CHAPTER TWO

LITERATURE OVERVIEW

2.1 Introduction

The induction motor finds its place amongst more than 85% of industrial motors as well as in its single-phase form in various domestic usages. Markedly a constant-speed motor with shunt characteristic, speed drops only by a few percent from no-load to full load. Hence in the past, induction motors have been used primarily in constant speed applications. Traditional methodologies employing speed control have either been high-priced or very inefficient, unlike the dc motor. Nonetheless, the presence of Commutator and brushes in the latter, which require recurrent maintenance make dc motor drives improper for use in hazardous and polluted environments. On the other hand, owing to the simple, rugged, cheaper, smaller and subsequently lighter build of induction motor drives (particularly squirrel-cage type); they are designed for fans, blowers, cranes, traction, conveyers, etc. in spite of finding stiff competition from dc drives for such applications [9].

2.2 Construction and Operation

In general, three phase AC machines have stator and rotor. The stator is usually made of laminated sheet steel (to reduce eddy current loses) which is attached to an iron frame. This stator consists of mechanical slots of high aspect ratio (height to width ratios) to bury the insulated copper conductors inside the stator structure, and then the stator conductors are connected in three phase delta or star configurations[9].

The wire wound rotor contains three electrical phases just as the stator does and they (coils) are connected star or delta. The electrical terminals are connected to the slip rings. Unlike the wire wounded, the squirrel-cage's rotor contains bars of aluminum or copper imbedded in the rotor, which are short circuited at the end of each bar by an end disc thereby placing all rotor wires in parallel and placed equally spaced around the Rotor circumference. The wire wound rotor and squirrel-cage rotor are each shown in Fig.2.1 for comparison [9].

Under normal operation, an induction motor runs at a speed which is lower than the synchronous speed, so that a time changing magnetic field is created to couple stator and rotor windings. At start up this time varying magnetic field is maximized geometrically, but at near synchronous speed the time derivative is reduced [9].Therefore operating the motor at a rotor speed which is close to the synchronous speed of the stator magnetic field makes the motor self-limit according to the difference of the motor and load torques. The synchronous motor speed is directly proportional to the input AC line frequency driving the stator fields and inversely proportional with the number of magnetic poles, created in the stator by the choice of stator winding coil positions [9].

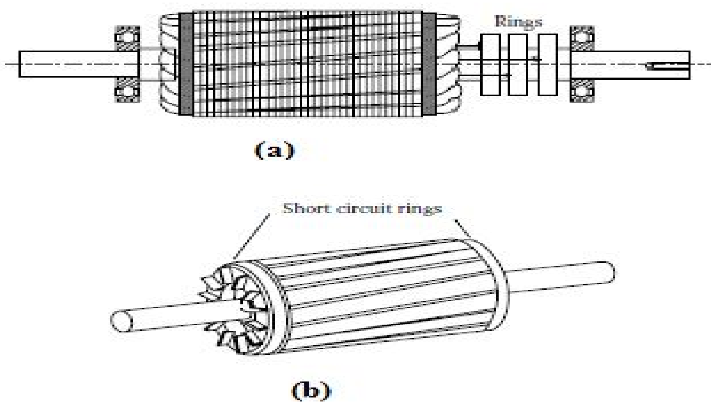

Fig.2.1 Induction motor rotor types (a) Wounded rotor (b) Squirrel-Cage rotor.

2.2.1 Principle of rotating magnetic field

When energizing the three phase stator from a three phase supply, a rotating magnetic field sets up round the stator which rotates at synchronous speed. This field passes through the air-gap and cuts the stationary rotor conductors. Owing to the relative speed between the rotating flux and the static rotor, electromotive forces are induced in the rotor conductors. For the reason that the rotor circuit is short-circuited, currents start flowing in the rotor conductors. Again, these conductors are placed in the magnetic field produced by the stator. As a result, mechanical force acts on the rotor conductors [9].

A torque, produced as a result of this force, tends to move the rotor in the same direction as the rotating field. This is justified by Lenz's law, according to which the direction of rotor currents will be such that they have a tendency to oppose the cause producing them. Now, the relative speed between the rotating field and the standstill rotor conductors is the cause generating the rotor currents. Thus to reduce this speed, the rotor starts running in the same direction as that of stator field and tries to catch it. Clearly, the rotor speed is always less than the stator field speed [9].

