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Research Article

Neuro-fuzzy Logic Control of Single Phase Matrix Converter Fed Induction Heating System

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Abstract: This study presents a design and simulation of Neuro-Fuzzy Logic Controlled (NFLC) Single Phase Matrix Converter (SPMC) fed Induction Heating (IH) system. Single phase matrix converter system is an AC-AC converter which eliminates the usage of reactive storage elements and its performance over varying operating frequencies can be controlled by varying the Pulse Width Modulation (PWM) signal fed to the switches of single phase matrix converter. In the existing system a Fuzzy Logic Controller (FLC) was designed to control the matrix converter which yielded low Total Harmonic Distortion (THD) values when compared to previous systems. In this study a Neuro-Fuzzy Logic Controller was designed to control the single phase matrix converter and the results obtained prove its advantage over the existing Fuzzy Logic based control system.

Keywords: Induction heating system, neuro-fuzzy logic control, single phase matrix converter, total harmonic distortion

INTRODUCTION

Induction Heating (IH) system is a prime choice of electric heating system which employs two different techniques namely electromagnetic induction and joule's effect of heating. Induction heating system (Mollov *et al*., 2004; Nguyen-Quang *et al*., 2009a; Nguyen-Quang *et al*., 2007; Chudjuarjeen *et al*., 2009) is variably used in house hold applications and industrial applications namely melting, forging, annealing, welding, hardening etc. The main advantages of induction heating system are higher yield with improved quality, maximum productivity, quick start-up, flexibility of raw material, natural stirring, cleaner melting and compact installation which made it as principal application. Conventional Induction Heating systems employ AC-DC-AC conversion systems as shown in Fig. 1, which employs DC link storage reactive elements.

This reactive storage element can be eliminated by utilizing an AC-AC converter called Matrix Converter (MC) (Kim *et al*., 2000; Sugimura *et al*., 2008; Hamouda *et al*., 2011; Nguyen-Quang *et al*., 2006) which is a bidirectional converter which can operate over a range of frequencies when compared to conventional converters. The proposed AC-AC converter fed induction heating system is shown in following Fig. 2 which takes feedback signal from the output of Matrix Converter and produces a closed-loop control system using Neuro-Fuzzy controller (Karthikumar and Mahendran, 2013a and b).

In this study a Single Phase Matrix Converter (SPMC) fed Induction Heating (IH) system controlled by Neuro-Fuzzy Logic Controller (NFLC) is modelled and simulated through MATLAB/SIMULINK environment and the results are presented in following sections.

METHODOLOGY

Matrix Converter (MC) operating modes: A single phase matrix converter (Sugimura *et al*., 2008; Nguyen-Quang *et al*., 2006; Sünter and Aydoğmuş, 2008; Wheeler *et al*., 2002; Zhang *et al*., 1998) consists of a matrix of four bi-directional switching blocks as shown in Fig. 3. Each switching block consists of two-IGBT switches as shown in Fig. 4 connected in anti-parallel mode. The matrix converter output is connected to induction heating system load as shown in Fig. 3.

The single phase matrix converter operates in four basic switching sequences as explained below. In first mode of operation the matrix converter conducts the input positive half-cycle in forward direction across the load as shown in Fig. 5. The switches S_{1a} and S_{4a} and switched ON by the PWM signal to conduct in forward direction.

In second mode of operation the matrix converter conducts the input positive half-cycle in reverse direction across the load as shown in Fig. 6. The switches S_{2a} and S_{3a} and switched ON by the PWM signal to conduct in reverse direction.

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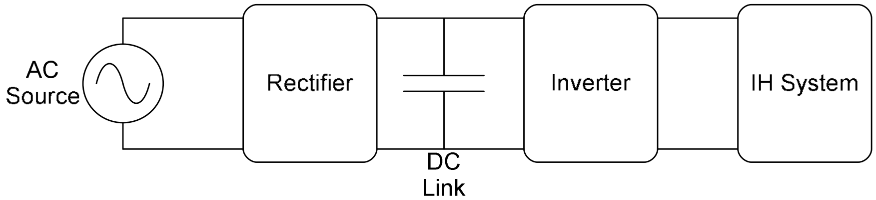

