UNIVERSITI TEKNIKAL MALAYSIA MELAKA

FACULTY OF ELECTRICAL ENGINEERING

MODELLING AND ANALYSIS OF SENSORLESS PERMANENT MAGNET SYNCHRONOUS MOTOR BY USING FUNDAMENTAL EXCITATION

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Bachelor of Electrical Engineering

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APPROVAL FORM

“ I hereby declare that I have read through this report entitle “Modelling and Analysis of Sensorless Permanent Magnet Synchronous Motor by using Fundamental Excitation” and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)”

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A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)

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2016

I declare that this report entitle “Modelling and Analysis of Sensorless Permanent Magnet Synchronous Motor by using Fundamental Excitation” is the result of my own research except as cited in the reference. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : SITI ZAHRAH BINTI ANUAR

Date : ....

To my beloved mother and father

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First and foremost, I would like to express my thanks to Allah for giving me strength and ability to complete this final year project in time. I would like to express my great appreciation to my supervisor Dr Jurifa Binti Mat Lazi for her guidance and advice that really help me to understand about my topic.

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ABSTRACT

Over the past few years, the usage of sensorless motor drive has been widely used in various servo applications for its reliability, lower cost and small size. The most common type of motor drive used is Permanent Magnet Synchronous Motor (PMSM). This project presents the sensorless PMSM by using fundamental excitation. Permanent Magnet Synchronous Motor is used because during transformation of abc to direct and quadrature (d-q), the sinusoidal varying inductance will become constant in d-q frame. In which show that PMSM is suitable to be used in d-q system. However the operation of PMSM requires sensor to determine the rotor position. The problem about sensor is the high cost, machine size and it will decrease the reliability of the system. Besides that, research being done about sensorless PMSM experimentally is less compared to motor drive with sensor. Therefore sensorless method is presented to overcome the problems mentioned. Sensorless motor drives uses complex Clarke's and Park's transform to determine the shaft positions, thus making it more reasonable to be used with the PMSM. The aim of this study is to model, develop, simulate and investigate the behavior of sensorless Permanent Magnet Synchronous Motor drives using Fundamental Excitation. The results prove that the speed and position estimator is capable to give output response near to the actual speed.

ABSTRAK

Sejak beberapa tahun kebelakangan ini, penggunaan pemacu motor tanpa sensor telah digunakan secara meluas dalam pelbagai aplikasi servo kerana faktor seperti kebolehpercayaan, kos yang lebih rendah dan saiz kecil. Jenis pemacu motor yang paling banyak digunakan ialah magnet kekal motor segerak. Projek ini membentangkan tentang sistem magnet kekal motor segerak tanpa sensor dengan menggunakan pengujaan asas. Magnet kekal motor segerak digunakan kerana semasa transformasi abc ke mengarah dan kuadratur (d-q), kearuhan mengubah sinusoidal akan menjadi tetap di dalam bingkai d-q. Ini, menunjukkan bahawa magnet kekal motor segerak adalah sesuai untuk digunakan dalam sistem d-q. Untuk magnet kekal motor segerak beroperasi, ianya memerlukan sensor untuk menentukan kedudukan pemutar. Walaubagaimanapun, pengunaan sensor mempunyai beberapa kelemahan seperti kos yang tinggi, saiz mesin dan turun kebolehpercayaan sistem. Selain daripada itu, kajian yang dilakukan mengenai magnet kekal motor segerak tanpa sensor adalah kurang berbanding dengan sistem yang menggunakan sensor. Pemacu motor tanpa sensor menggunakan kaedah penukaran Clarke dan Park untuk menentukan kedudukan aci, menjadikan ia lebih sesuai untuk digunakan dengan magnet kekal motor segerak. Tujuan kajian ini dijalankan adalah untuk mereka bentuk, membangunkan , simulasi dan menyiasat kelakuan pemacu motor tanpa sensor menggunakan pengujaan asas. Berdasarkan keputusan simulasi, ianya membuktikan bahawa kelajuan dan kedudukan penganggar mampu untuk memberikan keluaran tindak balas berhampiran dengan kelajuan sebenar.

