CHAPTER 1

INTRODUCTION

1.1 REVIEW OF INDUCTION MOTOR DRIVE

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

The only effective way of producing variable speed induction motor drive system is to supply the induction motor with three phase voltages of variable frequency and variable amplitude. With the enormous advances made in semiconductor technology during the last few years, there has been a tremendous amount of research work done in the development of induction motor drives. This is due to:
The decreasing cost and improved reliability of power electronic switching devices

The possibility of implementing complex algorithms in the new microprocessors.

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

(i) **Scalar controllers: (V/F) controller** is also known as scalar controller which controls the magnitude of the voltage and frequency only, disregarding the coupling effect in the machine. Voltage is controlled to control the flux, and frequency is controlled to control the slip so that the torque is controlled. Although, structure of this controller is very simple, it does not achieve good accuracy in both speed and torque responses, mainly due to the fact that stator flux and torque are not directly controlled. The accuracy of the speed control is poor and the dynamic 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 in the independent control of flux and torque and has superior dynamic performance. The 3-phase stator current phasor \( i_s \) produces the rotor flux linkage \( \psi_r \) and torque \( T_e \). It can be transformed into 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 shown clearly.

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

1. 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. (Krishnan, 1998).

2. Indirect vector control – The field angle is obtained by using rotor position measurement and with estimation of machine parameters (Krishnan 1998).
(iii) **Direct Torque Control:** Direct Torque Control has emerged over the last decade to become the best possible alternative to the well-known 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 scheme in flux-weakening region. (Habetler et al 1992, Thomas G. Habetler et al 1992, Giovani Griva et al 1995, Kevin D. Hurst et al 1995, Jun–Koo Kang et al 1999, Domenico Casadei et al 2002, Arcker Hissel et al 1998).

**Features of DTC**

(i) Direct control of flux and torque  
(ii) Indirect control of stator voltages and currents  
(iii) Approximately sinusoidal stator fluxes and stator currents (Domenico Casadei et al 2002)  
(iv) Better dynamic performance
The main advantages of DTC are

(i) The absence of PI regulators;
(ii) The absence of coordinate transformations;
(iii) The absence of current regulators;
(iv) Faster torque response (Thomas G. Habetler et al 1992)

However, some disadvantages are also present in DTC such as:

(i) Possible problem during starting
(ii) Parameter variations
(iii) Inherent torque and flux ripple. (Vas Peter, 1998)

1.2 REVIEW ON LITERATURE

Many researchers have investigated on DTC methods to improve the performance of induction motor. They are as follows:

(i) Achievement of torque ripple reduction by switching table modification

Many modifications of the basic Switching Table Direct Torque Control (ST-DTC) scheme 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. During starting and very-low-speed operation the basic ST-DTC scheme selects many times the zero voltage vectors resulting in flux level reduction owing to the stator resistance drop. This drawback can be avoided by using either a dither signal (Buja et al 2004, Noguchi et al 1999) or a modified switching table in order 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 lies on first zone (-30 to +30 degree). In improved DTC, first zone starts from 0 to +60 degree.
- Number of sectors is increased from six to twelve.

(ii) Torque ripple reduction by increased number of generated inverter switching states

Subdivision of the sampling period into two or three (Domenico Casadei et al 2002) equal time intervals leads to 12 or 54 voltage vectors, respectively. The increased number of available voltage vectors allow the subdivision of both the hysteresis of torque and flux controllers into more levels and to create a more accurate switching table that also takes into account the speed value.

(iii) DTC with constant switching frequency for torque ripple reduction

Basically the DTC strategies operating at constant switching frequency can be implemented by means of closed loop schemes with PI, predictive/dead-beat or neuro-fuzzy (NF) controllers. The controllers calculate the required stator voltage vector, averaged over a sampling period. The voltage vector is finally synthesized by a PWM technique, which is called as the space-vector modulation (SVM). Therefore, compared to
conventional DTC algorithm, the switching harmonics are neglected in DTC-SVM based control algorithm. (Buja et al 2004).

