THE DEVELOPMENT OF SIMULINK MODEL OF VECTOR CONTROL OF AN INDUCTION MACHINE

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NOVEMBER 2005

"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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"I hereby declared that this report is a result of my own work except for the excerpts that have been cited clearly in the references."

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ABSTRACT

Developments of machine model for vector-controlled induction motor drives will be presented in this paper. The machine representations associated with vector control methods referring to various frames including stator, rotor and air-gap flux frame. This paper presents the most popular control strategies for induction motor drives. That is about Vector-Oriented Control (VOC). The main objective of this method is to independently control the torque and the flux as in separately excited DC machines. This thesis is based on various criteria including basic control characteristics, step response and dynamic performance. This project is done by simulation using Simulink/Matlab.

ABSTRAK

Pembangunan model mesin iaitu pacuan mesin aruhan kawalan vektor akan dibentangkan di dalam tesis ini. Mesin ini di persembahkan dengan mengaitkan kaedah kawalan vector merujuk kepada pelbagai sudut termasuk stator, rotor dan lubang udara bingkai flux. Tesis ini membentangkan strategi kawalan yang paling terkenal di dalam pacuan motor. Ianya adalah mengenai *"Vector-Oriented Control (VOC)"*. Objektif utama kaedah ini adalah mengawal daya kilas dan fluk secara bebas dan berasingan seperti mesin arus terus. Tesis ini berdasarkan pelbagai kritiria termasuk ciri-ciri asas kawalan, langkah reaksi dan dinamik prestasi. Projek ini dijayakan dengan penyerupaan dalam menggunakan Simulink/Matlab.

LIST OF CONTENTS

LIST OF TABLE

LIST OF FIGURES

LIST OF APPENDICES

NOMENCLATURE

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
V_s, I_s	Stator voltage and current space vectors
ω_e	Stator electrical frequency (rad/s)
ω_m	Rotor speed (rad/s)
ω_{sl}	Slip frequency (rad/s)
θ_e	Unit vector
θ_m	Rotor angle
θ_{sl}	Slip angle
Vdc	Dc link voltage
Sa, Sb, Sc	Inverter gating signal (0 or 1)
ψ_s, ψ_r	Stator and rotor flux linkages
Ls, Lr, Lm	Stator, rotor and mutual inductances
Rs, Rr,	Stator and rotor resistance
$\tau_r = L_r / R_r$	Rotor time constant
$\sigma = 1-(L_m^2 / L_s L_r)$	Total leakage factor
s	Laplace operator
p	Number of poles
*	Star denoting a reference value

CHAPTER 1

INTRODUCTION

1.1 Overview

It is well known the advantages of induction motors over traditional dc motors include simpler and cheaper mechanical structure and easy maintenance [3, 12]. The complicated control issues associated with the adjustable speed drives applications of induction motor drives are solved by recent developments in the theory of vector oriented control, or vector control, fast digital processors and power devices.

Vector oriented-control (VOC) is one of the most excellent control strategies of torque control in induction machine [3]. Both control strategies are different on the operation principle but their objectives are the same. They aim to control effectively the torque and flux [2, 9, 12].

In early years, DC motor had significant advantages over other types of ac induction machine. The primary advantage is due to the torque control that can be provided by DC drives through the direct control of the armature current. In contrast, the early generation of AC drives, used pulse width modulation (PWM) to provide adjustable frequency sinusoidal currents to the AC machine stator, which was best suitable for speed control but did not have direct torque capability. DC motor drives provides instantaneous torque which is proportional to the product of the armature current and the field current while ac motor, on the other hand, involves complex, nonlinear relationship between voltages, current, flux and torque [4]. After some development, the AC induction machine could nearly achieve torque control but was limited due to the limitation of microelectronic devices and unknown model parameters. However the progress in the field of power electronics, microprocessors and control theory have made it possible to overcome the difficulty of control AC motors and to apply AC drives for high performance variable speed applications.

