IMPLEMENTATION OF DIRECT TORQUE CONTROL OF INDUCTION MACHINE UTILIZING DIGITAL SIGNAL PROCESSOR

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Bachelor of Electrical Engineering

June 2012

" I hereby declare that I have read through this report entitle *"Implementation of Direct Torque Control of Induction Machine Utilizing Digital Signal Processor"* and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Power Electronics and Drive)"

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JUNE 2012

I declare that this report entitle *"Implementation of Direct Torque Control of Induction Machine Utilizing Digital Signal Processor"* is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : NOOR HASINA BINTI ALI

Date : 25/6/2012

DEDICATION

Specially dedicated to my beloved family especially my father (Ali Bin Ibrahim) and my mother (Siti Khalijah Binti Hj Ali); whose very concern, understanding, supporting and patient. Thanks for everything. To All My Friends, I also would like to say thanks. The Work and Success will never be achieved without all of you.

ABSTRACT

This project presents the implementation of Direct Torque Control (DTC) of induction machine drive utilizing Digital Signal Processor. In Direct Torque Control system, the precise of flux estimation is very important since it mainly influence the overall DTC performance. The simplest method for estimating the stator flux is by using the stator voltage model. The model does not require information of rotor speed and it only needs a single machine parameter which is the stator resistance. However, improper measurement of current due to offset might cause initial and drift can pose significant problem in estimating the flux, particularly at low speed operation. In this project, to overcome the problem, a pure integrator in flux estimation is replaced by an integrator with a low pass filter. A suitable cut-off frequency was set up at 5 rad/s for the DTC computation sampled at 50μs. Although the cut off frequency is quite small, but it can solve the problem very significantly. The DTC algorithm was modeled or programmed uses IQ-math blocks which are available in MATLAB software (Version R2011a). By using IQ-math blocks, it can be directly loaded to ezdsp F28335 controller board. The solution of the problem and proper DTC operation were verified via simulation and experimentation.

ABSTRAK

Projek ini membentangkan pelaksanaan pemacu Kawalan Daya Kilas Terus (DTC) untuk mesin aruhan menggunakan Pemproses Isyarat Digital. Dalam sistem Kawalan Daya Kilas Terus, ketepatan anggartan fluks adalh sangat penting terutamanya dalam mempengaruhi keseluruhan prestasi DTC Kaedah yang paling mudah untuk penganggaran fluks pemegun adalah dengan menggunakan model voltan pemegun. Model ini tidak memerlukan maklumat kelajuan pemutar dan ia hanya memerlukan satu sahaja parameter mesin seperti rintangan pemegun. Walaubagaimanapun, pengukuran yang tidak wajar semasa mengimbangi mungkin menyebabkan awal dan hanyut yang boleh menimbulkan masalah yang ketara dalam menganggarkan fluks, terutamanya dalam opersai kelajuan rendah. Dalam projek ini, untuk mengatasi masalah ini, penyepadu tulen dalam penganggaran fluks digantikan dengan pengamir dengan penapis lulus rendah. Kekerapan yang telah digunakan ialah 5 rad/s untuk pengiraan sampel 50μs DTC. Walaupun kekerapan frekuensi adalah sangat kecil, tetapi ia boleh menyelesaikan masalah yang sangat ketara. Algoritm DTC telah dimodelkan atau diprogramkan menggunakan blok IQ-matematik yang terdapat di perisian MATLAB (versi R2011a). Dengan menggunakan blok IQ-matematik, ia boleh terus dimuatkan kepada ezdsp F28335 papan pengawal. Penyelesaian kepada masalah dan opersai telah disahkan melalui simulasi dan eksperimen.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In recent years, field oriented control (FOC) has been employed that enables an induction machine to attain as quick torque response as a DC motor. The principle of its torque generation is based on the interaction between the flux and current like a DC motor. This method which uses frame transformation, de-coupled the torque and flux components of the stator current therefore has transformed the performance of induction machine similar that of the DC motor [1]. The implementation of this system however is complicated and furthermore FOC, in particularly indirect method which is widely used, is well known to be highly sensitive to parameter variations due to the feed-forward structure of its control system. Because of that, many studies have been developed to find out different solutions for the induction motor control to give fast and good dynamic torque responses and to reduce the complexity of structure. There exist two main types of high performance torque controlled ac drive like Vector Controlled Drives and Direct Torque Controlled (DTC) Drives.

