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Analysis of Proportional Integral Controller and Fuzzy Logic Controller for Single Phase Induction Motor

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Abstract: ***Nowadays problems are occurring due to power quality issues which causes major impression in power system. Most of the times problem is of harmonics in the supply system. It occurs due to Non-Linear Load and it could be rectified by using filters, controllers and artificial intelligence. In this paper, the Fuzzy logic controller is designed using Takagi- Sugeno fuzzy inference system to eliminate harmonics and uncertainty in the supply system thereby improving the response of whole system. The Selective Harmonic Elimination Pulse Width Modulation (SHEPWM) control scheme is used to generate the necessary pulses to eliminate the lower order harmonics. The results for both fuzzy logic controller (FLC) and PI Controller are compared, and the simulation is designed in MATLAB Simulink.***

Keywords: ***Fuzzy logic controller, PI Controller, Voltage Source Inverter, SHEPWM, THD***

I. INTRODUCTION

Though in twentieth century, one of the biggest problems is of harmonics due to the fast development of industry which has caused simultaneous increase in demand for electric drives. Generally, harmonics in the system are divided in two types (i) voltage harmonics and (ii) Current harmonics. Voltage and current source harmonics imply power losses, pulsating torque in AC motor drives. When AC loads are fed through inverters, it is required that the output voltage of desired magnitude and frequency should be achieved. If the DC input voltage is fixed, a variable output voltage is often obtained by varying the gain of the inverter, which is generally accomplished by pulse-width-modulation (PWM) control within the inverter. Power systems experience harmonics due to power electronic devices-based switching. As per IEEE-519 standard, the total harmonic distortion (THD) should be less than 5%. There are different ways to eliminate harmonics and reduce the THD of the output voltage. By Selective Harmonic Elimination (SHE) method, the low order harmonics can be thoroughly removed and therefore, less value of voltage THD is achieved. Control algorithms supported symbolic logic are implemented in many processes. The application of such control techniques has been motivated for the following reasons:

1. Improved robustness over the conventional linear control algorithms.
2. Simplified control design for difficult system models.
3. Simplified implementation.

In recent years, fuzzy logic control has emerged as a powerful tool and is used in various power system applications. The application of symbolic logic control techniques appears to be best suited one whenever a well-defined control objective can't be specified, the system to be controlled may be a complex one or its exact mathematical model isn't available. In recent years, artificial intelligence techniques are also used in power system applications such as planning and scheduling, operation, control, and protection, particularly where imprecise information needs to be processed to obtain accurate outcomes.

II. VOLTAGE SOURCE INVERTER FED INDUCTION MOTOR

Inverters are circuits which convert DC supply to AC supply. It transfers power from DC source to AC load. The main purpose of designing the inverter is to create an AC voltage when only a DC voltage source is available, a way to decrease the total harmonic distortion (THD) of load current. In PWM technique the amplitude of the output voltage can be controlled. Based on their operation inverters are categorised as Voltage Source Inverter and Current Source Inverter.

A. Voltage Source Inverter

According to the sort of AC output waveform, these topologies are often considered as voltage source inverters (VSIs), where the independently controlled AC output is a voltage waveform. These structures are the most widely used because they naturally behave as voltage sources as required by uninterruptible power supplies, battery vehicle drives, High voltage D.C transmission lines etc. Similarly, these topologies are often found as current source inverters (CSIs), where the independently controlled AC output is a current waveform. These structures are widely utilized in solar photovoltaic system, AC motor drives etc. Static power converters, especially inverters are constructed from power switches and therefore the AC output waveforms are made from discrete values. This results in the generation of waveforms that feature fast transitions instead of smooth ones. The single-phase full bridge PWM IGBT voltage source inverter considered for study has the following specifications.

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Maximum permissible voltage limit	230V
Number of bridge arms	2
Snubber resistance Rs	5000 Ω
Snubber capacitance Cs	inF
Ron	0.001Ω

B. Induction Motor

Single Phase induction motors are widely accepted motor because of their energy efficient characteristics. To drive varying mechanical loads for long duty the machine must be controlled to extend its efficiency and minimize transient. With the support of PWM the output voltage control is often obtain without addition of any external components and PWM minimizes the lower order harmonics, while the upper order harmonics are often eliminated employing a filter.

In Split Phase Induction Motor, main winding is made up of thick wire and large turns resulting in low resistance and high reactance. Since auxiliary winding is made up of fewer turns of a thin wire, it has high resistance and low reactance. Two windings are connected in parallel across the source. The necessary phase difference between main and auxiliary winding current is obtained because of the difference between impedance angles. In some motors the auxiliary winding is used only during start and run up and disconnected by centrifugal switch or relay around 75% of full load speed. The auxiliary winding is also called starting winding.

