DIRECT TORQUE CONTROL INDUCTION MOTOR DRIVES

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A project report submitted in partial fulfillment of the requirement for the award of
the Master of Electrical Engineering

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JULY 2014

For my beloved mother and father

ACKNOWLEDGEMENT

First of all, I would like to express my deep sense of gratitude and appreciation to my supervisor, Ir. Dr Goh Hui Hwang for his assistance and progressive advices from time to time until the completion of the project. All the knowledge's that has been given by him during this period will always being my precious treasure and experience. His generously showered toward me throughout the project will be last in my memory.

Last but not least, I would also like to thank every single man, which are willing to help me in contributing their idea and help in indirect or direct way. Thank you very much for their advice and support, where only God could pay back their kindness and will appreciate it till the rest of my life. The experience I gained during completing this project made me realized the challenging and competition in the future.

Finally, I want to dedicate this thesis to my mom, Ramlah Binti Harun who support, encourage me throughout this course. She is responsible to give me this opportunity to further my study until this level. Her advice and guidance will be last forever bare in my mind. Not to forget, my father Mat Hussin Bin Muhammad for giving his concern during my study as well as my sisters and brother. Not forget also to my be lover Rafizal Binti Ariffin @ Yahaya for giving her support and take care of my children.

ABSTRACT

This paper presents an implementation of a direct torque control (DTC) strategies to control the operation induction motor (IM). The aim is to control effectively the torque and flux. Torque control of an induction motor base on DTC strategy has been developed and a comprehensively study in this thesis. Direct torque control is the first technology to control the real motor control variable of torque and flux. This method made the motor more accurate and fast torque control, high dynamic speed response and simple to control. This report presents a principle of the DTC; switching table, and selection of the amplitude of the hysteresis band of torque and flux. The basic dynamic performance of DTC is investigated. The performance is including in when the motor in starting drives and when motor in nominal value. The performance of this control method has been demonstrated by simulation using a versatile simulation package, MATLAB/SIMULINK. The author also present the simulation results related to the theoretical aspects mentioned in the paper. The result shows that the proposed direct torque control is capable to control the operation of the induction motor

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LIST OF SYMBOLS AND ABBREVIATIONS

IM	Induction Motor
MMF	Stator Resistance
Rr	Rotor Resistance
Rr’	Rotor Resistance Referred to Stator side
Im	Magnetizing Current
s	Slip
ωs	Synchronous Speed
ωm	Rotor Speed (Machine Speed)
f	Supply Frequency
p	No. of Poles
T	Torque Developed by the motor
ωref	Reference Speed
ω_{sl}	Slip Speed
V_{qs}	q-axis Stator Voltage with stationary frame
V_{ds}	d-axis Stator Voltage with stationary frame
I_{qs}	q-axis Stator Current with stationary frame
I_{ds}	d-axis Stator Current with stationary frame
I_{qr}	q-axis Rotor Current with stationary frame
I_{dr}	d-axis Rotor Current with stationary frame
F_{ds}	d-axis Stator flux with stationary frame
F_{qs}	q-axis Stator flux with stationary frame
F_{dr}	d-axis Rotor flux with stationary frame
F_{qr}	q-axis Rotor flux with stationary frame
F_s	q-axis Rotor flux with stationary frame
L_s	Stator Self-Inductance
L_r	Rotor Self-Inductance
L_m	Stator Mutual-Inductance

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Industrial loads require operation at wide range of speed. Such loads are generally termed as variable speed drives. These drives demand precise adjustment of speed in a stepless manner over the complete speed range required. The loads may be constant torque or function of speed. These loads are driven by hydraulic, pneumatic or electric motors. An industrial drive has some special features when driven by electric motors. Induction motor have provide the most common form of electromechanical drive for industrial, commercial and domestic application that can operate at essentially constant speed. Induction machines have simpler and more rugged structure, higher maintainability and economy than dc motor. They are also robust and immune to heavy loading. The possible forms of drive motors are dc drives, ac drives. Dc motor are versatile for the purpose of speed control but they suffer from disadvantage impose by the commutator. On the other hand ac drives are variable competitor with the advent of the power electronic controller technology.

