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A MODIFICATION OF DIRECT TORQUE CONTROL FOR HIGH- EFFICIENCY AND QUICK RESPONSES INDUCTION MACHINE

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A project report submitted in partial fulfillment of the requirement for a ward of the degree of Bachelor of Electrical Engineering (Power Electronics & Drives)

Faculty of Electrical Engineering

Universiti Teknikal Malaysia Melaka

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I declare that this thesis entitled "A Modification of Direct Torque Control for High-Efficiency and Quick Responses Induction Machine" is the result of my own research except for works that have been cited in the reference. The thesis has not been accepted any degree and not concurrently submitted in candidature of any other degree.

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Date : ____________________________________

To my dearest mother, father and family for their encouragement and blessing

To my beloved classmates for their support and caring…

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ABSTRAK

Tesis ini membentangkan suatu pengubahsuaian skim konvensional Torque Kawalan Langsung (DTC) mesin induksi. DTC terkenal kerana kaedah ini telah diterima dalam kawalan motor di dalam banyak applikasi industri dengan tawaran kesederhanaan dan prestasi daya kilas kawalan tinggi. Walaupun kesederhanaannya, DTC mempunyai beberapa masalah utama iaitu mempunyai riak daya kilas yang lebih besar, frekuensi pensuisan yang berubah-ubah disebabkan oleh kawalan histeresis dan penghayutan integrasi dalam menganggar fluk yang disebabkan oleh penggunaan pengkamiran asli. Projek penyelidikan ini bertujuan untuk mengurangkan kekerapan frekuensi pensuisan dan dengan itu menukar kerugian dengan mengubah struktur DTC itu. Oleh itu, lokus fluk boleh dikawal dengan membentuk bentuk yang heksagon. Perubahan lokus fluk dari bulat ke bentuk heksagon boleh diperolehi dengan mengubah status ralat fluk daripada pengawal histerisis itu. Oleh itu, pemilihan vektor voltan yang sesuai diperlukan untuk mengikuti kehendak dari pengawal. Dengan melakukan strategi yang dicadangkan ini, jalur lebar histerisis serta riak daya kilas boleh diatur di dalam kumpulan yang boleh menyelesaikan masalah frekuensi pensuisan yang berubah-ubah.Hasil penambahbaikkan pretasi DTC akan dikenal pasti melalui keputusan simulasi dan eksperiment.

ABSTRACT

This report presents a modification of conventional Direct Torque Control (DTC) scheme of induction machine. DTC is well-known because its method has widely been acceptance for advanced motor control in many industrial applications due to its simplicity and high-torque control performance. Despite its simplicity, the DTC has some major problems which are larger torque ripples, variable switching frequency due to the hysteresis controllers used for torque and flux hysteresis comparator and inaccurate the stator flux estimator because of used the pure integrator hence can decrease the drive performance of induction motor. The research project aims to minimize switching frequency and hence switching losses by modifying the DTC structure. Thus, the flux locus can be controlled to form a hexagonal shape. The changing of the flux locus from circular to hexagonal locus shape which can obtained by modifying the flux status error of the hysteresis controller. Therefore, the selection of appropriate voltage vectors is needed to follow the requirement of output signal of the comparator. By doing this proposed strategy, the bandwidth of hysteresis as well as the torque ripple can be regulated within its band which can solved the problem of switching frequency. The modification of DTC and the improvements via experimental results were verified.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Not until 1970s, the induction motor extensively employed a scalar control method to obtain desired motor speeds, by controlling the magnitude and frequency of AC voltage. The control of the magnitude and frequency of AC voltages is made such that the ratio of the magnitude to the frequency is constant, so that the rated flux can be produced in order to achieve higher torque capability. Despite its simplicity of control technique, the control of speed is only valid on steady state operations. The method results in poor dynamic control performances and unable to reject any disturbance (i.e. load torque application or variation on motor parameters) that degrades the control performances.

In line with the advanced technology development of power switching devices and microprocessor, the control of three-phase induction motor using vector control which is based on field orientation was possible after 1970s. The first attempt to apply the vector control which referred to as Field Orientation Control (FOC) was introduced by Blaschke [1]. The FOC method provided excellent torque and flux instantaneous controls which are comparable to that of DC motor. However, the FOC has a complex structure since it requires frame transformations, current controllers (or space voltage vector modulator) and speed sensor. Later, around middle of 1980's, Takahashi introduced a simple technique which is called Direct Torque Control (DTC) [2][3] that is based on hysteresis controllers and switching voltage vectors table. After a few years later, a similar concept of control was proposed by Dapenbrock which is referred to as Direct Self Control (DSC) [4]; that operates the flux locus into hexagonal shape to obtain superior torque dynamic control.

