DEVELOPMENT OF SIMULINK MODEL OF DIRECT TORQUE CONTROL OF INDUCTION MACHINE

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"I hereby declared that I have read through this report and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)."

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ABSTRACT

Direct torque control (DTC) is one of the most excellent control strategies of torque control in induction motor. The aim is to control effectively the torque and flux. Torque control of an induction motor (IM) based on DTC strategy has been developed and a comprehensive study is present in this thesis. Direct torque control is the first technology to control the real motor control variables of torque and flux. This method made the motor more accurate and fast torque control, high dynamic speed response and simple to control. The reference value can be calculated using the flux and torque estimated and also motor parameter. This report presents a principle of the DTC; switching table, and selection of the amplitude of the hysterisis band of torque and flux. The basic dynamics performance of DTC is investigate. The performance is including in when the motor was in starting drives and when motor in nominal value. The performance of this control method has been demonstrated by simulations using a versatile simulation package, matlab/simulink.

ABSTRAK

Direct Torque Control (DTC) merupakan salah satu teknik yang paling baik untuk mengawal daya kilas dalam motor aruhan. Tujuannya adalah untuk mengawal daya kilas dan fluk secara efektif. Kawalan daya kilas pada motor aruhan berpandukan strategi. DTC dibina dan pembelajaran secara menyeluruh dibentangkan dalam tesis ini. *Direct Torque Control* adalah teknologi pertama yang mangawal motor sebenar dengan daya kilas dan fluk yang boleh diubah. Kaedah ini menjadikan motor lebih tepat, dapat mengawal daya kilas dengan cepat, bertindak balas terhadap kelajuan yang tinggi dan mudah dikawal. Nilai rujukan dikira menggunakan daya kilas dan fluk anggaran disamping parameter motor. Tesis in mengandungi peranan DTC; jadual suis, dan pemilihan amplitud untuk *hysterisis band* pada daya kilas dan fluk. Persembahan dinamik DTC juga dikaji termasuklah apabila motor dalam keadaan permulaan bekerja dan juga apabila mempunyai beban. Persembahan ini dibuat dengan membuat simulasi menggunakan pakej simulasi serba boleh iaitu matlab/simulink.

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LIST OF PRINCIPLE SYMBOLS

v_{as}, v_{bs}, v_{cs}	stator voltages
i_{as}, i_{bs}, i_{cs}	stator currents
i_{ds}, i_{qs}	direct and quadrature-axis stator currents
$\overline{V}_s$, $\bar{I}_s$	stator voltage and current space vectors
ω_e	stator electrical frequency
ω_{sl}	slip frequency
θ_e	unit vector
θ_{sl}	slip angle
Vdc	dc link voltage
Sa, Sb, Sc	inverter gating signals (0 or 1)
$\overline{\psi}_s$, $\overline{\psi}_r$	stator and rotor flux linkages
L_s, L_r, L_m	stator, rotor and mutual inductance
R_s, R_r	stator and rotor resistance
$\tau_r = L_r / R_r$	
$\sigma = 1 - \frac{L_m^2}{L_s L_r}$	
s	Laplace operator
p	number of poles
*	star denoting a reference value

CHAPTER 1

INTRODUCTION

1.1 Background Review

Direct Torque Control or DTC is the world's most advanced alternating current (AC) drive technology based on the of field oriented control of induction machines, published by German scientist Blaschke and Depenbrock in 1971 and 1985. It is the very latest AC drive technology developed by ABB is set to replace traditional Pulse Width Modulation (PWM) drives of the open and closed-loop type in many applications [6].

The technique of Direct Torque Control works is control of torque and speed are directly based on the electromagnetic state of the motor, similar to Direct Current (DC) motor, but contrary to the way in which traditional PWM drives used input frequency and voltage. DTC is the first technology to control the 'real' motor control variables of torque and flux [6]. It is more advantages such as of not requiring a feedback device that is using AC motor which is very rugged and inexpensive and no need external excitation.

The benefits of this method is significantly reduces the speed drop during time a load transient. It's very useful to cranes or elevator, when the load needs to be started and stopped regularly without any jerking. Also important imprecision applications like winder, used in the paper industry, where an accurate and consistence level of winding is critical.

1.2 Structure of the Thesis

The work presented in this thesis is organized in six main chapters. The remaining five chapters are structured as follows. Chapter 2 is entitle Literature Reviews. Its gives an overview of the basic concept of the DTC. Other theses are done by other researchers and their results also discussed in this chapter.

Theoretical background of DTC has explained in Chapter 3. It is included the general Induction motor (IM) space vector equations and DTC scheme. Chapter 4 has presented the development of direct torque control simulink model. This chapter described in detailed of each block for DTC scheme. The simulation results were discussed in Chapter 5. These results were carrying out the behaviour of induction motor. Finally, Chapter 5 was concludes of the thesis of the development.

