FUZZY LOGIC CONTROL OF INDUCTION MOTOR DRIVE FOR PERFORMANCE IMPROVEMENT

Madhusmita Nayak(109EE0290**)**
Smrutidhara Singh(109EE0307**)**

Department of Electrical Engineering
National Institute of Technology, Rourkela
Rourkela- 769008, Odisha

FUZZY LOGIC CONTROL OF INDUCTION MOTOR DRIVE FOR PERFORMANCE IMPROVEMENT

A PROJECT THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

In

Electrical Engineering

By

Madhusmita Nayak

(Roll 109EE0290)

Smrutidhara Singh

(Roll 109EE0307)

Under Supervision of

Prof. Kanungo Barada Mohanty

Department of Electrical Engineering

National Institute of Technology, Rourkela

Rourkela- 769008, Odisha

DEPARTMENT OF ELECTRICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA- 769 008

ODISHA, INDIA

CERTIFICATE

This is to certify that the draft report/thesis titled "**Fuzzy logic control of induction motor drive for performance improvement** ", submitted to the National Institute of Technology, Rourkela by **Miss Madhusmita Nayak ,Roll No:109EE0290 and Miss Smrutidhara Singh, Roll No**: **109EE0307** for the award of **Bachelor of Technology** in Electrical Engineering, is a bonafide record of research work carried out by him under my supervision and guidance.
The candidate has fulfilled all the prescribed requirements.

The draft report/thesis which is based on candidate's own work, has not submitted elsewhere for a degree/diploma.

In my opinion, the draft report/thesis is of standard required for the award of a **Bachelor of Technology** in Electrical Engineering.

Prof. K.B.Mohanty

Associate Professor

Department of Electrical Engineering

National Institute of Technology

Rourkela – 769 008 (ODISHA)

Acknowledgment

We are grateful to **The Department of Electrical Engineering** for giving us the opportunity to carry out this project, which is an integral fragment of the curriculum in B. Tech programme at the National Institute of Technology, Rourkela.

We would like to express our heartfelt gratitude and regards to our project guide, **Prof. K. B. Mohanty**, Department of Electrical Engineering, for being the corner stone of our project. It was his incessant motivation and guidance during periods of doubts and uncertainties that has helped us to carry on with this project.

We would like to thank **Prof. A.K. Panda**, Head of the Department, Electrical Engineering for his guidance, support and direction. We are also obliged to the staff of Electrical Engineering Department for aiding us during the course of our project. We would also like to offer our sincere thanks to **Prof. P.C. Panda** and **Prof. B.Chitti Babu** the Department of Electrical Engineering, for their continual guidance in project. We offer our heartiest thanks to our friends for their help in collection of data samples whenever necessary.

Last but not the least, we want to acknowledge the contributions of our parents and family members, for their constant and never ending motivation.

Thanking You,

Madhusmita Nayak	Smrutidhara Singh
109EE0290	109EE0307

Abstract

This thesis paper portrays the way of implementing fuzzy logic in improving the performance of induction motor drive. Here a rule-based fuzzy logic based controller is designed and simulated with the help of MATLAB. A PI controller is also designed in SIMULINK. Then performances of both the controller are simulated and compared. For controlling speed here scalar control method is employed, where magnitude of the stator voltage and frequency is changed proportionately. For this V/F control, a reference speed is chosen and controller is designed as such, it can provide that desired (reference) speed in case of frequent load changes.

The major merit of Fuzzy controller over PI controller is use of linguistic variable and user defined rule base that makes it possible to incorporate human intelligence in the controller. Fuzzy logic based controller also has the capability to control both linear and nonlinear system.

Inputs given to the fuzzy logic based controller are speed error (e) and change in speed error (Δe). And output is the change of control (ω_{sl}) , which is the frequency correction. So the inputs error and change in error are processed according to the rule base, which is user defined and output correction is provided to the inverter. The membership functions and the rules are defined in FIS editor window. Based on rules, control surface is also generated. The system or model for speed controlling of induction drive is simulated both with PI and Fuzzy controller and results are analysed and compared and Fuzzy controller is found to perform better than the conventional PI controller.

CONTENTS

CHAPTER-3

SPEED CONTROL TECHNIQUES

CHAPTER-4

PI CONTROLLER

CHAPTER-5

FUZZY SET THEORY

CHAPTER-6

FUZZY LOGIC CONTROLLER

CHAPTER-7

DESIGN OF FUZZY LOGIC CONTROLLER

CHAPTER-8

MATLAB SIMULATION

CHAPTER-9

CONCLUSION

List of Tables

List of Figures

CHAPTER 1

Introduction

1.1 Introduction

In recent years the control of high-performance induction motor drives has received widespread research interests. It has been valued more not only because it is the most used motor in industries but also due to their varied modes of operation. Also it has good self-starting capability, simple, rugged structure, low cost and reliability etc. Main property that makes it more useful for industries is its low sensibility to disturbance and maintenance free operation. Despite of many advantages of induction motor there are some disadvantages also. Like it is not true constant speed motor, slip varies from less than 1% to more than 5%. Also it is not capable of providing variable speed operation. But as it is so useful for industries we have to find some solution to solve these limitations and the solution is speed controller, that can take necessary control action to provide the required speed. Not only speed, it can control various parameters of the induction machine such as flux, torque, voltage, stator current. Out of the several methods of speed control of an induction such as changing no of pole, rotor resistance control, stator voltage control, slip power recovery scheme and constant V/f control, the closed loop constant V/f speed control method is most popular method used for controlling speed. In this method, the V/f ratio is kept constant which in turn maintains the magnetizing flux constant that eliminates harmonic problem and also the maximum torque also does not change. So, it’s a kind of complete utilization of the motor. And the controller used are conventional P-I controller, and fuzzy logic controller.

1.2 Merits of Fuzzy Logic based Controller:

1. It can corporate human intelligence in control algorithm.
2. No perfect mathematical model of the process plant is necessary.
3. It can work effectively both for linear and non-linear system.
4. Speed of response is high and overshooting is less.
5. Linguistic variables are used in place of numerical variable.
6. Degree of precision is very high.

1.3 Objective of the Project:

The main objective of the project is to design and develop a Fuzzy Logic based Controller which can take necessary control action to provide the desired speed. The control method used here is scalar control method where magnitude of the stator voltage and frequency is changed proportionally to keep the main flux constant.

1.4 Scope of the Project:

Scope of the project is:

- Designing and developing a speed controller using the fuzzy logic approach employing the scalar control model.
- producing a learning package of Fuzzy Logic Controller which can be used for future reference

1.5 Organization of the Report:

This document deals with the proposed idea of using Fuzzy Controller as the speed controller to efficiently control the speed in the scalar control method. Conventional controller is also there. But in this document it is compared and proved the fuzzy controller works more efficiently than other conventional controller to control the speed of the induction motor drive.

Total document is divided into 9 different chapters.

Chapter 2 briefly explains the induction motor drive

Chapter 3 explains all the speed control techniques available to control the speed of the induction motor drive including V/F control.

Chapter 4 is the designing of a speed controller using conventional PI controller.

Chapter 5 overviews the fuzzy set, membership functions and operations on fuzzy sets.

Chapter 6 is the brief discussion on fuzzy controller and chapter 7 is the complete design of the fuzzy based controller.

Chapter 8 shows all MATLAB simulations and results and finally chapter 9 is the conclusion.

CHAPTER 2

Induction Motor Drive

2.1 Introduction

The most commonly encountered electric motors in industry are induction motors. In recent years the control of high-performance induction motor drives has received widespread research interests. It has been valued more not only because it is the most used motor in industries but also due to their varied modes of operation. It has good self-starting capability, simple, rugged structure, low cost and reliability etc. Induction motors have been used in past mainly in applications requiring a constant speed. It has attracted the attention because such machine are made and used in largest numbers and also due to their varied mode of operation both under steady state and dynamic states. Induction motor finds its place amongst more than 85% of industrial motor drives and as well as single phase form in various domestic usages.

2.2 Construction of Induction Motor

2.2.1 Stator Parts

Frame: The frame of an induction motor may be cast or fabricated, depending upon the size of the motor. It is cheaper to use cast iron where losses and efficiency is of a lesser consideration than economy and where new designs and modifications are not to be done on the machine. However, for medium-sized and (in particular) large induction motors, fabricated frame structure is exclusively used. The outer surface is provided with cooling fins so as to increase the heat dissipating area without increasing the overall diameter. The chief advantage of fabricated construction is in its application to new design and modifications. And these modifications can be made without reference to previously existing patterns.

Frame gives full support and protection to the other parts and an eye-bolt on its top is useful for transit purposes.

Stator Core: The stator core provides the space for housing for the three-phase stator windings and also forms the path for the rotating magnetic field. They are built up of thin sheets of thickness (called stampings or laminations) of 0.35 mm to 0.65 mm with of a special core of steel, insulated one from the other by paper insulation. The gap facing inner circumference of the plates have suitable slots punched out, either open, semi-closed or it may be completely closed. Normally, the stator core has semi-closed slots where the number of slots, S, is an integral multiple of 3 times the number of poles. Every part of the stator core is subject to alternate changes in polarity of the magnetic field (due to its rotating nature) so hysteresis losses and eddy-current losses take place. To reduce this, about 3-5% of silicon is added to high grade steel and to reduce eddy current loss a larger no of thin laminations are used.

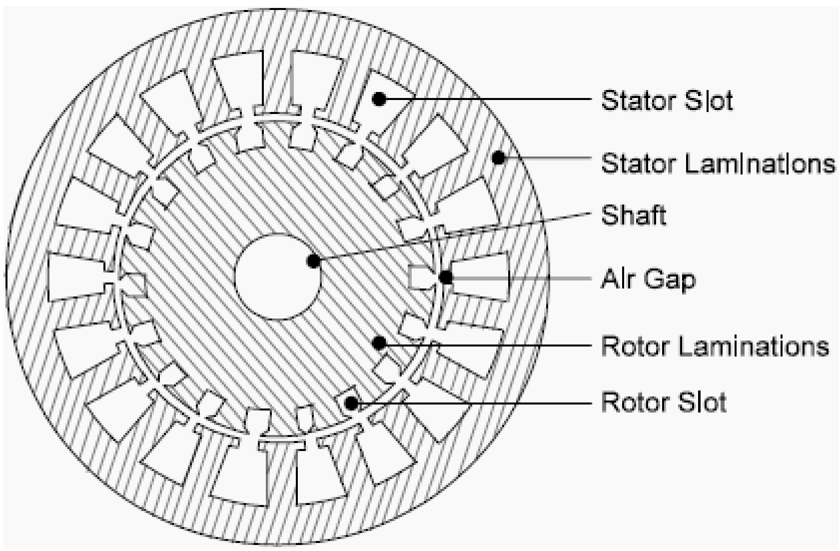


Fig: 1 Showing Stator and Rotor Arrangment

2.2.2 Rotor Parts

Rotor Core: The construction of the rotor core should be separately discussed for (1) squirrel cage motors, and (2) slip-ring motors. Some common features are as follows:

a. Both types have rotors constructed to thin sheets of special core steel, but here the thickness is larger than that of stator stampings because no appreciable iron loss is incurred in the rotor.
b. In small motors, the rotor core is directly mounted on the shaft, to which it is keyed, and clamped between end-plates on the shaft and a shrink-ring.
c. For large motors, the rotor is built up on a fabricated spider, the cross-section of which is shown below :

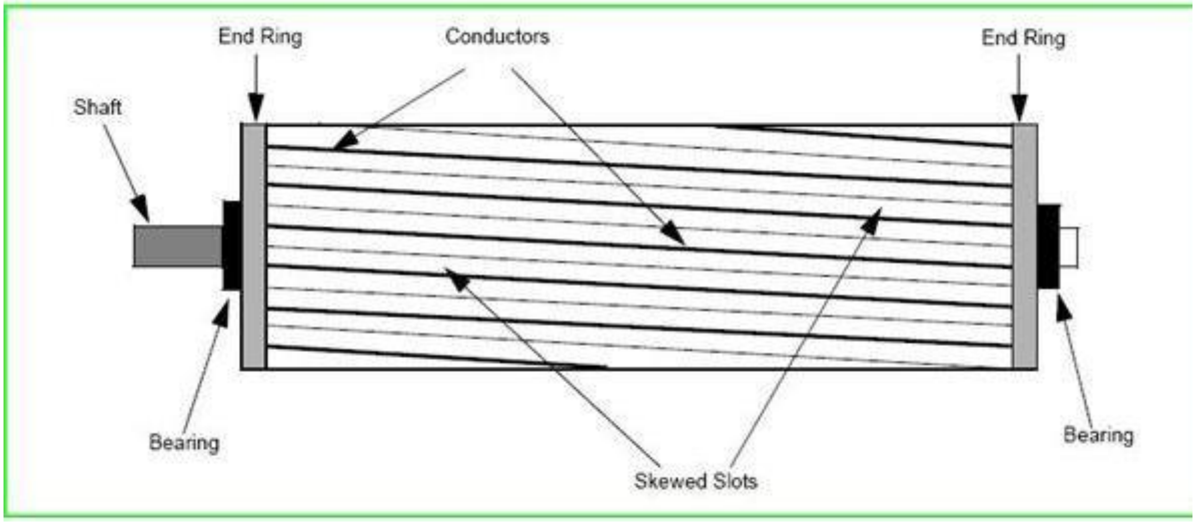


Fig: 2 Rotor Parts

d. The rotor core surface have to be ground to obtain an accurate air-gap.

e. For dynamic balancing of rotor, after the winding of cage has been done, there should be a provision in the rotor core, all along the periphery, for small amount of weights to be attached, which finally forms an integral part of the rotor.