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PMSM	-	Permanent Magnet Synchronous Motor
IM	-	Induction Motor
PM	-	Permanent Magnet
SVPWM	-	Space Vector Pulse Width Modulation
d-q	-	Direct and Quadrature
BDCM	-	Brushless DC Motor
EKF	-	Extended Kalman Filter
DSP	-	Digital Signal Processor
FPGA	-	Field Programmable Gate Array
FSM	-	Finite State Machine
BEMF	-	Back Electromotive Force
AC	-	Alternating Current

CHAPTER 1

INTRODUCTION

1.1 Overview

In recent years, Induction Motor (IM) and PMSM are becoming popular among machine drives. Permanent Magnet (PM) motor drives have been receiving much attention due to its significant advantages capability to operate at high motor and high energy efficiency with wide speed ranges. A PMSM is an AC synchronous motor that uses permanent magnet rather than windings in the rotor to produce air gap magnetic field rather than using electromagnetic. The PMSM is extensively used in the industry for several different reasons such as its high torque to inertia ratio and superior power density compared to other motors. Other advantages of PMSM include compactness, high performance motion control with fast speed and better accuracy.

1.2 Motivation

The design of PMSM does not require commutator equipped with brushes as there is no need to supply current to the rotor. This is because it uses permanent magnet rather than winding in the motor. Input of a PMSM can be analogue voltage or switches. The switches can be controlled using two methods which are SVPWM and Hysteresis current controller. In this project the control scheme used is SVPWM as it has high magnitude of output voltage. Simulation of the permanent magnet motor drive system of this project is developed by using MATLAB/Simulink.

In allowing effective vector control of a permanent magnet synchronous motor, a motor shaft position sensor is needed. The sensor is placed in rotor shaft in order to operate a PMSM. However the sensor increases the cost of the drive and reduces its reliability. Other than that, PMSM is known to be constructed with fixed rotor field which is supplied by rotor mounted magnet. The rotor position can be obtained by using resolver and encoder but then the components used contributed several disadvantages such as noise immunity and reliability. By taking into consideration the disadvantages mentioned, a sensorless control of permanent magnet synchronous motor is suggested to be used. The sensorless technologies are able to increase the reliability and reduce the cost. A benefit of the sensorless control is it can be use in small space because it replaces encoder or resolver with estimator.

1.3 Project Background

1.3.1 Permanent Magnet Synchronous Motor Drive System

A motor drive system consists of four main components which include Permanent Magnet motor, inverter, control unit and position sensor. The motor drive system is as shown below in Figure 1.1.

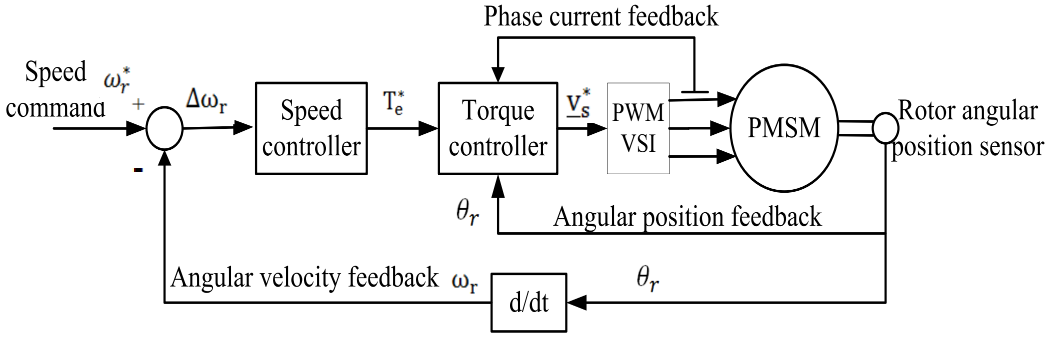

Figure 1.1: Motor drive system [10]

1.3.2 Permanent Magnet Synchronous Motor

A PMSM is an AC synchronous motor that uses permanent magnet rotor to produce the air gap magnetic field. PMSM motor is attracting industry sector and researchers to use it in varies of application because it can perform at high torque and low speed, good energy density and have higher energy efficiency than other motors.

I. Permanent magnet radial field motors

In PM motor, there are two different configurations on how the magnet can be placed in the rotor [10]. The two types of magnet configurations are surface permanent magnet motor or interior permanent magnet motor [11].

