Performance and Analysis of Multi-Level Inverters Integrated to Induction Motor with V/f Principle Speed Control

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Abstract: In this paper three different levels, 3ph multilevel inverters are integrated to Induction Motor (IM) using V/f principle for speed control of the motor. The multilevel inverter used is diode clamped inverter, considering 7-level 9-level and 11-level for the analysis. The V/f control system is further updated with fuzzy logic interface system replacing the closed loop conventional PI controller. The efficiency of the induction motor is studied with different multilevel inverters using PI and fuzzy controllers. The design and analysis are carried out in MATLAB Simulink GUI environment and graphs are represented with respect to time

Keywords: 3ph (3 phase), GUI (graphical user interface), MATLAB (Matrix Laboratory), PI (Proportional gain and Integral gain), V/f (Voltage/frequency).

1. Introduction

Power electronic voltage source inverters [1] are needed to be employed for operating any 3-phase or single-phase loads with change in voltage magnitude or varying frequency. However, the voltage magnitude can be varied by connecting a transformer with different turns ratios but the frequency cannot be changed using the transformer. Some applications which doesn't need frequency variation can be integrated with transformers for change in voltage magnitude. Whereas, some applications like speed control of induction motor (IM) [1] requires to have voltage magnitude change and also frequency change for controlling the speed. A two-stage conversion system is used to achieve control over voltage magnitude and frequency using rectifier and inverter. Considering a three-phase sinusoidal source as input, a rectifier [2] is associated with this source to convert 3-phase sinusoidal voltage to fixed DC. The fixed or constant DC voltage is converted over required voltage magnitude and frequency for 1-phase or 3-phase AC voltage fed to the load.

The rectifier employed to convert 3-phase sinusoidal AC input utilizes six diodes connected in three leg formats [2]. As the diodes are uncontrolled switches, no external switching is needed to operate the rectifier for transforming 3-phase AC voltage into DC voltage. This DC voltage is further converted to 3-phase AC voltage with the help of six IGBT switches. As the IGBT switches needs pulses to operate, an external pulse generation unit is required to be connected. This external control unit utilizes sinusoidal pulse width modulation (SPWM) technique [3] which generates pulses by comparing the reference sinusoidal waveforms with high frequency triangular waveform. The assemblage of controlled voltage magnitude and frequency operating an induction motor is shown in Fig. 1.

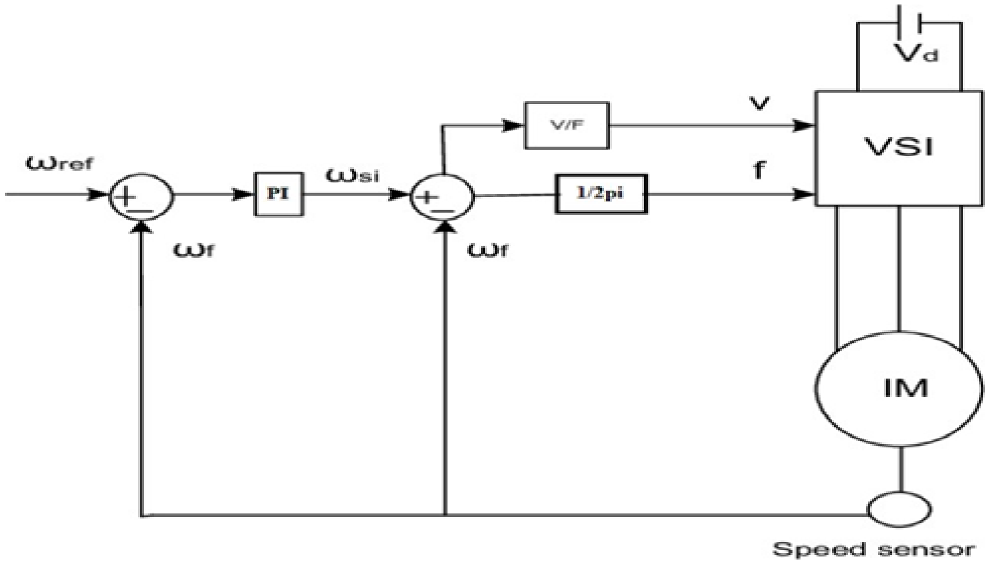

Fig. 1. 2-stage structure of induction motor operation

A conventional 6- switch inverter generates PWM AC voltage [4] with only two levels which creates harmonics in the induction motor. These generated harmonics in the motor may increase hysteresis loss and increases heat in the conductors. This increased heat in the conductors results in the damage of the insulation thus creating short circuit in the motor. This occurrence will not get affected immediately but happens after few days leading to reduction in the reliability of the motor. The 2-stage operation for controlling the motor speed is accomplished, but with the cost of reliability of the motor.

