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Supervisor's Name : Dr.AUZANI BIN JIDIN

Date : 18 JUNE 2014

SIMULATION OF DIRECT TORQUE CONTROL OF INDUCTION MACHINE USING THREE-LEVEL CASCADED H-BRIDGE MULTILEVEL INVERTER

MOHAMAD RASYIDI BIN NAZIR ALI

A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering (Power Electronic and Drives)

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

YEAR 2014

I declare that this report entitle “SIMULATION OF DIRECT TORQUE CONTROL OF INDUCTION MACHINE USING THREE-LEVEL CASCADED H-BRIDGE MULTILEVEL INVERTER” 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	:	MOHAMAD RASYIDI BIN NAZIR ALI
Date	:	18 JUNE 2014

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ABSTRACT

Direct torque control (DTC) is a method based on vector control that attracts many researchers since it been introduced in 1986. Mostly this method has significant implementation on the induction machine compared to other machine. This is because the simple structure and less parameter required in order performing this mechanism. However, this method has several disadvantages when applying with the two-level inverter such as less selection of effective voltage vector and high switching frequency. This is because the possible number of voltage vector that can be selected is only six. Thus, this problem leads to the losses during the operation of induction machine and increase the torque ripple. Therefore, this research project is to replace the conventional two-level inverter with the cascaded H-Bridge multilevel inverter (CHMI). One of the aims of this project is to formulate an optimal voltage vector selection according to the speed operation for direct torque control of induction machines. Besides that, this project aims to verify the proposed selection of voltage vectors which improve efficiency and reduce torque ripple. In order to achieve the objective, a comprehensive study done by emphasizing on current technical papers to develop the simulation model. First and the foremost, is to construct the induction machine model based on it mathematical equation. By having crystal clear of understanding of the CHMI topology, the next step is to formulate the look-up table. This look-up table consist of three important parameters that are flux magnitudes which control by two-level hysteresis comparator, torque magnitude which control by seven-level hysteresis comparator and the sectors definition of the stator flux plane. In addition, verification of efficiency is done by construct the switching calculation algorithm. The finding highlighted significant improvement of efficiency especially during low speed that is reduction of 61.4% compared to the conventional inverter. The zoom images manage to prove that the torque have reduce significantly compared to conventional.

ABSTRAK

Kawalan tork langsung adalah satu kaedah berdasarkan kawalan vektor yang menarik minat ramai penyelidik sejak ia diperkenalkan pada tahun 1986. Kebanyakan kaedah ini mempunyai pelaksanaan yang ketara pada mesin induksi berbanding dengan mesin lain. Ini adalah kerana strukturnya yang mudah dan parameter yang kurang diperlukan bagi melaksanakan mekanisme ini. Walaubagaimanapun, kaedah ini mempunyai beberapa kelemahan apabila diaplikasikan dengan penyongsang dua tingkat seperti pemilihan vektor voltan yang kurang berkesan dan kekerapan yang tinggi. Ini adalah kerana jumlah kemungkinan vektor voltan yang boleh dipilih hanya enam. Oleh itu , masalah ini membawa kepada kerugian dalam operasi mesin induksi dan meningkatkan ganguan kepada tork . Oleh itu, projek penyelidikan ini adalah untuk menggantikan penyongsang dua peringkat konvensional dengan penyongsang bertingkat H-Bridge. Salah satu matlamat projek ini adalah untuk merumuskan pilihan vektor voltan yang optimum mengikut kelajuan operasi. Selain itu, projek ini bertujuan untuk mengesahkan pemilihan vektor voltan yang betol bagi meningkatkan kecekapan dan mengurangkan ganguan tork. Untuk mencapai objektif ini, satu kajian komprehensif dilakukan dengan memberi penekanan terhadap kertas kerja teknikal semasa untuk membangunkan model sumulasi. Langkah pertama dalah untuk membina model mesin induksi berdasarkan persamaan matematik . Dengan mempunyai pemahaman yang terhadap topologi CHMI , langkah seterusnya adalah untuk merangka jadual carian. Jadual carian ini terdiri daripada tiga parameter penting iaitu magnitud fluks yang dikawal oleh dua tahap histerisis comparator , magnitud tork yang dikawal oleh tujuh peringkat histerisis comparator dan definisi sektor. Di samping itu, pengesahan kecekapan dilakukan dengan membina algoritma pengiraan pensuisan . Dapatan menekankan peningkatan yang ketara kecekapan terutamanya semasa kelajuan rendah yang menunjukkan pengurangan sebanyak 61.4 % apabila dibandingkan dengan penyongsang konvensional. Imej-imej zoom juga membuktikan ganguan tork juga berjaya dikurangkan.

