DIRECT TORQUE CONTROL OF INDUCTION MOTOR DRIVES USING SPACE VECTOR MODULATION (DTC-SVM)

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Specially dedicated from ‘Abe Long’ to

my beloved mother, father, brother, sister and a special friend who have

encouraged, guided and inspired me throughout my journey of education

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ABSTRACT

Direct Torque Control is a control technique used in AC drive systems to obtain high performance torque control. The conventional DTC drive contains a pair of hysteresis comparators, a flux and torque estimator and a voltage vector selection table. The torque and flux are controlled simultaneously by applying suitable voltage vectors, and by limiting these quantities within their hysteresis bands, de-coupled control of torque and flux can be achieved. However, as with other hysteresis-bases systems, DTC drives utilizing hysteresis comparators suffer from high torque ripple and variable switching frequency. The most common solution to this problem is to use the space vector depends on the reference torque and flux. The reference voltage vector is then realized using a voltage vector modulator. Several variations of DTC-SVM have been proposed and discussed in the literature. The work of this project is to study, evaluate and compare the various techniques of the DTC-SVM applied to the induction machines through simulations. The simulations were carried out using MATLAB/SIMULINK simulation package. Evaluation was made based on the drive performance, which includes dynamic torque and flux responses, feasibility and the complexity of the systems.

ABSTRAK

Sistem kawalan tenaga putaran secara terus adalah teknik kawalan yang digunakan dalam pemacu sistem arus ulang-alik dimana ia bertujuan mencapai kawalan tenaga putaran yang lebih baik. Sistem kawalan yang ada sekarang ini terdiri daripada pembanding histeresis, penafsiran fluks dan tenaga putaran dan juga jadual pemilihan vektor voltan. Fluks dan tenaga putaran dapat dikawal secara serentak dengan mengenakan vektor voltan yang sesuai dan menghadkan kuantiti-kuantiti ini dalam batasan yang telah ditetapkan, maka kawalan tenaga putaran dan fluks secara berasingan dapat dicapai. Walaubagaimanapun, pengunaan pembanding histeresis boleh menghasilkan riak tenaga putaran yang tinggi di samping perubahan yang tidak menentu dalam frekuensi pensuisan. Biasanya, penyelesaian untuk masalah ini adalah dengan menggunakan ruangan vektor (space vector) yang bergantung kepada fluks dan tenaga putaran. Voltan rujukan kemudiannya direalisasikan menggunakan pemodulat vektor voltan. Beberapa kaedah DTC-SVM telah dicadangkan dan dibincangkan dan pelaksanaan tugas untuk projek ini adalah untuk mengkaji, menilai dan membuat perbandingan secara simulasi bagi beberapa teknik DTC-SVM yang diaplikasikan terhadap motor induktor. Simulasi dijalankan dengan menggunakan pakej MATLAB/SIMULINK. Penilaian dibuat berdasarkan perihal prestasi pemacu yang mana terdiri daripada dinamik untuk tenaga putaran, kebolehlaksaan, dan kerumitan dalam sistem.

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a - 120° operator.

$i_{ri}(t)$ - Rotor current per phase.

$\bar{i}_r$ - Space phasor of the rotor current expressed in the rotor reference frame.

$\bar{i}'_r$ - Space phasor of the rotor current expressed in the stator reference frame.

$i_{si}(t)$ - Stator current per phase.

$\bar{i}_s$ - Space phasor of the stator current expressed in the stator reference frame.

$\bar{i}'_s$ - Space phasor of the stator current expressed in the rotor reference frame.

L_m - Three phase magnetizing inductance.

L_r - Total three phase rotor inductance.

$\bar{L}_r$ - Rotor self-inductance.

L_{rl} - Leakage rotor inductance.

L_{rm} - Rotor magnetizing inductance.

L_s - Total three phase stator inductance.

