Faculty of Electrical Engineering

SIMPLIFIED FUZZY LOGIC CONTROLLER TO IMPROVE DISTURBANCE REJECTION WITH SPACE VECTOR IN INDUCTION MOTOR DRIVES

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DECLARATION

I declare that this thesis entitled "Simplified Fuzzy Logic Controller to Improve Disturbance Rejection with Space Vector in Induction Motor Drive" is the result of my research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature : ....
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Date : 29.11.2021

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 Doctor of Philosophy.

Signature : Marizan Sulaim ....

Supervisor Name : Professor Ir. Dr. Marizan bin Sulaiman

Date : 29.11.2021 ....

DEDICATION

To my beloved mother and father

ABSTRACT

Induction motor control is a specific and challenging topic in electrical engineering. The development of renewable energy and electric vehicles is growing rapidly, the topic of induction motor control is gaining major attention for industry and academia. The fast capabilities of modern microprocessors offer consideration of more intelligent and powerful control strategies. Conventional control approaches require complex mathematical models for motors to design controllers for quantities such as speed, torque, and position. Model-based calculations must be performed accurately for each motor, and the resulting model-based controllers may not perform well. This research addresses these problems by introducing a new Fuzzy Logic (FL) Controller incorporating space vector pulse width modulation (SVPWM) strategy with vector control for controlling inverter-fed induction motor. The most basic technique used to design FL controllers is based on fixed parameters of two inputs and one output through trial-and-error tuning according to the desired response of the system. Membership functions (MFs), rule bases, and control models refer to the engineering skills and behavioural aspects of the controlled system experience. However, the conventional FL controller also has a demerit due to a high computational burden while running large sale fuzzy rules. Computing time directly affects the performance of the motor drive system during the experiments performed. Simplification of fuzzy rules is one of the popular techniques to reduce the FL controller's computational demand. However, this technique affects the FL control system's variable coverage and accuracy in performance degradation. The MFs can be optimised by changing the FLC peak value of the MFs in the drive system to increase the system's robustness. Thus, this research presented the simplified fuzzy rules based on the phase plane trajectory method and optimised MFs to optimise the speed control performance. This research covered the controller design, modelling, and construction of digital signal processing (DSP). It implemented the designed controller to the experimental setup to improve disturbance rejection at various loads and speeds. The simplified 5-rule FL controller was tested and compared with several simplified standard rules; 25-rules, 9-rules, and 7-rules. The experimental validation has been performed on hardware using a three-phase induction motor, controller, inverter, current and voltage sensors and DSP board. The experiment results have confirmed that the recovery time, Tre of load disturbance for optimised MFs 5-rule is 10ms faster than optimised MFs of 7-rule and the almost identical performance as optimised MFs 9-rule. Therefore, the proposed controller has a significant ability to rapidly overcome load disturbances that can be applied in high-speed motor applications such as electric vehicles and traction systems.

PENGAWAL LOGIK KABUR DIPERMUDAH BAGI MENINGKATKAN PENOLAKAN GANGGUAN DENGAN VEKTOR RUANG DALAM PACUAN MOTOR ARUHAN

ABSTRAK

Kawalan motor aruhan merupakan topik khusus dan mencabar dalam kejuruteraan elektrik. Perkembangan tenaga boleh diperbaharui dan kenderaan elektrik berkembang pesat, topik kawalan motor aruhan mendapat perhatian utama bagi industri dan ahli akademik. Keupayaan pantas mikropemproses moden menawarkan pertimbangan strategi kawalan yang lebih pintar dan berkuasa. Pendekatan kawalan konvensional memerlukan model matematik yang rumit untuk motor bagi mereka bentuk pengawal untuk kuantiti seperti kelajuan, tork, dan kedudukan. Pengiraan berasaskan model mesti dilakukan dengan tepat untuk setiap motor, dan pengawal berasaskan model yang dihasilkan mungkin tidak berfungsi dengan baik. Untuk menagani masalah ini, penyelidikan ini memperkenalkan Pengawal Logik Kabur (FL) baharu yang menggabungkan strategi pemodulatan lebar denyut vektor ruang (SVPWM) dengan kawalan vektor untuk mengawal motor aruhan yang disuap penyongsang. Teknik utama digunakan untuk mereka bentuk pengawal FL didasarkan pada parameter tetap dua masukkan dan satu keluaran melalui talaan percubaan-dan-ralat mengikut tindak balas yang diinginkan sistem. Fungsi keahlian (MFs), asas aturan, dan model kawalan dirujuk kepada kemahiran kejuruteraan dan aspek tingkah laku pengalaman sistem terkawal. Walau bagaimanapun, pengawal FL konvensional juga mempunyai kekurangan kerana beban pengkomputeran yang tinggi semasa menjalankan peraturan kabur yang berskala besar. Masa pengkomputeran mempengaruhi secara langsung prestasi sistem pemacu motor semasa eksperimen dilaksanakan. Pemudahan peraturan kabur adalah salah satu teknik yang popular untuk mengurangkan permintaan komputerasi pengawal FL. Tetapi, teknik ini menjejaskan liputan dan ketepatan pemboleh ubah sistem kawalan FL dari segi kemerosotan prestasi. MFs boleh dioptimumkan dengan mengubah kedudukan nilai puncak MFs FLC dalam sistem pemacu untuk meningkatkan keteguhan sistem. Oleh itu, penyelidikan ini mengemukakan peraturan kabur yang dipermudahkan berdasarkan kaedah lintasan satah fasa dan MF yang dioptimumkan bagi pengoptimuman prestasi kawalan kelajuan. Penyelidikan ini merangkumi reka bentuk pengawal, pemodelan, dan pembinaan pemprosesan isyarat digital (DSP). Ia menetapkan pengawal yang direka bentuk bagi membina ujikaji untuk meningkatkan penolakan gangguan pelbagai beban dan kelajuan. Pengawal FL 5-peraturan dipermudah diuji dan dibandingkan dengan beberapa peraturan piawai yang dipermudah; 25-peraturan, 9-peraturan, dan 7-peraturan. Pengesahan eksperimen telah dilakukan pada perkakasan menggunakan motor induksi tiga fasa, pengawal, penyongsang, sensor arus dan voltan dan papan DSP. Hasil percubaan telah mengesahkan bahawa masa pemulihan, gangguan beban untuk MF 5-peraturan yang dioptimumkan adalah 10ms lebih cepat daripada MF yang dioptimumkan dengan 7 peraturan dan prestasi yang hampir sama dengan MF 9-peraturan yang dioptimumkan. Oleh itu, kemampuan pengawal yang dicadangkan untuk mengatasi gangguan beban dengan cepat dapat diterapkan dalam aplikasi motor berkelajuan tinggi seperti kenderaan elektrik dan sistem daya tarikan.