In Split Phase AC motor, the starting winding is used only for starting motor and has high resistance and low inductive reactance. The main winding has low resistance and high reactance. When power is applied both windings are energized. Because of their different inductive reactance, the main winding current lags the starting winding current, creating a phase difference between two. Ideally the phase difference should be 90 degrees. The windings develop fields that are out of phase which creates a rotating magnetic field in the air gap. When power is applied to a Split Phase Induction Motor both main and auxiliary winding draw about 4-5 times their normal full load current. This means that heat loss in these windings is from 16 to 25 times higher than normal. The starting period must be kept short to stop overheating of the windings. The split phase induction motor considered for study has the following specifications

Power Rating	0.25HP
Maximum permissible voltage limit	230V
Main Winding Stator resistance Rs	2.02Ω
Main winding Stator Leakage Inductance Lls	0.0074H
Main Winding Rotor resistance R'r	4.12Ω
Main winding Rotor Leakage Inductance L'lr	0.0056H
Main winding mutual Inductance Lms	0.17719H
Auxiliary winding stator resistance RS	7.14Ω
Auxiliary winding stator leakage inductance Lls	0.0085001H
Inertia J	0.00146 kgm
Friction factor F	0.00099N.m.s
Pole pair P	2
Turn	1.18 S/Ns

III. PULSE WIDTH MODULATION IN INVERTERS

Output voltage from an inverter also can be adjusted by exercising a control in the inverter itself. The most efficient technique of doing this is by pulse-width modulation control used within an inverter.

The advantages owned by PWM techniques are as under:

i. The output voltage control with this method are often obtained without no other additional components.
ii. With the technique, lower order harmonics are often eliminated or minimized along with the output voltage control. As higher order harmonics are often filtered easily, the filtering requirements are minimized.

It is generally accepted that performance of inverter with any switching strategies can be related to the harmonic content of its output voltage. There are many techniques applied to inverter topology. Several known modulation topologies are as follows

1. Single Pulse Width Modulation.
2. Sinusoidal Pulse Width Modulation (SPWM).
3. Selective Harmonic Eliminated Pulse Width Modulation. (SHE-PWM)

A. Single Pulse Width Modulation.

In this control, there's just one pulse per half cycle and hence width of the pulse is varied to control the inverter output. The gating signals are produced by comparing a rectangular reference signal of AR amplitude with triangular carrier wave of AC amplitude, the frequency of the carrier wave determines the fundamental frequency of output voltage. By varying AR from 0 to Ac, the width of the pulse is often varied from 0 to 100 percent. The ratio of AR to AC is control variable and is called as the modulation index.

B. Sinusoidal Pulse Width Modulation.

Instead of maintaining the width of all pulses of same just in case of multiple pulse width Modulation, the width of each pulse is varied in proportion to the amplitude of a sine wave evaluated at the center of the same pulse. The distortion factor and lower order harmonics are minimized significantly. The gating signals are generated by comparing a sinusoidal reference signal with a triangular carrier signal of frequency Fc. The frequency of reference signal Fr, determines the inverter output frequency and its peak amplitude AR which controls the modulation index M and RMS output voltage Vo. The number of pulses each half cycle depends on carrier frequency

C. Selective Harmonic Elimination.

The main aim is to get sinusoidal AC output voltage waveform where the basic component can be adjusted arbitrarily with a variety of intrinsic harmonics selectively eliminated. This is achieved by mathematically by generating the exact instant of turn on and turn off power valves. The principle of SHEPWM is to compute the suitable switching angle so as to provide the output waveform.

In our study the target is to cancel the 3 rd , 5 th , 11th harmonics as well as to control the fundamental voltage. In selective harmonic elimination method selected lower order harmonics gets eliminated and upper order harmonics gets eliminated with the help of filter.

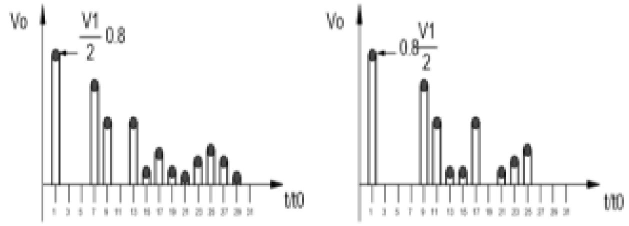

Fig.1 Harmonic spectrum of SHE PWM

For two level PWM technique waveform with odd and half wave symmetry and N switching per quarter cycle as shown in fig 2.

