MODELING AND SIMULATION OF DIRECT TORQUE CONTROL OF BRUSHLESS DC MOTOR DRIVES

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DECLARATION

I declared that this report entitle “Modeling and Simulation of Direct Torque Control of Brushless DC Motor Drives” 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.

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“I hereby declared that I have read through this report entitled “Modeling and Simulation of Direct Torque Control of Brushless DC Motor Drives” and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Power Electronic and Drives)”

Supervisor’s Signature : ……………………………………..

Supervisor’s Name : ……………………………………..

Date : ……………………………………..

DEDICATION

Specially dedicated to my family

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In the name of ALLAH, Most Generous and Most Merciful. With the deepest sense of gratitude to ALLAH the Almighty for giving me strength and ability to complete this final year project report. These special thanks goes to my supervisor namely Dr Auzani Bin Jidin for his cooperation and advice that really help me to understand about my topic.

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ABSTRACT

Direct Torque Control (DTC) operates in two-phase conduction mode; where only two-phase produce switching at one time while the switching in conventional Torque Hysteresis Controller (THC) method resulted in three-phase. Thus, the significant of study is to prove that the switching frequency in THC is lower than DTC for every speed operating ranges. The problem in THC method is poor torque regulation performance due to the current or torque ripple is not restricted within predefined hysteresis bandwidth. As for DTC, the problem occur when small hysteresis bandwidth produce high switching frequency than THC in order to minimize torque ripple. This research project aims to model and simulate the DTC of BLDC and make comparison between the switching frequency and torque/current control performances produced in DTC and THC of BLDC drive. This simulation is conducted by using Matlab/ Simulink. The first things to look at are the mathematical modeling of BLDC motor. The anatomy of motor is required to understand basic operation of BLDC motor drive. Besides, principle of DTC and theory about THC are also important in order to analyze the performance of DTC and THC. The outcomes resulted from the simulation shows that DTC have better torque regulation due to optimum voltage vector selection but higher switching frequency than THC. As for the conventional THC, it produces poor torque regulation performance and low switching frequency than DTC. It is proved that both THC and DTC have its own advantages and disadvantages.

ABSTRAK

Kawalan Terus Daya Kilas (DTC) beroperasi dalam mod pengaliran dua- fasa; di mana hanya dua- fasa menghasilkan arus pada satu masa manakala pensuisan dalam konvensional Tork Histeresis Controller (THC) menghasilkan tiga fasa. Oleh itu, kepentingan kajian adalah untuk membuktikan bahawa kekerapan pensuisan dalam THC adalah lebih rendah daripada DTC bagi setiap kelajuan julat operasi. Masalah dalam kaedah THC adalah semakin prestasi peraturan tork kerana riak semasa atau tork tidak terhad dalam ditentukan histerisis bandwidth. Bagi DTC, masalah berlaku apabila jalur lebar histerisis kecil menghasilkan frekuensi pensuisan tinggi daripada THC untuk mengurangkan tork riak. Projek penyelidikan ini bertujuan untuk menjadi dan mensimulasikan DTC daripada BLDC dan membuat perbandingan antara kekerapan switching dan persembahan kawalan tork / semasa dihasilkan di DTC dan THC pemacu BLDC. Simulasi ini dijalankan dengan menggunakan Matlab / Simulink . Perkara pertama yang perlu dilihatt adalah model matematik BLDC motor. Anatomi motor diperlukan untuk memahami operasi asas BLDC memandu motor. Selain itu, prinsip DTC dan teori mengenai THC juga penting untuk menganalisis prestasi DTC dan THC. Hasil daripada simulasi menunjukkan bahawa DTC mempunyai peraturan tork yang lebih baik tetapi kekerapan suis lebih tinggi daripada THC. Bagi THC konvensional, ia menghasilkan prestasi yang lemah peraturan tork dan frekuensi pensuisan rendah daripada DTC. Ia membuktikan bahawa kedua-dua THC dan DTC mempunyai kelebihan dan kekurangan tersendiri.

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BLDC	–	Brushless DC Motor
CSI	–	Current Source Inverter
DTC	–	Direct Torque Control
FOC	–	Field Oriented Control
IM	–	Induction Motor
PMSM	–	Permanent Magnet Synchronous Motor
THC	–	Torque Hysteresis Control
VSI	–	Voltage Source Inverter

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CHAPTER 1

INTRODUCTION

1.1 Overview

In recent years, the research on brushless DC motor (BLDC) drives has received enormous attention due to its excellent dynamic response, high efficiency, wide speed and high torque capability performances. There are many methods to control the torque, flux and current in BLDC motor. These includes the use of Torque Hysteresis Controller (THC), Field Oriented Control (FOC) and Direct Torque Control method. Figure 1.1 shows the BLDC motor control.

