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PMSM SENSORLESS CONTROL USING BACK-EMF BASED POSITION AND SPEED ESTIMATION

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PMSM SENSORLESS CONTROL USING BACK-EMF BASED POSITION AND SPEED ESTIMATION

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

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2013/2014

"I declare this report entitle "PMSM Sensorless Control Using Back-EMF Based Position and Speed Estimation" is the result of my own research except as cited in the references. The report wasn't accepted for any degree and is not concurrently submitted in the candidature of any other degree"

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ABSTRACT

This report presents the progress report on research for "PMSM Sensorless Control Using Back-EMF Based Position and Speed Estimation". The objectives is to model and simulate a position and speed estimator based on back-EMF sensorless control on PMSM and to analyze the performance of sensorless operation related to the back-EMF of the PMSM. These motor drives are very essential for industrial applications. In the applications of PMSM drive, the rotor position signal is obtained from a mechanical sensor that will reduce the reliability of the system and added the cost of the drives. Therefore, a strong desire arises in the alternative of PMSM sensorless control, where the estimators are employed to provide the feedback data required by the control system. Because of that, the development position and speed estimation based on back-EMF sensorless control for PMSM is performed. The performance of the back-EMF based sensorless vector control is mainly determined by the sensorless algorithms to relate to the position and speed estimation. The appropriate controller use in this project such as vector control, hysteresis current controller and PI controller. In this project, sensorless control approach using back-EMF method. The overall system is simulated by using SIMULINK/MATLAB software. This case study presents a position and speed estimation method based on back-EMF sensorless control by measuring the phase currents and voltages of the PMSM drive estimator to get the exact position and speed estimator. On the other hand, the sensorless control method provides satisfactory efficiency when use in PMSM drive.

ABSTRAK

Laporan ini membentangkan pelaksanaan laporan penyelidikan untuk "PMSM Tanpa Pengesan Kawalan Menggunakan Balikan-EMF Berdasarkan Anggaran Kedudukan Dan Kelajuan". Objektifnya adalah untuk untuk memodelkan dan mensimulasikan kedudukan dan kelajuan penganggar berdasarkan balikan-EMF kawalan tanpa pengesn pada PMSM dan untuk menganalisis prestasi operasi tanpa pengesan berkaitan dengan balikan-EMF daripada PMSM. Pemacu motor adalah sangat penting bagi kegunaan industri. Dalam aplikasi pemacu PMSM, isyarat kedudukan pemutar diperolehi daripada pengesan mekanikal yang akan mengurangkan kebolehpercayaan sistem dan menambahkan kos pemacu. Oleh itu, keinginan yang kuat timbul dalam alternatif kawalan tanpa pengesan pada PMSM, di mana penganggar digunakan untuk menyediakan data-data maklum balas yang diperlukan oleh sistem kawalan. Oleh kerana itu, kedudukan dan kelajuan anggaran dibangunkan berdasarkan kawalan balikan-EMF tanpa pengesan untuk PMSM dilakukan. Prestasi daripada balikan-EMF tanpa pengesan berasaskan kawalan vektor ditentukan terutamanya oleh algoritma tanpa pengesan berkaitan dengan anggaran kedudukan dan kelajuan. Penggunaan pengawalan yang sesuai digunakan di dalam projek ini adalah seperti kawalan vektor, kawalan arus histerisis dan pengawalan PI. Di dalam projek ini , pendekatan kawalan tanpa pengesan yang menggunakan kaedah balikan-EMF. Keseluruhan sistem adalah disimulasikan dengan menggunakan perisian SIMULINK / MATLAB. Kajian kes ini membentangkan kaedah anggaran kedudukan dan kelajuan berdasarkan kawalan tanpa pengesan pada balikan-EMF dengan langkah mengukur arus fasa dan voltan pada penganggar PMSM untuk mendapatkan kedudukan dan kelajuan penganggar yang tepat. Sementara itu, kaedah kawalan tanpa pengesan menyediakan kecekapan yang memuaskan apabila digunakan di dalam PMSM.

