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REDUCED TORQUE RIPPLE OF DIRECT TORQUE CONTROL OF INDUCTION MOTOR USING HYSTERESIS BASED CONTROLLER

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Date : JUNE 2018

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ASHRAF NUKMAN BIN AZLAN

A report submitted in partial fulfilment of the requirements for the degree of bachelor of electrical engineering

Faculty of Electrical Engineering

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2018

I declare that this report entitles "*Reduced Torque Ripple of Direct Torque Control of Induction Motor Using Hysteresis Based Controller*" is the result of my own research except as cited in the reference. The report has not been accepted for any degree and is not concurrently submitted in candidate of any other degree.

Signature **:** **……………………………………**

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Date **:** JUNE 2018

DEDICATION

A million thanks for all people who help me to finish the research especially to my beloved mother, father, supervisor, lecturers and friends. Thank you everyone.

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ABTRACT

Alternating Current (AC) motor drives required the precision and faster response controller to achieve the excellent and optimal performance. Therefore, the vector control has been introduced to control the AC drive, either steady-state or dynamic response. One of the vector control method is Field Oriented Control (FOC) to control the AC motor. Although the FOC is the first controlling method was introduced, but this vector control method is complicated configuration and difficult to design. After a few decades, Direct Torque Control (DTC) was introduced. This vector control scheme is popular method, simplest structure and easy implementation for controlling the AC motor. DTC is widely used in industry as well as the electric vehicles because it is easy to design the configuration. Asynchronous motor is one of the AC motor. Asynchronous motor namely induction motor has some advantages due to economical, maintenance and weight. The conventional DTC controller has some major problems such as high torque ripple and switching devices do not operate at optimal performance during hardware implementation. The switching frequency controlled by the Voltage Source Inverter (VSI). DTC drive can operate at different of speed condition with applied the voltage vector which generated by using Voltage Source Inverter (VSI) by appropriate selection of voltage vectors. To improve the performance of induction motor, this thesis proposed a new topology circuit of VSI to ensure the switching devices operate at optimal performance. The torque is controlled by using hysteresis-based controller. The tolerant band of the hysteresis band are being control as the performances of the motor will improve. In summary, the torque is reduced by the hysteresis-based controller and the switching frequency is being adapted by new structure of switching devices.

ABSTRAK

Pemacu motor Arus Ulang-alik (AC) memerlukan pengawal tindak balas yang lebih pantas dan pantas untuk mencapai prestasi cemerlang dan optimum. Oleh itu, kawalan vektor telah diperkenalkan untuk mengawal pemacu AC, sama ada tindak balas mantap atau dinamik. Salah satu kaedah kawalan vektor adalah Kawalan Berorientasikan Lapangan (FOC) untuk mengawal motor AC. Walaupun FOC adalah kaedah kawalan pertama diperkenalkan, tetapi kaedah kawalan vektor ini adalah konfigurasi rumit dan sukar untuk direkabentuk. Selepas beberapa dekad, Kawalan Langsung Tork (DTC) diperkenalkan. Skim kawalan vektor ini adalah kaedah yang popular, struktur mudah dan pelaksanaan yang mudah untuk mengawal motor AC. DTC digunakan secara meluas dalam industri serta kenderaan elektrik kerana mudah untuk merancang konfigurasi. Motor tidak sejajar adalah salah satu motor AC. Motor tidak sejajar iaitu motor induksi mempunyai beberapa kelebihan terhadap ekonomi, penyelenggaraan dan berat. Pengawal DTC konvensional mempunyai beberapa masalah utama seperti riak tork tinggi dan peranti pensuisan tidak beroperasi pada prestasi optimum semasa pelaksanaan perkakasan. Kekerapan menukar yang dikawal oleh Sumber Voltan Penyongsang (VSI). Pemacu DTC boleh beroperasi pada keadaan kelajuan yang berbeza dengan menggunakan vektor voltan yang dihasilkan dengan menggunakan Sumber Voltan Penyongsang (VSI) dengan pemilihan vektor voltan yang sesuai. Untuk meningkatkan prestasi motor induksi, tesis ini mencadangkan litar topologi baru VSI untuk memastikan peranti pensualan beroperasi pada prestasi optimum. Tork dikawal dengan menggunakan pengawal berasaskan histerisis. Toleran pengikat histeris dikecilkan menyebabkan prestasi motor akan bertambah baik. Ringkasnya, tork dikurangkan oleh pengawal berasaskan histeresis dan kekerapan penukaran disesuaikan dengan struktur peranti pensuisan baru.

