Faculty of Electrical Engineering

SELF-TUNING FUZZY LOGIC SPEED CONTROLLER OF INDUCTION MOTOR DRIVES

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DECLARATION

I declared that this thesis entitled “Self-Tuning Fuzzy Logic Speed Controller of Induction 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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APPROVAL

I hereby declared 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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ABSTRACT

Induction motor drives are commonly applicable in various industrial applications, such as traction system, electric vehicle and home appliances. This high performance drive require robust controller to obtain satisfactory performance in terms of speed demand change, load disturbance, inertia variation and non-linearity. Fuzzy Logic Control (FLC) is suitable for controller design especially when the system is difficult to be modelled mathematically due to its complexity, nonlinearity and imprecision. However, FLC with fixed parameters may experience degradation when the system operates away from the design point, and encounters parameter variation or load disturbance. The purpose of this project is to design and implement Self-Tuning Fuzzy Logic Controller (ST-FLC) for Induction Motor (IM) drives. The proposed self-tuning mechanism is able to adjust the output scaling factor of the output controller for main FLC. This process enhances the accuracy of the crisp output. This research begins by designing Indirect Field Oriented Control (IFOC) method fed by Hysteresis Current Controller (HCC) induction motor drive system. The FLC with fixed parameters for the speed controller comprises 9-rules are tuned to achieve best performance. Then, a simple self-tuning mechanism is applied to the main fuzzy logic speed controller. All simulations are executed by using Simulink and fuzzy tools in MATLAB software. The effectiveness of the proposed controller is determined by conducting a comparative analysis between FLC with fixed parameters and ST-FLC over a wide range of operating conditions, either in forward and reverse operations, load disturbance or inertia variations. Finally, experimental investigation is carried out to validate the simulation results by the aid of digital signal controller board dSPACE DS1104 with the induction motor drives system. Based on the results, ST-FLC has shown superior performance in transient and steady state conditions in term of various performance measures such as overshoot, rise time, settling time and recovery time over wide speed range operation. In comparison to fixed parameter FLC, the proposed ST-FLC reduced the settling time by 40.5%, rise time by 47.3% and speed drop by 19.2%. The proposed self-tuning mechanism is relatively simpler and consumes less computational burden compared to other self-tuning methods. This is proved by measuring the computational burden of another Self-Tuning method which used fuzzy rules to tune the output scaling factor. The execution time of the proposed self-tuning found to be $0.5\ x10^{-3}$ seconds compared to $1.2\ x10^{-3}$ seconds for the other self-tuning.

ABSTRAK

Pemacu motor aruhan biasanya digunakan dalam pelbagai aplikasi perindustrian, seperti sistem daya tarikan, kenderaan elektrik dan peralatan rumah. Pemacu prestasi tinggi ini memerlukan satu pengawal yang mantap untuk mendapatkan prestasi yang memuaskan dari kepelbagaian permintaan kelajuan, gangguan beban, variasi inersia dan tidak linear. Kawalan Logik Kabur (FLC) sesuai untuk reka bentuk pengawal terutamanya apabila sistem itu sukar dimodelkan secara matematik kerana kerumitan, tidak linearan dan masalah ketepatan. Walau bagaimanapun, FLC dengan parameter tetap mungkin mengalami kemerosotan apabila sistem beroperasi jauh dari titik reka bentuk, dan menghadapi variasi parameter atau gangguan beban. Projek ini bertujuan untuk mereka bentuk dan melaksanakan Kawalan Logik Kabur Talaan Sendiri (ST-FLC) bagi pemacu Motor Aruhan (IM). Mekanisme penalaan sediri yang dicadangkan dapat menyesuaikan faktor skala keluaran bagi pengawal untuk FLC utama. Proses ini dapat meningkatkan ketepatan keluaran pengawal. Penyelidikan ini bermula dengan merekabentuk kaedah Kawalan Orientasi Medan Tidak Langsung (IFOC) yang disandarkan oleh sistem pemacu motor aruhan Pengawal Arus Hysteresis (HCC). FLC dengan parameter tetap untuk pengawal kelajuan merangkumi 9 aturan yang ditalakan untuk mencapai prestasi terbaik. Kemudian, mekanisme penalaan sendiri mudah digunakan untuk pengawal kelajuan logik kabur utama. Semua simulasi dilaksanakan dengan menggunakan Simulink dan perkakasan kabur dalam perisian MATLAB. Keberkesanan pengawal yang dicadangkan ditentukan dengan menjalankan analisis perbandingan di antara FLC berparameter tetap dan ST-FLC dalam pelbagai keadaan operasi, sama ada dalam operasi kehadapan dan kebelakang, gangguan beban atau variasi inersia. Akhirnya, siasatan eksperimen dijalankan untuk mengesahkan keputusan simulasi dengan bantuan papan pengawal isyarat digital dSPACE DS1104 dengan sistem pemacu motor aruhan. Berdasarkan dapatannya, ST-FLC telah menunjukkan prestasi yang unggul sama ada di dalam keadaan fana dan mantap dari pelbagai aspek prestasi ukuran seperti lajak atas, masa menaik, masa pengenapan dan masa pemulihan dengan operasi julat kelajuan yang besar. Jika dibandingkan dengan FLC berparameter tetap, ST-FLC yang dicadangkan mengurangkan masa pengenapan sebanyak 40.5%, masa menaik sebanyak 47.3% dan masa pemulihan sebanyak 19.2%. Mekanisme penalaan sendiri yang dicadangkan agak mudah dan menggunakan beban komputasi yang kurang berbanding dengan kaedah penalaan sendiri yang lain. Ini dibuktikan dengan membuat pengukuran beban komputasi bagi kaedah talaan sendiri yang lain yang menggunakan aturan kabur sebagai penala faktor skala keluaran. Masa pelaksanaan bagi penalaan sendiri yang dicadangkan adalah $0.5\ x10^{-3}$ *saat berbanding dengan* $1.2\ x10^{-3}$ *saat untuk penalaan diri yang lain.*