Rotor Core (Squirrel Cage IM)

Closed slots of either circular or rectangular shapes are provided in the stamping. After the stacking of laminations, the shaft of the rotor is inserted. The rotor bars are slightly inclined to the shaft axis due to the 'skew' provided while stacking the rotor stampings. Skewing is done because:

(a) It helps the motor to run quietly by reducing magnetic hum.

(b) It reduces the locking tendency of the rotor.

Stator Winding : Three-phase stator winding is done on the stator core. One starting end and one finishing end for each of the phase windings is brought out for inter-connection in Y or Δ fashion. Single layer mesh winding is used for machines of smaller capacity and medium sized machines have double-layer lap windings. Large capacity motors employ single layer concentric winding.

Rotor Cage or Rotor Winding

In slip ring motors, there is a rotor winding on the rotor cage and hence are called the wound rotor motors. The rotor is wound for the same number of poles as that of stator. The winding is normally connected in star and the resultant three terminals are connected to three slip-rings provided on one end of the shaft.

2.2.3 Working Of Induction Motor:

Principles of Rotating Magnetic Field.

The principle of operation of the induction machine is based on the generation of a rotating magnetic field. The rotor receives power due to Induction from stator rather than direct conduction of electrical power. When three phase voltage is applied to the stator winding a rotating magnetic field of constant magnitude is produced which rotates at synchronous speed. This rotating field is produced by the contributions of space-displaced phase windings carrying appropriate time displaced currents. These currents are time displaced by 120^0 electrical degrees.

According to Faraday's law an emf induced in any circuit is due to the rate of change of magnetic flux linkage through the circuit. As the rotor winding in an induction motor are short circuited through an external resistance and it cuts the stator rotating magnetic field, an emf is induced in the rotor circuit and due to this emf a current flows through the rotor conductor.

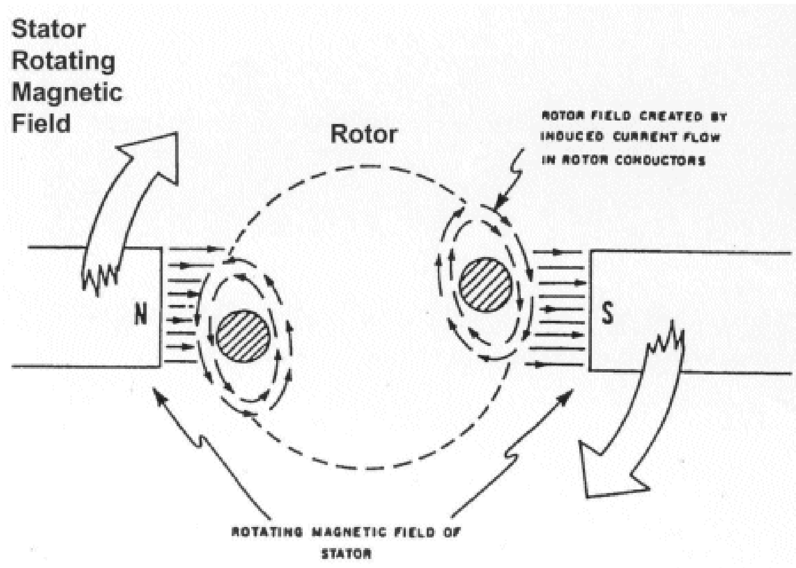


Fig: 3 Rotating Magnetic Field

Here the relative velocity between the rotating flux and static rotor conductor is the cause of electric current generation, hence per Lenz's law rotor will rotate in the direction to reduce the cause i.e the relative velocity.

From working of Induction Motor it may be observed that the rotor should not reach the synchronous speed .If the speed equals there would be no relative velocity. So there will be no cutting of flux so no emf can be generated, means no current will be flowing. And no torque will be generated. The difference between the stator speed and rotor speed is called slip.

Summary: This chapter describes about principle of induction motor, it includes its constructional details, working and operation of Induction motors. It is a singly-fed motor unlike the synchronous motor which calls for ac supply on the stator side and dc excitation on the rotor. Torque developed Induction motor originates from interaction of rotor current and flux. It is also known as asynchronous machine. The air-gap excitation current is much larger in an induction motor than in a transformer for the same power rating, it inherently has a power factor less than unity as the energy conversation is taking place via air gap.

CHAPTER 3

Speed Control Techniques

3.1 Introduction:

The speed control of induction motor is more complicated than that of dc motor, especially when , comparable accuracy is desired. The main reason for this can be attributed to the complexity of the mathematical model of the induction machine, as well as the non-linear power converters supplying this motor. It is very important to control the speed of induction motor for the application in industries and in engineering.

There are many types of speed control. Speed control techniques of induction motors can be broadly classified into two types scalar control and vector control. Scalar method only the magnitude of voltage or frequency of the induction motor.

3.2 Types Of speed control:

Mathematically, the relation between the speed of an induction motor and the synchronous speed(speed of rotating flux) can be stated as:

$N_r = (1\text{-}s)\ N_s$

$N_s = 120f/p$

Where, N_r is the rotor speed

N_s Is the synchronous speed.

s is the slip

f is the supply frequency

as speed is a function of frequency and no. of poles , speed can be varied by varying these parameters.

Different ways of controlling speed of induction motor are:

1. Changing no. of poles
2. Stator voltage control
3. Rotor resistance control
4. Slip power recovery scheme, and
5. Constant V/f control

AC motors have traditionally operated at fixed frequency and speed .when load changes speed also gets changed. With increasing load, speed gets decreased and with decrease of load, speed rises. but as that drop is small percentage of full load speed, so that speed is considered to be constant with changing load.

Out of all the above methods induction motor speed variation can be easily achieved for a short range by either stator voltage control or rotor resistance control. But it may leads to lower efficiency.

Also in stator voltage control method, as voltage is varied to vary the speed and torque is proportional to square of applied stator voltage, so in this method to vary speed, torque also gets affected. Also in other methods like rotor resistance control, part of power get lost in the resistor. So, efficiency gets reduced. So, this is also not a suitable control.

The most efficient scheme for speed control of induction motor is by varying supply frequency.

3.3 V/f Control Overview:

Induction motor speed variation can be easily achieved for a short range by either stator voltage control or rotor resistance control. But at low speed it result in low efficiency. The most efficient scheme for speed control of induction motor is by varying supply frequency. This results in scheme with wide speed range but also improves the starting performance.

The v/f ratio is kept constant, when the machine is operating at speed below base speed, so that flux remains constant. Maximum torque remains constant in this case. At frequency less than rated frequency, the torque capability decrease and this drop in torque has to be compensated by increasing the applied voltage.

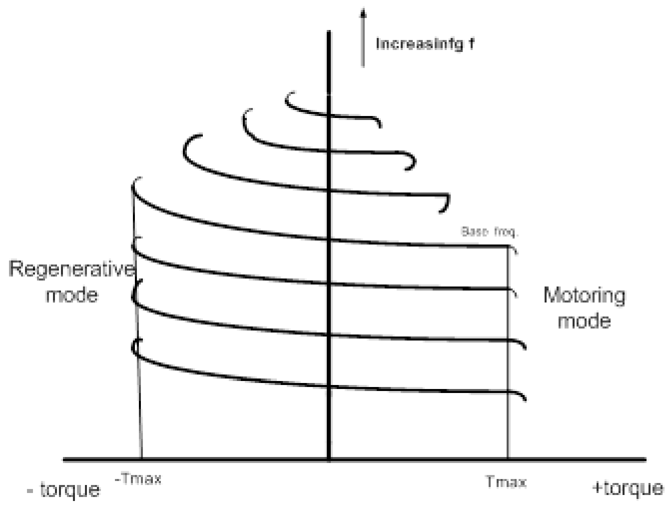


Fig: 4 Torque Vs Frequency

The curve suggests that the speed control and braking operation are available from nearly zero speed to above synchronous speed.

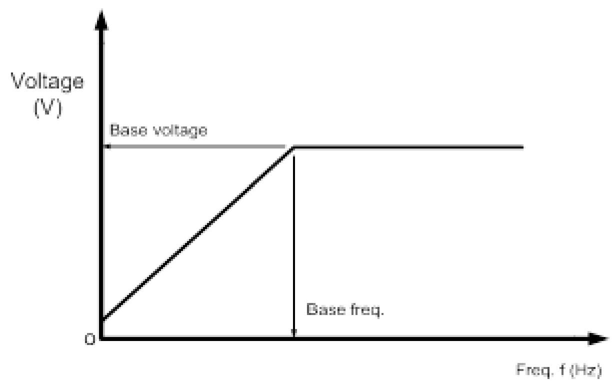


Fig: 5 voltage and frequency variation in VSI fed Induction motor

In Fig. 5 it is noted that frequency is increasing keeping voltage constant after reaching the rated speed. The variable frequency control provides good running and transient performance because of the following features:

(a) Speed control can be possible from zero to above base speed.

(b) During starting, braking and speed reversal, the operation can be done at the maximum torque.

(c) Copper losses gets decreased, efficiency and power factor are improved.

(d) no load to full load speed drop is small.

3.4 constant v/f control

The base speed of the induction motor is α the supply frequency and no.of poles of induction motor. As the no. of poles are fixed during the design, the best way to control the speed of induction motor by varying supply frequency.

The electromagnetic torque developed by the induction motor is directly proportional to the ratio of the applied voltage and the frequency. So, the torque developed can be kept constant throughout the speed range, by varying the voltage and the frequency and keeping their ratio constant. This is what V/F control does.