$\overline{L}_s$ - Stator self-inductance.
L_{sm} - Stator magnetizing inductance.
L_{sl} - Leakage stator inductance.
$\overline{M}_r$ - Mutual inductance between rotor windings.
$\overline{M}_s$ - Mutual inductance between stator windings.
$\overline{M}_{sr}$ - Maximal value of the stator-rotor mutual inductance.
p - Derivation operator.
P - Pair of poles.
R_r - Rotor resistance.
R_s - Stator resistance.
s - Slip.
1/s - Integrator operator.
Te - Instantaneous value of the electromagnetic torque.
T_{pc} - Instant torque referred to the nominal torque and in percentage.
Ts=Tz - Sampling time.
$u_{ri}(t)$ - Rotor voltage per phase.
$\overline{u}_r$ - Space phasor of the rotor voltage expressed in the rotor reference frame.
$\overline{u}'_r$ - Space phasor of the rotor voltage expressed in the stator reference frame.
$u_{si}(t)$ - Stator voltage per phase.
$\overline{u}_s$ - Space phasor of the stator voltage expressed in the stator reference frame.

$\bar{u}'_s$ - Space phasor of the stator voltage expressed in the rotor reference frame.

ω_m - Mechanical speed

ω_g - General speed

ω_r - Rotor pulsation

ω_s - Stator pulsation

ρr - Phase angle of the rotor flux linkage space phasor with respect to the direct-axis of the stator reference frame.

ρs - Phase angle of the stator flux linkage space phasor with respect to the direct-axis of the stator reference frame.

θm - Stator to rotor angle.

θr - Rotor angle.

θs - Stator angle.

$\psi_{ri}(t)$ - Flux linkage per rotor winding.

$\bar{\psi}_r$ - Space phasor of the rotor flux linkage expressed in the rotor reference frame.

$\bar{\psi}'_r$ - Space phasor of the rotor flux linkage expressed in the stator reference frame.

$\psi_{si}(t)$ - Flux linkage per stator winding.

$\bar{\psi}_s$ - Space phasor of the stator flux linkage expressed in the stator reference frame.

$\bar{\psi}'_s$ - Space phasor of the stator flux linkage expressed in the rotor reference frame.

α/β - Direct- and quadrature-axis components in the rotor reference frame.

d/q	-	Rotor direct- and quadrature-axis components in the stator reference frame.
D/Q	-	Stator direct- and quadrature-axis components in the stator reference frame.
g	-	General reference frame.
m	-	Magnetizing.
r	-	Rotor
ra,rb,rc	-	Rotor phases.
Ref	-	Reference.
s	-	Stator.
sA,sB,sC	-	Stator phases.
x/y	-	Direct- and quadrature-axis components in general reference frame or in special reference frames.
x	-	Cross vector product.
*	-	Complex conjugate.

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW OF INDUCTION MOTOR

The induction motors have more advantages over the rest of motors. The main advantage is that induction motors do not require an electrical connection between the stationary and the rotating parts of the motor. Therefore, they do not need any mechanical commutator (brushes), leading to the fact that they are maintenance free motors.

Besides, induction motors also have low weight and inertia, high efficiency and a high overload capability. Therefore, they are cheaper and more robust, and less proves to any failure at high speeds. Furthermore, the motor can work in explosive environments because no sparks are produced.

Taking into account all of the advantages outlined above, the induction motors must be considered as the perfect electrical to mechanical energy converter. However, mechanical energy is more than often required at variable speeds, where the speed control system is not an insignificant matter.

The only effective way of producing an infinitely variable induction motor speed drive is to supply the induction motor with three phase voltages of variable frequency and variable amplitude. A variable frequency is requires because the rotor speed depends on the speed of the rotating magnetic field provided by the stator. A variable voltage is required because the motor impedance reduces at the low frequencies and consequently the current has to be limited by means of reducing the supply voltages.[1][2]

Induction motors are also available with more than three stator windings to allow a change of the number of pole pairs. However, a motor with several windings is more expensive because more than three connections to the motor are needed and only certain discrete speeds are available.