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DTC	Direct Torque Control
FOC	Field Oriented Control
VSI	Voltage Sources Inverter
CHMI	Cascaded H-Bridge Multilevel Inverter
NPC	Neutral Point Clamped
FCMI	Flying Capacitor Multilevel Inverter
EMC	Electromagnetic Compatibility
GTO	Gate Turn-Off Thyristor
IGBT	Insulated Gate Bipolar Transistor

CHAPTER 1

INTRODUCTION

1.1 Overview

In the real industry world, control of induction machine play a vital role as it has many application in real work place. Induction machine has several advantages such as rugged, less complex and affordable in price. Direct torque control (DTC) is a vector based control technique that proposed in early 1980 where it involves the combination control of torque and flux by feedback and closed loop estimation process. A comprehensive researches and latest update based on this control technique has been proved by hundreds of paper related to this DTC are published since the last two decade. Furthermore, DTC only required information of resistance in stator which make it simpler control technique compared to field oriented control (FOC) which required both stator and rotor parameters. Nowadays, development of multilevel inverter recently has been a solution to the major problem highlighted in conventional inverter since it provides more effective voltage selection. For instance, cascaded H-Bridge multilevel inverter (CHMI), neutral point clamped (NPC) and flying capacitor multilevel inverter (FCMI) are among the three multilevel inverters that popular and many research related this have been publish. This is because the advantages that highlighted by multilevel inverter such as ability to achieve high power from medium source, can generate the output voltages with very low distortion and reduce the rate of change of voltage (dv/dt) which improve the electromagnetic compatibility (EMC) problem.

1.2 Project motivation

DTC technique that proposed using conventional inverter has several disadvantages such as less selection of effective voltage vector hence lead to high switching frequency. The limited voltage vectors selection are as shown in Figure 1.1 which comprise of six voltage amplitude. Less effective voltage vector happen because the fixed of two level in the conventional inverter has cause inappropriate selection of switching occur especially when changes of the speed happen. The high rate change of voltage (dv/dt) has cause increase in torque ripple [1]. By this improper selection of switch also lead to the increase in switching frequency. High switching frequency has cause losses to the operation of induction machine and increase possibility of overshoot to happen [1].

Therefore, by replacing the conventional inverter with the CHMI it bring significant improvement since the level of effective voltage has increase and lead to more strategy switching state during changes of speed occurs. By having proper selection of effective voltage vector, the torque ripple reduces [1]. Therefore, the efficiency of direct torque control of induction machine improves by the minimization of torque ripple since the switching frequency of inverter is also reduces.

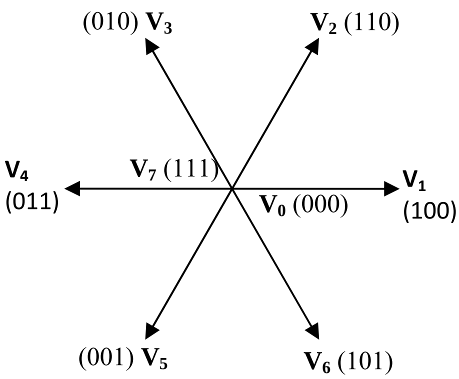

Figure 1.1: Limited voltage vector in conventional inverter lead to inappropriate selection of switching occurs

1.3 Objective

(i) To formulate n optimal voltage vector selection according to speed operations for DTC of induction machine.