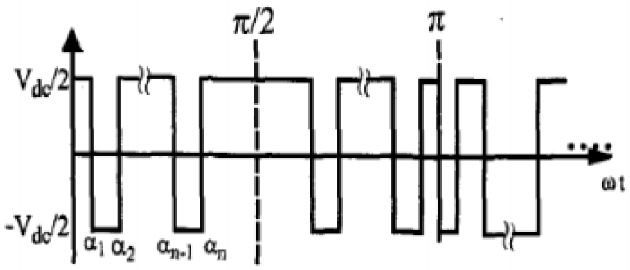

Fig. 2 Waveform of SHE PWM

$$h1 = \left(4\frac{Vdc}{\pi}\right).[1 - 2\cos\alpha_1 + 2\cos\alpha_2 - 2\cos\alpha_3 \ldots + 2\cos\alpha_n]$$

$$h3 = \left(4\frac{Vdc}{\pi}\right).[1 - 2\cos 3\alpha_1 + 2\cos 3\alpha_2 - 2\cos\alpha_n \ldots + 2\cos 3\alpha_n]$$

$$hk = \left(4\frac{Vdc}{\pi}\right).[1 - 2\cos k\alpha_1 + 2\cos k\alpha_2 - 2\cos k\alpha_3 .. + 2\cos k\alpha_n]$$

Mathematical Modeling of Switching Angle and SHE Equation:

In general, the Fourier series expansion of o/p voltage waveform.

$$V(an) = \sum_{n=1,3,5}^{\infty} 4\frac{Vdc}{\pi}\cos(n\alpha 1 + \cos(n\alpha 2) \pm \ldots \mp \cos(n\alpha s)\sin(nwt)$$

In the natural sinusoidal PWM strategy, a large number of switching is required which causes increase in switching losses. With the method of Selective Harmonic Elimination, only selected harmonics are eliminated with the smallest number of switching. This method however is difficult to be implementing on-line due to computations and memory requirements and needs to solve a set of complex nonlinear equations. In a two level PWM single phase full bridge-controlled inverter, with odd harmonics and half wave symmetry N chops per quarter cycle which is shown in Fig.2. The magnitude of the harmonic components including the basic, are given by:

$$H_1/_E = -(^4/_\pi).[1 - 2\cos\alpha_1 + 2\cos\alpha_2 - 2\cos\alpha_3 + 2\cos\alpha 4] = M$$

$$H_3/_E = -(^4/_{3\pi}).[1 - 2\cos 3\alpha_1 + 2\cos 3\alpha_2 - 2\cos 3\alpha_3 + 2\cos 3\alpha_4] \quad = 0$$

$$H_n/_E = -(^4/_{n\pi}).[1 - 2\cos n\alpha_1 + 2\cos n\alpha_2 - 2\cos n\alpha_3 .. + 2\cos n\alpha_n] \quad = 0$$

Where,

Hn is the magnitude of the nth harmonic (odd harmonics)

M is the modulation index

E is the input DC voltage

Also, it must satisfy the following condition

$\alpha_1 < \alpha_2 < \ldots\ldots\ldots \alpha_n < \pi/2$

Generally, one switching angle is used for fundamental voltage selection and remaining (s-1) switching angle are used to eliminate certain predominating lower order harmonics. The expression for fundamental voltage in terms of switching angle is given by

$4Vdc/\pi\ (\cos(\alpha 1) + \cos(\alpha 2) + \ldots\ldots + \cos(\alpha s) = V1$

IV. FUZZY LOGIC CONTROLLER

The fuzzy logic controller (FLC) require control variable which define the control surface to be expressed in fuzzy set notations. The fuzzy controller is used for nonlinear load because it does not use complex mathematical equation. The fuzzy logic input uses membership function to determine input value of fuzzy.

A. Takagi Sugeno-type fuzzy inference:

This section talks about the so-called Sugeno, or Takagi-Sugeno-Kang, method of fuzzy inference. Introduced in 1985, it is similar to the Mamdani method in many regards. The first two parts of the fuzzy inference process, fuzzifying the inputs and applying the fuzzy operator, are entirely the same. In the Sugeno-type fuzzy inference the input membership functions either constant or linear, so the Sugeno-type inference is useful for the in hand proposed circuit. The design of fuzzy logic block represent that the input is a numeric number. Therefore, the membership function may differ from language once, and the output of the block which are also a numeric number. This is achieved by using Sugeno-type fuzzy inference which take this idea and gives the chance to implement the input data and output data.

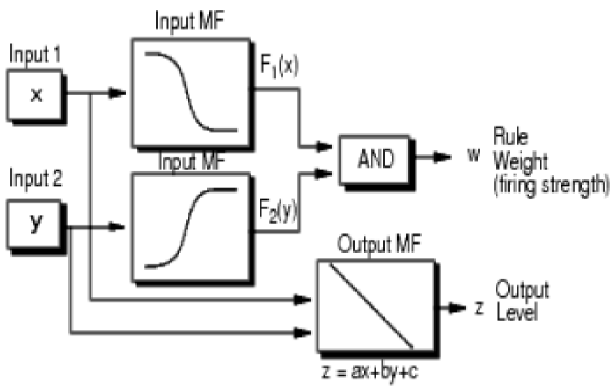

Fig.3 Rules of Sugeno inference system

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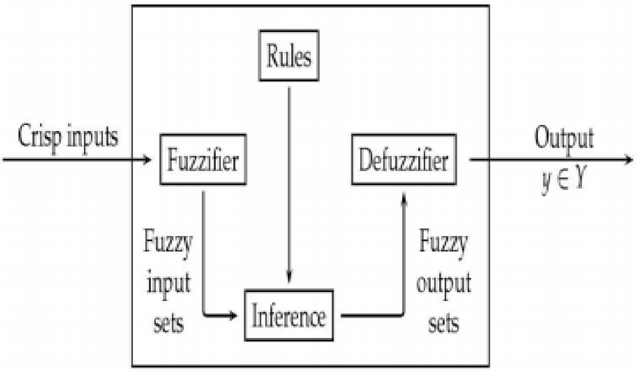