The evolution of ac variable speed drive technology has been partly driven by desire to emulate the performance of dc drive such as fast torque and speed accuracy, while utilizing the advantage offered by standard ac motor. Direct torque control induction motor DTC is the world’s most advance 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 close-loop type in many applications [1]. DTC make direct use of physical interactions that take place within the integrated system of the machine and its supply.

The DTC scheme adopts simple signals processing methods and relies entirely on the non-ideal nature of the power source that is use to supply an induction machine within the variable speed drive system. It can therefore be applied to power electronic converter-fed machine only. The most frequently discussed and used power electronic converter in DTC drives is a voltage source inverter [2].

1.2 Problems Statement

The DTC control consist of two hysteresis comparator (flux and torque) to select the switching voltage in order to maintain flux and torque between upper and lower limit. The presence of hysteresis controllers which depend on speed, flux, stator voltage and hysteresis band also leads to a variable switching frequency operation, torque ripples and flux dropping at low speed due to the hysteresis comparator used for the torque and flux comparator. Theses drawback affect the flux and torque by hysteresis band. This project will investigate and some improvement in controlling the induction motor.

1.2.1 Project Objectives

The main objective of this thesis can be divided into three main parts which are:

i. To develop a direct torque control induction motor (DTC) model using a MATLAB /SIMULINK package.

ii. Evaluation of the developed DTC model under the torque control mode.

iii. To evaluate the effect of flux and torque hysteresis band.

1.2.2 Scope Project

The purpose of this project is to develop a direct torque control (DTC) for induction motor model using MATLAB/SIMULINK package. In this simulation, the test machine is a three phase 50 Hz. The simulation is to study the hysteresis band effect on the flux and torque controller and process of work as shown in Figure 1.1