To overcome this problem of harmonics in the motor, multi-level inverters [7] are adopted replacing the conventional 6-switch inverters. The multi-level inverters generate AC voltage having voltage levels replicating sinusoidal waveform. The harmonics generated in the motor are reduced with the creation of voltage levels thereby improving the performance levels of the motor. Numerous types of multi-level inverters which includes flying capacitor, diode clamped [7] etc. Out of these, the latter one is considered as more effective due to its proficiency in controlling when compared to other topologies. Thus, this kind of inverter is considered as best to operate an induction motor with reduced harmonics.

2. Diode Clamped Multi-Level Inverter

The diode braced multi-level inverter has diodes connected at convergence of each voltage level [8]. These voltage level’s input given to the inverter are created using capacitors connected in series which share the input voltage equally. The inverter is divided into upper and lower regions in which the upper part creates multi-level voltage on the positive side whereas the lower one creates multi-level voltage in negative side [9]. By rising the range of levels, there is an increase in the number of modules in the inverter. A simple 5-level diode braced inverter topology can be seen in the Fig. 2.

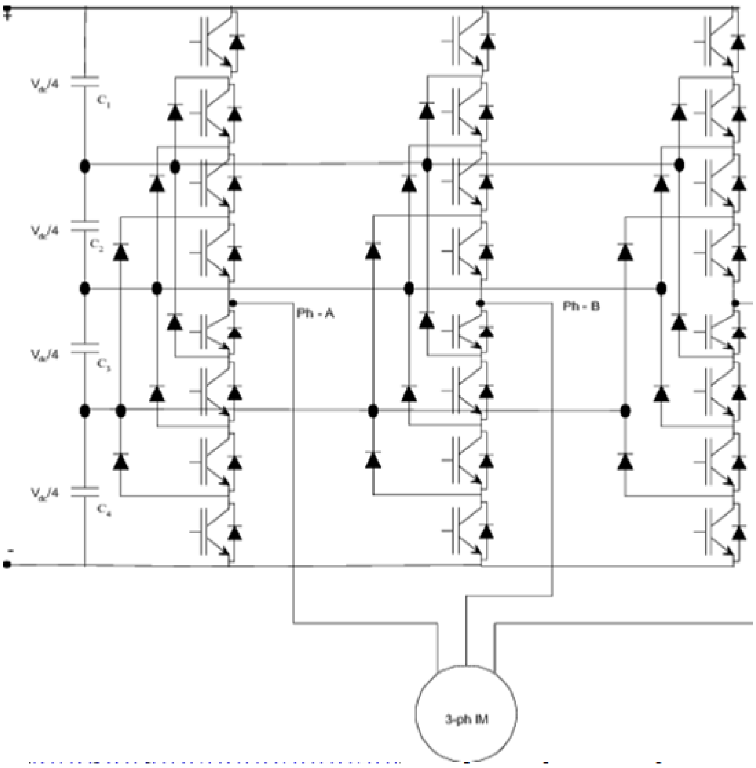

Fig. 2. Seven level diode clamped inverter topology with induction motor

Control of IGBT switches associated in the topology helps to control the output voltages. Based on the necessity of voltage levels, the quantity of IGBT switches that are to be connected in upper or lower regions is decided [9]. The relation between number of switches to that of levels is given as,

$N = V_{level} - 1$ (1)

Here, N is the number of IGBT switches either in upper or lower region. The control of these IGBT switches is worked out by level shifted sinusoidal PWM technique [10], where multiple level shifted triangular waveforms are contrasted with reference sinusoidal waveform producing pulses for IGBTs of the diode braced inverter. The level shifted PWM technique for the diodebraced inverter of 7-level is indicated in Fig. 3

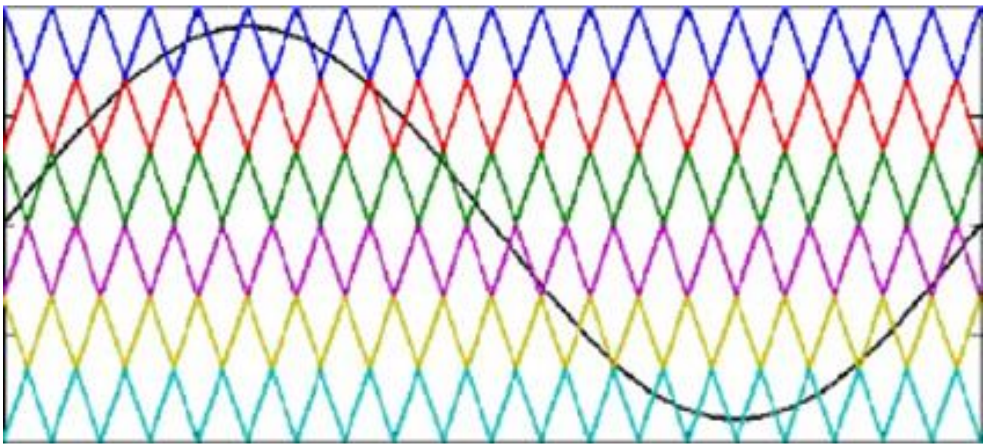

Fig. 3. Level shifted PWM technique for 7-level diode clamped Inverter

With the above reference, the triangular waveforms and IGBTs (in upper or lower region) used for 7-level are 6, 9-level are 8 and 11-level are 10 in number [10]. Inverter's output voltage relies on the referenced sinusoidal waveform compared to these triangular waveforms. Change in magnitude (modulation index), phase of the reference waveforms alters the inverter's output voltage. The reference generation has been done for V/f principle for controlling the induction motor's speed.