Fig. 4 Fuzzy Logic Diagram

1. **Crisp Inputs:**
   Crisp input is in the form of numbers and the output is in the form of values of alphabets or alphanumeric values. If then rules are going to be used in it.
2. **Fuzzification:**
   Fuzzy logic uses linguistic variable and the error between reference signal and output signal is assign. The process of fuzzification converts real number to a fuzzy number.
3. **Rule Editor:**
   In rule editor rules are defined to evaluate the output.
4. **Defuzzification**:
   Defuzzification evaluates the rules to defuzzify the system and then send it for evaluation to get the required output.

B. Fuzzy Inference system:

Fuzzy inference is the process of formulating the mapping from the given input to an output using fuzzy logic. The mapping then gives a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference includes all of the process that are described in the previous sections: Membership Functions, Logical Operations, and if then Rules. We can use two types of fuzzy inference systems in the toolbox i.e. Mamdani-type and Sugeno-type. These two types of inference systems vary somewhat in the way outputs are determined.

V. PI CONTROLLER

The combination of proportional and integral is termed as PI controller. It is used to eliminate the error

$$K_p\,\Delta + K_I \int \Delta dt$$

Ki = integral gain
Kp=proportional gain,

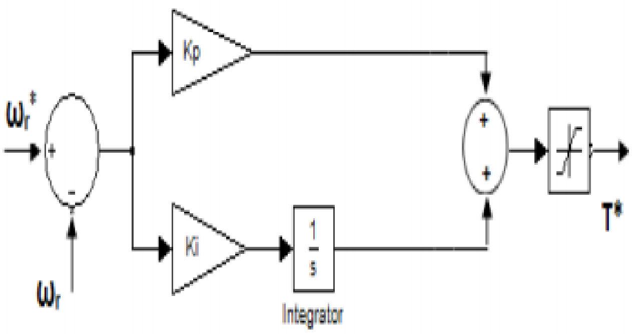

Fig. 5 Block Diagram of PI controller

Equation for PI Controller: A PI controller (proportional – integral controller) is s special case of the PID controller in which the derivative (D) of the error is not used. The controller output is given by

$$\mathbf{K_p\,\Delta + K_I \int \Delta dt}$$

Where, Δ is the error or derivation of actual measured value (PV) from the set point (SP)
A PI controller can be modeled easily in software such as Simulink using a "flow-chart" box involving Laplace operator

$$C = \frac{G(1+\tau s)}{\tau s}$$

Where,
G= Kp = proportional gain

$$G/\tau = K_I = \text{integral gain}$$

VI. SIMULATION DIAGRAMS AND RESULTS

A. Simulation of the Single-Phase Induction Motor without Controller.

DC supply of 155.5 V is given to inverter which is fed to Split Phase Induction Motor and simulation of Induction Motor at no load and for a load of 2Nm is carried out and waveform for speed, voltage and current is observed.

