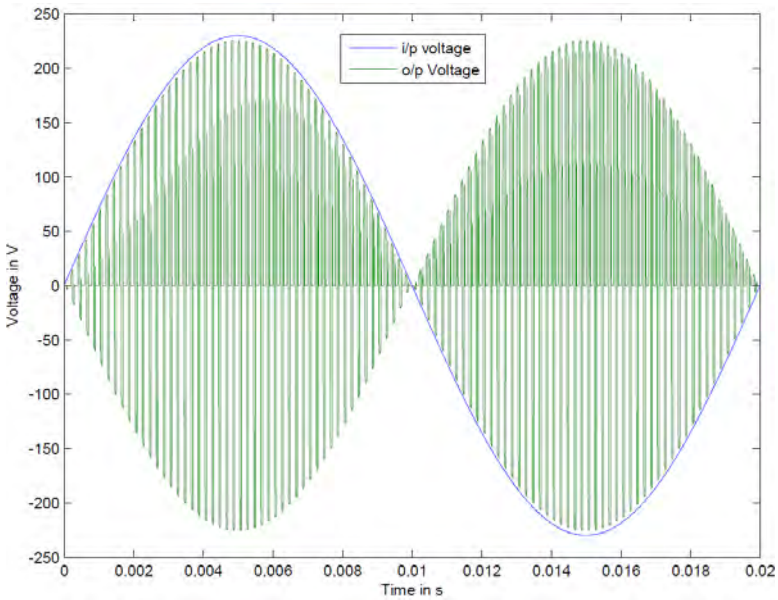

Fig. 23. Input and Output Voltage waveform for f_o = 10 kHz

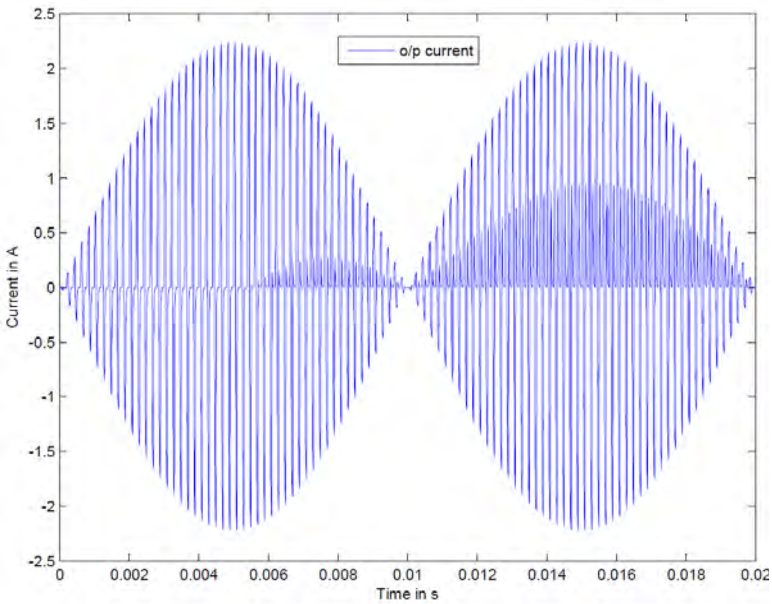

Fig. 24. Output Current waveform for f_o = 10 kHz

Figure 25 shows the input voltage and output voltage for operating frequency of 100 kHz and figure 26 shows the corresponding output current fed to the single phase Induction Heating system load. The THD for the corresponding operating frequency output is being measured as 4.34.