The aim of this project is to implement of Direct Torque Control of Induction Machine utilizing Digital Signal Processor. Direct Torque Control or DTC as it is called. This is very latest AC drive technology where it is control of torque and speed are directly based on the electromagnetic state of the motor. Although the principles of DTC were introduced more than ten years ago, it is only recently that industrial DTC drives have become available. Direct Torque Control (DTC) has received the attention of motor drive designers due to its relatively simple implementation.

1.2 Problem Statement

The simplest method for estimating the stator flux is by using the stator voltage model. The model does not require information of rotor speed and it only needs a single machine parameter which is the stator resistance. However, improper measurement of current due to offset might cause initial and drift can pose significant problem in estimating the flux, particularly at low speed operation. In this project, to overcome the problem, a pure integrator in flux estimation is replaced by an integrator with a low pass filter.

1.3 Project Objective

There are two objectives of this project to make it successful. There are:

1.3.1 To implement of DTC of induction machine using ezdsp F28335.

1.3.2 To solve initial and drift problem in estimating the flux by using a low pass filter.

1.4 Scope of Project

In this project, the simulation and hardware implementation will be conduct. In the simulation part, MATLAB software simulation will be used to develop basic configuration consist of a pair of hysteresis comparator, torque and flux calculator sector detection and also to improve stator flux estimation problem by using low pass filter. In hardware implementation, the proposed controllers are simple in concept and easy to implement. The main components of the experiment set-up consist of a Digital Signal Processor board.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews existing project created to get an idea about the project design, conception and any information that related to improve the project. There are many creations and innovations of projects that have been done by other researchers with differences concept and design. This chapter also covers the researches related to the subject. This will provide a clearer understanding of the system and its design. This chapter will discuss on overall theories and concept of the project. The purpose of this chapter is to explain the review of the theories used to in order to implement the project. The understanding of the basic theory is a very important as a guideline. This project is all about the implementation of Direct Torque Control.

2.2 Evolution of AC motor

A variable speed drive is a one of the equipment that regulates the speed and rational force, or torque output of an electric motor. This is to control the flow of energy from the mains to the process. In most drives AC motor are applied and are millions of motors in use in industry. Variable speed drive is often used in pumps, electrical vehicle, fans, elevators, heating, robotics, wind generation systems so on.

As we know before this, DC machines were used for variable speed drives because they could easily achieve a good torque and speed response with high accuracy. However, DC motors have disadvantages which that the DC motors can be costly to purchase, the fact that brushes and commutators wear down and need regular servicing. The AC motor do not have the disadvantages of DC machines which mean they are robust, require less maintenance, cheaper, and operate at higher speed. The evaluation of AC variable speed drive technology has been built with emulate the performance of the DC drive, such as fast torque response and speed accuracy while utilizing the advantages offered by the standard AC motor. Figure 2.1 showing the general classification of variable frequency induction machine control methods.