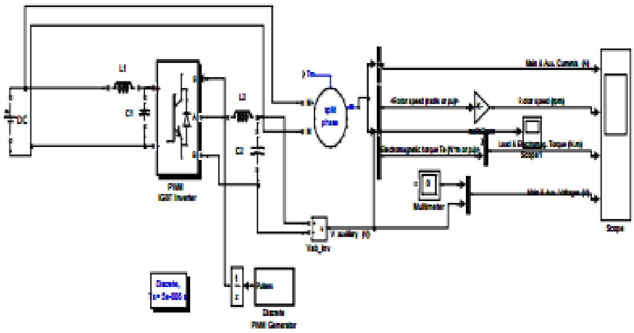

Fig. 6 Simulation Diagram of Induction motor without controller

B. Simulation result of the Single-Phase Induction Motor without Controller for a load of 2NM

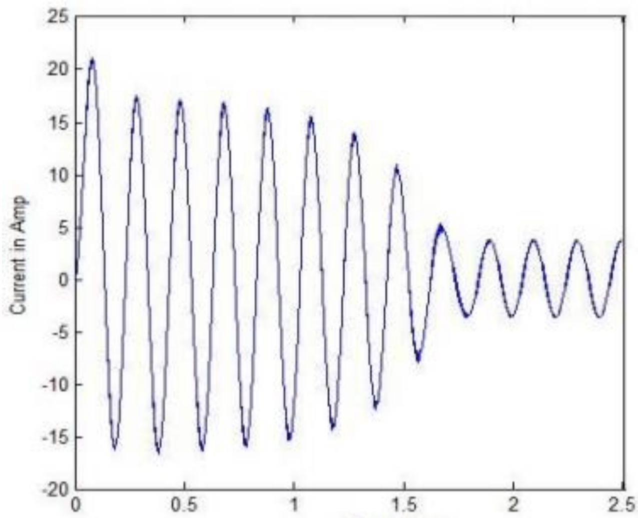

Fig. 7 Current of Induction motor

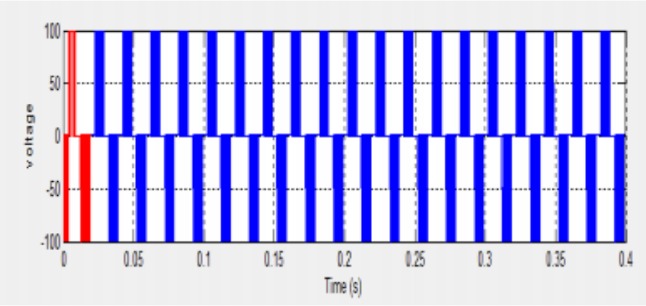

Fig. 8 Voltage of Induction Motor

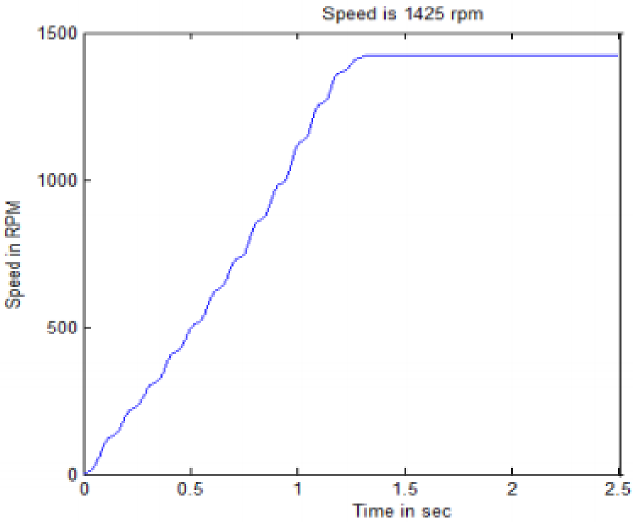

Fig. 9 Speed of Induction motor

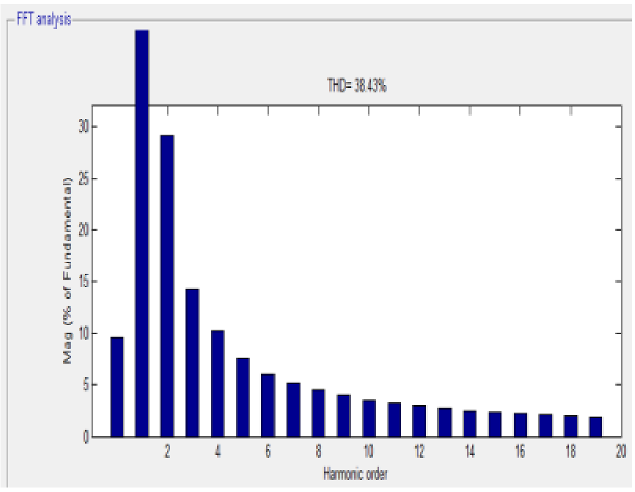

Fig. 10 FFT analysis of voltage of Induction Motor

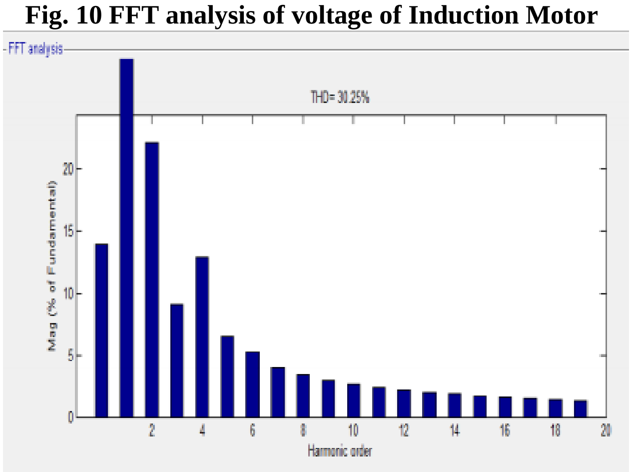

Fig. 11 FFT analysis of current of Induction Motor

C. Simulation of Single-Phase Induction Motor with PI controller.

DC supply of 155.5V is given to inverter which is fed to Split Phase Induction Motor and simulation of Induction Motor at no load and for a load of 2Nm has been done and waveform for speed, voltage and current is observed. In this scheme SHEPWM block and PI controller is used. In SHEPWM method the selected lower order harmonics gets eliminated by varying the firing angle and modulation index. PI Controller is implemented to minimize the voltage and current harmonics