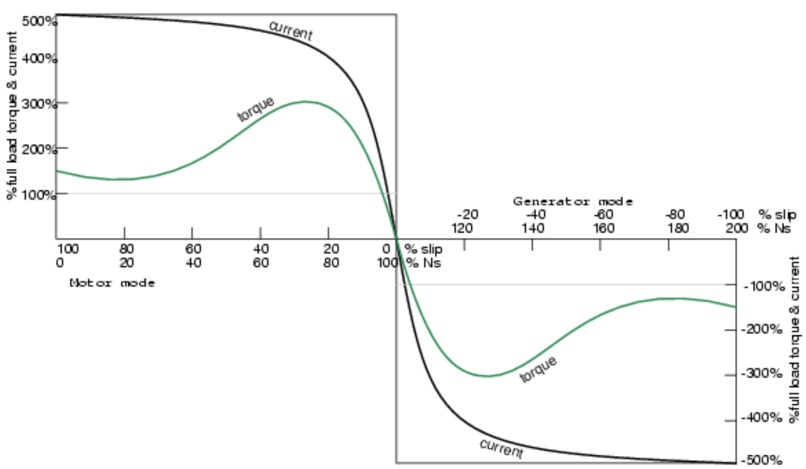


Fig: 6 Torque- Slip characteristics

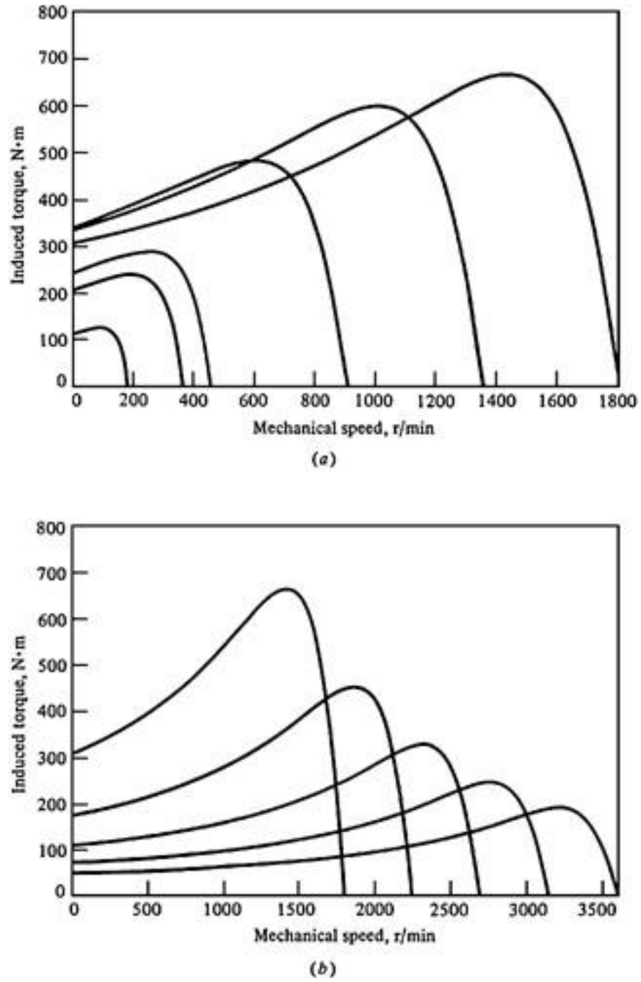


Fig: 7 Torque- Speed Characteristic

The speed- torque characteristics of the V/F control reveal the following:

• The starting current required will be less.

• The stable operating region of the motor is increased. Motor can now run at 5% of synchronous speed instead of simply running at base speed. The torque generated by the motor can be kept constant throughout this region.

• At base speed, the voltage and frequency both reach the rated values. By increasing the frequency we can drive motor to run more than base speed. However, the applied voltage cannot be increased beyond the rated voltage. So after reaching the rated voltage, only frequency can be increased which results in torque reduction.

• By controlling the supply frequency to the motor, the acceleration and deceleration of the motor can be controlled with respect to time.

3.5 Summary:-

In this chapter we studied about different types of speed control techniques in Induction Motor. The most favourable way of speed control is V/F control as Speed can be changed above and below the base speed by this method and the starting current requirement is also very low. Due to many advantages V/F control is adopted for the speed control of Induction Motor.

CHAPTER 4

P-I CONTROLLER

4.1 Introduction

Induction machines are most frequently used in industries due to their robustness, low cost and reliability and high efficiency. Squirrel cage rotor, is the most widely used source of mechanical power fed from AC power system due to its low sensitivity to disturbance.

In spite of many advantages Induction motor has two inherent limitations.

- It is not a true constant speed machine (slip varies from 1% to 5% during operation).
- It is not capable of providing variable speed operation.

During starting , Induction motor draws large current which produces voltage dips oscillatory torques and also able to generate harmonics in the power system.

When accuracy in speed response is a concern, closed-loop speed control is implemented with the constant V/F control. A PI controller is employed to regulate the slip speed of the motor to keep the motor speed at its set value.

4.2 Closed loop V/F speed control method by using PI controller:

Speed control could have been done with open-loop also. Open-loop control is the simplest type of control without any feedback loop, and without much complexity. But there lies many advantages of closed loop control over open loop control, for which closed loop control is preferred over open loop control.

(1) The controlled variable (speed) accurately follows the desired value(specified speed).
(2) Effect of external disturbances on controlled variable(speed) is very less
(3) Also, use of feedback in the control greatly improves the speed of its response compared to that of open-loop case.

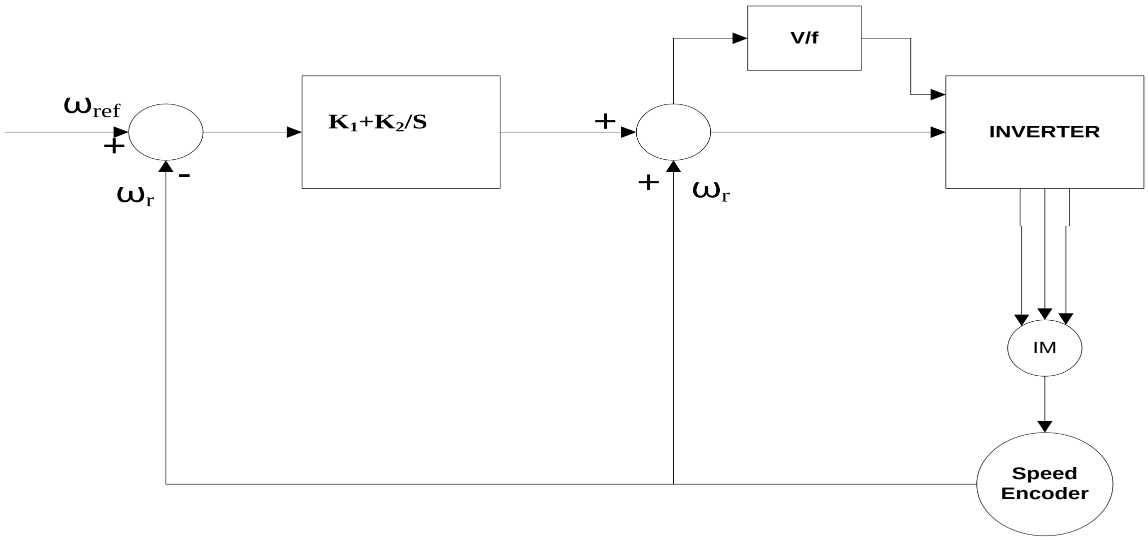


Fig: 8 Block Diagram of V/F control using PI controller

Closed loop speed controller with P-I controller adds some performance improvement to open-loop V/f control. The speed loop error generates a command through the P-I controller and limiter. That slip command again added to the feedback speed signal to generate frequency command. The frequency command again generates corresponding voltage command to have constant flux. With change in loading generally speed gets decreased to some value lower than the previous value. But as this drive is constant speed drive, if speed gets decreased with loading, the speed error loop start working spontaneously and give the command to increase the frequency to such a value so as to maintain that constant value of speed.

First a closed loop V/f control with P-I controller is simulated where P-I controller and VSI will be connected to the induction motor. Then a feedback of rotor speed will be taken from the induction motor and compared with the reference speed and then the error will be fed to the controller and output of the P-I controller will fed to the VSI. In that way performance of induction motor with this controller is studied.

4.3 Summary:

A systematic approach of achieving robust speed control of an induction motor drive by means of P-I has been investigated. Whenever the induction machine was loaded the speed of the machine fell, but constant speed drive demands a constant speed throughout its application irrespective of loading. So to provide that constant speed P-I controller in a closed V/f loop is used where it generates the required speed command to provide the desired constant speed. From the speed vs time graph it can be seen and concluded that speed remains constant irrespective of motor loading, and from stator current vs time it can be seen that current increases with increasing load.

CHAPTER 5

FUZZY SET THEORY

5.1 Introduction:

Fuzzy logic is a superset of Boolean logic which has been extended to handle the concept of partial truth- truth values between "completely true" and "completely false". It is the logic basic modes of reasoning which are approximate rather than exact. Fuzzy logic replicates human knowledge in to control logic. The essential characteristics of fuzzy logic as founded by Zader Lotfi are as follows.

- Any logical system can be fuzzified.
- In fuzzy logic, knowledge is interpreted as a collection of elastic or, equivalently , fuzzy constraint on a collection of variables
- No need of any exact mathematical model.

5.2Fuzzy Set Operations

5.2.1 Containment or Subset

Fuzzy set A is contained in fuzzy set B (or, equivalently, A is a subset of B) If for all . The following figure clarifies this concept.

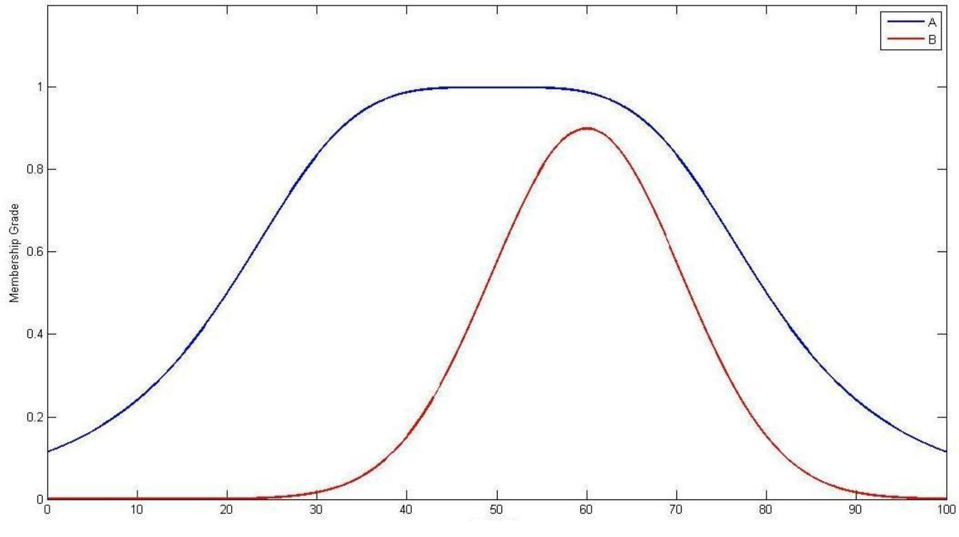


Fig. 9 containment or subset

5.2.2 Union

The membership function of the Union of two fuzzy sets A and B with membership functions μ_A and μ_B respectively is defined as the maximum of the two individual membership functions. This is called the maximum criterion.[1]

5.2.3 Intersection (Conjunction)

Intersection of two fuzzy sets can be written as C=A or B. where C is the resultant set Intersection of A and B is the *largest* fuzzy set contained both in A and B. An intersection of two fuzzy sets A and B

5.2.4 Complement (Negation)

The complement of fuzzy set A, symboled by Ā (A, NOT A).

5.3 Membership Function:-

5.3.1 Triangular MFs

A triangular MF is specified by three parameters {a, b, c} as follows:

$$\text{Triangle}(x; a,b,c)=\begin{cases} 0, & x \le a \\ \frac{x-a}{b-a}, & a \le x \le b \\ \frac{c-x}{c-b}, & b \le x \le c \\ 0, & c \le x \end{cases}$$

The parameters {a, b, c} (with a < b < c) determine the x coordinates of the three corners of the underlying triangular MF.