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AC	Alternating Current
A/D	Analogue to Digital
AFOC	Air-Gap-flux-Oriented Control
AI	Artificial Intelligent
ANN	Artificial Neural Network
CAV	Centre-Average
CCS	Code Composer Studio
CSI	Current Source Inverter
COG	Centre of gravity
DC	Direct Current
DCCPFL	Design Case Constant Parameter Fuzzy Logic
DFOC	Direct Field Oriented Control
DM	Delta Modulation
DSMC	Discrete Sliding Mode Control
DMC	Digital Motor Control
DSP	Digital Signal Processor
DTC	Direct Torque Control
FL	Fuzzy Logic
FLC	Fuzzy Logic Control
FOC	Field Oriented Control
FPGAs	Field Programmable Gate Arrays
FPU	Floating Point Unit
GA	Genetic Algorithm
IAE	Integral Absolute Error
IDE	Integrated Development Environment
IFOC	Indirect Field Oriented Control
IGBT	Insulated Gate Bipolar Transistor

IM	Induction Motor
ISB	Incremental System Build
ITAE	Integral Time Absolute Error
JTAG	Joint Test Action Group
MF	Membership Function
MRAC	Model Reference Adaptive Control
NB	Negative Big
NL	Negative Large
NS	Negative Small
PI	Proportional plus Integral (controller)
PID	Proportional, Integral plus Derivative (controller)
PB	Positive Big
PL	Positive Large
PS	Positive Small
PWM	Pulse Width Modulation
QEP	Quadrature Encoder Pulse
RFOC	Rotor-Flux-Oriented Control
SCPFL	Standard Constant Parameter Fuzzy Logic
SFOC	Stator-Flux-Oriented Control
SMC	Sliding Mode Controller
SVPWM	Space Vector Pulse Width Modulation
TI	Texas Instrument
UoD	Universe of Discourse
VSD	Variable Speed Drive
VSI	Voltage Source Inverter
ZE	Zero

LIST OF SYMBOLS

B	Friction coefficient, Nm/(rad/sec)
$e(t)$	Speed error, rpm
d	lumped uncertainties
e	speed error
ce	change of speed error
cu	Control increment
G_e	Error gain
G_{ce}	Change of error gain
G_{cu}	output gain
i_{ds}, i_{qs}	d and q axis stator currents, A
i_{dr}, i_{qr}	Rotor current in d and q axis, A
f	Nonlinear function
J	Inertia, kg-m^2
K_T	torque constant
L_{ls},	Stator-leakage inductance, H
L_{lr}	Stator-referred rotor-leakage inductance, H
L_m	Magnetising inductance, H
L_s	Stator self-inductance, H
L_r	Stator-referred rotor self-inductance, H
K	Linear feedback gain of the sliding mode control
K_p	Proportional gain
K_i	Integral gain
K_c	Critical gain
R_s	Stator resistance, Ω
R_r	Stator-referred rotor-phase resistance, Ω
S	Sliding surface
T_s	Sampling time

T_d	Derivative time constant
T_e	Electromagnetic torque
Ti	Integral time constant
T_L	Load torque
T_r	Rotor time constant
Tre	Recovery time
V_{dc}	DC link voltage
V_{ds}, V_{qs},	d and q axis stator voltage, V
ω_{emax}	Maximum speed error
ω_m	Actual speed
ω_{m*}	Reference speed
ω_r	Rotor speed, rpm
ω_r^*	Rotor speed reference, rpm
φ_r	Rotor flux leakage
φ_{qs}, φ_{ds}	Stator flux linkage in q and d axis, V-s
φ_{qr}, φ_{dr}	Rotor flux linkage in q and d axis, V-s

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