3. V/F Principle For Speed Control of IM

3- phase IM speed control could be accomplished with voltage as well as frequency control of the inverter connected to it. Variation in voltage magnitude with variation in fundamental frequency of the input voltages alters the motor's speed to some ideal referenced values specified by the user. For understanding its V/f speed control [1], an example motor rating is considered in which mathematical calculations are applied to generate reference sinusoidal waveforms for the inverter. Considering motor rating [4] of voltage 440Vrms, frequency 50Hz, rated speed during no load 1500rpm, theproportion of this rating is given as,

$$R = {}^{V}/_{f} \qquad (2)$$
$$= {}^{440}/_{50} = 8.8$$

For 1500 rpm speed, the V/f proportion determined is 8.8 which should be same for some random referenced speed. Thevoltage and frequency for 1000rpm sample value is estimated as,

$$f_{1000} = \frac{1000}{1500} * 50 = 33.33\text{Hz}$$

Therefore, the voltage is given as

$$V1000 = R * f1000 \qquad (3)$$
$$= 8.8 * 33.33 = 293.3\text{Vrms}$$

Input voltage should be 293.3Vrms and frequency should be 33.33Hz for running the motor with 1000rpm speed. The referenced voltage generation for the level shifted PWM technique is given as

$$_{f} = Kv * Vm\ Sin\ (wt) \qquad (4)$$

$$V_{bref} = Kv * Vm\ Sin\ (wt - \frac{2pi}{3}) \qquad (5)$$

$$V_{cref} = Kv * Vm\ Sin\ (wt + \frac{2pi}{3}) \qquad (6)$$

Here, Vm is voltage magnitude, w is angular frequency given as 2*pi*f [1]. The extent of the referenced voltage is reduced to per-unit parameters using a gain Kv for the controller to generated pulses. The 3 per-unit reduced referred sinusoidal waveforms are contrasted with level shifted triangular waveforms producing pulses for the IGBTs which are giving necessary voltage output for operating an induction motor at required speed [4]. The controller employed for controlling speed is normal PI controller which produces the error of speed controlling the V/f proportion so that the motor maintains constant speed. The PI controller is additionally upgraded using fuzzy interface network for quick responses thereby assisting the speed of the motor to settle quicker

4. Fuzzy Interface System

Fuzzy logic interface system is an optimal control structure used as a substitute to PI controller in numerous applications for faster responses of the plant to the given changes. A fuzzy interface system [11] utilizes multiple membership functions for input and output variables. These membership functions were interlinked using rule bases with if-and-then logic generating error for the controller. A 'mamdani' fuzzy structure is utilized for the interface network with 2 input and 1 output variables [12]. One input variable is 'error' which is generated by comparing the reference speed with measured speed and other input is 'change in error' which is generated by comparing the present error with past error input. The change in error input is brought about by the derivative of error input. Both of these variable membership functions are indicated in figures.

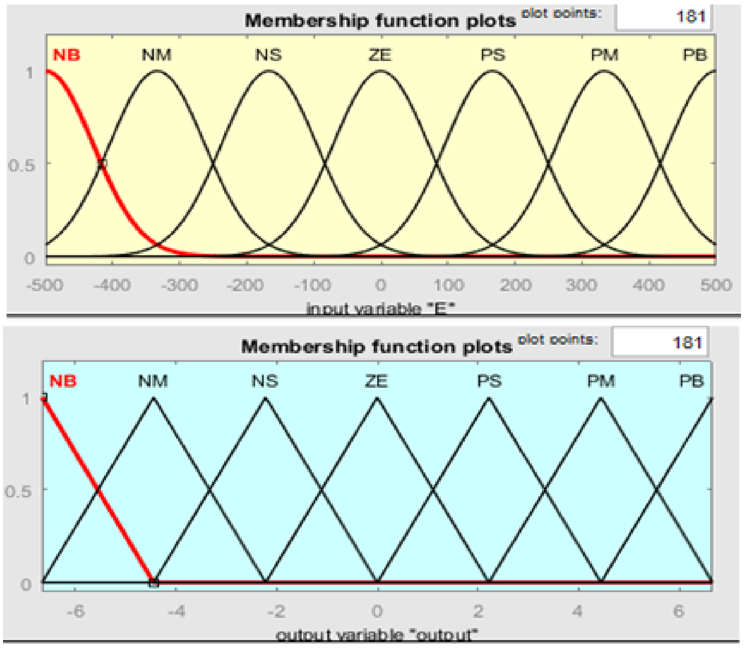

Fig. 4. Input and output variable membership functions

As observed, there are 7 membership functions in each variable named as NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), PB (Positive Big) [13]. These 7 terms have been linked with 49 rule bases with if-and-then logic given below.

