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Speed Control of Three phase Induction motor using 13-level Cascaded H-Bridge Multilevel inverter with PID, FUZZY and ANFIS Controller

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ABSTRACT: This paper presents comparative analysis of control strategies for Thirteen level Cascaded H-Bridge Multilevel inverter (CHBMLI) fed Three phase Induction motor for industrial applications. The Three phase CHBMLI consists of twelve switches per phase, totally thirty six switches to achieve thirteen levels. The analysis of thirteen level CHBMLI with PID, FUZZY and ANFIS controllers are expounded. It compares the performance of the controllers at four different speeds of three phase Induction motor under open loop and closed loop operations. The simulation is carried out using MATLAB / SIMULINK and harmonics at various speeds of Induction motor have been presented.

KEYWORDS: Thirteen level Cascaded H-Bridge Multilevel inverter, Three phase Induction motor, PID controller, FUZZY controller, ANFIS controller.

I.INTRODUCTION

The concept of multilevel converters was introduced in 1975. The term multilevel began with the three level converter. A multilevel converter is a power electronic system that synthesizes a desired output voltage from several levels of dc voltages as inputs. With an increasing number of dc voltage sources, the converter output voltage waveform approaches a nearly sinusoidal waveform while using a fundamental frequency-switching scheme. Compared with the traditional two-level voltage converter, the primary advantage of multilevel converters is their smaller output voltage step, which results in high power quality, lower harmonic components, better electromagnetic compatibility, and lower switching losses [1].

Multilevel inverters include an array of power semiconductors and capacitor voltage sources, the output of which generate voltages with stepped waveforms. The commutation of the switches permits the addition of the capacitor voltages, which reach high voltage at the output, while the power semiconductors must withstand only reduced voltages [3]. Cascaded multilevel inverters are based on a series connection of several single-phase inverters. This structure is capable of reaching medium output voltage levels using only standard low-voltage mature technology components [4]. Induction motor offers desirable operating characteristics such as robustness, reliability and ease of control are extensively used in various applications ranging from industrial motion control systems to home appliances where speed is predominantly a function of frequency [5]. The voltage source inverter produce a voltage or a current with levels either 0 or ±Vdc, they are known as two level inverter. AC voltage is constructed by switching these two voltages.

II. MULTILEVEL INVERTER

The concept of multilevel converters has been introduced since 1975. The term multilevel began with the three-level converter. Subsequently, several multilevel converter topologies have been developed. However, the elementary concept of a multilevel converter to achieve higher power is to use a series of power semiconductor switches with several lower voltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform. The commutation of the power switches aggregate these multiple dc sources in order to achieve high voltage at the output;

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however, the rated voltage of the power semiconductor switches depends only upon the rating of the dc voltage sources to which they are connected.

III. CASCADED H-BRIDGE MULTILEVEL INVERTER

The Cascaded H-bridge multi level inverter employ capacitors and switches and requires less number of components in each level. This topology consists of series of power conversion cells and power can be easily scaled. The combination of capacitors and switches pair is called an H-bridge and gives the separate input DC voltage for each H-bridge. It consists of H-bridge cells and each cell can provide the three different voltages like zero, positive DC and negative DC voltages. One of the advantages of this type of multi level inverter is that it needs less number of components compared with diode clamped and flying capacitor inverters. The price and weight of the inverter are less than those of the two inverters. Soft-switching is possible by some of the new switching methods. The Block diagram of the Multilevel invereter fed induction motor is shown in figure 1.