Another alternative method of speed control can be realized by means of a wound rotor induction motor, where the rotor winding ends are brought out to slip rings. However, this method obviously removes most of the advantages of the induction motors and it also introduces additional losses. By connecting resistors or reactance in series with the stator windings of the induction motors, poor performance is achieved.[2][33]

Historically, several general controllers have been developed:

- Scalar controllers: Despite the fact that “Voltage-Frequency” (V/f) is simplest controller, it is the most widespread, being in the majority of the industrial applications. It is known as a scalar control and acts by imposing a constant relation between voltage and frequency. The structure is simple and it is normally used without speed feedback. However, this controller does not achieve a good accuracy in both speed and torque responses, mainly regarding to the fact that the stator flux and torque are not directly controlled. Even though, as long as the parameters are identified, the accuracy in the speed can be 2% (except in a very low speed), and the dynamic response can be approximately around 50ms.[3][4]

- Vector Controllers: In these types of controller, there are control loops for controlling both the torque and the flux.[5] The most widespread controllers of this type are the ones that use vector transform such as either Park or Ku. Its accuracy can reach values such as 0.5% regarding the speed and 2% regarding the torque, even when at stand still. The main disadvantages are the huge computational capability required and the compulsory good identification of the motor parameters.[6]

- Field Acceleration Method: This method is based on the maintaining the amplitude and the phase of the stator current constant, whilst avoiding electromagnetic transients. Therefore, the equations can be simplified saving the vector transformation, which occurs in the vector controllers. This technique has achieved some computation reduction, thus overcoming the main problem with vector controllers and allowing this method to become an important alternative to vector controllers.[8][10]

