



**COMPARATIVE ANALYSIS OF PERMANENT
MAGNET SYNCHRONOUS MOTOR
PERFORMANCE BY USING FUZZY LOGIC WITH
PI CONTROLLER**

by

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LIST OF ABBREVIATIONS

DC	Direct Current
AC	Alternating current
MATLAB	Matrix Laboratory
FLC	Fuzzy Logic Controller
PID	Proportional- Integral- Derivative
BLDC	Brushless Direct Current
MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor
IGBT	Insulated- Gate Bipolar Transistor
GTO	Gate Turn- Off thyristor
P	Proportional
(e)	Error
(ce)	Change in Error
Kp	Proportional Gain
Ki	Integral Gain
Kd	Derivative Gain
D	Derivative Term
I	Integral Term
UniMAP	Universiti Malaysia Perlis
PMDC	Permanent Magnet DC Motor
EMF	Electromotive Error
R _a	Phase Resistance
L _a	Phase Inductance
K _e	Back electromotive force constant
K _b	Damping friction of the mechanical system
J	Moment of inertia of the rotor
V(s)	Input Voltage
PI	Proportional- Integral
T	Motor Torque
K _t	Torque constant
trimf	Triangular Membership
V _a ,V _b ,V _c	Phase voltage
I _a ,I _b ,I _c	Phase current

Ea,eb,ec	Back EMF for each phase
B	Damping coefficient
TL	Load Torque
RPM	Rotational Speed
PWM	Pulse Width Modulation
Vdc	Voltage source
Ea	Electromotive force
N.m	Electromagnetic torque
Ia	Stator current
Rad2rpm	Conversion block
N(ref)	Reference input
N(actual)	Reference actual
FIS	Mamdani-type Fuzzy Inference System
NB	Negative Big
NS	Negative Small
ZZ	Zero
PS	Positive Small
PB	Positive Big
S	Small
M	Medium
B	Big
VB	Very Big
VVB	Very Very Big
Vab	Line-line Voltage
PMSM	Permanent Magnet Synchronous Machine

LIST OF SYMBOLS

Ω	Resistance Value
A	Field Current
V	Voltage
s	Seconds
ω	Angular velocity
θ	Angle
$f(\theta)$	EMF waveform

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Analisis Perbandingan Prestasi Motor Sinkron Magnet Kekal Menggunakan Logik Kabur dengan Pengawal PI

ABSTRAK

Kajian ini menyelidik prestasi Motor Sinkron Magnet Kekal (MSMK) di bawah kawalan Pengawal Logik Kabur (FLC) dengan Pengawal Proporsional-Integral (PI). MSMK diakui secara meluas kerana kecekapan tinggi, kebolehpercayaan, dan keperluan penyelenggaraan rendah, menjadikannya sesuai untuk pelbagai aplikasi industri seperti robotik, aeroangkasa, dan kenderaan elektrik. Walaupun penggunaan pengawal PI adalah meluas, mereka sering menghadapi kesukaran dengan dinamik tak linear MSMK, yang mengakibatkan lebihan (overshoot) yang signifikan, masa telera (settling time) yang lama, dan kepekaan terhadap variasi parameter. Cabaran-cabaran ini boleh menyebabkan prestasi yang tidak optimum dan peningkatan kehausan sistem. Untuk menangani isu-isu ini, penyelidikan ini meneroka pelaksanaan FLC, yang mahir dalam menguruskan ketidaktepatan dan ketidakpastian dalam tingkah laku sistem tanpa memerlukan model matematik yang tepat. Kajian ini menggunakan MATLAB Simulink untuk mereka bentuk dan mensimulasikan kedua-dua sistem PI dengan FLC untuk kawalan kelajuan MSMK. Metrik prestasi utama, termasuk ketepatan kelajuan, tindak balas sementara (transient response), dan kestabilan sistem, dinilai dengan teliti di bawah pelbagai keadaan operasi. Hasil simulasi menunjukkan bahawa FLC mengatasi pengawal PI, menawarkan tindak balas sementara yang dipertingkatkan, lebihan yang dikurangkan, dan masa telera yang lebih cepat. Tambahan pula, keupayaan auto-tuning FLC membolehkan penyesuaian yang lebih mudah dan kebolehsuaian yang lebih baik kepada persekitaran industri yang berbeza-beza, meningkatkan kebolehpraktisannya. Kajian ini menyimpulkan bahawa FLC menyediakan strategi kawalan yang lebih teguh dan adaptif untuk MSMK, yang merupakan alternatif yang berharga kepada kaedah kawalan PI tradisional dalam aplikasi industri.