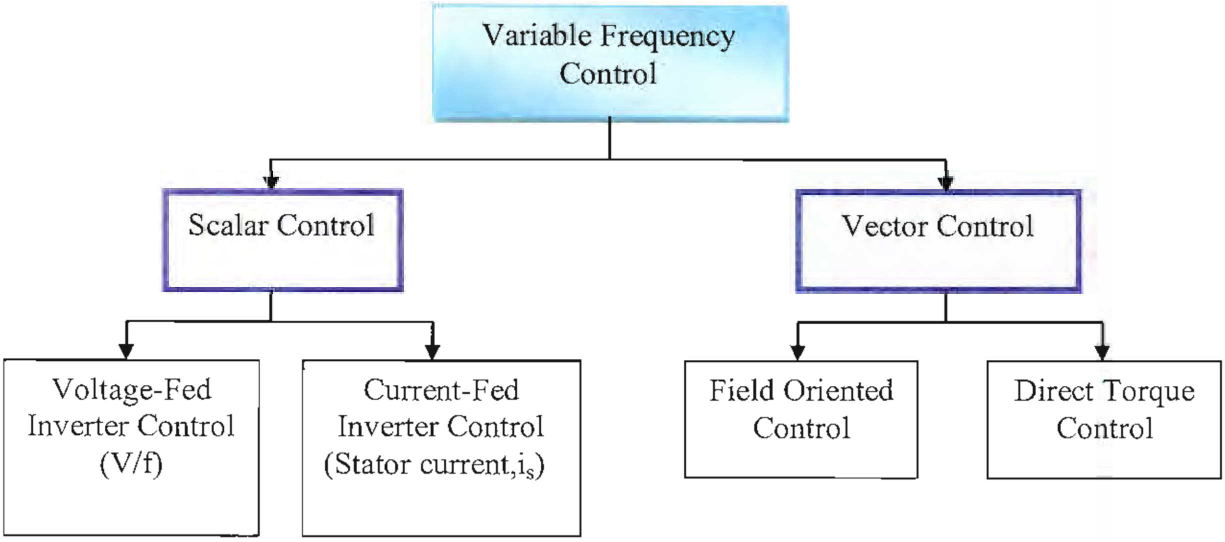

Figure 2.1 : Classification of induction machine control method

As generally in this figure showing the induction machine control method is divided into two categories such as scalar and vector control. In scalar control is divided into two categories, namely voltage-fed Inverter control and current-fed inverter control. Voltage-fed inverter control of an induction motor are most popular method of speed control because of its simplicity (open loop), and also these type are widely used in industry. In current-fed inverter control, the dc link current and inverter frequency are the two control variables where the current can be controlled by varying the firing angle. Unfortunately, a current-fed inverter system cannot be operated in an open loop like a voltage-fed inverter drive [1].

Vector control methods are also divided into two categories, namely Field Oriented Control and Direct Torque Control. The invention of Field-Oriented Control (FOC) in early 1970 enables rugged induction machines to be controlled similar to that of DC machines [2]. In recent years, field oriented control (FOC) has been employed that enables an induction motor to attain as quick torque response as a dc motor. The principle of its torque generation is based on the interaction between flux and current, like a dc motor [3]. The FOC method guarantees flux and torque decoupling. However, the induction motor equations are still nonlinear fully decoupled only for constant flux operation. Although the FOC enables an induction machine to attain fast torque response, some problems still exists. An accurate flux estimator had to be employed to ensure the estimated value used in calculation does not deviate from the actual value. Besides, the coordinate transformation had increased the complexity of this control method. In *'A New Quick-Response And High-Efficiency Control Strategy Of An Induction Motor'* paper, it is highlight that the inverter switching frequency, torque ripple, and harmonic losses of the machine increase in the steady-state operation if the hysteresis-based current-controlled inverter is used [3].

2.3 Vector Control

Vector control are known when the electrical drive controls become more accurate in the sense that only are the dc current and voltage controlled but also the three phase currents and voltages. Where the principle of vector control of electrical drive is based on the control of both the magnitude and the phase of each phase current and voltage. In the industrial variable speed drive system, induction motor are must popular and also widely used because with the development of the vector control technology. The invention of vector control in the beginning of 1970s, and the demonstration that an induction motor can be controlled like a separately excited DC motor, brought a renaissance in the high-performance control of ac drives. Because of dc machine like performance, vector control are also known as decoupling, orthogonal, or trans vector control [1]. Vector control is important in high-performance drive application such as traction drives and spindle drive. Vector control is also can be divided into types, namely is direct or feedback vector control and the other one is indirect or feed forward vector control.

Table 2.1 : Comparison between FOC and DTC.

	FOC	DTC
Advantages	• Modulator • Constant switching frequency • Unipolar inverter output voltage • Low switching losses • Low sampling frequency • Current control loops	• Structure independent on rotor parameters, universal for IM and PMSM. • Simple implementation of sensorless operation. • No coordinate transformation. • No current control loops.
Disadvantages	• Coordinate transformation. • A lot of control loops. • Control structure depended on rotor parameters.	• No modulator • Bipolar inverter output voltage. • Variable switching frequency. • High switching losses. • High sampling frequency.

2.4 Direct Torque Control

Not until mid 1980's, when Direct Torque Control (DTC) was first introduced, Field Oriented Control (FOC) of induction machines was considered the only scheme capable of delivering high performance torque control in AC machines [3]. Since it's introduced in 1986, the direct torque control (DTC) [3] principle was widely used for IM drives with fast dynamics. Despite its simplicity, DTC is able to produce very fast torque and flux control. The DTC scheme can be considered as an alternative to the field oriented control (FOC) technique [4]. In DTC, the torque and flux are directly controlled using optimum voltage vectors, whereas the FOC, which is uses q- and d- axis components of the stator current to control the torque and flux [5]. Two of the major issues which are normally appearing in DTC are variation of the switching frequency of the inverter during operation and the high torque ripple. To achieve this, various implementation schemes are proposed, which is increase the complexity of the DTC drive.