For many years, induction machine have provided the most common form of electromechanical drive for industrial, commercial and domestic applications that can operate at essentially constant speed. Induction machines have simpler and more rugged structure, higher maintainability and economy than dc motors. They are also robust and immune to heavy loading.

This paper will presents the most popular strategies for induction motor drives which is concentrated in Vector Oriented-Control (VOC). It based on various criteria including basic control characteristics, dynamic performance, parameter sensitivity and implementation complexity.

1.2 Objectives Of The Thesis

The main objective of the development of simulink model of vector control of an induction machine are as follows:

- To develop the simulink model of Vector Control of an Induction Machine by using simulink/matlab to control motor torque and flux.
- Evaluate at the developed VOC model under torque control mode.
- To produce good performance in terms of steady state, position and torque of VOC.

1.3 Structure Of The Thesis

The work presented in this thesis is organized in six chapters. The remaining five chapters are structured as follow:

Chapter 2 is entitled "Literature-Review". This chapter will give an overview including some theoretical about Vector Oriented Control (VOC) and discuss about the basic idea, types and principle of VOC.

Chapter 3 is entitled "Theoretical Analysis". This chapter introduces the mathematical model of VOC.

Chapter 4 is entitled "The Development of Vector Oriented-Control Simulink Model" This chapter presents about development of the project using Simunlink/Matlab.

Chapter 5 is entitled "Simulation Result and Discussion". This chapter shows the result from simulation. Which is included starting the induction motor drive and dynamic performance of the induction motor drive. Also it discusses these results.

Chapter 6 is entitled "Conclusion and Future Work". This chapter is the last chapter of this thesis and it is more to about the conclusion and future work of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Vector Oriented-Control

The Vector-Oriented Controller (VOC) is also know as Field Oriented-Controller (FOC) for induction motors was introduced for the first time by Blaschke in the early 1970s [1][5]. Since the 1980s new approaches for vector control methods have appeared in the literature, Yamamura (phase segregation, spiral vector); Takahashi (d-q components), Depenbrock (α, β components), De Donker (generalized d-q component) [5]. Other proposal is basically a direct consequence of these. The main objective of this control method is to independently control the torque and the flux as in separately excited DC machines [3][5][9]. This is done by choosing a *d-q* rotating reference frame synchronously with the rotor flux space vector. 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 [3].

In direct field-oriented control, both the instantaneous magnitude and position of the rotor flux are supposed to be precisely known. Crucial to the success of this well-known control technique is a priori knowledge of the rotor electrical time-constant which varies with temperature, frequency and saturation.

2.2 The Basic Idea Of Vector Oriented Control

The idea behind vector oriented control is to control the ac induction motors in the similar way for dc motor control. For a permanent-magnet (PM) excitation dc motor control can be achieved by controlling its armature current. Since the torque results from the interaction of two perpendicular magnetic fields, which are the stator field generated by the PM excitation and armature field, created by armature current. Once the flux level of stator field is keep constant, the torque can be controlled by armature current [12].

In the so called "scalar control methods" for induction machines, the machine model is considered just for steady state [5]. Therefore, it is expected that a controller based on these methods can not achieve the best performance during transients. This is the basic drawback of scalar control methods for induction machines.

In "vector control methods," the motor model considered is valid for transient conditions. The idea of the vector oriented control (VOC) proposed by Blaschke [3][5][9] can be understood from the "reference frame theory". The reference frame used in the FOC is one whose real axis coincides with the rotor flux vector. This frame is not static and does not have a constant speed during transients. Actually, it was not a commonly used reference frame for the analysis of electric machines. The great advantages of this "non inertial" frame is that for impressed stator currents, this method allows independent flux and torque controls as in separately excited dc machine. Impressed stator current that is current controlled by a fast current loop that can be implemented using cheap hall effect current sensors and power electronics, are usual in the industry practice [5]. Furthermore, the control proposed by Blaschke is the well-known control used for separately excited dc machines, and his theory could be name "vector oriented modeling".