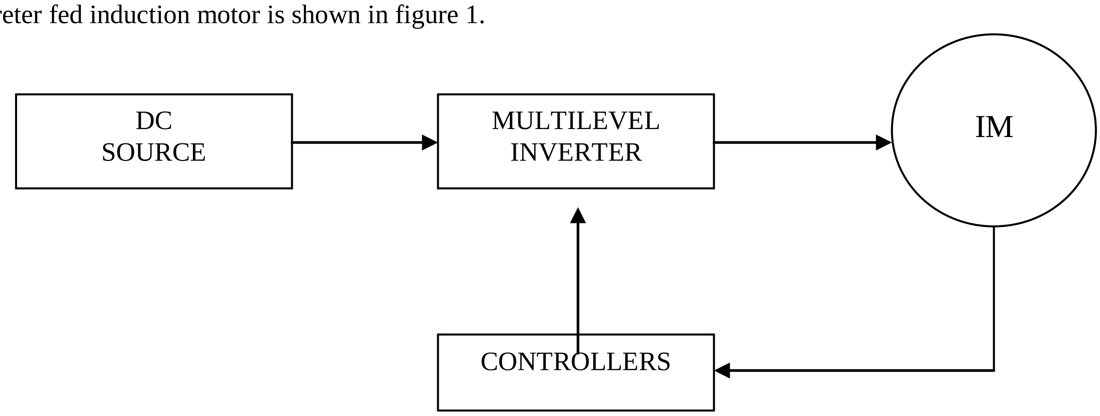

Fig. 1 Block diagram of the Multilevel inverter fed induction motor

The source given to the the multilevel inverter is Direct Current (DC) source. Multilevel inverter uses thirty six switches to produce a thirteen level voltage waveform to employ speed control in three phase Induction motor multilevel inverter. Closed loop control is carried out using PID, FUZZY and ANFIS controllers.

IV. OPEN LOOP SYSTEM

The figure 2 shows the MATLAB/SIMULINK model for Thirteen level Cascaded H-Bridge Multilevel Inverter (CHBMLI) using SPWM method. It consists of 12 switches per phase and totally 36 switches are used to achieve thirteen levels. A three phase induction motor is connected to the output of CHBMLI. The subsystem for CHBMLI is shown in the figure 3.This subsystem consists of 36 switches and each phase consists of 12 switches namely s1 to s12 for R Phase, sa1 to sa12 for Y Phase and sb1 to sb12 for B Phase.

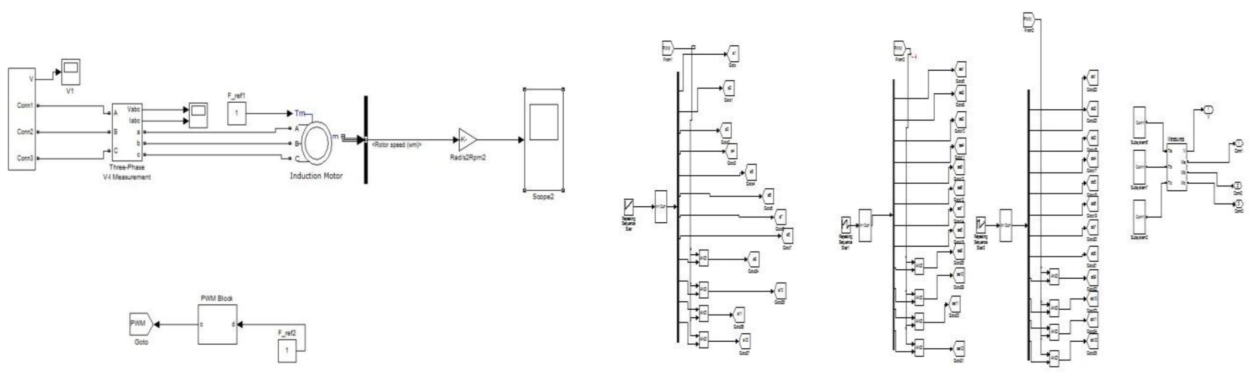

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Fig. 2 SIMULINK model of open loop system