Until now, further improvement of motor control performances still receives high attentions for fulfilling important requirements, e.g. high-efficiency and excellent dynamic control performances, especially in traction or electric vehicle applications. Some modifications on FOC or DTC were proposed with the use of multilevel inverters [5], more intelligent control approaches (e.g. fuzzy logic controller [6] and predictive control [7]) and other types of motor [8].

1.2 Problem Statement

Despite the DTC simplicity, it may produce high switching frequencies due to the excessive switching which might occur in the hysteresis controller. Note that, the switching frequency of inverter is influenced by the switching in torque and flux hysteresis controllers.

In order to reduce the torque and flux ripples, the bandwidth of hysteresis controllers should be reduced. This consequently causes high switching frequency as the time taken for the torque/flux error travels from one band to another band becomes shorter. The excessive switching frequency is significant as the slope of torque/flux becomes extreme at worst operating conditions such as at very low speeds, at very high speeds, sudden large demands and etc. For example, flux hysteresis controller results in high switching at high speeds. This is because the switching of active voltage vectors to form a circular flux shape, either to increase or decrease the flux becomes more often and significant as the duration of zero vector application to halt the flux is short.

It is emphasized that the switching frequency that exceeds beyond the limitation of switching devices will degrade the performance of switching, in terms of blocking/conducting capability and efficiency.

1.3 Objectives of Research

There are two objectives to accomplish this research which are as follows:

1. To minimize switching frequency and hence switching losses by modifying the DTC structure so that flux locus can be controlled to form a hexagonal shape.
2. To verify the operation of the modified DTC and its improvements via experimental results.

1.4 Scopes of Research

There were a few scopes that are underlined for this project. Firstly, to implement a minor modification on the original DTC structure by introducing a new sector definition for controlling the flux locus into a hexagonal shape. Secondly, to develop an experimental set-up that can perform the DTC with circular flux control and the modified DTC with hexagonal flux control. The experimental setup will include several components such as DS1104 DSP-Board, Gate Driver and Induction Motor. Next, to compare the performances for both schemes which under the same conditions in terms of speed and load and also the experiment platform. Lastly, to verify the improvements of modified DTC scheme, i.e. reduction of switching frequency.

1.5 Research Methodology

The research work for this project is undertaken by several development stages which briefly explain the methods or procedures to do research or modify the DTC until verify the improvements via experimentation. Figure 1.1 illustrates how the project process is conduct from one step to another step until it fully complete. Besides, Gantt chart was enclosed in Appendix A for activities for complete this project.

