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SPEED CONTROL OF INDUCTION MACHINE USING FUZZY LOGIC CONTROL

DISSERTATION II

Submitted in partial fulfillment of the

Requirement for the award of the degree

Of

MASTER OF TECHNOLOGY

IN

Power systems

By

Ayushi Dogra

Under the Esteemed Guidance of

Mr. Sanjeev Kumar Bhalla

School of Electrical & Electronics Engineering
Lovely Professional University
Punjab

May 2015

CERTIFICATE

This is to certify that the dissertation-II “**SPEED CONTROL OF INDUCTION MOTOR USING FUZZY LOGIC CONTROLLER”** that is being submitted by, **Ayushi Dogra** is in partial fulfillment of the requirements for the award of MASTER OF TECHNOLOGY DEGREE, is a record of bonafide work done under my/our guidance. The contents of this Thesis, in full or in parts, have neither been taken from any other source nor have been submitted to any other Institute or University for award of any degree or diploma and the same is certified.

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(To be signed by the student)
Reg. No. 11306304

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This is to certify that **Ayushi Dogra** bearing Registration no. 11306304 has completed objective formulation of thesis "**SPEED CONTROL OF INDUCTION MOTOR USING FUZZY LOGIC CONTROLLER"** under my guidance and supervision. To the best of my knowledge, the present work is the result of her original investigation and study. The contents of this Thesis, in full or in parts, have neither been taken from any other source nor have been submitted to any other Institute or University for award of any degree or diploma and the same is certified.

Signature
Mr. Sanjeev Kumar Bhalla,
Designation: Associate Professor
School of Electrical Engineering
Lovely Professional University
Phagwara, Punjab.
Date:

DECLARATION

I **Ayushi Dogra**, student of M-Tech under Department of Electronics & Electrical Engineering of Lovely Professional University, Punjab, hereby declare that all the information furnished Dissertation-II report is based on my own intensive research and this is genuine.

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ABSTRACT

This paper presents some design approaches to hybrid control systems combining conventional control techniques with fuzzy logic. Such a mixed implementation leads to a more effective control design with enhanced system performance and robustness. While conventional control allows diverse design objectives, fuzzy logic are to overcome the problems with uncertainties encountered in the classical model-based propose.

Induction motors are characterised by multifarious, highly non-linear and time-varying dynamics and isolation of some states and outputs for measurements, and hence can be considered as a challenging engineering problem. The advent of vector control techniques has partially solved induction motor control problems; because they are sensitive to drive parameter variations and performance can deteriorate if conventional controllers are used. Fuzzy logic controllers are considered as potential applicant for such an application. Two control approaches are developed and compared the speed of the drive system. A simulation study of these methods is presented and results are compared. The effectiveness of this controller is demonstrated using MATLAB/SIMULINK.

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ABBREVIATIONS

CSI – Current source inverter

DFOC – Direct feedback vector control

DTC – Direct torque control

FOC – Field oriented control

FLC – Fuzzy logic controller

IGBT – Insulated gate bipolar transistor

IFOC – Indirect feedback vector control

PAM – Pole amplitude modulator

PI – Proportional integral

SCIM – Squirrel cage induction motor

VFD - Variable frequency drive

VSI – Voltage source inverter

V/F – Voltage /frequency

CHAPTER 1

INTRODUCTION

1.1 Induction motor

An induction motor (asynchronous motor) is an ac motor in which the electric current needed to fabricate torque is obtained by electromagnetic induction from the magnetic field. Therefore, it does not rivet any separate excitation, as in universal, large synchronous motors and DC. An induction motor’s rotor can be both wound type or squirrel cage type. Three phase squirrel cage induction motors are used widely in industries because of their robust, reliable and reasonable characteristics. Single phase Induction motors are used for miniature loads, such as household appliances. Induction motors are extensively used in variable speed for variable frequency drives (VFDs). Squirrel cage induction motors are used in both fixed speed and VFD applications.

1.1.1 Construction

Induction motor consists of two main parts stator and rotor.

1. Stator consist of three main parts:-

   Outer frame- its outer part of the motor which protects the inner periphery.

   Stator core- It is built up of high grade silicon steel carrying the alternating magnetic field.

   Stator winding- It consist of three phase winding.

2. Rotor

   It consists of a laminated cylindrical core which have semi closed circular slots at the external periphery. In these slots, copper/aluminum bar conductors are located and short circuited at each end by copper/aluminum rings. The rotor winding is eternally short circuited because of which no external resistance can be added to it. For rotor currents to be induced, the speed of the substantial rotor should be lower than that of the stator’s rotating magnetic field. Otherwise the magnetic field would not be moving comparative to the rotor conductors and no current would be induced in the rotor.

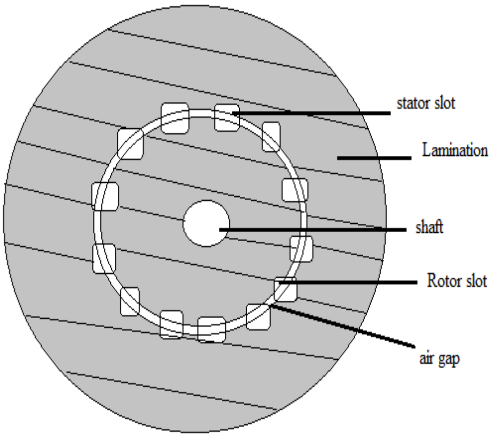

Fig 1.1 Basic construction of induction motor

1.1.2 Principle of operation

The balanced three-phase winding of the stator is supplied with a balanced three phase voltage. The current in the stator winding produces a rotating magnetic field, the magnitude of which relics constant. The axis of the magnetic field spins at a synchronous speed, a function of the supply frequency (f), and number of poles (p) in the stator winding. The magnetic flux lines in the air gap engrave both stator and rotor (being stationary, as the motor speed is zero) conductors at the same speed. The emfs in both stator and rotor conductors are tempted at the same frequency, i.e. line or supply frequency, with No. of poles for both stator and rotor windings (assuming wound one) being same. The stator conductors are constantly stationary, with the frequency in the stator winding being identical as line frequency. As the rotor winding is short-circuited at the slip-rings, current gushes in the rotor windings. The electromagnetic torque in the motor is in the same trend as that of the rotating magnetic field, due to the interaction between the rotating flux fabricated in the air gap by the current in the stator winding, and the current in the rotor winding. This is as per Lenz's law; as the developed torque is in such direction that it will counter the cause, which upshots in the current flowing in the rotor winding. This is irrespective of the rotor type used −cage or wound one, with the cage rotor, with the bars short-circuited by two end-rings, is deemed equivalent to a wound one. The current in the rotor bars cooperates with the air-gap flux to develop the torque, irrespective of the no. of poles for which the winding in the stator is devised. Thus, the cage rotor might be termed as universal one. The induced emf and the current in the rotor are owing to the relative velocity between the rotor conductors and the rotating flux in the air-gap, which is maximum, when the rotor is inactive. As the rotor establishes rotating in the same direction, as that of the rotating magnetic field due to production of the torque as stated former, the relative velocity decreases, along with lower values of induced emf and current in the rotor. If the rotor speed is equal that of the rotating magnetic field, which is phrased as synchronous speed, and also in the same direction, the relative velocity is zero, which originates both the induced emf and current in the rotor to be reduced to zero. Under this condition, torque will not be produced. So, for production of positive (motoring) torque, the rotor speed must always be worse than the synchronous speed. The rotor speed is never equal to the synchronous speed in an induction motor. The rotor speed is concluded by the mechanical load on the shaft and the total rotor losses, chiefly comprising of copper loss.

1.1.3 Mathematical modeling

During the entire report, a complex vector notation and some reference frame conversions are used. Since this is quite essential to the understanding of the rest of the theory, it will shortly be described in the next subsection.

1.1.3.1 Three- phase Transformations

In the study of generalized machine theory, mathematical transformations are often used to decouple variables, to facilitate the solutions of difficult equations with time varying coefficients, or to refer all variables to common reference frame. The most commonly used transformation. Important subsets of the general n-phase (or two-axis) transformation, though not necessary power invariant, are briefly discussed in the following part.

1.1.3.2 3-Φ to 2- Φ Transformation:

Consider a symmetrical three-phase induction machine with stationary as-bs-cs axes at 2π/3-angle apart, as shown in Fig.1.2. Our goal is to transform the three-phase stationary reference frame (as-bs-cs) variables into two-phase stationary reference frame (d^s-q^s) variables and then transform these to synchronously rotating reference frame (d^e-q^e), and

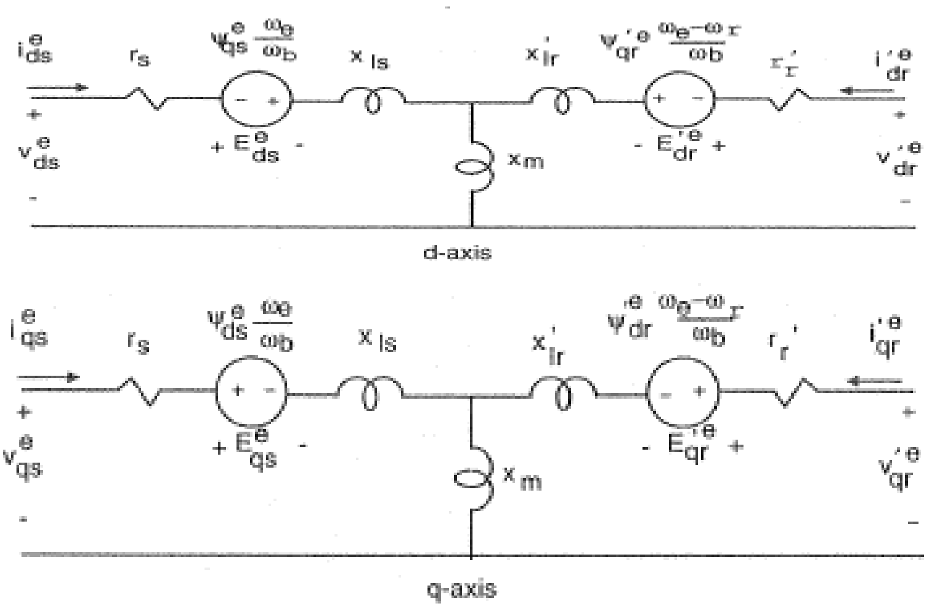

Fig 1.2 Equivalent model of induction machine in synchronously rotating field.

Assume that the (d^e – q^e) axes are oriented at Y angle. The voltages V_{ds}^{s} and V_{qs}^{s} can be resolved into (as-bs-cs) components and can be represented in the matrix form as

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta-120^0) & \sin(\theta-120^0) & 1 \\ \cos(\theta+120^0) & \sin(\theta+120^0) & 1 \end{bmatrix} \begin{bmatrix} V_{qs}^{s} \\ V_{ds}^{s} \\ V_{os}^{s} \end{bmatrix} \qquad 1.1$$

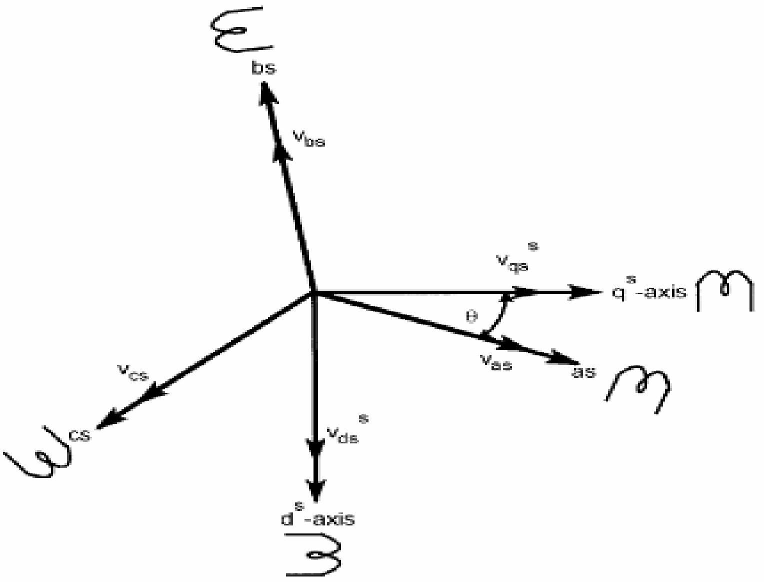

Fig 1.3 3 phase to 2 phase transformation

The corresponding inverse relation is

$$\begin{bmatrix} V_{qs}^{s} \\ V_{ds}^{s} \\ V_{os}^{s} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta - 120^0) & \cos(\theta + 120^0) \\ \sin\theta & \sin(\theta - 120^0) & \sin(\theta + 120^0) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \tag{1.2}$$

Where V_{os}^{s} is added as the zero sequence component, which may or may not be present. We have considered voltage as the variable. The current and flux linkages can be transformed by similar equations. It is convenient to set θ = 0, so that the q ^{s} – axis is aligned with the as-axis. Ignoring the zero sequence components, the transformation relations can be simplified as

$$V_{as} = V_{qs}^{s} \tag{1.3}$$

$$V_{bs} = -\frac{1}{2}V_{qs}^{s} - \frac{\sqrt{3}}{2}V_{ds}^{s} \tag{1.4}$$

$$V_{cs} = -\frac{1}{2}V_{qs}^{s} + \frac{\sqrt{3}}{2}V_{ds}^{s} \tag{1.5}$$

And inversely

$$V_{qs}^{s} = \frac{2}{3}V_{as} - \frac{1}{3}V_{bs} - \frac{1}{3}V_{cs} = V_{as} \tag{1.6}$$

$$V_{ds}^{s} = -\frac{1}{\sqrt{3}}V_{bs} + \frac{1}{\sqrt{3}}V_{cs} \tag{1.7}$$

1.1.3.3 Clarke Transformation

The Clarke transformation is basically employed to transform three-phase to two- phase quantities. The two-phase variables in stationary reference frame are sometimes denoted as α and β. As shown in fig 1.3 the α axis coincides with the phase- a axis and the β- axis lags the α- axis by 90^0.

$$[f\alpha\beta o]=[T\alpha\beta o]\ [fabc] \tag{1.8}$$

Where the axes transformation matrix [Tαβo]:

$$[T\alpha\beta o] = 2/3\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \tag{1.9}$$

Where the transformation matrix [Tαβo] is given by:

$$[T\alpha\beta o] = 2/3\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \tag{1.10}$$

The inverse transformation matrix:

$$[T\alpha\beta o]^{-1} = \begin{bmatrix} 1 & 0 & 1 \\ -1/2 & \sqrt{3}/2 & 1 \\ -1/2 & -\sqrt{3}/2 & 1 \end{bmatrix} \tag{1.11}$$

1.1.3.3 Park’s Transformation

The Park’s transformation is a well- known transformation that converts the quantities to two- phase synchronously rotating frame. The transformation is in form of:

$$[fdqo]=[Tdqo\ (\theta d)]\ [fabc] \tag{1.12}$$

Where the dqo transformation matrix is defined as:

$$[Tdqo(\theta d)] = 2/3\begin{bmatrix} \cos\theta d & \cos(\theta d - 2\Pi/3) & \cos(\theta d + 2\Pi/3) \\ -\sin\theta d & -\sin(\theta d - 2\Pi/3) & -\sin(\theta d + 2\Pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \tag{1.13}$$

And the inverse is given by:

$$[Tdqo(\theta d)]^{-1} = \begin{bmatrix} \cos\theta d & \sin\theta d & 1 \\ \cos(\theta d - 2\Pi/3 & -\sin(\theta d - 2\Pi/3) & 1 \\ \cos(\theta d + 2\Pi/3) & -\sin(\theta d + 2\Pi/3) & 1 \end{bmatrix} \tag{1.14}$$

Where the θd is the transformation angle.