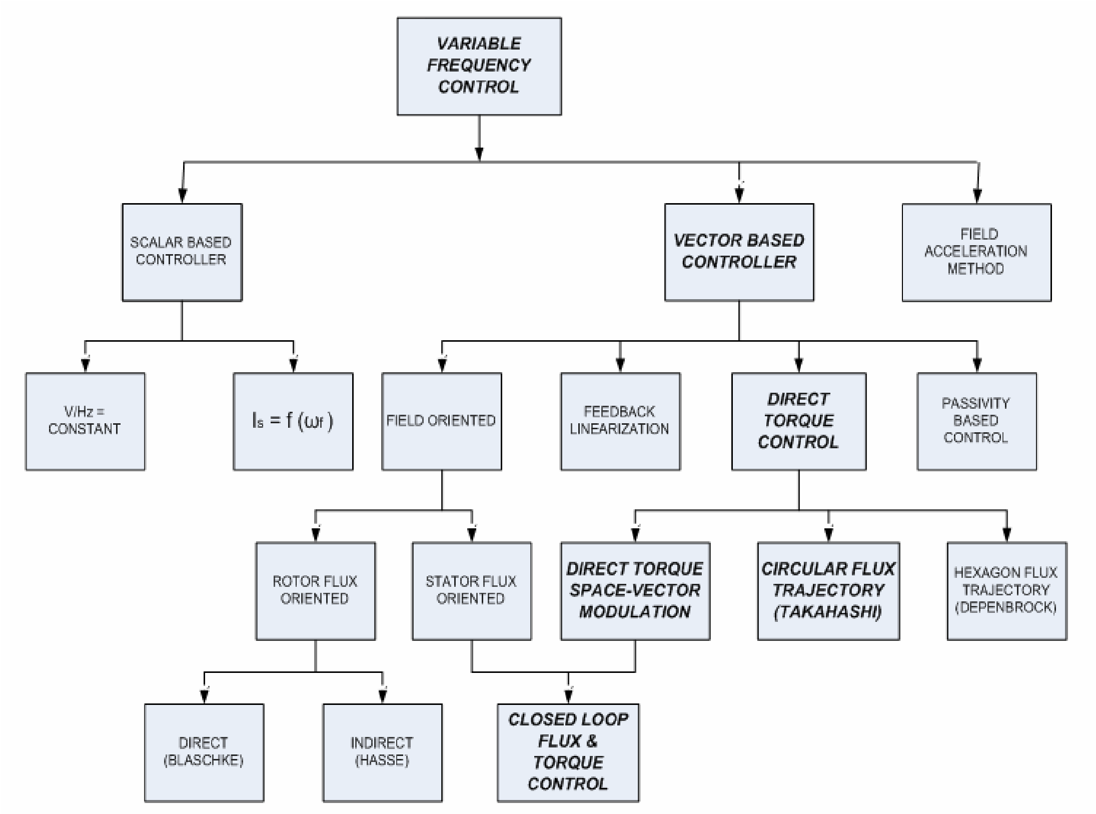

Figure 1.1: Overview of induction motor control methods.[11][9]

Direct torque control (DTC) has emerged over the last decade to become one possible alternative to the well-known Vector Control of Induction Machines. Its main characteristic is the good performance, obtaining results as good as the classical vector control but with several advantages based on its simpler structure and control diagram.[7]

DTC is said to be one of the future ways of controlling the induction machine in four quadrants.[1][11] In the DTC, it is possible to control directly the stator flux and the torque by selecting the appropriate inverter state. This method still required further research in order to improve the motor's performance, as well as achieve a better behavior regarding environment compatibility (Electro Magnetic Interference and Energy), that is desired nowadays for all industrial applications.

1.2 AIM OF THE RESEARCH PROJECT

The main objective of this project is to study on the various techniques of direct torque control (DTC) based on Space Vector Modulation (DTC-SVM) applied to induction motor drive systems. With DTC-SVM, it is possible to achieve fixed switching frequency and low torque ripple, hence overcoming the major drawbacks of conventional DTC. This project will simulate and perform analysis on some of the present DTC-SVM drives using MATLAB/SIMULINK simulation package.

The conventional DTC is firstly analyzed and proved by means of MATLAB/SIMULINK simulation. Then, the various technique of direct torque control based on Space Vector Modulation will be presented and also the pros and cons of the present DTC-SVM control strategies will be highlighted.

1.3 SCOPE OF WORK PROJECT

The project is divided into three stages. This is to ensure that the project is conducted within its intended boundary and is heading to the right direction to achieve it objectives:

- The first stage is to study on the working principle of the direct torque control of induction motor drive that utilizes hysteresis comparators and to understand on the limitations of this conventional control technique.

- Secondly, it will concentrate on performing the simulations on the various types of DTC-SVM for induction motor drive systems.

- The third stage of the project is to analyze on the performance of the various control techniques of DTC-SVM based on the MATLAB/SIMULINK simulation results.

1.4 THESIS OUTLINE

This section will give an outlines of the structure of the thesis. The following is an explanation for each chapter.

Chapter 2 discusses a mathematical model of cage rotor induction motors. Different ways of implementing these models are presented. The elements of space phasor notation are also introduced and used to develop a compact notation. Then, all the model equations will be applied on the further chapter.

Chapter 3 is devoted to introduce different Direct Torque Control (DTC) strategies. This chapter summarizes different induction motor controllers, such as the very well known vector control and “V/Hz”. The principles of DTC are thoroughly discussed and presented.

Chapter 4 deals with different kinds of Direct Torque Control with Space Vector Modulation (DTC-SVM) control techniques. All the basic principles and detail derivation of voltage reference for each control schemes are discussed within this chapter. Actually, the comparison between each control algorithm already can be observed on this chapter.

Chapter 5 gives the analysis and states the differences between conventional DTC, DTC-SVM with torque control, DTC-SVM with flux loop control and DTC-SVM with torque and flux loop control in term of torque response, control technique, stator flux trajectory and etc.

Chapter 6 presents the conclusions and recommendation for future works.

Finally, all C-programming used in the simulations are listed in the appendixes.

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