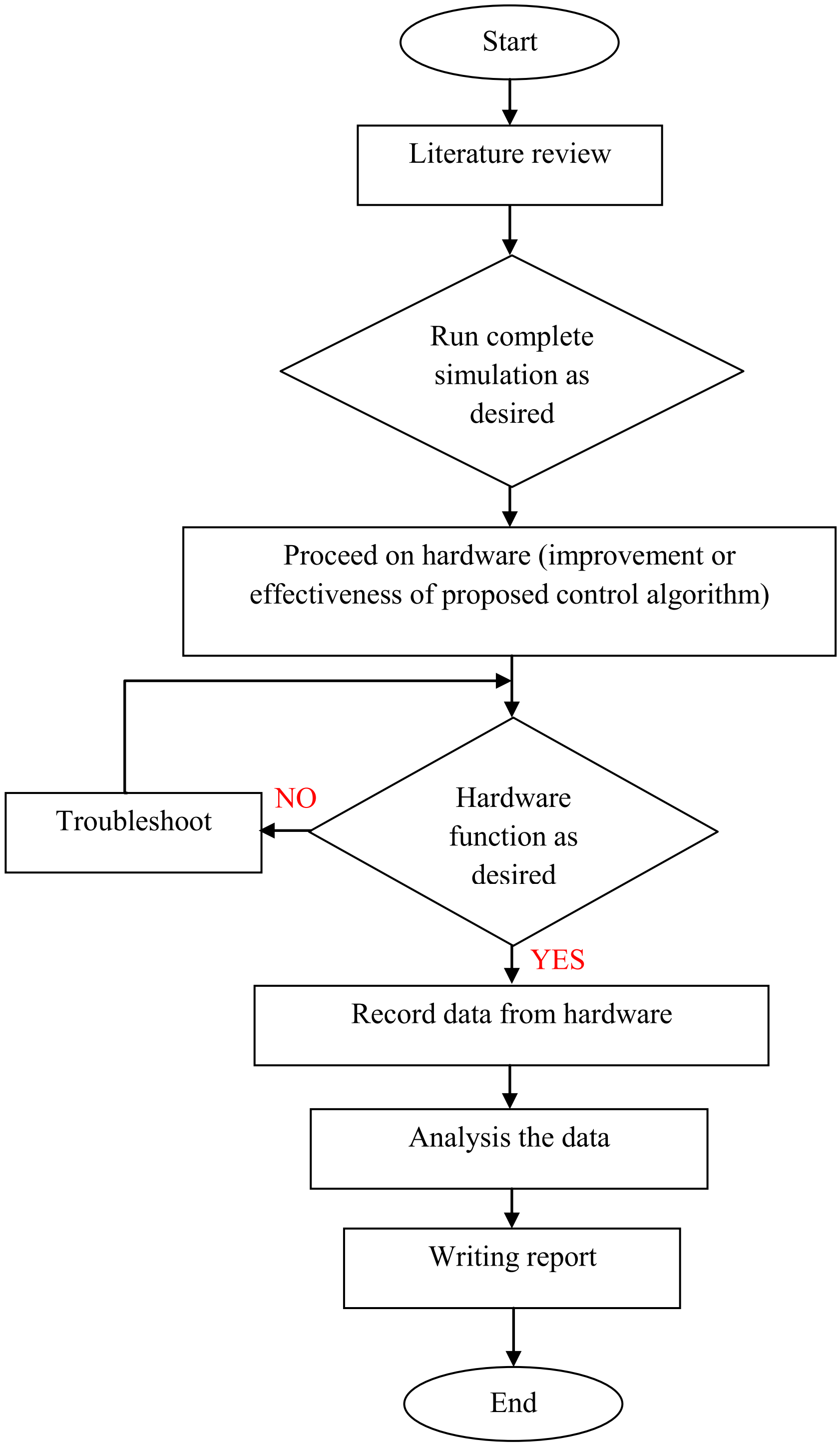

Figure 1.1 : Research Methodology

1.5.1 Literature Review

For this section will review the summary and synthesize the idea of other publisher of journal or technical report related to DTC, but more concentrating on the switching frequency of direct torque control of induction machines. In order, to understand all the entire DTC algorithm.

1.5.2 Experimental Set-up

After the simulation design of DTC complete with a modification structure, now the hardware installation was proceed. The VHDL code of look-up table and blanking time generators will be developed for complied into FPGA. If there any problems with the hardware installation, process of troubleshoot on the hardware for solving the problem will conducted until the hardware is functional as desired.

1.6 Outline of Thesis

Below are the brief descriptions for the rest chapters:

Chapter 2 discusses previous works related to the research project which include the topic of Direct Torque Control (DTC) which based on circular flux control. Other than that, operation of Direct Torque Control (DTC) which produced hexagonal flux control will discuss.

Chapter 3 explains the method to realize the modified DTC algorithms which retain the most part of DTC conventional scheme. The related mathematical modelling will be discussed to clearly understanding of DTC algorithm. This chapter also explains the implementation of hardware which to verify the improvement or effectiveness of proposed control algorithm.

Chapter 4 will presents and analyzes the experimental results that tested under same conditions in terms of speed and load torque to get the ideal comparison. Thus, evaluation is done by experimental platform.

Chapter 5 gives the conclusions for this project.

CHAPTER 2

LITERITURE REVIEW

2.1 Introduction

In this chapter, some previous works related to the research project will be reviewed to analyze and compare in terms of principle strategy and performance improvement. In general, the review emphasizes some DTC strategies that improve the power efficiency and torque dynamic control by selecting suitable voltage vectors for each control of flux; either performs the circular or hexagonal flux shape.

2.2 Direct Torque Control of Induction Machine based on Circular Flux Control

Direct Torque Control (DTC) has gained popularity because of its simplicity and high performance of dynamic control which can be obtained with the application of suitable voltage vectors. Figure 2.1 shows the structure of DTC as proposed in [3] which consists of two distinct control loops, i.e. torque and flux control loops. Both torque and flux are controlled using hysteresis comparators by restricting their errors within the hysteresis bandwidths. This can be obtained as the output status produced from the comparators are used to choose suitable voltage vectors in the look-up table in restricting the errors within their respective hysteresis bandwidths.

