CHAPTER 1

INTRODUCTION AND REVIEW OF PREVIOUS WORK

1.1 GENERAL

The induction motor is very popular and extensively used in many industries because of its many attractive features. The main advantage is that induction motor does not require any electrical connection between stationary and rotating parts of the motor for its operation. Therefore, it does not require any mechanical commutator and brushes, leading to the fact that it is a maintenance free motor. The induction motor has relatively less weight and inertia, high efficiency, and high overload capability. Therefore, it is cheaper, more robust and has less chance of any failure at high speeds. Furthermore, this motor can be used in an explosive environment, because no sparks will be produced. Taking all the advantages into account, the induction motor is considered as a perfect electrical to mechanical energy converter.

These factors led to its very widespread adoption as the main source of drive in most of the industries. The Induction Motors consume the largest amount of electrical energy in industrial sector due to its well-known beneficial attributes including mechanical rigidity, consistent performance, low cost, maintenance free operation. It is extensively used in wide range of applications, such as pumping of fluids, fans, compressed air systems, conveyors, transportation, elevators, home appliances and office equipment in
both industries as well as in commercial sectors. Pumping schemes consume for nearly 20% of the world's electrical energy demand and range from 25-50% of the energy usage in certain industrial applications. The influence of these motors (regarding energy consumption) in energy intensive industries is significant in total input cost.

Electric motor-driven systems consume around 70% of the electricity used in industries and hence, even a small increment in the efficiency by providing better control, or optimum design can result in a substantial saving in the long period.

The efficient and effective operation of the electric motor is possible by having a suitable drive system, which is matched to the operational characteristic of the motor. The only effective way of producing adjustable speed drive system is supplying induction motor with variable voltage and variable frequency. With the massive advances made in semiconductor technology in recent years, there has been a remarkable amount of research work done in the development of induction motor adjustable speed drives. This is due to:

- The reduction in price and improved dependability of power electronic switching devices.
- The advancements in new processors and controllers support implementing complicated algorithms.

Historically, several controllers for induction motor drive system have been developed which are described as follows:

(i) **Scalar controllers**: (V/F) it controls the speed and torque of machine by controlling voltage and frequency. It does not consider the
coupling effect present in induction machines. Flux is controlled by controlling voltage, and frequency control controls slip. Control of slip leads to control of torque. It is the simple controller with easy control structure to implement. The only hitch in it is that stator flux and torque are indirectly controlled. It does not attain real precision in both speed and torque performance. The accuracy of the speed control is poor, and the operational response is also very slow (Krishnan 2001).

(ii) Vector Control (or) Field oriented control: Vector control of Induction motor is rotor flux oriented control method, and it is equivalent to the control of a separately excited DC motor drive by independent control of flux and torque and has superior dynamic performance. The 3-phase stator current phasor produces the rotor flux linkage $\theta_f$ and torque $\theta_e$. It is converted to d and q axes currents in the synchronous reference frames by using the Park’s transformation in which d- axis current controls the flux and q- axis current controls the torque. In this control strategy, an assumption made is that the position of rotor flux linkage is known. Rotor flux linkage is at an angle of $\theta_f$ called field angle from stationary frame. Field angle is the sum of rotor position $\theta_r$ and the slip angle $\theta_{sl}$. Figure 1.1 shows the phasor diagram of vector controller in which the field and slip angles are displayed clearly.

Vector control is classified based on the field angle calculation as,

- Direct vector control – field angle calculation from stator voltage and current by using hall sensors. Flux – sensing windings are also used to acquire the field angle. (Lee, B.S & Krishnan 1998).
- Indirect vector control – The field angle is obtained by using rotor position measurement and with estimation of machine parameters (Lee, B.S & Krishnan 1998).
(iii) Direct Torque Control: Direct Torque Control has emerged over the last decade to become the best possible alternative to the common vector control of induction machines. Its characteristics are as good as the classical vector control but with several advantages based on its simpler structure and control algorithm. Direct torque control (DTC) is a stator flux oriented control method. This method uses feedback control of torque and stator flux, which are computed from the measured stator voltages and currents. Stator reference model of the induction motor is used for its implementation. Since this is a stator flux oriented control, the flux weakening operation of the motor is straightforward when compared to rotor flux oriented control. The stator flux is directly proportional to the induced emf, whereas the rotor flux does not have the same relationship. DTC scheme depends only on stator resistance and on no other parameters and thus making it a robust system in the flux-weakening region. (Habetler et al. 1992; Thomas G. Habetler et al. 1992; Giovani Griva et al. 1995; Kevin D. Hurst et al. 1997; Jun–Koo Kang et al. 1999; Domenico Casadei et al. 2002; Arcker Hissel et al. 1998).
1.2 OBJECTIVES OF THE RESEARCH

The task of this thesis is to develop an efficient closed loop inverter fed variable structure controlled drive for induction motor, and it can be listed as follows:

1. Developing a simulation model for the variable structure controlled drive employing a traditional PI controller and to analyze its performance using MATLAB / Simulink.