(ii) To verify the proposed selection of voltage vectors can improve efficiency and reduce torque ripple.

1.4 Scope of research

The scope of this project focuses on the development of optimal look-up table for DTC utilizing on 3-level CHMI by using simulation only. The simulation was carried out using Matlab/Simulink simulation package. The simulation is then verified by adding switching frequency algorithm to the DTC simulation to carry the analysis. Comparison between 3-level CHMI and conventional inverter will be discussed after the final result is achieved to highlight the advantages of 3-level CHMI.

1.5 Report outline

The general description of this report outline is discussed in this subsection. Basically these reports are based on five chapters. The executive summary was provided before the first chapter to give overview of the whole project.

First and foremost, chapter one provides overview to give better understanding of the project. This chapter also highlights the significant of the problem statement, objective and scope of the project.

The second chapter provides information based on the conventional and basic topology of the project. The previous works based on the previous research will be discussed in detail to provide guideline to construct the next chapter.

Chapter three will discuss and highlight the method that use to model and construct the simulation. The result will be proving in the chapter four where it based on the work done in previous chapter.

Last but not least, conclusion section provide summary of the whole project. Recommendations based on the finding during the project also will be emphasize for the improvement on next project.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory

2.1.1 Introduction

The process of undertaking a literature review is an integral part of doing this project on simulation of DTC of induction machine using 3-level CHMI. It is a critical evaluation to gain an understanding of the continuously research on various control technique of induction machine and the advances strategies used in latest development of multilevel inverter. This section also will discuss the review of technical report that related to latest finding in DTC and CHMI. Thus provides a clear, better and deeper understanding on technique to improve dynamic performance in correspond to compare the performance with conventional finding.

2.1.2 Control technique

Generally the control techniques to control speed of induction motor are based on scalar and vector control. Firstly, scalar controls proposed less complex technique to working with and bid better steady-state response. However, the dynamic response take long times since the transient are uncontrollable. Frequency of voltage and current is the parameter to be controlled in scalar. Early in 1970, to control induction machine, the field oriented control which emphasize on the principle of torque and flux control was introduced. Later on, a decade after, DTC was proposed. Figure 2.1 summarized the flowchart of variable frequency control. The highlight part to indicate the focuses of this project that is DTC.