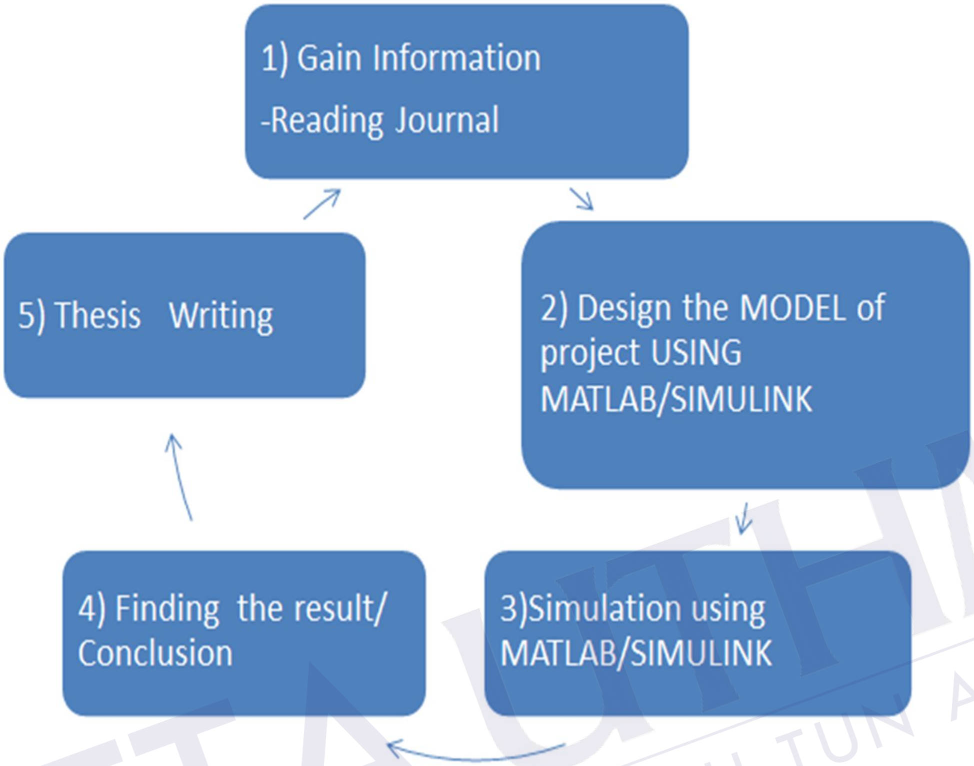


Figure 1.1: Project Flow Diagram

1.2 Thesis Overview

This thesis contains 5 chapters with appendices at the end. Each of the chapters represents of enough information for better understanding due on this project.

Chapter 1

Briefly explain the scope and objective for this project to achieve and a general view of induction motor.

Chapter 2

Entitled "Literature Review. It give an overview of principle induction motor, design and operation of induction motor, basic concept and principle of DTC and DTC development include the mathematical model ..

Chapter 3

Describe about methodology for induction motor modelling and Development of Direct Torque Control simulink model. This chapter explain the DTC and mathematical equation is use in developement of DTC using MATLAB/SIMULINK package .

Chapter 4

This chapter entitled "simulation result of the Developed Direct Torque Control Model" a numerical simulation has been perform and the validity of the developed DTC model under torque, flux control mode and hysteresis effect being analyzed and presented.

Chapter 5

These chapters entitled "conclusions and further work" where all achievements are summarized and appropriate conclusion and further work are drawn.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the review on the research is done for a past semester. The review included the principle of induction motor efficiency and parameter or formula to be use in designing the direct torque control induction motor. It also includes the switching technique for controlling the DTC. These research are been done through the journals, induction motor control design book and from the competence person who has a great knowledge in this field.

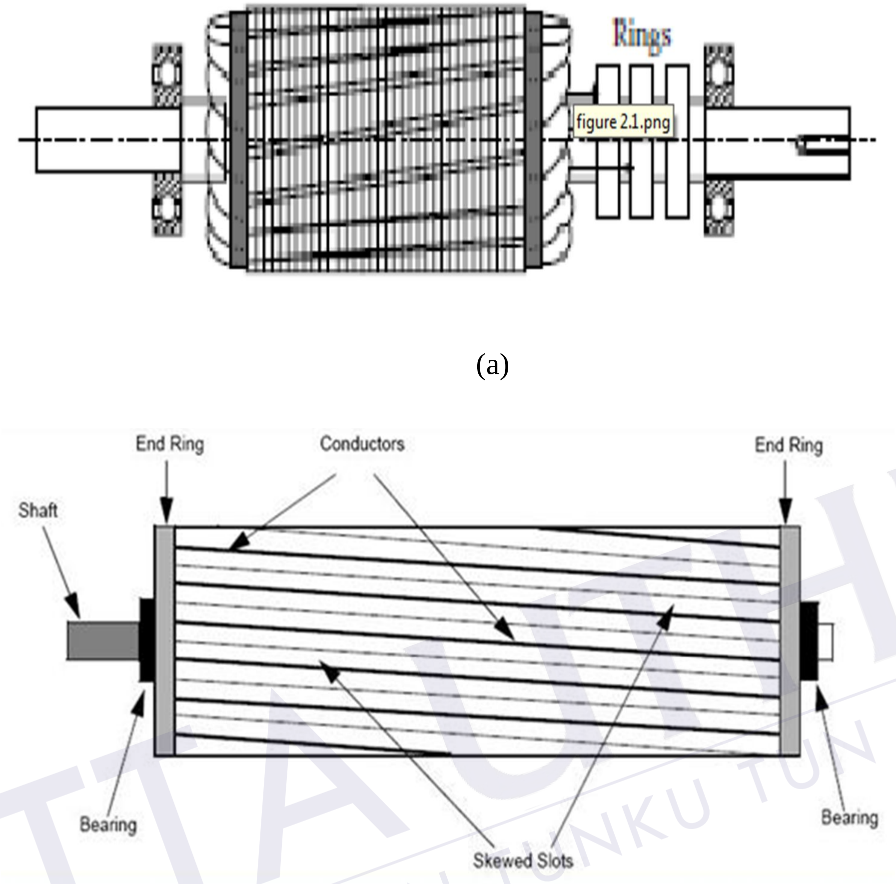
2.2 Induction Motor (IM)