Fig. 3 SIMULINK model of open loop subsystem

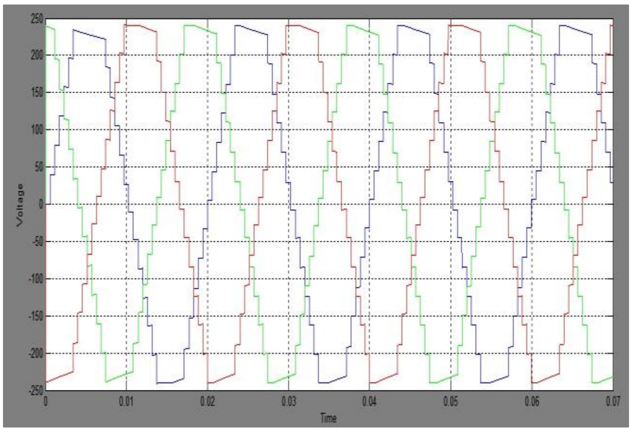

Fig. 4 Simulation result for open loop 13 level CHBMLI voltage waveform

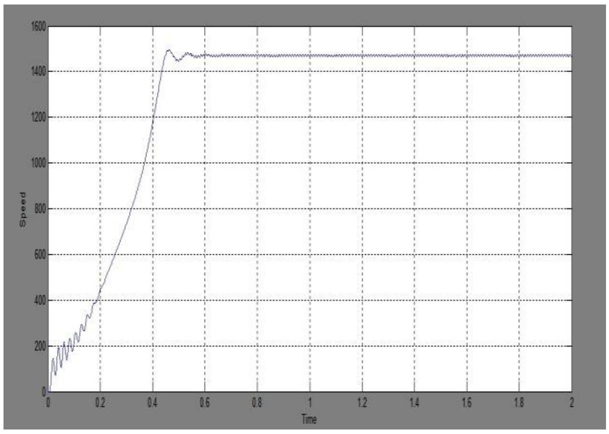

Fig. 5 Simulation result for open loop 13 level CHBMLI speed waveform

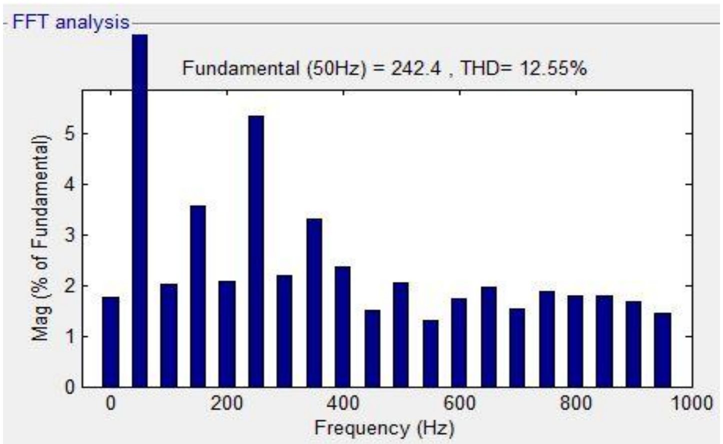

Fig. 6 Harmonics spectrum of open loop system

The speed of the open loop system settles at 1425 rpm. So the steady state error value is 5 % . Figure 4 represents the simulation resuls for open loop Induction motor system fed by 13 level CHBMLI. Figure 5 represents the speed waveform for open loop system. Figure 6 shows the harmonic spectrum of open loop system.

The THD value of Open loop system is 12.55 % . In the harmonics spectrum third, fifth and seventh order harmonics are more dominant. Other harmonic orders are less dominant. The settling time for open loop system is 0.64 seconds. The peak time of open loop system for 1500 rpm is 0.43 secs. The steady state error value of open loop system for 1500 rpm is 5.

V. CLOSED LOOP CONTROL WITH PID CONTROLLER

The SIMULINK model for the closed loop control of induction motor with PID controller for 1500 rpm is shown in the figure 7. The Thirteen level voltage waveform for 1500 rpm is shown in the figure 8. The simulation result of closed loop speed waveform for 1500 rpm is shown in the figure 9. The harmonics spectrum of 1500 rpm is displayed in the figure 10.

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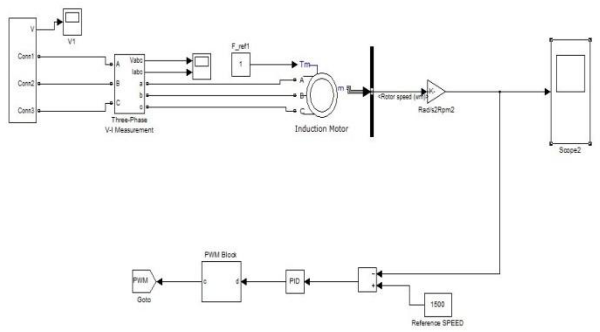

Fig. 7 SIMULINK model of closed loop 13 level CHBMLI with PID controller for 1500 rpm.