2. Analyzing the Fuzzy logic based VSC controller scheme to enhance the performance of the drive.

3. Simulating a Fuzzy gain scheduling PI Controller based VSC drive and analyzing its performance.

4. Developing and simulating a Model Reference Adaptive System in variable structure controlled drive.

5. Developing and simulating a variable structure control in direct torque control for improved performance of the drive.

6. Comparing the performance of the traditional controller based drive with various proposed modern controller schemes and demonstrating the superiority of the proposed schemes.

1.3 LITERATURE SURVEY

Sabanovic Asif & Izosimov DB (1981) analyzes variable structure systems theory for the problem of induction motor control system. The procedure of control systems synthesis for the control of position, speed and torque is given, as well as basic experimental results and problems related to the realization of the proposed control algorithms.
Colin Schauder (1992) describes a model reference adaptive system (MRAS) for the estimation of induction motor speed from measured terminal voltages and currents. The estimated speed is used as feedback in a vector control system, thus achieving moderate bandwidth speed control without the use of shaft-mounted transducers.Simulation results are validated with experimental analysis.

Utkin (1993) discusses the basic concepts, mathematics, and design aspects of variable structure systems, as well as those with sliding modes as a principle operation mode, are treated. The main arguments for sliding-mode control order reduction, decoupling design procedure, disturbance rejection, insensitivity to parameter variations, and simple implementation using power converters. The variable structure systems with various control algorithms and data processing are analyzed. The potential of sliding mode control method is demonstrated for the adaptability of electric drives and functional goals of control.

Benchaib et al. (1999) presented a sliding mode controller (SMC) and compared with the well-known field orientation and input-output linearization techniques. To estimate the rotor flux, a sliding mode observer is used. Experimental results are given to highlight the performances and disadvantages of these methods concerning rotor resistance variations.

Benchaib & Edwards (2000) proposed a new nonlinear sliding mode controller for induction motors. In this method of control, the motor speed and stator current are measured and seeks to provide asymptotic tracking of speed and flux. The sliding mode observer is incorporated in the control system and uses back stepping ideas to synthesis the non-linear
controller sliding surfaces. Good results have been obtained in the benchmark simulations.

Gadoue et al. (2010) proposed two novel adaptation schemes to change the classical PI controller used in MRAS speed estimation schemes concerning rotor flux. One of the proposed adaptation schemes is based on sliding mode theory. A new speed estimation adaptation law is derived using Lyapunov theory to ensure estimation stability as well as fast error dynamics. The other adaptation mechanism is based on fuzzy logic strategy. A detailed experimental comparison between the new and conventional schemes is carried out at very low speed in both open and closed-loop sensorless modes of operation a vector control drive. Better performance has been obtained by the new sliding mode and fuzzy logic adaptation mechanisms in both modes of operations.

Orlowska-Kowalska & Dybkowski (2010) deals with an analysis of the model reference adaptive system (MRAS)-type rotor speed estimator vector-controlled induction motor (IM) drive with a novel. A stability analysis method of this novel MRAS estimator is shown. The influence of equivalent circuit parameter variation of the IM on the pole placement of the estimator transfer function and the stability of the entire drive scheme are analyzed and tested. The control of the adaptation algorithm coefficients of the MRAS-estimator scheme is also tested. The permissible range of motor parameter variation is determined, which assures the stable operation of the sensorless field-oriented IM drive with this speed and flux estimator. Dynamical performances of the current-type MRAS estimator in a vector control system with the are tested in a laboratory setup.

Khan et al. (2010) discuss different methods for sensorless control of induction motor drive. Model Reference Adaptive system (MRAS)
finds a lot of consideration due to its superior performance. Usually, the sensorless speed control performance of induction motor drive deteriorates at low speeds nearing zero speed range. Due to this aspect, research has been diverted to enhance the concert of the induction motor drive at minimum speeds. In this paper, a new adaptation scheme is proposed which replaces traditionally used PI controller by a fuzzy logic controller in MRAS adaptation mechanism. Simulations of MRAS based speed sensorless control of induction motor drive by using a fuzzy logic controller are presented and compared with PI controller. It is seen that the performance of the motor has improved when FLC is used in place of PI controller.