2.3 Speed Control of Induction Motors

The speed control of induction motors involves more complicacy than the control of dc motor, especially if comparable accuracy is desired. The main reason for the same can be attributed to the complexity of the mathematical model of the induction machine, as well as the complicated power converters supplying this motor.

Variable speed induction motor drives employ various control algorithms [9].

The process control benefits that may be provided by an adjustable speed drive are as follows [9]

- Smoother operation.
- Acceleration control as an added incentive.
- Varying operating speed for each process.
- Compensates for fluctuating process parameters.
- Permits slow operation for setup purpose.
- Allows accurate positioning.
- Provides torque control.

2.3.1Speed Control Techniques

Mathematically, the relation between the speed of an induction motor and the synchronous speed (i.e., the speed at which the revolving flux rotates) can be stated as [9]

$$n = (1 - s)n_s \tag{2.1}$$

$$n_s = \frac{120f}{p} \tag{2.2}$$

The torque produced by three phase induction motor is given by

$$T = \frac{3}{2\pi N_S} X \frac{sE_2^2R_2}{R_2^2+X_2^2} \tag{2.3}$$

Where:

E_2 is the rotor EMF

N_s is the synchronous speed

R_2 is the rotator resistance

X_2 is the rotor inductive reactance

This implies that there are two basic ways of speed control [9]:

1. Slip-control for fixed synchronous speed.
2. Control of synchronous speed

To control the induction motor there are different types of control [10]

- Variable supply voltage control
- Variable rotor resistance control
- Constant Volts/Hz control (scalar control)
- Vector Control
- Direct torque control

2.3.2 Variable rotor resistance control

In this method of speed control a resistances can be connected in the rotor circuit externally during starting. At starting slip s =1, this increases the starting torque and reduces the starting current. The maximum torque during starting can be achieved by using appropriate value of resistors. Once the motor is started acceleration, the resistance can be connect externally should be cut out to obtain high torque throughout the accelerating range. As external resistances are connected, most of the I^2Rloss is dissipated through them thus the rotor temperature rise during starting is limited. This method can be used in applications requiring high starting torque. This method is used only for wound motor; an external resistance is added to it through slip rings [10,11]

2.3.3 Variable Stator Voltage

The developed torque of an induction motor is proportional to square of the supply voltage to its stator terminals, by varying the supply voltage; the electromagnetic torque developed by the motor can also be varied. The value of maximum torque also decreases, with decrease in supply voltage. But it still occurs at the same slip as earlier. This method is generally used for small rating cage type motors where cost is an important factor. However, this method has rather limited range of speed control [11] .

2.3.4 Scalar control

Scalar control as the name indicates, is due to magnitude variation of the control variable only, and disregards the coupling effect in machine. For example, the voltage of machine can be controlled to control the flux, and frequency or slip can be controlled to control the torque. However flux and torque are also function of voltage and frequency respectively. A scalar controlled drive gives somewhat inferior performance. Scalar control is easy to implement. Scalar controlled drives have been widely used in industry, but the inherent coupling effect (both torque and flux are function of voltage or current and frequency) gives sluggish response and system is easily prone to instability because of higher order (fifth order) system effect. To make it clearer, if torque is increased by incrementing the slip (the frequency), the flux tends to decrease .it has been noted that the flux variation is also sluggish [12].

Decreases in flux then compensated by the sluggish flux control loop feeding an additional voltage, this temporary dipping of flux reduces the torque sensitivity with slip and lengthens the response time. However, their importance has diminished recently because of the superior performance of vector or Field orientated control (FOC) drives. To improve speed control performance of the scalar control method, an encoder or speed tachometer is required to feedback the rotor angle or rotor speed signal and compensate the slip frequency. However, it is expensive and destroys the mechanical robustness of the induction motor. So these are the limitation of scalar control which is overcome by Field orientated control (FOC) for induction motor drive [13].