THC is one of the technique to control the torque and phase current of the BLDC machine. This method is used to replace the conventional voltage control that results in very high current overshoot. The value of torque and current stay within certain limit in hysteresis band by using THC, as it will provide current protection. However, the drawback of THC is poor current or torque regulation performance. This disadvantage of THC encourages the development of two-phase DTC in order to have better regulation performance [1]. However, the use of DTC may give another problem namely higher switching frequency eventhough it operates based on two-phase conduction mode. Later, this thesis will prove that high switching frequency in DTC compared to that obtained in THC.

As for the FOC, it is use to decouple the control of flux and torque. The main disadvantages of FOC is because it is complex than DTC due to the presence of co-ordinate transformation that requires information on the instantenous positon of the appropriate flux space vector [2].

Theory and principles of Direct Torque Control was introduced in the mid 1980's [2]. It is a newer concept and have been quickly accepted in industry in only ten years rather than twenty years for vector control [2-3]. First implementation of DTC was originally developed for induction machine drives. However, this project are focusing on DTC of BLDC. These two fundamental of DTC of IM and DTC of BLDC are having slightly different and will be explained further. DTC requires simple signal processing method. In its basic form, DTC give simple control structure as it is sensitive to only variation of stator resistance [3,21]. Figure 1.2 and Figure 1.3 shows the control stucture between DTC and FOC. DTC recognizes that, it is possible to control flux and torque directly. The idea of DTC development was initiated from conventional vector control strategy. In vector control approach, the flux and torque able to be controlled instantenously using the respective producing current components. Similarly to that of DTC approach where the flux and torque can be controlled simultaneously based on the respective flux and torque error status to select the suitable voltage vectors for satisfying the demands.

Error exist in torque and flux can be used directly to drive the inverter without any current control loops that necessary for co-ordinate transformation in conventional FOC [3] is the basic idea of DTC. In order for the errors in flux and torque remain within the hysteresis bands, the output from the flux and torque controller are used to determine which of the possible inverter states should be applied to the machine terminal. In torque mode operation, correct estimation of stator flux and torque is very important for accurate operation of hysteresis controller. Thus, MATLAB/SIMULINK will be used as a simulation tools to analyze the performance of THC and DTC.

In addition, an accurate mathematical model of a Brushless DC Motor (BLDC) is important in DTC. It is fact that BLDC have become current trend for many applications. Computer hard drives, electronic-component cooling fans, electric or hybrid car are those that rely on BLDC motor [4-6]. BLDC known as synchronous motor because the rotor and stator turn at the same frequency. Thus, it eliminating slip that is normally seen in induction machine. Besides, BLDC is capable of providing large amount of torque over a vast speed range and is consider to be high performance motor drives.