5.3.2 Trapezoidal MFs

A trapezoidal MF is specified by four parameters {a, b, c, d} as follows:

$$\text{Trapezoid}(x;a,b,c,d)=\begin{cases} 0, & x \le a \\ \frac{x-a}{b-a}, & a \le x \le b \\ 1, & b \le x \le c \\ \frac{d-x}{d-c}, & c \le x \le d \\ 0, & d \le x \end{cases}$$

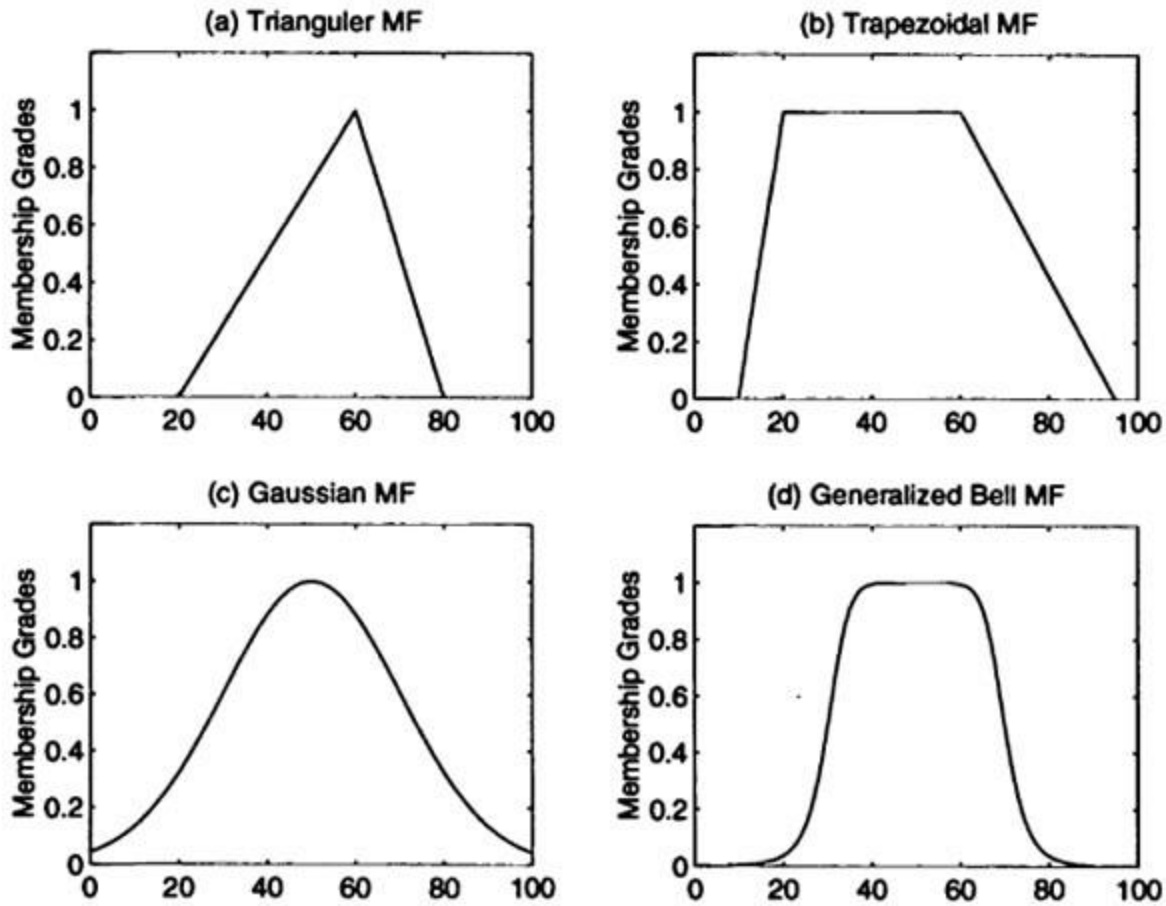


Figure : 10 Examples of four classes of parameterized MFs: (a) triangle (x; 20, 60, 80); (b) trapezoid (x; 10, 20, 60, 95); (c) Gaussian (x; 50, 20); (d) bell (x; 20, 4, 50)

5.3.3 Gaussian MFs

A Gaussian MF is specified by tow parameters :

$$\text{Gaussian}(x;c,\sigma)=e^{-\frac{1}{2}\left(\frac{x-c}{\sigma}\right)^2}$$

A Gaussian MF is determined complete by c and σ; c represents the MFs centre and σ determines the MFs width.

5.3.4 Generalised bell MFs

A generalized bell MF (or Bell-shaped Function) is specified by three parameters {a, b, c}:

Bell(x;a,b,c)=$\frac{1}{1+(\frac{x-c}{a})^{2b}}$

Where, the parameter b is usually positive.

The Gaussian MFs and bell MFs achieve smoothness, they can not specify asymmetric MFs, which is needed in some applications. Then the sigmoid MF is either open left or right.

5.3.5 Sigmoid MFs

A sigmoid MF is defined by

Sig(x;a,c)=$\frac{1}{1+exp[-a(x-c)]}$

5.4 Summary:

This chapter briefs the fuzzy set, some of the operation performing on the fuzzy set, membership function types and their representation. It also explains the difference between classical set and fuzzy set, how fuzzy set deals with linguistic variable.

CHAPTER 6

Fuzzy Logic Controller

6.1 Introduction

As discussed previously Fuzzy logic is a technique to inculcate human-like thinking into a control system. So the main purpose of designing fuzzy controller is to embody the human intelligence or human like thinking in the controller to control the process parameters. Fuzzy controller basically contains four essential segments.

6.2 CONFIGURATION OF FLC

Principal components of Fuzzy logic controller:

1. Fuzzification block or fuzzifier
2. Knowledge base
3. Decision making block
4. Defuzzification block or defuzzifier

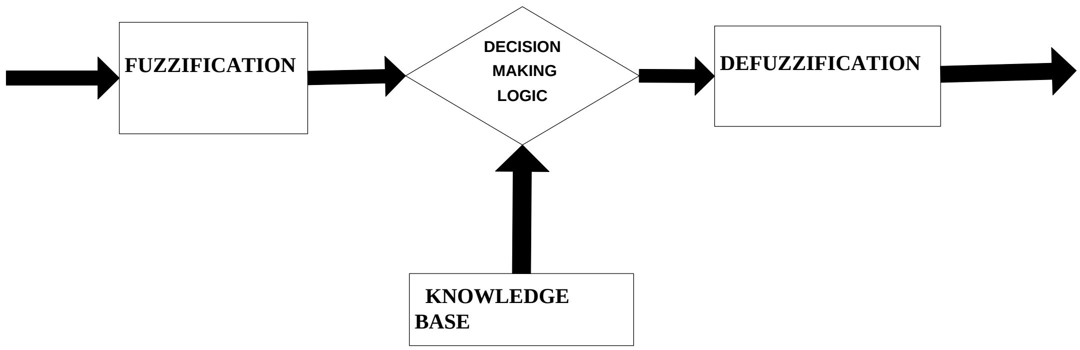


Fig:11. Fuzzy block diagram

6.2.1 Fuzzifier:

As discussed previously fuzzy logic based on linguistic variable but since input given to the FLC block is in numeric form so first thing to be done is to convert the numerical data/variable into linguistic variable. And this task is performed by the fuzzifier. So fuzzifier converts the numerical variable given to the FLC into linguistic variable. This fuzzification task includes choosing proper MF for the variables so that the crisp inputs can be converted into fuzzy sets.

6.2.2 Knowledge base:

Knowledge base is consist of rule base and data base. The main aim of data base is to provide necessary definitions needed to define the linguistic control rules and the aim of rule base is to characterize the control goals and policies by using a set of linguistic or If-Then rules. In the If-Then statement, the if part is called antecedent and the then part is called consequence.

6.2.3 Decision Making Block:

It is the most important component of a fuzzy controller because it is the block the decides the output depending upon the input. Based on fuzzy concepts , data and rule bases, it provide reasonable output.

6.2.4 Defuzzifier:

İt performs the task just opposite to that of fuzzifier. So the task of defuzzifier is to convert the linguistic variable into crisp one.

There are different types of defuzzification techniques present for defuzzication.

1. Centroid of Area (COA)
2. Bisector of Area (BOA)
3. Mean of Maximum (MOM)
4. Smallest of Minimum (SOM)
5. Largest of Maximum (LOM)

In our controller design centroid of area technique is used for defuzzification.

6.3 Summary:

So steps to design a Fuzzy Logic Controller at a glance is as follows:

1. Selecting the input to the FLC
2. Selecting proper MFs both for input and output variables
3. Fuzzification of the input variable
4. Preparing a Fuzzy rule base for the controller
5. Selecting proper defuzzification technique
6. Defuzzification of output that is to be given to the system for desired operation.

CHAPTER 7

Design of fuzzy logic controller

7.1 Introduction

For designing a fuzzy logic based controller, first thing we have to decide is what will be the inputs. As our main aim is to provide constant speed during load changes so the variable to be controlled will be speed.

Fig.11 is showing the block diagram to control the speed of the induction motor using the FLC.

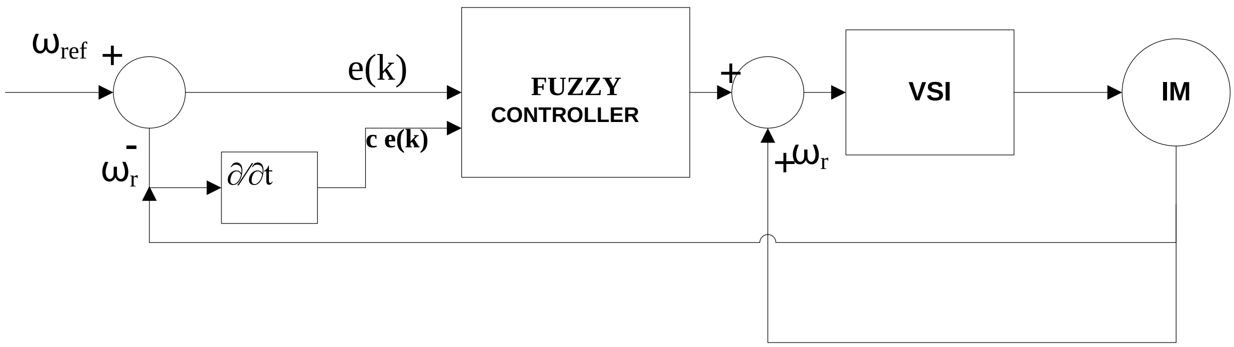


Fig: 12 block diagram for speed control of IM using fuzzy controller

As shown in the diagram by the feedback mechanism ω_m(motor speed) is fed back and compared with the ω_{ref} (reference speed) .The importance of feedback mechanism or closed loop method is already discussed in the previous sections. Then the error and the change in error is given as input to the fuzzy controller.

The fuzzifier fuzzifies theses two inputs and then the decision making block or the inference system processes the inputs based upon the rule bases and provides output, which is defuzzified by defuzzifier and provided as the output of the controller. This output is called change in control (ω_{sl}). This ω_{sl} is then added with ω_m(motor speed) and the result is fed to the VSI. As control method is scalar control method, so frequency and magnitude of supply voltage of the induction motor are varied such that it operates at the desired speed and at constant flux. So in nutshell

FLC has two input and one output. Inputs are error, e(k) and change of error, Δe(k) and output is change in control (ω_{sl}). Where error (e) = $\omega_{ref} - \omega_m$

7.2 Design of fuzzy logic controller:

For designing the controller, first step is to choose the reference speed. Second step is to select the inputs. Then membership functions for both input and output variable has to be chosen and then a rule base has to be prepared.

