MODEL PREDICTIVE CONTROL OF PERMANENT MAGNET SYNCHRONOUS MOTOR DRIVE

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DECLARATION

I declare that this thesis entitled “MODEL PREDICTIVE CONTROL OF PERMANENT MAGNET SYNCHRONOUS MOTOR DRIVE 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 :

Name : HAZEA SALEM NASSER AHMED

Date : 05/07/2021

APPROVAL

I hereby declare that I have checked this report entitled “title of the project” and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature :

Supervisor Name : DR.JURIFA BT MAT LAZI

Date : 5 JULY 2021

DEDICATIONS

To my beloved mother and father

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ABSTRACT

This project focuses on the development of a PMSM drive system based on model predictive control (MPC). This thesis explains the overall performance analysis of torque, speed, and current control. Moreover, the goal of this method is to improve the step response, and to reduce THD and torque ripple of the system. The performance of the MPC is compared with FOC using MATLAB/Simulink. PMSM drive provides many advantages such as high torque, high efficiency, and low noise. The developments of PMSM drive make it desirable for motion control applications. However, due to PMSM's extremely nonlinear characteristics, it needs a more complex controller (advanced controller) to achieve high-performance drive applications. Therefore, in the last decades, PMSM has been applied to several variable speed drive methods. Among these, controller vector control is the most popular. Moreover, vector control is represented by the main types, field-oriented control (FOC) and direct torque control (DTC) with the PMSM drive considered as high dynamic drives. However, the dynamic response can be improved by using MPC with less complexity and higher efficiency. Finally, the simulation results have verified the effectiveness of the MPC method for PMSM drive compared the FOC controller.

ABSTRAK

Projek ini memberi tumpuan kepada pembangunan sistem pemacu PMSM berdasarkan model kawalan ramalan (MPC). Tesis ini menerangkan keseluruhan analisis prestasi tork, kelajuan, dan kawalan semasa. Lebih-lebih lagi, tujuan kaedah ini adalah untuk meningkatkan tindak balas langkah dan mengurangkan THD dan torsi riak sistem. Prestasi MPC dibandingkan dengan FOC menggunakan MATLAB / Simulink. Pemacu PMSM memberikan banyak kelebihan seperti tork tinggi, kecekapan tinggi, dan kebisingan rendah. Perkembangan pemacu PMSM menjadikannya wajar untuk aplikasi kawalan gerakan. Namun, kerana ciri-ciri PMSM yang sangat tidak linear, ia memerlukan pengawal yang lebih kompleks (pengawal lanjutan) untuk mencapai aplikasi pemacu berprestasi tinggi. Oleh itu, dalam beberapa dekad yang lalu, PMSM telah digunakan untuk beberapa kaedah pemacu kelajuan berubah. Antaranya, kawalan vektor pengawal adalah yang paling popular. Lebih-lebih lagi, kawalan vektor diwakili oleh jenis utama, kawalan berorientasikan medan (FOC) dan kawalan tork langsung (DTC) dengan pemacu PMSM dianggap sebagai pemacu dinamik tinggi. Walau bagaimanapun, tindak balas dinamik dapat ditingkatkan dengan menggunakan MPC dengan kerumitan yang kurang dan kecekapan yang lebih tinggi. Akhirnya, hasil simulasi telah mengesahkan keberkesanan kaedah MPC untuk pemacu PMSM berbanding pengawal FOC.

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LIST OF SYMBOLS AND ABBREVIATIONS

AC	-	Alternating current
DC	-	Direct current
EMF	-	Electromotive force
VSI	-	Voltage Source Inverter
CSI	-	Current Source Inverter
VSD	-	Variable Speed Drives
THD	-	Total harmonic distortion
FOC	-	field-oriented control
DTC	-	Direct torque control
MPC	-	Model Predictive Control
PMSM	-	permanent magnet synchronous motor
PM	-	permanent magnet
f	-	Frequency
p	-	poles
PWM	-	Pulse width modulation
V	-	Voltage
PI	-	peripheral interface
I	-	Current
Hz	-	hertz
a	-	unitary vector
ψ_s	-	Stator flux
L_s	-	Stator inductance
ψ_m	-	Magnetic flux
ω_r	-	Rotor speed
r	-	Rotor
s	-	Stator
R_s	-	Stator resistance
T_e	-	Electrical torque
J	-	Inertia
B	-	friction coefficient
T_s	-	Sampling time
g	-	Cost function