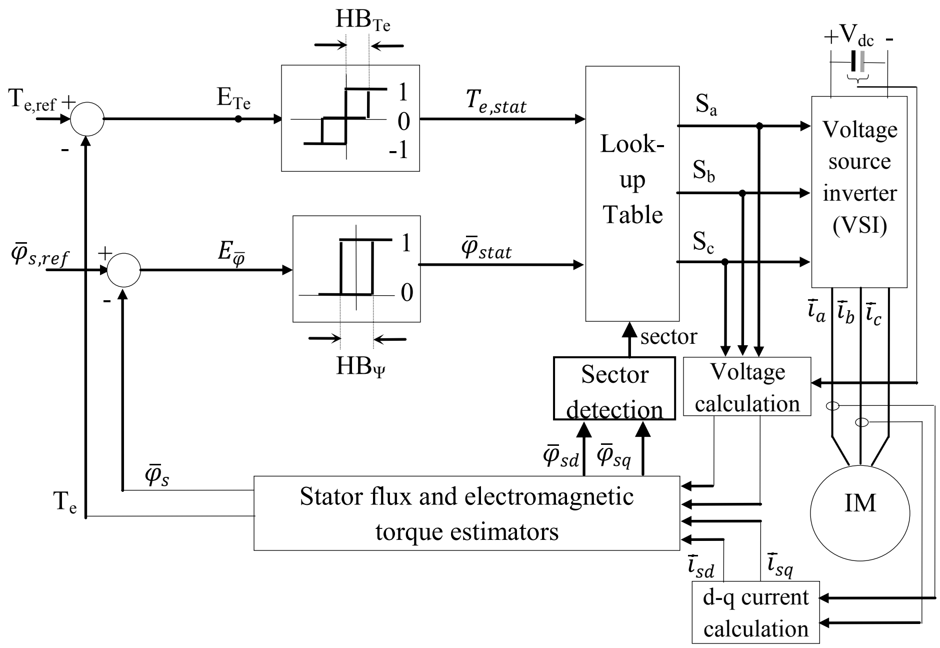

Figure 2.1 : Schematic of DTC based induction machine

In [2], the flux space vector is controlled such that its locus forms into a circular shape by selecting suitable active voltage vectors for every sector of flux. Taking into account that the change of flux vector ($\overline{\Delta\varphi}$) is mainly influenced by applied voltage vectors ($\bar{v}_{sn}$) as the ohmic drop voltage can be assumed to be neglected:

$$\overline{\Delta\varphi} = \bar{v}_{sn}.\Delta t \tag{2.1}$$

As shown by Figure 2.2, a different set of two active voltage vectors is switched for every flux sector to form a circular flux locus, either in counter clockwise or clockwise rotation. For example, considering the flux vector has just entered into Sector II (i.e. from Sector I) and it has to move towards the Sector III; it can be noticed that the voltage vector $\bar{v}_{s3}$ is the most tangential component to flux locus at the boundary of Sector I and II, while the voltage vector $\bar{v}_{s4}$ is the most tangential component to flux locus at the boundary of Sector II and III. Note that, the voltage vector that has the most tangential to flux locus is the most effective voltage vector that produces the maximum amplitude as well as angular velocity of flux vector. This is why these two voltage vectors $\bar{v}_{s3}$and $\bar{v}_{s4}$ are identified and chosen as the suitable voltage vectors when the flux vector is controlled in Sector II. In this sector, according to (2.1), the selection of $\bar{v}_{s3}$will increase the flux magnitude, otherwise the selection of $\bar{v}_{s4}$ will decrease the flux magnitude.

The control of circular flux locus may cause high switching frequency since the switching of active vectors will become more often, especially at high speed operations. During high speeds, the angular velocity of flux vector needs to be increased to maintain the capability of torque [9] in which the number application of zero vector that ideally halt the flux has to be reduced. Thus, selection of active vectors would be dominated and switched more often as the motor speed increases.

In order to reduce and limit the switching frequency, some modifications on DTC structure were proposed by many researchers. These include the use of multilevel inverters [10][11], carrier-based torque and flux controller [3][12], predictive control [7] and hexagonal flux controller [3][4]. For example, [10][11] suggested to apply suitable amplitude of vectors according to speed operations that can minimize the rate of torque/flux changes and hence the switching frequency. However, all methods above require complex control algorithms which not retain the simplicity the original DTC structure.