Reference Speed for the controller : 1000rpm

Inputs for the controller:

A. Speed error (e)
B. Change or derivative of speed error(Δe)

7.3 Selecting and Designing Membership Functions :

A. For speed error(e)

Table no.1 Fuzzy set and MFs for input speed error(e)

Fuzzy set	Range of MFs	Membership Function chosen
NL (Large Negative)	-0.8 to -0.8 -0.8 to -0.6 -0.6 to -0.4	Trapezoidal
NM(Medium Negative)	-0.4 to -0.2 -0.2 to -0.02	Triangular
NS (Small Negative)	-0.2 to -0.1 -0.1 to 0	Triangular
ZE (Zero)	-0.02 to 0 0 to 0.02	Triangular
PS (Small Positive)	0 to 0.1	Triangular

	0.1 to 0.2	
PM (Medium Positive)	0.02 to 0.2 0.2 to 0.4	Triangular
PL (Large Positive)	0.4 to 0.6 0.6 to 0.8 0.8 to 0.8	Trapezoidal

B. For change in(derivative of) speed error:

Table no.2 Fuzzy set and MFs for input change in speed error(e)

Fuzzy set	Range of MFs	Membership Function chosen
NL (Large Negative)	-0.8 to -0.8 -0.8 to -0.6 -0.6 to -0.4	Trapezoidal
NM(Medium Negative)	-0.4 to -0.2 -0.2 to -0.02	Triangular
NS (Small Negative)	-0.2 to -0.1 -0.1 to 0	Triangular
ZE (Zero)	-0.02 to 0 0 to 0.02	Triangular
PS (Small Positive)	0 to 0.1 0.1 to 0.2	Triangular
PM (Medium Positive)	0.02 to 0.2 0.2 to 0.4	Triangular
PL (Large Positive)	0.4 to 0.6 0.6 to 0.8 0.8 to 0.8	Trapezoidal

Output of the controller:

A. Change in control(ω_{sl})

7.4 Selecting and Designing Membership Functions for Change in control(ω_{sl}):

Table no.3 Fuzzy set and MFs for output change in control(ω_{sl})

Fuzzy set	Range of MFs	Membership Function chosen
NL (Negative Large)	-1.0 to -1.0 -1.0 to -0.8	Triangular
NLM(NegativeLargeMedium)	-1.0 to -0.8 -0.8 to -0.6	Triangular
NM (Negative Medium)	-0.8 to -0.6 -0.6 to -0.4	Triangular
NMS(NegativeMediumSmall)	-0.6 to -0.4 -0.4 to -0.2	Triangular
NS (Negative Small)	-0.4 to -0.2 -0.2 to 0	Triangular
ZE (Zero)	-0.2 to 0 0 to 0.2	Triangular
PS (Positive Small)	0 to 0.2 0.2 to 0.4	Triangular
PMS (Positive Medium Small)	0.2 to 0.4 0.4 to 0.6	Triangular
PM (Positive Medium)	0.4 to 0.6 0.6 to 0.8	Triangular
PLM(Positive Large Medium)	0.6 to 0.8 0.8 to 1.0	Triangular
PL (Positive Large)	0.8 to 1.0 1.0 to 1.0	Triangular

7.5 Rule base:

As 7 speed error variables and 7 change in speed error variables are taken, so there will be total 49 rules, which will govern the decision making mechanism.

Table no.4 rule base table

Δe \ e	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NLM	NM	NMS	NS	ZE
NM	NL	NLM	NM	NMS	NS	ZE	PS
NS	NLM	NM	NMS	NS	ZE	PS	PMS
ZE	NM	NMS	NS	ZE	PS	PMS	PM
PS	NMS	NS	ZE	PS	PMS	PM	PLM
PM	NS	ZE	PS	PMS	PM	PLM	PL
PL	ZE	PS	PMS	PM	PLM	PL	PL

7.6 Programing with MATLAB:

To simulate the fuzzy controller in MATLAB, first the rules have to be coded.

Coded rules:

```
[System]

Name='rules'

Type='mamdani'

Version=2.0

NumInputs=2
```

NumOutputs=1

NumRules=49

AndMethod='min'

OrMethod='max'

ImpMethod='min'

AggMethod='max'

DefuzzMethod='centroid'

[Input1]

Name='Error'

Range=[-0.8 0.8]

NumMFs=7

MF1='NL':'trapmf',[-0.8 -0.8 -0.6 -0.4]

MF2='NM':'trimf',[-0.4 -0.2 -0.02]

MF3='NS':'trimf',[-0.2 -0.1 0]

MF4='ZE':'trimf',[-0.02 0 0.02]

MF5='PS':'trimf',[0 0.1 0.2]

MF6='PM':'trimf',[0.02 0.2 0.4]

MF7='PL':'trapmf',[0.4 0.6 0.8 0.8]

[Input2]

Name='ChangeInError'

Range=[-0.8 0.8]

NumMFs=7

MF1='NL':'trapmf',[-0.8 -0.8 -0.6 -0.4]

MF2='NM':'trimf',[-0.4 -0.2 -0.02]

MF3='NS':'trimf',[-0.2 -0.1 0]

MF4='ZE':'trimf',[-0.02 0 0.02]

MF5='PS':'trimf',[0 0.1 0.2]

MF6='PM':'trimf',[0.02 0.2 0.4]

MF7='PL':'trapmf',[0.4 0.6 0.8 0.8]

[Output1]

Name='ChangeOfControl'

Range=[-1 1]

NumMFs=11

MF1='NL':'trimf',[-1 -1 -0.8]

MF2='NLM':'trimf',[-0.7 -0.5 -0.3]

MF3='NM':'trimf',[-0.6 -0.4 -0.2]

MF4='NMS':'trimf',[-0.3 -0.2 -0.1]

MF5='NS':'trimf',[-0.4 -0.2 0]

MF6='ZE':'trimf',[-0.2 0 0.2]

MF7='PS':'trimf',[0 0.2 0.4]

MF8='PSM':'trimf',[0.1 0.2 0.3]

MF9='PM':'trimf',[0.2 0.4 0.6]

MF10='PML':'trimf',[0.3 0.5 0.7]

MF11='PL':'trimf',[0.8 1 1]

Procedure to simulate the fuzzy controller in MATLAB:

1. First rules have to coded and written in m-file and saved with .fis extension.
2. Then the FIS editor will be opened by typing fuzzy in the command window.
3. Then the required fis file has to be imported by browsing.
4. After the loading of fis file the controller is ready to be operated.

All the above procedures are explained with figure in below.

- After giving the fuzzy command in the command window, this FIS Editor window will be opened.

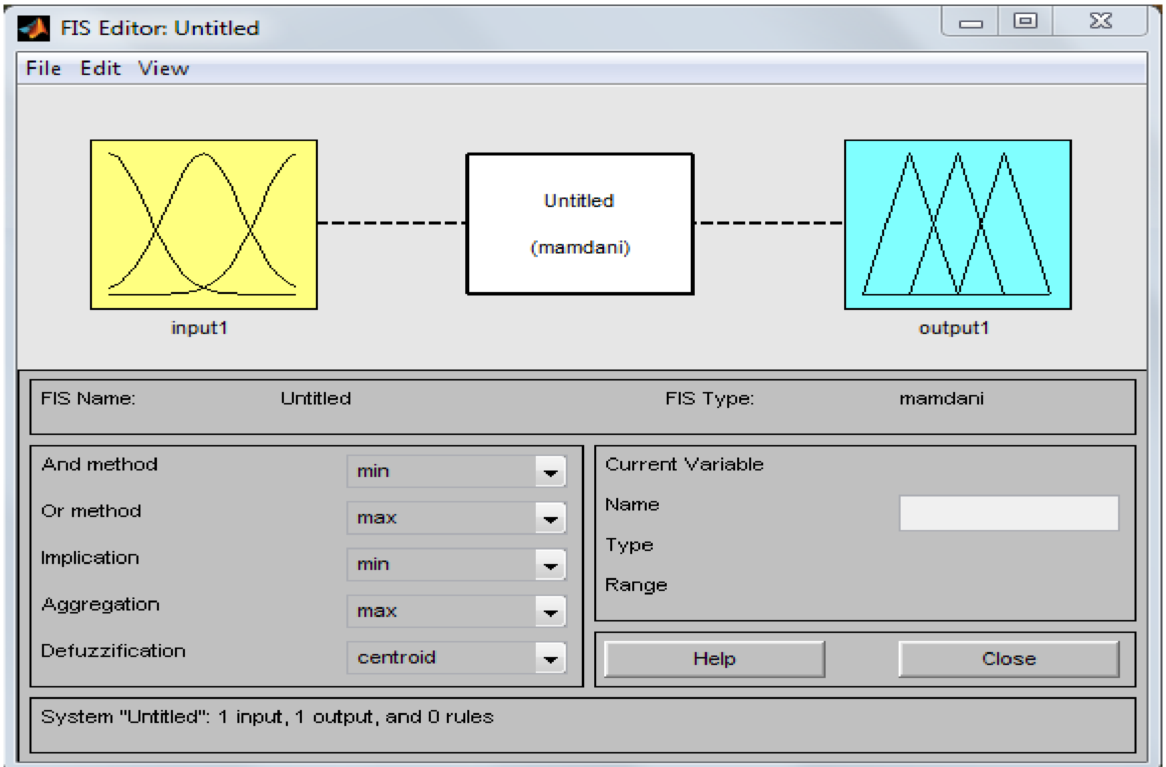


Fig .13 FIS Editor window

- Then after importing the fis file FIS Editor: rules window will be opened.

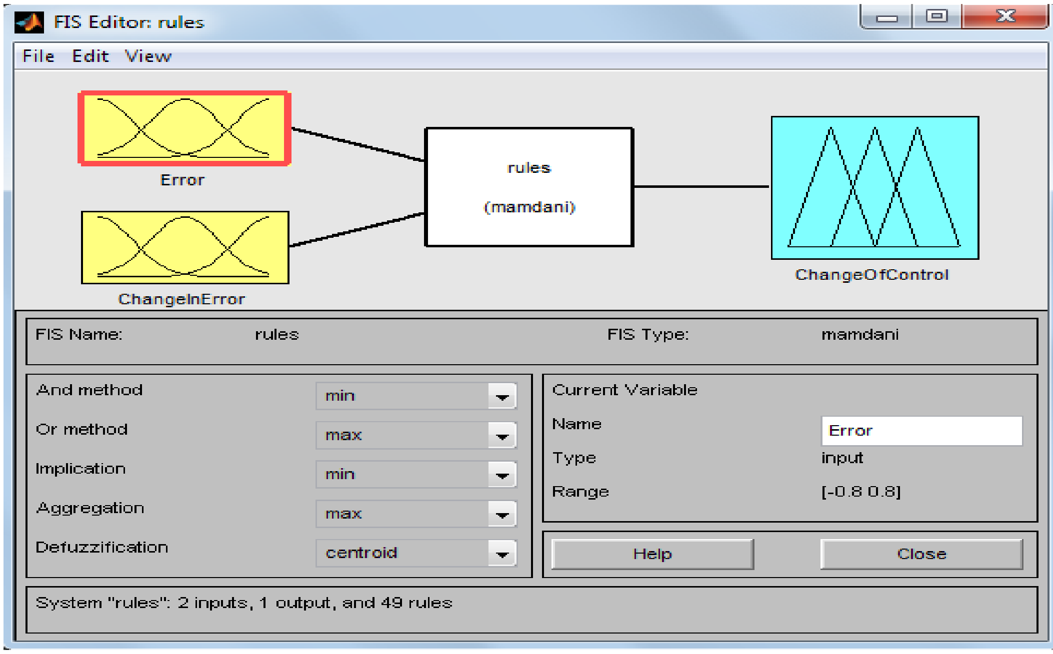


Fig.14 FIS Editor: rules window

➢ From this rules: FIS Editor membership functions of any input or output variables can be seen clicking on any input or output. Here is the membership function of the input speed error.

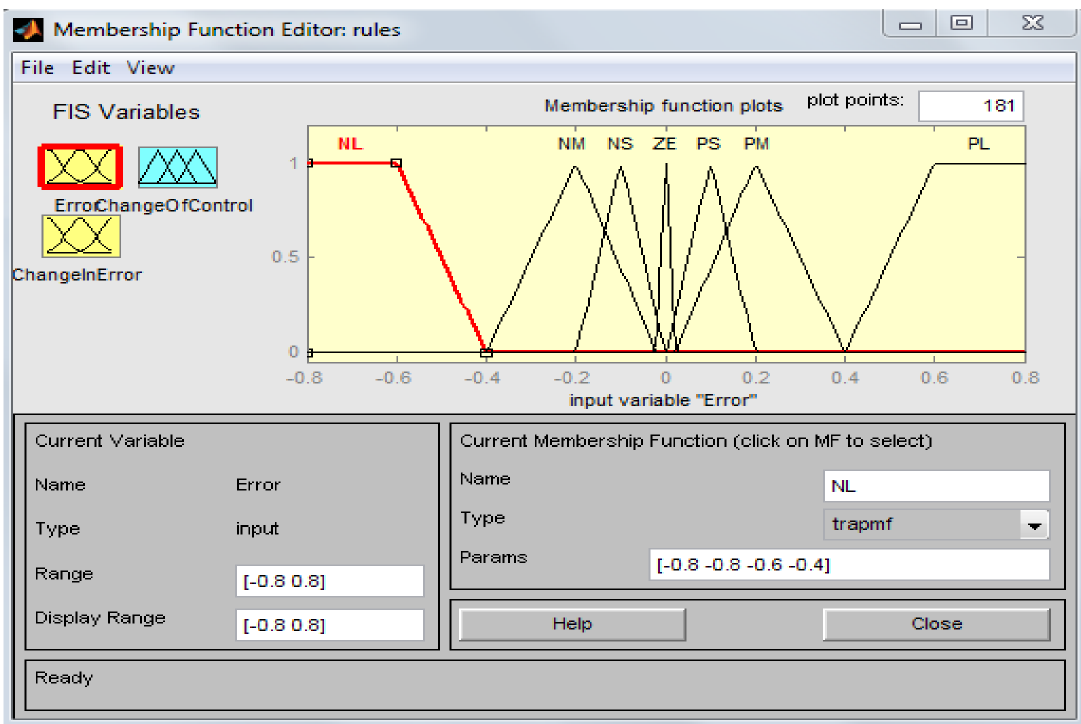


Fig.15 Membership Function of Input Error (e)

- Similarly membership function of output can also be seen.