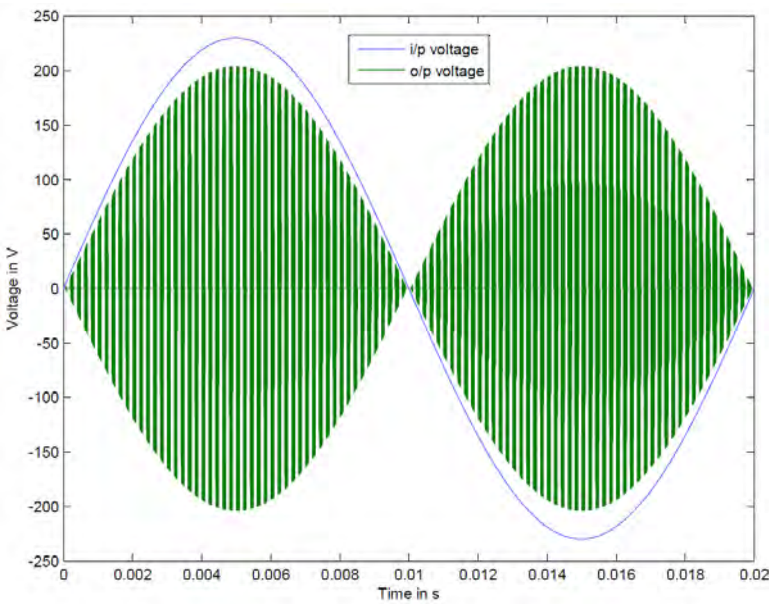

Fig. 25. Input and Output Voltage waveform for f_o = 100 kHz

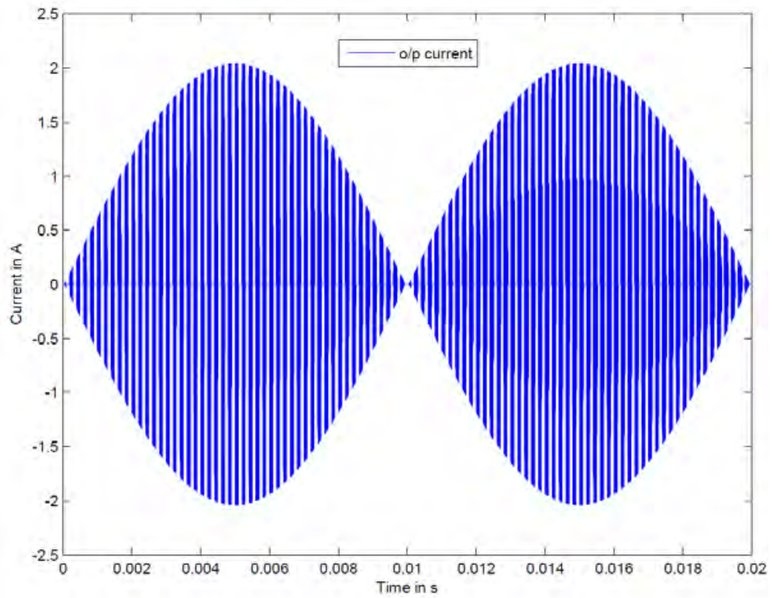

Fig. 26. Output Current waveform for f_o = 100 kHz

The following Table III represents the THD measured for the various operating frequencies in the FLC controlled SPMC fed Induction Heating system.

TABLE III
Measurement of THD for Various Operating Frequencies Of FLC Controlled SPMC Fed Induction Heating System

S. No	Frequency in Hz	THD in %
1	25	7.25
2	50	6.78
3	100	6.62
4	1 k	6.23
5	10 k	5.02
6	100 k	4.34

Figure 27 shows the graph for THD Vs various operating frequencies for the proposed system.

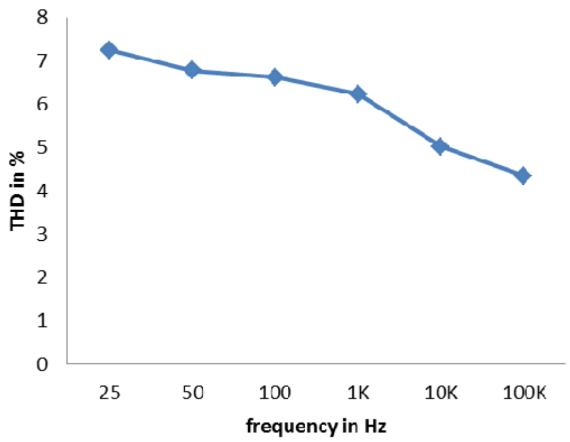

Fig. 27. THD Vs frequency plot

V. CONCLUSION

The Fuzzy Logic Controlled Single Phase Matrix Converter fed Induction Heating designed for closed loop current control system for a rating of 230 V, 2.25 A depicts robust operation of the system for various operating frequencies and the system exhibit very low total harmonic distortion and unity power factor.