2.3 Types Of Vector Orientation

The basis of the vector orientation algorithm is to use the flux angle, usually the rotor flux angle to decouple the torque and flux components of the stator current [2]. The most challenging and ultimately the limiting feature of field orientation is the method whereby the flux angle is measured or estimated. Direct field orientation (DFO) method, in which direct measurement of flux is performed using flux sensing coil or hall-effect devices, proved to be impractical for general use. Indirect field orientation (IFO) method has become much more common [5]. In this case, the flux angle is not measured directly but is estimated from the equivalent circuit model and from measurements of the rotor speed, the stator current and the voltage. One common technique for estimating the rotor flux is based on the slip relation, which requires measurement of the rotor position and the stator current. Given sufficiently accurate current and position sensors, this method performs reasonably well over the entire speed range. Most high-performance ac adjustable-speed drives (ASD) in operation today employ indirect field orientation based on the slip relation.

A significant disadvantage of the slip relation is that it requires rotor position feedback from a shaft-mounted sensor, typically an optical encoder. As mentioned above, "sensor less" (no shaft sensor) field-orientated control algorithms are a subject of active research. Most of these schemes depend on integrating the block electromagnetic field (emf) voltage, which buy Faraday's law produces the stator flux. At high speeds, the back emf is approximately equal to the terminal voltage since the stator voltage drop is negligible and integration of the stator voltage accurately estimates the field orientation angle. At low speeds, however back emf-based schemes fail for two reasons. First, Faraday's Law implies that for a given distribution of linked flux, a coil induced voltage amplitude is proportional to the fundamental frequency. Thus at low speeds, the back emf is small and voltage measurement is degraded by the relative increase in noise.

A second problem of emf methods is that while the voltage magnitude decreases with frequency, the load current for given load torque does not change significantly with frequency. Thus at low speeds, the stator winding resistance, but this varies with temperature. Therefore, a back emf-based field orientation scheme works well except when the drive frequency is reduced to the low speed range, where the dependence on the stator voltage measurement becomes increasingly unreliable due to noise and parameter detuning. Back emf-based schemes cannot provide field-orientation does not use the rotor speed directly, actual speed feedback is often important for steady-state speed regulation and these schemes generally do not provide accurate rotor sped estimation because off detuning.

The literature mentions both DFO and IFO methods. The original approach was developed based on rotor flux, but in literature vector drive methods based on stator flux and air-gap flux can also be found.

2.4 Principle Of VOC

In principle, field orientation provides similar decoupled control of torque and flux which is inherently possible in the dc machine [2][5]. There are certain fundamental differences. However, field-orientation provides what can be term "asymptotic decoupling", the torque and field producing elements are decoupled if the field current is fixed. This is a minor concern in most applications, since the field current is not usually adjusted rapidly in a drive application. A more significant difference is the need for precise motor information. The transformations and control algorithms presume ideal knowledge of various resistances and induction within the machine. In a dc machine, small parameter errors alter the output torque but not the decoupling. In an ac machine, parameter errors alter the transformation and can cause torque ripple and other problems. A motor must be carefully characterized and measures for use with a field-oriented drive (a process called commissioning that is often automated in commercial units).

CHAPTER 3

THEORETICAL ANALYSIS

3.1 Basic Induction Machine Equations

The state – space equations of induction machine in stator fixed reference frame in discrete time form (for small values of the sample time) are as follows:

$$\frac{\Delta \lambda s}{\Delta t} Vs\ RsIs \tag{3.1}$$

$$\frac{\Delta \lambda r}{\Delta t} = -RsIs + j\omega\lambda r \tag{3.2}$$

$$\lambda s = LsIs + LmIr \tag{3.3}$$

$$\lambda r = LrIr + LmIs \tag{3.4}$$

$$Te = 3P(\lambda s + Is) \tag{3.5}$$

$$\omega m = \frac{\omega}{P} \tag{3.6}$$