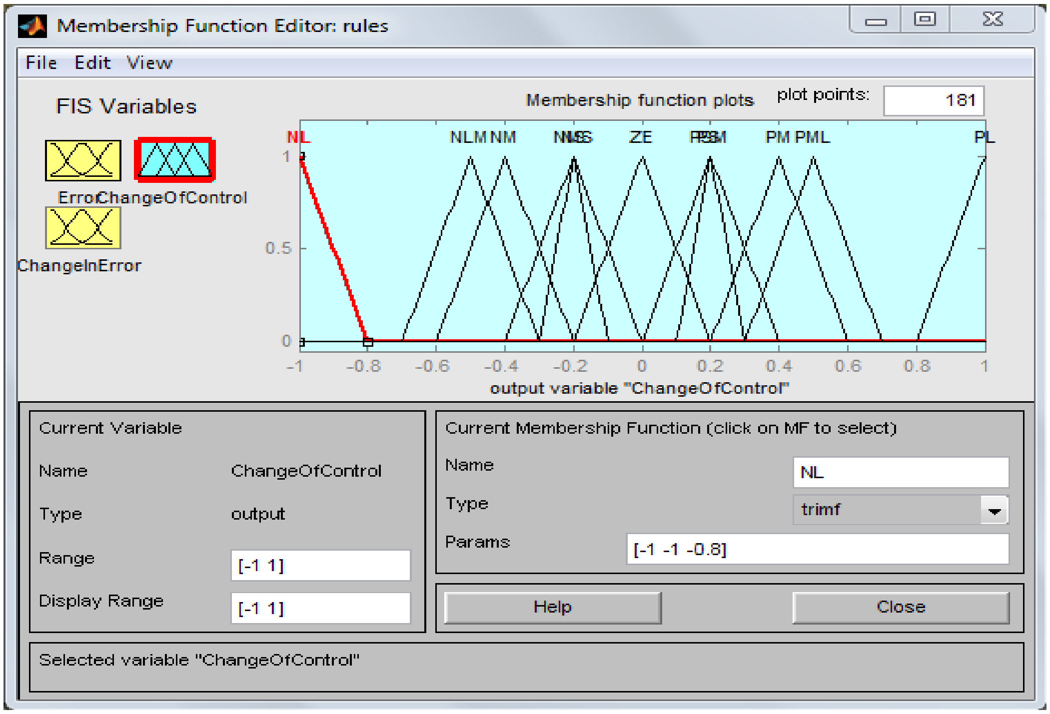


Fig.16 Membership Function of Input change in Error (Δe)

- In the FIS Editor: rules window, by clicking on view, rules and surface can also be seen.

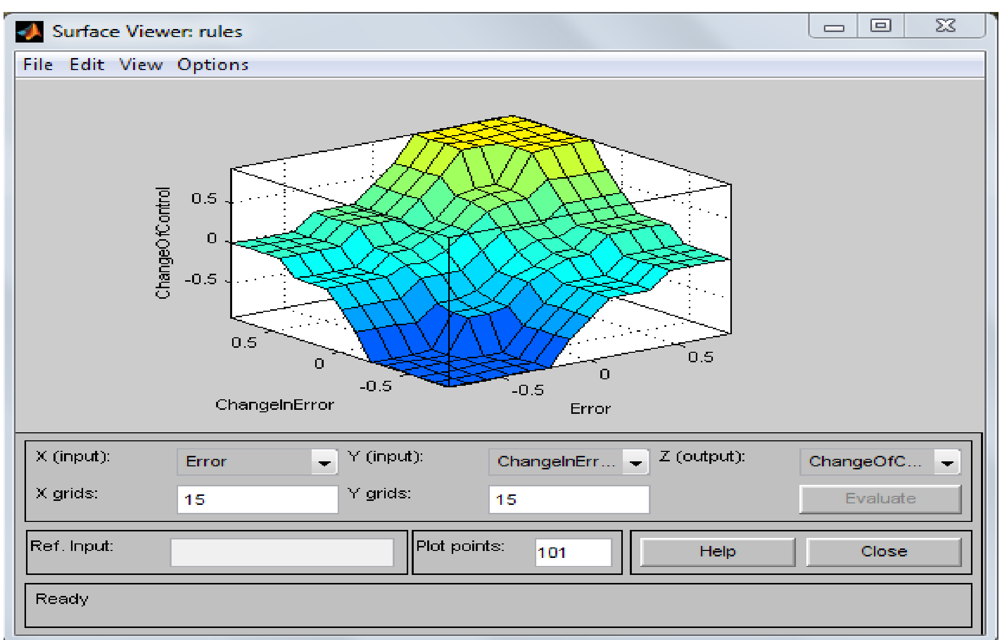


Fig.17 3-dimensional view of control surface

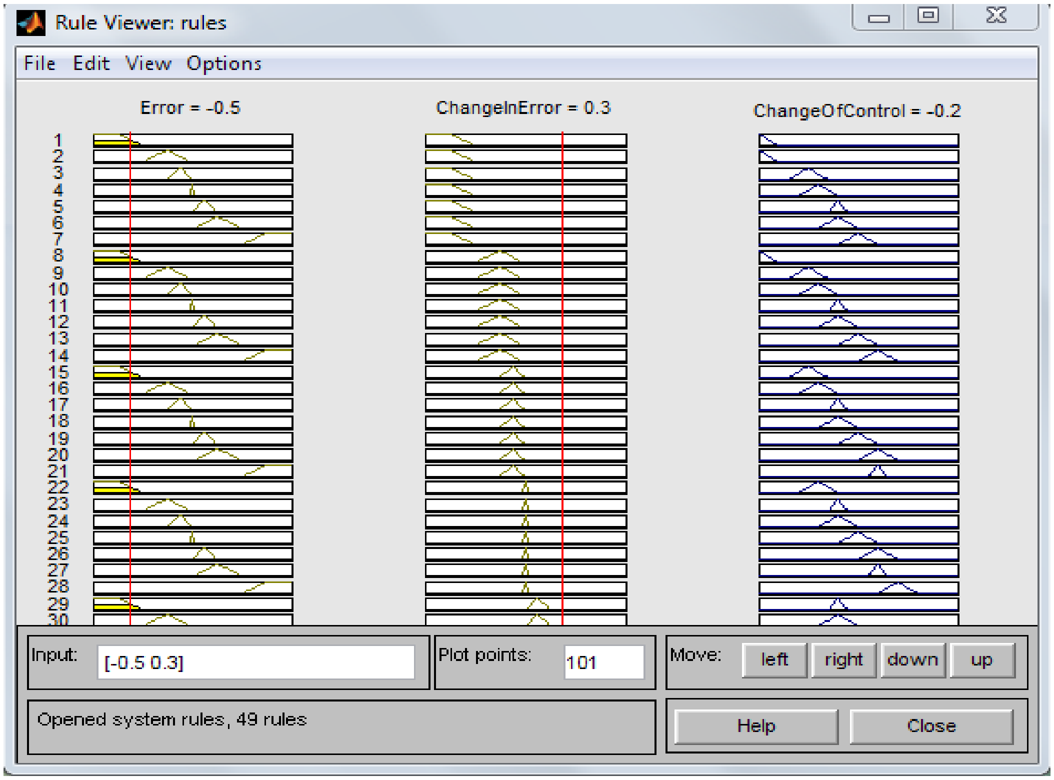


Fig.18 Rule Viewer with input e= -0.5 and Δe=0.3

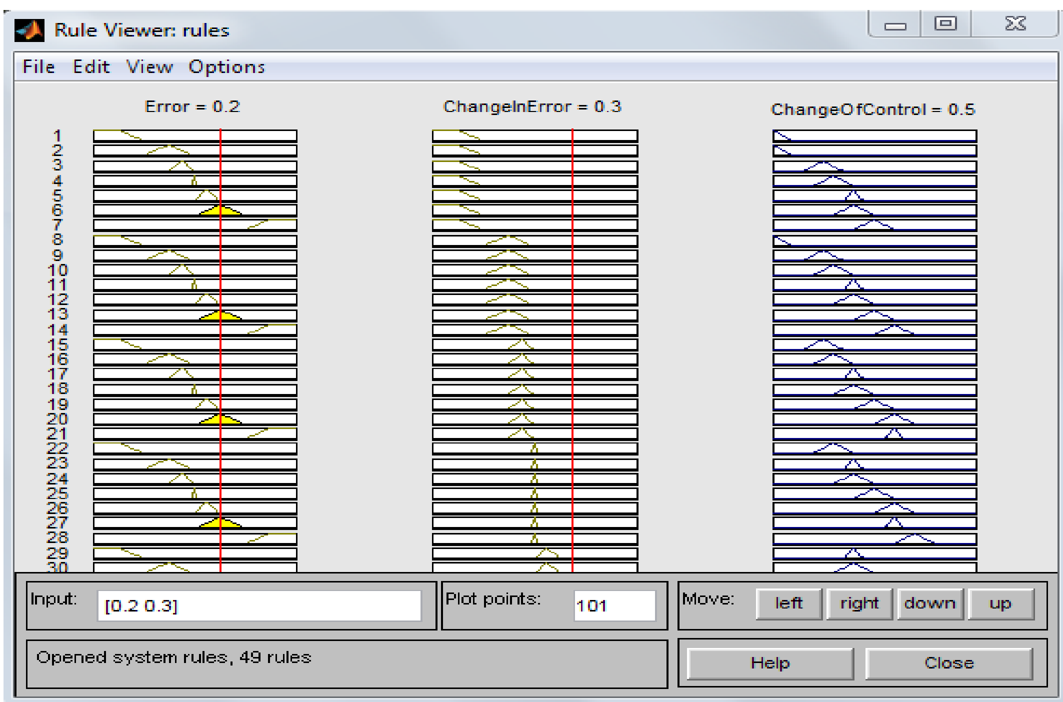


Fig.19 Rule Viewer with e = 0.2 and Δe = 0.3

7.7 Summary:

Here in this chapter we have designed a fuzzy logic based controller. To design the controller, first fuzzy set and membership functions are chosen, then rule base is designed. Rules, surfaces and membership function of input and output variables are also verified in the FIS Editor window. The controller designed has used the mamdani model with Centroid Of Area defuzzification technique.

CHAPTER 8

MATLAB Simulation

8.1 Simulink model for controlling speed of a induction drive

Fig.20 of below shows the simulink model to control the speed of the induction motor. The speed controller block used may be PI or Fuzzy depending upon the their performance. The improvement provided by PI and Fuzzy is discussed and compared in the later section.