Fig. 1: Conventional AC-DC-AC conversion fed IH system

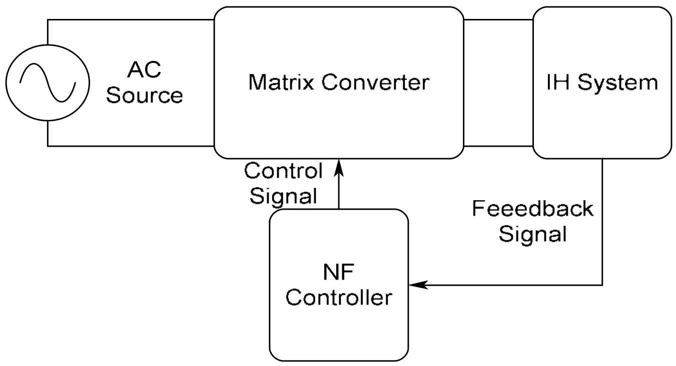

Fig. 2: Proposed AC-AC converter fed IH system

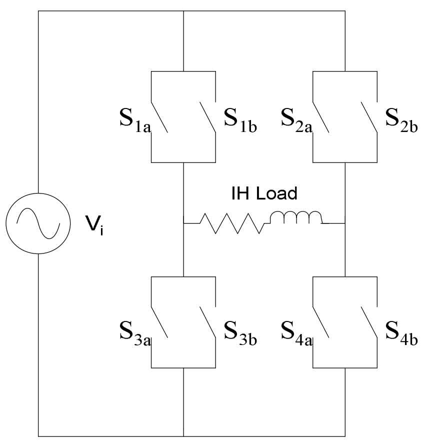

Fig. 3: Single phase matrix converter switching logic

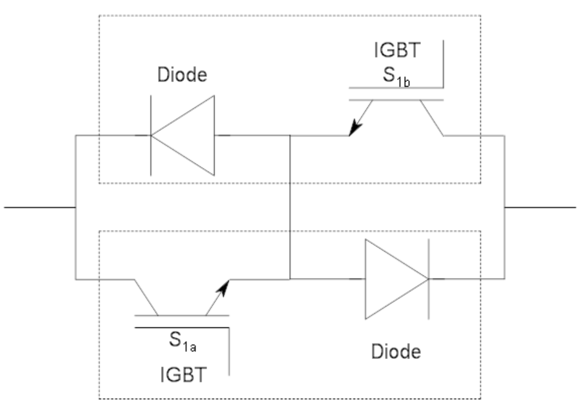

Fig. 4: Bi-directional switching logic

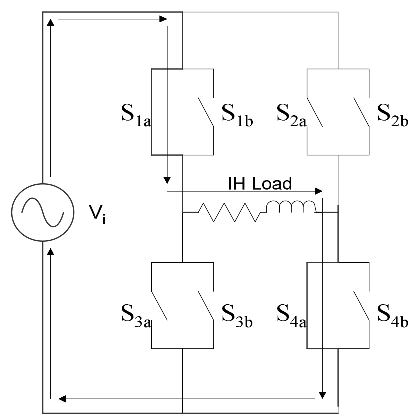

Fig. 5: Power flow in mode 1 operation

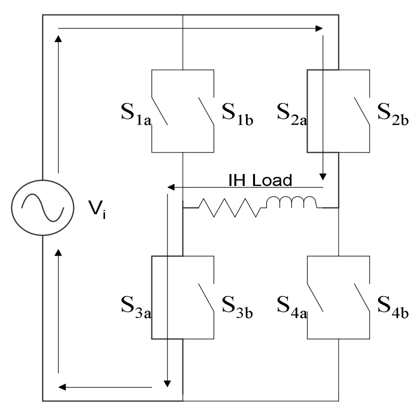

Fig. 6: Power flow in mode 2 operation

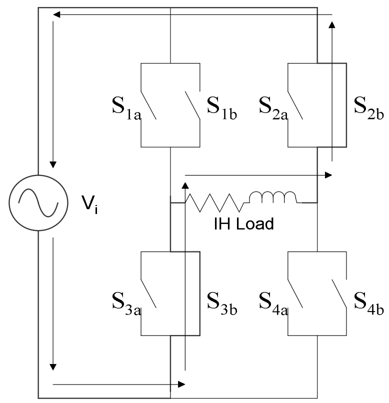

Fig. 7: Power flow in mode 3 operation

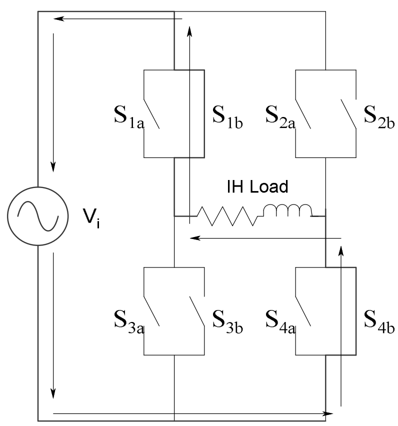

Fig. 8: Power flow in mode 4 operation

In second mode of operation the matrix converter conducts the input negative half-cycle in forward direction across the load as shown in Fig. 7. The switches S_{2b} and S_{3b} and switched ON by the PWM signal to conduct in forward direction.