In steady state operation for DTC of induction machine, flux estimation is importance to ensure proper drive operation and stability in high performance. To ensure that, flux estimation have a 3 techniques such as based on voltage model, current model and combination of voltage and current model. Flux estimation technique based on current model applied at low frequency, compared with voltage model, is used in a high speed range. It solves the low speed problem but it needs to monitor the rotor speed. In the other words, it requires additional speed sensor or observer. Voltage model technique become a problems if applied at low speed, such as noise or measurement error inherently present in the current sensor, where can cause the integrator to saturate. Although this model does not require rotor speed and only need a single machine parameter such as the stator resistance. To overcome this problem, the pure integrator must be replacing with low pass filter.

DTC has disadvantages such as variable switching frequency and high torque ripple which makes many researchers try to overcome this problem in which to improve the performance of DTC. Several reviews are concentrated to relate the study of this thesis such as torque ripple reduction and constant switching frequency. Basically, the output torque ripple can be reduced by reducing the hysteresis band and also by injecting high frequency triangular waveform to the error of torque and flux. However it still produces variable switching frequency. Various methods have been proposed to produces constant switching frequency and also reduce torque ripple [6-7]. In [6], PI controller and pulse counter are used at each comparator to adjust band with but it causes complication in the DTC and not sure whether to reduce torque ripple or not. Other ways to reduce torque ripple is use duty ratio where based on optimal switching instant that satisfied the minimum torque ripple condition [7]. As purposed by [4], triangular carrier-based are used to replace the hysteresis based in the operating principles of DTC.

2.5 Principle of DTC

The basic principle of DTC is the direct selection of a space vector and corresponding control signals, in order to regulate instantaneously the electromagnetic torque and stator flux magnitude [3]. This section will briefly review the whole control model, which includes the 3-phase Voltage Source Inverter (VSI), voltage space vector, as well as the flux estimator.

2.5.1 3-phase Voltage Source Inverter (VSI)

The three-phase two level VSI consist of six active switches. The basic topology of the inverter is shown in figure 2.2. The converter consists of the three legs with IGBT transistor or GTO thyristors (in the case of high power) and free-wheeling diodes. The inverter is supplied by a voltage source composed of a diode rectifier with a C filter in the dc-link. The capacitor C is typically large enough to obtain adequately low voltage source impedance for the alternating current component in the dc-link. Sa, Sb, and Sc are the switching are always complimentary to each other. Sa, Sb, and Sc equals to 1 indicates that the upper switch of the leg is ON while the value of 0 shows that the lower switch of the lag is OFF. The line-to-neutral voltage Va, Vb, and Vc are determined by the inverter switching modes.

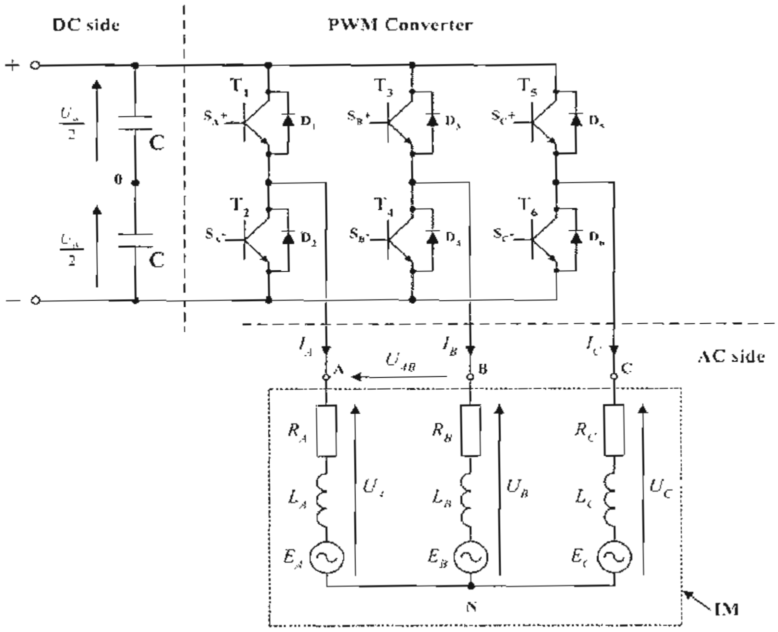

Figure 2.2: Topology of the voltage source inverter [11].