The output generated is fed to a unit vector template generation which generates the reference waveforms for the level shifted PWM technique. The control structure with fuzzy logic interface system is shown below.

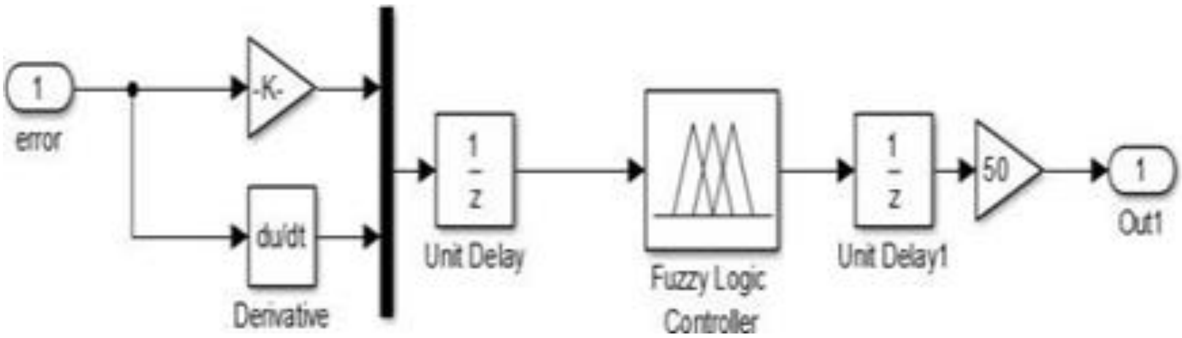

Fig. 5. Fuzzy logic interface system control structure

5. Simulation Results and Discussion

With the above modules, a simulation is modelled with 7, 9 and 11-level diode clamped multi-level inverter operating an induction motor. The simulation is run for 5secs generating graphs of inverter and motor. Comparison of speeds of the induction motor is shown using PI and fuzzy logic interface system. Total harmonic distortion analysis is carried out on voltages and currents of the inverter using FFT analysis tool from ‘powergui’ block.