2.3.5 Vector Control or Field Orientated Control (FOC)

Blaschke in 1972[14] has introduced the principle of field orientation to realize dc motor characteristics in an induction motor drive. For the same, he has used decoupled control of torque and flux in the motor and gives its name trans vector control [14].

In DC machine the field flux is perpendicular to the armature flux. Being orthogonal, these two fluxes produce no net interaction on one another. Adjusting the field current can therefore control the DC machine flux, and the torque can be controlled independently of flux by adjusting the armature current [14].

An AC machine is not so simple because of the interactions between the stator and the rotor fields, whose orientations are not held at 90 degrees but vary with the operating conditions. We can obtain DC machine-like performance in holding a fixed and orthogonal orientation between the field and armature fields in an AC machine by orienting the stator current with respect to the rotor flux so as to attain independently controlled flux and torque. Such a control scheme is called flux-oriented control or vector control. Vector control is applicable to both induction and synchronous motors [14].

The cage induction motor drive with vector or field oriented control offers a high level of dynamics performance and the closed-loop control associated with this derive provides the long term stability of the system. Induction Motor drives are used in a multitude of industrial and process control applications requiring high performances. In high-performance drive systems, the motor speed should closely follow a specified reference trajectory regardless of any load disturbances, parameter variations, and model uncertainties. In order to achieve high performance, field-oriented control of induction motor (IM) drive is employed. However, the controller design of such a system plays a crucial role in system performance. The decoupling characteristics of vector-controlled IM are adversely affected by the parameter changes in the motor [14].

So the vector control is also known as an independent or decoupled control [15]. There are two methods of vector control

(I) Direct or feedback method

In direct vector control method, directly measures the rotor flux & using that flux to determine the transformation angle. This method also called as open loop vectorcontrol. Direct measurement of flux is physically difficult, so estimated value offlux is calculated using stator voltages & currents value. At higher speed, valueof estimated flux may be reliable but at lower speed, this is subjected to errorsfrom harmonics. The direct method of vector control attempts to directly measureor estimate the machine flux, and use this to determine the transformation angle. While direct flux measurements are difficult physically, an estimate value of fluxis calculated using the stator voltages and currents equations. At the higher speed ranges, the flux estimate may be reliably estimated from the integral of the stator voltage. However, this method is subject to errors from harmonics, and is not useful at lower speeds [16].

Due to the difficulty in reliably obtaining an estimate of the rotor flux direction, the direct method of vector control is not commonly used. Instead, the indirect method has gained popularity [16].

(II)Indirect or feed forward method

This method does not depend on the measurement of air-gap magnetic flux, Torque can be controlled by either changing or the slip speed ($\omega e - \omega r$) [17].

The algorithm of indirect vector control is given as

1. The induction motor is fed by a variable frequency, variable voltage PWM IGBT inverter, which operates in current control mode. The motor speed is compared with the reference speed and the error is produced which is fed to the speed controller. The output of speed controller is electromagnetic torque [17].

2. Thequadrature-axis stator current reference i_{qs}^{*} is calculated from electromagnetic torque reference Te* as [17]

$$i_{qs}^{*} = (2/3) * (2/P) + (L_r/L_m) + (T_e^{*} / \widetilde{\psi_r}) \quad (2.4)$$

Where $\widetilde{\psi_r}$ is the estimated value of rotor flux linkage given by

$$\widetilde{\psi_r} = L_m * I_{ds} / (1 + \tau_r) \quad (2.5)$$

Where,$\tau_r = \frac{L_r}{R_r}$ is the rotor time Constant.

3. The direct-axis stator current reference is obtained from reference rotor flux input$|\psi_r|^*$ [17].

$$i_{ds}^{*} = \frac{|\psi_r|^*}{L_m} \quad (2.6)$$

4. The rotor flux position θ_e required for coordinates transformation is obtained from the rotor speedω_r and slip frequencyω_{sl}.

e is calculated as [17]

$$\theta_e = \int \omega_e \, dt = \int (\omega_r + \omega_{sl}) = \theta_r + \theta_{sl} \quad (2.7)$$

5. The slip frequency is calculated from the stator reference current and the motor parameters. Is given by [17]

$$\omega_{sl} = \frac{L_m R_r}{\psi_r L_r} i_{qs} \quad (2.8)$$

6. The i_{qs}^{*} , i_{ds}^{*} current references are converted into phase current references i_a^*, i_b^*, i_c^*using inverse park transform (two phase to three phase conversion) and fed to the current controller.