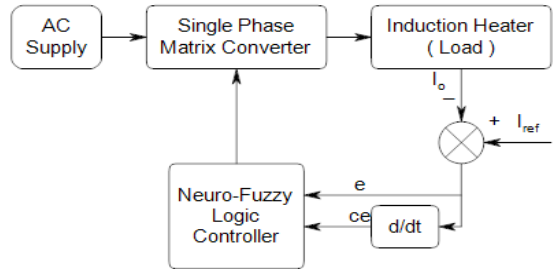

Fig. 9: Block diagram of neuro-fuzzy controlled system

In second mode of operation the matrix converter conducts the input negative half-cycle in reverse direction across the load as shown in Fig. 8. The switches S_{2b} and S_{4b} and switched ON by the PWM signal to conduct in reverse direction.

The following Table 1 shows the switching sequence of matrix converter for various input and output frequencies with their different switching modes for corresponding frequencies.

Neuro-fuzzy logic controller modelling: Neuro-Fuzzy Logic Controller (NFLC) (Karthikumar and Mahendran, 2013a and b) one of the non-linear controllers is modelled to control the switching sequence of the matrix converter to yield an AC output to the induction heater for a specific frequency. The following Fig. 9 represents the block diagram of the Neuro-Fuzzy controlled system.

The Neuro-Fuzzy logic system comprises of a fuzzifier, Adaptive Neuro Fuzzy Inference System (ANFIS) and a de-fuzzifier. The fuzzifier takes the inputs and based on the ANFIS rules it produce an

Table 1: Power flow switching sequence of matrix converter

Input frequency (Hz)	Output frequency (Hz)	Time interval	Switching mode
50	25	1	S_{1a}-S_{4a}
		2	S_{3b}-S_{2b}
		3	S_{2a}-S_{3a}
		4	S_{4b}-S_{1b}
	50	1	S_{1a}-S_{4a}
		2	S_{4b}-S_{1b}
	100	1	S_{1a}-S_{4a}
		2	S_{2a}-S_{3a}
		3	S_{3b}-S_{2b}
		4	S_{4b}-S_{1b}