2.2.1 Three-Phase Induction Motor

Like any electric motor, a 3-phase induction motor has a stator and a rotor. The stator carries a 3-phase winding (called stator winding) while the rotor carries a short-circuited winding (called rotor winding). Only the stator winding is fed from 3-phase supply. The rotor winding derives its voltage and power from the externally energized stator winding through electromagnetic induction and hence the name. The induction motor may be considered to be a transformer with a rotating secondary and it can, therefore, be described as a “transformer type” a.c. machine in which electrical energy is converted into mechanical energy [3].

2.2.2 Induction Motor Construction

The induction machine can be operated as a motor or a generator. The selection of the motor mode requires understanding the various types of induction motor squirrel cage winding choices. Induction of voltages between the rotor and stator depends on mechanical design, primarily air gap geometries between the static stator and moving rotor. Rotor geometry and materials choice determine the rotor moment of inertia, for dynamical mechanical modeling.In general, three phase AC machines have similar construction. The stator is usually made of laminated sheet steel (to reduce eddy current loses) which is attached to an iron frame. This stator consists of mechanical slots of high aspect ratio (height to width ratios) to bury the insulated copper conductors inside the stator structure, and then the stator conductors are connected in three phase delta or wye configurations. The wire wound rotor contains three electrical phases just as the stator does and they (coils) are connected wye or delta. The electrical terminals are connected to the slip rings. Unlike the wire wounded, the squirrel-cage's rotor contains bars of aluminum or copper imbedded in the rotor, which are short circuited at the end of each bar by an end disc thereby placing all rotor wires in parallel and placed equally spaced around the Rotor circumference. The wire wound rotor and squirrel-cage rotor are each shown in Figure. 2.1 for comparison. Under normal operation, an induction motor runs at a speed which is lower than the synchronous speed, so that a time changing magnetic field is created to couple stator and rotor windings. At start up this time varying magnetic field is maximized geometrically, but at near synchronous speed the time derivative is reduced. Therefore operating the motor at a rotor speed which is close to the synchronous speed of the stator magnetic field makes the motor self-limit according to the difference of the motor and load torques. The synchronous motor speed is directly proportional to the input AC line frequency driving the stator fields and inversely proportional with the number of magnetic poles, created in the stator by the choice of stator winding coil positions. Motor speed is given in Equations 2.1 and 2.2.



(a)

(b)

Figure 2.1: Induction motor rotor types

(a) Wounded rotor (b) Squirrel-Cage rotor [4]

$$Ns = \frac{120f}{p} \tag{2.1}$$

$$\omega_s = \frac{2\pi Ns}{60} = \frac{4\pi f}{p} \tag{2.2}$$

2.2.3 Design and Operation of Induction Motor

The induction motor (IM) is an alternating current machine having the armature winding on the stator and the field winding on the rotor as in Figure 2.2.

