SENSORLESS SPEED CONTROL OF INDUCTION MOTOR USING DIFFERENTIAL ALGEBRAIC SPEED ESTIMATOR

HAFIDZAH BINTI AHMAD

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To my beloved family, lecturers and friends who have given me a lot of support and encouragement. Thank you so much.

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ABSTRACT

There are multiple techniques that have been proposed to estimate the speed of induction motor without the shaft sensor. Since at low speed range most induction motor normally has poor driving performance, there are speed estimation concern at this range. Sensorless speed estimator based on the differential-algebraic approach is implemented in this project. The methodology used is based on advanced modeling capabilities, represented by dynamic modeling of induction motor. It begins with deriving the mathematical model of the induction motor. It also shows that the dynamic equation of induction motor had been transform into suitable model by using Direct-Quadrature (d-q) transformation. Then, the estimator is designed based on differential equations properties. A differential algebraic approach is applied in this project to estimate the speed of induction motor using the measured voltages and current. The second and third order polynomial equation which the coefficient is depend on the stator voltage, stator current and their derivatives is shown to be satisfied. The determined speed is then used in the stabilize dynamic estimator to obtain the smooth estimated speed. With full knowledge of the machine parameters the simulations using MATLAB Simulink is implemented. The estimator demonstrates that the response of induction motor speed is improved especially at a low speed, high precision in speed control, and is more robust to parametric variation and load torque variation.

ABSTRAK

Terdapat pelbagai teknik yang telah dicadangkan untuk menganggar kelajuan motor aruhan tanpa sensor. Oleh kerana julat kelajuan rendah induksi motor paling biasanya mempunyai prestasi yang rendah dan agak lemah, kebimbangan anggaran pada julat ini menjadi tumpuan. Penganggar kelajuan tanpa sensor berdasarkan pendekatan perbezaan algebra dilaksanakan dalam projek ini. Metodologi yang digunakan adalah berdasarkan kepada keupayaan model maju, diwakili oleh model dinamik motor aruhan. Ia bermula dengan memperolehi model matematik motor aruhan. Ia juga menunjukkan bahawa persamaan dinamik motor induksi telah mengubah ke dalam model yang sesuai dengan menggunakan *direct quadrature* (DQ) transformasi. Kemudian, penaksir direka berdasarkan persamaan pembezaan hartanah. Satu pendekatan algebra pembezaan digunakan dalam projek ini untuk menganggarkan kelajuan motor aruhan menggunakan voltan yang diukur dan semasa. Perintah kedua dan ketiga persamaan polinomial yang pekali bergantung kepada voltan pemegun, pemegun arus dan derivatif mereka ditunjukkan untuk berpuas hati. Kelajuan yang telah ditentukan kemudian digunakan dalam pengukur menstabilkan dinamik untuk mendapatkan anggaran kelajuan lancar. Dengan pengetahuan penuh parameter mesin simulasi menggunakan MATLAB Simulink dilaksanakan. Penganggar menunjukkan bahawa tindak balas kelajuan motor aruhan adalah lebih baik terutamanya pada kelajuan rendah, ketepatan tinggi dalam kawalan kelajuan, dan lebih kukuh kepada perubahan parametrik dan beban perubahan tork.

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CHAPTER 1

INTRODUCTION

Recently, the sensor-less operation of three phase induction motor (1M) drives became of great interest. The addition of a speed sensor to the 3-phase 1M drive is a considerable drawback. In the small drive systems, the cost of the speed sensor is comparable to the cost of the motor. In the harsh environments, the speed sensor is the drive weakest part, which reduces the whole system reliability. Where the available space is critical, the additional volume due to the speed sensor becomes unacceptable. Moreover, an extension to the motor shaft is required. The noise in the speed measurements is another challenge.

The elimination of the speed sensor at the machine shaft without reducing the dynamic performance of the drive control system has been concentrated in ongoing research. The advantages of speed sensorless induction motor drives include reduced hardware complexity and lower, reduced size of the drive machine, elimination of the sensor cable, better noise immunity, increase reliability and less maintenance requirements.

1.1 Control Of Induction Machine

Induction motor control for starting, braking, speed reversal and speed change has been given great interest. In operating at constant torque without severe requirement on speed regulation, open loop control of the machine with variable frequency is satisfactory. Otherwise, if the drive requires fast dynamic response and accurate speed control closed loop mode employed.

Several techniques in controlling the induction motor have been proposed that can be classified into two main categories.

1. Scalar control:
   a) Voltage/frequency (V/f) control
   b) Stator current and slip frequency control
2. Vector control:
   a) Field Oriented Control (FOC)
   b) Direct Torque and stator flux vector control

1.1.1 Voltage / Frequency (V/f) Control

The V/f control principle adjusts a constant V/Hz ratio of the stator voltage by feedforward control. It is used to maintain the magnetic flux in the machine at a desired level. However, it satisfies only moderate dynamic requirement.