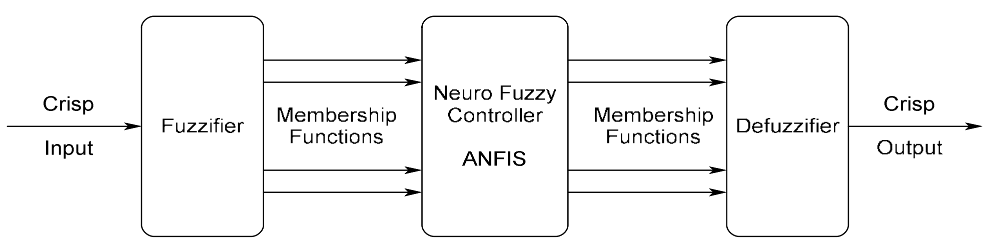

Fig. 10: Neuro-fuzzy logic controller block diagram

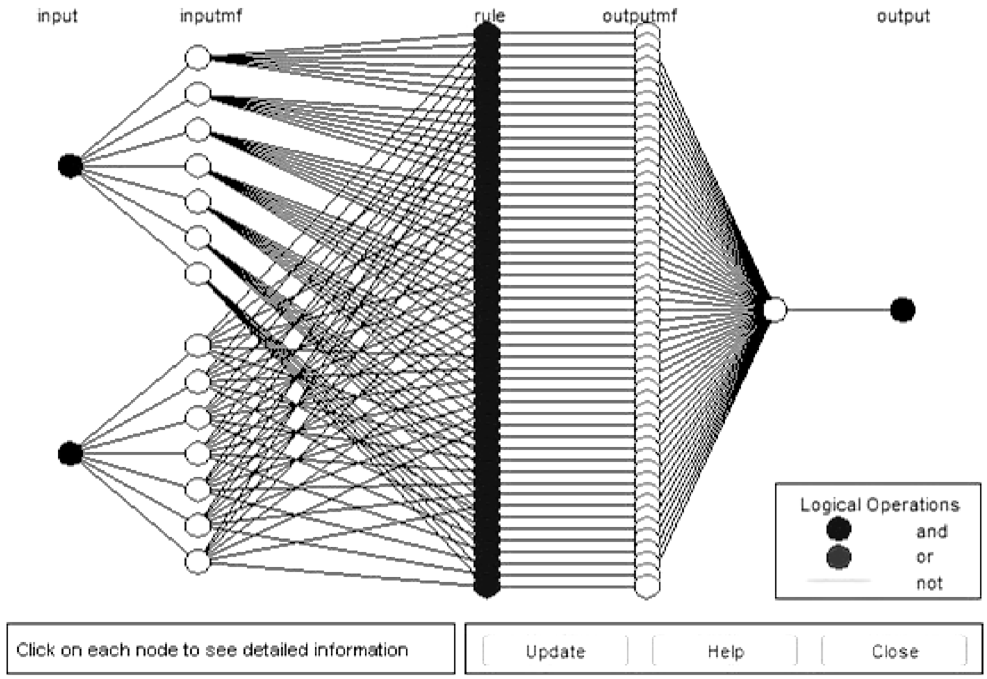

Fig. 11: ANFIS architecture

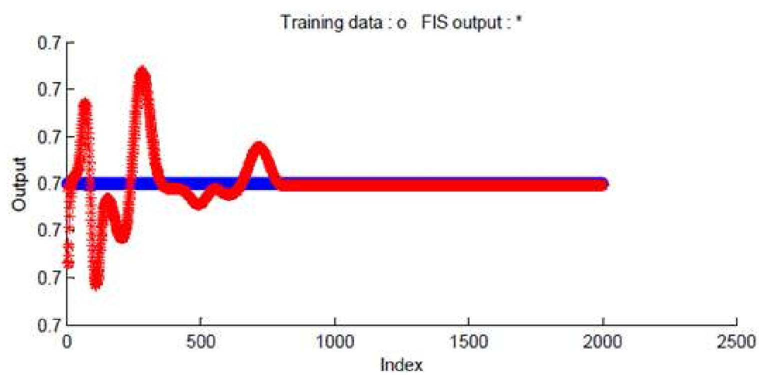

Fig. 12: ANFIS architecture training data and FIS output

output signal to de-fuzzifier which produce a corresponding control signal. The following block diagram in Fig. 10 depicts the Neuro-Fuzzy logic controller internal structure. In which fuzzifier takes the input of error in output current with respect to reference value and the change in error as another input to fuzzifier. The output of de-fuzzifier is duty cycle which is used to generate PWM switching signal (Kumaran *et al*., 2011), fed to the matrix converter switches.

The ANFIS structure modelled is a mamdani model of five layers. The input layer is fuzzifier memberships error (e) and change in error (ce) and the membership functions are classified into five Gaussian membership functions in second layer of ANFIS as Negative Big (NB), Negative Medium (NM), Zero (ZE), Positive Medium (PM) and Positive Big (PB). The third layer forms the 25 rules which transmit the values to fourth layer nodes which is the output membership function

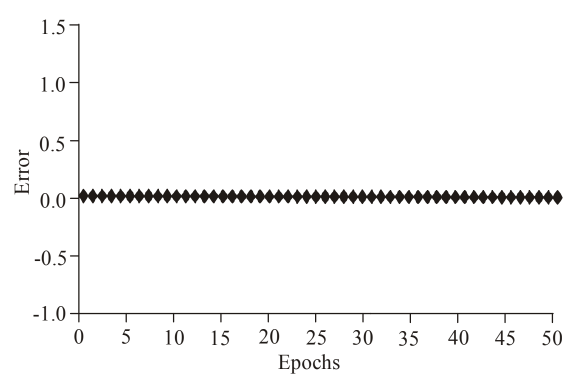

Fig. 13: ANFIS architecture training error

classifications which send the data to fifth layer node which is de-fuzzifier membership or the output node as shown in Fig. 11.

