SENSORLESS PMSM DRIVE USING EXTENDED KALMAN FILTER

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DECLARATION

I declare that this thesis entitled “SENSORLESS PMSM DRIVE USING EXTENDED KALMAN FILTER” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	
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Date	:	30 MAY 2019

APPROVAL

I hereby declare that I have checked this report entitled "SENSORLESS PMSM DRIVE USING EXTENDED KALMAN FILTER" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

To my beloved family, lecturers and friends for their never-ending help

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ABSTRACT

This thesis presents a sensorless control technique for Permanent Magnet Synchronous Motor (PMSM) by using the Extended Kalman Filter (EKF). The detailed modeling, analysis, and design have been made to achieve the estimation of speed, torque and other parameter estimation or joint state. A lot of automation control field use the PMSM drives because of their advantages such as high density and performance motion control for high-speed application and better accuracy. The conventional PMSM control drive, however, requires the mechanical sensor to measure the speed of the rotor and feedback the speed to the gain controller in order to achieve the required speed. The current problem is that the mechanical sensor such as tachometer and encoder used to measure the speed and current are usually too expensive, decrease the system's stability and increase the budget. Therefore, the sensorless method of PMSM drive is used. In the field of research, the sensorless control method using the EKF has now been explored a year by year. The main objective of this project is to model and simulate sensorless control for PMSM drives by using EKF and to analyze sensorless operation performance using EKF in terms of rotor speed and mechanical torque. The simulation is performed using MATLAB / Simulink to measure the performance of the overall motor drives. The results of the simulation show that sensorless PMSM drives using Extended Kalman Filter have better efficiency, great accuracy, and better operating system.

ABSTRAK

Tesis ini membentangkan teknik kawalan tanpa sensor untuk Motor Penyegerakan Magnet Tetap (PMSM) dengan menggunakan Penambahan Kalman Filter (EKF). Pemodelan, analisis dan reka bentuk terperinci telah dibuat untuk mencapai anggaran kelajuan, tork dan anggaran parameter lain atau keadaan bersama. Banyak bidang kawalan automasi menggunakan pemacu PMSM kerana kelebihan mereka seperti kepadatan tinggi dan kawalan pergerakan prestasi untuk aplikasi berkelajuan tinggi dan ketepatan yang lebih baik. Pemacu kawalan PMSM konvensional, bagaimanapun, memerlukan sensor mekanikal untuk mengukur kelajuan pemutar dan memberi maklum balas kelajuan kepada pengawal keuntungan untuk mencapai kelajuan yang diperlukan. Masalah semasa ialah sensor mekanik seperti tachometer dan pengekod yang digunakan untuk mengukur kelajuan dan arus biasanya terlalu mahal, mengurangkan kestabilan sistem dan meningkatkan belanjawan. Oleh itu, kaedah PMPS tanpa sensor digunakan. Dalam bidang penyelidikan, kaedah kawalan tanpa sensor menggunakan EKF kini telah diterokai setahun demi tahun. Objektif utama projek ini adalah untuk memodelkan dan mensimulasikan kawalan tanpa sensor untuk pemacu PMSM dengan menggunakan EKF dan untuk menganalisis prestasi operasi tanpa sensor menggunakan EKF dari segi kelajuan pemutar dan tork mekanikal. Simulasi dilakukan menggunakan MATLAB / Simulink untuk mengukur prestasi pemacu motor secara keseluruhan. Hasil simulasi menunjukkan bahawa pemacu PMSM tanpa menggunakan Penapis Kalman Extended mempunyai kecekapan yang lebih baik, ketepatan yang besar, dan sistem operasi yang lebih baik.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	-	Ampere
V	-	Volt
I	-	Current
R	-	Resistance
λ	-	Flux Linkages
L	-	Inductance
ω	-	Speed
ρ	-	Differential Factor
P	-	Pole
T	-	Torque
B	-	Damping Coefficient
J	-	Inertia
α	-	Alpha
β	-	Beta
Ω	-	Ohm

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This thesis presents the modelling of sensorless control technique for Permanent Magnet Synchronous Motor (PMSM) by using the Extended Kalman Filter (EKF) to estimate speed, torque and other parameter estimation or joint state.