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LIST OF ABBREVIATIONS

PMSM	-	Permanent Magnet Synchronous Machine
FOC	-	Field Oriented Control
EMF	-	Electro Motive Force
EVs	-	Electric Vehicles
AC	-	Alternating Current
DC	-	Direct Current
SVPWM	-	Space Vector Pulse Width Modulation
PM	-	Permanent Magnet
T	-	Operation Times
PI	-	Proportional Integral
Kp	-	Proportional Controller
Ki	-	Integral Controller
PWM	-	Pulse Width Modulation
VSI	-	Voltage Source Inverter
THD	-	Total Harmonic Distortion
SVM	-	Space Vector Modulation
R	-	Resistance
L	-	Inductance
IGBT	-	Insulated Gate Bipolar Transistor
DSP	-	Digital Signal Processor
EMI	-	Electro Magnetic Interference

LIST OF SYMBOLS

i_q	-	Current on q-axis
i_d	-	Current on d-axis
V_d	-	Voltage on d-axis
V_q	-	Voltage on q-axis
R_m	-	Resistance Motor
L_{md}	-	Direct-axis Magnetization Inductance
R_s	-	Resistance Stator
Ψ_d	-	Flux on d-axis
Ψ_q	-	Flux on q-axis
V_{dc}	-	Voltage DC source
d, q	-	2-axis rotaring frame
α, β	-	2-axis orthogonal
ω	-	Speed of the Motor
e_α	-	α-axis of Back-EMF
e_β	-	β-axis of Back-EMF
i_α	-	Current Alpha
i_β	-	Current Beta
V_α	-	Voltage Alpha
V_β	-	Voltage Beta
L_α	-	Inductance Alpha
L_β	-	Inductance Beta
ϕ_m	-	Maximum Flux
θ	-	Angle
i_{sqref}	-	Reference Stator Phase Currents on q-axis
i_{sdref}	-	Reference Stator Phase Currents on d-axis
t	-	Times
θ_r	-	Angular Rotor Position

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The permanent magnet synchronous machine (PMSM) has been commonly used in industrial application [2]. This is because a lot of the advantages of PMSM such as high power density and efficiency, high torque to inertia ratio, easy to control and high reliability. Other than that, in higher performance applications of machine drive, the PMSM drive are ready to use in sophisticated requirements such as fast dynamic response, high power factor and wide operating on the speed range [3]. This has opened up new possibilities for large scale application of PMSM drive.

The PMSM drive using field oriented control (FOC) or vector control techniques need an exact position of the rotor and speed estimator for the current and speed control. Other than that, the sensorless have been more popular for the AC motor drive because their system is easier to implement and have a low cost by removing position feedback. In addition, there is no fault occurred when the motor shaft misaligned to the position sensor in the production process [6].

This report presents and discusses a sensorless control algorithm for permanent magnet synchronous motor (PMSM) drives based on the back Electro Motive Force (EMF) to determine the rotor position and speed estimation. Estimation of the back EMF is made by the reference voltages given by the current controller. This research will be conducted by using a SIMULINK/MATLAB software. The result will be discussed at the end of the research.

1.2 Motivation

In the last years, given the increase in oil consumption, such as by cars, there is a fast growing interest to find another source of non-polluting energy. For this in the automotive field, the industry has opted for the use of electric vehicles (EVs). However, the energy storage is the weak point of EVs that delays their progress. For this reason, the motor scheme development needs to build more efficient, lightweight, compact and electric propulsion systems, to maximize driving range per charge [10].

In addition, the control planning developed for variable speed drives working on PMSM are based of the current control on space vector in a rotor frame. This method requires the knowledge of the rotor shaft position for coordinate transformations and information about the speed. The applications of PMSM drive, the rotor position signal is obtained from a mechanical sensor that will reduce the reliability of the system and added the cost of the drives [2]. Therefore, a strong desire arises in the alternative of PMSM sensorless control, where the estimators are employed as transducers software or electronic commutation to provide the feedback data required by the control system.