The controller processes the measured andreference currents to produce the inverter gating signals [17].

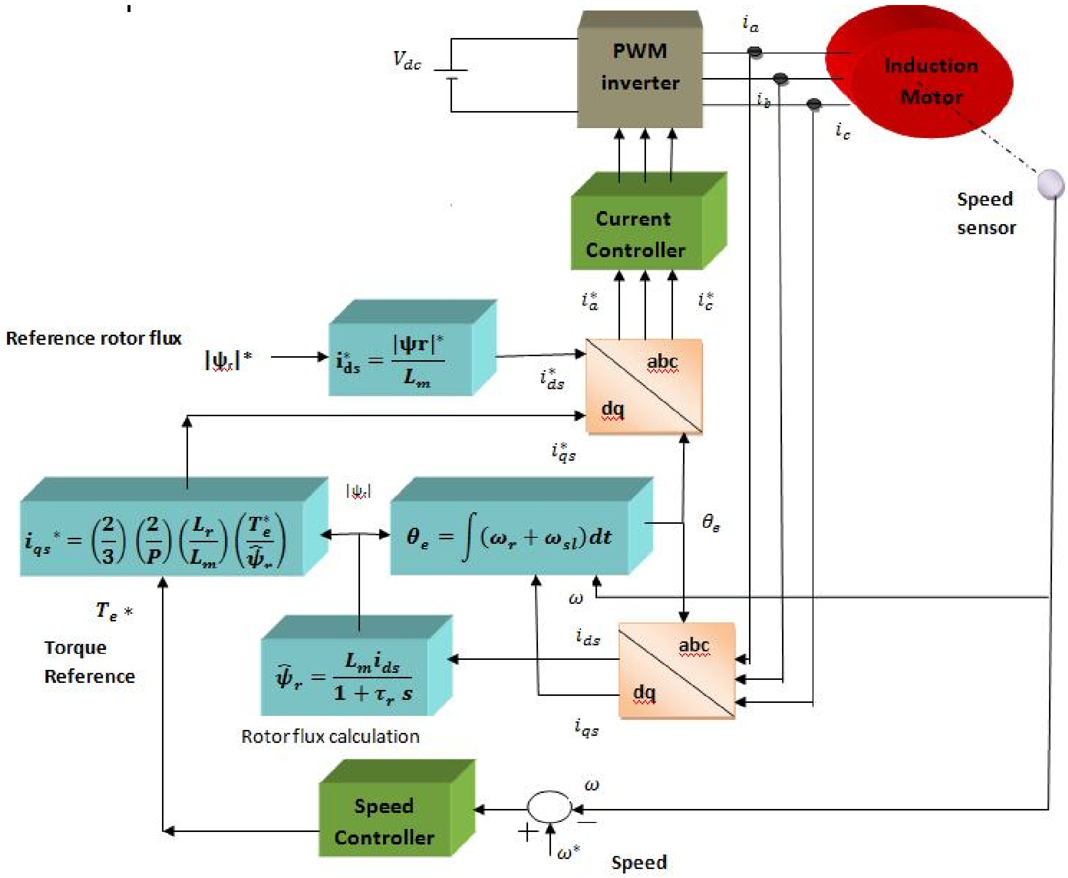

Fig 2.2 complete diagram of indirect vector control induction motor

2.3.6 Proportional – Integral (PI) control

In this research complete mathematical model of FOC induction motor is described and simulated in MATLAB for studies a 10 HP induction motor has been considered .The performance of FOC drive with proportional plus integral (PI) controller are presented and analyzed [18].

Control law used for this strategy is given by [18]

$$T = K_i e + k_p \int e \, dt \tag{2.9}$$

Its output is the updating in PI controller gains ($K_p \& K_i$) based on a set of rules to maintain excellent control performance even in the presence of parameter variation and drive nonlinearity [18].

The use of PI controllers for speed control of induction machine drives is characterized by an overshoot during tracking mode and a poor load disturbance rejection. This is mainly caused by the fact that the complexity of the system does not allow the gains of the PI controller to exceed a certain low value [18].