1.1.3.5 Transformation from d-q stationary axes to d-q synchronously rotating axes

Figure 1.4 shows the synchronously rotating d^e- q^e, which rotate at synchronous speed ω_e with respect to the d^s-q^s axes and the angle $\theta_e = \omega_e t.$ the two-phase d^e- q^s windings are transformed into the hypothetical windings mounted on the d^e-q^e axes. The voltages on the d^s-q^s axes can be converted (or resolved) into the d^e-q^e frame as follows:

$$V_{qs} = V_{qs}^s \cos\theta_e - V_{ds}^s \sin\theta_e \tag{1.15}$$

$$V_{ds} = V_{qs}^s \sin\theta_e + V_{ds}^s \cos\theta_e \tag{1.16}$$

For convenience, the superscript e has been dropped from now on from the synchronously rotating frame parameters. Again, resolving the rotating frame parameters into a stationary frame, there relations are

$$V_{qs}^s = V_{qs} \cos\theta_e + V_{ds} \sin\theta_e \tag{1.17}$$

$$V_{ds}^s = -V_{qs} \sin\theta_e + V_{ds} \cos\theta_e \tag{1.18}$$

As an example, assume that the three-phase stator voltages are sinusoidal and balanced, and are given by

$$V_{as} = V_m \cos(\omega_e t + \phi) \tag{1.19}$$

$$V_{bs} = V_m \cos(\omega_e t - \frac{2\pi}{3} + \phi) \tag{1.20}$$

$$V_{cs} = V_m \cos(\omega_e t + \frac{2\pi}{3} + \phi) \tag{1.21}$$

Substituting Equations (1.18) - (1.19) in (1.20) - (1.21) yields

$$V_{qs}^s = V_m \cos(\omega_e t + \phi) \tag{1.22}$$

$$V_{ds}^s = -V_m \sin(\omega_e t + \phi) \tag{1.23}$$

Again, substituting Equations, we get

$$V_{qs} = V_m \cos\phi \tag{1.24}$$

$$V_{ds} = -V_m \sin\phi \tag{1.25}$$

1.1.3.6 Dynamic Model State – Space Equations

The dynamic machine model in state-space format is important for transient analysis, particularly for computer simulation study. Although the rotating frame model is generally preferred the stationary frame model can also be used. The electrical variables in the model can be chosen as fluxes, currents or a mixture of both. In this section, we will derive state space equations of the machine in rotating frame with flux linkages as the main variables.

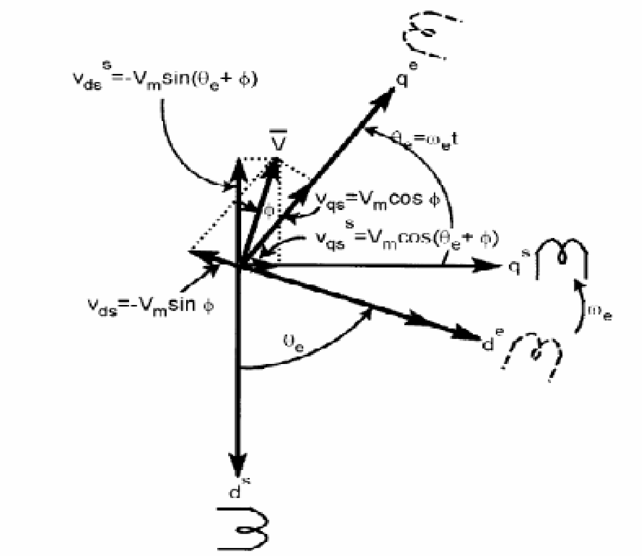

Fig 1.4 Stationary Frame d_s-q_s to Synchronously Rotating Frame d_e-q_e Transformation

1.1.3.7 Dynamic Model State – Space Equations:

The dynamic machine model in state-space format is important for transient analysis, particularly for computer simulation study. Although the rotating frame model is generally preferred the stationary frame model can also be used. The electrical variables in the model can be chosen as fluxes, currents or a mixture of both. In this section, we will derive state space equations of the machine in rotating frame with flux linkages as the main variables. Let’s define the flux linkage variables as follows:

$$F_{qs} = \omega_b \psi_{qs} \tag{1.26}$$

$$F_{qr} = \omega_b \psi_{qr} \tag{1.27}$$

$$F_{ds} = \omega_b \psi_{ds} \tag{1.28}$$

$$F_{dr} = \omega_b \psi_{dr} \tag{1.29}$$

Where ω_b = base frequency of the machine.

Substituting the above relations in (1.26) - (1.27) and (1.28) - (1.29), we can write

$$v_{qs} = R_s i_{qs} + \frac{1}{\omega_b}\frac{dF_{qs}}{dt} + \frac{\omega_e}{\omega_b} F_{ds} \tag{1.30}$$

$$v_{ds} = R_s i_{ds} + \frac{1}{\omega_b}\frac{dF_{ds}}{dt} - \frac{\omega_e}{\omega_b} F_{qs}$$

$$\tag{1.31}$$

$$v_{qr} = R_s i_{qr} + \frac{1}{\omega_b}\frac{dF_{qr}}{dt} + \frac{\omega_e}{\omega_b} F_{ds}$$

1.1.3.8 The electromagnetic torque developed by the machine:

Electromagnetic torque is the cross product of 2 space vectors such as ψs*is, where as in the complex notation it will appear as Im(ψs is) or in terms of the d-q components as (ψqs ids- ψds iqs).

Te= (3/2) (p/2) (ψs*is)

Te= (3/2) (p/2)M (ψs.is) (1.32)

Where M is matrix of order 2*2 whose value is M=[0 -1; 1 0].

Te=(3/2) (p/2)(ψqs.ids-ψdsiqs) (1.33)

Ψqs, ψds are replaced in terms of Fqs, Fds the electromagnetic torque is modified as

$$Te= (3/2)\,(p/2)(1/\omega b)(Fqs\ ids-Fds\ iqs) \tag{1.34}$$

This describes the complete model in state space form where Fqs, Fds, Fqr, Fdr are the state variables.The matrix M is nothing but equivalent to a unit vector or space rotator which is rotated at an angle 90^0 actually the matrix M is as follows.

$$M=\begin{bmatrix} \cos\theta e & -\sin\theta e \\ \sin\theta e & \cos\theta e \end{bmatrix} \tag{ 1.35}$$

1.1.4 Induction motor types based upon the construction of their Rotors

1) Squirrel cage rotor type induction motor: - Its rotor is cylindrical in shape having slots on its periphery. The slots are twisted to each other averting the magnetic locking of stator and rotor teeth making the working smooth and quite. It consists of aluminum, brass or copper bars. The squirrel cage winding is through symmetrical. As the bars are permanently shorted by end rings, rotor resistance develops into very small and it’s not possible to add external resistance. The dearth of slip rings and brushes make the construction very simple and robust. These motors have the plus of adapting any number of pairs of poles.

   The stator is the outer most component in the motor which can be seen. It may be constructed for single phase, three phase or even poly phase motors. But basically only the windings on the stator vary, not the basic layout of the stator. It is almost same for any given synchronous motor or a generator. It is made up of number of stampings, which are slotted to receive the windings. Let’s see the construction of a three phase stator. The three phase windings are placed on the slots of laminated core and these windings are electrically spaced 120 degrees apart. These windings are connected as either star or delta depending upon the requirement. The leads are taken out usually three in number, brought out to the terminal box mounted on the motor frame. The insulation between the windings is generally varnish or oxide coated. The rotor conducting bars are usually not parallel to the shaft, but are purposely given slight skew. In small motors, the rotor is fabricated in a different way. The entire rotor core is placed in a mould and the rotor bars & end-rings are cast into one piece. The metal commonly used is aluminium alloy.

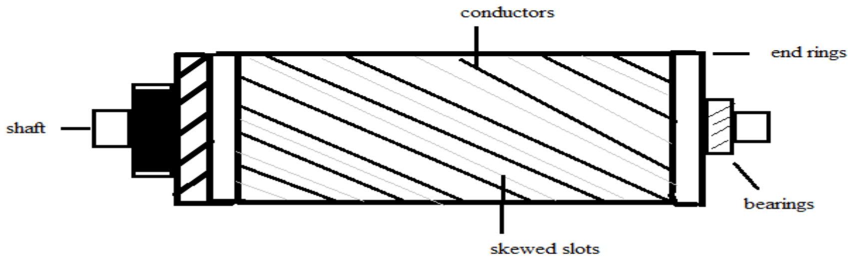

Fig. 1.5 Squirrel cage rotor

2) Wound rotor type induction motor: - In this type of induction motor the rotor is wound for same number of poles than that of stator. The rotor also carries star or delta winding parallel to the stator winding. The rotor consists of number of slots where the rotor winding are placed. The three ends terminals when connected together figures a star connection. The external resistance can easily be bonded through brushes or slip rings and can be used for speed control and upgrading of the starting torque of three phase induction motor. Due to presence if brushes and slip rings its construction is fairly complicated. Therefore, it is less used than the squirrel caged motor.

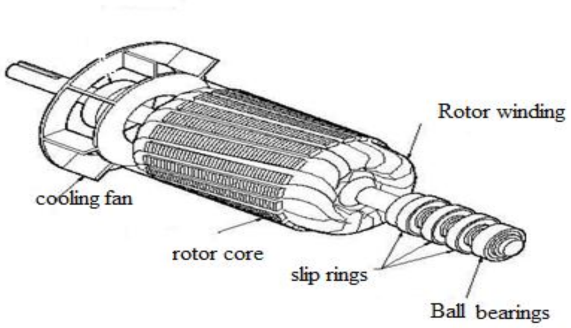

Fig 1.6 Wound rotor motor

1.1.5 Speed control methods for induction motor

Speed control of induction motor is very important particularly for industrial purposes. Construction of this motor is simple and robust; its outlay is also low. It also has good power factor, good speed ruling, high efficiency and starting torque. In industries motors must assure very good speed characteristics i.e. both in terms of speed and its downy control. So the speed control of electrical motors in general is of great practical importance.

We know that an induction motor cannot run at synchronous speed, its speed is always less than that of synchronous speed. The disparity between the synchronous speed n_s and actual rotor speed n_r is called slip.

$$\text{Fractional slip(s)} = \frac{n_s - n_r}{n_s}$$

It is also known that,

$$n_s = \frac{120f}{p}$$

Where f and p are the supply frequency and number of poles respectively. Therefore,

$$n_r = \frac{120f}{p(1-s)} \qquad \text{…..(i)}$$

From equation (i) it is observed that there are three factors which controls the speed of induction motor. These factors are: Supply frequency f, Number of poles P, Slip s. Methods of speed control are distinguished according to the main action on the motor – from the stator side and from the rotor side.

Various methods of speed control from stator side are:

a) Variation of supply frequency

b) Variation of applied voltage

c) Changing the number of poles

From the rotor side the speed may be controlled in the following ways:

a) Changing resistance in the rotor circuit and

b) Introducing additional emf (same frequency as fundamental emf) into rotor circuit.

Now we will go through a small description of each of the speed control methods of an induction motor. The methods are:

1.1.5.1 Speed control by varying the supply frequency

In this method with steady variation of speed throughout a wide range of speed control is provided. The major complexity in this method is to get the variable frequency supply. Requirement of auxiliary apparatus for this purpose results in a high cost, increased maintenance and lowering of largely efficiency. That is why this method is not generally used but there are firm applications where this method is most appropriate like if an induction motor is to be operated at different frequencies (with constant values of p.f, efficiency, slip, overload capacity).

The synchronous speed of an induction motor is given by

$$n_s = \frac{120f}{p}$$

The synchronous speed and the speed of the motor can be controlled by varying supply frequency. The emf induced in the stator of the induction motor is given by

$$E_1 = 4.44\ k\ f\ \varphi\ T_1$$

From the emf equation it can be examined that a change in frequency will result in amendment of the flux level unless the induced emf is changed in the same ratio. An imbalance will result in an excessive flux and saturation and reduced torque per ampere of current. Extreme flux will also cause rise in iron losses. In order to evade saturation and to minimize losses, motor is operated at rated air gap flux by varying terminal voltage with frequency so as to maintain constant (V/f) ratio. This control method is known as constant volts per hertz. The variable frequency supply is acquired by the following devices:-

1. Inverter (it changes fixed voltage dc to fixed/variable voltage ac of variable frequency) – voltage source inverter (VSI) and current source inverter (CSI).
2. Cycloconverter (it converts fixed voltage, frequency ac to inconsistent voltage and frequency ac)

1.1.5.2 Speed control by varying the supply/rotor voltage

By varying the supply voltage (V) we can diverge the speed of an induction motor. This is a slip control method with constant frequency variable supply voltage. From the torque equation

$$T \ \alpha \ \frac{sE_2^2 R_2}{R_2^2+(sX_2)^2} \times \frac{3}{2\pi n_s}$$

In low slip area (sX^2) is very small as compared to R_2. So it can be ignored and torque becomes

$$T \ \alpha \ \frac{sE_2^2}{R_2}$$

Since rotor resistance, R_2 constant so the equation of torque further reduces to

$$T \ \alpha \ sE_2^2$$

From the above equation it can be seen that if we decrease the supply voltage torque will also be decreased. But for supplying the same load, the torque must be the same and it is only probable if we will increase the slip. This method is exceptionally used because small change in speed requires large reduction of voltage due to which the current drawn by motor can enlarge causing overheating of induction motor.

1.1.5.3 Speed control by varying the no. of poles

This method of speed control is only valid for squirrel cage motors and not for wound motors. It is suitable for squirrel cage motors because it usually develops number of poles equal to the poles of stator windings. The number of stator poles can be changed by the following methods:-

a) Using multiple stator poles
b) Method of consequent poles and
c) Pole amplitude modulation (PAM).

In multiple stator pole method, the stator is provided with two separate independent windings, each wound for different number of poles, placed in same stator slots. One winding is wound up at a time. This method is very costly and less resourceful.

1.1.5.4 Rotor resistance control

As the name specifies this method is only applicable for the wound rotor induction motor and it is not applicable for squirrel cage motors. This control method is achieved by connecting peripheral resistances in the rotor circuit through slip rings. Speed control is provided from rated speed to minor speed. It is a very simple speed control method. In this method it is possible to have a massive starting torque, low starting current and large pull-out torque at slip value.

Drawbacks of this method are:

- Reduction in speed is done by reduction in efficiency
- The external rotor resistors provided are bulky and expensive.

This method is used in fan or pump drives and also in cranes.

1.1.6 Applications

Squirrel cage induction motor

Squirrel cage induction motors are simple and rugged in construction, are relatively cheap and require little maintenance. Hence, squirrel cage induction motors are preferred in most of the industrial applications such as in

1. Lathes
2. Drilling machines
3. Agricultural and industrial pumps
4. Industrial drives.

Slip ring induction motors

Slip ring induction motors when compared to squirrel cage motors have high starting torque, smooth acceleration under heavy loads, adjustable speed and good running characteristics. They are used in

1. Lifts
2. Cranes
3. Conveyors

1.1.7 Necessity of starters for 3 phase induction motor

When a 3- phase motor of higher rating is switched on directly from the mains it draws a starting current of about 4 -7 times the full load (depending upon on the design) current. This will cause a drop in the voltage affecting the performance of other loads connected to the mains. Hence starters are used to limit the initial current drawn by the 3 phase induction motors.

The starting current is limited by applying reduced voltage in case of squirrel cage type induction motor and by increasing the impedance of the motor circuit in case of slip ring type induction motor. This can be achieved by the following methods.