According to the combination of the switching modes, the voltage vectors are specified for the eight different voltage vector. There are six active voltage vector ($\bar{V}_{s,1} - \bar{V}_{s,6}$) and two zero voltage vectors $\left(\bar{V}_{s,0}\ and\ \bar{V}_{s,7}\right)$ at the origin are shown in figure 2.3.

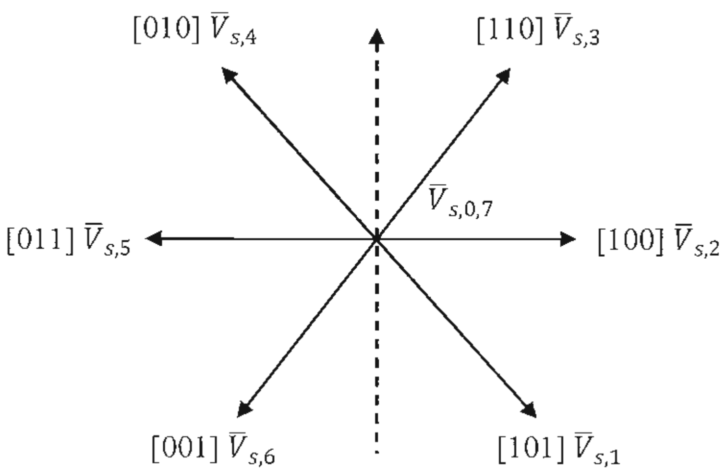

Figure 2.3: Voltage space vector [11].

It can be shown that the voltage vector is given by :

$$\bar{V}_s = \frac{2}{3}V_{dc}\left[S_a + e^{j\frac{2\pi}{3}}S_b + e^{j\frac{4\pi}{3}}S_c\right] \qquad \text{where } e^{j\frac{2\pi}{3}} = a \tag{1.0}$$

2.5.2 Stator Flux Estimation

In order to exactly the stator flux and torque errors, an accurate estimator of stator flux is a must. There are two most popular model used to estimate the stator flux, namely the stator voltage and the current model.

2.5.2.1 Stator Voltage Model

Stator voltage model is generally accepted as the simplest form of the flux estimation technique. The stator flux in stationary frame can be estimated as

$$\bar{\varphi}_{S}= \int (\bar{V}_s - R_s \bar{\imath})dt \tag{1.1}$$

The estimation is based on an open loop integration of the stator back emf and requiring only stator resistance, stator current and voltage. It provides an accurate stator flux estimate at high speeds. However at low speed, the stator resistance drop becomes significant causing inaccurate estimation [3], [8], [9]. Consequently, the voltage model is generally not capable of achieving high dynamic performance at low and zero speeds.

2.5.2.2 Current Model

A current model estimator is globally stable in stationary frame and does work at very low speed and even zero speed. However, this model is much more complex compare to the voltage model. It requires the knowledge of the rotor speed and stator current to estimate the rotor flux linkage, then the stator flux is calculated based on the estimated rotor flux linkage [8]. A closed-loop integrator which makes the current model based estimator stable with no drift problems at low speed region [10]. Nevertheless, [8] highlights that the current model will lead to numerical instabilities at higher velocities when digitally implemented due to the rotor velocity measurement.

Based on the unique feature gained by both models respectively, it is ideal to combine both of them to achieve an accurate estimation range from zero speed to high velocity. A simple approach to provide a smooth transition between models was developed by Takahashi, which combined two stator flux models via a simple first-order lag-summing network. It enables the two models switches automatically and smoothly based on the specified time constant [3].

2.6 Chapter Conclusion

After revising all the related article and journal about this project, understanding for this project is more convincing. A summary of the principles of DTC are given a problem that are usually associated which noise in voltage measurement and integration drift can pose significant problem at low speed. The effective method of overcome this problem, the cut-off frequency of low pass filter which varies with the frequency of the stator current detected in low speed region is proposed. Many researchers try to overcome this problem in which to improve the performance of DTC.