(iv) Dead-beat control for torque ripple reduction

The main idea behind a dead-beat DTC scheme is to force torque and stator flux magnitude to achieve their reference values in one sampling period by synthesizing a suitable stator voltage vector applied by Space Vector modulation. In this approach (Sheng-Ming Yang et al 2002, Barbara Kenny et al 2003, Buja et al 2004) the changes of torque and flux over one sampling period are predicted from the motor equations, and then a quadratic equation is solved to obtain the command value of stator voltage vector in stationary coordinates.

(v) Deducing RMS torque ripple equation for torque ripple reduction

RMS torque-ripple equation is derived using instantaneous torque equations and, at each switching cycle, an optimal switching instant, which satisfies the minimum torque ripple condition, is determined. (Kyo-Beum Lee et al 2002).

(vi) Sampling frequency approach

The inverter frequency is maintained constant which is greater than the sampling frequency, which will reduce the torque and flux ripple dramatically. Different space vector modulation techniques are used. (Jun-Koo Kang et al 1999, Yen-Shin Lai et al 2001).
1.3 PROPOSED METHOD

This research is focused to achieve smooth torque and flux with better accuracy. The proposed technique is based on determination of the flux vector spatial orientation and rotational speed, which defines the unique solution for reference stator voltage. This control technique provides decoupled control of the torque and flux with constant inverter switching frequency. Calculation of desired flux increments and voltage command for a desired change in torque are proposed and implemented on a 3 phase induction motor.

1.4 CONTRIBUTIONS

The main contributions of the research are

(i) Design of a prototype hardware for induction motor drive
(ii) Implementation of intelligent direct torque control methods and comparison with the conventional DTC strategy
(iii) Proposal and implementation of a new DTC algorithm for torque and flux ripple minimization

1.5 OUTLINE OF THE THESIS

This thesis is organized into seven chapters in which, the contributions of the author, investigations undertaken, significant results and conclusions are presented. These seven chapters are structured as follows.

Chapter 1 presents the general introduction to the problem and previous investigations reported in the literature. It concludes with the
statement of main objectives of the research and the contributions of the author.

Chapter 2 describes the basic theory and mathematical modeling of induction motor. This model is formulated by means of two-axis theory equations and the space phasor representations and it is developed for both stator and rotor reference frames. The phasor representations of voltage, current and flux linkages are given and the mathematical representations in stationary and rotating reference frames are explained in detail. Torque expressions are also derived from the direct and quadrature axes flux linkages. Finally, steady state conditions of the motor are also discussed in this chapter.

Chapter 3 explains the principle of different direct torque control (DTC) strategies. A detailed comparison of conventional DTC and other DTC strategies such as Fuzzy, Neural network, ANFIS and Genetic algorithm based DTCs are carried out based on the performance characteristics. The principle of DTC states that the decoupled control of torque and flux is achieved by choosing appropriate voltage vectors of inverter. Stator flux and torque are estimated by sensing the stator voltage and stator current of the motor. Switching table explains the basic switching states of inverter and input quantities are flux and torque error. Flux error is derived from a two level hysteresis comparator (Flux increasing and decreasing) and torque error is derived from a three level hysteresis comparator (Torque increasing, zero value and torque decreasing).

Chapter 4 explains the proposed DTC strategy, which will focus to give smooth torque and flux with better accuracy. The proposed technique is based on the flux vector spatial orientation and rotational speed, which defines the unique solution for reference stator voltage. This control technique provides decoupled control of the torque and flux with constant inverter
switching frequency. The main contribution of this research is to provide the calculation of desired flux increments according to desired change in torque and the implementation aspects of voltage command calculation.

Chapter 5 explains the hardware implementation of direct torque controlled induction motor drive using high-speed digital signal processor. The selection of power inverter, its components ratings and steps involved in fabrication are presented. Design of power circuit, control circuit, voltage and current sensing circuits, a description of DSP processor used in this research are described in detail. The different modes of operation of prototype drive and the experimental results of conventional, intelligent and proposed DTC strategies are presented.

Chapter 6 draws the conclusions from the work done in this thesis and discusses the further research possible in the future.