1. Star –delta starter
2. Auto transformer starter
3. Soft starter

Star delta starter

The star delta starter is used for squirrel cage induction motor whose stator winding is delta connected during normal running conditions. The two ends of each phase of the stator winding are drawn out and connected to the starter terminals as shown in the following figure

Initial States:

KM3 (MainContactor)-NC
KM2 (DeltaContactor)-NO
KM1 (StarContactor)-NC

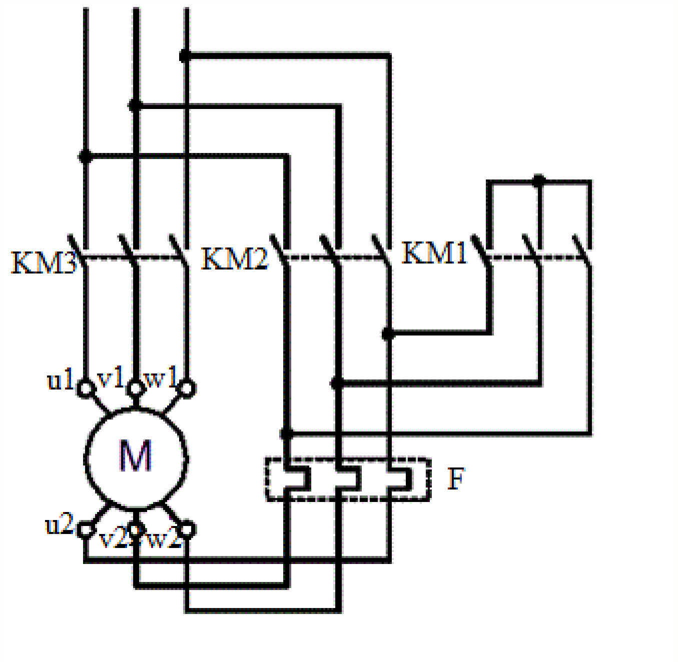

Fig 1.7 Star delta starter

When the power is fed into the circuit, KM3 allows current to flow to the motor since it is NC (Normally Closed).Current flows into the motor and out to the KM1 which is the star-connected starter. After a specified period defined by the clock delay

(Usually 5sec) the KM2 (Delta) Closes and KM1 opens to allow the motor to receive the full load current and run at delta. During staring the starter switch is thrown on to the STAR - START. In this position the stator winding is connected in star fashion and the voltage per phase is 1/√3 of the supply voltage. This will limit the current at starting to 1/3 of the value drawn during direct switching. When the motor accelerates the starter switch is thrown on to the DELTA - RUN side. In this position the stator winding gets connected in the Δ fashion and the motor draws the normal rated current.

Autotransformer

An autotransformer (sometimes called auto stepdown transformer) is an electrical transformer with only one winding. The "auto" (Greek for "self") prefix refers to the single coil acting on itself and not to any kind of automatic mechanism. In an autotransformer, portions of the same winding act as both the primary and secondary sides of the transformer. In contrast, an ordinary transformer has separate primary and secondary windings which are not connected.

The winding has at least three taps where electrical connections are made. Since part of the winding does "double duty", autotransformers have the advantages of often being smaller, lighter, and cheaper than typical dual-winding transformers, but the disadvantage of not providing electrical isolation. Other advantages of autotransformers include lower leakage reactance, lower losses, lower excitation current, and increased KVA rating for a given size and mass.

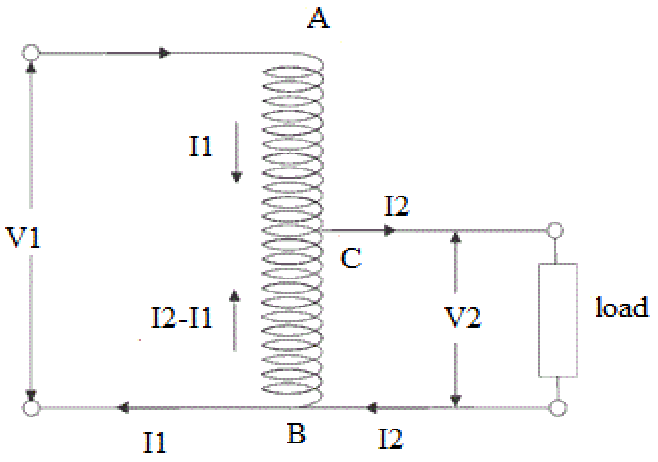

Fig 1.8 Autotransformer

1.2 Vector Control

Vector control is also recognized as field-oriented control (FOC), it is a variable-frequency drive (VFD) control scheme where the stator currents of a three-phase AC electric motor are conceded as two orthogonal components that can be envisaged with a vector. One component defines the magnetic flux of the motor, the additional is the torque. The managing system of the drive calculates the flux and torque references specified by the speed of the control the equivalent current component references.

Mostly proportional-integral (PI) controllers are utilized to maintain the measured current constituents at their reference values. The pulse-width modulation of the variable-frequency drive describes the transistor switching according to the stator voltage references that are the yield of the PI current controllers.

FOC is used to direct the AC synchronous and induction motors. It was initially developed for high-performance motor applications that are needed to function smoothly over the stuffed speed range, generate full torque at zero speed, and have high dynamic performance mutually with fast acceleration and deceleration. However, it is becoming increasingly striking for lower performance applications also due to FOC's motor size, cost and power consumption decline dominance.

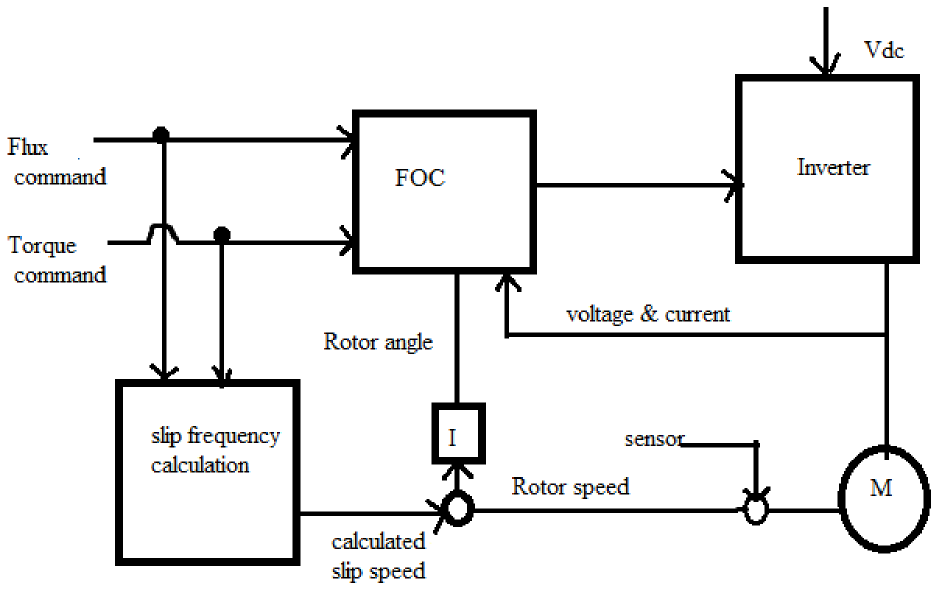

Fig 1.9 Field oriented vector control

In order to understand the spirit of the field oriented control technique, start with an outline of the separately excited direct current (DC) motor. In this type of motor, the excitation for the stator and rotor is separately controlled. Electrical study of the DC motor shows that the produced torque and the flux can be independently adjusted. The potency of the field excitation (the magnitude of the field excitation current) sets the value of the flux. The current throughout the rotor windings determines how much torque is produced. The commutator on the rotor co-operates an interesting part in the torque production. The commutator is in contact with the brushes, and the mechanical construction is designed to switch into the circuit the windings that are mechanically united to produce the maximum torque. This pact then means that the torque production of the machine is fairly near finest all the time. The explanation point here is that the windings are managed to keep the flux produced by the rotor windings orthogonal to the stator field. Flux and torque are independently controlled and the current through the rotor windings concludes how much torque is produced as shown above. FOC control permits you to get around these limitations, by decoupling the effect of the torque and the magnetizing flux. With decoupled control of the magnetization, the torque producing component of the stator flux can at present be thought of as independent torque control. Decoupled control, at low speeds, the magnetization can be continued at the proper level, and the torque can be controlled to normalize the speed.

There are two vector control methods, direct or feedback vector control (DFOC) and indirect or feed forward vector control (IFOC), IFOC being more commonly used because in closed-loop mode such drives more effortlessly operate throughout the speed range from zero speed to high-speed field-declining. In DFOC, flux magnitude and angle response signals are directly calculated using so-called voltage or current models. In IFOC, flux space angle feed forward and flux magnitude signals first measure stator currents and rotor speed for then deriving flux space angle suitable by summing the rotor angle equivalent to the rotor speed and the calculated reference value of slip angle corresponding to the slip frequency.

In many industrial applications, Direct torque control (DTC) of induction motor is renowned control method which provides fast dynamic response compared with other control methods like field oriented control (FOC). The DTC has been put forward for induction motor control in 1985 by Takahashi [1] and similar idea that the name of Direct Self Control devoloped in 1988 by Depenbrock [2]. Over the precedent years, the DTC has gained great attention due to its advantages like simple control structure, robustness to parameters variations, fast dynamic response, not need to current regulators...etc. However, DTC has still some disadvantages and they can be recapitulated as follows; high current and torque ripples, difficulty to control torque and flux at very low speed, variable switching frequency conduct and high sampling frequency needed for digital implementation.

1.2.1 DIRECT TORQUE CONTROL

The basic proposal of the DTC technique is to choosing the optimum vector of the voltage, which makes the flux rotate and generate the torque desired. In usual DTC method, the control of an induction motor engrosses the direct control of stator flux vector by applying inverter’s optimum voltage switching vectors. For this control, the stator current should be decoupled two independent components as flux and torque components like dc motors. The clarke transformation method is used in this decoupling process in the DTC method. The DTC permits for very rapid torque responses, and supple control of the induction motor. The DTC bases on the assortment of the optimum voltage vector which makes the flux vector rotate and produce the desired torque. In this process, the amplitude of the flux and the torque inaccuracy are kept within acceptable limits by hysteresis controllers [12]. The rotation of the stator flux vector and an pattern for the effects of the applied inverter switching vectors are given in the Fig

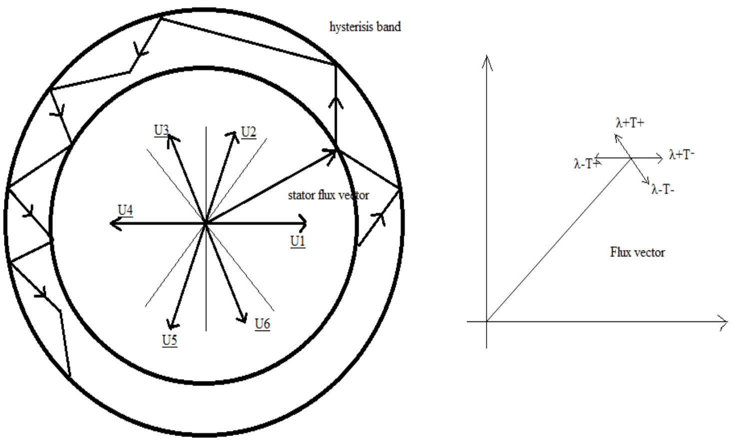

Fig 1.10 rotation of stator flux vector

The stator flux vector is estimated by using Eq.

$$\lambda_a = \int (v_a - R_s i_\alpha) dt$$

$$\lambda_b = \int \left(v_b - R_s i_\beta\right) dt$$

$$\lambda = \sqrt{\lambda_\alpha^2 - \lambda_\beta^2}$$

Where λ is stator flux vector, $i_\alpha$and i_β stator voltages two phase components, i_α and i_β line currents in α-β reference frame and R_s (stator resistance). After the calculation of the α-β components of the stator flux vector electromagnetic torque of the induction motor can be intended as given in Eq.

$$T_e = \frac{3}{2} p\left(\lambda_\alpha i_\beta - \lambda_\beta i_\alpha\right) dt$$

Where, p is the number of pole duos. In DTC method, stator flux rotate trajectory divided six region and well-named of stator flux region is straightly affects on control performance. The stator flux α-β components that can be calculated use the defining of the stator flux region as given in Eq.

$$\theta_z = tan^{-1} \left(\frac{\lambda_b}{\lambda_a}\right)$$

These observed values of the flux and the torque errors are compared to reference the flux and the torque values and the consequential errors are as inputs applied to the hysteresis comparators. The two different hysteresis comparators, as flux and torque comparators, which produces other control parameters on this method. But the hysteresis comparators outputs accordingly, the observed angle of flux linkage and a switching table, optimum voltage vectors are selected and applied to the inverter.

1.3 Fuzzy control

Fuzzy logic techniques are basically an attempt to copy human thought process into the technical environment. By doing this approach allows the designer to knob efficiently very complex closed loop control troubles reducing the time and the outlay. It also supports non linear design techniques. Fast fuzzy control usually requires the use of hardware processor. Fuzzy logic allows a simpler and more robust control elucidation.

From the application of fuzzy control two crises can be seen i.e. how to set the fuzzy rules and membership functions. Generally two approaches are tracked. The first one consists of directly acquiring acquaintance from the expert operators and translating it into fuzzy rules. This process is quite difficult to implement and also time overriding. An alternate fuzzy rule can be obtained through machine learning techniques, where the data can be brought out from the sample cases. We need to have two fundamental input magnitudes to use the fuzzy logic. Let's take the two inputs x and y. we need to follow three basic steps for the fuzzy process:-

3) Fuzzification of the inputs
4) Fuzzy- inference
5) Defuzzification

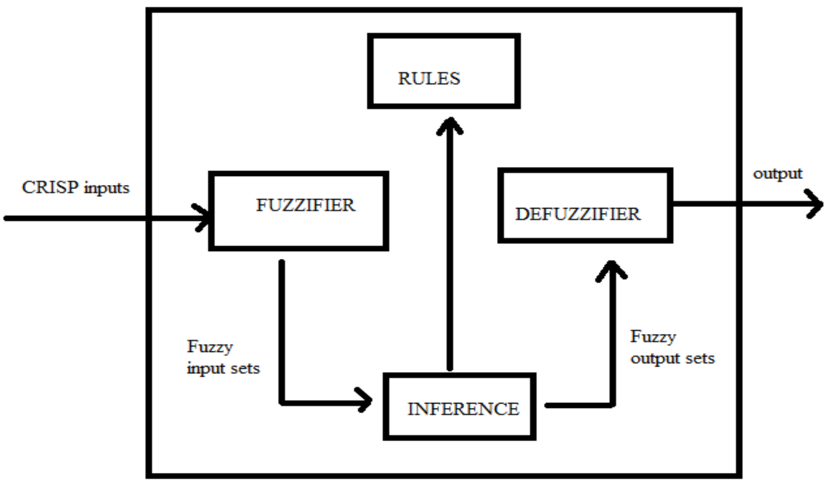

Fig1.11 Basic fuzzy process

For fuzzification we must have fuzzy set for each input. These sets are kind of linguistic variables for instance far, warm, small, high etc. once the fuzzy set is defined; degree of membership has to be calculated for all input. Minimum degree of membership is zero and highest is 1. It is easiest to use linear functions to calculate degree of membership Such as presented below;

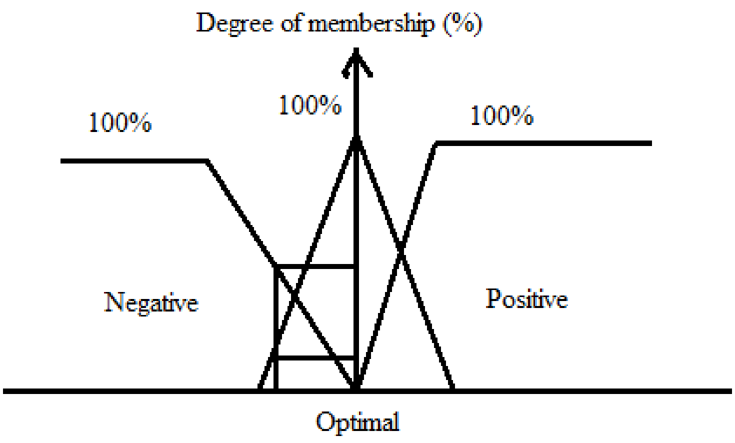

Fig 1.12 Membership functions

However the computations related to degree of membership is not limited to linear functions only. Degree of membership has to be calculated for every fuzzy set for the given input. After the end of the first step data should be further processed in the second step. All the data obtained must be evaluated using "if then" rules. This procedure is known as fuzzy inference. There are several options to choose how to determine output from compared numbers in each "if then" rule.