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CHAPTER 1

INTRODUCTION

1.1 Research Background and Motivation

Several decades ago, almost all industries used brush Direct Current (DC) motor drive due to its structure and fast torque dynamic control. The fast dynamic control can be run by controlling the armature current due to the armature current is always perpendicular to the magnetic flux. However, the brush DC motor is expensive, high maintenance and not able to operate at very high speeds. The construction of brush DC motor based on commutator and brushes which can contribute limitation such as frictional. In additional, the brush DC motor requires regular maintenance due to degrading of winding insulator, particularly for the dc motor applications that require at high speed and high current or dirty environment. Due to the mentioned limitation, nowadays, there is a type of Alternative Current (AC) motor known to offer less maintenance requires, rugged and high efficiency. This AC motor is preferable for many industrial applications. Since 1970's, several vector control technique were introduced to provide excellent dynamic control performance compare to DC motor drives. [1]

At early stage, the vector control called as Field Oriented Control (FOC) was introduced in 1972 by Blaschke which enables to control the torque and flux using their respective current producing components in synchronous reference frame. In such way, the current components are DC quantities, so the armature current and field current in DC motor drive which control the torque and flux respectively. However, FOC needs a frame of transformer to convert the DC quantities of the currents to phase current. In additional, the FOC method required knowledge of machine parameters, speed information and current controllers to establish the control of torque and flux. In other words, FOC is a method with complex structure of design. Figure 1.1 shown the whole structure of Field Oriented Control (FOC).

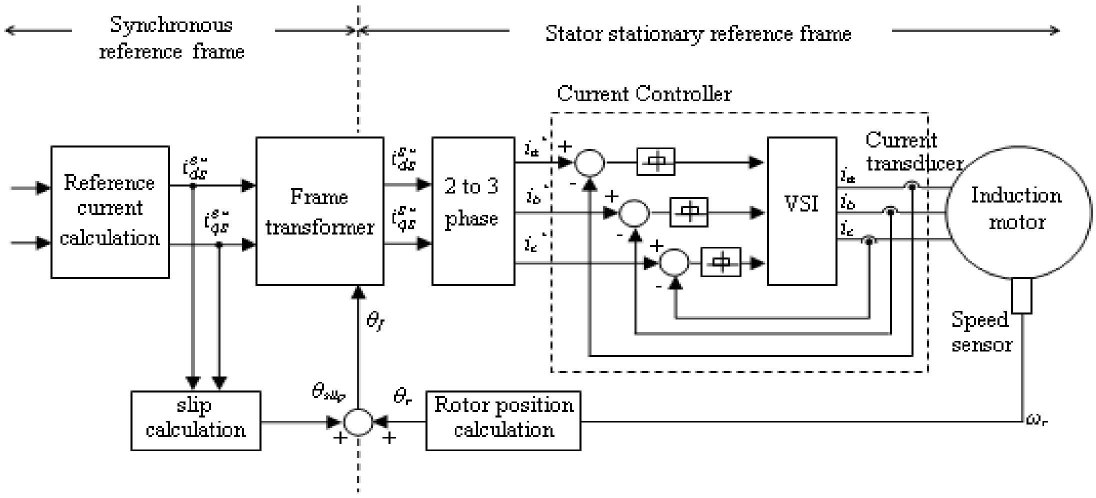

Figure 1.1: Structure of FOC of Induction Machine

After a few years later, a new method to control the torque and flux was introduced by Takahashi and Noguchi called Direct Torque Control (DTC). The structure of DTC is simpler than the structure of FOC. Figure 1.2 shows the DTC general structure which eliminates the use of current controller, frame of transformer and the speed sensor. In additional, the DTC method has less sensitivity on parameter variations due to the changes of temperature. Since, the DTC does not totally depends on machine parameters to estimate the control parameters, as the FOC control method. DTC is the simplest method model to estimate the stator flux which only required a stator resistance information. A decouple control structure employed in DTC scheme, where the torque is being controlled by using three-level hysteresis comparator while the flux is controlled by using two-level hysteresis comparator as shown in Figure 1.2. The comparators are used to restrict the errors within the limitation of the hysteresis bands by providing error statuses to the switching table. So, the restriction errors can be accomplished as the switching states to switch the appropriate voltage vector. The appropriate selection of voltage vector, can control the torque and flux. Figure 1.2 below shows the structures of Direct Torque Control (DTC).