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CHAPTER 1

INTRODUCTION

1.1 Background

The electrical motors are the main component to start developing an electrical drive system that is commonly used in many industrial applications. There are two types of electrical motors, which are DC-motor and AC-motor. Both motors have the same function, which is of converting electrical energy into mechanical energy, Figure 1.1 shows the classification of the electrical motors. In the past, DC-motors are the most used for the electrical machines to control the variable speed drives. However, there are disadvantages using the DC-motors such as higher cost, higher rotor inertia, switching and brushing maintenance problems. They are also unable to operate in dirty and explosive environments [1]. Therefore, in the last three decades, DC motors were steadily replaced by AC drives. One of the AC-drive is widely used nowadays is PMSM. PMSM has many advantages including high torque, high power density and efficiency, and excellent dynamic response, which make it more desirable for a full range of motion control applications. PMSM drive, have the same work function of synchronous motors, which is permanent magnets (PM) provide field excitation and have a sinusoidal EMF waveform. Moreover, the electrical current produced for producing torque in the rotor is obtained by electromagnetic induction from the spinning magnetic field of the stator winding. Therefore, Due to its construction, the speed of the rotor is rigidly connected to the frequency of the stator and a voltage source inverter is needed for variable speed operation [1]. For the operation of power converters and drives, several control strategies have been developed. Some of them are shown in Figure 1.2 Several control strategies have been applied for the PMSM. Well-established methods are FOC and DTC. The performance of the FOC strategy depends on the output of a current controller's which are PWM and PI controllers. However, the FOC and DTC are complex and hard to apply the constraints and nonlinearities [2].

Therefore, compared those methods MPC provides many benefits that make it ideal for machine control such as, the principles are clear and simple to understand, it can be implemented to a variety of systems, reduce complexity, it is easy to include constraints and nonlinearities, multivariable case can be easily considered, and it is easy to implement from the resulting controller [2].