Among the AC motor drives, PMSM drive systems have a famous demand in many industrial applications. PMSM is used in low to medium power applications (up to several hundred HP) such as fiber spinning roller mills, cement mills, marine propellers, electric vehicles, servo and robotic drives. PMSM is an ideal contender for high-performance drive. The features of the motor are simple structure, reliable operation, better energy efficiency and high power density.

In our market, PMSM drive system come with a shaft sensor such as optical encoder, hall effect sensor or resolver to measure the speed of rotor, torque current and flux current. The total number of sensor will cause the complexity of model and weight of the system. Besides that, it will increase the cost of the model and effected the reliability of the drive system. In some application, it is impractical to link the actual sensed speed or current signal from the load to the controller because of heavy or harsh environment and excessive wire length. Speed and current or other parameters for sensorless control of motor drive remarkably reduce the system complexity, narrow the cost, minimize the weight and improves the overall system reliability and dynamic performance. From this remarkably benefits have prompted the research and technology development of sensorless control scheme for the PMSM and other types of motor such as induction motors [1, 2] and brushless DC motors [3, 4].

Five estimation methods for the *Speed and Position Estimation* block have been reported in the literature in chapter 2. Method 1 is by using Model Reference Adaptive System (MRAS). Method 2 is by using Luenberger Observer. Method 3 is by using Reduce Order Observer. Method 4 is by using Sliding Mode Observer. Lastly, Method 5 is by using Extended Kalman filter. This current project choosen methods is by using EKF as it is perfectly suited to solving noise reduction, robustness and linear problem.