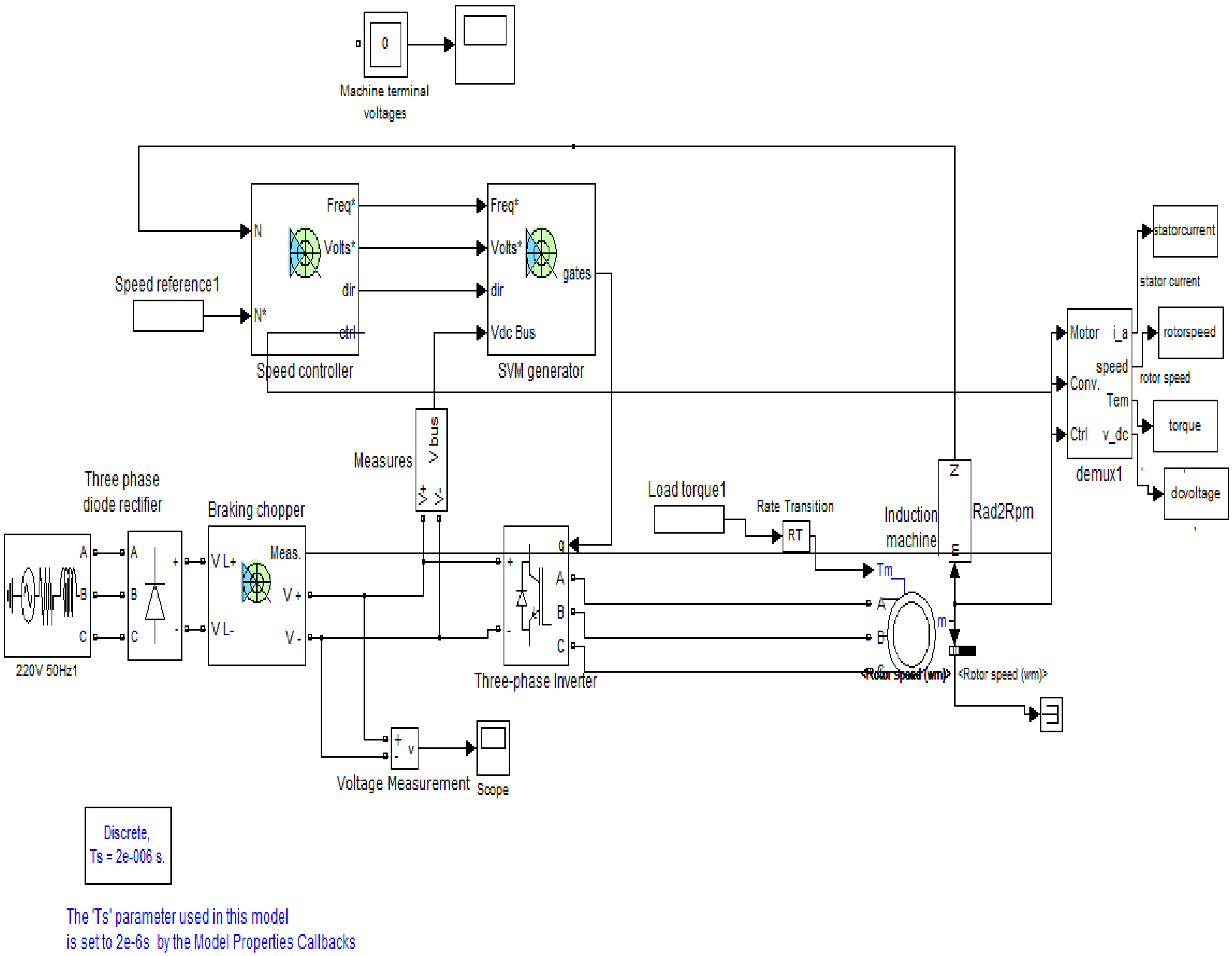


Fig.20 Block diagram for controlling speed of the induction motor using speed controller

Parameters and rating of the induction machine are as below:

Nominal Power: 3HP

Voltage (line-line): 220volt

Frequency: 50 Hz

Stator Resistance: 0.435 p.u.

Stator Inductance: 0.002 p.u.

Rotor Resistance: 0.816 p.u.

Rotor Inductance: 0.002 p.u.

Moment of Inertia: 0.089 p.u.

Number of Poles: 2

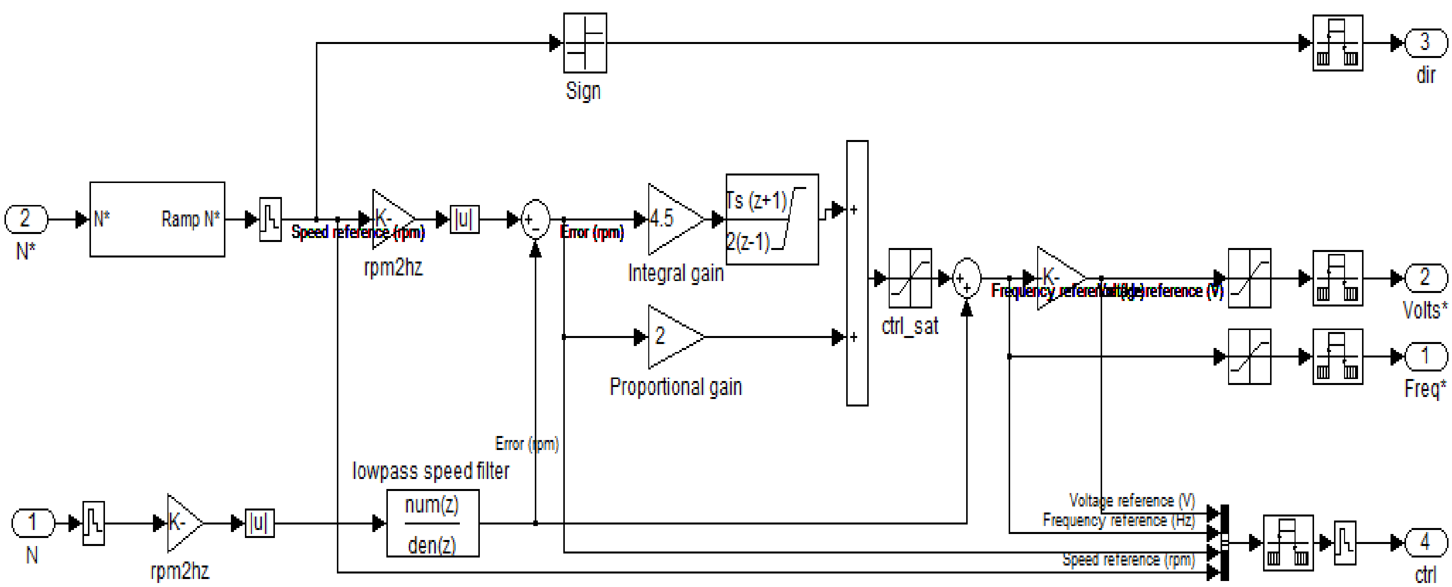


Fig.21 Block diagram of PI Speed controller

Parameters of PI controller used here to improve the performance of induction drive are:

Proportional constant: 2

Integral constant: 4.5

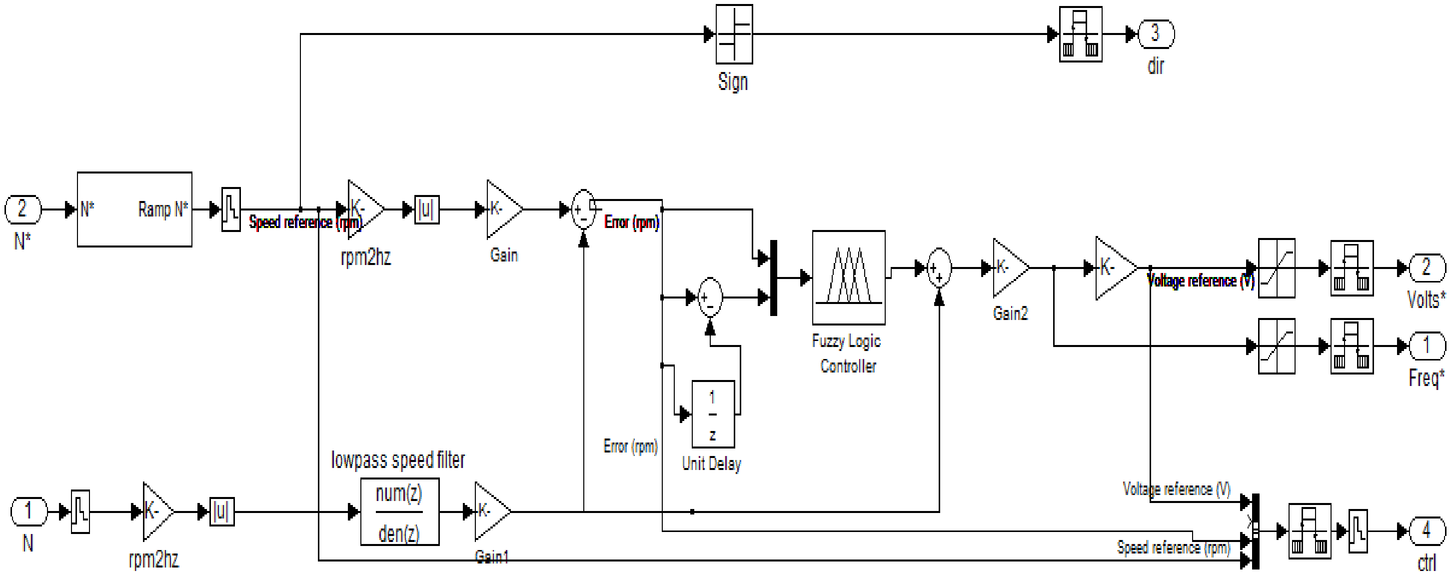


Fig.22 Block diagram of Fuzzy Logic based Speed controller

Fig. 21 shows the speed controller block using PI and fig.22 shows the speed controller block using fuzzy controller.

8.2 Simulation And Result:

Fig.13 block is simulated using both the PI and Fuzzy controller and plots for speed , load torque and stator current are taken and compared.

Fig.16 is the speed vs time plot for using PI controller and Fig.17 is the speed vs time plot for using Fuzzy controller for change of load:

At 0.25sec load torque applied is 11Nm

At 0.5sec load again changed to 20Nm

Again at 1sec load torque changed to 15Nm and then at 2.5sec it is changed to 20Nm