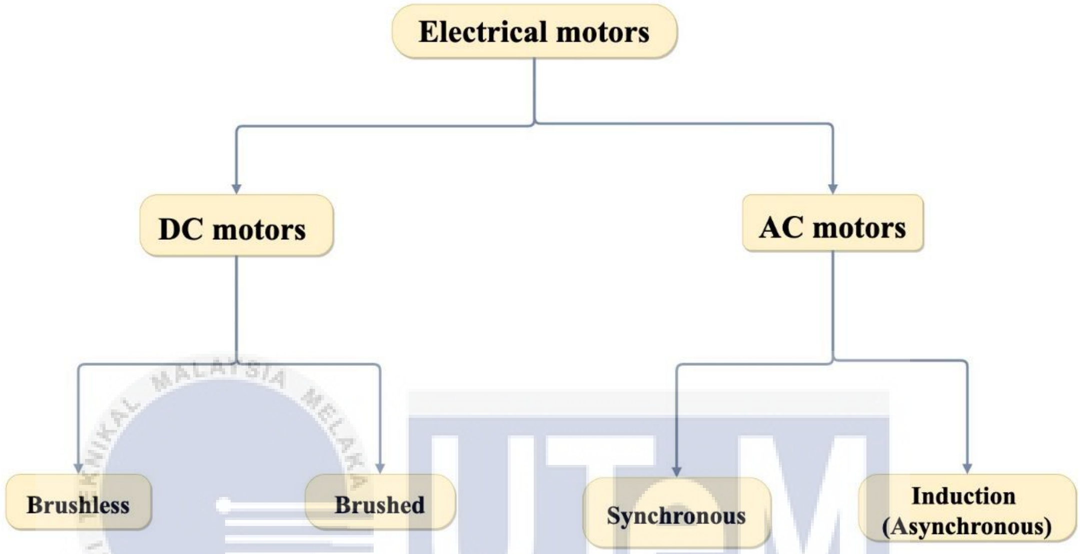

Figure 1.1 Classification of the electrical motors

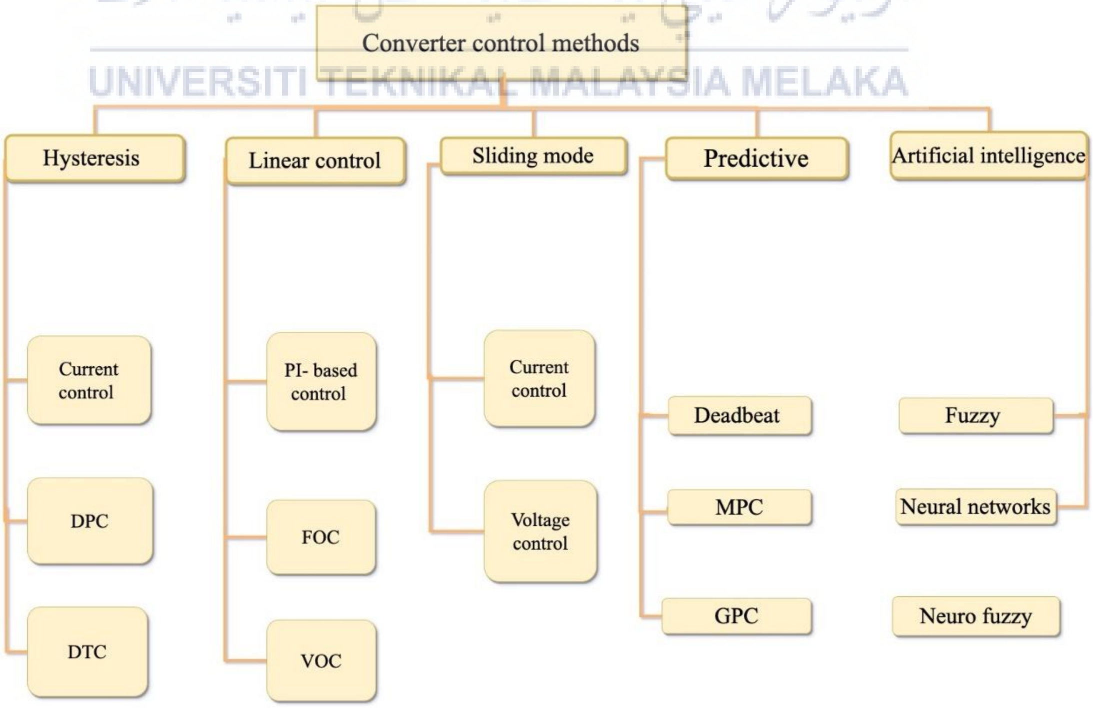

Figure 1.2 different converter control methods

1.2 Motivation

Speed control drive is the electric drives which widely used in the industry and many of the drive are using AC motors. PMSM is one of these motors, that is broadly used because of the advantages that this drive is given such as large power to weight ratio, high torque to current ratio, high efficiency, high power factor, low noise and robustness, etc. For the PMSM drive, the parameters are extremely significance, such as, Speed, torque and flux. Analysis of the control method shows that, it is understood that various techniques particularly for low V/ I/ Hz ratio strategies to advanced senseless control systems can be used to control PMSM drive parameters. The high performance of a PMSM drive is depending on the control method. Therefore, many control methods have been applied to PMSM such as vector control methods, FOC and DTC. Neural Networks, neuro-Fuzzy, and other sophisticated control methods are other control systems found in the literature. However, MPC has many advantages to make it the best control method to give the high performance to PMSM drive [3].

MPC covers many control strategies that is recently used for electrical drives systems. The main idea of the predictive control is to predict the future behavior of the system and use that information by the controller to a predefined optimization criterion, optimal actuation. One of the advantages of the predictive control are more easy and more efficient [3].