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TABLE OF CONTENTS

PAGE

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

AC - Alternate Current

ADC - Analog to Digital Converter

ASD - Adjustable Speed Drive

AWPI - Anti-Windup Proportional integral controller

CoG - Center of Gravity

DC - Direct Current

DSP - Digital Signal Processor

DTC - Direct Torque Control

DSPACE - Digital Signal Processing And Control Engineering

FL - Fuzzy Logic

FLC - Fuzzy Logic Controller

FMRLC - Fuzzy Model Reference Learning Control

FNN - Fuzzy Neural Network

FOC - Field Oriented Control

HCC - Hysteresis Current Control

IAE - Integral Absolute Error

IGBT - Insulated Gate Bipolar Transistor

IFOC - Indirect Field Oriented Control

IM - Induction Motor

ITAE - Integral Time Absolute Error

MF	-	Membership Function
MRAC	-	Model Reference Adaptive Control
MRAS	-	Model Reference Adaptive System
PI	-	Proportional Integral
PMSM	-	Permanent Magnet Synchronous Motor
PWM	-	Pulse Width Modulation
RTI	-	Real Time Interface
SPWM	-	Sinusoidal Pulse Width Modulation
ST-FLC	-	Self-Tuned Fuzzy Logic Controller
SVPWM	-	Space Vector Pulse Width Modulation
TS	-	Takagi-Sugeno
THD	-	Total Harmonics Distortion
UoD	-	Universe of Discourse
VSI	-	Voltage Source Inverter

LIST OF SYMBOLS

B	-	Friction
$\alpha\beta$-frame	-	Stator reference frame
dq-frame	-	Rotor reference frame
d-axis	-	Direct axis
q-axis	-	Quadrature axis
e	-	Speed error
Ce	-	Change of speed error
G_e	-	Error gain
G_{ce}	-	Change of speed gain
G_{cu}	-	Output gain
i_a, i_b, i_c	-	Stator phase a ,b and c current
I_a	-	Armature current
I_f	-	Field current
i_{sd}	-	Direct axis stator current
i_{sq}	-	Quadrature axis stator current
K_p	-	Proportional gain for PI
K_i	-	Integral gain for PI
K_t	-	Torque constant
L_s	-	Stator self-inductance

L_r - Rotor self-inductance

L_m - Mutual inductance

P - Number of poles

OS - Overshoot

R_r - Rotor Resistance

R_s - Stator Resistance

T_e - Electromagnetic torque

T_L - External load

T_r - Rise time

T_s - Settling time

T_{st} - Sampling time

v_r - Rotor voltage

v_s - Stator voltage

v_{sd} - Direct axis voltage

v_{sq} - Quadrature axis voltage

φ_r - Rotor flux leakage

φ_s - Stator flux leakage

σ - Leakage coefficient factor

ε - Damping ratio

θ_f - Field angle

θ_r - Rotor position angle

θ_{sl} - Slip angle

ω_e - Synchronous speed

ω_n - Natural frequency

ω_r - Rotor speed or actual speed

ω_{sl} - Slip speed

$\omega_r *$ - Reference speed

τ_m - Mechanical torque time constant

τ_r - Rotor time constant

τ_s - Stator time constant

LIST OF PUBLICATIONS

A. Journal Publications

Farah, N.S.Y., Talib, M.H.N., Ibrahim, Z., Rasin, Z. and Rizman, Z.I., 2018. Experimental investigation of different rules size of fuzzy logic controller for vector control of induction motor drives. Journal of Fundamental and Applied Sciences, 10(6S), pp.1696-1717.