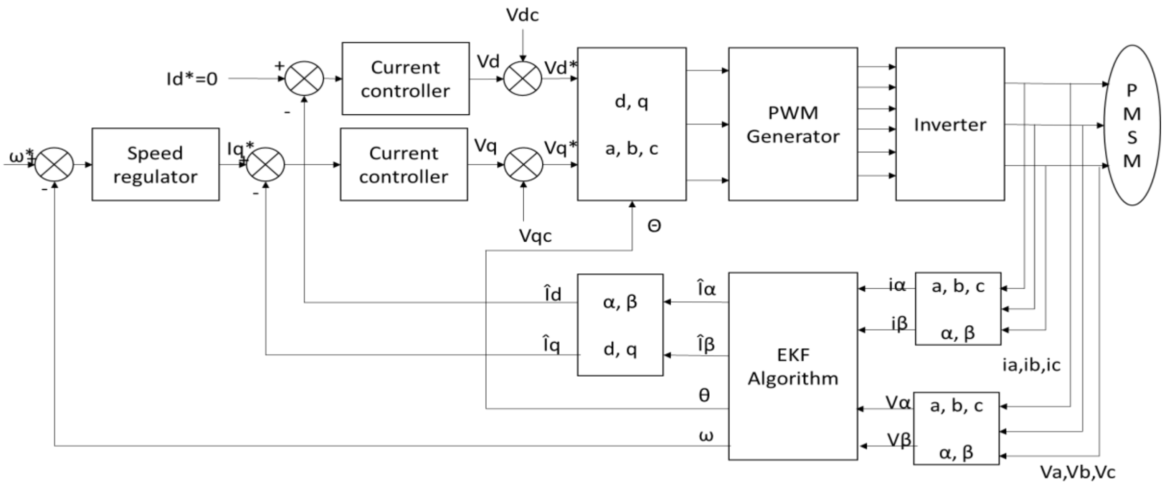

Figure 1.1 Block Diagram Sensorless PMSM Drive Using EKF

The block diagram in Figure 1.1 starts with reference torque current (I_d*) is equal to zero. This reference torque current and speed is fed into the summation block to compare with the actual torque producing current and actual speed gain by PMSM. The comparison in the summation block producing error. The error from torque current will be moved into *current controller* block while an error from speed will move into *speed regulator* block producing reference current of flux (I_q*) and into the *current controller* block. Both current controllers producing torque voltage and flux voltage. Then it will be compared with coupling voltage in the summation block to producing the reference voltage. Both reference voltages (V_d*, V_q*) then fed into the converter which are converted from *d-q* component into 3-phase voltages. The voltages now entering *PWM generator* block then into *inverter* block before supply the PMSM. The current and voltage from motor supply are then converted into alpha and beta component. Both alpha beta component entering the *EKF algorithm* block to calculate producing I_α, I_β, rotor angle (θ) and speed reference(ω). The reference currents now are converted into actual torque and flux currents including speed then compared in summation block earlier. The actual rotor angle is fed into park converter. So that is the overall scheme of sensorless vector control for PMSM.

1.2 Motivation

With conventional PMSM drive systems, accurate measurement of rotor position and speed is typically performed using sensor devices such as rotary encoders or rotary detectors. This device can measure the rotational position of a shaft by converting a mechanical movement into an electrical signal. The use of this sensor increases the cost, size and complexity of wiring. It also reduces the mechanical property of a strong and healthy constitution. Apart from that, this reduces the reliability of the PMSM drive system.

According to the characteristics of the encoder, this element has the environmental conditions. The encoder cannot operate at certain temperatures and be exposed to dirt, oil, and dust. Resolvers and encoders do not provide the best accuracy in corrosive environments. From the simulation, controlling the speed with sensor will give a huge noise and ripple.

Because of this problem, many researchers have removed the sensor and replaced it with a fundamental equation to gain position and speed of the motor as a new and good drive system. Basically, there are three categories for sensorless methods such as basic stimulation or model-based methods, expression and signal injection method and artificial intelligence method. Therefore, different methods and techniques are presented for each category proposed by the researchers for controlling the speed and position of the motor sensor.

1.3 Problem Statement

In vector control of a PMSM, the position of the rotor must be known instantly, which can be achieved by using a position sensor, the cost of mechanical sensors, the difficulty of robustness and noise behavior of the motor encourage researchers to avoid these sensors. There are different solutions to evaluate the mechanical quantities of the engine. Three different categories can be distinguished techniques based on the machine's physical properties.

a) Back-EMF estimation based techniques.

b) State observers

c) Extended Kalman filter.

By using back-EMF, the position sensor is only suitable for low-current, low - speed applications and the following phase to neutral voltages it is not easily detected due to the unavailability of the neutral point.

Other than that, the state observer is used to record the direct current and the stator current. This observer has been successfully demonstrated for the commutation requirements and can be implemented with low-cost electronics. The observer can, however, be complex and lead to inadvertent performance problems. Apart from this, expensive electronic components were required.

On the other hand, the EKF algorithm is a sub-optimal recursive estimation algorithm for non - linear systems that process all available measurements to provide a fast and accurate estimation of state variables and also allows for noise reduction. This EKF technique requires neither the knowledge of the mechanical parameters nor the initial position of the rotor, so it is a simple system and easy to construct. Therefore, this current study proposes to use an Extended Kalman Filter (EKF) technique because it can work perfectly for solving the noise and ripple problem.

1.4 Objective

The objective of this project are:

a) To model and formulate sensorless control drive system of Permanent Magnet Synchronous Motor (PMSM) by using Extended Kalman Filter (EKF) technique.

b) To constuct a PMSM sensorless control model based on EKF method in MATLAB/Simulink.

c) To validate the performance of the proposed EKF in speed accuracy, noise reduction and robustness.

1.5 Scope

The scope of this project are:

a) Design a modulation technique by using voltage control which is Space Vector Pulse Width Modulation (SVPWM).

b) Design of a mathematical model for the Extended Kalman Filter Observer.

c) Use the Matlab / Simulink software to simulate the model.

d) Analyze the results.

1.6 Report Outline

There are five chapters in this thesis. The first chapter presents a comprehensive review and evaluation of the literature and the advantages and limitations of the existing PMSM control methods, together with the goals of the thesis.

Chapter 2 discusses literature research such as the study of the article relating to the Permanent Magnet Synchronous Motor (PMSM) Drive and Sensorless control methods of PMSM Drives

Chapter 3 presents the details of the theoretical background and formulation of the discrete Kalman filter and EKF theory. A detailed real-time PMSM model in MATLAB/Simulink simulation environment is developed.