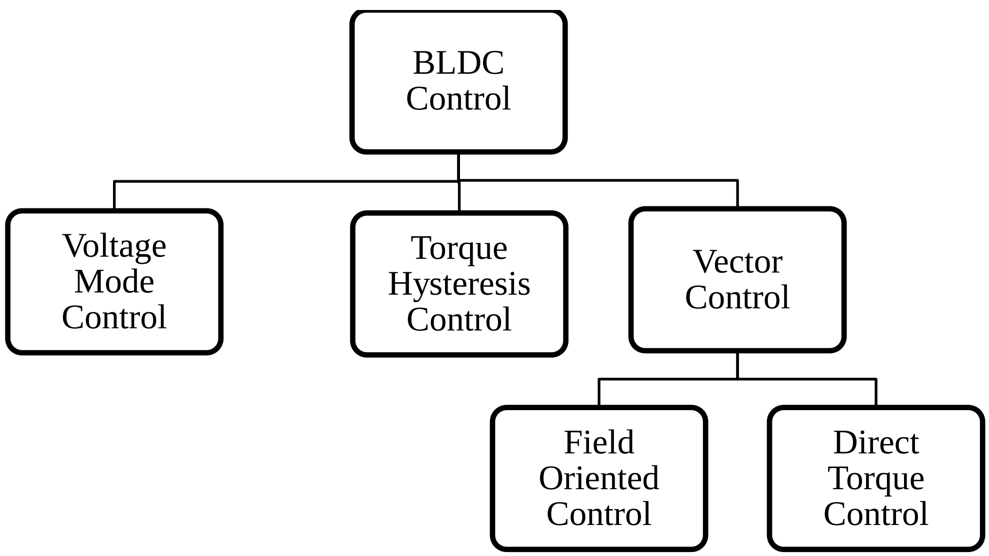

Figure 1.1 : BLDC Motor Control

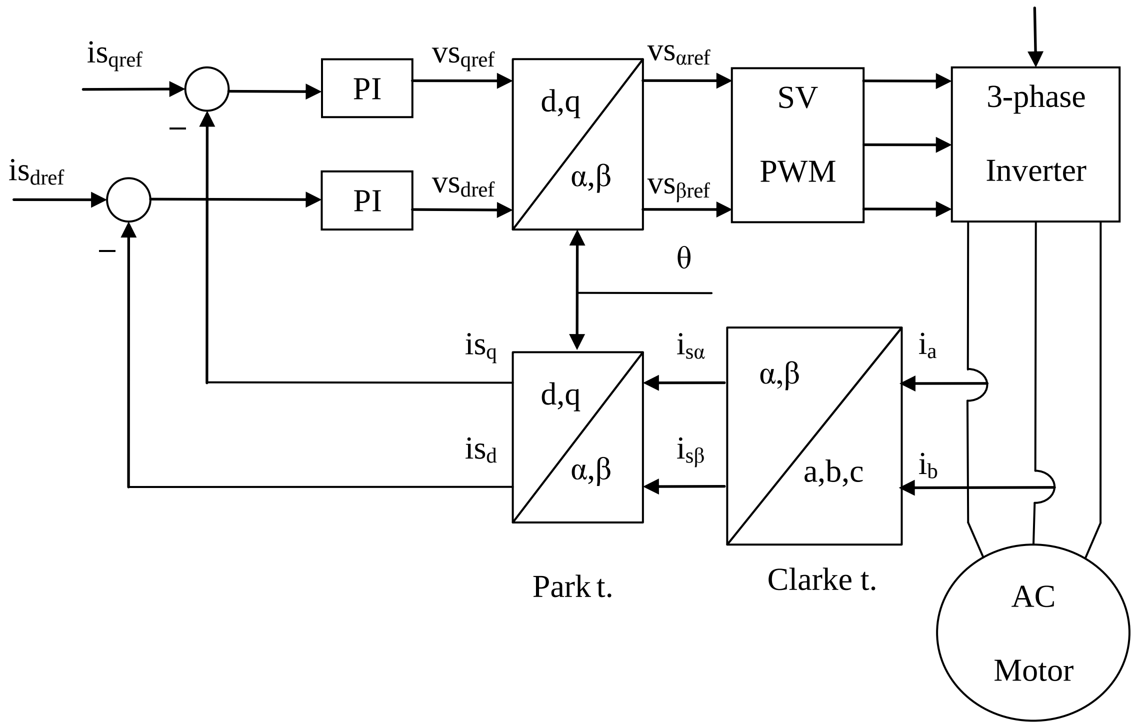

Figure 1.2: Basic Scheme of FOC of AC Motor

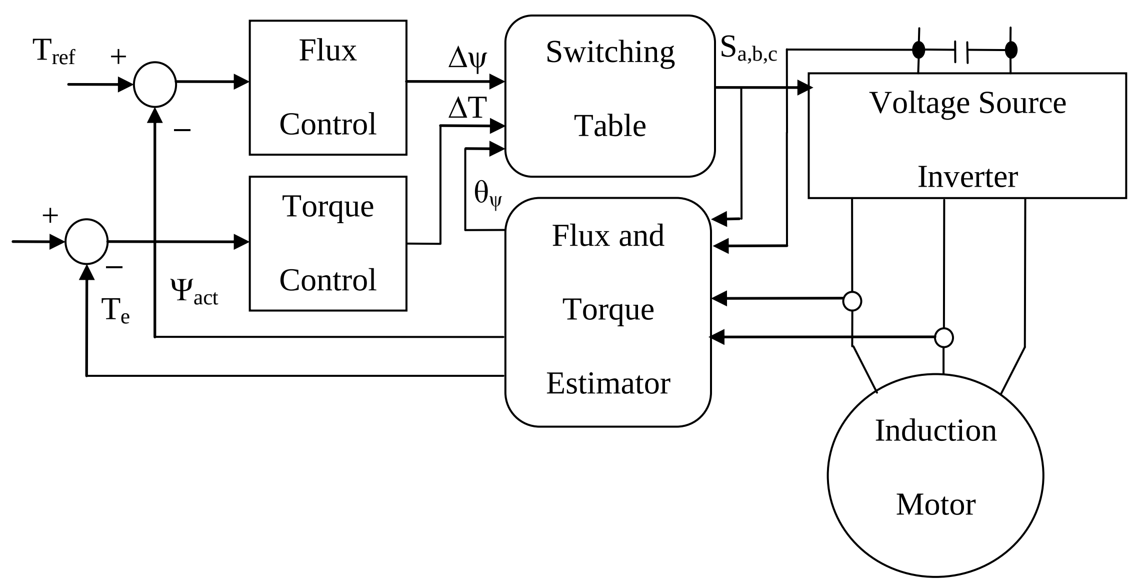

Figure 1.3: **Basic Scheme of DTC of AC Motor**

1.2 Significant of Research

Nowadays, the research on brushless DC motor (BLDC) drives has received enormous attention due to its excellent dynamic response, high efficiency, wide speed and high torque capability performances. It is known that the BLDC motor is the best option among other types of motor to replace the conventional brushed DC motor as it can achieve comparable DC motor performance however with less maintanence due to elimination of commutators and brushes in its construction. Moreover, the construction of BLDC motor allows the speed to operate for wide speed of range operations. However, the component used for the proposed topologies that is DTC of BLDC is lesser than the conventional (FOC). Thus, the implementation cost can be reduced.

In addition, it is well known that DTC has gained popularity because it offers excellent torque dynamic control. In DTC, it operates in two-phase conduction mode; where only two-phase produce switching at one time. As opposed to conventional THC method, the switching resulted in three-phase. It is engaged that the switching in DTC produces lower switching frequency and hence switching losses than that obtained in THC. However, the simulation results indicate otherwise. Meaning that, DTC produce higher switching frequency than THC. Thus, the significant of study is to prove that the switching frequency in THC is lower than DTC for every speed operating ranges.

1.3 Problem Statement

In the last two decade, several variations of BLDC drives have been proposed which includes the use of torque hysteresis controller (THC), and direct torque control (DTC). However, these methods have an essential difference in their implementation. The major problem in THC method is poor torque regulation performance. Current or torque ripple is not restricted within predefined hysteresis bandwidth. Simulation result in Figure 1.4 shows the torque or current regulation performance in THC.