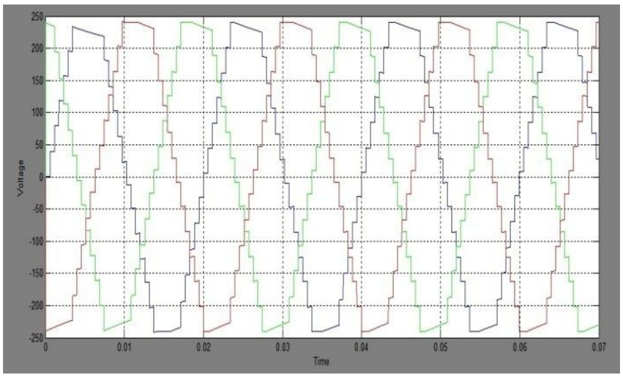

Fig. 8 Thirteen level voltage waveform for 1500 rpm

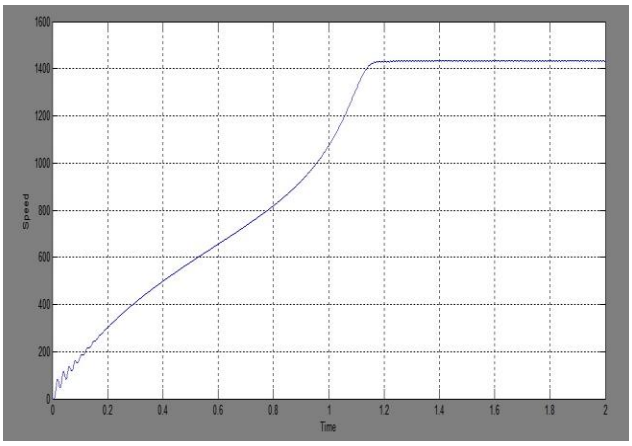

Fig. 9 Simulation result of closed loop speed waveform for 1500 rpm

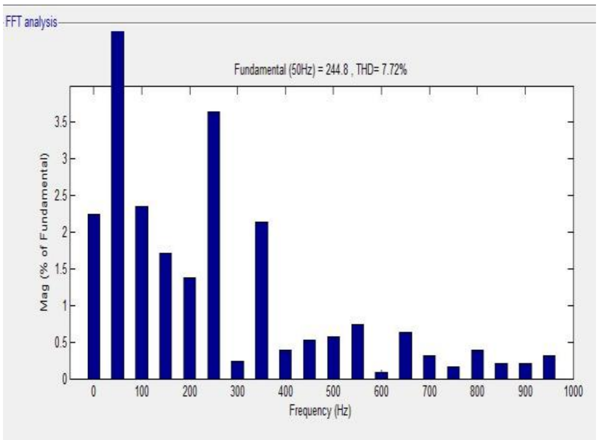

Fig. 10 Harmonics spectrum of 1500 rpm

The speed of the closed loop system with PID controller for 1500 rpm settles at 1455 rpm. So the steady state error is 5%. In the harmonics spectrum shown in figure 10, it can be seen that fifth and seventh order harmonics or more dominant than other harmonic orders. Figure 9 shows the settling time for 1500 rpm as 1.15 seconds and the figure 10 displays the Total Harmonic Distortion (THD) value as 7.72%.

VI. CLOSED LOOP CONTROL WITH FUZZY CONTROLLER

The SIMULINK model for the closed loop control of induction motor with Fuzzy logic controller for 1500 rpm is shown in the figure 11. The Thirteen level voltage waveform for 1500 rpm is shown in the figure 12. The simulation result of closed loop speed waveform for 1500 rpm is shown in the figure 13.

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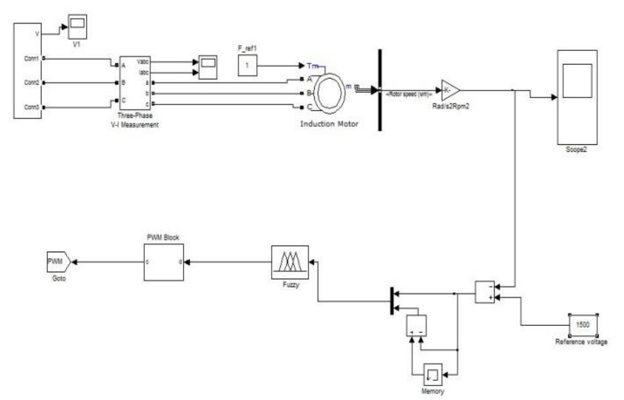

Fig. 11 SIMULINK model of closed loop 13 level CHBMLI with FUZZY controller for 1500 rpm