Chapter 4 deals with the outcome and analysis of the project. The detailed comparison between estimator and reference input. The analysis of the existing system and the improvement of the technology are then proposed.

Chapter 5 summarizes the conclusions and the future research recommendations.

CHAPTER 2

LITERATURE REVIEW

This chapter presents the several sensorless PMSM control drive technique based on several references, data, and source such as books, reports, conference, journal, thesis and the guidance from the supervisor. It consists of a few sections for literature PMSM drive for instance PMSM with and without sensor at section 2.1 and modulation technique at section 2.2. This modulation technique consists of Hysteresis Current Control(HCC) and Space Vector Pulse Width Modulation (SVPWM). Sensorless control methods of PMSM drives consist of Model Reference Adaptive System (MRAS) at section 2.3.1, Luenberger Observer at section 2.3.2, Reduced Order Observer at section 2.3.3, Sliding Mode Observer at section 2.3.4 and Kalman Filter at section 2.3.5.

2.1 PMSM With and Without Sensor

Many algorithms control methods have been studied and report in the literature for the speed, torque and any other parameter control of the PMSM [6-10, 12-21]. In the common PMSM drive system, speed, current and any other parameter control is achieved by using shaft sensors such as optical encoders, Hall-Effect sensors or resolvers. Figure 2.1 shows a model block diagram of a PMSM controlled drive system with shaft sensor.

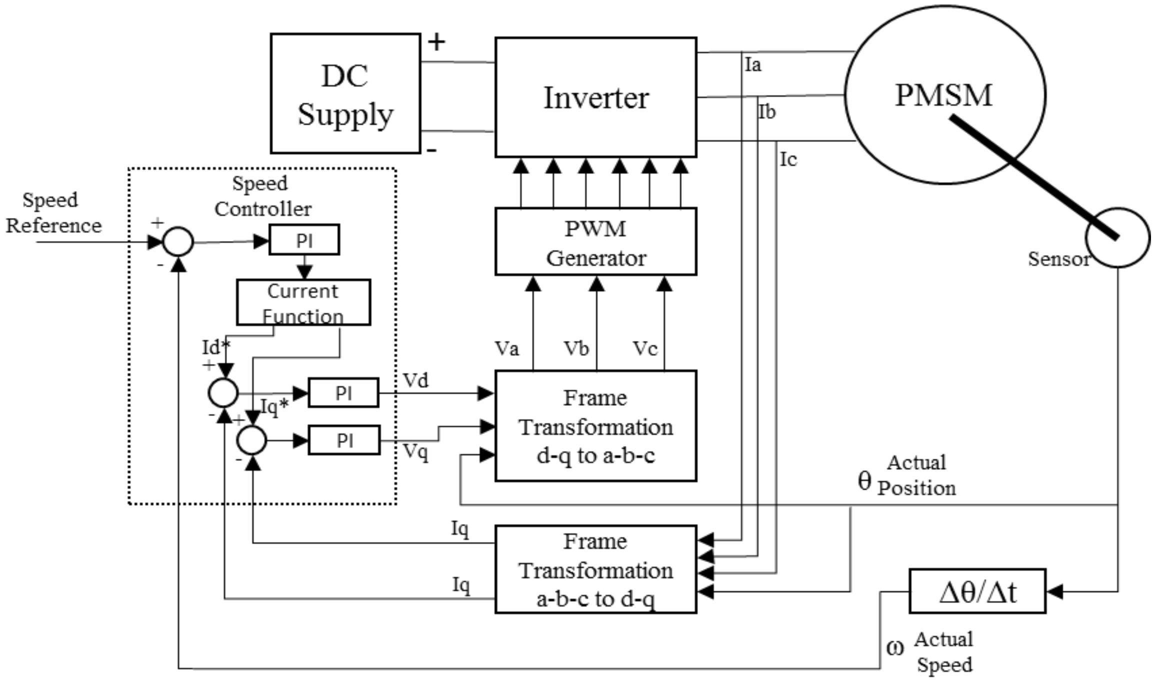

Figure 2.1 PMSM control with sensor.