1.3 Problem Statement

The vector control of a PMSM requires knowledge of the rotor shaft position and information on the speed. These mechanical quantities of a PMSM have usually been measured by shaft mounted motion sensors such as a tachometer, an encoder and resolvers. Based on the previous research by Fabio Genduso, on “Back-EMF Sensorless Control Algorithm for High Dynamics Performances PMSM” discover that the availability of these sensors, there are some of several disadvantages using that methods such as additional system cost, a higher number of connections between the motor and the frequency converter and reduced robustness [13]. Other than that, in an industrial environment using these sensors are easily damaged by mechanical impacts, especially in lower power ranges the motion sensor can be the most expensive component in the entire drive system. For this reason several strategies to detect the speed and position without sensors have been developed for PMSM [3].

1.4 Objective

The main objectives of this project are:

i. To model and simulate a position and speed estimator based on back-EMF sensorless control for PMSM using SIMULINK/MATLAB software.
ii. To analyze the performance of sensorless operation related to the back-EMF of the PMSM.

1.5 Project Scope

The project scope is the limitations for each project that have been conducted. The scope of this project are:

i. Focus on position and speed estimation of PMSM sensorless drives
ii. Model and simulate using MATLAB/SIMULINK software.
iii. Analyze the performance of the back-EMF based on measurement phase currents and voltages.
iv. Design and develop position and speed estimator algorithms.

1.6 Project Outline

This paper is organized as follows; Chapter 2 introduces the basic principle about permanent magnet synchronous machine (PMSM) model, field-oriented control (FOC), space vector pulse width modulation (SVPWM) and back-EMF. Chapter 3 describes about the method that will be used to conduct to do this project until success. Chapter 4 describes about the result and analysis that will come out of this project. Finally, conclusions and recommendation are presented in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory And Basic Principles

In this chapter it is basically more on the understanding the literature review of a permanent magnet synchronous machine (PMSM) model. This chapter presents the review of PMSM principle when using back-EMF in sensorless control. The reviews are from the recent and past journals, technical papers and reference books which have been studied to understand the related topic area of this project. In addition, this chapter will go through deeply regarding PMSM sensorless control using back-EMF such as its principle, equation and about the testing used in order to know the properties of the PMSM.

2.1.1 Permanent Magnet Synchronous Machine (PMSM)

A PMSM is a motor drive that uses permanent magnets to produce the air gap magnetic field rather than using electromagnets. The power density of PMSM is higher than one of induction motors with the same ratings due to the no stator power dedicated to the magnetic field production. PMSM is designed not only to be more powerful but also with lower mass and lower moment of inertia [1]. Permanent magnet motors, one of the magnetic fields is created by permanent magnets and the other is created by the stator coils. The maximum torque is produced when the magnetic vector of the rotor is at 90° to the magnetic vector of the stator [1].

2.1.1.1 PMSM Drive System

The motor drive consists of four main components, which are the PM motor, inverter, and the position sensor. The components are connected as shown in Figure 2.1.