Nabil Farah, M. H. N. Talib, Z. Ibrahim, J. M. Lazi, Maaspaliza Azri., 2018. Self-tuning Fuzzy Logic Controller Based on Takagi-Sugeno Applied to Induction Motor Drives. International Journal of Power Electronics and Drive System ,Vol. 9, No. 4, pp. 1967-1975

B. Conference Publications

Farah, N., Talib, M.H.N., Ibrahim, Z., Azri, M. and Rasin, Z., 2017, October. Self-tuned output scaling factor of fuzzy logic speed control of induction motor drive. In System Engineering and Technology (ICSET), 2017 7th IEEE International Conference on (pp. 134-139).

Farah, N., Talib, M.H.N., Ibrahim, Z., Isa, S.M. and Lazi, J.M., 2017, October. Variable hysteresis current controller with fuzzy logic controller based induction motor drives. In System Engineering and Technology (ICSET), 2017 7th IEEE International Conference on (pp. 122-127).

Nabil Farah, M.H.N. Talib, Z. Ibrahim, M. Azri, Z. Rasin and J Mat Lazi.,In Press. Self-Tuning Fuzzy Logic Control Based on MRAS For Induction Motor Drives .In CEAT 2018 International Conference on Clean Energy and Technology.

CHAPTER 1

INTRODUCTION

1.1 Research background

Induction Motor (IM) is one of the most popular electrical machines with a wide range of applications, such as electric vehicle, oil and gas excavations, mills, conveyors and many more (Zeraoulia &Benbouzid, 2006). The induction motor generally consists of a stator, which is the stationary part of the motor, and a rotor, which is the rotating part of the motor. There are two types of induction motor depending on the rotor construction, namely squirrel cage and wound rotor induction motor. Squirrel cage is the most widely used induction motor due to its simplicity, ease of construction, rugged and it requires less maintenance and is relatively cheaper (Dorrell et al., 2012).

Variable Speed Drive (VSD) can be defined as an electric motor which its speed can be adapted by utilizing additional controllers. Utilizing VSD in the control process of the motor is advantageous as energy saving, especially for large and high power electric motor. The function of VSD is to match the speed of the electric motor to the system requirements through adjusting the motor speed accordingly to the required tasks of the system. This can be achieved by compensating the changes on the system through external controllers (Saidur et al., 2012).

Scalar control is one of the first control method used to drive the AC motor. This method, however, only provides satisfactory performance during steady state condition but not in transient condition. Therefore, this method is only suitable for applications which do not require precise control and crucial transient of speed and torque response behaviors. The demands of high performance motor drives with good transient and steady state performances can be achieved by vector control or FOC and DTC. FOC and DTC become the standard control method for high performance motor drive system, which the flux and torque can be decoupled control. These methods directly control the instantaneous position of the voltage, current and flux vectors. It controls the flux and torque component independently, similar to separately excited Direct Current (DC) machine. The invention of the FOC and DTC overcomes the disadvantages of scalar control method. Further discussion of this topic is covered in Chapter 2. This project implements Indirect FOC (IFOC) method due to its excellent record in control high performance drive. In addition, this method applies simpler sensing techniques and is more reliable.

Speed, torque or flux of the motor can be controlled to follow the desired requirements. The IM speed needs to be effectively controlled as it can impact the overall system performance directly. Proportional Integral (PI) controller is a common technique to control the induction motor drives. This controller has grown due to its simplicity and is easy to implement with satisfactory performance. However, their scaling parameters are sensitive to the motor parameters variation or load disturbance. This will degrade the performance of the system, and will results in a big speed drop with long recovery time to any load disturbance. In order to overcome the drawbacks associated with conventional controllers, Fuzzy Logic Controller (FLC) is proposed. FLC is an effective method to control the speed of the motor without parameters dependency. Two inputs and one output fuzzy are utilized in the FLC speed controller. Speed error and changes in speed error are used as the crisp input variables of the FLC. They are converted into fuzzy variables, and then combined with the designed fuzzy rules to produce the desired output. A scaling factor placed for each input and output fuzzy variables can be calculated depending on the system requirements. These factors have a crucial influence on the system performance. However, the fixed values of these scaling