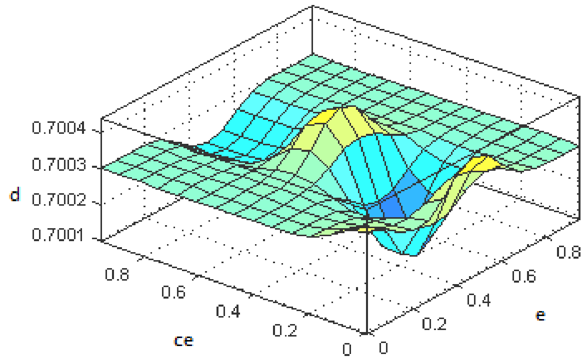

Fig. 14: ANFIS rule base surface view

The ANFIS architecture is trained with the data obtained from the workspace for 50 epochs and minimum error is obtained as shown in the following Fig. 12 and 13.

The rule base surface view obtained after ANFIS training is shown in following Fig. 14.

SIMULATION RESULTS

The results obtained from simulation of a 50 Hz input, 25 Hz output, Neuro-Fuzzy controlled Matrix converter fed induction heating system is shown in Fig. 15 and 16. Figure 15 shows the input and output

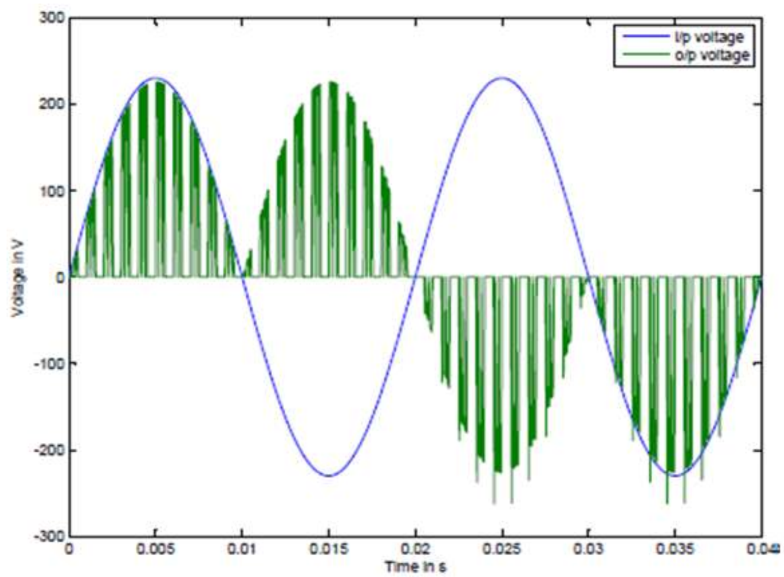

Fig. 15: Voltage waveform for 25 Hz output system

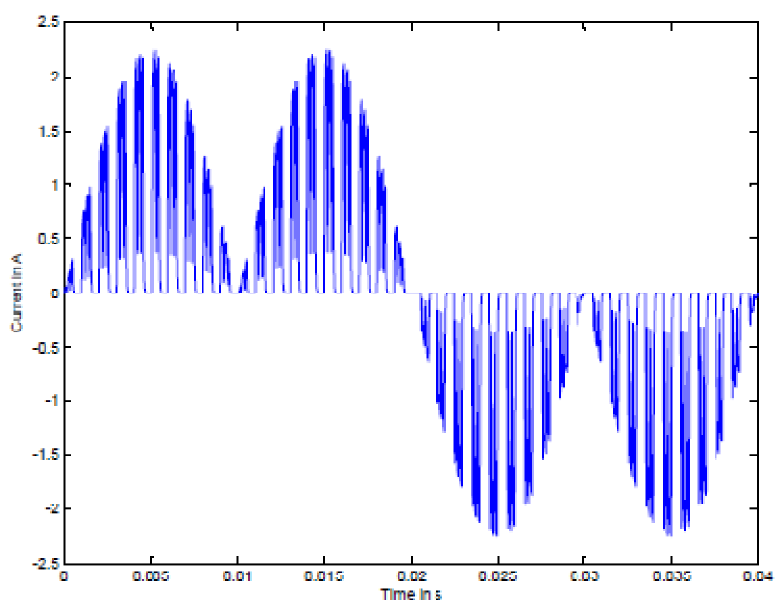