- Choose minimum: $\mu = \min\{x,y,z\}$
- Choose maximum: $\mu = \max\{x,y,z\}$
- Choose complement $\mu_c = 1-\mu$

After fuzzy inference we have many values to ensue as there was “if then” rules. Last step is Defuzzification which is used to acquire a crisp output from numbers obtained in step fuzzy inference.

1.3.1 Fuzzy Logic as an Evolutionary Computational Tool

Fuzzy logic, was first initiated by Lotfi A. Zadeh in 1965, which embodies human-like idea into a control system. The fuzzy controller utilizes a mode of approximate reasoning bordering on the decision making route of humans, that is, the process people use to infer conclusions from what they acquire. Fuzzy control has been primarily applied to the control of processes through fuzzy linguistic explanations stipulated by membership functions. The conventional Boolean logic has been widened to deal with the concept of partial truth - truth values which exist between “completely true" and "completely false", and what we shall be referring to as fuzzy logic. This is achieved through the theory of degree of membership. The core of fuzzy logic respites on a set of linguistic if-then rules. It has met a growing interest in many motor control purposes due to its non-linearity handling features and liberty of plant modeling. Moreover, the fuzzy logic concepts cooperate a vital role in developing controllers for the plant since it isn’t necessitate of the much complicated hardware and all it necessitates are only some set of rules.

1.3.2 Inference System

The inference system comprises of the following three patterns:

1. Rule Base: - It consists of various If-Then rules. Where the If side of the rule is known as the antecedent and the Then part is known as the consequence. These rules are very much alike to the Human thinking process and the computer uses the linguistic variables which are received after fuzzification for implementation of the rules. They very simple to understand and write and hence programming for the fuzzy logic controller is very unproblematic. The control policy is stored in more or less than the normal language.
2. Database: - It consists of the all the tagged membership functions that are to be used by the rules.
3. Reasoning Mechanism: - It performs the inference procedure on the rules and the data given to offer a reasonable output. It is basically the codes of the software which are process the rules and the all the associate based on a particular situation. It exercises a human brain type of characteristic to methodically hold out the inference steps for processing the information.

1.3.3 Defuzzification Block or Defuzzifier

A defuzzifier carries outs the exact opposite function of a fuzzifier. It transforms the fuzzy variables (which are obtained as output after dealing out of the inputs) to crisp sets. The defuzzifier is necessary because in the real world the crisp values can only be taken as inputs to the systems. Although the fuzzy sets look like the human thought process, their functionality is restricted only to the above processes. In designing the controller, when the Mamdani Fuzzy Model is used a defuzzifier is generally required. There are other types of buildings that can be used are:

1. Tagaki-Sugeno Fuzzy Model
2. Tsukamoto Fuzzy Model

As Mamdani model chases the Compositional Rule of Inference firmly in its fuzzy reasoning mechanism it is preferred here.. Unlike the Mamdani model, the outputs are defined with the aid of a specific function for the other two models (first order polynomial in the input variables) and thus the output is not fuzzy it is crisp.

Since a fuzzy model must be able to proliferate the fuzziness from inputs to outputs in an proper mode this is counter sensitive.
There are five basic defuzzification strategies and they are defined as follows:

1. Centroid of Area (COA): It's very popular technique used for defuzzification, as it is suggestive of the calculation of expected values of probability distributions. It can be defined as follows:

$$z_{coa}=\frac{\int_z \mu_A(z)zdz}{\int_z \mu_A(z)dz}$$

Where the combined output is MF.

3. Bisector of Area (BOA): This method satisfies the equation:

$$\int_{\alpha}^{zboa} \mu_A(z)dz = \int_{zboa}^{\beta} \mu_A(z)dz$$

   Where α= min{ z/zϵZ } and β= max{z/zϵZ }. That is the vertical line z= z_{BOA} detaches the region between z = α, z = β and y = 0, y = μ_A (Z) into two regions with same area.
4. Mean of Maximum (MOM): z_{MOM} is the average of the maximizing z at which the MF achieves a maximum μ. It can be represented by equation as follow:

$$z_{MOM} = \frac{\int_{z^1} zdz}{\int_{z^1} dz}$$

   where z' = {z | μA (z) = μ*}
5. Diminutive of Minimum (SOM): z_{SOM} is the minimum of the maximizing z (i.e in terms of magnitude).
6. Largest of Maximum (LOM): $z_{LOM}$is maximum when maximizing z (in terms of magnitude).

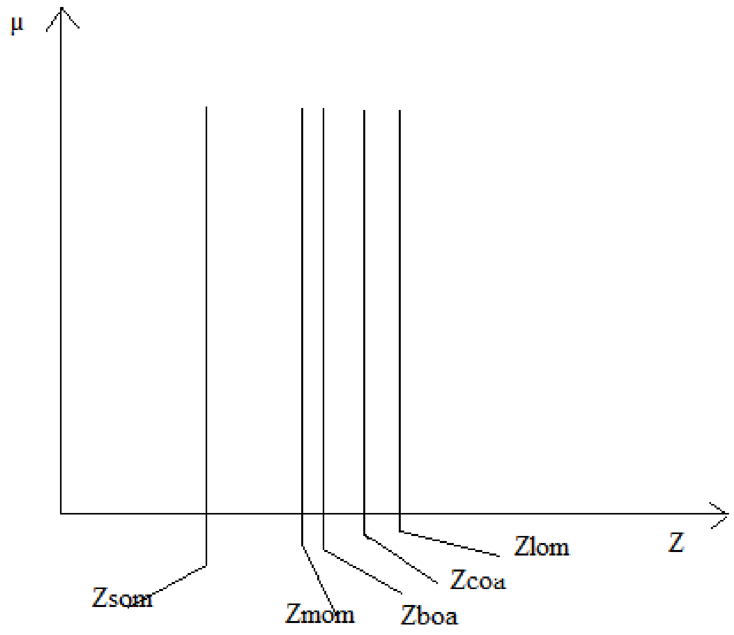

Fig 1.13 various diffuzification schemes for different crisp values

Above fig. shows different deffuzification schemes for being paid different crisp values. The last two defuzzification techniques are rarely used because of their intolerance nature. The most used technique is the Centre of Area (COA) method.

1.3.4 Summary

Thus, we have observed that the designing of a Fuzzy Logic Controller (using the Mamdani Fuzzy Model) entails:

1. The selection of suitable inputs and their fuzzification.
2. The defining of the input and output membership functions.
3. The defining of the Fuzzy Rule Base.
4. The defuzzification after the giving out of the linguistic variables with the aid of a appropriate defuzzification technique.

Each of them has to be result oriented designed that is needed from the system.

1.3.5 Application Areas of Fuzzy Logic Controllers

The fuzzy logic Controllers are basically used when

1) The system is highly non-linear by this means making the making the mathematical modeling of the system very grueling.
2) The analytical form of the system is not provided, instead a linguistic form is provided.
3) The strict identification of the system parameters.
4) The system behavior has a vague characteristic under precisely defined stipulations.
5) The conditions in the system are vague.

CHAPTER 2

LITERATURE SURVEY

Mouloud azzedine denai, Sid Ahmed Attia (2002) represents [1] 'fuzzy and neural control of an inuction motor**'.** The conventional control allows different design objectives such as steady state and transient characteristics of closed loop system. Fuzzy logic and neural networks are combined to overcome problems with uncertainties in the plant parameters. Induction motors are characterized by their complex, highly non linear and time varying dynamics. The use of vector control has partially solved induction motor control problems as they are sensitive to drive parameters variations. Three control approaches are developed to adjust speed of the drive system. The first combines the variable structure theory with the fuzzy logic concept. In second approach neural networks are used in the internal model of the control system. Then the final fuzzy state feedback controller is developed based on the technique of the pole placement.

The performance and robustness of the proposed controller have been evaluated under variety of conditions and the result shows the effectiveness of these control structures. NIMC and FVFC achieved slightly improved results than the FVSC. The control techniques are very suitable for real time implementation due to their simplicity and robustness.

V . Chitra and R. S. Prabhakar (2006) represents [2] 'Induction motor speed control using fuzzy logic controller**'.** The speed control of the induction machine is very important to achieve as it has many applications in industries. For achieving maximum torque with minimum loss fuzzy logic is applied for speed control of induction motor. Testing of the simulation design has been done and tested using membership functions chosen according to the various tool boxes in MATLAB. Over the entire speed range the proposed speed controller gives maximum torque.

K kaur, adar. S.Chowdhury, Dr. S.P.Chowdhury, Dr. K.B.Mohanty,Prof.A.Domijan (2008) represents [3] 'Fuzzy logic based control of variable speed induction machine wind generation system**'.** The performance of the variable speed wind generation system is analyzed using fuzzy logic principles for efficiency optimization and performance enhancement. The system performance is studied with the matlab simulation.

Three fuzzy controllers are used in which first one is FLC-1 which searches online the generator speed to maximize the aerodynamics efficiency of the turbine is maximum. Second one i.e. FLC-2 programs the machine flux to optimize the machine converter efficiency. And the third one performs control against turbine oscillatory torque. In this paper the fuzzy algorithm used are universal and performance of the system is found to be excellent using fuzzy logic controllers.

Ashok Kusagar. Dr. S.F Kodad, Dr. BV. Sankar Ram (2009) represents [4] 'Modelling of induction motor and control of speed using hybrid Controller technology**'.** The fuzzy control strategy has been investigated for achieving speed control of an induction motor drive. For speed control of IM, simulink models were developed in matlab with hybrid controllers. The main advantage f designing the TS based fuzzy coordination scheme to control the speed is to increase the dynamic performance and provide good stabilization.

The simulation result shows that this control method is reliable simple and cost effective. And when this scheme is implemented in real time, the size of the controller will become small and provides faster settling time, good dynamic response and stabilization.

T.-J Ho and L.-Y Yeh (2010) represents [5] 'Design of hybrid PID plus fuzzy controller for speed control of induction motors**'.** The parameters of Ziegler-nichols (Z-N) PID can be chosen using simple rule of thumb. In this paper speed control of direct field-oriented induction motor (DFOIM). On the basis of PID controller output FLC is developed. On the squirrel cage induction moto closed loop scheme is implemented. The proposed controller has exhibited the combined advantages of a PID controller and a FLC.

D. Ben Attous and Y. Bekakra (2010) represents [6] 'Speed control of a doubly fed induction motor using fuzzy logic techniques**'.** A comparison between fuzzy lgic and a conventional PI controller for speed control of the doubly fed induction motor is done. Under different operating conditions the effectiveness of the control strategy is evaluated. The fuzzy PI controller under different operating conditions has shown robustness against the rotor resistance variation and insensitivity to load torque disturbance. Also the simulation results show faster dynamics with negligible steady state error at all dynamic operating conditions.

Ravi maloth (2012) represents [7] 'Speed control of induction motor using fuzzy logic controller**'.** the v/f ratio is maintained constant to get constant torque. The good system performance scalar controlled induction motor drive is achieved with fuzzy logic controller. fuzzy logic controller has the capability of controlling non linear, uncertain systems even in case where no mathematical models are available.

The PWM technique using MATLAB is used for the scalar control of induction motor for both open and closed loop. By using fuzzy logic the results obtained are near to the reference value when the torque is applied.

Divya Rai, Swati Sharma, Vijay Bhuria (2012) represents [8] 'Fuzzy speed controller design of three phase induction motor**'.** The most used motor is induction motor because of its unique characteristics. A rule based mamdani type fuzzy controller is applied to the induction motor to provide an intelligent and advanced speed control to achieve maximum torque and efficiency. For controlling the speed scalar control method is used. Simulation is done and results are compared showing that fuzzy logic controller is having fast control response and gives maximum torque over the entire speed range.

Mohammad Abdul Mannan, Asif Islam.et.all(2012) represents [9] 'Fuzzy logic based speed control of induction motor considering core loss into account**'.** If the core loss is neglected the actual flux and torque are not reached to the reference flux and the torque**.** Thus, in this paper fuzzy logic speed controller of induction motor is proposed where flux and torque decoupling strategy is decoupled in terms of magnetizing current instead of stator current to alleviate the effects of core loss. Simulation is conducted for the verification of the effectiveness of the proposed FLC. At last the results are compared and it is seen that the performance of the proposed FLC in both transient and steady state are better than those of conventional PI controllers.

Fatih Korkmaz, Ismail.et.all.(2013) represents [10] 'Fuzzy logic based direct torque control of induction motor with space vector modulation**'.** Induction motor due to its well known advantages have wide range of applications in industries. In this paper a new approach is done for the direct torque control of induction motor using fuzzy logic and also to overcome high torque ripple. The induction motor has been tested for low speed (250 rpm) and rated speed

Marwan A. Badran, Mostafa A. Hamood, Waleed F. Faris (2013) represents [11] 'Fuzzy logic based speed control system for three phase induction motor**'.** Variable frequency drives (VFDs) can be used for easy control of speed of the induction motor. In this paper fuzzy logic base speed control system is being proposed using MATLAB software and it is tested for various operating conditions. A comparison between the FLC and PI controller is done and it is seen that FLC showed better speed control and provides an accurate and fast response with relatively no overshoot and no steady state error.

C.Sasikumar, Dr.C.Muniraj (2013) represents [12] 'Performance analysis of fuzzy flatness based speed control of three phase induction motor**'.** Fuzzy flatness based tracking controller is an important tool for nonlinear controller design. This method for induction machine reduces tracking error and torque ripple. The closed loop control has been achieved by using inductive type proximity sensor. The performance of fuzzy flatness controller for the speed control voltage source inverter fed induction motor is compared with the conventional PI controller performance.

K.M Makwana, Dr. B.R.Parekh, Sheetal Shinkhede (2013) represents [13] 'Fuzzy logic controller Vs PI controller for induction motor drive**'.** The motor drive system is comprised of a voltage source inverter fed induction motor (VSIIM). The squirrel cage induction motor voltage equations are based on the d-q reference rotating frame. In this paper novel fuzzy logic controller for closed loop Volts/Hz motor drive system is being presented. It provides a simple and robust fuzzy logic speed controller for high performance induction motor drives.

G Srinivasan, Dr, S.Tarakalyani (2013) represents [14] 'Fuzzy logic controller and sensorless vector control of induction motor using efficiency optimization technique. By indirect vector controlled drive system on line efficiency optimization control is used which is fuzzy logic based. The performance of the drive without fuzzy controller and when it is incorporated is compared and results are analyzed. The analysis is done on Matlab/simulink. Input power minimization is done and input power is decreased.