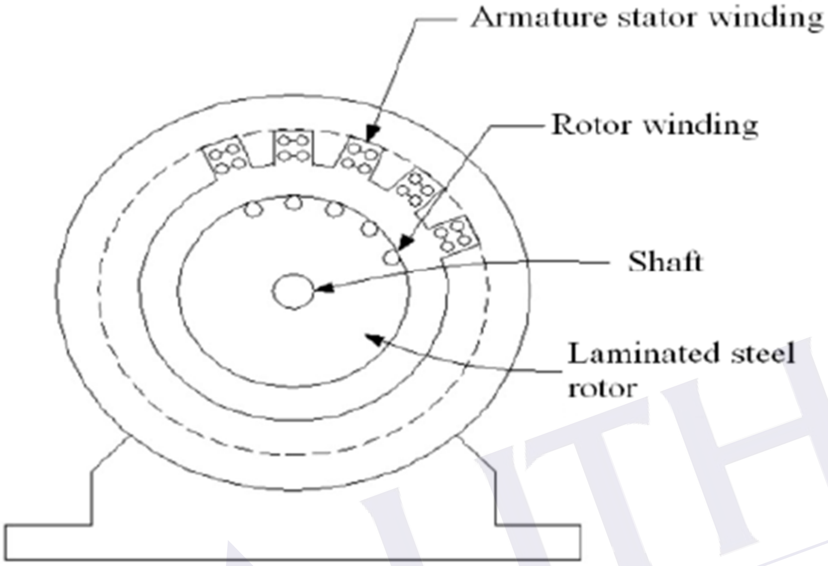


Figure 2.2: Induction motor cross-section [5]

When a three phase is supplied to the stator winding terminals, three phase balanced current flow in the armature and consequently a rotating magnetic motive force (MMF) field is yielded [6]. This field rotates at synchronous speed (*Ns)* in rovolution per minute.

$$Ns = \frac{120f}{p}$$

f: Supply Frequency and

p: Numbers of poles.

By Faraday’s law, this rotating magnetic field induces voltage in the rotor winding causing balanced current to flow in the short circuit rotor. As a result, a rotor MMF is formed. An electromagnetic torque (Te) is produce due to the interaction between the stator and rotor magnetic fields. The difference between the rotor speed and the stator speed (synchronous speed) defines the unit slip (s) where

$$s = \frac{\omega_s - \omega_r}{\omega_s}$$

ω_s= Synchronous speed in radian per second

ω_r= Rotor shaft speed in radian per second

At zero roto speed (relaxed condition), a unity slip is produced. At synchronous rotor speed, a nil slip is obtained and hence no torque is produce. The monitoring operation of Induction Motor is typically in the region of 0< s <1. A typical torque-speed characteristic of an induction motor is shown in figure 2.3.

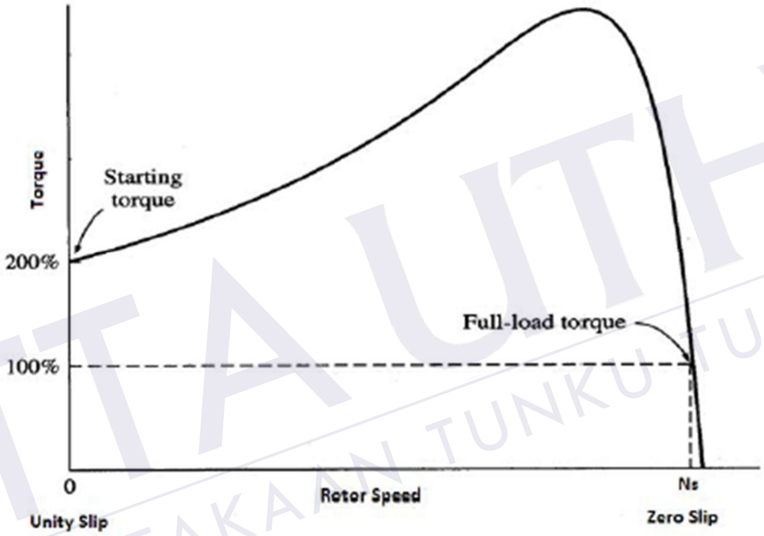


Figure 2.3: Typical torque-speed characteristic of IM

The rotor of induction machine can be either a wound rotor containing three winding similar to the stator once or a squirrel-cage rotor consisting of conducting bar shape like a squirrel-cage [7].