More improvements for the techniques used have been done for Model predictive control (MPC), Figure 1.3 shows the typical predictive control techniques in the controller used. In this thesis, the use of MPC for current control in a PMSM drive is presented [3].

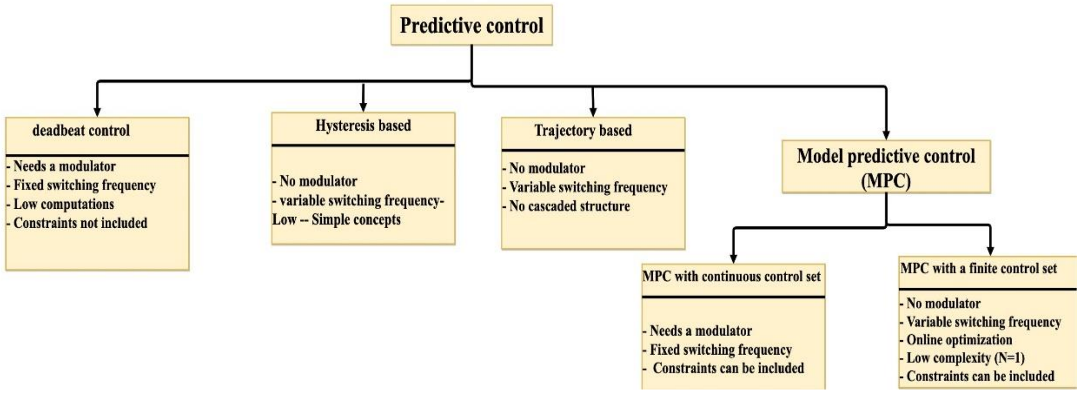

Figure 1.3 Predictive control classfication

1.3 Problem Statement

The PMSM drive provides many advantages such as high torque, high efficiency, low noise, and long life over other kinds of motors such as induction motors. The developments of PMSM drive make it desirable for motion control applications. However, due to PMSM's extremely nonlinear characteristics, it will need a more complex controller (advanced controller) to achieve high-performance drive applications. Moreover, PMSM requires the inverter to work at a higher switching frequency. To achieve interference control and noise reduction, but the affect is high switching losses and a reduction in overall drive performance. Therefore, controlling stator current is required to achieve the desired performance. Nevertheless, it hard to achieve the high performance, because of its highly non-linear nature. However, this issue was overcome by using vector controllers.

For the last decades, vector control represented by the common types, FOC and DTC, have been the most widespread methods used to control the AC drives including PMSM drives for high performance. “FOC method works in the principle of torque and flux where the stator currents decomposed into d-axis and q-axis representing flux and torque component respectively” [4]. However, it has cascade construction. Therefore, DTC is considered as a better established for it. DTC principle is “based on choosing the best voltage vector based on the errors of the torque and stator flux position” [4]. FOC and DTC drives are considered as high dynamics drives. However, MPC is a better strategy to control the PMSM drives, and it can give more accurate results compared to vector control.

MPC basic principle is to predict the future behavior of the system until a horizon in time and use that information by a cost function to a predefined optimization criterion. MPC construction scheme is less complex compared to FOC and DTC construction schemes. Moreover, it's easy inclusion of non-linearities in the model and the multivariable case can be easily considered.

1.4 Objectives

The main aim of this project is to develop a PMSM drive based on predictive control, hence these are objectives that need to be achieved:

i. To develop a PMSM drive system based on MPC.

ii. To analyze the performance of the MPC of PMSM drive in terms of speed variation and load disturbance.

iii. To verify the effectiveness of the proposed method by comparing PMSM drive with and without MPC through simulation study.

1.5 Scope

The scope of this project includes developing and simulating PMSM drive systems based on MPC. The scope of the project will cover the following:

i. Implementation of the modeling a (PMSM) by using mathematical modeling in MATLAB Simulink software.

ii. To develop a PMSM drive system based on MPC to control PMSM parameters. The predictive controller is predicting the future behavior of the system and use that information to control the parameters of the system.

iii. To analyze the performance of MPC based on torque ripple, step response and current THD by using MATLAB Simulink software.