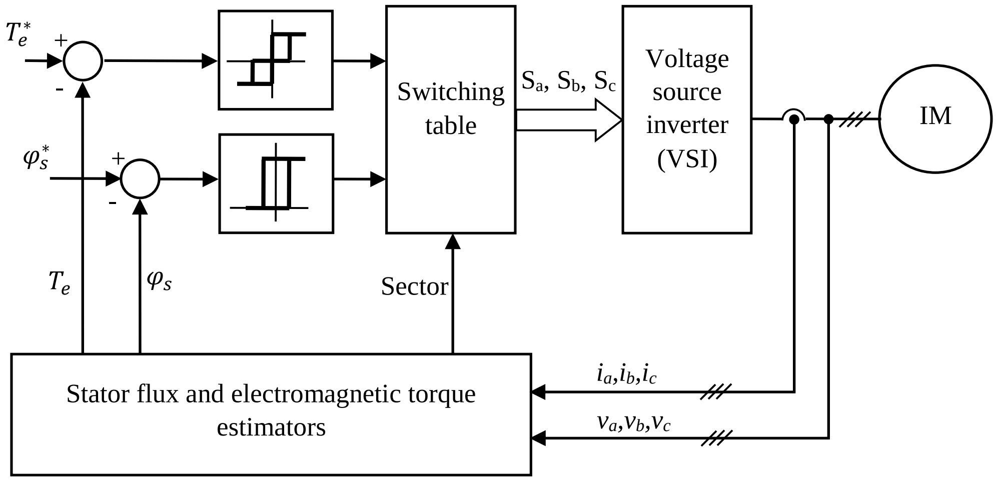

Figure 1.2: Structure of DTC of Induction Machine

In 1985, Depenbrock proposed a new method to control the induction motor call Direct Self Control (DSC). The Direct Self Control (DSC) method makes the induction motor possible to achieve precise control of torque and speed in an inverter-fed induction motor drive system. The DSC is well suited to high power drives with low switching frequency. The DSC method gives an inverter and fed into induction motor with excellent dynamic performance. The DSC control method is the improvement from DTC method but the DSC general structure is more complex compared to DTC. The control principle of the torque and flux are same with the DTC control principle which based on hysteresis comparisons by selecting the optimum inverter switching modes. Generally, the Depenbrock upgraded the DTC control method and introduced the same technique with complex structures named DSC Figure 1.3 shows the DSC structure of induction motor.

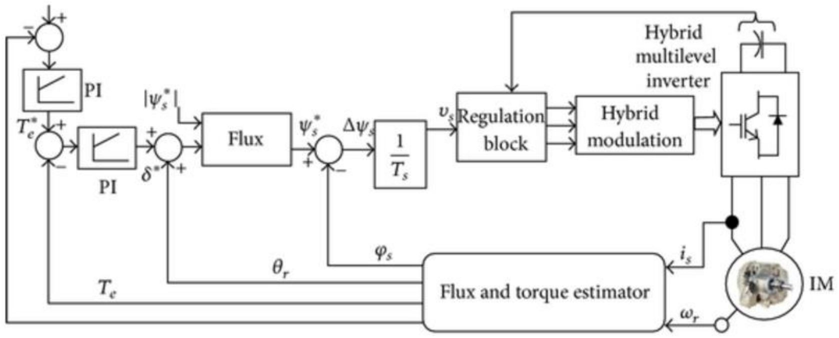

Figure 1.3 Structure of DSC of Induction Machine

Refers to the structure of the control method, DTC is the more simplicity compared to others. In fact, DTC is DTC is a fast instantaneous control performance. DTC is widely used and replaces the FOC for many industrial applications, while DSC is used for the high power drives. However, the DTC control method has major drawbacks such as larger torque ripple and variable switching frequency cause by the hysteresis operation in controlling the stator flux and torque.

