Faculty of Electrical Engineering

SIMPLIFIED FUZZY LOGIC CONTROL OF SINUSOIDAL PERMANENT MAGNET SYNCHRONOUS MOTOR DRIVES

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DECLARATION

I declare that this thesis entitled “Simplified Fuzzy Logic Control of Sinusoidal Permanent Magnet Synchronous Motor Drives” 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.

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Date : ……

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electrical Engineering.

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Date	:	……..

DEDICATION

To my beloved mother, father and family

To my beloved husband

ABSTRACT

Fuzzy Logic Control (FLC) is suitable for a controller design when the system is difficult to model mathematically due to its complexity, nonlinearity and imprecision. It is widely used in high performance drives to obtain precise speed control irrespective of load disturbances and parameter variations. The purpose of this project is to investigate and evaluate speed performance of the FLC in vector controlled Sinusoidal Permanent Magnet Synchronous Motor (SPMSM) drives. The SPMSM is controlled by a vector control technique operating like a separately excited DC motor. The mathematical model of SPMSM drives is simulated using the MATLAB Simulink program. The standard FLC which comprise of 49 rules is initially designed based on common criteria. From investigation on the FLC tuning, two simplified FLCs are designed based on fuzzy rules reduction with systematic and reasonable approaches. The efficacies of the FLC simplification are determined by conducting a comparative analysis between standard FLC and simplified FLCs over a wide range of operating conditions. This is based on simulation approach including various initial step speed commands, load disturbance, step reduction in speed command, inertia variations, and speed reversal operation. The FLCs are developed using the Fuzzy Logic Toolbox in MATLAB. The simulation results show that the simplified FLCs obtain comparable performance with the standard FLC in some cases while in others, they perform better than the standard FLC. The simulation results are further evaluated by an experimental investigation. The FLC, co-ordinate transformation and hysteresis current controllers are implemented in the software using Simulink, Fuzzy logic Toolbox and Real-time interface. The hardware implementation consisting of digital signal processor, voltage source inverter, resolver-to-linear DC converter, current sensors and SPMSM are equipped with a speed resolver. As a result, the simplified FLCs are capable to obtain high performance standards with simple rules, less complex structure, less computation time besides solving the limitation of processor and memory resources.

ABSTRAK

Kawalan fuzzy logic (FLC) sesuai untuk merekabentuk pengawal apabila sistem sukar untuk dimodelkan dengan kaedah matematik kerana kerumitan, ketidaklelurusan dan ketidaktetapan. Ia digunakan secara meluas dalam pemacu berprestasi tinggi untuk mendapatkan kawalan kelajuan yang tepat tanpa mengira gangguan beban dan variasi parameter. Tujuan projek ini adalah untuk menyiasat dan menilai prestasi kelajuan oleh FLC dalam kawalan vector pada pemacu Motor Segerak Magnet Kekal Sinusoidal (SPMSM). SPMSM ini dikawal oleh teknik kawalan vektor untuk beroperasi seperti motor arus terus aruhan berasingan. Model matematik pemacu SPMSM disimulasi menggunakan program MATLAB Simulink. 'Standard FLC' yang terdiri daripada 49 peraturan fuzzy yang pada mulanya direka berdasarkan kriteria yang biasa.Dari siasatan ke atas penalaan FLC, dua 'simplified FLC' direka bentuk berdasarkan pengurangan peraturan fuzzy dengan pendekatan yang sistematik dan munasabah. Keberkesanan permudahan FLC ditentukan dengan menjalankan analisis perbandingan diantara 'standard FLC' dan dua 'simplified FLC' dengan pelbagai keadaan operasi. Ini adalah berdasarkan kepada pendekatan simulasi termasuk pelbagai arahan kelajuan, gangguan beban, pengurangan arahan kelajuan, variasi inersia, dan operasi pembalikan kelajuan. FLC ini dibangunkan menggunakan Fuzzy Logic Toolbox yang terdapat dalam MATLAB. Keputusan simulasi menunjukkan bahawa 'simplified FLC' menghasilkan prestasi setanding dengan 'standard FLC' dalam beberapa kes manakala dalam kes yang lain, mereka lebih baik daripada 'standard FLC'. Keputusan simulasi dinilai lagi dengan siasatan ujikaji. FLC, transformasi koordinat dan pengawal arus 'hysteresis' dilaksanakan dalam perisian menggunakan Simulink, 'Fuzzy Logic Toolbox' dan 'Real-time interface'. Pelaksanaan perkakasan yang terdiri daripada pemproses isyarat digital, penyongsang sumber voltan, penukar resolver-kepada-linear DC, pengesan arus dan SPMSM dilengkapi dengan resolver kelajuan. Hasilnya, 'simplified FLC' mampu untuk mendapatkan standard prestasi tinggi dengan peraturan fuzzy yang mudah, struktur yang kurang kompleks, masa pengiraan yang kurang selain menyelesaikan had pemproses dan sumber memori.