At starting mode the high value of the error is amplified across the PI controller provoking high variations in the command torque. If the gains of the controller exceed a certain value, the variations in the command torque become too high and will destabilize the system [18].

To overcome this problem we propose the use of a limiter ahead of the PI controller [19].

This limiter causes the speed error to be maintained within the saturation limits provoking, when appropriately chosen, smooth variations in the command torque even when the PI controller gains are very high. The motor reaches the reference speed rapidly and without overshoot, step commands are tracked with almost zero steady state error and no overshoot, load disturbances are rapidly rejected and variations of some of the motor parameters are fairly well dealt with [20].

2.3.7 Fuzzy Logic Control

Due to continuously developing automation systems and more demanding small Control performance requirements, conventional control methods are not always adequate. On the other hand, practical control problems are usually imprecise.

The input output relations of the system may be uncertain and they can be changed by unknown external disturbances. New schemes are needed to solve such problems.

One such an approach is to utilize fuzzy control, since the introduction of the theory of fuzzy sets by L. A. Zadeh in 1965[21], and the industrial application of the first fuzzy controller by E.H. Mamadani in 1974[21]; fuzzy systems have obtained a major role in engineering systems and consumer's products in 1980s and 1990s.

New applications are presented continuously. A reason for this significant role is that fuzzy computing provides a flexible and powerful alternative to contract controllers, supervisory blocks, computing units and compensation systems in different application areas [21]. With fuzzy sets nonlinear control actions can be performed easily.

One of the reasons for the popularity of Fuzzy Logic Controllers is its logical resemblance to a human operator. It operates on the foundations of a knowledge base which in turn rely upon the various if then rules, similar to a human operator [22].

Unlike other control strategies, this is simpler as there is no complex mathematical knowledge required. The FLC requires only a qualitative knowledge of the system thereby making the controller not only easy to use, but also easy to design [22].

2.3.8 Components of FLC

The inputs to a Fuzzy Logic Controller are the processed with the help of linguistic variables which in turn are defined with the aid of membership functions [23].

The membership functions are chosen in such a manner that they cover the whole of the universe of discourse. To avoid any discontinuity with respect to minor changes in the inputs, the adjacent fuzzy sets must overlap each other , Because of a small time constant in Fuzzy Logic Controllers, this criterion is very important in the design of the same [23].

There are basically three essential segments in Fuzzy Logic Controller, shown in figure 2.3 [23]

1. Fuzzification block or Fuzzifier.
2. Inference System.
3. Defuzzification block or Defuzzufier.

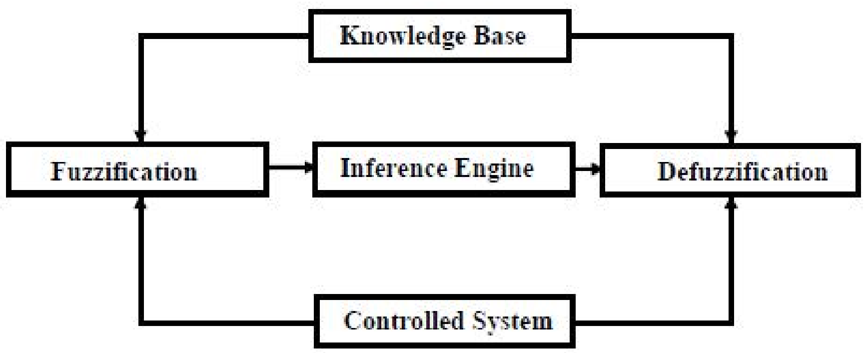

Fig.2.3 Fuzzy Logic Controller Structure

(1)Fuzzification Block or Fuzzifier

The first step towards designing a Fuzzy Logic Controller is choosing appropriate inputs which will be fed to the same. These input variables should be such that, they represent the dynamical system completely. Then the function of the Fuzzifier comes into picture. As discussed before, instead of using numerical variables, fuzzy logic uses linguistic variables for processing information. But since the inputs to the FLC are in the form of numerical variables (or in other words, crisp sets), they need to be converted into linguistic variables. This function of converting these crisp sets into fuzzy sets (linguistic variables) is performed by the Fuzzifier [23].