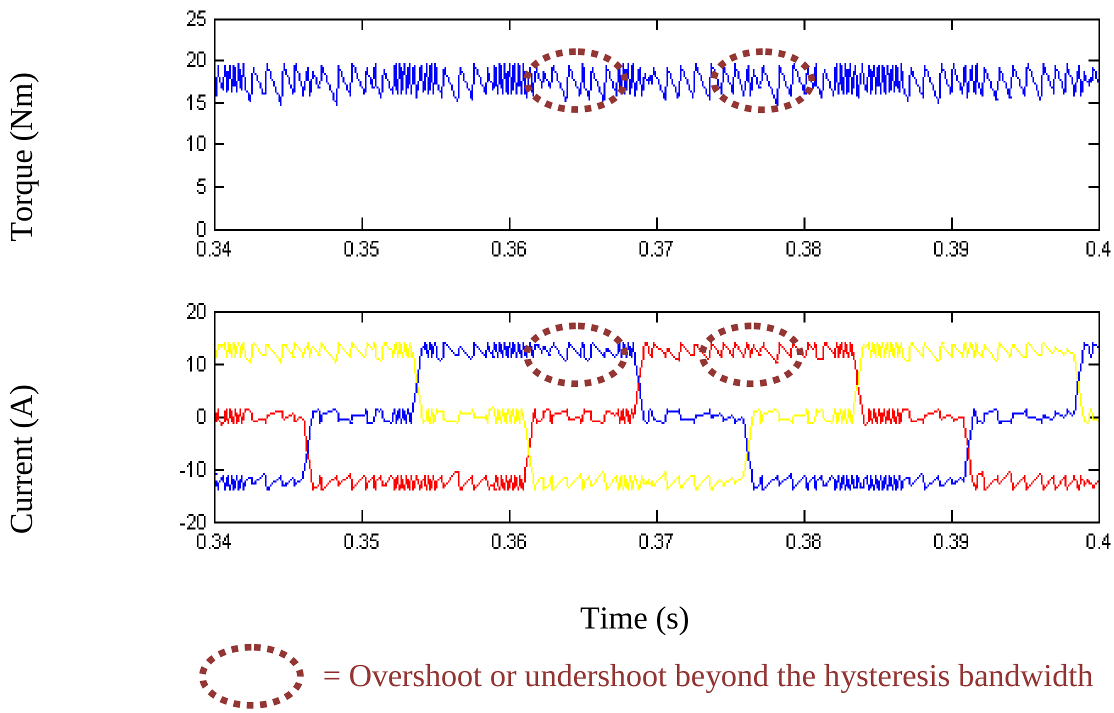

Figure 1.4 : Torque and Current Regulation Performance of THC

Besides, larger torque ripple in hysteresis controller both for DTC and THC need to be minimized ideally by reducing the bandwidth. However, reduce hysteresis bandwidth produce high frequencies since the regulation within bandwidth is more often. It shorten the time to travel (torque variation in bandwidth) from one band to another band. This phenomena lead to production of frequency exceed beyond the limitation of switching device known as IGBT. It affects the performance of the IGBT in terms of drop voltage, efficiency and the reliability of the switching device itself. Note that, it is desirable to provide high power efficiency of the BLDC drive system in order to prolong the energy battery source. The high switching frequencies caused in DTC is highlighted by using simulation results in Figure 1.5. It can be observed from right hand side of the figure (after zooming) that the switching frequency of DTC is high when small bandwidth is applied. It is analyzed by referring only to current in phase A. The torque hysteresis bandwidth (HB_T) is calculated in terms of percentage of peak current which is 12.714A and Table 1-1 below is the value of bandwidth for each percentage of current.

Table 1-1: Percentage and Torque Bandwidth in DTC

% of Peak Current	10% of Peak Current	25% of Peak Current
Torque Bandwidth (HB_T)	0.88998	2.22495

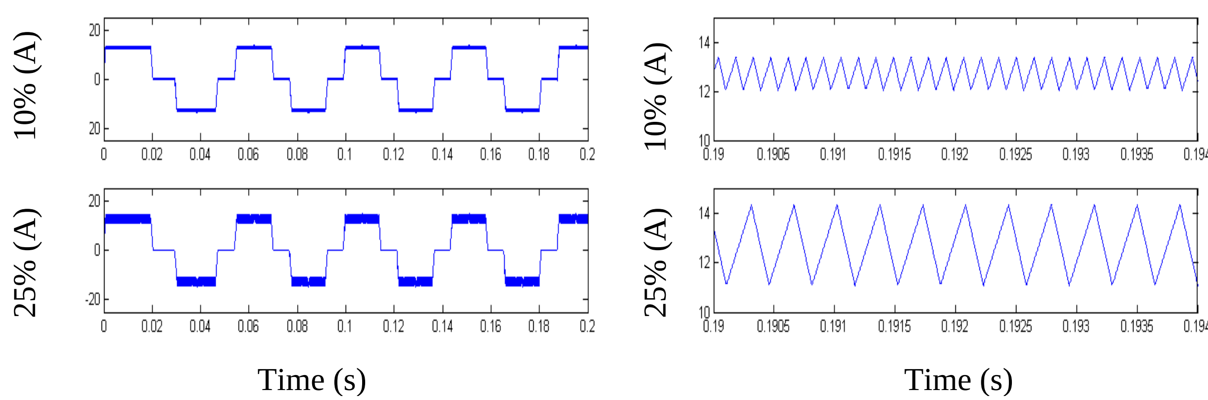

Figure 1.5 Switching Frequency Based on Hysteresis Bandwidth In DTC

1.4 Objective

The aims of this project are to:

i. model and simulate the Direct Torque Control (DTC) of Brushless DC Motor (BLDC) by using Matlab or Simulink.

ii. analyze and compare the switching frequency and torque/current control performances produced in Direct Torque Control (DTC) and Torque Hysteresis Control(THC) of Brushless DC Motor (BLDC) drive.

1.5 Scope of Research

This project mainly focuses on:

i. Mathematical modeling of BLDC motor.

ii. Modeling and simulation of DTC for BLDC motor using Matlab or Simulink.

iii. Evaluate the performances of DTC and THC of BLDC motor in terms of switching frequency and torque/current control.

1.6 Research Methodology

Upon completion of this research, several steps of process are made according to a sequence. All the steps or procedures in conducting this research are briefly explained in Chapter 3 with assistance of flowchart, milestone and Gantt chart that are given below.