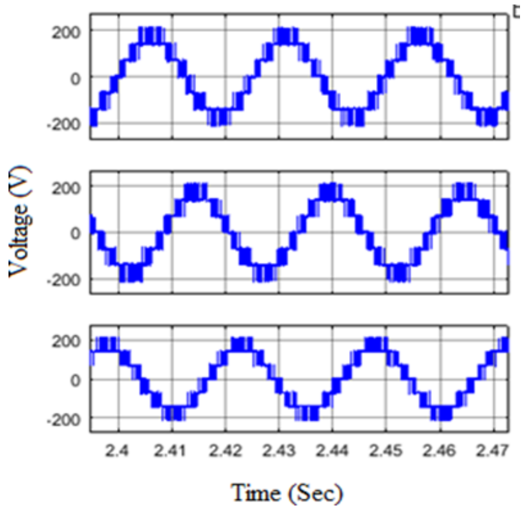

Fig. 6. 3-phase 7-level voltages

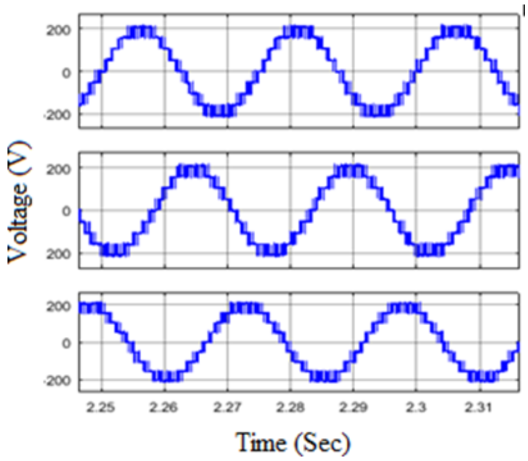

Fig. 7. 3-phase 9-level voltages

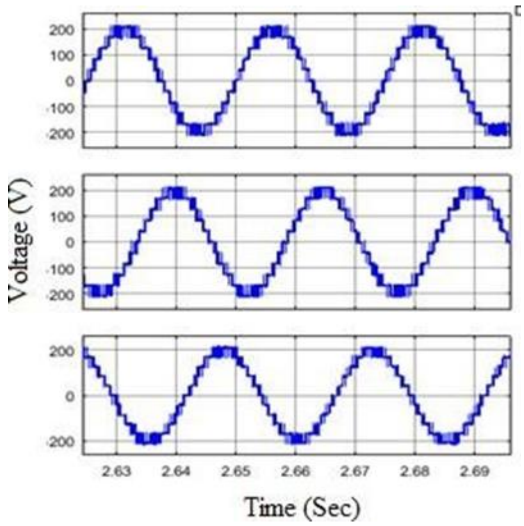

Fig. 8. 3-phase 11-level voltages

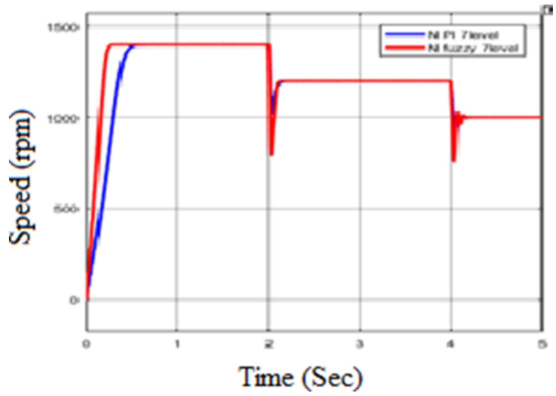

Fig. 9. Speed variation of 7-level PI and FIS

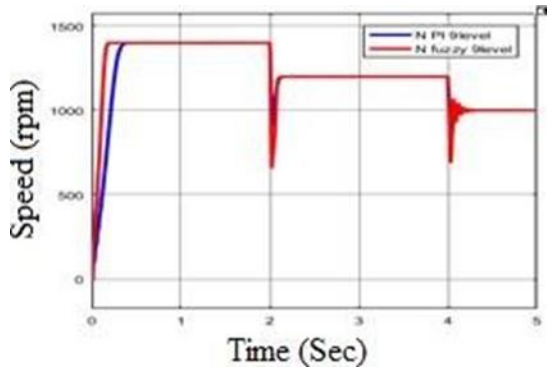

Fig. 10. Speed variation of 9-level PI and FIS

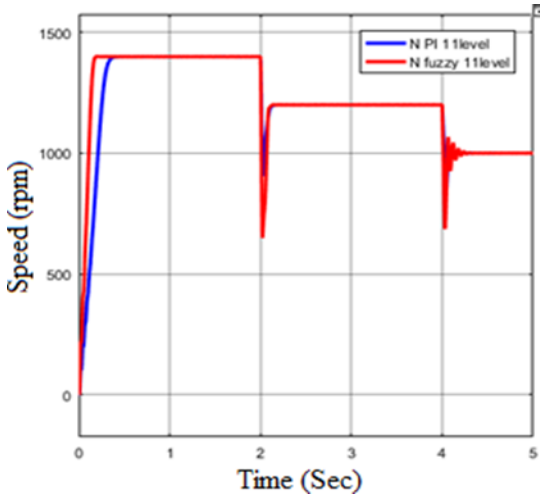

Fig. 11. Speed variation of 11-level PI and FIS

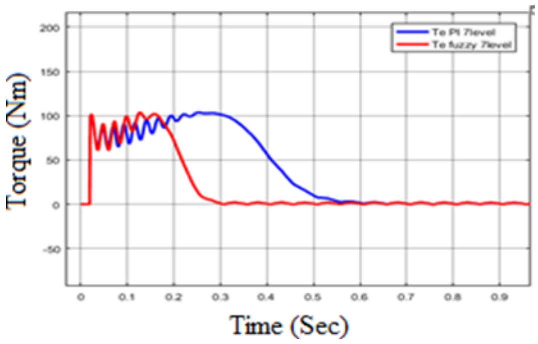

Fig. 12. Torque comparison of 7-level PI and FIS

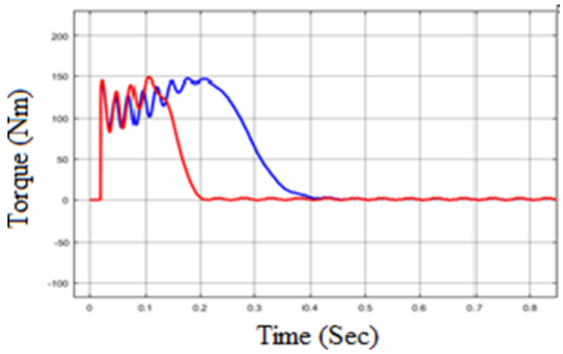

Fig. 13. Torque comparison of 9-level PI and FIS

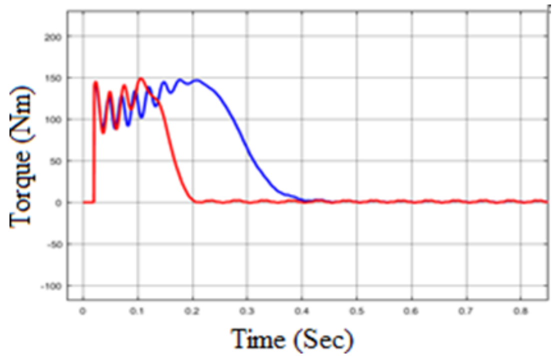