Kamini Devi, Shailendra gautam, Deepak Nagaria (2014) represents [15] 'Speed control of three phase induction motor using self tuning fuzzy PID controller**'.** The fuzzy logic controller can also be introduced in the system to maintain the motor speed constant when there is a load variation. In this paper a rule based fuzzy logic controller applied to a scalar loop Volts/Hz induction motor control. The results in this paper are obtained by considering the strong non linearity in the IM model. The results are compared of the conventional PID and fuzzy logic controller PID and it is analyzed that better output is shown by the fuzzy logic controller PID. It can be seen that the fuzzy logic approach is feasible.

(1500 rpm) working conditions to get the output for both control methods. The numerical simulation shows that the torque and speed responses are significantly improved with the proposed technique. The hysteresis controllers are removed and the torque ripples are lesser about 40%.

Mohammed wasim ansari.K.et.all.(2014) represents [16] 'Fuzzy logic based soft starting of three phase induction motor**'.** The control of the current is done using fuzzy logic. As the starting equipment ac voltage inverter is used while an optimally tuned proportional integral controller is used for motor current regulation. An ac voltage inverter fed induction motor with conjunction with PI controller is optimized using fuzzy logic which is included in the drive system. The objective is to start the induction motor at rated current. PIC16F87XA microcontroller is used as the feedback controller. For ac pulse generator firing pulse generator is used.

Ashutosh Mishra, Prashant Choudhary(2014) represents [17] 'Speed Control Of An Induction Motor By Using Indirect Vector Control Method'. In this paper, an implementation of intelligent controller for speed control of an induction motor (IM) using indirect vector control method have been developed and examined in facet. The project is complete mathematical model of field orientation control (FOC) induction motor is depicted and simulated in MATLAB, cage type induction motor has been considered .The relative performance of Fuzzy Logic control technique has been presented and analyzed in this work. The present approach evades the use of flux and speed sensor which increase the installation cost and mechanical robustness. The fuzzy logic controller is found to be a very practical techniques to obtain a high performance speed control. The indirect vector controlled induction motor drive engross decoupling of the stator current in to torque and flux producing components.

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CHAPTER 3

PROJECT WORK

3.1 Problem formulation

An induction motor is an asynchronous motor, speed of which can be varied by varying the supply frequency. The control strategy to be adopted in any meticulous case depends on a number of factors including load reliability, investment cost and any special control requirements. Thus, for any particular application, a detailed review of the load characteristics, historical data on the features required of the speed control system and the investment cost would be a must to the selection of a speed control system.

The load characteristics are chiefly important. Load refers essentially to the output torque and equivalent speed required. Loads can be broadly classified either as constant power or Constant torque. Constant torque loads are those for which with the speed of operation output power requirement may contrast but the torque does not vary. Typical examples of constant torque loads are Conveyors, rotary kilns, and constant-displacement pumps. Variable torque loads are those for which the torque required varies with the speed. Centrifugal pumps and fans are typical examples of variable torque loads (torque show a discrepancy as the square of the speed). Constant power loads are those for which the torque required typically change inversely with speed. For constant power load Machine tools are a typical example. AC motors, particularly the squirrel-cage induction motor (SCIM), enjoy several inherent advantages like simplicity, reliability, low cost and virtually maintenance-free electrical drives. However, for high dynamic performance industrial applications, their control remains a challenging problem because they exhibit significant non-linearities and many of the parameters, mainly the rotor resistance, vary with the operating conditions. Field orientation control (FOC) or vector control (Vas, 1990) of an induction machine realizes decoupled torque and flux dynamics primary to independent control of the torque and flux as for a separately excited DC motor. FOC methods are striking but suffer from one major disadvantage: they are sensitive to motor parameter variations such as the rotor time constant and an erroneous flux measurement or estimation at low speeds (Trzynadlowski, 1994). Consequently, performance deteriorates and conventional controller such as a PID is incapable to maintain satisfactory performance under these conditions. The largest potential for savings of electricity with variable speed drives is commonly in variable torque applications, for example centrifugal pumps and fans, where the power requirement transform as the cube of speed. The main problem come across is the smooth rotation over the entire series of the motor, full torque control at zero speed, fast acceleration and decelerations. The Fundamental requirements for the FOC are the acquaintance of two currents (if the induction motor is star connected) and the rotor flux position. Knowledge of the rotor flux point is the core of the FOC. In fact if there is an error in this variable the rotor flux is not aligned with d-axis and the current apparatus are incorrectly estimated. In the induction machine the rotor speed is not alike to the rotor flux speed (there is a slip speed; as such, a special process to calculate the rotor flux position (angle) is needed. The crucial method is the use of the current model. Using FOC it becomes possible to control, directly and discretely, the torque and flux of the induction motors. Field oriented controlled induction machines gain every DC machine advantage: immediate control of the separate quantities allowing accurate transient and steady state supervision.

As a power strategy used in variable frequency drives, vector control provides a viable solution to torque/speed control of AC machines by controlling the phase currents into the machine even if it gives rise to a considerable calculation burden for the processor where the control algorithms are put into practice. The most obvious merit of vector control is to get rid of machine speed craving on power grid frequency and make it possible to reach the desired machine speed within safety and power limits. Usually in a vector control system, the phase currents of the machine and the DC-link voltage of the inverter and occasionally the rotor shaft position and/or the machine speed are taken as the control system inputs, while the phase voltages to the machine are selected as the outputs. Two important alterations are involved in the vector control system to transform AC machine into a separately magnetized DC machine, explicitly Clarke Transformation and Park Transformation. With these transformations the three-phase sinusoidal quantities can be altered into DC quantities in steady state.

3.2 Scope

This paper presents some design looms to hybrid control systems combining vector control technique with fuzzy logic. Such a hybrid implementation directs to a more efficient control devise with improved system performance and sturdiness. While conservative control allows different design objectives such as steady state and transient characteristics of the closed loop system to be specified, fuzzy logic is to overcome the problems with qualms in the plant parameters and structure encountered in the conventional model-based design. Induction motors are characterized by complex, extremely non-linear and time-varying dynamics and diffidence of some states and outputs for measurements, and hence can be measured as a challenging engineering problem. The advent of vector control techniques has moderately solved induction motor control problems; because they are receptive to drive parameter variations and performance may depreciate if conventional controllers are used. Fuzzy logic and neural network-based controllers are considered as potential entrants for such a purpose. Two control advances are developed and applied to amend the speed of the drive system. The first control design merges the variable structure theory with the fuzzy logic theory. Finally, a fuzzy state feedback controller is developed. A simulation study of these methods is obtainable. The effectiveness of this controller is demonstrated for different operating conditions of the drive scheme and transient characteristics of the closed loop system to be specified.

3.3 Objectives

The main objective of this project is to develop a fuzzy logic based controller to control the speed of the induction motor, employing the vector control model. The voltage and frequency input to the induction motor are to be proscribed in order to attain the desired speed response.

The main objectives of this project is to

- Analyze the performance of an induction motor via fuzzy logic principles using MATLAB/SIMULINK.
- And to boost the performance and optimization of the efficiency.
- Improvement of an artificially intelligent speed controller using the fuzzy logic approach and based on vector control model.
- To fabricate a learning package of Fuzzy Logic Controller, for vector speed control of Induction Motor, for outlook reference purpose.

3.4 Research methodology

First we will design a basic simulation block for the vector control of the induction motor as shown in fig 3.1

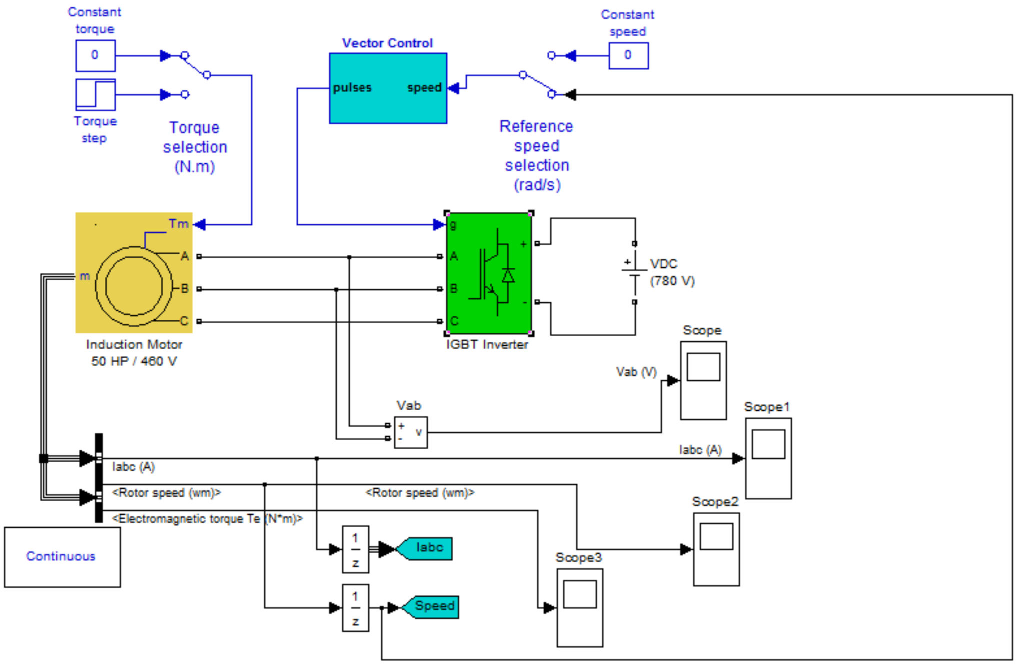


Fig 3.1 Basic simulation model of induction motor

The Fig 3.2 shows the basic functioning of the vector control in speed control of induction motor using indirect method. The vector controller allows the speed and flux demands and generates the commanded values of torque- and flux-producing elements of stator current and, correspondingly, which is processed through a proportional plus integral (PI) controller. The commanded current values are again processed through two autonomous pairs of PI controllers (and synchronous frame current control) to engender two sets of command /reference voltage vector. These reference voltage vectors are used to produce two sets of three-phase command reference voltage vectors and phase shifted by an arbitrary (pre-set value) angle, through double transformation (d–q synchronous to D-Q stationary to abc / xyz phase variables). The controlled voltage vectors in concurrence with the bidirectional triangular waveform, i.e., forks of the carrier signal and the commanded voltage vectors present the switching signals to the base drive of the inverter switches. It will be worthwhile to mention here that the parameter detuning effect is neglected.

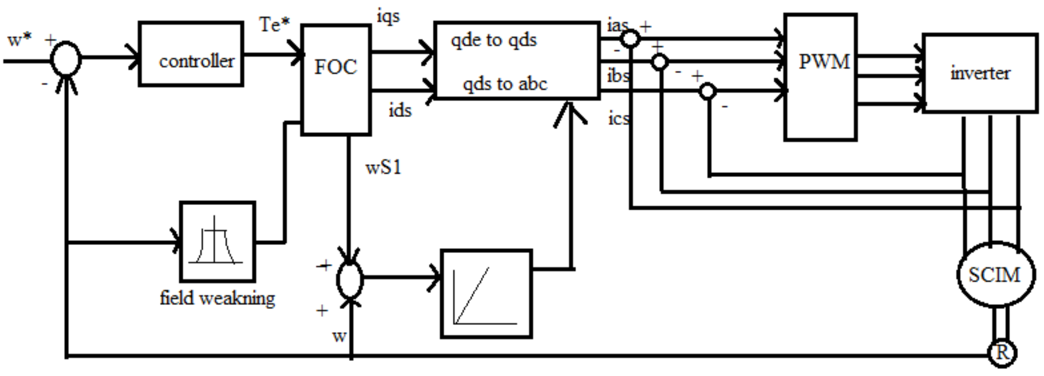


Fig 3.2 Basic block diagram for FOC control of the induction motor

The Block diagram utilizing speed control of an induction motor is shown in Fig. It can be seen that vector control method is employed in the given block diagram. The frequency and supply voltage of the induction motor are mottled such that it operates at steady state, at the desired speed. The Vector control approach where it is torque/flux and reference current, respectively. Even though vector control drives offer excellent performance in terms of dynamic speed regulation, accomplishment of the same is monotonous owing to on-line coordinate transformations that alter line currents into two axis representation and vice versa.

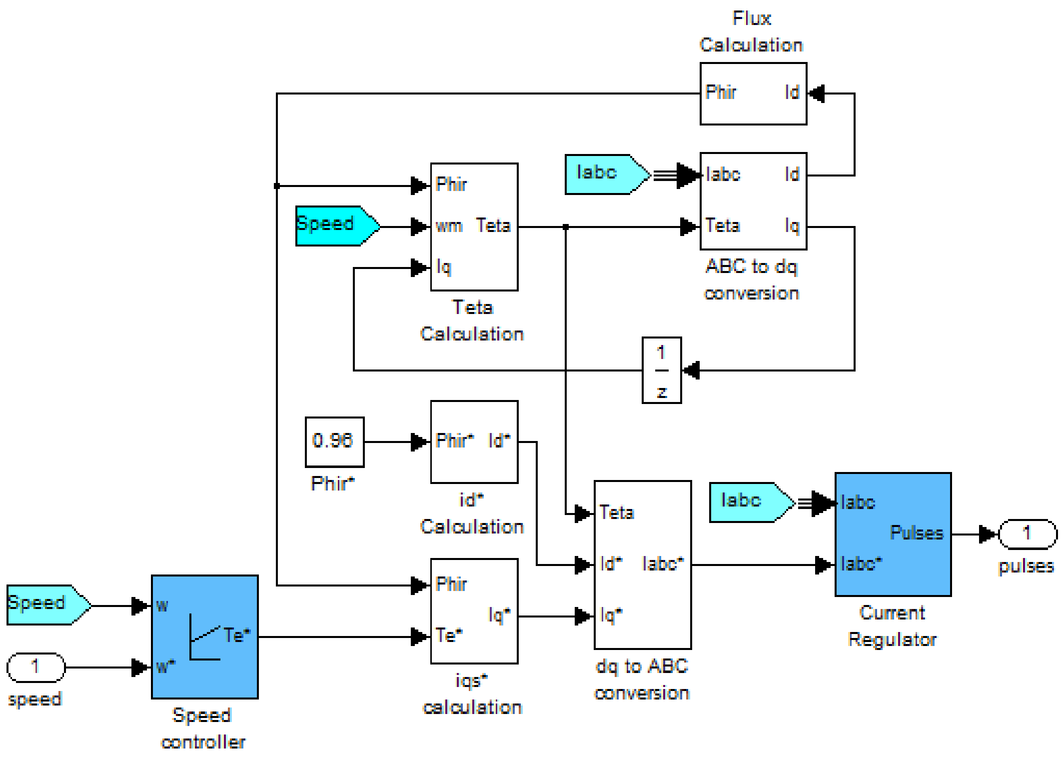


Fig 3.3 Vector control of induction motor using matlab

As shown in the block diagram, (ω_m^*) is taken as the reference signal. The use of speed as reference signal is defensible as the output of the system is speed and our aim is to control the speed of the induction motor. A tacho-generator, attached to the shaft of the induction motor, make available the current speed of the motor (ω_m) which is compared with the reference speed (ω_m^*), thus providing us with the speed error (e). This mechanism is entitled the feedback mechanism. A feedback mechanism is used to provide the eminence of automation to the control system. The information about the direct state of the output is fed back to the input which in turn is used to revise the same in order to achieve a desired output. Change-of-error (Δe), that is, the imitative of speed error is computed and both e and Δe are fed to the fuzzifier for fuzzification. The inference system then processes these two fuzzy inputs using the fuzzy control rules and the catalog, which are defined by the programmer based on the preferred membership function and fuzzy rule table, to give an output fuzzy variable. The fuzzy output thus obtained is defuzzified by the defuzzifier to give a crisp value, i.e. change-of-control (ω_{sl}). This is then added to the motor speed (ω_m) which in turn figures the input to the IGBT.