1.3 Objectives of the Thesis

The main objectives of the thesis can be divided three parts. There are:

a. Developing DTC model using matlab.

b. Evaluate of the developed DTC model under torque control mode.

c. Evaluate of the developed DTC model under speed control mode.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of DTC

Direct torque control (DTC) of induction motor was introduced by Takahashi in Japan and also by Depenbrock in Germany more than 10 years ago. It is use widely in industry because it's simple structure and ability to achieve fast response of flux and torque. It is an emerging technique for controlling the PWM inverter-fed induction motor drives in which the control of torque and speed are directly based on the electromagnetic state of the motor.

Research in this technique has done in much method by many researchers. Hoang Le-Huy using Simulink Power Blockset (PSB) was studied to compare the criteria between DTC and Field Oriented Control (FOC) including basic control characteristic, dynamic performance, and parameter sensitivity and implementation complexity [4]. The software developed in his study allows complete representation of the power section (inverter and induction motor and the control system.

Buja, Casadei and Serra were describing the three of DTC based strategies using switching table (ST), direct self control (DCS) and space vector modulation (SVM) [3]. They used a data from the experimental to make a selection of the amplitude of the hysterisis band of the flux and torque control to solve the problem of their tutorial. They also make a comparison between DTC and FOC. A new approach to direct torque control of induction motor were presented by Lai and Chen [9]. They made a comparison with the conventional technique. The technique does not invoke any concept of deadbeat control but just reducing the computations.

In [5], the performance of DTC using PI Stator Resistance Compensator was studied. This method was proposed to estimate stator resistance. They were using digital controller with limited sampling frequency, stator current vector amplitude varies as a function of speed, sampling period and switching strategy to investigate the effects. The general results, the variation of motor torque does not influence the fluxes, DTC can assure independent flux and torque control.

2.2 Control Characteristics

Basic configuration consists of hysterisis controller, torque and flux estimator and switching table. The instantaneous values of flux and torque are calculated from stator variables by using a closed loop estimator. Stator flux and torque can be controlled directly and independently by properly selecting the inverter switching configuration.

Inputs of a three level hysterisis comparator are from the error between the estimated torque and the reference torque. The error between the estimated flux magnitude and the reference stator flux magnitude is the input of a two level hysterisis comparator. With the switching table (ST), the inverter voltage space vector is selected for each sampling period in order to maintain the torque and stator flux amplitudes within the limits of two hysterisis bands. [3]. By controlling of hysterisis for magnitude stator flux and torque, inverter fed IM will select one of the six non-zero and two zero inverter space vectors.

2.3 Parameters and Drawbacks

This control strategy can provide the same performance as is achieved from a separately excited DC motor, and is proven to be well adapted to all type of electrical drives associated with induction motor.[2]. The main objective of DTC method is, as is in separately excited DC machines, to independently control the torque and the flux. It is done by choosing a *d-q* rotating reference frame synchronously with the rotor flux space vector [5]. Once the orientation is correctly achieved, the torque is controlled by the torque producing current, which is the q-component of the stator current space vector. At the same time, the flux is controlled by the flux producing current, which is the d-component of the stator current space vector.

There have several DTC based strategies [9], e.g., voltage vector selection strategy using switching table [2], direct-self control [3], and inverse model (deadbeat) based strategy [6]. Direct self-control and switching table strategies are very simple and have a rather straightforward implementation, but their switching frequency varies according to the motor speed and the hysterisis band of torque and flux comparator. This results in a large torque ripple unless a very short sampling time below 25μs is provided [6]. DTC on deadbeat (inverse) solution to the motor equation, utilize an inverse model to calculate the theoretical voltage vector needed to move the motor torque and stator flux to the desired values in one sample period. This voltage vector, synthesize over the sample period by the use of Space Vector Modulation (SVM) techniques. However the calculation of the voltage vector requires the solution of quadratic equations, which results in two solutions and an optimal solution are determined.

CHAPTER 3

THEORETICAL BACKGROUND

3.1 IM Space Vector Equations

3.1.1 General Equation of IM

The flux and voltage equations of IM, written in terms of space vectors related to a rotating *d,q* reference frame fixed to common to stator and rotor, become

$$\overline{\psi}_s^{\,t} = L_s \bar{i}_s^{\,t} + L_m \bar{i}_r^{\,t} \tag{3.1}$$

$$\overline{\psi}_r^{\,t} = L_m \bar{i}_s^{\,t} + L_r \bar{i}_r^{\,t} \tag{3.2}$$

$$\overline{V}_s^{\,t} = R_s \bar{i}_s^{\,t} + \frac{d\overline{\psi}_s^{\,t}}{dt} + j\omega_t \overline{\psi}_r^{\,t} \tag{3.3}$$

$$0 = R_r \bar{i}_r^{\,t} + \frac{d\overline{\psi}_r^{\,t}}{dt} j(\omega_t - \omega_{me})\overline{\psi}_s^{\,t} \tag{3.4}$$