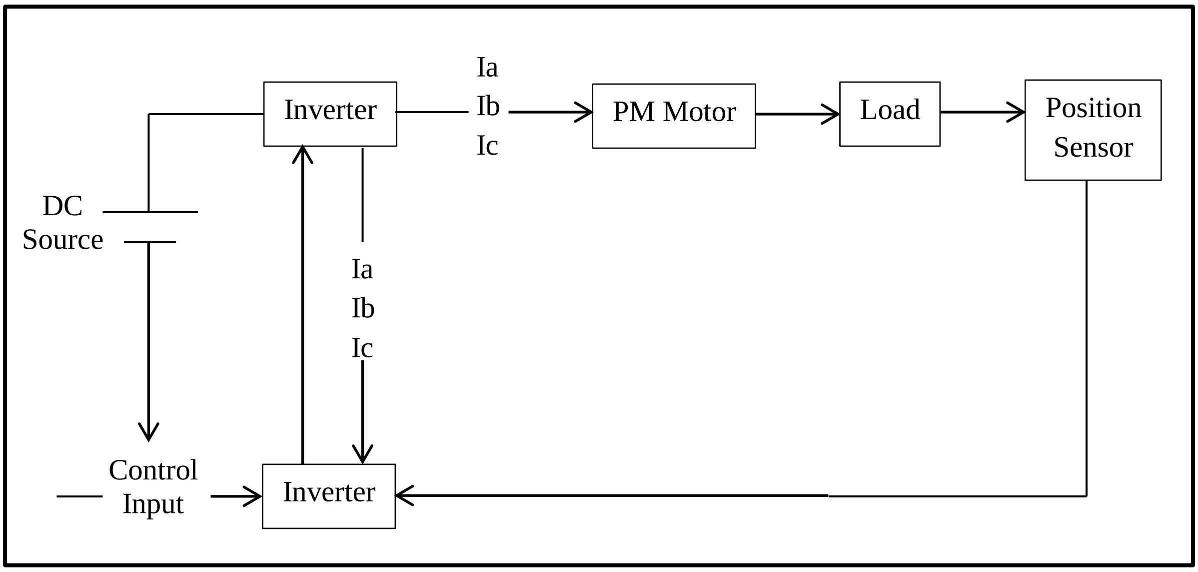


Figure 2.1: Basic block diagram of PMSM

This is a description of the block diagram of PMSM in Figure 2.1.

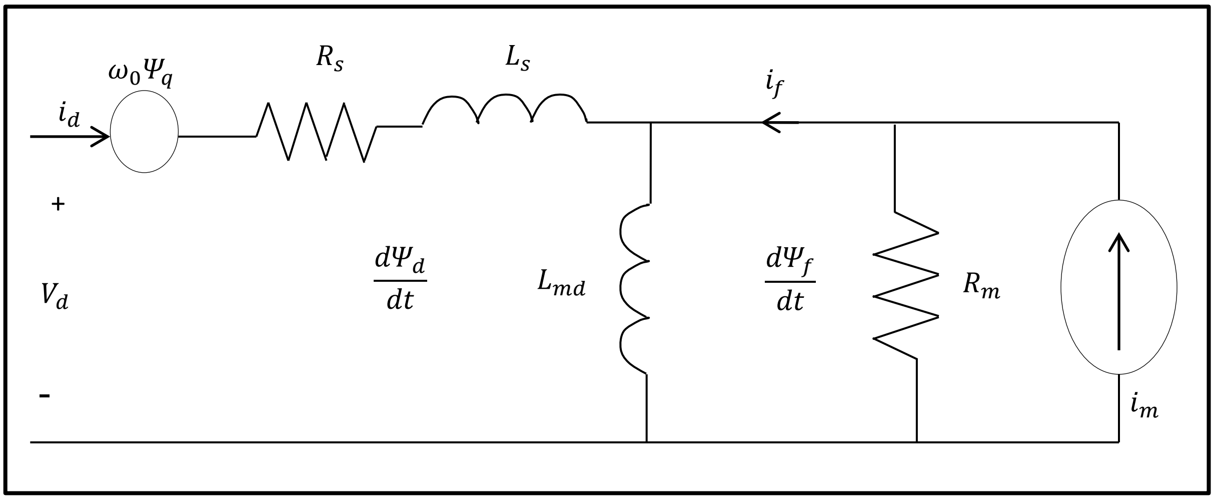
i. Inverter

Convert a DC voltage to AC voltage of variable frequency and magnitudes. It also use for adjustable speed drives and are characterized by a well defined switched voltage wave form in the terminals [9].