The fuzzification technique involves outlining the membership functions for the inputs. These membership functions should cover the whole universe of discourse and each one represents a fuzzy set or a linguistic variable [23].

The crisp inputs are thus transformed into fuzzy sets. Triangular MF, Trapezoidal MF, Bell MF, Generalized Bell MF or Sigmoidal MF [23] can be used. Even a hybrid of any of the above Membership Functions can be used for fuzzification [23].

(2)Inference System

The inference system of a Fuzzy Logic Controller consists of the following [23]

(I). Rule Base

It consists of a number of If-Then rules. The if side of the rule is called the antecedent and the Then side is called the consequence. These rules are very much similar to the Human thought process and the computer uses the linguistic variables, derived after fuzzification for execution of the rules. They very simple to understand and write and hence the programming for the fuzzy logic controller becomes very simple. The control strategy is stored in more or less the normal language [23].

(II). Database

It consists of the all the defined membership functions that are to be used by the rules [23].

(III). Reasoning Mechanism

It performs the inference procedure on the rules and the data given to provide a reasonable output. It is basically the codes of the software which are process the rules and the all the knowledge based on a particular situation. It exercises a human brain type of attribute to methodically carry out the inference steps for processing the information [23].

(3)Defuzzification Block or Defuzzifier

A defuzzifier performs the exact opposite function of a fuzzifier. It transforms the fuzzy variables (which are obtained as output after processing 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 other systems. Even though the fuzzy sets resemble the human thought process, their functionality is limited only to the above processes [23].

A defuzzifier is generally required only when the Mamdani Fuzzy Model is used for designing a controller. There are other types of architectures that can be used like [23]

- Tagaki-Sugeno Fuzzy Model.

In Takagi-Sugeno, method of fuzzy inference the first two parts of the fuzzy inference process (i.e. fuzzifying the inputs and applying the fuzzy operator) are exactly the same as Mamdani method. The main difference between Mamdani and Sugeno is that the Sugeno output membership functions are either linear or constant. A typical rule in a Sugeno fuzzy model has the form if Input 1 (e) is zero and Input 2 (Δe) is zero,Then Output is $z = a *e + b * (\Delta e) + c$. [23]

Where a, b and c are all constants [23].

Mamdani model is preferred here because it follows the Compositional Rule of Inference, strictly in its fuzzy reasoning mechanism. Unlike the Mamdani model, the outputs are defined with the help of a specific function for the other two models (first order polynomial in the input variables) and hence the output is crisp instead of fuzzy. This is counterintuitive since a fuzzy model should be able to propagate the fuzziness from inputs to outputs in an appropriate manner [23].

There are five basic defuzzification strategies and, the most wide used technique is the Centre of Area (COA) method [23].

Centroid of Area (COA): It is one of the most popular techniques used for defuzzification, as it is reminiscent of the calculation of expected values of probability distributions. It can be defined as follows [23]

$$\Delta T = \frac{\sum_{i=1}^{n} \Delta T_i \mu_A(T_i)}{\sum_{i=1}^{n} \mu_A(\Delta T_i)} \tag{2.10}$$

Where:

n :Number of discrete elements

T_i: Value of discrete elements

$\mu_A(T_i)$: The corresponding MF Value at The point T_i

The MATAB program shown in Appendix A .

2.3.9 Direct torque control

The basic concept of the Direct Torque Control (DTC) method was proposed by Takahashi and Noguchi in 1986[24]. This method is more used in controlling the induction motor, because it is considered a simple and robust method [24].

The power inverter operational control is an important key in this method and modern power electronics has made this cost effective as well [24].

The simple objective is to control two quantities which are the stator flux vector and the electromagnetic torque, those quantities are directly controlled by selecting the proper inverter state with a combination of sense, command and control feedback loops and by power electronics drive control in the inverter stage. High dynamic performance can be achieved by the stator flux because the latter is close to being sinusoidal [24].

The magnitude of the stator flux and the developed electromagnetic torque can be adjusted by selecting the state of the inverter of space vectors of the stator voltage [24, 25].