Fig. 14. Torque comparison of 11-level PI and FIS

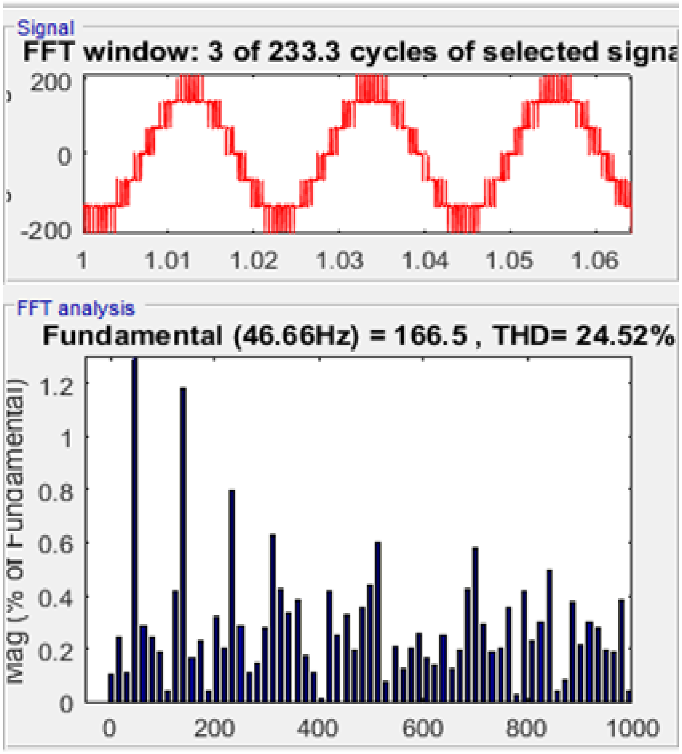

Fig. 15. THD of 7-level inverter voltage with PI controller

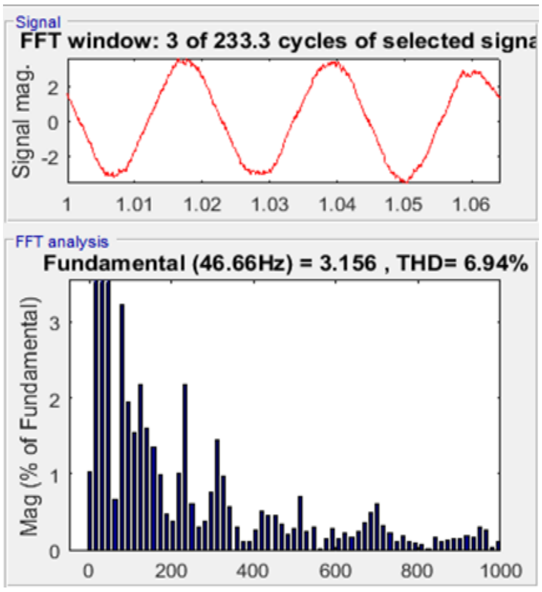

Fig. 16. THD of 7-level inverter current with PI controller

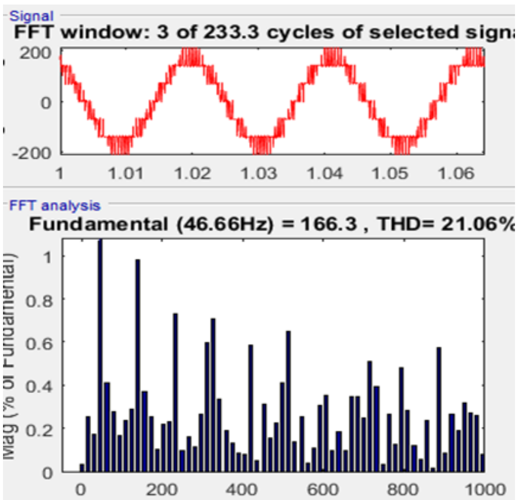

Fig. 17. THD of 7-level inverter voltage with FIS controller

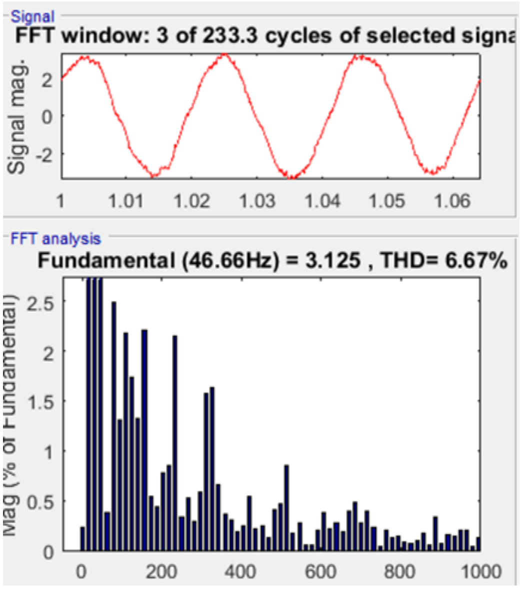

Fig. 18. THD of 7-level inverter current with FIS controller

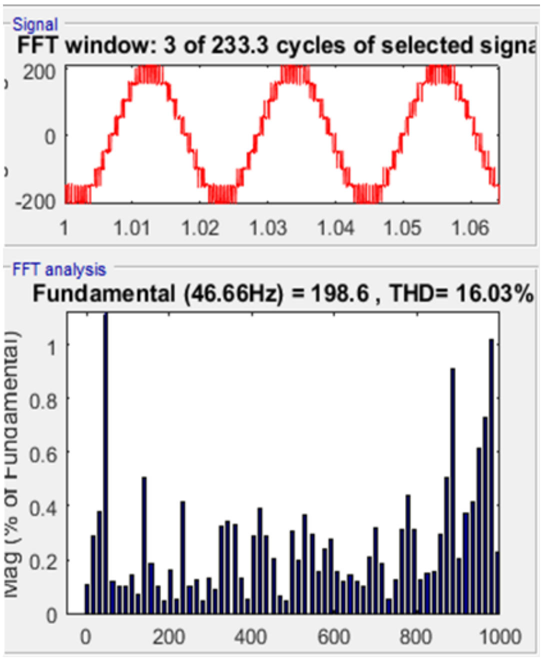

Fig. 19. THD of 9-level inverter voltage with PI controller

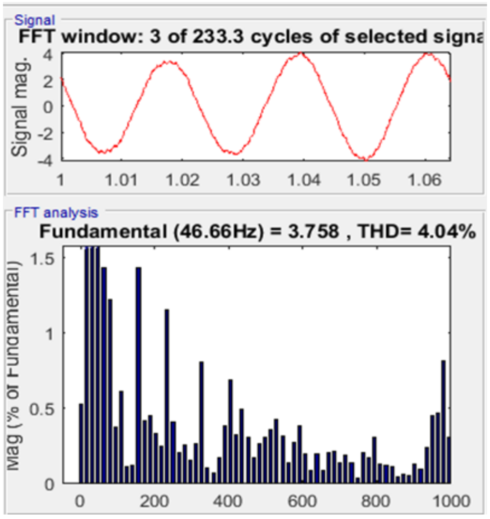

Fig. 20. THD of 9-level inverter current with PI controller

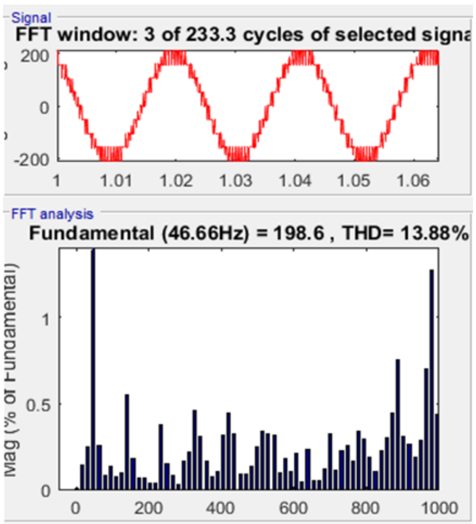