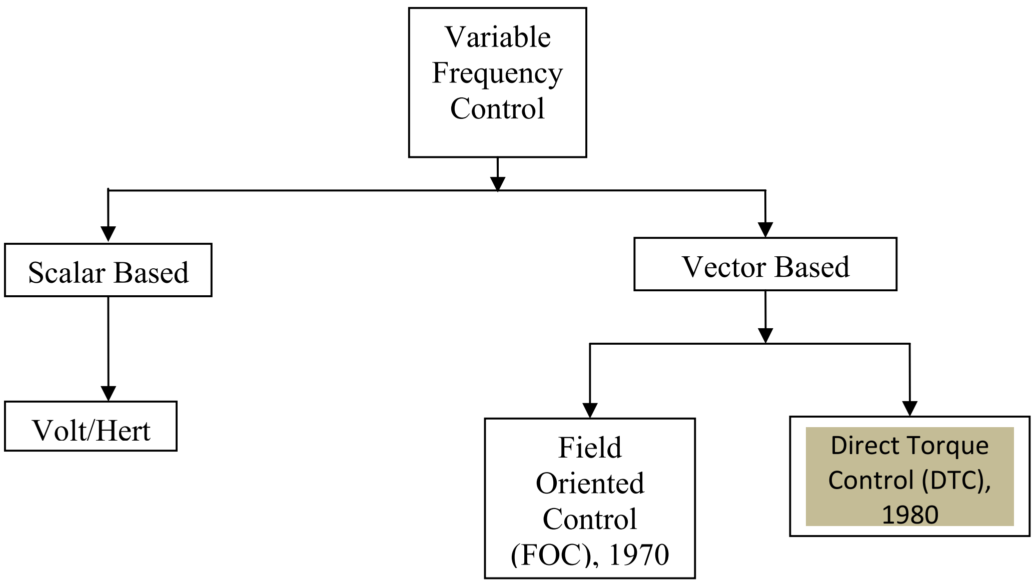

Figure 2.1: Summarization on the evolution of control technique scheme

2.1.3 Conventional three phase voltage source inverter (VSI)

This subsection provides a review about conventional three phase two level inverter. Inverter function basically is to convert direct current (DC) to alternating current (AC). Figure 2.2 shows three phase VSI that contain six numbers of insulated gate bipolar transistor (IGBTs) or gate turn-off thyristor (GTOs) where each leg made up of a pair power switching devices. This power switching devices is complimentary to one another on operation. For instance, when voltage is supply to the IGBTs, if upper switch (S_{a1}) is ON the lower switch (S_{a2}) must be OFF and vice versa.

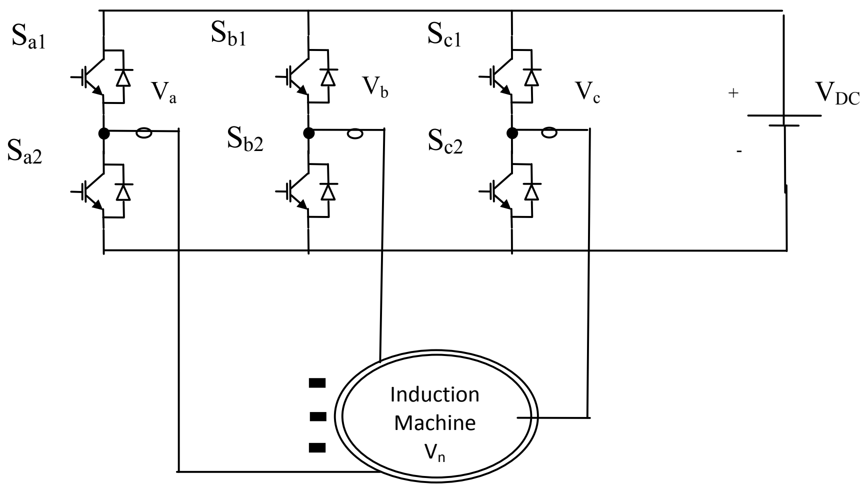

Figure 2.2: Topology of Voltage Sources Inverter (VSI)

In general, the switching state can have 8 different possibilities of switching from the equation 2^{n}, where n=3 are the number of legs contain in VSI. The possibilities are show in Figure 2.3 based on type of voltage vector plotted by the given equation [2.1]

$$V_k = \frac{2}{3} V_{DC} (S_a + aS_b + a^2 S_c) \quad \text{where } a = e^{j2\pi/3} \text{ and } k = 0, 1, 2 \ldots 7. \qquad (2.1)$$

where V_k is the different possibilities of switching in voltage space vector

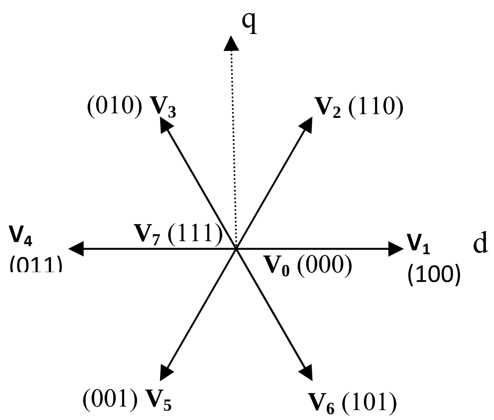

Figure 2.3: Voltage space vectors of a 3-phase inverter with the corresponded switching states

2.1.4 Basic principle in direct torque control (DTC)

In order to construct a look-up table, the basic principle in general must be followed to ensure all the requirement parameter included in this part. Three important parameter in this part is flux error status, torque error status and sector definition. Firstly, direct flux control are as shown in Figure 2.4 where the flux error enter the two level hysteresis comparator to produce flux error status φ^+ either 0 or 1. The error is obtaining by comparing the reference input flux, $\varphi_{s,\,ref}$ and estimated stator flux, φ_s. The summary of this process are highlighted in Figure 2.5.