2.3 Basic Concept and Principle of DTC

2.3.1 Basic Concept

The DTC principle was introduce in the late 1980s [8]. In contrast to vector control which became accepted by drive manufacturer after 20 years of extensive research. A direct torque controlled induction motor drive has been manufacturer commercially by ABB since the mid-1990s [9]. In the direct torque controller developed by ABB, the optimum inverter switching pattern is determine in every sampling period 25(Us). The core of the control system in DTC is the sub-system containing torque and flux hysterisis controller and optimal inverter switching logic induction motor [10]. In this system the instantaneous values of the flux and torque are calculated from only the primary variables. They can be controlled directly and independent by selecting optimum inverter switching modes. The selection is made so as to restrict the erroes of the flux and torque within the hysteresis band and to obtain the faster torque respone and highest efficiency at every instant [11].

In an induction motor the stator flux can vary quickly compared to rotor flux. DTC makes use of this property. The DTC uses two hysteresis controllers namely flux controller and torque controller to achieve this. The control variables flux and torque are expressed in terms of stator variables. So the estimation and control of these variables becomes simple. The output of the controller determines the switch positions of the inverter which in turn accelerate or decelerate the stator flux. Hence the torque is changed at faster rate. At the same time flux controller tries to keep the operating flux around the reference value [12].

2.3.2 Control characteristic

A block diagram of a DTC system for an induction motor is shown in Figure 2.4 [13]. The DTC scheme is very simple; in its basic configuration it consists of hysteresis controller, torque and flux estimator and switching table. The configuration is much simple that the vector control systems due to the absence of coordinate transformation between stationary frame and synchronous frame and PI regulator. It also does not need a pulse with modulator and a position encoder, which introduce delays and requires mechanical transducer respectively.

DTC base drive is controlled in the manner of a closed loop system without using the current regulation loop. In addition, this controller is very insensitive to parameter detuning in comparison with vector control. DTC scheme use a stationary d-q frame reference frame (fixe to the stator) having its d-axis aligned with the stator q-axis. Torque and flux are controlled the stator voltage space vector defined in this reference frame.