Fig. 21. THD of 9-level inverter voltage with FIS controller

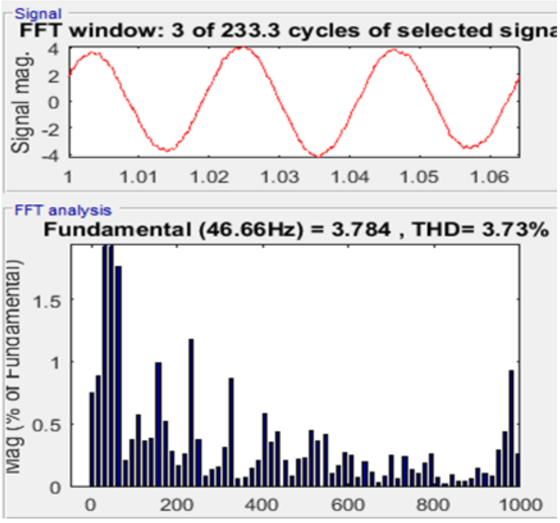

Fig. 22. THD of 9-level inverter current with FIS controller

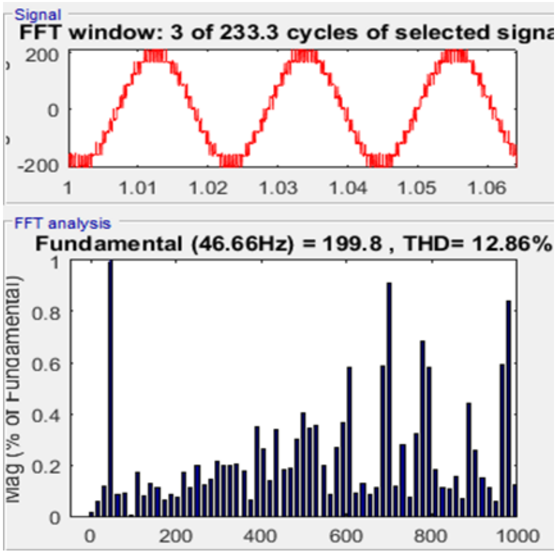

Fig. 23. THD of 11-level inverter voltage with PI controller

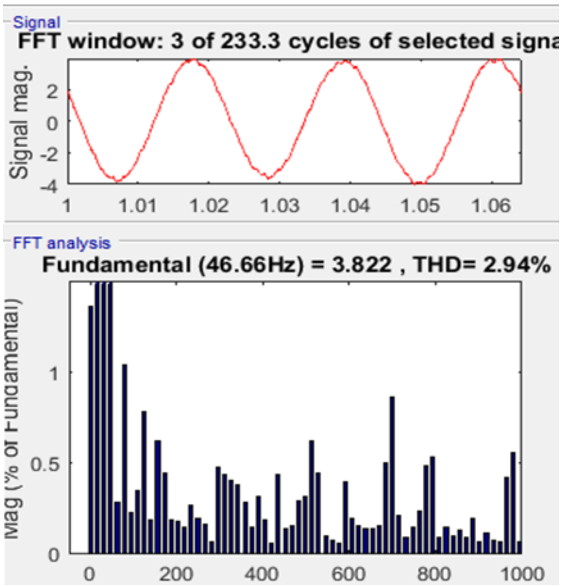

Fig. 24. THD of 11-level inverter current with PI controller

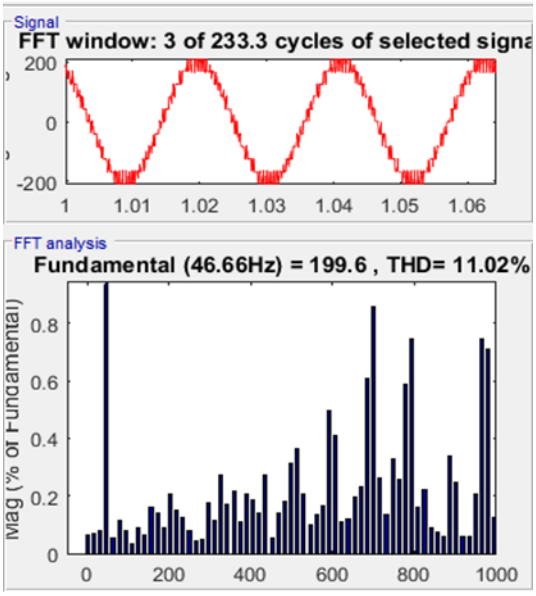

Fig. 25. THD of 11-level inverter voltage with FIS controller

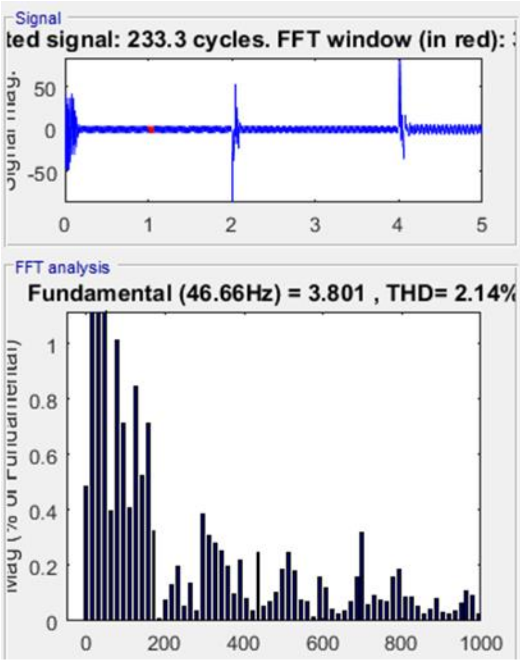

Fig. 26. THD of 11-level inverter current with FIS controller

6. Conclusion

On the basis of the outcomes, it came in to notice that the speed of the induction motor is settle faster at 1500rpm with FIS controller as compared to that of PI controller. As fuzzy interface system generates error at faster response rate, the reference value generation also has faster reaction rate with respect to time. Along with speed response, the THD of the voltages and currents are declining gradually with increase in voltage levels. A comparison tables of the THDs for different levels voltages and currents is given below.

Table I THDs for Different Levels Voltages

	7-level	9-level	11-level
THD of V with PI	24.52%	16.03%	12.86%
THD of V with FIS	21.06%	13.88%	11.02%

Table II THDs for Different Levels Currents

	7-level	9-level	11-level
THD of I with PI	6.94%	4.04%	2.94%
THD of I with FIS	6.67%	3.73%	2.14%

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