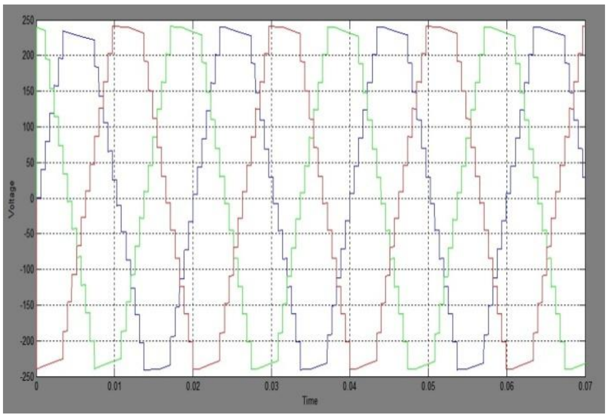

Fig. 12 Thirteen level voltage waveform for 1500 rpm

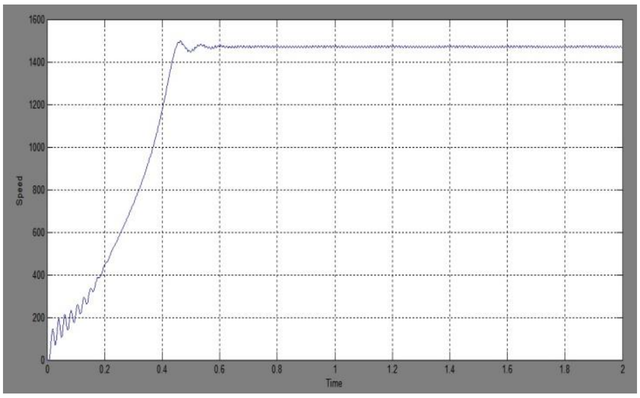

Fig. 13 Simulation result of closed loop speed waveform for 1500 rpm

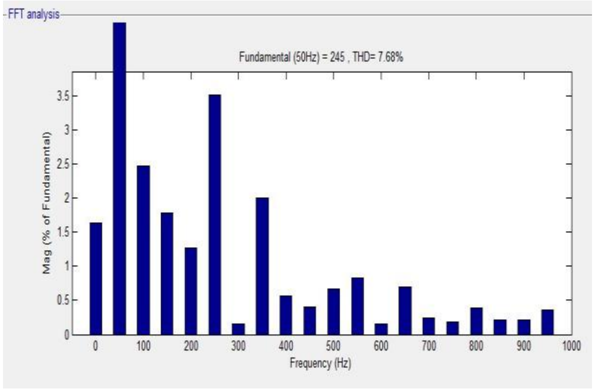

Fig. 14 Harmonics spectrum of 1500 rpm

The harmonics spectrum of 1500 rpm is displayed in the figure 14. The speed of the closed loop system with FUZZY controller for 1500 rpm settles at 1462 rpm. So the steady state error is 2.53%. In the harmonics spectrum shown in figure 14, it can be seen that fifth and seventh order harmonics are more dominant than other harmonic orders. Figure 13 shows the settling time for 1500 rpm as 0.6 seconds and the figure 14 displays the Total Harmonic Distortion (THD) value as 7.68%.

VII. CLOSED LOOP CONTROL WITH ANFIS CONTROLLER

The SIMULINK model for the closed loop control of induction motor with ANFIS controller for 1500 rpm is shown in the figure 15. The Thirteen level voltage waveform for 1500 rpm is shown in the figure 16. Simulation result of closed loop speed waveform for 1500 rpm is shown in the figure 17. The harmonics spectrum of 1500 rpm is displayed in the figure 18.

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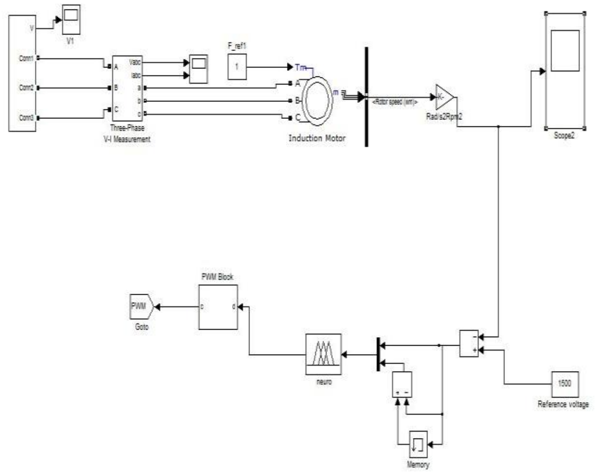

Fig. 15 SIMULINK model of closed loop 13 level CHBMLI with ANFIS controller for 1500 rpm.