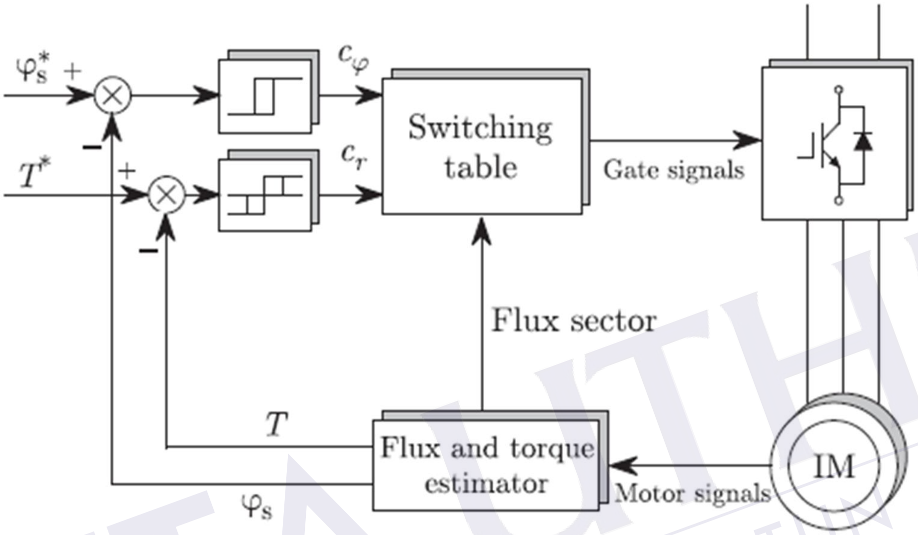


Figure 2.4: Direct torque control of induction machine

2.3.3 Basic Direct Torque Control (DTC).

The basic concept of DTC is to control directly the stator flux linkage (or rotor flux linkage or magnetizing flux linkage) and electromagnetic torque of machine simultaneously by the selection of optimum inverter switching modes [14, 15]. The use of a switching table for voltage vector selection provides fast response, low inverter switching frequency and low harmonic losses without the complex field orientation by restricting the flux and torque errors within respective flux and torque hysteresis bands with the optimum selection being made. The DTC controller comprises hysteresis controllers for flux and torque to select the switching voltage vector in order to maintain flux and torque between upper and lower limit [16,17]. The presence of hysteresis controller which depend on speed, flux, stator voltage and hysteresis band also leads to a variable switching frequency operation, torque ripples and flux dropping at low speed due to the hysteresis comparator used for the torque and flux comparators.

These drawbacks affect the result in increased sub-harmonic currents, current ripple and variable switching losses in the inverter [18]. It is show that, the switching frequency is mainly affected by the torque hysteresis band and increases with the width of the band. For a fixed band controller, it is therefore necessary to set the band to the maximum (or worst case) condition so that the switching frequency is guaranteed not to exceed its limit which is determined by the thermal restriction of the power devices [19]. An adaptive hysteresis band control strategy has been proposed where the band is controlled in real time by variation of the applied voltage vector in order to keep the switching frequency constant at any operation condition. This method reduces the torque ripple while maintaining a constant torque switching frequency.

Stator flux is a time integral of stator EMF

$$\frac{d\Psi_s}{dt} = V_s - i_s R_s \tag{2.3}$$

Selection of appropriate voltage vector in the inverter is based on stator equation in stator coordinates

$$\Delta\Psi_s = \int_0^{TL}(V_s - i_s R_s)dt = V_s(i)T_i \tag{2.4}$$

Electromagnetic torque can be expressed as

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\Psi_s \tag{2.5}$$

$$\Psi_s = \Psi_{qs-}j\Psi_{ds} \tag{2.6}$$

$$I_s = i_{qs-}ji_{ds} \tag{2.7}$$

$$\Psi_s = \frac{L_m}{L_r}\Psi_r + jL_sI_s \tag{2.8}$$

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\frac{L_m}{L_rLs}\Psi_r X \Psi_s \tag{2.9}$$

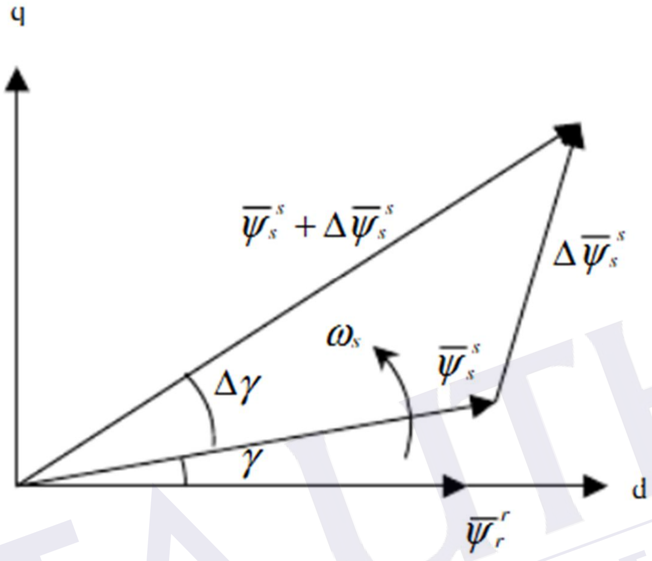


Figure 2.5: Stator and rotor flux space vector

Figure 2.5 shows the phasor for equation 2.10 indicating that the vectors, $\Psi_s, \Psi_{r,}$ *and I* for positive developed torque. If the rotor flux remains constant and the stator flux is changed incrementally by the stator voltage V_s as shown, the corresponding change of γ angle is Δγ and the incremental torque $\Delta T\,e$ is given as

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)|\Psi^r{}_r||\Psi^s{}_s + \Delta\Psi^s{}_s|Sin\Delta\delta \tag{2.10}$$

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