Surface PM motor magnet position is mounted in the surface of the rotor. It is simple to build as the PM is mounted on the surface of the rotor. Furthermore to reduce cogging torque, specially skewed poles that are easily magnetized are placed on this surface mounted type. This kind of structure is used for low speed application as magnets will fly apart in high speed operation. Since these motor have small saliency, it have equal inductance for both axes. The relative permeability of permanent magnet is close to one which cause machine to have large effective air gap. Surface permanent magnet is a nonsalient pole so, that the direct axis's inductance and quadrature axis's inductance are same ($L_d = L_q$) [12]. The rotor has an iron core that may be solid or may be made of punched laminations for simplicity in manufacturing [10]. Adhesives are used to mount the thin permanent magnet on the surface of its core. Radial directed flux density across the air gap is produce by the alternating process of magnet of the opposite magnetization direction. In producing torque the produced flux density then react with the current in windings located in slots of the inner surface of stator. Figure 1.2 below shows the motor cross section.

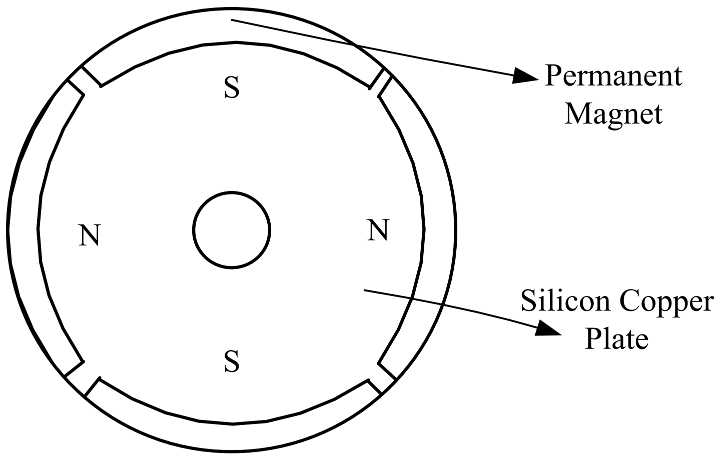

Figure 1.2: Surface Permanent Magnet motor [12]

Unlike surface permanent magnet motor, the interior permanent magnet motor magnets are mounted inside the rotor. The most typical configuration is shown Figure 1.3. The difference geometrical shape of the magnet compared to the normal shape allows a much higher speed operation. Since the air gap of direct axis is larger than quadrature axis, the machine is considered having salient pole ($L_d < L_q$) [12].

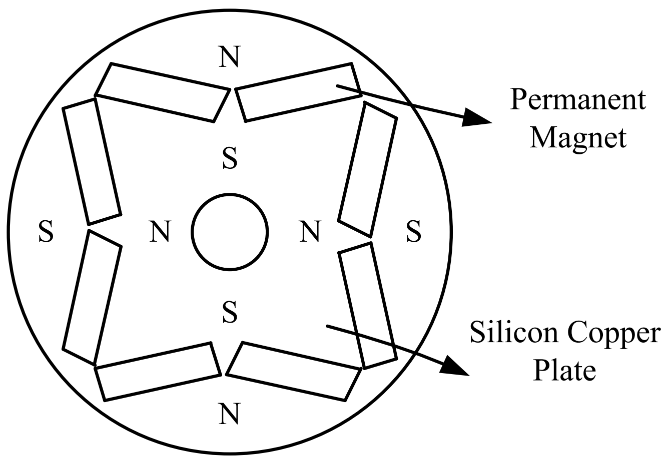

Figure 1.3: Interior Permanent Magnet motor [12]

1.3.3 Position Sensor

Position sensor is placed in rotor shaft to operate a PMSM. In order for the rotor position to be known, position measurement device can be use. A few of the devices used to measure the position includes optical encoder, linear variable differential transformer, potentiometer and resolver. Among them, the most commonly used for motors are resolver and encoders. However the price of a position sensor is expensive and a special mechanical arrangement needs to be made for mounting the position sensors and extra signal wires are required to be attached from the sensor to the controller.

i. Optical Encoders

Optical encoder design consists of LED light source, light detector, rotating disk and light sensor (photo detector). The disk has opaque and transparent segment and is placed at the shaft. As it rotate, the disc intercept light beams to create codded pattern or generate digital pulse. The optical encoder is as shown in Figure 1.4. There are two types of encoder which are incremental encoder and absolute encoder