1.1.2 Stator Current And Slip Frequency Control

The instantanueous values of motor current are compared with the three phase reference current when the current regulated technique is applied. The input to the controllers and pulse width modulation (PWM) logic unit is to be the error. Function generator block will generate the amplitude of the reference current, while the encoder and slip frequency signal controlled the stator frequency. In the case of torque controlled drives, the output of the speed controller or the efficiency optimized slip table is referred to obtain the slip frequency. The controllers and PWM Generation block can be either hysteresis controllers or proportional-integral (PI) controllers with PWM [6].

1.1.3 Vector Control

In high-performance application of induction machine, vector control techniques are possible to apply. By using this scheme the induction machine can be control in the same way like the separately excited DC motor.

In using the field oriented control technique, the state variable representation or another coordinate system is being transferred to mirror the properties of a separately excited DC machine. The stator current is expressed in the stationary reference frame is then transform into rotating frame. It rotates around the selected flux-linkage or space vector. Selection of the flux linkage space or space vector can be categorized into three which are the stator flux linkage vector, rotor flux linkage vector or magnetizing flux linkage vector.

Since FOC has better performance and the technology of FOC is becoming mature, there is a strong interest by drive manufacturers to replace V /f drives by FOC drives[3],[6]. However, minimal extra cost is incurred since the number of current and speed sensors in the system to be taken into consideration. To reduce complexity and lower the cost, it is also possible to implement FOC without any shaft sensor.

The speed estimation in induction machines without the use of a speed sensor is proposed. The speed estimator is needed for flux estimation in field-oriented drives.

1.2 Sensorless Control Of Induction Machine

The ongoing research has been concentrated on the elimination of the speed control system. In the induction motor drive, speed estimation is a fundamental issue where the mechanical speed of the rotor is generally different from the speed of the revolving magnetic field. The advantages of speed-sensorless induction motor drives are the hardware complexity is reduced and therefore lowering the cost, the size of the drive machine is reduced, the sensor cable can be eliminated, noise immunity become better, reliability is increased, and maintenance requirements is less. Most adverse environments, it requires motor operation without a speed sensor.

1.2.1 Flux And Speed Estimators In Sensorless Induction Motor

Sensorless drives are becoming predominant when only up to 100 to 1 speed control range is required even in fast torque response applications (1-5ms for step rated torque response)[16]. There is a rich literature on the subject with quite a few solutions proposed and some already on markets worldwide.

1.2.2 Performance Criteria

Listed below are the performance criteria of flux and speed observer for sensorless induction motor that have to be taken into consideration:

1. steady state error
2. torque response quickness
3. low speed behaviour (speed range);
4. Noise and parameter detuning sensitivity
5. complexity versus performance

1.2.3 A Classification Of Speed Estimator

The classification of the speed estimation principles are as follow:

1) Speed estimators
2) Model reference adaptive systems (MRAS)
3) Luenberger speed observers

4) Kalman filters
5) Rotor slot ripple

With the exception of rotor slot ripple all the other methods imply the presence of flux observers to calculate the motor speed.

1.3 Project Background

A sensorless speed control using a differential algebraic speed estimator of induction motor is designed. The schematic block diagram for the implemented control of induction motor is shown below.

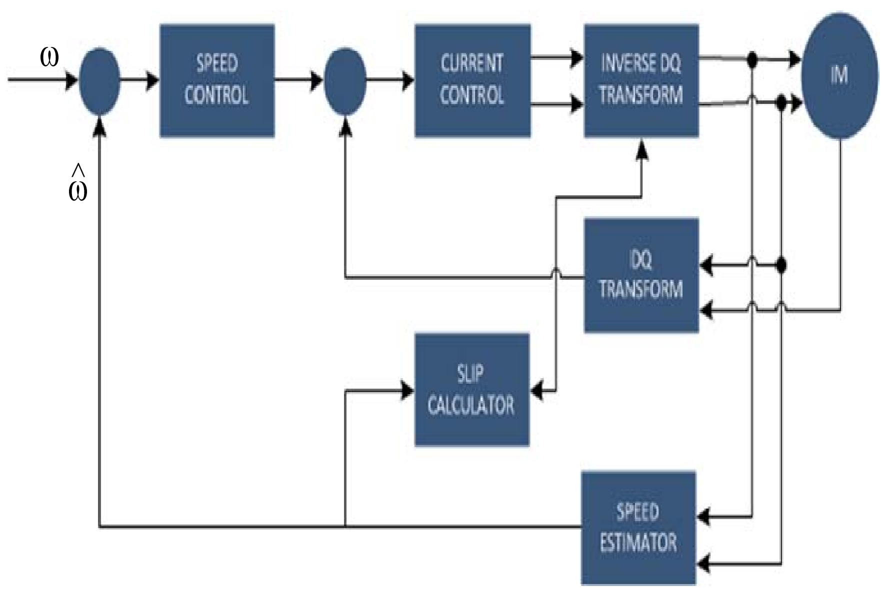

Figure 1.1: Overall Block Diagram

1.4 Objectives

The aim of this project is to design the differential approach estimator that has the speed response according to the reference speed. The estimator should be able to handle parameters uncertainties and load torque perturbation.