REFERENCES

[1] Mollov S. V., Theodoridis M., Forsyth A. J. “High frequency voltage-fed inverter with phase-shift control for induction heating”, IEE Proc.-Electr. Power Appl. Vol. 15, January 2004
[2] Saichol Chudjuarjeen, Anawach Sangswang, and Chayant Koompai, “An Improved LLC Resonant Inverter for Induction Heating with Asymmetrical Control”, Seoul Olympic Parktel, Seoul, 2009, pp.1612-1617
[3] Hisayuki Sugimura, Sang-Pil Mun, Soon-Kurl Kwon, Tomokazu Mishima, Mutsuo Nakaoka, “High-Frequency Resonant Matrix Converter using One-Chip Reverse Blocking IGBT-Based Bidirectional Switches for Induction Heating”, IEEE, pp.3960-3966, 2008
[4] N. Nguyen-Quang, D.A. Stone, C.M. Bingham, M.P. Foster, “Comparison of single-phase matrix converter and H-bridge converter for radio frequency induction heating”, IEEE International Symposium on Industrial Electronics (ISlE), 2009
[5] Mahmoud Hamouda, Farhat Fnaiech, Kamal Al-Haddad, “Input-State Feedback Linearization Control of Three-Phase Dual-Bridge Matrix Converters Operating Under Unbalanced Source Voltages”, IREMOS, Vol. 4, 2011, pp. 467-477
[6] Majid Aghasi, Vahid Faraji, Hamid Behnia, Davood Arab Khaburi Ali Dehghan Banadaki, “Predictive DTC-ISVM for Doubly-Fed Induction Machine System Fed by Indirect Matrix Converter”, IREMOS, Vol. 5, 2012, pp.854-864
[7] Sedat Sünter, Ömür Aydo˘gmu¸s, “Implementation of a single-phase matrix converter induction motor drive”, Electr Eng., Vol. 90, 2008, pp.425–433
[8] M.Senthil Kumaran, R.Siddharth, M.Stalin, A.Divakhar, Ranganath Muthu, “Constant Pulse Width Switching Strategy for Matrix Converter”, IREMOS, Vol. 4, 2011, pp.2954-2960
[9] A. Djahbar, B. Mazari, “Matrix Converter for Six-Phase Induction Machine Drive System”, IREMOS, Vol. 2, 2007, pp.232-241
[10] N. Nguyen-Quang, D.A. Stone, C.M. Bingham, and M.P. Foster, “A three-phase to single-phase matrix converter for high-frequency induction heating”, 2009
[11] Wheeler P. W., Rodriguez J., Clare J. C., Empringham L., Weinstein A, “Matrix Converters: A Technology Review”, IEEE Trans. Ind. Electron. Vol. 49, 2002, pp.276-288
[12] Kim S., Sul S. -K., Lipo T. A, “AC/AC Power Conversion Based on Matrix Converter Topology with Unidirectional Switches”, IEEE Trans. Ind. Appl. Vol. 36, 2000, pp.139-145
[13] Mutschler P., Marcks M. “A Direct Control Method for Matrix Converters”, IEEE Trans. Ind. Electron. Vol. 49, pp.362-369
[14] Zhang L., Watthanasarn C., Shepherd W. “Analysis and comparison of control techniques for AC-AC matrix converters”, IEE Proc.-Electr. Power Appl. Vol. 145, 1998, pp.284-294
[15] Nguyen-Quang N., Stone D. A., Bingham C. M., Foster M. P. “Single phase matrix converter for radio frequency induction heating”, SPEEDAM 2006, pp.614-618