Comparative Analysis of Permanent Magnet Synchronous Motor Performance by using Fuzzy Logic with PI Controller

ABSTRACT

This study investigates the performance of Permanent Magnet Synchronous Motors (PMSMs) under the control of a Fuzzy Logic Controller (FLC) with a Proportional-Integral (PI) controller. PMSMs are widely recognized for their high efficiency, reliability, and low maintenance requirements, making them suitable for various industrial applications such as robotics, aerospace, and electric vehicles. Despite the prevalent use of PI controllers, they often struggle with the nonlinear dynamics of PMSMs, leading to significant overshoot, prolonged settling times, and sensitivity to parameter variations. These challenges can result in suboptimal performance and increased system wear and tear. To address these issues, this research explores the implementation of an FLC, which is adept at managing imprecision and uncertainty in system behavior without requiring an exact mathematical model. The study utilizes MATLAB Simulink to design and simulate both PI with FLC systems for PMSM speed control. Key performance metrics, including speed accuracy, transient response, and system stability, were rigorously evaluated under various operating conditions. Simulation results indicate that the FLC outperforms the PI controller, offering enhanced transient response, reduced overshoot, and quicker settling times. Additionally, the FLC's auto-tuning capability allows for easier adjustments and better adaptability to varying industrial environments, increasing its practical applicability. This study concludes that the FLC provides a more robust and adaptive control strategy for PMSMs, presenting a valuable alternative to traditional PI control methods in industrial applications.

CHAPTER 1 : INTRODUCTION

1.1 Research Background

Permanent Magnet Synchronous Motors (PMSM) have become essential in various industries due to their high efficiency, reliability, and performance. Unlike traditional brushed motors, PMSM use electronic commutation, eliminating the need for physical brushes and reducing maintenance requirements. This makes them ideal for applications such as electric vehicles, aerospace, medical devices, and household appliances, where reliability and longevity are crucial (Ahmed & Ali, 2020; Chen & Liu, 2020).

Precise control of PMSM is vital for optimal performance. Conventional PI controllers, while effective in many linear systems, often struggle with the nonlinear characteristics and parameter variations of PMSMs, leading to issues like overshoot, long settling times, and steady-state errors (Gupta & Sharma, 2020). These limitations have prompted the exploration of advanced control strategies.

Fuzzy Logic Controllers (FLC) offer a promising alternative. Introduced by Lotfi Zadeh in 1965, fuzzy logic handles imprecision and uncertainty by mimicking human reasoning. Fuzzy Logic Controllers (FLC) do not require an exact mathematical model of the system, making them suitable for complex and nonlinear systems like PMSMs (Chen, W. & Liu, Y., 2020). They use linguistic rules derived from expert knowledge, allowing for adaptive and robust control in dynamic environments.

Studies have shown that Fuzzy Logic Controllers (FLC) can improve transient response, reduce overshoot, and achieve faster settling times compared to PI controllers

(Patel & Mehta, 2020). Additionally, Fuzzy Logic Controllers (FLC) can auto-tune, eliminating the need for manual adjustment of control parameters, which is beneficial in industrial settings with varying system parameters. Despite these advantages, the adoption of Fuzzy Logic Controllers (FLC) in PMSM control faces challenges such as designing effective fuzzy rules and the computational demands of real-time implementation (Gomez & Hernandez, 2022). However, advancements in computing power and efficient algorithms are addressing these issues.

This research aims to design, implement, and evaluate a fuzzy logic-based speed control system for PMSM, leveraging FLC's flexibility and adaptability. By enhancing PMSM control performance, this study seeks to provide a robust solution for various industrial applications, potentially leading to broader adoption of Fuzzy Logic Controllers (FLC) in the motor control industry.

1.2 Problem Statement

The performance of traditional controllers for PMSM (Permanent Magnet Synchronous Motor) can be adversely affected by nonlinear characteristics such as saturation and friction. To address these issues, advanced model-based control methods like variable structure control and model reference adaptive control have been developed. However, the effectiveness of these approaches relies heavily on the accuracy of the system models and parameters. Finding an accurate nonlinear model for a real PMSM motor is challenging, and parameter values obtained from system identification may only be approximate (Ali & Khan, 2020; Zhang & Zhao, 2020).

In industrial applications, control systems that can provide a fast response to maintain the desired speed of the PMSM motor with minimal overshoot, steady-state error, settling time, and rising time are crucial. While conventional control has been effective for system control tasks, it depends on an exact mathematical model of the plant rather than simple mathematical operations (Lee & Choi, 2020; Zhang, K. & Zhao, M., 2020).

1.3 Research Objectives

The aim of this thesis is to investigate the speed control of Permanent Magnet Synchronous Motor (PMSM) using Fuzzy Logic. The objectives of this study are:

- a) To design a fuzzy logic controller (FLC) for control a permanent magnet synchronous motor (PMSM).
- b) To vary the load performance of Permanent Magnet Synchronous Motor (PMSM) using Fuzzy Logic Controller (FLC) in MATLAB Simulink.
- c) To analyse the response of Speed performance, Stator Current, Electromotive Force and Electromagnetic Torque in a Permanent Magnet Synchronous Motor (PMSM).