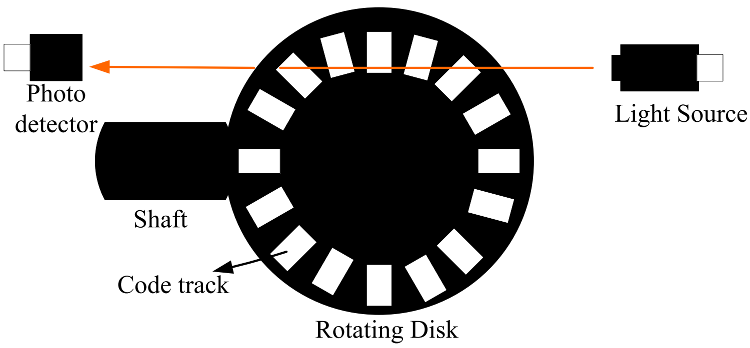

Figure 1.4: Optical Encoder [13]

i. Incremental encoders

Incremental encoders consist of two squares waves as their output with each corresponding to increase of rotation. The output from the encoder consists of two detection signal known as “A” and “B” to detect position. The beam is split to produce a beam light 90° degrees out of phase. The light “A” and “B” passes through the disc and is then converted into two square signal, widely known as quadrature output indicating the position and direction of rotation. If “B” leads “A”, the disk rotates in a counter clockwise direction and vice versa if “A” leads “B”. Incremental encoders also include a third output channel called as zero that supplies a single pulse per revolution. This third signal is used to acquire precise reference position. Figure 1.5 shows the channels of quadrature encoder.

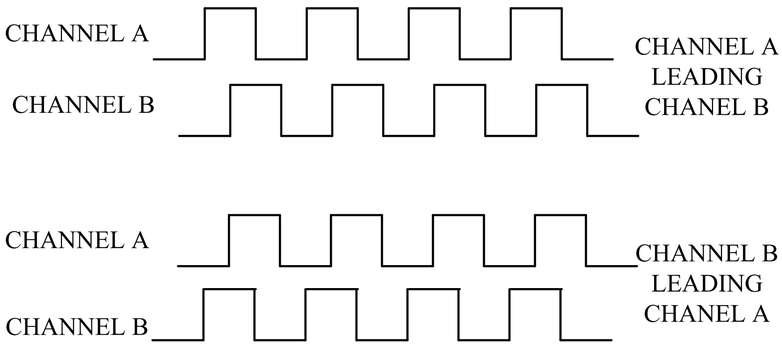

Figure 1.5: The channels of quadrature encoder for an Incremental encoder [28].

ii. Absolute encoders

Each position of absolute condition is provided by a binary “word”. Absolute means that every position is unique. The combination of numbers of channel determines how high resolution is possible. In determining the actual position, the encoder will emit a combination of signals with precision directly related to the number of bits in the encoder. Absolute encoder does not need to find fixed reference point. This is because it can still measure or obtain the exact position as soon as the voltage is turned on and even if the motor stop.

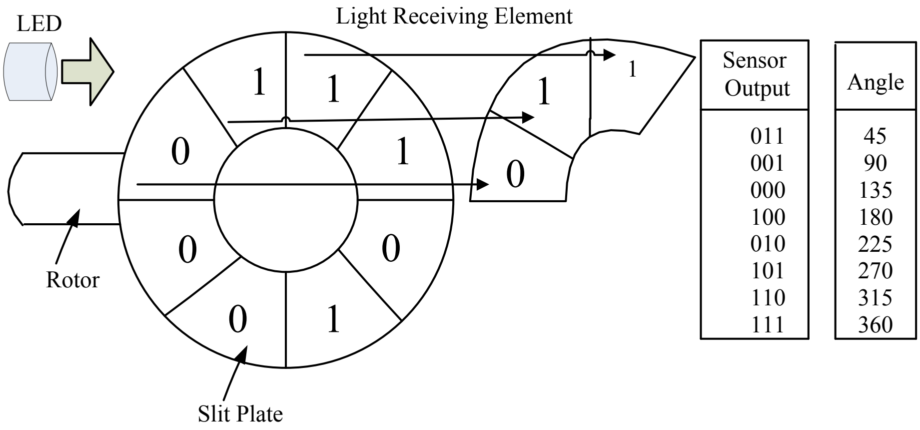

Figure 1.6: Absolute encoder [28]

The output from these detectors is depending on the code disc pattern for that particular position either HI (light) or LOW (dark). Absolute encoders are mainly used in robotic tools in which the device is usually moves at a slow rate [14]. The absolute encoder is shown in Figure 1.6 above.