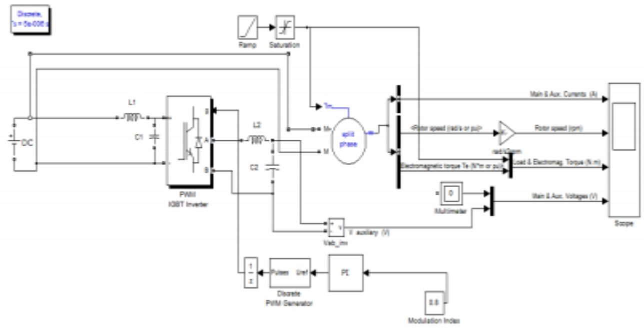

Fig. 12 Simulation Diagram of Induction motor with PI controller

Simulation result of Single-Phase Induction Motor with PI controller for a load of 2Nm.

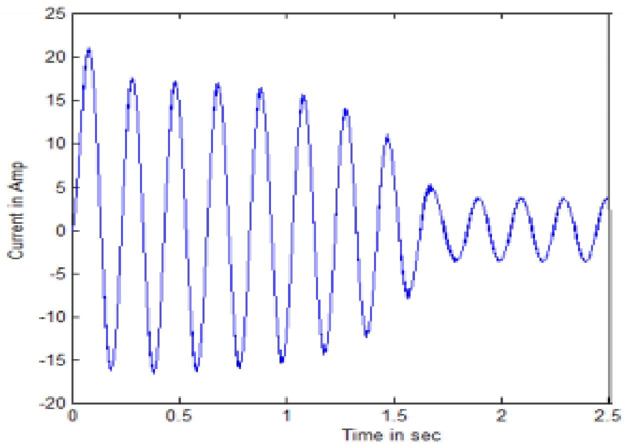

Fig. 13 Current of Induction Motor

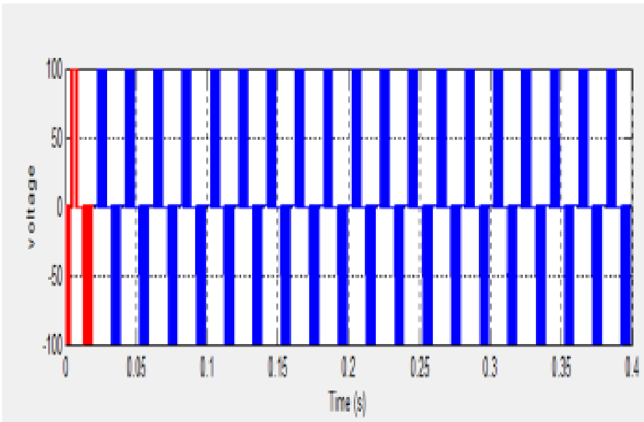

Fig. 14 Voltage of Induction Motor

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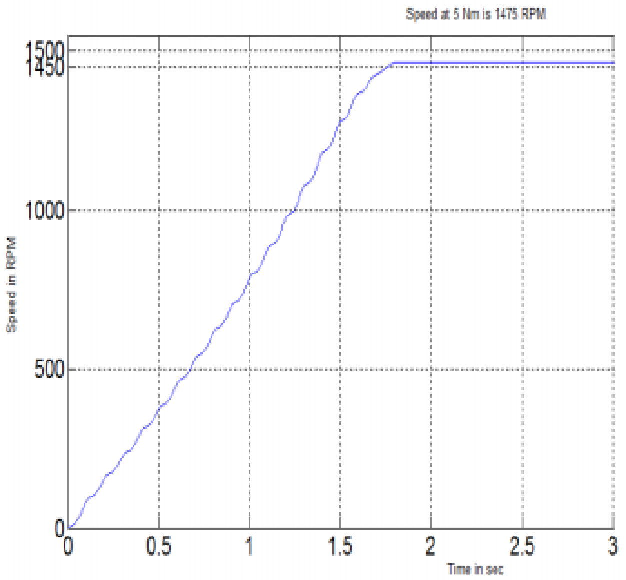