Figure 2.1 present a block diagram of a PMSM controlled drive with a shaft sensor. In controlled drive system, current and voltage are time-varying. Frame transformation of the motor parameter is used (e.g., *abc*-to-*dq*) to convert the time varying system into a time-invariant one in order to gain an effective control. In Figure 1.1, current reference is produced from the error of reference speed and actual/measured speed. The component of reference current on *d* and *q* axis are (I_d^* and I_q^*), are compared to the *dq* component of the measure three-phase current individually produce error. The error then produces the V_d and V_q control variable. These component are convert back into the stator (*abc*) frame by using *dq*-to-*abc* frame transformation to obtain three phase voltage. The reference value of three-phase voltage is then fed to *PWM Generator*. This generator produces the Pulse Width Modulating (PWM) signals for the inverter. Finally, the voltage output from the inverter are supplied to PMSM.

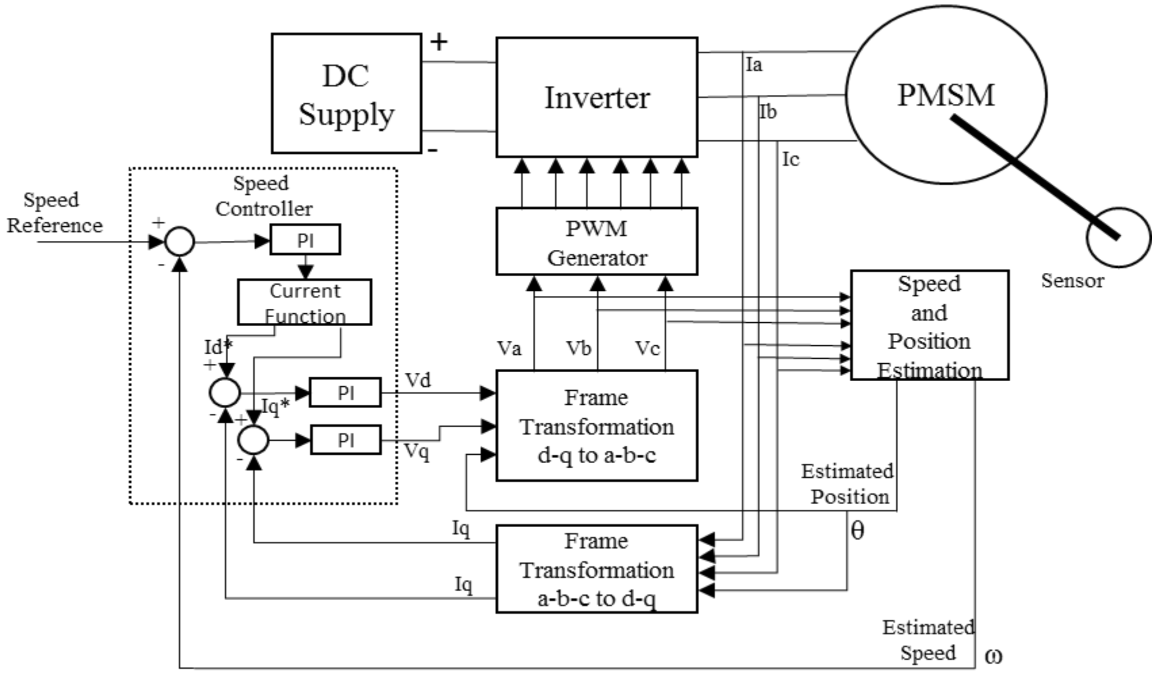

Figure 2.2 PMSM control without sensor.

Figure 2.2 illustrate a sensorless PMSM block diagram. The difference with and without sensor is that in without sensor, a *Speed and Position Estimation* block is used instead of sensor to gain measurement. Besides, the sensor of PMSM is remove. The estimated value is calculated from the terminal voltage and current. The value of speed estimation used for speed control while estimated position is fed into *abc*-to-*dq* frame transformation.