i. Design estimator
ii. Apply estimator into induction motor

1.5 Scope Of Project

Scope of this project including:

i) Induction motor structure and their modelling
The structure of induction motor is studied and mathematical model of induction motor is derived.

ii) Speed estimator design for induction motor
The mathematical equation of induction motor is then transforms into differential equation to design the estimator.

iii) Computer simulation
The simulation is done by using MATLAB Simulink

1.6 Methodology

The implementation plan of this project is illustrated in Figure 1.1, the structure of induction motor is studied and the mathematical equation of IM is then derived. These equations will be transformed into suitable form by using DQ transformation. Then, the estimator is designed based on differential equations properties. Computer simulation is done using MATLAB Simulink and the performance of the estimator is then observed by varying the reference speed and load torque pertubations. The thesis is written upon completion of this project.

1.7 Thesis Outline

This thesis consists of f six chapters. Chapter 1 is about the introduction, objectives, scope of project and methodology. The purpose of this chapter is to give a brief overview of this project.

Chapter 2 is the literature review. It summarizes the existing technology of sensorless control in induction motor.

Chapter 3 describes the derivation of mathematical model of induction motor. It also shows that the dynamic equation of induction motor had been transform into suitable model by using DQ transformation.

Chapter 4 explains the differential algebraic approach to speed estimation of the induction motor.

Chapter 5 shows the simulation results done in MATLAB Simulink of the differential algebraic approach to speed estimation of induction motor. The results had been discussed in detail.

Chapter 6 provides the conclusion and some suggestion for future works for this project.

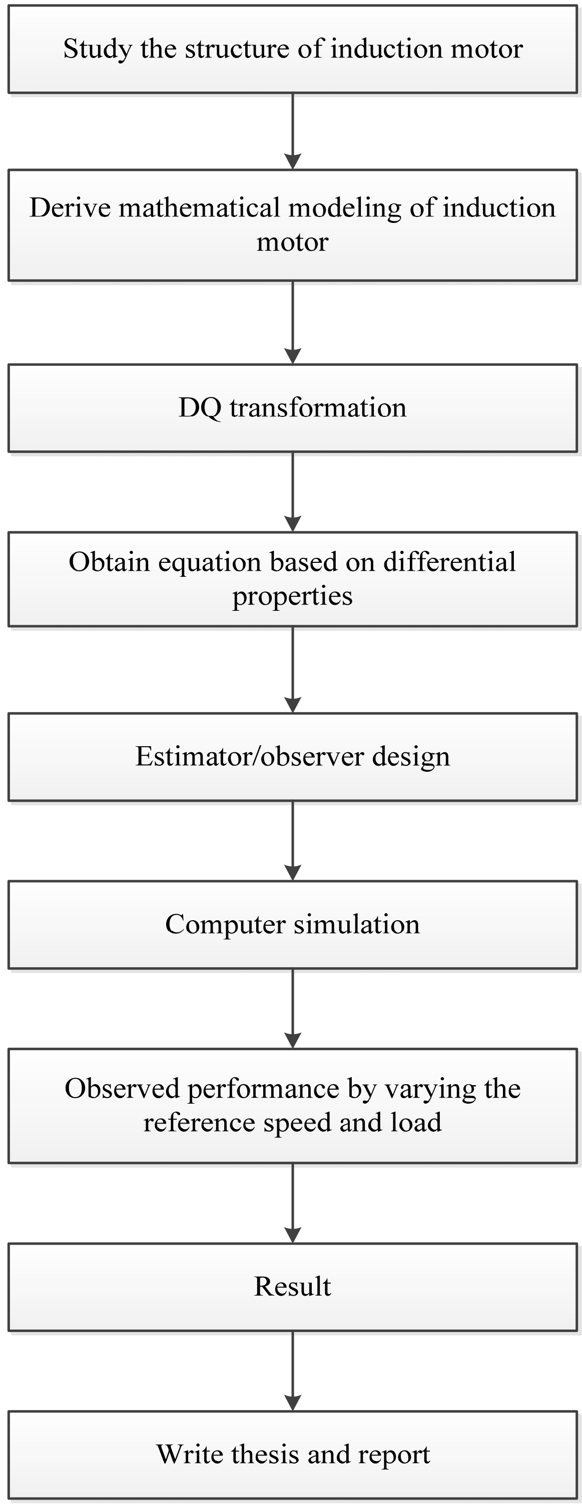

Figure 1.2: Project Flowchart

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