IGBT:- The insulated-gate bipolar transistor (IGBT) is a three-terminal power semiconductor device principally used as an electronic switch which, as it was developed, came to coalesce high efficiency and fast switching. It switches electric power in many up to date appliances: variable-frequency drives (VFDs), electric cars, trains, variable speed refrigerators, lamp weights, air-conditioners and even stereo systems with switching amplifiers. Since it is designed to turn on and off rapidly, amplifiers that use it frequently synthesize complex waveforms with pulse width modulation and low-pass filters. In switching applications modern devices feature pulse repetition rates well into the ultrasonic range—frequencies which are at least ten times the highest audio frequency knobbed by the device when used as an analog audio amplifier. The IGBT combines the simple gate-drive characteristics of MOSFETs with the high-current and low-dispersion-voltage capability of bipolar transistors. The IGBT combines an isolated gate FET for the control input, and a bipolar power transistor as a switch, in a particular device. The IGBT is used in medium- to high-power applications in the vein of switched-mode power supplies, traction motor control and induction heating. Large IGBT modules typically consist of many devices in parallel and can have very high current conduct capabilities in the order of hundreds of amperes with blocking voltages of 6000 V, associate to hundreds of kilowatts.

The first-generation IGBTs of the 1980s and early 1990s were prone to failure through such means as latchup (in which the device will not turn off as long as current is flowing) and secondary breakdown (in which a localized hotspot in the device goes into thermal runaway and smolders the device out at high currents). Second-generation devices were much improved, and the current third-generation ones are even better, with speed rivaling MOSFETs, and excellent ruggedness and tolerance of overloads. The extremely high pulse ratings of second- and third-generation devices also build them useful for generating large power pulses in areas including particle and plasma physics, where they are starting to supplant older devices such as thyratrons and triggered spark gaps.

The Fuzzy Logic Controller is to be designed. This is prepared using the FIS editor. The membership functions and the rules have to be designed by the programmer so as to attain the desired results. The FIS program thus generated is to be fed to the FLC before scheduled with the simulation.

3.4.1 Fuzzy Logic Controller Design

The design of a Fuzzy Logic Controller requires the choice of Membership Functions. The membership functions should be chosen such that they cover the whole universe of discourse. It should be taken care that the membership functions overlap each other. This is done in order to avoid any kind of discontinuity with respect to the minor changes in the inputs. To achieve finer control, the membership functions near the zero region should be made narrow. Wider membership functions away from the zero regions provide faster response to the system. Hence, the membership functions should be adjusted accordingly. After the appropriate membership functions are chosen, a rule base should be created. It consists of a number of Fuzzy If-Then rules that completely define the behavior of the system. These rules very much resemble the human thought process, thereby providing artificial intelligence to the system. Fuzzy Sets and MFs for Input

3.4.1.1 Membership Function Design

Input Linguistic Variables

The inputs to the Fuzzy Logic Controller are:

1) Speed Error (e).
2) Change in Error (Δe) or derivative of speed error

3.4.1.2 Variable Speed Error (e)

Fuzzy set	**Range**	**Membership function**
Negative large (NL)	**-1.0 to -1.0** **-1.0 to -0.8**	triangular
Negative large medium (NLM)	**-1.0 to -0.8** **-0.8 to -0.6**	triangular
Negative medium (NM)	**-0.8 to -0.6** **-0.6 to -0.4**	triangular
Negative medium small (NMS)	**-0.6 to -0.4** **-0.4 to -0.2**	triangular
Negative small (NS)	**-0.4 to -0.2** **-0.2 to 0**	triangular
Zero (ZE)	**-0.2 to 0** **0 to 0.2**	triangular
Positive small	**0 to 0.2** **0.2 to 0.4**	triangular
Positive medium small	**0.2 to 0.4** **0.4 to 0.6**	triangular
Positive medium	**0.4 to 0.6** **0.6 to 0.8**	triangular
Positive large medium	**0.6 to 0.8** **0.8 to 1.0**	triangular
Positive large	**0.8 to 1.0** **1.0 to 1.0**	triangular

Table 3.1

3.4.1.3 Rule Base Design for the Output ( )

The Rule Base for deciding the output of the inference system consists of 49 If-Then rules in this case since there are 7 fuzzy sets in each of the inputs. The table representing the rule base is as follows:

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

Table 3.2

3.4.2 Fuzzy logic approach

This approach is widely used in machine control. The term fuzzy refers to the fact that logic involved can deal with concepts that can be partially true. Conceptually fuzzy controllers are very simple. They consist of input stage, processing stage and an output stage. The processing stage is based on a collection of logic rules of If-THEN statements.

e.g. If (temperature is “cold”) THEN (heater is “high”).

A typical architecture of a FLC is shown below:-

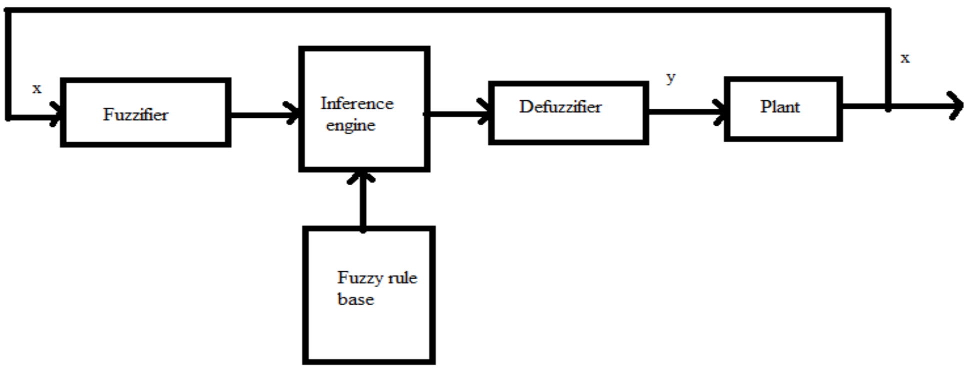


Fig- 3.4 Basic fuzzy technique

Fuzzifier: - the fuzzifier has the effect of the transforming measured crisp data into suitable linguistic values (i.e. fuzzy sets).

Fuzzy rule base: - it stores the empirical knowledge of the operation of the experts of the domain.

Inference engine: - it acts as kernel to FLC. It has capability to simulate human decision making by performing approximate reasoning to achieve a desired control strategy.

Deffuzzifier: - it is used to yield a non fuzzy decision or control action from an inferred fuzzy control action by the inference engine.

3.4.3 Input and output spaces

A proper choice of process state variables is essential for the characterization of the operation of fuzzy logic control system. Typically, the input variables in a FLC are the state, state error, state error integral and so on. After that the fuzzy partition of the input and output spaces are decided and membership function for the input and output linguistic is obtained. The FLC are usually parametric functions such as triangular functions and trapezoidal function

Example- considers an anti-lock braking system, directed by a microcontroller chip. This microcontroller has to make decisions based on brake temperature, speed and other variables in the system. The variable "temperature" in the system can be subdivided into a range of "states", "cold", "cool", "warm", "hot", "very hot". An arbitrary static threshold can be set to divide "warm" from "hot". E.g. at exactly 90 degrees, warm ends and hot begins. This will result in discontinuous change when the input value is passed over that threshold. The way around this is to make the states fuzzy in nature. We start defining the input temperature states using "membership functions"

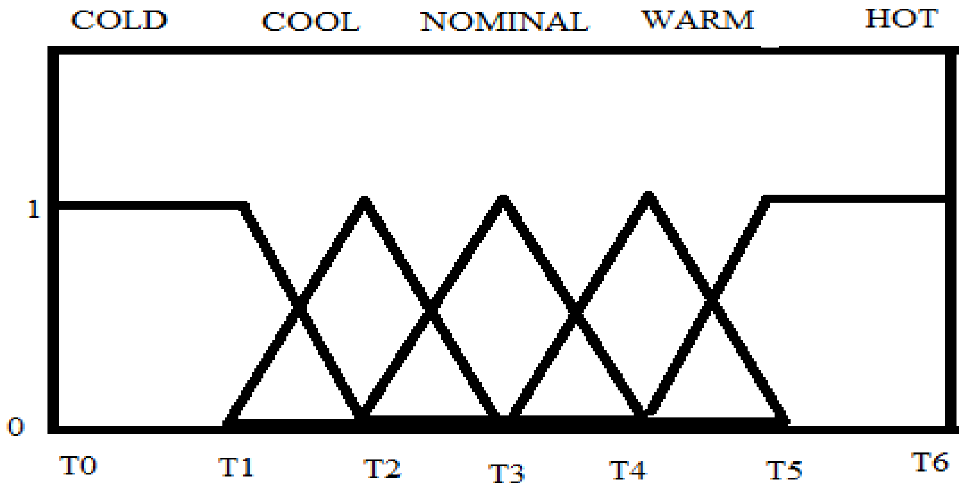


Fig 3.5 Membership function

The above example demonstrates a simple application, using the abstraction of values from multiple one. This only represents one kind of data. At any sampled timeframe the truth value of the temperature will almost always be in some degree part of two membership functions.

3.4.4 Design of the Fuzzy Logic Controller using MATLAB

While simulating the block diagram in MATLAB/SIMULINK®, the Fuzzy Logic Controller has to be programmed according to the aforementioned rules and knowledge base. The program is saved as an FIS file and it is later embedded into the Fuzzy Logic Controller. This FIS program can be checked with the help of FIS editor in MATLAB itself. The steps for the following are shown below, along with the membership functions, the rules and the surface plot viewed with the help of the FIS editor. eΔe

Step 1:

1. The program for scheming of the Fuzzy Logic Controller is written in a word file.
2. For all the shown membership functions definitions are written in the program.
3. The 49 rules shown in tabular form in are written in the program according to the syntax presented by MATLAB.
4. The document is saved with the extension .fis. All the 49 If- Then Rules of the Rule Base are as follows used for the design of the Fuzzy Logic Controller:

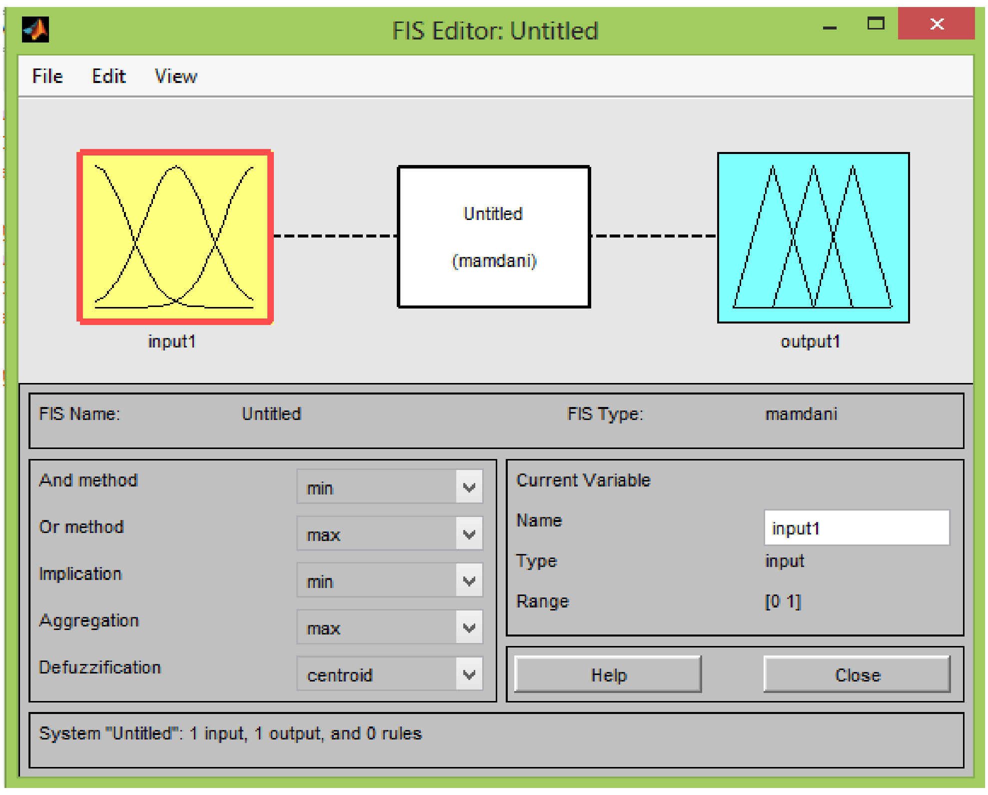
IF (Error IS NL) AND (ChangeInError IS NL) THEN (ChangeOfControl IS NL)
IF (Error IS NM) AND (ChangeInError IS NL) THEN (ChangeOfControl IS NL)
IF (Error IS NS) AND (ChangeInError IS NL) THEN (ChangeOfControl IS NLM)
IF (Error IS ZE) AND (ChangeInError IS NL) THEN (ChangeOfControl IS NM)
IF (Error IS PS) AND (ChangeInError IS NL) THEN (ChangeOfControl IS NMS)
IF (Error IS PM) AND (ChangeInError IS NL) THEN (ChangeOfControl IS NS)
IF (Error IS PL) AND (ChangeInError IS NL) THEN (ChangeOfControl IS ZE)
IF (Error IS NL) AND (ChangeInError IS NM) THEN (ChangeOfControl IS NL)
IF (Error IS NM) AND (ChangeInError IS NM) THEN (ChangeOfControl IS NLM)
IF (Error IS NS) AND (ChangeInError IS NM) THEN (ChangeOfControl IS NM)
IF (Error IS ZE) AND (ChangeInError IS NM) THEN (ChangeOfControl IS NMS)
IF (Error IS PS) AND (ChangeInError IS NM) THEN (ChangeOfControl IS NS)
IF (Error IS PM) AND (ChangeInError IS NM) THEN (ChangeOfControl IS ZE)
IF (Error IS PL) AND (ChangeInError IS NM) THEN (ChangeOfControl IS PS)
IF (Error IS NL) AND (ChangeInError IS NS) THEN (ChangeOfControl IS NLM)

IF (Error IS NM) AND (ChangeInError IS NS) THEN (ChangeOfControl IS NM)
IF (Error IS NS) AND (ChangeInError IS NS) THEN (ChangeOfControl IS NMS)
IF (Error IS ZE) AND (ChangeInError IS NS) THEN (ChangeOfControl IS NS)
IF (Error IS PS) AND (ChangeInError IS NS) THEN (ChangeOfControl IS ZE)
IF (Error IS PM) AND (ChangeInError IS NS) THEN (ChangeOfControl IS PS)
IF (Error IS PL) AND (ChangeInError IS NS) THEN (ChangeOfControl IS PMS)
IF (Error IS NL) AND (ChangeInError IS ZE) THEN (ChangeOfControl IS NM)
IF (Error IS NM) AND (ChangeInError IS ZE) THEN (ChangeOfControl IS NMS)
IF (Error IS NS) AND (ChangeInError IS ZE) THEN (ChangeOfControl IS NS)
IF (Error IS ZE) AND (ChangeInError IS ZE) THEN (ChangeOfControl IS ZE)
IF (Error IS PS) AND (ChangeInError IS ZE) THEN (ChangeOfControl IS PS)
IF (Error IS PM) AND (ChangeInError IS ZE) THEN (ChangeOfControl IS PMS)
IF (Error IS PL) AND (ChangeInError IS ZE) THEN (ChangeOfControl IS PM)
IF (Error IS NL) AND (ChangeInError IS PS) THEN (ChangeOfControl IS NMS)
IF (Error IS NM) AND (ChangeInError IS PS) THEN (ChangeOfControl IS NS)
IF (Error IS NS) AND (ChangeInError IS PS) THEN (ChangeOfControl IS ZE)
IF (Error IS ZE) AND (ChangeInError IS PS) THEN (ChangeOfControl IS PS)
IF (Error IS PS) AND (ChangeInError IS PS) THEN (ChangeOfControl IS PMS)
IF (Error IS PM) AND (ChangeInError IS PS) THEN (ChangeOfControl IS PM)
IF (Error IS PL) AND (ChangeInError IS PS) THEN (ChangeOfControl IS PLM)
IF (Error IS NL) AND (ChangeInError IS PM) THEN (ChangeOfControl IS NS)
IF (Error IS NM) AND (ChangeInError IS PM) THEN (ChangeOfControl IS ZE)
IF (Error IS NS) AND (ChangeInError IS PM) THEN (ChangeOfControl IS PS)
IF (Error IS ZE) AND (ChangeInError IS PM) THEN (ChangeOfControl IS PMS)
IF (Error IS PS) AND (ChangeInError IS PM) THEN (ChangeOfControl IS PM)
IF (Error IS PM) AND (ChangeInError IS PM) THEN (ChangeOfControl IS PLM)
IF (Error IS PL) AND (ChangeInError IS PM) THEN (ChangeOfControl IS PL)
IF (Error IS NL) AND (changeinError IS PL) THEN (ChangeOfControl IS ZE)
IF (Error IS NM) AND (ChangeInError IS PL) THEN (ChangeOfControl IS PS)
IF (Error IS NS) AND (ChangeInError IS PL) THEN (ChangeOfControl IS PMS)
IF (Error IS ZE) AND (ChangeInError IS PL) THEN (ChangeOfControl IS PM)
IF (Error IS PS) AND (ChangeInError IS PL) THEN (ChangeOfControl IS PLM)
IF (Error IS PM) AND (ChangeInError IS PL) THEN (ChangeOfControl IS PL)
IF (Error IS PL) AND (ChangeInError IS PL) THEN (ChangeOfControl IS PL)

Step 2:

The .fis file now is to be loaded in the FIS editor to view the membership functions, the rules and the rule surface plot.