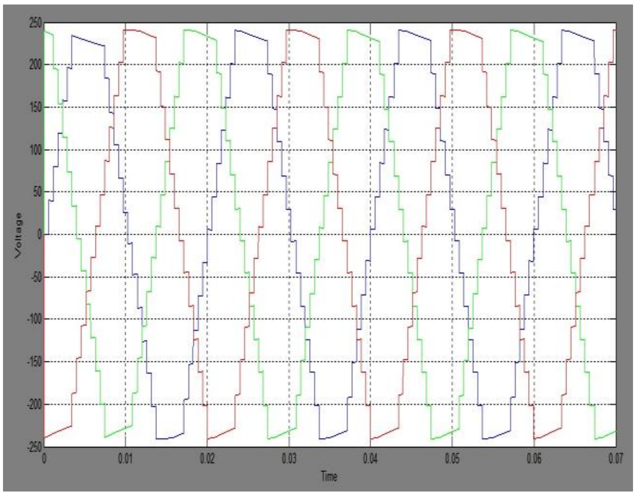

Fig. 16 Thirteen level voltage waveform for 1500 rpm

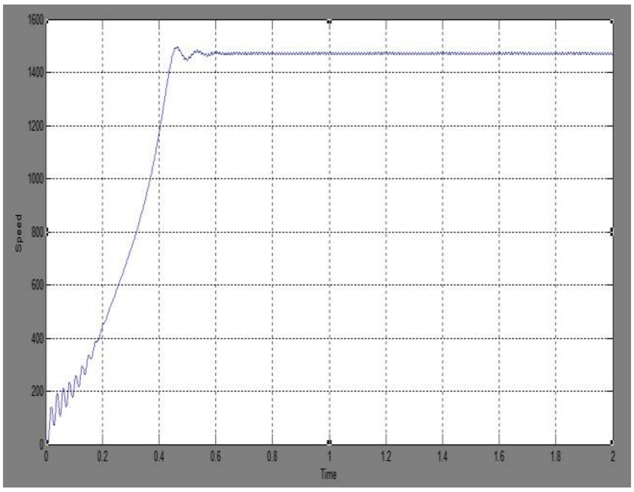

Fig. 17 Simulation result of closed loop speed waveform for 1500 rpm

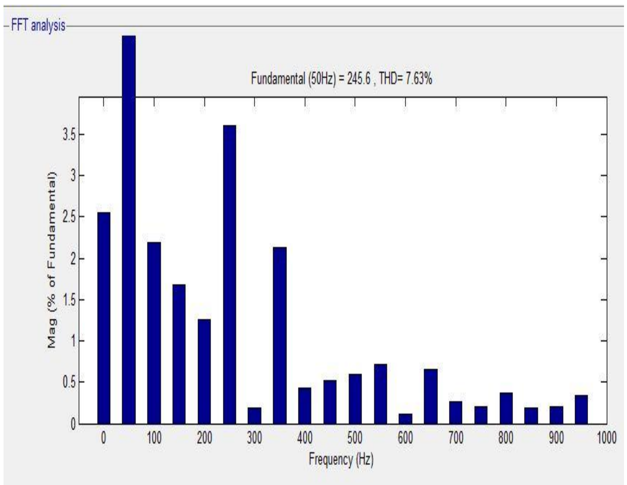

Fig. 18 Harmonics spectrum of 1500 rpm

The speed of the closed loop system with ANFIS controller for 1500 rpm settles at 1470 rpm. So the steady state error is 2%. In the harmonics spectrum shown in figure 18, it can be seen that fifth and seventh order harmonics or more dominant than other harmonic orders.

The speed of the closed loop system with ANFIS controller for 1500 rpm settles at 1470 rpm. So the steady state error is 2%. In the harmonics spectrum shown in figure 18, it can be seen that fifth and seventh order harmonics or more dominant than other harmonic orders. The harmonic order analysis of open loop and closed loop CHBMLI with PID, FUZZY, ANFIS controller for 1500 rpm, 1250 rpm, 1000 rpm and 800 rpm are shown in Table I.

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TABLE I HARMONIC ORDER ANALYSIS OF OPEN LOOP AND CLOSED LOOP CHBMLI WITH PID, FUZZY, ANFIS CONTROLLER

SPEED \ HARMONIC ORDER		3	5	7	9	11	13	15	17	19
OPEN LOOP(1500 RPM)		3.58	5.34	3.31	1.52	1.31	1.97	1.87	1.80	1.43
1500 RPM	***PID***	1.71	3.63	2.13	0.53	0.74	0.63	0.17	0.20	0.31
	FUZZY	1.78	3.52	2.00	0.40	0.83	0.7	0.19	0.21	0.35
	ANFIS	1.67	3.60	2.14	0.52	0.71	0.66	0.20	0.18	0.34
1000 RPM	***PID***	1.80	3.69	2.11	0.52	0.77	0.69	0.19	0.18	0.35
	FUZZY	1.72	3.66	2.14	0.54	0.76	0.66	0.20	0.21	0.31
	ANFIS	1.62	3.61	2.15	0.52	0.72	0.64	0.17	0.21	0.32
1250 RPM	***PID***	1.82	3.69	2.10	0.53	0.79	0.67	0.21	0.19	0.33
	FUZZY	1.71	3.67	2.13	0.52	0.76	0.67	0.21	0.20	0.33
	ANFIS	1.56	3.58	2.16	0.50	0.76	0.67	0.21	0.20	0.33
800 RPM	***PID***	1.76	3.58	2.20	0.47	0.77	0.66	0.23	0.20	0.34
	FUZZY	1.71	3.64	2.14	0.52	0.74	0.65	0.21	0.22	0.30
	ANFIS	1.69	3.64	2.16	0.53	0.72	0.64	0.20	0.22	0.30