Suman & Aditya (2011) proposed a novel Space Vector Pulse width modulation (SVPWM) for sensor less control of induction motor using model reference adaptive system (MRAS). The steady state ripples in the torque are present in the conventionally used MRAS sensorless control of induction motor that utilizes normally used voltage source inverters. Also, the performance of motor at the steady state speed is not as perfect as required having disturbances in steady state region. Hence to improve the performance of MRAS based speed observer a novel method of SVPWM based on reference voltage vector that utilizes the control variables as stator flux components are proposed. The proposed SVPWM control of induction motor minimizes the speed disturbances, and the speed performance is improved. Also, the ripples present in the electromagnetic torque are reduced.

Kumar et al. (2012) developed a vector controlled induction motor drive operating without a speed or position sensor but having a dynamic performance comparable to a sensor vector drive. Vector control of induction motor depends upon the field-oriented coordinates associated with the path of the rotor m.m.f. Even though, an absence of direct means of a measuring system of the rotor flux linkage position $\rho$ and so a spectator is required to
estimate \( \rho \) for the execution of sensorless vector control. Initially, in the arbitrary reference frame, the dynamic model of induction machine was produced. Employing the synchronous reference frame scheme the indirect field oriented vector control, which is well known and suitable method in real time an execution was developed. Third, Model Reference Adaptive System is analyzed as a state estimator. The rotor flux estimation method is applied to MRAS algorithm to calculate the rotor speed.

Mahor et al. (2012) demonstrated that invariant regulator and superior servo performance can be obtained, through a total sliding mode control system, which is inconsiderate to uncertainties including parameter deviation and external disturbance in the whole control process. The simulation result of the control schemes for a given servo Induction Motor is discussed. The position of a field oriented induction servomotor drive for a given reference input signal was controlled using the PID controller, computed torque controller, sliding mode controller and total Sliding-Mode control schemes and by comparing the all, it is concluded that the total sliding mode control scheme is more robust and efficient. Even though it may be a robust method of control, PID controller is still motor parameter dependent.

Lufei & Nan Guangqun (2012) proposed the direct torque control of Induction Motor for the high-performance control system. It has been developed actively for its concise system method, outstanding dynamic and static performances. DTC scheme directly controls the stator flux and electromagnetic torque, utilizing the method of space vector and stator flux orientation. Finally, this has been implemented on DSP in a 1.1 kW drive. It is analyzed with a constant load only.

Basha & Suryakalavathi (2013) analyzed neural network based speed sensorless controlled induction motor drive. The rotor flux based Model
Reference Adaptive System (MRAS) is more popular. In MRAS, the model voltage equations are used in the reference model, which leads to poor performance of the drive at low speeds. In this measured stator currents of the induction motor are adopted as a reference model to evade the use of a pure integrator. Calculated stator currents are used as an adjustable model. From the voltage or current model, information of the rotor flux can be obtained to estimate the stator current. This leads to instability and dc drift.

Cherifi et al. (2013) presented Self-Tuning Fuzzy Logic Controller for sensorless vector controlled induction motor drives. This paper uses a Self-Tuning Fuzzy Logic Controller to improve the control performance. The control gain of the controller is tuned on-line by fuzzy rules concerning the current trend of the controlled process. Adjustment of the output gain has been given the highest priority because of its strong influence on the performance and stability of the system. The rotor speed is calculated using Model Reference Adaptive System (MRAS) for sensorless vector control.

Shrinivas & Chandulal Guguloth (2013) presented a model reference adaptive system-based sensorless induction motor drive. In this method, an adaptive pseudo reduced-order flux observer is used instead of the adaptive full-order flux observer. Simulation results show that proposed scheme can estimate the motor speed under various adaptive PI gains and estimated speed can replace to measured speed in sensorless induction motor drives.

Lokriti et al. (2013) proposed a self-tuning-PI controller for induction machine speed drive. The controller tuning strategy is based on a Fuzzy adjustor. The effectiveness proposed drive is compared with the two other controllers such as classical PI and the fuzzy-like-PI. Experimental
analysis validates simulation results. The performance of the self-tuning PI-based derive is analyzed in the aspects of computation time, tracking performances and disturbances rejection. Control of speed is well analyzed and torque performance is not discussed.

Rafa et al. (2014) analyzed a fuzzy vector control of an induction motor. Type 1 fuzzy logic is proposed for fuzzy vector control drive. The paper presents a new approach to control an induction motor using type-1 fuzzy logic. The induction motor is modelled as the nonlinear model, uncertain and strongly coupled. The vector control technique, which is based on the inverse model of the induction motors, solves the coupling problem.

However, the fuzzy vector control provides the inconsiderateness to parameter deviation compared to the conventional one. The fuzzy vector control scheme is successfully examined in real-time using a digital signal processor board dSPACE 1104. The efficiency of this technique is verified experimentally as well at different dynamic operating conditions such as sudden load changes, parameter variations, speed changes, etc. The fuzzy vector control was found to give best control for the induction motor. This method consists of many fuzzy logic controllers that decide the vector control parameter. It necessitates perfect tuning and takes high processing time.