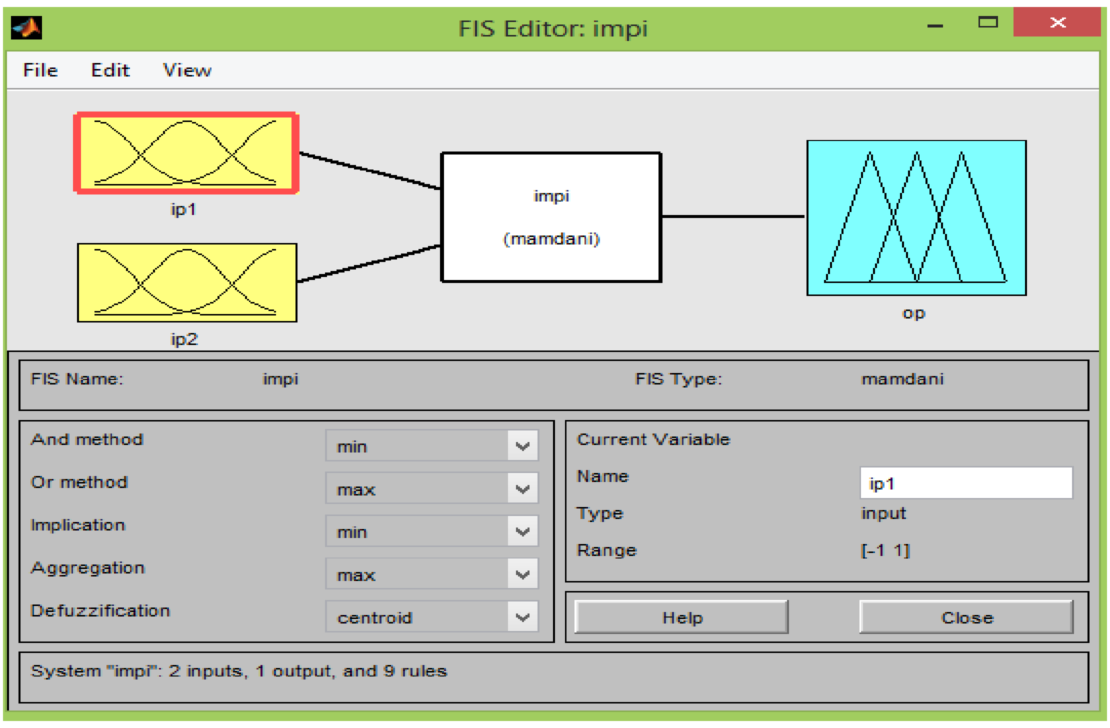
1. On the command window of MATLAB type fuzzy to open the FIS editor.



FIS Name: Untitled
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: input1
Type: input
Range: [0 1]
System "Untitled": 1 input, 1 output, and 0 rules

Fig 3.6 Fis editor

2. Click File > Import > From file and then browse the .fis file to open FIS editor: rules. The window will be opened as shown below where the input and output is shown and rules can be seen by clicking the specific block as per the need of the person.
3. 3. Click any of the input or output to view the respective membership functions. The membership functions for inputs Error and Change in Error and for output Change in Control are shown in Fig 3.6, Fig 3.7 and Fig 3.8 respectively.



FIS Name: impi

FIS Type: mamdani

And method: min

Or method: max

Implication: min

Aggregation: max

Defuzzification: centroid

Current Variable

Name: ip1

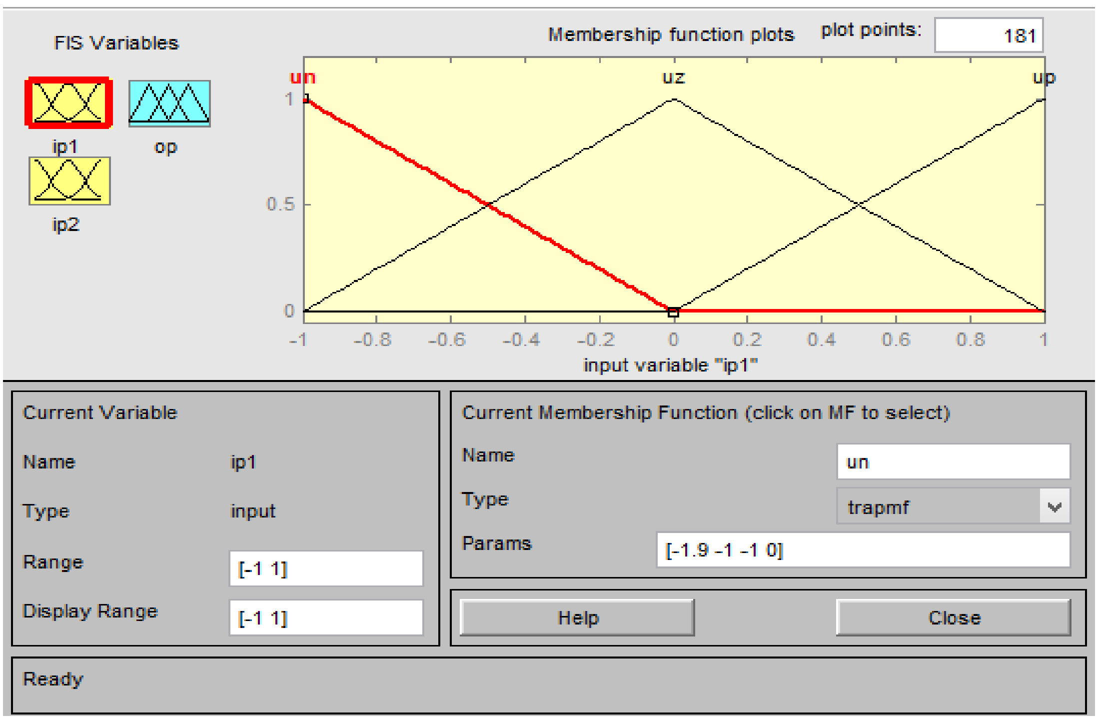
Type: input

Range: [-1 1]

System "impi": 2 inputs, 1 output, and 9 rules

Fig 3.7 impi

4. In the FIS editor: rules window click on View > Surface to view the three dimensional plot of the control surface. This plot is shown in Fig 3.8.
5. Then in the FIS editor: rules window click on View > Rules to see the rules. The inputs can be changed in the window and respective outputs can be viewed.



plot points: 181

Current Variable

Name: ip1

Type: input

Range: [-1 1]

Display Range: [-1 1]

Current Membership Function (click on MF to select)

Name: un

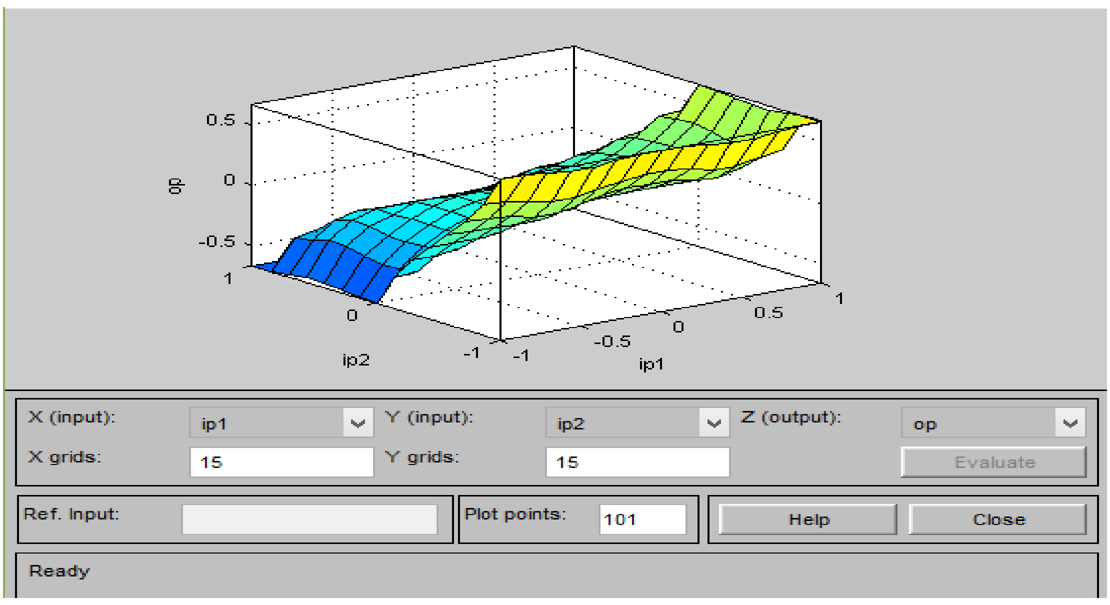
Type: trapmf

Params: [-1.9 -1 -1 0]

Ready

Fig 3.8 Membership function plot

After this we can see the surface of the three area plot of the controller as shown below



X (input): ip1

Y (input): ip2

Z (output): op

X grids: 15

Y grids: 15

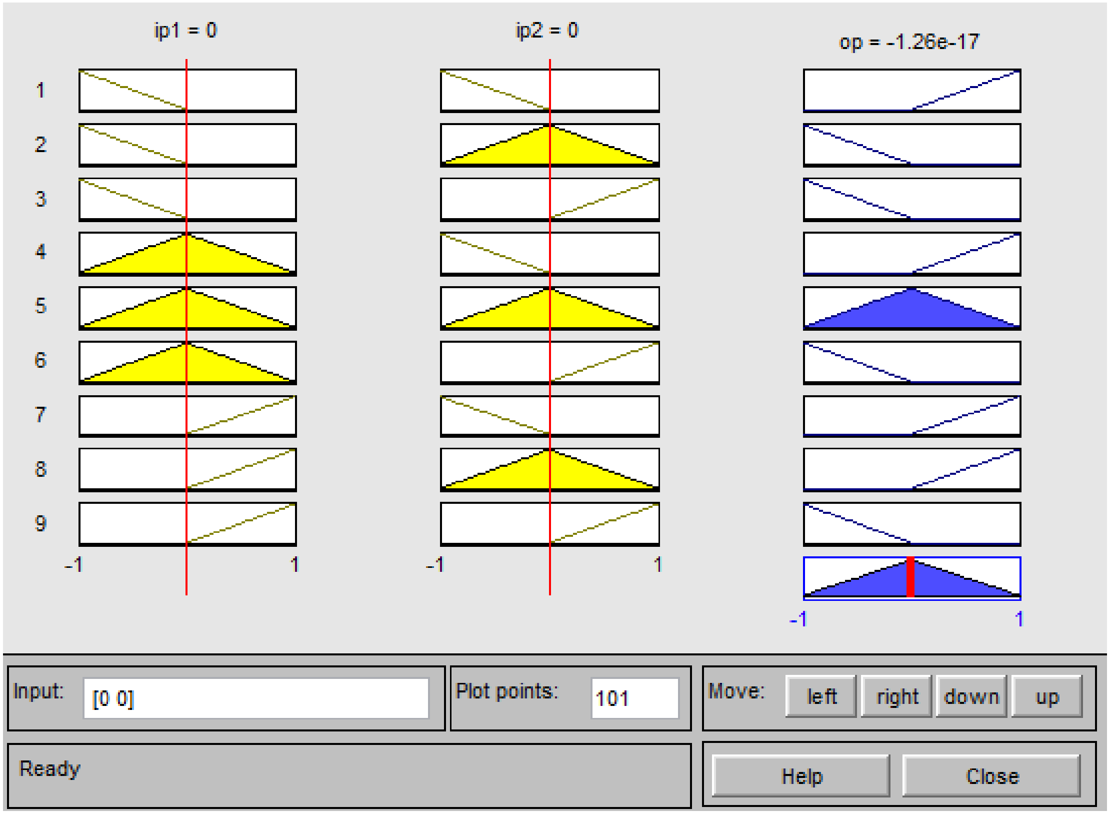
Ref. Input:

Plot points: 101

Ready

Fig 3.9 surface view of three dimension model

The Fuzzy Logic Controller is thus designed and using the rule viewer the outputs are verified. Hence designing of the Fuzzy Logic Controller is now complete. This FIS file can currently be loaded into the Fuzzy Logic Controller in the MATLAB/SIMULINK® and the simulation can be run. The controller can be refined accordingly to get the needed result throughout the simulation. Hence, we find that designing a Fuzzy Logic Controller using the Mamdani Fuzzy Model is fairly expedient and does not require any weighty procedures.



ip1 = 0

ip2 = 0

op = -1.26e-17

Input: [0 0]

Plot points: 101

Ready

Fig 3.10 Input and output

The fig below shows the fuzzy based vector control of induction motor using Matlab/simulink. The fuzzy logic controller is designed as mentioned above and then with the help of PI controllers it is adjusted with the vector controller to get the desired output.