TABLE II COMPARISON OF THD, SETTLING TIME AND STEADY STATE ERROR OF OPEN LOOP AND CLOSED LOOP SYSTEM

SPEED \ INVERTER AND CONTROLLER PARAMETERS		THD (%)	Settling Time (secs)	Steady State Error (secs)
OPEN LOOP (1500 RPM)		12.55	0.64	5
1500 RPM	***PID***	7.72	1.15	3
	FUZZY	7.68	0.6	2.53
	ANFIS	7.63	0.5	2
1000 RPM	***PID***	7.77	0.9	2.8
	FUZZY	7.70	0.53	2.38
	ANFIS	7.66	0.46	2.1
1250 RPM	***PID***	7.76	1.08	2.95
	FUZZY	7.71	0.52	2.2
	ANFIS	7.63	0.44	2.15
800 RPM	***PID***	7.70	0.75	3.15
	FUZZY	7.67	0.38	2.56
	ANFIS	7.64	0.31	2.17

The harmonic order values for third, fifth, seventh, ninth, eleventh, thirteenth, fifteenth, seventeenth and nineteenth harmonic orders for four different speeds of open loop and closed loop system are tabulated in table I. It can be seen that the harmonic order values of open loop system are more than the values obtained closed loop system. This shows that the harmonic content in the open loop system has been suppressed by employing closed loop system.

The comparison of open loop and closed loop system shown in table II infers that the closed loop system is more efficient than the open loop system since the THD content, settling time and steady state error values of open loop system is more than the values obtained in closed loop system. It can also be seen that while using ANFIS controller, the values obtained are smaller than the values that are obtained by using PID and FUZZY controller.

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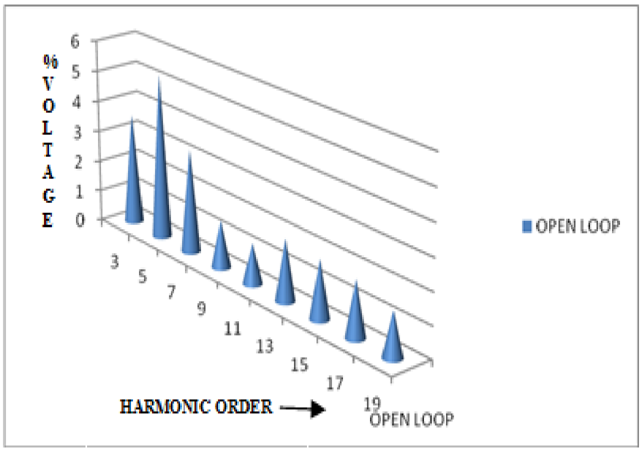