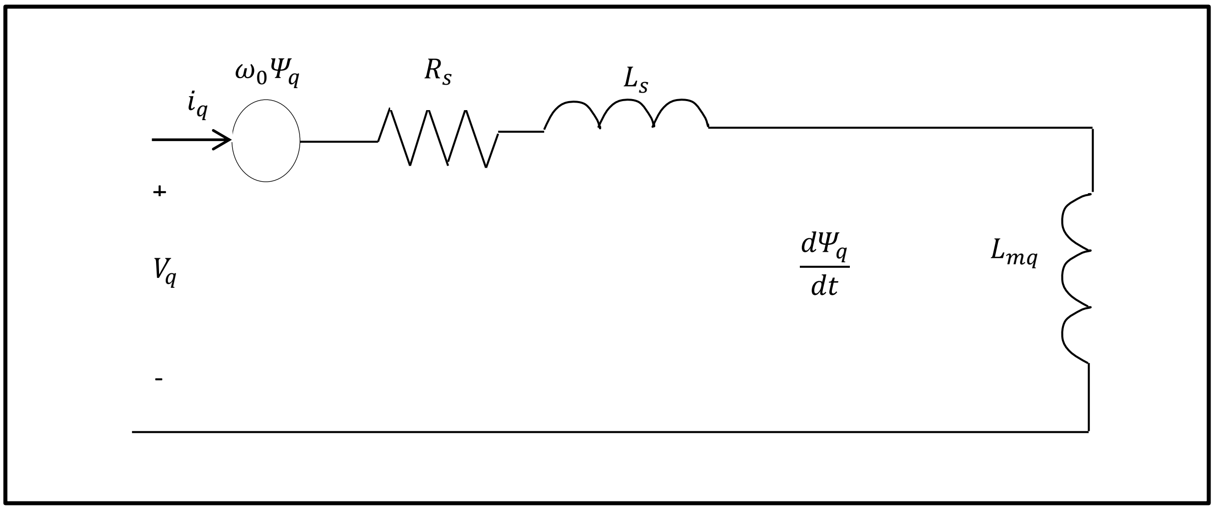
ii. Position sensor

Requires position sensors in the rotor shaft when operated without damper winding and the development of devices for position measurement [9].

2.1.1.2 Modelling Of PMSM



(a)



(b)

Figure 2.2: Equivalent circuit of the PMSM (a) *d*-axis (b) *q*-axis

Where i_d and i_q is *d*-axis and *q*-axis current. V_d and V_q is *d*-axis and *q*-axis input voltage. Constant current source, i_m located at the stator direct axis. Essentially resistance, R_m connected across the direct-axis magnetization inductance, L_{md} shows this effect and no leakage inductance in the field. The permeability of the magnet material is almost unity, so the air gap inductance seen by the stator is the same in direct and quadrature axes and also no saturation will happen inside the machine [4].

From Figure 2.2, the equations for the model PMSM are:

$$\frac{d\Psi_d}{dt} = V_d - R_s i_d - \omega\Psi_q \tag{2.1}$$

$$\frac{d\Psi_f}{dt} = R_m i_m - R_m i_f \tag{2.2}$$

$$\frac{d\Psi_q}{dt} = V_q - R_s i_q + \omega\Psi_d \tag{2.3}$$

2.1.2 Field Oriented Control (FOC)

The Field Orientated Control (FOC) as known as vector control consists of controlling the stator currents represented by a vector. This control is based on the projections which transform a three-phase time and speed dependent system into a two coordinate (d and q coordinates) time invariant system. These projections lead to a structure similar to that of a DC machine control. FOC machines need two constants as input references, which are torque component (aligned with the q coordinate) and flux component (aligned with the d coordinate) [4].

As FOC is simply based on projections the control structure handles instantaneous electrical quantities. This makes the control accurate in every working operation it is in steady state and transient. Beside that, it also independent of the limited bandwidth on mathematical model [4].

2.1.2.1 The Basic Block Diagram Of The FOC

The diagram summarizes the basic scheme of torque control with FOC.