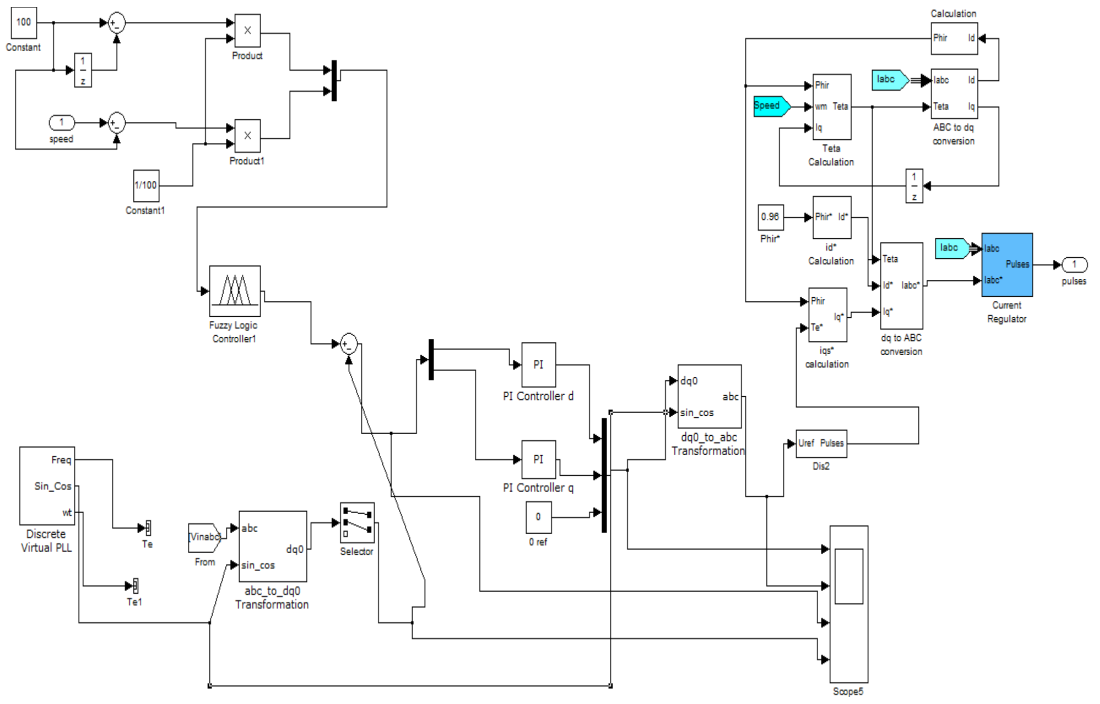


Fig 3.11Fuzzy logic based vector control of induction motor

After this the simulation is done in MATLAB and resuts are compared as desired.

Chapter 4

Results and Discussion

The response of the controller is examined by means of MATLAB/SIMULINK, fuzzy logic and simpower system toolbox. Numerical simulations have been conceded out to evaluate the effectiveness of the intended fuzzy logic basedvector control. It’s made using Matlab/Simulink. The induction machine that utilized in the simulation works, have the parameters given in Table 4.1

In the above model squirrel cage induction motor used is of ratings

Frequency	50Hz
voltage (L-L)	460 v
Rotor resistance	0.87 pu
Stator resistance	0.228 pu
Rotor inductance	0.8e-3 pu
Stator inductance	0.8e-3 pu
Inertia	1.662
No. of pole pairs	2

Table 4.1 In the above model squirrel cage induction motor of ratings

IGBT inverter with source of 780v is connected to the induction motor Some tests have been carried out to compare the performances of the proposed fuzzy logic based vector control method with conventional vector control method. In order to fair compare the performances with the vector control and the proposed FLC based vector control on induction motor drive, different speed and load range applied to the induction motor. The dynamic performances of the methods are performed by applying step change on load. In first step of the simulation studies, the induction motor has been tested at rated. The simulation results of speed and torque responses at 1000 rpm reference are shown in Figure 4.3, 4.4, 4.5 and 4.6 respectively.

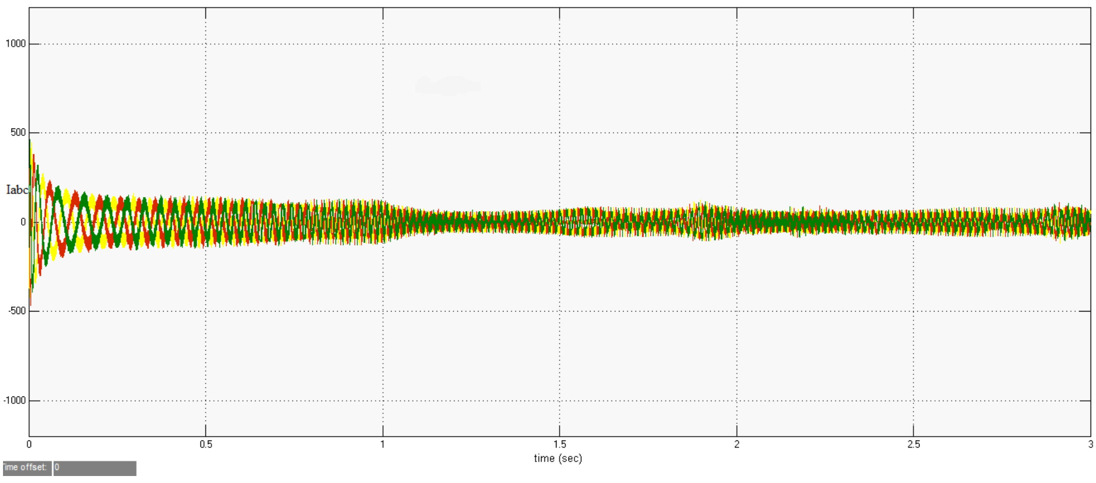


Fig 4.1 graph for Rotor current in case of vector control

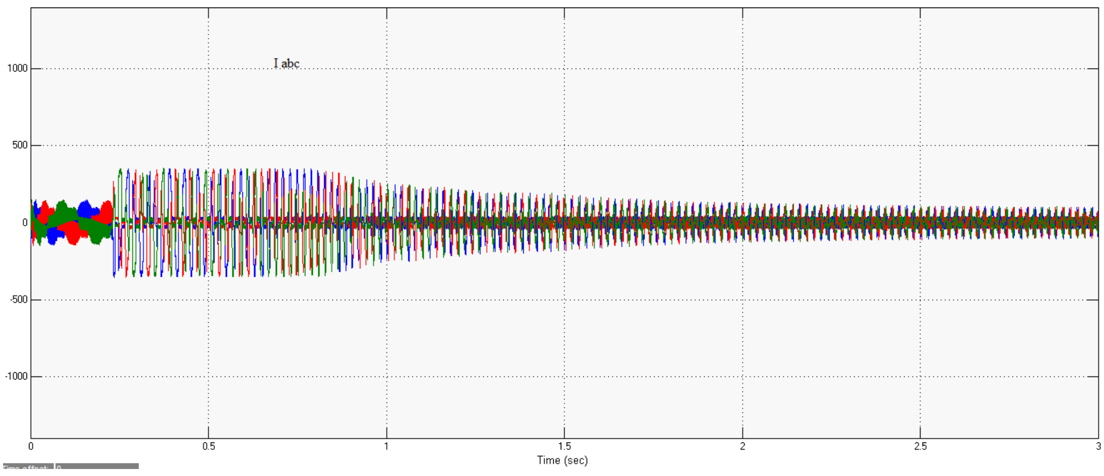


Fig 4.2 Rotor current varying with time for FLC based vector control

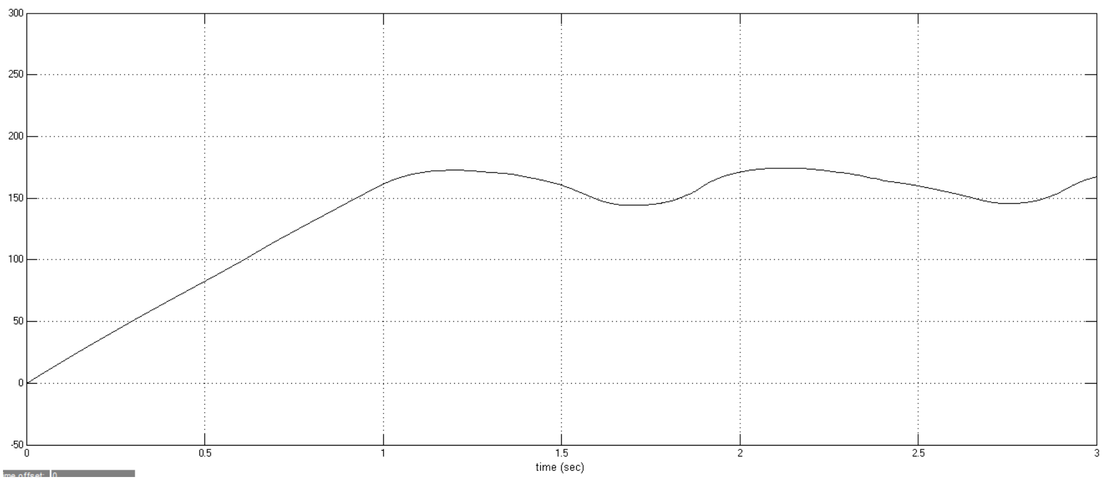


Fig 4.3 Speed V/s time graph for conventional control

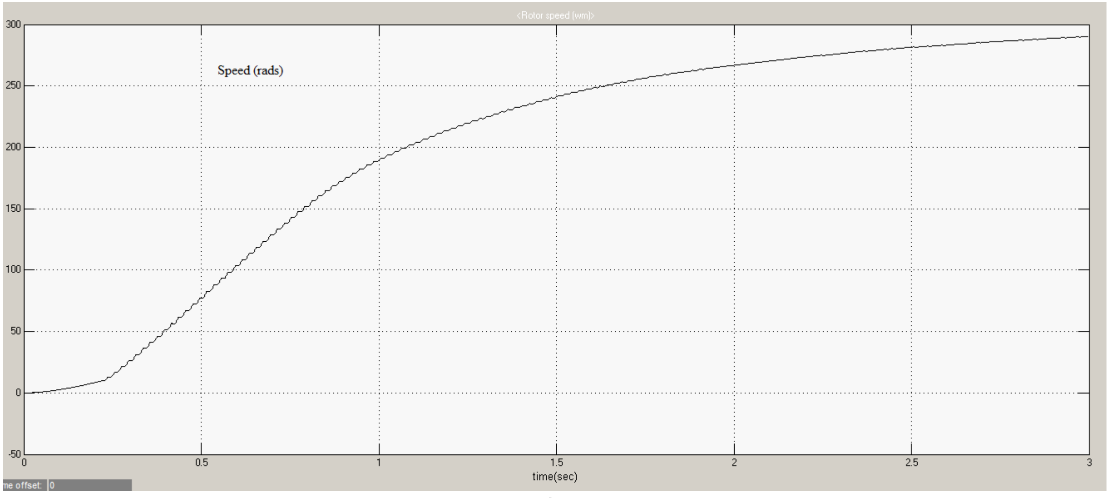


Fig 4.4 Speed V./s time for FLC based FOC

According to the speed curve which given in Figure 4.4, the motor has reached the reference speed at about 1 sec. for both control method. So, it can be said that there are no difference between vector control and FLC based vector control speed rising times but the motor has almost different performance at transient conditions for vector control method FLC based controller. It means, proposed FLC control method has fast transient conditions performance.

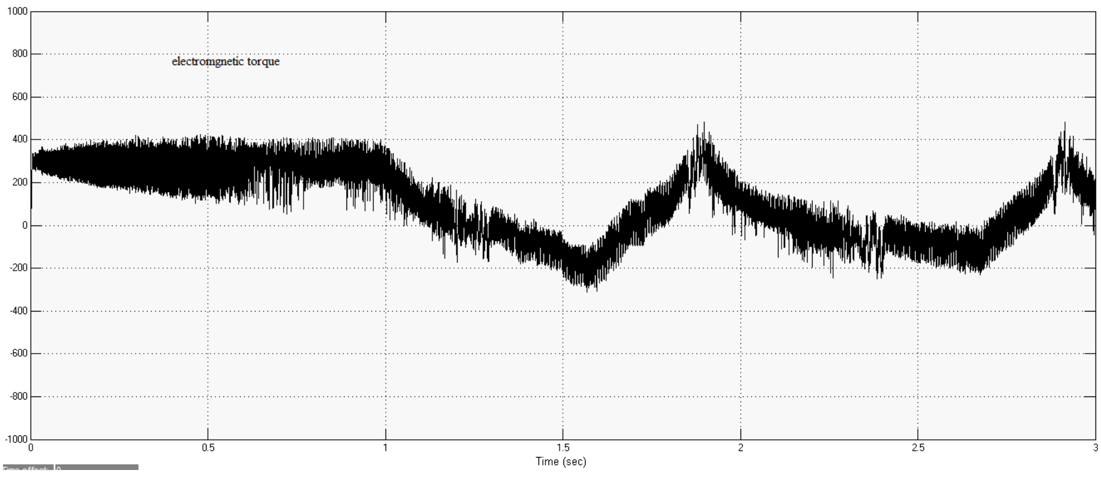


Fig 4.5 Torque V/s time for vector control

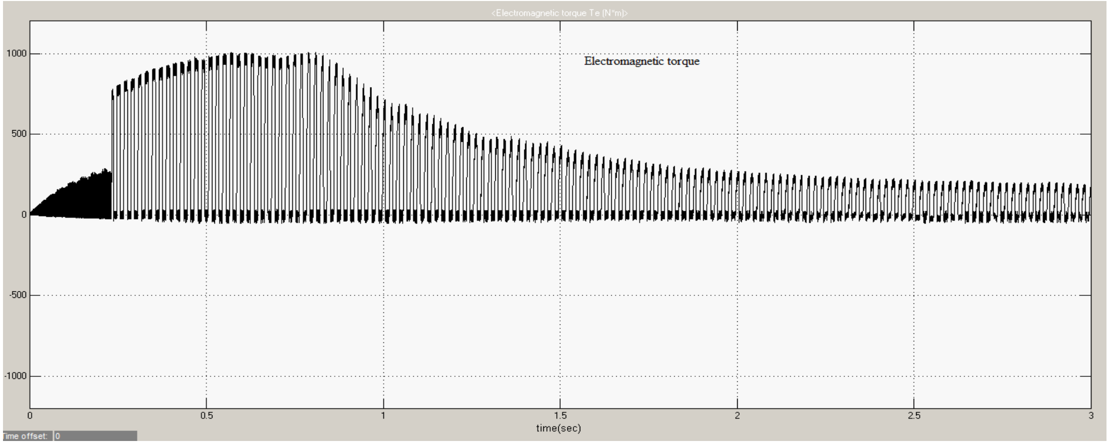


Fig 4.6 Torque V/s time graph for FLC based FOC

However, the main differences have appeared at torque responses of both control methods at steady state conditions. It can be seen that, with fuzzy logic controller based FOC the immediate speed fluctuations and torque ripples of the motor are condensed significantly.

CONCLUSIONS

In this paper, an innovative fuzzy logic based vector technique has been proposed for the induction motor drivers and the simulation studies have been carried out with Matlab/Simulink to evaluate the proposed system conducts at vary load and speed conditions.

1. In the study, the induction motor has been tested for low speed (250 rpm reference).
2. The numerical simulations verify that torque and speed responses of the motor are considerably improved with the proposed technique for both working conditions.
3. The torque ripples of the motor are lesser, in parallel, the speed fluctuations are abridged according to conventional direct torque control technique.

FUTURE SCOPE

The simulated results confirmed the viability of the model used in this work and it has been shown that the model is suitable for transient as well as steady state condition. These results also confirmed that the transient torque and current never exceed the maximum permissible value. Among all the speed controllers discussed, Fuzzy Logic Controller makes the system robust as there is no speed overshoot and also minimum pulsation in torque and current The implementation of additional control techniques like unity power factor control, constant mutual air gap flux linkages control, optimum torque per ampere control and sensorless control can be taken up for detailed simulation and performance calculation of PMSM drive systems. Detailed modeling and simulation of types of synchronous motor drives can also be taken up for transient and steady state analysis.

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