1.6 Thesis organization

This thesis is organized into five main chapters. Chapter discusses the background and general idea of the proposed project. In addition, the objectives and scopes of the project are explained in detail. Chapter 2 presents the theoretical background of PMSM and control methods. Where, chapter 3 includes the methodology which shows the steps of each design stage. The details of the topology are discussed including the project flow chart and design procedures of MPC. Chapter 4 represent simulation results and the discussion. Finally, chapter is the summary of the project finding and outcomes and future work suggestion are presented in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In recent decades electrical drives have been widely used in many different industry applications. Figure 2.1 shows a typical drive system. Moreover, many electrical motors used for different reasons. However, PMSM drive has a great characteristic that make it widely used over the other electrical motor drives. Moreover, PMSM provides more advantages such as high efficiency, less rotor losses, high power density, simple structure, small size which make the maintenance cost low [4]. PMSM is an AC motor that fed which supplied by an AC power. consequently, an inverter is required to change the DC source power to an AC power and fed the PMSM. However, because of the highly nonlinear characteristic it has unstable response, therefore give a high performance. However, this issue can be fixed to give more accurate response and a great performance need to use an advanced control strategy to control the input power of the PMSM. Moreover, it will need to control the output of the inverter (voltage, current and frequency) [5].

There are different methods of control which have been applied in order to control the high-performance system. Such as the vector controllers, FOC and DTC. However, MPC has many advantages that make it ideal in order to control the PMSM drive system. The principle of MPC is an intuitive and easy to understand, it can be applied to variety system, constraints and nonlinearities can be easily included, reduce the complexity, multivariable case can be easily considered and easy to apply the resulting controller. Compared to the other methods it needs a higher number of calculations. MPC function is based on production of future behavior of a system and give the best action for the requirement [6].

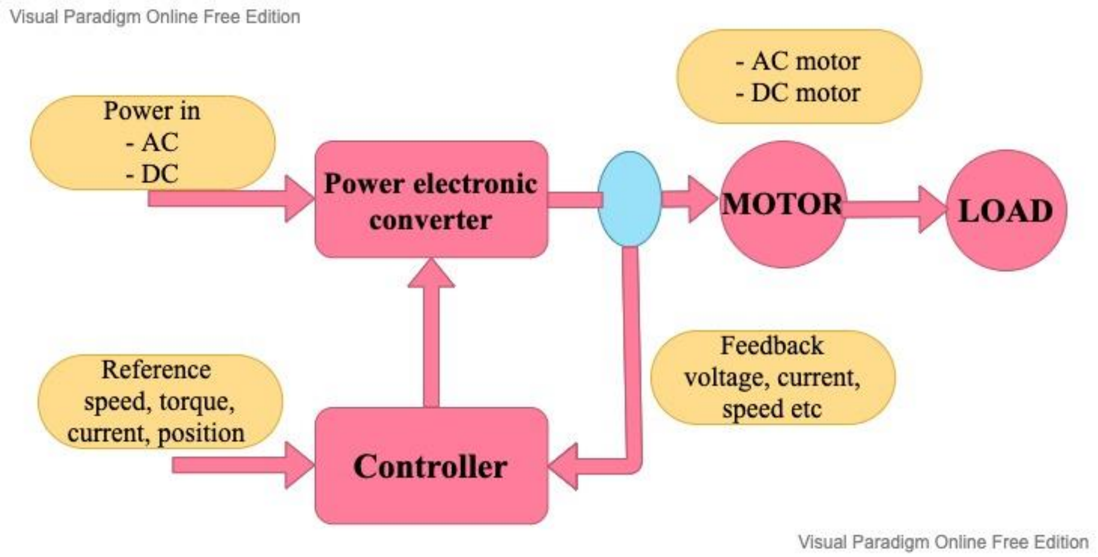

Figure 2.1 Typical drive system

2.2 AC motors

AC motors are commonly used in industrial applications because of the high performance of these motors produce. Few advantages are as follows, high power density, high reliability, less cost for the implementation and less maintenance is required. The disadvantage of using these motor that it will need more complex control method because of the high nonlinear characteristic of these motors. The AC motors has different types and configurations. The configuration of the AC motor is based on the AC power supply, it can be a single phase, three-phase or multiphase. Moreover, the AC motors has been categorized on two main types, asynchronous motors and synchronous motors, Figure 2.2 shows the AC motor types [7].