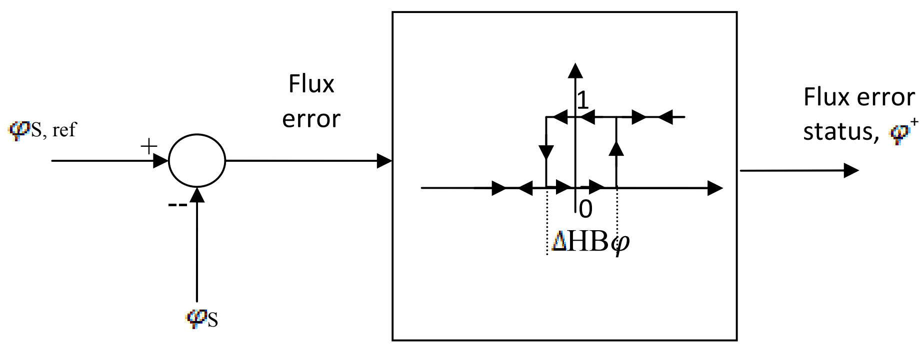

Figure 2.4 Control of flux magnitude using a 2-level hysteresis comparator

Flux error status
- 1 Touches lower band, stator flux need to be decrease
- 0 Touches upper band, stator flux need to be increase

Figure 2.5: Summary of flux error status in hysteresis band

Beside flux, torque also needs to be controlled. Secondly, DTC are as shown in Figure 2.6 where the torque error enter the three level hysteresis comparator to produce torque error status, T_{stat} either 1,0 or -1. The errors are obtained by comparing the reference input torque, $T_{e,ref}$ and estimated torque flux, T_e. The summary of this process are highlighted in Figure 2.7.

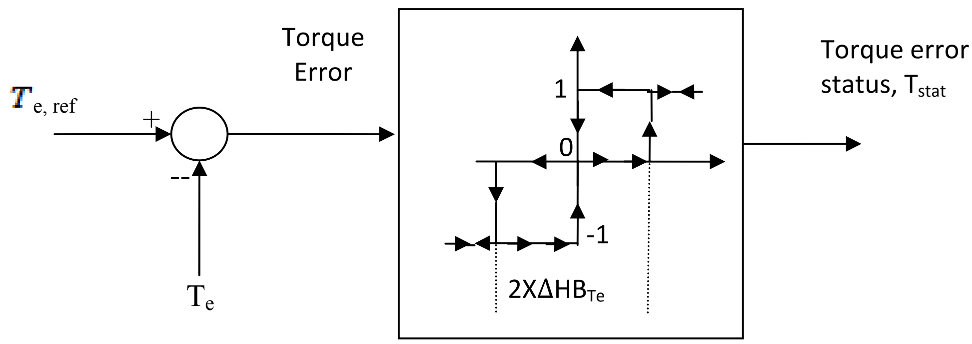

Figure 2.6: Control of torque using a 3-level hysteresis comparator

Torque error status
- 1 Touches upper band, active forward voltage vector
- 0 Touches middle band, zero voltage vector selected
- -1 Touches lower band, active reverse voltage vector

Figure 2.7: Summary of torque error status in hysteresis band

Last but not least are the sector definitions, which are divided equally to six sectors. For example, Figure 2.8 illustrates on how the flux is increased and decreased with the use of voltage vectors V_1 and V_2 respectively when it lies in Sector II. This pattern continuous for one completes cycle with the pattern increase and decrease by the use of different voltage vector.