Fig. 19 Harmonics spectrum of open loop system at 1500 rpm

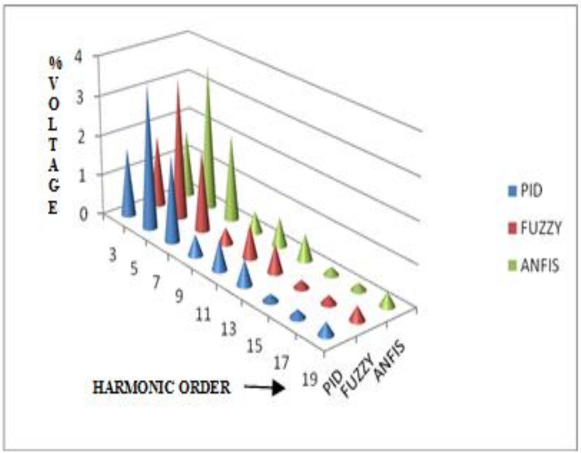

Fig. 20 Harmonics spectrum of Closed loop system at 1500 rpm

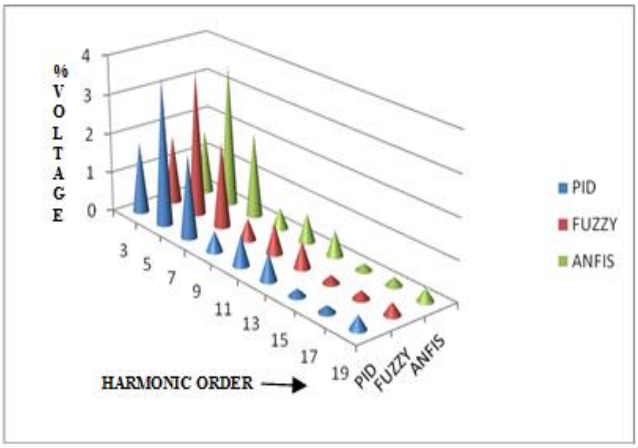

Fig. 21 Harmonics spectrum of Closed loop system at 1000 rpm

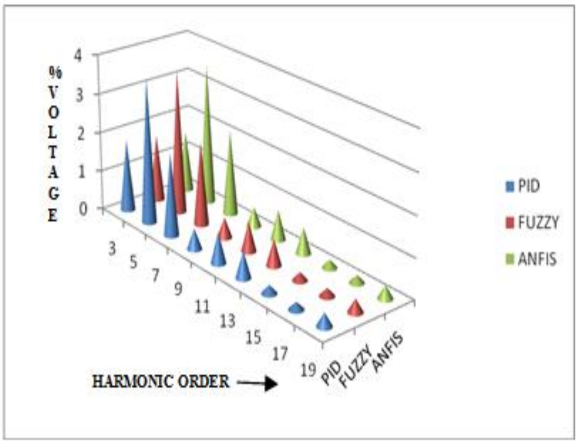

Fig. 22 Harmonics spectrum of Closed loop system at 1250 rpm

The harmonics spectrum of open loop system at 1500 rpm and closed loop system with PID, FUZZY and ANFIS controller at 1500 rpm, 1250 rpm, 1000 rpm and 800 rpm are shown in the figures 19, 20, 21, 22 and 23. The numbers three, five, seven, nine, eleven, thirteen, fifteen, seventeen and nineteen shown below in X-axis of the following figures represents the harmonic orders. The third order, fifth order and seventh order harmonics are more dominant than all other harmonic orders in all the harmonics spectrum shown in the following figures. The ninth,eleventh and thirteenth harmonic order are more dominant than fifteenth, seventeenth and nineteenth harmonic orders but lesser than the remaining harmonic orders shown in the figures 20, 21, 22 and 23.

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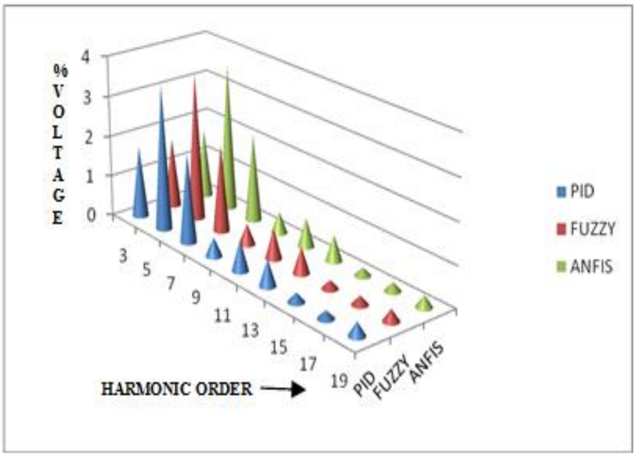

Fig. 23 Harmonics spectrum of Closed loop system at 800 rpm

VIII. CONCLUSION

This work has encompassed a detailed simulation study on controller parameters and harmonics in open and closed loop of thirteen level CHBMLI fed Three phase Induction motor. During rated speed, THD content of output is just 7.63 % in Closed loop whereas in Open loop it is 12.55 %. Many of the harmonic orders are eliminated in closed loop system. In the area of controller performance settling time and steady state error values for four different speeds of Induction motor are compared. The four different speeds are 1500 rpm, 1250 rpm, 1000 rpm and 800 rpm. The simulation results show that THD values, steady state error and settling time values of ANFIS controller is less compared to PID and FUZZY controller. It can be concluded that the performance of ANFIS controller is superior when compared to PID and FUZZY controller in a thirteen level Cascaded H-Bridge Multilevel inverter fed Induction motor.

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