The IM equation in stator equation can be expressed in the following equation.

$$T = \frac{3}{2} P \bar{i}_s \bullet j \overline{\psi}_s \tag{3.5}$$

3.1.2 DTC Scheme

The stator flux space vector is obtained by integrating the emf space vector [4]:

$$\overline{\psi}_s = \left(\overline{V}_s - R_s \bar{I}_s\right) dt \tag{3.6}$$

The stator voltage space vector is calculated as follows:

$$\overline{V}s = \frac{2V_{dc}}{3}\left[Sa + e^{j2\pi/3}Sb + e^{j4\pi/3}Sc\right] \tag{3.7}$$

The electromagnetic torque is computed as equation below:

$$Te = \frac{3}{2} P\left(\psi_d{}^s i_q{}^s - \psi_q{}^s i_d{}^s\right) \tag{3.8}$$

Parameters of interest for IM operation are the rotor time constant and the total leakage coefficient, given by

$$\tau_r = \frac{L_r}{R_r} \tag{3.9}$$

$$\sigma = 1 - \frac{L_m{}^2}{L_s L_r} \tag{3.10}$$

3.2 DTC Concept

The basic functional blocks used to implement the DTC scheme are represented in Figure 3.1. Hysterisis control of magnitude stator flux and torque selects one of the six non zero and two zero inverter voltage vectors. There are shown in Figure 3.3. The inverter can be depicted as Figure 3.2, E as a dc link voltage and the Sa, Sb and Sc is referred to a upper switches. When S=1, means the switch is on other wise switch is off when S=0. The states of the lower switches are the opposite of the upper ones to prevent short-circuit of the supply. Therefore the possible inverter configurations are 2^3=8.

For sector V_7 and V_8 holds for the two zero switching states. All switching space vector will be displayed by 90^o in the positive direction with respect to the switch vectors defined below.

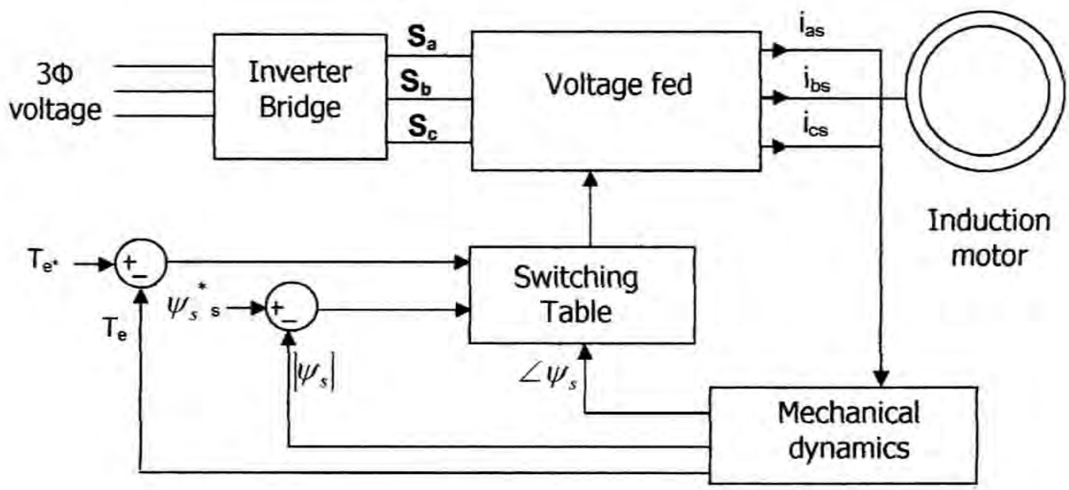

Figure 3.1: Basic control of DTC

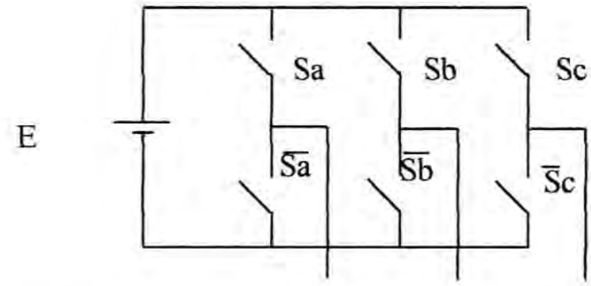

Figure 3.2: PWM schematic of PWM VSI inverter, the eight switching states and the corresponding switching space vectors

The upper switches can be expressed as below

$$v_{as} = \frac{2S_a - S_b - S_c}{3}E \tag{3.11}$$

$$v_{bs} = \frac{S_a + 2S_b - S_c}{3}E \tag{3.12}$$

$$v_{cs} = \frac{-S_a - S_b + S_c}{3}E \tag{3.13}$$

So, the space vector is

$$\overline{v}_s^{\,s} = \frac{2}{3}E\left(Sa + Sb^{e^{j2\pi/3}} + Sc^{e^{j4\pi/3}}\right) \tag{3.14}$$