1.4 Scope and Limitation

The scope of this study will focus on the comparative analysis of Permanent Magnet Synchronous Motor (PMSM) performance using a Proportional-Integral (PI) Controller integrated with a Fuzzy Logic Controller (FLC). This study limits itself to the

rules used in Fuzzy Logic and the tuning methods of the PI controller. The detailed scope of this research is as follows:

- a) This project aims to design, implement, and evaluate a control system that integrates a Fuzzy Logic Controller within a PI control framework for a PMSM. The project will encompass the integration of a PMSM, sensors for speed feedback, and the combined control algorithm for precise speed regulation.
- b) The focus will be on developing a fuzzy logic algorithm to adjust the PI controller's parameters dynamically based on input parameters such as motor speed error and the rate of change of error. The project will involve simulation studies using tools like MATLAB Simulink.
- c) Parameters of the PI controller will be tuned to optimize speed control performance, with the Fuzzy Logic Controller enhancing the PI control through dynamic adjustment. Evaluation will be based on performance metrics such as speed accuracy, transient response, and system stability under varying load conditions.
- d) The project aims to explore the possibility of real-time simulation, ensuring that the developed control system can respond effectively to dynamic changes in the motor's operating conditions within the simulation environment.
- e) The project is subject to limitations imposed by the specifications of the PMSM, including power ratings and communication interfaces. Constraints on

computational resources may limit the complexity and speed of the fuzzy logic algorithm, particularly in real-time applications.

- f) The accuracy of the motor model may introduce limitations in the precision of speed measurement, affecting the overall system performance. The project acknowledges that external disturbances, such as sudden load changes, may impact the speed control system and are considered external to the scope of this project.
- g) External environmental conditions, such as temperature and humidity, may affect the performance of the system, but these factors are not explicitly considered in this project.

1.5 Outline of Thesis

This thesis consists of five important chapters separate by its section. Chapter 1 is an introduction to the study's subject matter and serves as the basis for the rest of the main topic. As part of this section, these chapter also address the problem statement that focuses on the study's primary issues. This project's goals are analysed in order to define the objectives to be presented in this thesis. The scope is also discussed as a comment thread that explains how this assessment was conducted out. In addition, the first chapter also included scope of limitation and outline of thesis.

Chapter 2 will discuss about doing a literature review and then see what previous studies in journals and articles or case studies have found about the properties,

characteristics and performance of PMSM by using Fuzzy Logic Controller and PID Controller. Related articles used as a reference and guide to narrow the specific study for type of the PMSM.

In the next Chapter 3 will cover more of the method used in this project. In addition, chart and planning will be explored in detail in this section. This part will explain how the experiment conduct and the data collect. Experiments are conducted in order to obtain data and achieve the research objectives.

Furthermore Chapter 4 covers the results obtained based on this study. The results obtained based on data collected during the experiment. The finding of the experiments were analysed and compared to present the final results of the study as stated in the research objectives.

Finally, Chapter 5 focuses on the implications of the project's findings or analyse. The findings of the experiment review would be discussed in depth. This chapter will conclude the findings of the study and will suggest more detailed for future research in this study.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

Lotfi Zadeh developed fuzzy logic as a formal approach for representing heuristic knowledge (Ahmed & Ali, 2020). Fuzzy logic facilitates the development of readily comprehensible rules for the implementation of complicated system controllers (Ahmed & Ali, 2020). Fuzzy logic controllers (FLCs) are a useful substitute for a variety of control applications. They may efficiently handle nonlinear systems by employing heuristic data that the programmer intuitively provides (Ali, H. & Ahmed, R., 2020). Fuzzy controllers are inherently sturdy and inexpensive, in addition to having an intuitive design. Microprocessors, microcontrollers, and digital signal processor-based techniques are some of the ways that FLC systems can be implemented in hardware (Gomez & Hernandez, 2022).

Permanent Magnet Synchronous Motor (PMSM) are widely used in various applications due to their high efficiency and reliability. PMSM are known for their ability to provide high torque with a relatively small size, making them ideal for use in electric vehicles, robotics, and industrial automation (Smith & Jones, 2021). The integration of fuzzy logic controllers with PMSM offers significant advantages in terms of performance and adaptability. Fuzzy Logic Controller can effectively manage the nonlinear characteristics of PMSM, resulting in improved control precision and stability. This combination of FLCs and PMSMs allows for the development of advanced control strategies that enhance the overall efficiency and functionality of motor control systems (Brown & Green, 2023).