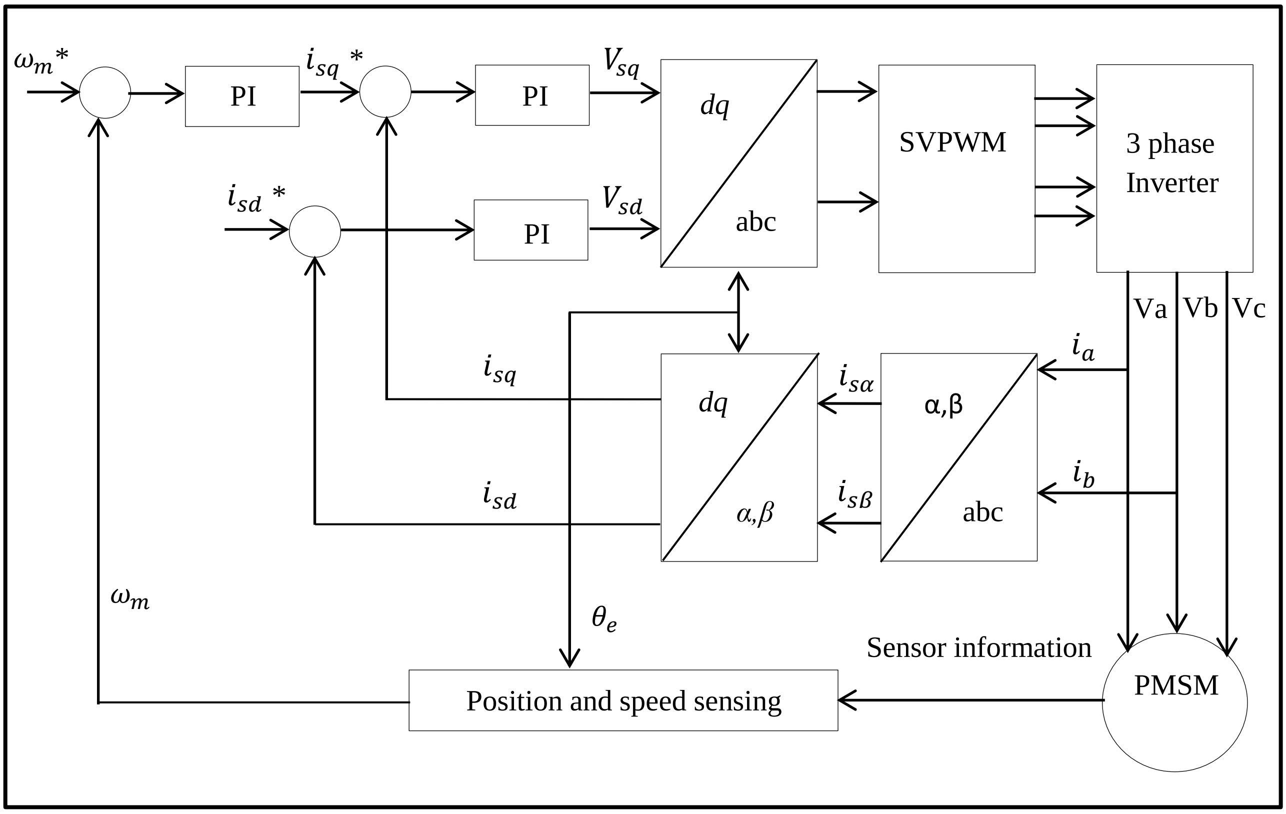


Figure 2.3: Basic scheme of FOC for AC motor

From the Figure 2.3, i_a and i_b are measured with a current sensor. The clarke transformation are applied to it to determine the stator current projection in a two coordinates nonrotating frame. The park coordinate transformation is then applied in order to obtain this projection in the (*d*, *q*) rotating frame. The (*d*, *q*) projections of the stator phase currents are then compared to their reference values i_{sqref} and i_{sdref} is set to zero and corrected by PI current controllers. The outputs of the current controllers are passed through the inverse park transformation and a new stator voltage vector is impressed to the motor using the space vector modulation technique. In order to control the mechanical speed of the motor (ω), an outer loop is driving the reference current, i_{sqref} [6].