Among the various modification of DTC, the Space Vector Modulation (SVM) was adapted in DTC structure has received widely acceptance. Due to SVM features can offer great reduction of torque ripple and a constant switching frequency (Mardani Borujeni and Ardebili, 2015, Bo et al., 2014, Tripathi et al., 2005, Lascu et al., 1992, Casadei et al., 1998). Although the implement of the SVM in DTC offers great reduction of torque ripple, but the present of the SVM increases the complexity which somehow degrades the accuracy of control performance and dynamic torque control performance.

Lately, the application of voltage source inverter has being popular and widely used to improve the DTC performances due to its attractive features such as low voltage stress on switching devices which allows to operate at high voltage or high current operations, low harmonic current or voltage distortion which eliminates the use of filter and improved efficiency and torque dynamic performance with optimal selection of voltage vectors.

1.2 Problem Statement

Direct Torque Control (DTC) is a simple method of controlling the torque and flux. Despite the simplicity, controlling induction motor by using DTC based on hysteresis controller will cause some major problem such as large torque ripple. Large torque ripple will increased the current as increased the current losses and lead to eddy current. However, by using the hysteresis controller, the torque can be adjusted to desired torque by changing the range of lower band and upper band. The middle of the band represented the torque reference or torque estimation. The band cannot be set too small because the incidents of overshoot in the estimated torque across the upper band in torque hysteresis band may occur and hence causes the reverse voltage vector to be selected. The selection reverse voltage vector causes torque decreased rapidly. The occurrence of torque changes rapidly will become more often and consequently produces larger torque ripple.

Although the torque ripple decreased, the switching frequency of the Voltage Source Inverter (VSI) will be increased. The rapidly increase of the switching frequency will cause heat at switching devices. The Integrated Gate Bipolar Transistor (IGBT) is being used as the switching devices. The heat produces will cause thermal losses. Furthermore, if the switching devices are withstanding the heat in a long period of time will affect the switching performance. The switching performance will be degraded due to thermal restriction.

1.3 Research Objective

The objective of this thesis to improve the performance of Direct Torque Control (DTC) of induction motor using Voltage Source Inverter (VSI) as the switching operation. The aim of this thesis is to reduce the torque ripple using the hysteresis-based torque controller. Next target of the project is to operate the switching devices, Integrated Gate Bipolar Transistor (IGBT) at optimal performance by replacing one switching device with a group of four switching device connected in parallel. Lastly, verify the technique and implement through simulation and experimentation result.

1.4 Project Scope

The scope of this project to conduct the proposed method to operate the induction motor with high performance. One of the scope of the project is to improve the Direct Torque Control (DTC) of induction motor performances by reducing the torque ripple using hysteresis-based controller. The other aim of the project is to ensure the switching operation is operating at optimal performance by replacing one switching device with a group of four switching devices connected in parallel in the structure of Voltage Sources Inverter (VSI). Lastly, the scope is to verify, evaluate and compare the improvements of the Direct Torque Control (DTC) method via simulations and hardware results.

1.5 Report Outline

This report consist of five chapters. This report starts with the introduction of the project, literature review, project methodology, result obtained, discussion and conclusion.

Chapter 1 covers the short explanation of project background, problem statement, objectives of the project and project scope.

Chapter 2 explains the basic operating principle of induction motor, short explanation of the control method and simple discussion about previous research of DTC of induction motor.

Chapter 3 covers the project methodology. This chapter consist of the mathematical model, flowchart of the project, milestone, Gantt chart, mapping of voltage vector selection, simulation model, switching operation of VSI, principle control of torque and flux and hysteresis operation.

Chapter 4 discusses the simulation results and hardware results then compare both results to verify the performances.

Chapter 5 is the summary of this project and recommendation for future work as to improve the performance of DTC of induction motor.