1.3.4 Position Revolver

Position revolver operates on the principle of transformer. It is also called as rotary transformers as shown in Figure 1.7. To obtain the position of motor, the primary winding is mounted on the rotor and the secondary windings are wound at 90° to each other on the stator core [15]. Position using revolver can be obtained using the two voltages. In simple word a resolver control transmitter consists of one rotating reference winding (V_{ref}) and two secondary winding (V_{sin} , V_{cos}). The reference winding is located in the rotor while the secondary winding is located at the stator. The two stator winding are placed 90° from one another thus generating the cos and sine voltages. Hence onward the two stator winding is referred as output windings. The voltage induced into the rotor is proportional with angular movement of the motor shaft (θ).

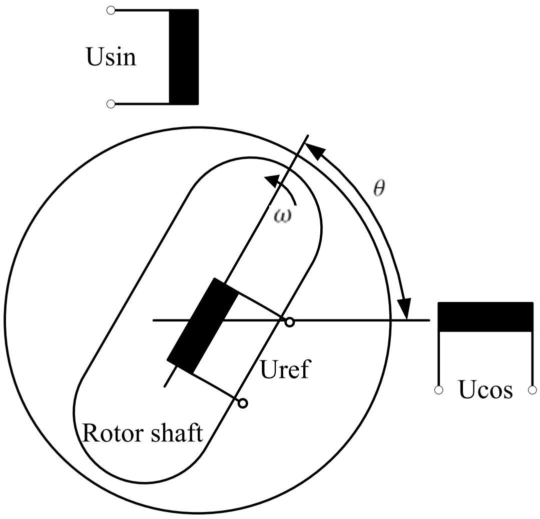

Figure 1.7: Structure of resolver [28]

The generated voltage frequency is similar to the reference voltage. Changes to the sine and cosine of the shaft angle vary their amplitude. If one of the output windings is aligned with the reference winding, thus full voltage is generated on that output and on the other output is zero voltage and vice versa [16]. Other than that, the rotor angle (θ_r) can be obtained from the voltage. Using the resolver output voltage (V_{sin} and V_{cos}) the shaft angle can be determined by an Inverse tangent [12] relationship expressed as in equation (1.1)

$$\theta = \alpha\, tan(\frac{U\, sin}{U\, cos}) \qquad (1.1)$$

1.4 Problem Statement

Recently, motor drive systems are widely used in various servo applications. The most used motor drive is PMSM as it has high-performance motion control with fast speed and accuracy. PMSM have permanent magnet located at the rotor, back electromotive force (EMF) and need stator current in producing constant torque [8]. PMSM uses permanent magnet to generate excitation and it does not have damper winding. Therefore it is suitable to be use in the direct and quadrature (d-q) model. In transforming three phase abc model to d-q, it causes the sinusoidal varying inductance to become constant in d-q frame [9]. However a major drawback to allow effective vector control of a PMSM is the position sensor. The usage of the position or speed sensor implies more space, extra wiring, additional electronic, frequent maintenance, high price, noise immunity, drive cost and decrease in reliability. In need to avoid these disadvantages a sensorless drives is used. The elimination of the sensor that is used to measure and calculate the shaft speed and position will reduce hardware complexity, size and allow cable elimination. Other advantages of the sensorless motor drives include the increase in reliability, increase in noise immunity, less maintenance and it lower the cost of the drive. There are several sensorless methods such as adaptive observer, sliding mode observer (SMO) and EKF. However by comparing the advantages and disadvantage for each sensorless technique, the speed and position estimator using adaptive controller is selected as its uses simple equation and system structure.

Besides that lack numbers of research is being done in sensorless PMSM drive compared to PMSM drive with sensor. Most of the analysis that has been done, only study about the simulation. In addition, some of the position sensors are temperature sensitive and their accuracy deteriorates when the system temperature exceeds the limit [10]. Therefore a sensorless method is introduced to replace the position sensor.

1.5 Objectives

The objectives of this project are:

1. To model and develop sensorless Permanent Magnet Synchronous Motor (PMSM) drives using Fundamental Excitation.
2. To simulate the sensorless Permanent Magnet Synchronous Motor (PMSM) drives using Fundamental Excitation
3. To investigate the behaviour of sensorless Permanent Magnet Synchronous Motor (PMSM) drives for wide speed range and load variation

1.6 Scope

The scope of this project is to conduct simulation study of PMSM drives using fundamental excitation. The MATLAB/Simulink software is used to simulate and analysed the behaviour of sensorless Permanent Magnet Synchronous Motor (PMSM) drives using Fundamental Excitation. The block diagram is also developed to study the speed of both sensor and sensorless PMSM drives. Furthermore, this project aims to show that sensorless system is comparable with system with sensor and it can reduce the cost of the drive.