Asynchronous motors, the stator windings are connected to AC supply where is the rotor has no connection from the stator or any other source supply. the power transferred from the stator to the rotor only by mutual induction. That’s why it also called as an induction motor. Moreover, the synchronous speed is higher than the rotating speed of the rotor [7].

The synchronous motors require an AC supply at the stator winding which will produce rotating magnetic flux and a DC supply at the rotor windings will produce a constant flux. moreover, it called a synchronous motor because it runs at the synchronous speed $N_s = 120f/p$. In addition, adjusting the filed excitation the important characteristic of a synchronous motor can be operated at a variety of power factor (Pf) (unity, leading, lagging) [7].

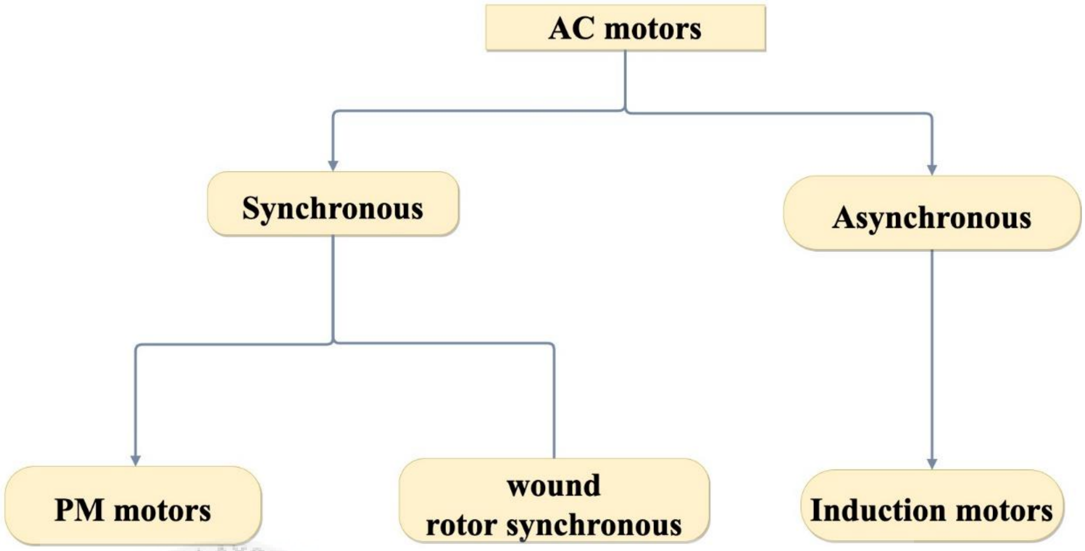

Figure 2.2 AC motors classfication

2.2.1 PMSM motor

PMSM is a synchronous motor, except that the permanent magnet (PMs) is replacing the field winding and the DC power supply. Replacing the field winding and the DC power supply by PMs is one of the advantages that make the PMSM widely used in many high-performance applications. Furthermore, there are many advantages for PMSM such as it has low torque ripple which it can produce a constate torque and it has the capacity to hold the maximum torque at low speeds, also since the rotor magnet produced by the PMs the rotor doesn't has coil. Therefore, the generated heat will be less, moreover, it is small, and it doesn't have brushes therefore it has low maintenance which make more suitable for the industrial applications. Which because the rotor induced by PMs, it provides a high flux density so there is no need for an excitation current, hence the excitation loss is removed [8].

Therefore, the PMSM works on the principal of the synchronous motor which is that rotor magnetic poles try to catch up stator magnetic motors and tries to synchronize and the motor will start rotating therefore, the rotor will be continuous to catch the stator and every communication, and the motor moves continuously.