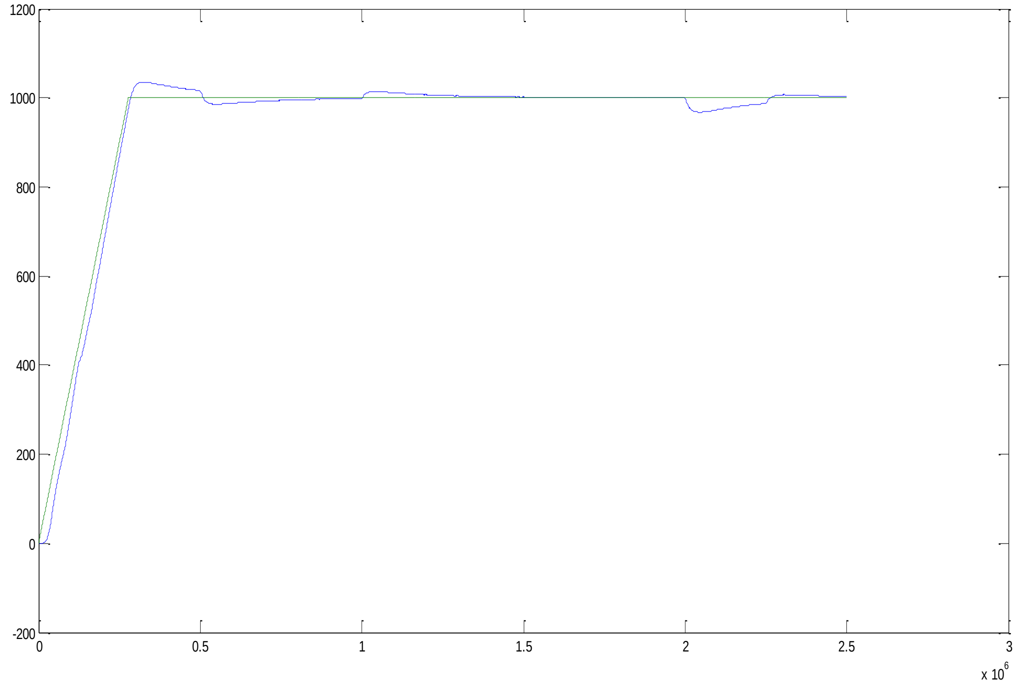


Fig.23 Speed vs. Time plot with reference speed of 1000rpm using PI controller

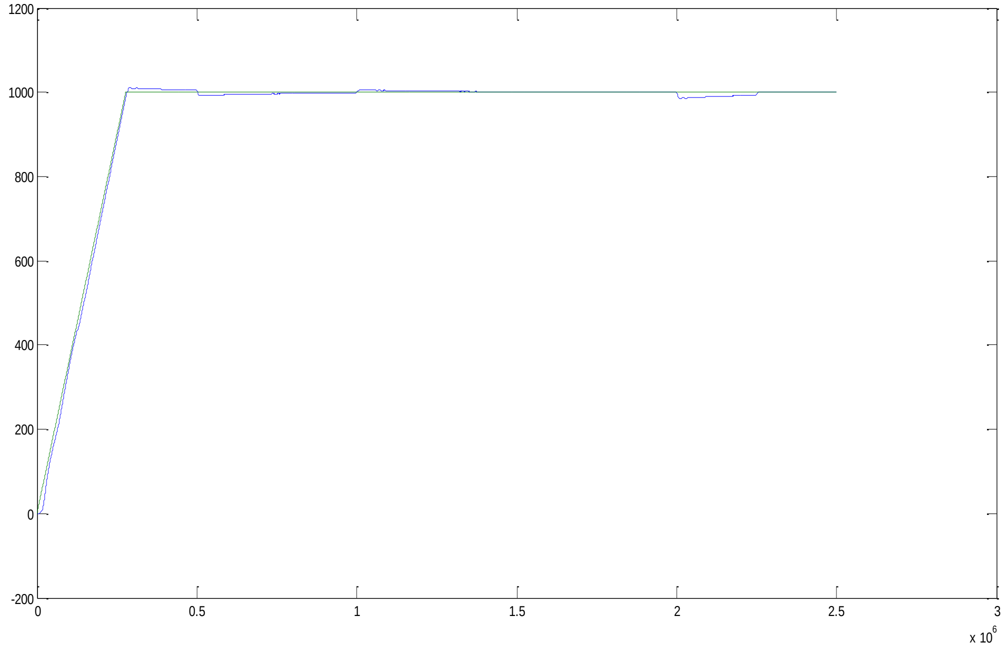
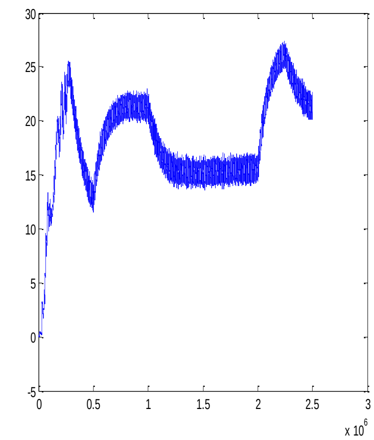
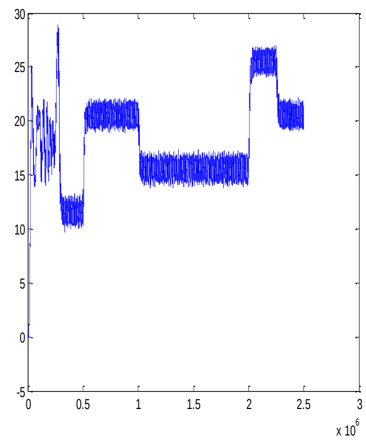
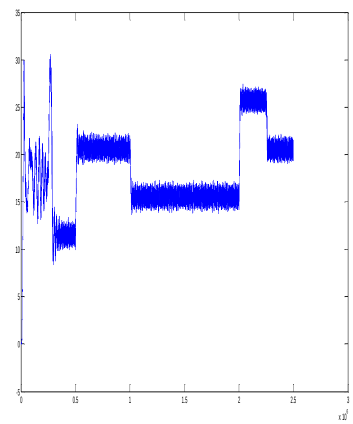
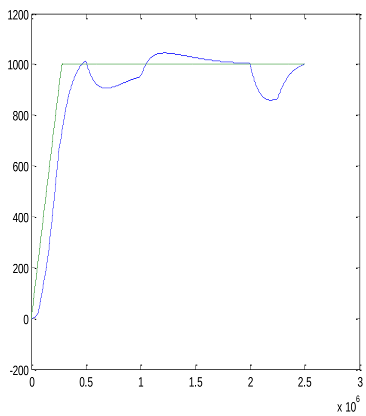
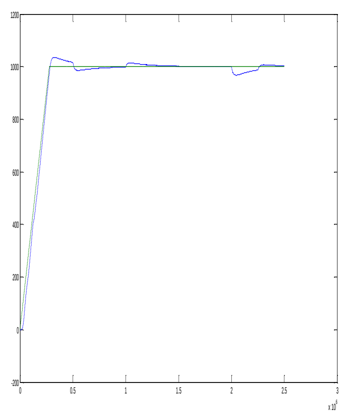
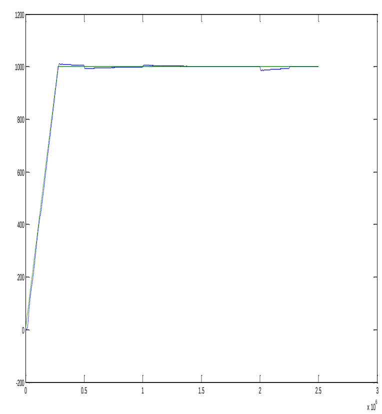
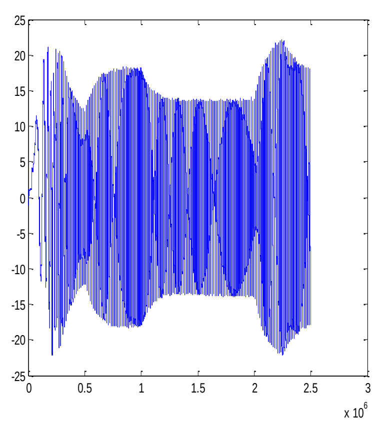
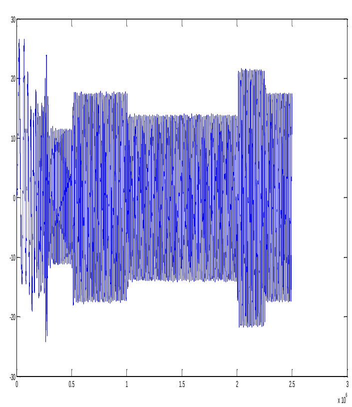
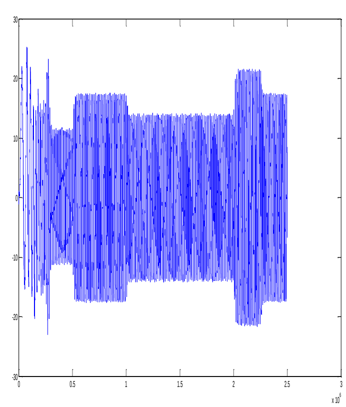


Fig.24 Speed vs. Time plot with reference speed of 1000rpm using Fuzzy controller

8.3 Comparison between results:

Table no.5 comparison table between different controller

<table>
<tr><th></th><th>With out any controller</th><th>PI controller</th><th>Fuzzy Controller</th></tr>
<tr><td>TORQUE</td><td>
</td><td>
</td><td></td></tr>
<tr><td>SPEED</td><td>
</td><td></td><td></td></tr>
<tr><td>Stator current</td><td>
</td><td></td><td></td></tr>
</table>

From the above figure it can be easily seen that without using a controller, drop of speed during load change is very high and also the torque and the stator current is not smoothly varying. It needs some time to provide the desired torque to the load.

But after using controller, all these problems are solved. Speed drop occurring during load changes reduced to a great amount and the torque is not much fluctuating and it does not take much time to change its magnitude and provide the desired torque. Stator current waveform is also smoothened after using the controller.

When comparing PI controller and fuzzy controller, it can be clearly seen that overshoot is more in PI controller. Also the settling time is more and it needs more time to reach at the steady state value. After every load change fuzzy controller based drive reach to the steady state speed of 1000rpm in lesser time as compared to PI controller controlled drive.

We can see that at the starting there is a distortion in current and torque waveform before the drive reaches to steady state. The reason behind this distortion is the transient during the starting of induction motor. Other than that part current is entirely sinusoidal and steady. Torque is also constant with only little oscillation.

8.4 Conclusion:

The fuzzy controller controlled drive is providing better results in improving the performance of the induction motor than PI controller. Whenever the machine is loaded, the speed of the machine fell to some extent but this fall in speed is very less in case of fuzzy controller controlled drive. So we can say that overshoot is more in case of PI controller. And overall we can say that Fuzzy controller is proving better result than PI controller

CHAPTER 9

Conclusion

9.1 Comparison between FLC and Conventional Controller:

A. Overshoot is high in case of conventional controller.
B. Settling time is also more in case of conventional controller.
C. Conventional controller provides better result for linear system. But as induction motor is a highly non-linear device, conventional does not guarantee good performance.
D. Fuzzy controller is based on rule base, which is user defined. So it is highly suitable for induction motor (highly non-linear device) and provides better result than conventional controller. By using the fuzzy controller in the induction motor drive, motor speed follows the desired speed with very minimum error.

From the results it is clearly seen and can be concluded that performance of the induction motor is getting better when controlled by a controller. Speed drop during the load change is reduced to a great extent. Also the torque and stator current waveform becomes better.

9.2 Discussion:

The main objective or the main concern of this project is to control the speed and provide better performance with frequent load changes. With this objective we focused to develop a fuzzy logic based controller with possible precision. For that we have chosen appropriate membership function and some If-Then rules. Also we tried to tune the controller by slightly changing MFs and rules.

In this project a Fuzzy Logic based Controller is designed with the help of MATLAB, which can be utilized in speed control of induction motor. The controller takes numerical input of speed error (e) and change in speed error (Δe), processes those inputs according to the rule framed and then provide a output called change in control. All the rules have been verified with the help of FIS editor rule viewer. Results are also shown for different error and change in error.

After simulating and comparing the results with conventional controller, it is concluded that fuzzy controller works efficiently for induction motor drive.

9.3 Future Scope:

Both the speed controller block based on fuzzy logic and the block diagram to control the speed of induction motor using that speed controller is shown in fig.22 and fig.20 respectively. These blocks are simulated and results are analysed. Also the controller is tuned when needed to provide desired results.

This control mechanism based on fuzzy logic is not restricted to the induction motor only. It is applicable and can be used for other areas also. Now days a number of fuzzy logic-based Precision environmental control systems are also available which are used for applications such as digital switching sites.

Tuning of fuzzy controller has become easy due to different strategies like Genetic Algorithm.

REFERENCES

[1] J.-S. R. Jang, C.-T. Sun, E. Mizutani, "Neuro-Fuzzy and Soft Computing," Pearson Education Pte. Ltd., ISBN 81-297-0324-6, 1997, chap. 2, chap. 3, chap. 4.

[2] Gilberto C. D. Sousa, Bimal K. Bose and John G**.** Cleland, "Fuzzy Logic Based On- Line Efficiency Optimization Control of an Indirect Vector-Controlled Induction Motor Drive" *IEEE* transaction on industrial electronics, vol 4, no 2, april 1995.

[3] G. El-Saady, A.M. Sharaf, A. Makky, M.K. Sherriny, and G. Mohamed, "A High Performance Induction Motor System Using Fuzzy Logic Controller," IEEE Trans. 07803-1772-6/94, pp. 1058-1061, 1994.

[4] R.Ouiguini, K. Djeffal, A.Oussedik and R. Megartsi, "Speed Control of an Induction Motor using the Fuzzy logic approach.", ISIE'97 - Guimariies, Portugal, IEEE Catalog Number: 97TH8280, vol.3, pg. 1168 – 1172.

[5] J. Martínez García, J.A. Domínguez, "Comparison between Fuzzy logic and PI controls in a Speed scalar control of an induction machine," CIRCE – ge3 – Departamento deIngeniería Eléctrica C.P.S., Universidad de Zaragoza, Conf. Paper

[6] K.L.Shi,T.F.Chan,Y. K. Yong and S.L.Ho: "Modeling and simulation of three phase induction motor using Simulink/Matlab",IEEE trnsactions on industry applications,vol.37,no.5,September/October2001.

[7] Abdullah I. Al-Odienat, Ayman A. Al-Lawama, "The Advantages of PID Fuzzy Controllers Over The Conventional Types," American Journal of Applied Sciences 5 (6):653-658, 2008, ISSN 1546-9239,pp.653–658.