Fig. 16: Current waveform for 25 Hz output system

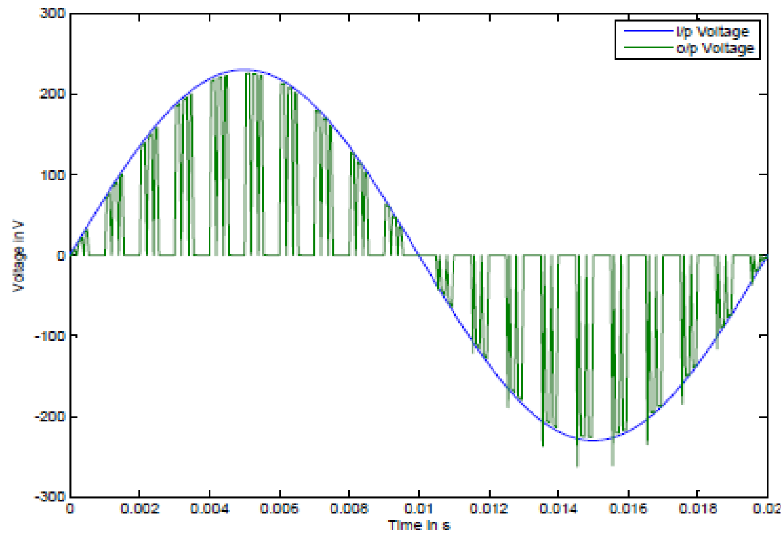

Fig. 17: Voltage waveform for 50 Hz output system

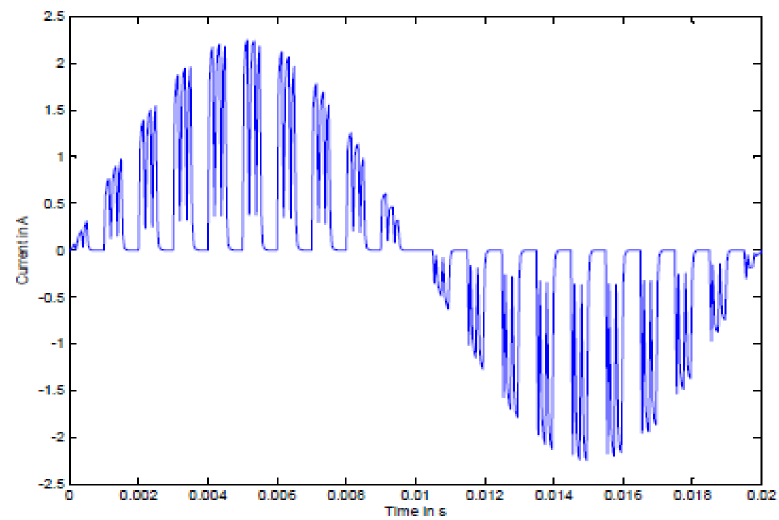

Fig. 18: Current waveform for 50 Hz output system

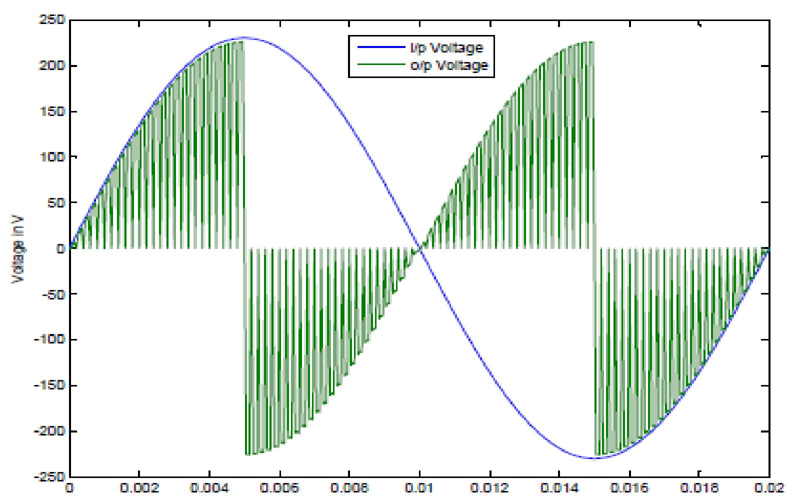

Fig. 19: Voltage waveform for 100 Hz output system

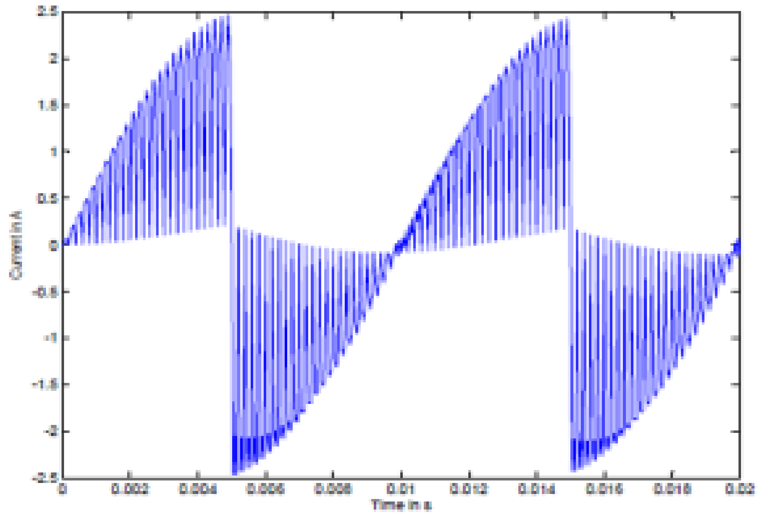

Fig. 20: Current waveform for 100 Hz output system

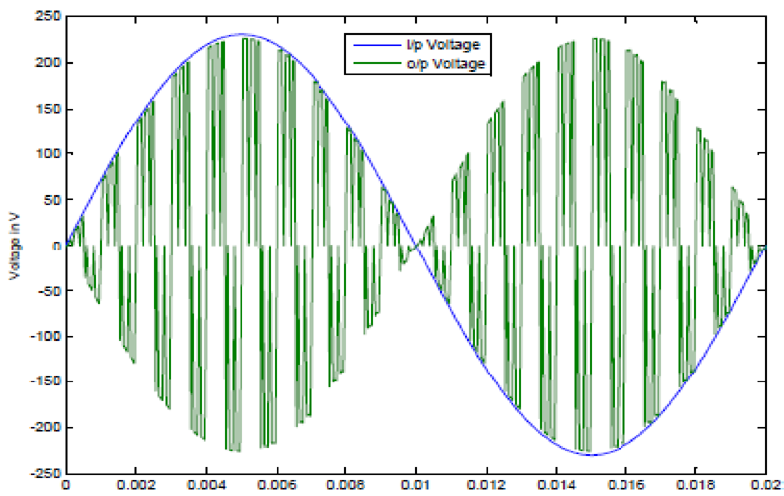

Fig. 21: Voltage waveform for 1 kHz output system

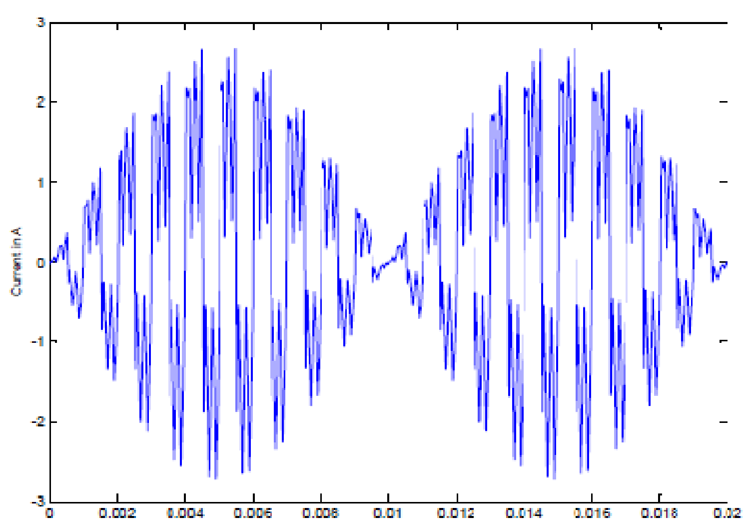

Fig. 22: Current waveform for 1 kHz output system

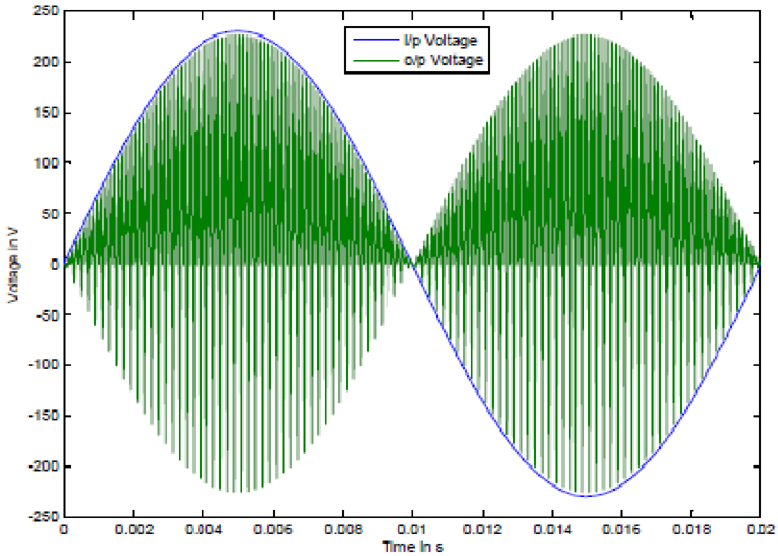

Fig. 23: Voltage waveform for 10 kHz output system

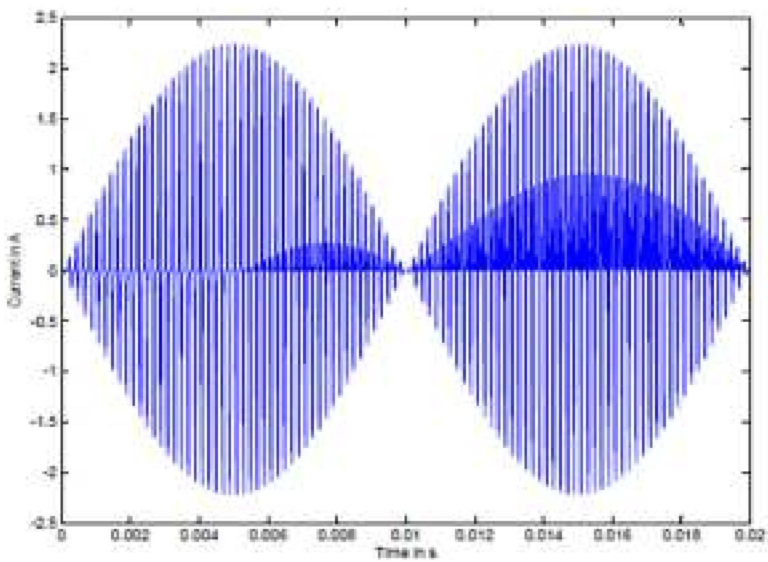