Fig. 15 Speed of Induction Motor

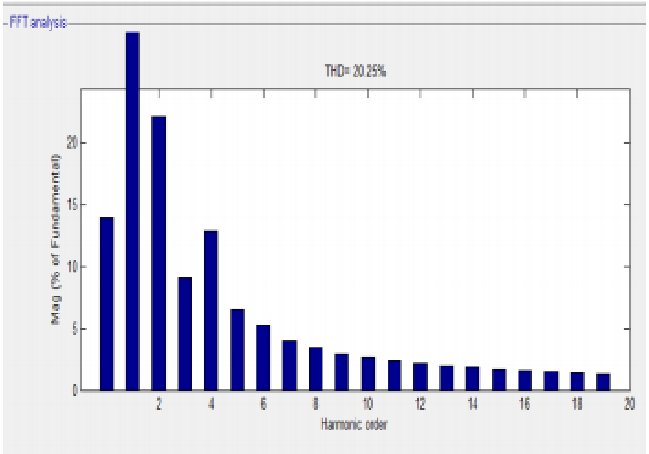

Fig. 16 FFT analysis of voltage of Induction motor

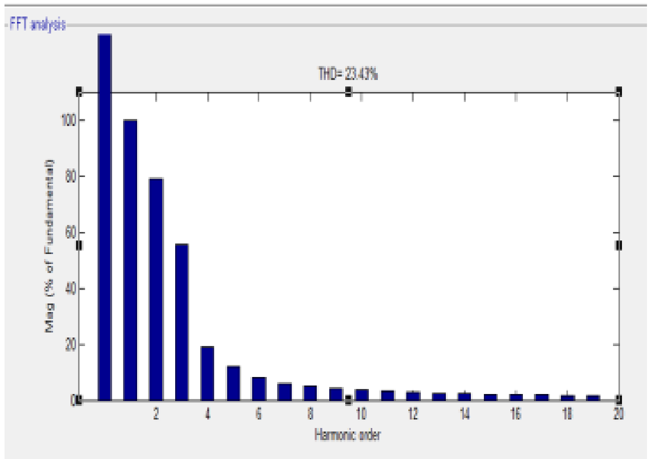

Fig. 17 FFT analysis of current of Induction motor

D. Simulation of Single-Phase Induction Motor with Fuzzy Logic Controller:

DC supply of 155.5V is given to inverter which is fed to Split Phase Induction Motor and simulation of Induction Motor at no load and for a load of 2Nm has been done and waveform for speed, voltage and current is observed. In this scheme SHEPWM block and fuzzy logic controller is used. SHEPWM block is used to eliminate the selected lower order harmonics. Fuzzy Logic Controller has been implemented to eliminate voltage and current harmonics.

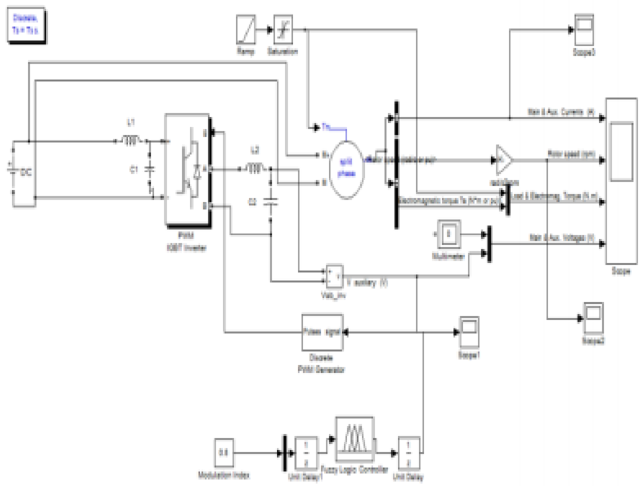

Fig. 18 Simulation of Induction Motor with Fuzzy Logic controller

Simulation result Single Phase Induction Motor with FLC for a load of 2Nm.