Wang et al. (2015) proposed an adaptive Takagi-Sugeno-Kang-fuzzy (TSK-fuzzy) speed controller (ATFSC) for use in direct torque control (DTC) induction motor (IM) drives to improve their dynamic responses. Based on Lyapunov stability theory the adaptive rules derived for online tuning of the parameters of the TSK-fuzzy controller. The PI control, fuzzy control, and ATFSC schemes were experimentally analyzed and compared. Sensorless control and fuzzy has more computations making the system complicated.
Gao et al. (2015) proposed an effective adaptive tracking control approach for the sixth-order induction motor model that is in discrete-time form. Based on the Lyapunov analysis approach, for the considered system, the stability is guaranteed. An advantage for the controlled system is that the proposed algorithm needs only fewer parameters that are different from the existing results. Therefore, it can reduce the computation load. The system performance depends on the design parameters and the design parameters are set using trial-and-error method.

The many modifications to the basic Switching Table Direct Torque Control (ST-DTC) schemes aimed at improving starting, overload conditions, very-low-speed operation, torque ripple reduction, variable switching frequency functioning, and noise level attenuation have been proposed during the last decade. While starting and very-low-speed operation, the basic STDTC scheme selects the zero voltage vector many times, results in flux level drop caused by the reduction in the stator resistance. This drawback can be avoided by using either a signal (Buja et al. 2004, Noguchi et al. 1999) or a modified switching table to apply all the available voltage vectors in appropriate sequence (Vas Peter 1998). Modification of switching table is done as follows:

- To change the zones of sectors and to change the switching table. In classical DTC, sector I lie on first zone (-30 to +30 degree). In improved DTC, first zone starts from 0 and extends to +60 degree.
- The number of sectors is increased from six to twelve.

With the advent of the vector control methods, an induction motor can be operated like a separately excited dc motor for high-performance applications. In the last decade, many control techniques have been developed
providing good performance. However, the desired drive specifications still cannot be perfectly satisfied, and their algorithms are too complex.

Recently the fuzzy logic approach has been the object of increasing interest and has found applications in many domains. The main advantage of fuzzy logic control as compared to conventional control resides in the fact that no mathematical modeling is needed for the design. Fuzzy logic has been effectively used to control ill-known or complicated systems where exact modeling is hard or impossible. In motion control schemes, fuzzy logic can be considered as an unconventional approach to conventional feedback control. It has been established that dynamic performance of electric drives as well as robustness with regards to parameter changes can be enhanced by espousing the non-linear techniques of speed control. Fuzzy control is a non-linear control, and it permits the design of optimized non-linear controllers to improve the dynamic performance of conventional regulators.

The motor control issues are traditionally handled by fixed gain proportional and proportional integral derivative (PID) controllers. However, the constant gain controllers are highly sensitive to parameter changes, load disturbances, etc. So, the controller parameters have to be adaptable. Hence, it is desirable to establish a fuzzy model with satisfactory accuracy and good interpretation capability.

In this research Fuzzy gain scheduling is proposed to tune PI controller in Variable structure control. Fuzzy gain scheduling controller automatically adjusts the controller gains based on speed error and enhances the speed performance.

MRAS based speed controller is proposed to enhance the starting performance of the drive. The above survey states the direct torque control
enhances the stability of drive in the aspect of speed and torque. Direct torque control is proposed with VSC for minimum torque ripple, to enhance the static and dynamic performance of the drive.

1.4 ORGANIZATION OF THE THESIS

The remaining chapters of the Thesis are organized as follows:

Chapter 1 describes the introduction to induction motor and its control method. It also includes the survey of various control techniques for an induction motor.

Chapter 2 describes the mathematical model of an induction motor and simulation study of the variable structure controlled drive employing traditional PI controller scheme. It also highlights the disadvantages of the scheme.

Chapter 3 illustrates the general theory of Fuzzy logic controller and Model Reference Adaptive System. It also includes simulation and analysis of Fuzzy logic controller to improve the static performance. Fuzzy gain Scheduling PI controller and MRAS based variable structure controlled induction motor drive to improve the dynamic performance.

Chapter 4 depicts the general theory and simulation of direct torque control of induction motor drive using variable structure control. The simulation studies have been done, and the static and dynamic performance of the scheme has been analyzed.

Chapter 5 compares the performance of the traditional controller method with the various proposed controller schemes. The superiority of the
proposed DTC based VSC schemes on the aspect of the static and dynamic performance of the control system is demonstrated.