Fig. 24: Current waveform for 10 kHz output system

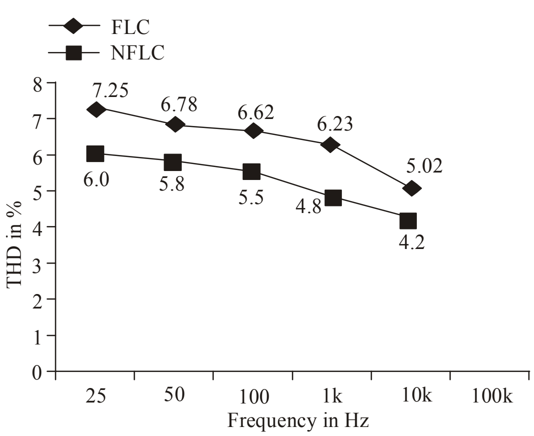

Fig. 25: THD of proposed system and existing system

voltage waveforms while Figure 16 shows the output current waveform.

Figure 17 shows the input and output voltage waveforms while Fig. 18 shows the output current waveform for a 50 Hz input, 50 Hz output system.

Figure 19 shows the input and output voltage waveforms while Fig. 20 shows the output current waveform for a 50 Hz input, 100 Hz output system.

Figure 21 shows the input and output voltage waveforms while Fig. 22 shows the output current waveform for a 50 Hz input, 1 kHz output system.

Figure 23 shows the input and output voltage waveforms while Fig. 24 shows the output current waveform for a 50 Hz input, 10 kHz output system.

Figure 25 shows the Total Harmonic Distortion (THD) obtained in the proposed system and the comparison of THD obtained with the existing system.

CONCLUSION

The Neuro-Fuzzy logic controller designed to control the single phase matrix converter fed Induction heating system of 230 V and a load current of 2.25 A reveal a robust operation for various operating frequencies providing a very low total harmonic distortion than the fuzzy logic controlled induction heating system with a single phase matrix converter which increases the efficiency of the system.

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