CHAPTER 2

LITERATURE RIVIEW

2.1 Introduction

There are three major type of electric motor machine. The main types of electric motors are Direct Current (DC) motor, Alternating Current (AC) motor and special motor machine. The DC motors are divided into groups depend on their construction which are shunt, series, compound, separately-excited and switched reluctance motor. The AC motors are divided into two types respectively such as asynchronous motor and synchronous motor. Usually, all the machine will be connected with selected power converter types depends on the types of motor and the supply applied to the machines. There are four major types of power converter which are rectifier, chopper, inverter and cycloconverter. The three phase motors are motors designed to operate on three phase Alternating Current (AC) power used in many industrial applications. AC electricity changes direction from positive to negative and repeated many times as well as the motors are operating. AC change power in a smooth continuous wave called sine wave. The three phase AC has three sources of AC power with different phase angle to another. The phases are separated by 120^{o} apart. There will be no two AC waves are ever at the same point at the same time. The important part in designing the construction of the motor is the controller. The basic function of the controller is to control the torque, flux or speed of the motor.

2.2 Asynchronous Motor

Asynchronous motor is an induction motor which is the motor most frequently and widely used in industry. Most of the induction motors are simple, rugged, low price and easy to maintain. The induction motors run at the constant speed from no load to full load. The speed is depending on the frequency respectively, therefore the induction motors are not easily adapted to speed control. However, there are some techniques can be used to control the operation of induction motor.

2.3 Operating Principle

The operation of a three phase induction motor is based upon the application of Faraday's Law and the Lorentz Force on a conductor. Consider a series of conductors of length, *l*, whose are short circuited by two bars. A permanent magnet placed above the conducting ladder, moves rapidly to the right at a speed, *v*, so that the magnetic field, *B*, sweep across the conductor. The sequence of events takes place:

1. By using Faraday's Law, a voltage $E = Blv$ is induced in each conductor while being cut by the flux.
2. The induced voltage produces a current, *I*, which flow down the conductor underneath the pole-face, through the end-bars and back through the other conductor.
3. The current flow through conductor lies in the magnetic field of the permanent magnet, produces a mechanical force called Lorentz Force.
4. The force always acts in a direction to drag the conductor along with magnetic field.

If the conducting ladder is free to move, the rotor will accelerate towards the right. However, as control the speed, the conductors will be cut less rapidly by the moving magnet, with the result that the induced voltage, *E*, and the current, *I*, will diminish. In addition, the force acting on the conductors will also decrease. If the ladder were to move at the same speed as the magnetic field, the induced voltage, *E*, the current, *I*, and the force dragging the ladder along would all become zero.

2.4 Voltage Source Inverter (VSI)

The Voltage Source Inverter (VSI) can be divided into square wave inverter and Pulse Width Modulation (PWM) inverter is fed by a Direct Current (DC) source of very small internal resistance. VSI are basically built with Insulated Gate Bipolar Transistor (IGBT) or Gate Turn-Off (GTO) thyristor. Normally, the input voltage of the inverter will parallel with a capacitor to produce a constant DC voltage. The output terminal is an Alternating Current (AC) will remain constant irrespective of the load current drawn theoretically. Figure 2.1 shows the topology circuit of Voltage Source Inverter (VSI).

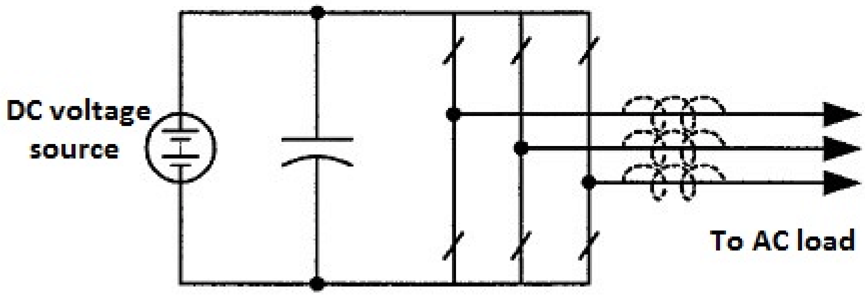

Figure 2.1: Topology Circuit of Voltage Source Inverter

2.5 Control Strategy of Induction Motor

The control method of induction motors can be classified into two groups named scalar control and vector control strategies. The scalar control method is based on two parameters simultaneously. The speed can be changed by varying the supply frequency. The impedance will be changing according to the operation of increasing or decreasing the supply frequency. In fact, the changes of the impedances will affect the current. If the supply frequency is decreasing or the voltage applied is increasing, the coils inside the induction motor can be burned or saturation in the iron of coils can occur. These problem can be avoided by using the scalar control. It is very necessary to control the frequency and vary the voltage simultaneously.