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LIST OF ABBREVIATIONS

1) Principle symbols

ce	change of error
e	error
G_e	scaling factor of error
G_{ce}	scaling factor of change of error
G_u	scaling factor of output signal
i_a, i_b, i_c	stator phase a, b, c current
i_{ds}	d -axis stator current
i_{qs}	q-axis stator current
J	total inertia
L	inductance
P	number of pole pairs
θ	rotor position angle
R	resistance
S	switching function
T_e	electromagnetic torque
T_L	load torque
T_s	sampling time
u	control signal
V_a, V_b, V_c	stator phase a, b, c voltage
V_{ds}	d-axis stator voltage

V_{qs}	q-axis stator voltage
φ	flux linkage
ω	speed
V_{dc}	DC link voltage

2) Superscript

*	commanded value

3) List of abbreviations

AC	alternative current
A/D	analog/digital
ADC	analog-to-digital converter
AI	artificial intelligent
ANN	artificial neural networks
ASIC	application specific integrated circuit
BJT	bipolar junction transistor
CoG	centre of gravity
D/A	digital/analog
DAC	digital-to-analog converter
DC	direct current
DTC	direct torque control
DSC	direct self control
DSP	digital signal processor
EMF	electromagnetic force
FL	fuzzy logic
FLC	fuzzy logic control
FOC	field oriented control

GA	genetic algorithm
GTO	gate turnoff thyristor
HB	hysteresis band
HCC	hysteresis current control
HPD	high performance drives
IC	Integrated circuit
IGBT	insulated gate bipolar transistor
IGCT	integrated gate commutated thyristor
I/O	input/output
MF	membership function
MOSFET	metal-oxide-semiconductor field-effect transistor
MRAC	model reference adaptive control
MRAS	model reference adaptive system
PI	proportional integral
PID	proportional integral derivative
PWM	pulse width modulation
R/LDC	resolver-to-linear DC converter
UoD	universe of discourse
SCR	silicon-controlled rectifier
SPMSM	sinusoidal permanent magnet synchronous motor
VSI	voltage source inverter

LIST OF PUBLICATIONS

Journal Paper

1. Zulkifilie Ibrahim, **Siti Noormiza Mat Isa**, Jurifa Mat Lazi and Md. Hairul Nizam Talib, "Simplified Fuzzy Logic Speed Controller for Vector Controlled Permanent Magnet Synchronous Motor Drives", International Review of Electrical Engineering (I.R.E.E.), vol. 8, n. 1, January-February 2013.

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1. **Siti Noormiza Mat Isa**, Zulkifilie Ibrahim, Jurifa Mat Lazi, Md Hairul Nizam Talib, Nurazlin Yaakop and Ahmad Shukri Abu Hasim, *"dSPACE DSP Based Implementation of Simplified Fuzzy Logic Speed Controller for Vector Controlled PMSM Drives"*, in IEEE International Conference on Power and Energy (PECon), Sabah, Malaysia, 2012, pp. 898-903.
2. **Siti Noormiza Mat Isa**, Zulkifilie Ibrahim, Jurifa Mat Lazi, Md Hairul Nizam Talib and Nurazlin Mat Yaakop *"Fuzzy Logic Speed Controller with Reduced Rule Base for Vector Controlled PMSM Drive",* in Power and Energy Conversion Symposium (PECS), Melaka, Malaysia, 2012, pp. 94-101.
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CHAPTER 1

INTRODUCTION

1.1 Background

Electrical drives are known as drives that use electric motors as the prime movers to provide motion control. In general, the electrical drives control speed, torque, and direction thus, resulting the horsepower of a motor. Traditionally, the operation of motor drives is uncontrolled where the motor runs at a constant speed such as compressor motor in a refrigerator when it turns ON. In order to fulfill the industry requirements for different speed applications such as electric vehicle, an adjustable method is introduced to determine the controlled operation where the motor is able to be operated at variable speeds.

The components of electrical drives consist of motor, power source, power processor, control unit and sensors. The motors are available in two types, namely Direct Current (DC) and Alternating Current (AC) motors. The motor obtains power from the electrical sources. Selection of the type of motor depends on application, cost, environmental factor and type of sources available. The power sources, either utility interface or renewable energy, or AC/DC supplies, are used to provide energy for the electrical motors. For high efficiency operation, the power obtained from electrical sources needs to be regulated using the power processor. The conventional power processor is the variable impedance or relay. The power electronics converters are normally used in the modern electrical drives. The possible conversions are from AC to DC, DC to AC, DC to DC, and AC to AC. The control unit depends on the desired performance and the type of