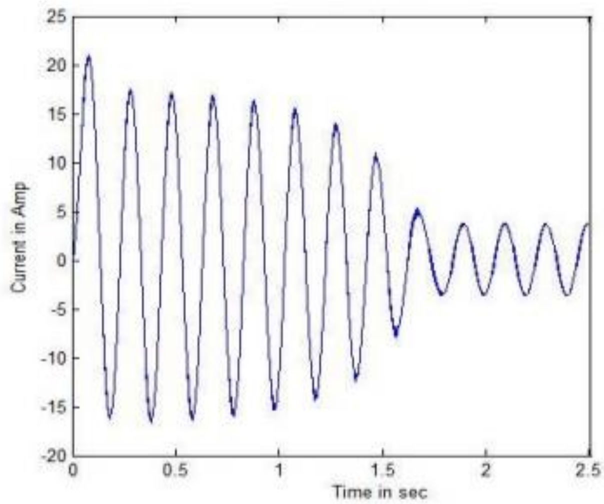

Fig. 19 Current of Induction Motor

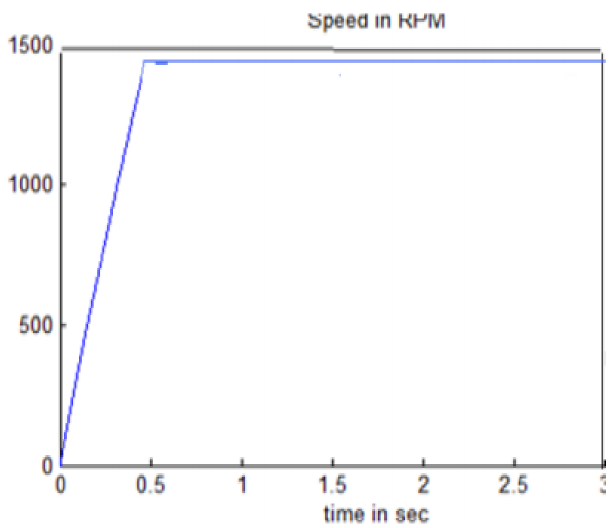

Fig. 20 Voltage of Induction Motor

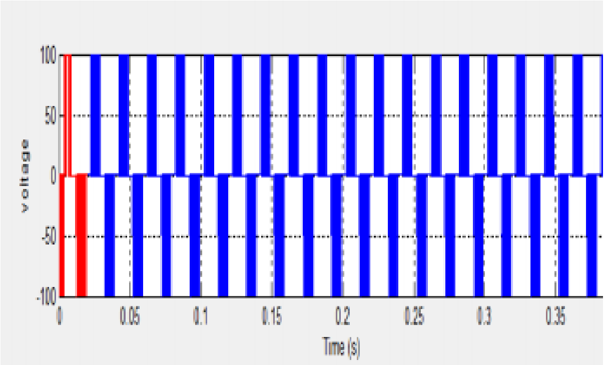

Fig. 21 Speed of Induction Motor

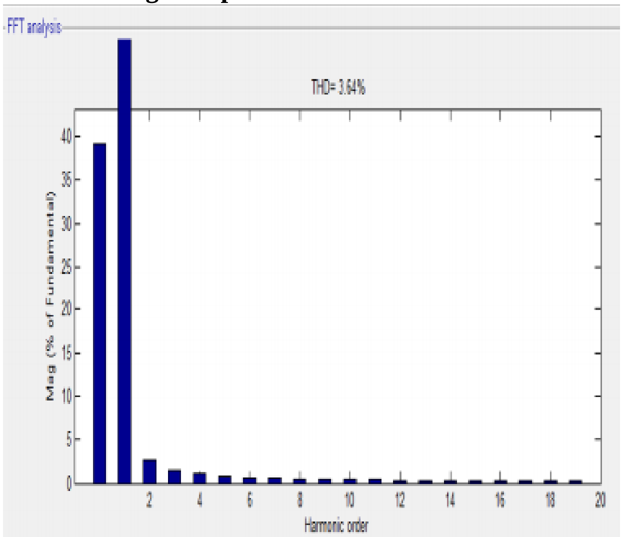

Fig. 22 FFT analysis of voltage of Induction Motor

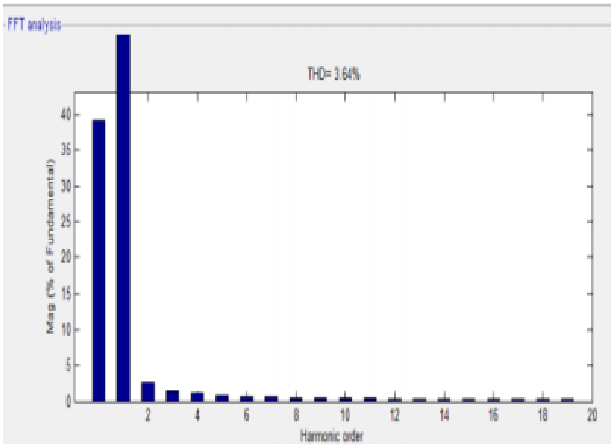

Fig. 23 FFT analysis of current of Induction Motor

VII. COMPARATIVE ANALYSIS

Parameters	Without controller	With PI Controller	With Fuzzy logic Controller
No load speed	1500	1500	1500
Drop in speed at full load	1425	1475	1495
Total harmonic Distortion(THD) of Current	30.25	20.25	3.64
Total harmonic Distortion(THD) of voltage	38.43	23.43	3.64
Percentage slip	5%	1.60%	0.30%

VIII. CONCLUSIONS

A Simulink model for voltage source inverter fed Single Phase Induction Motor system is designed. The system without any controller gives harmonics. The system is designed with PI and FLC controller.

Voltage harmonics in motor without any controller are 38.43 % and current harmonics are 30.25%.

Voltage harmonics in PI controller are 23.43% and current harmonics are 20.25% which are reduced by 15% and 10% as compared with motor without any controller.

Voltage harmonics in FLC are 3.64% and current harmonics are also 3.64 % which are reduced by 34% and 26.61% as compared with motor without any controller and 19.75% and 16.25% as compared with motor with PI controller.

Slip of motor gets reduced in Fuzzy Logic controller as compared with Motor without any controller and with Proportional Integral controller. Hence harmonics gets reduced and speed response of motor is improved.

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