Fakulti Teknologi dan Kejuruteraan Elektrik

A NEW APPROACH OF SECTOR ROTATION STRATEGIES FOR IMPROVING THE DYNAMIC AND CAPABILITY OF INDUCTION MOTOR

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MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

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DECLARATION

I declare that this thesis entitled "A New Approach of Sector Rotation Strategies for Improving the Dynamic and Capability of Induction Motor " 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 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.

Signature	:..
Name	: Dr. Siti Azura Binti Ahmad Tarusan
Date	: 17 September 2025

DEDICATION

A special dedication to my beloved parents,

Muhamad Sabri Bin Noor and Salome Reyes Soriano

For your endless prayers, unwavering support, and belief in myself throughout this journey. Thank you being my source of strength, inspiration, and motivation.

To My Respected Supervisor,

Dr. Siti Azura Binti Ahmad Tarusan

Thank you for your guidance, patience, and encouragement from beginning to end.

To My Respected Co-Supervisor,

Dr. Auzani Bin Jidin

Thank you for your support, insights, and valuable advice.

May God bless all of us.

ABSTRACT

Direct Torque Control (DTC) is a well-established control technique for three-phase induction motors due to its simple structure, fast torque response, and independence from coordinate transformation. However, DTC faces notable performance degradation at low speeds, primarily caused by the influence of stator resistance. At low speed, the reduced back-electromotive force (back-EMF) makes it difficult to sustain the desired flux level, and the voltage drop across the stator resistance significantly impacts flux estimation. This condition results in flux droop, particularly evident during the application of zero-voltage vectors and across the boundaries of conventional fixed sectors. The conventional DTC's sector-based switching strategy becomes less effective as the contribution of active voltage vectors becomes uneven due to stator resistance, which disrupts flux symmetry and reduces the control accuracy of flux under dynamic and low-speed operations. To address these limitations, this thesis introduces a new approach of sector rotation strategy that dynamically adjusts the voltage vector selection based on real-time torque and speed variations. This is achieved through the development of an analytical model that calculates the appropriate shifted angle to rotate the sector position. By adjusting the sector boundaries, the proposed strategy enables the optimal alignment of voltage vectors with the stator flux trajectory, effectively minimizing the adverse effects of stator resistance and improving flux magnitude consistency during transitions. This adaptive approach retains the inherent simplicity of DTC while significantly enhancing its performance under low-speed and dynamic conditions. The effectiveness of the proposed method was validated through extensive simulations using MATLAB/Simulink and real-time experimental verification using a DS1104 dSPACE digital signal processor. The experimental testbed includes a 1.1 kW three-phase induction motor coupled with a 2 kW DC generator load and a two-level inverter for control implementation. Comparative studies were performed against the conventional DTC method under identical conditions. The results show that the proposed strategy achieves a significant improvement, including: 1) a reduction in stator flux droop up to 65.4%, 2) stabilizes flux error status, and 3) smoother current waveforms with reduced distortion, approaching a sinusoidal form. Overall, the proposed sector rotation strategy demonstrates a practical and effective enhancement to the conventional DTC method, providing improved control precision, smoother motor operation, and robustness in low-speed regions while maintaining the low computational burden and simplicity that make DTC attractive for industrial applications. This advancement holds relevance for applications requiring precise control in dynamic or low-speed environments, such as electric vehicles and robotics.

PENDEKATAN BARU SECTOR PUTARAN STRATEGI UNTUK MENINGKATKAN DINAMIK DAN KEUPAYAAN MOTOR ARUHAN

ABSTRAK

Kawalan Tork Terus (Direct Torque Control, DTC) merupakan satu teknik kawalan yang dikenali untuk motor aruhan tiga fasa disebabkan oleh struktur kawalannya yang ringkas, tindak balas tork yang pantas, dan tidak bergantung kepada transformasi koordinat. Walau bagaimanapun, prestasi DTC merosot pada kelajuan rendah, terutamanya disebabkan oleh pengaruh rintangan stator. Pada kelajuan rendah, daya gerak balas (back-EMF) yang berkurang menyukarkan pengekalan aras fluks yang dikehendaki, dan kejatuhan voltan merentasi rintangan stator memberi kesan besar kepada anggaran fluks. Keadaan ini menyebabkan fenomena kejatuhan fluks, yang jelas kelihatan ketika penggunaan vektor voltan sifar dan di sempadan sektor tetap konvensional. Strategi pensuisan berasaskan sektor dalam DTC konvensional menjadi kurang berkesan kerana sumbangan vektor voltan aktif yang tidak sekata disebabkan oleh rintangan stator, yang mengganggu simetri fluks dan mengurangkan ketepatan kawalan fluks semasa operasi dinamik dan berkelajuan rendah. Bagi mengatasi kekangan ini, tesis ini memperkenalkan satu pendekatan baharu iaitu strategi putaran sektor yang melaraskan pemilihan vektor voltan secara dinamik dalam jejari fluks bulat berdasarkan perubahan tork dan kelajuan masa nyata. Pendekatan ini dibangunkan melalui satu model analitik yang mengira sudut anjakan yang sesuai untuk memutarkan kedudukan sektor. Dengan melaraskan sempadan sektor, strategi yang dicadangkan ini membolehkan penyelarasan yang optimum antara vektor voltan dan trajektori fluks stator, sekaligus meminimumkan kesan negatif rintangan stator dan meningkatkan kestabilan magnitud fluks semasa peralihan. Pendekatan adaptif ini mengekalkan kesederhanaan asas DTC sambil meningkatkan prestasi kawalan dalam keadaan kelajuan rendah dan dinamik. Keberkesanan kaedah yang dicadangkan telah disahkan melalui simulasi menyeluruh menggunakan MATLAB/Simulink dan juga ujian eksperimen masa nyata menggunakan pemproses isyarat digital (DSP) dSPACE DS1104. Sistem ujian eksperimen terdiri daripada motor aruhan tiga fasa berkuasa 1.1 kW yang digandingkan dengan beban penjana DC 2 kW serta inverter dua peringkat untuk pelaksanaan kawalan. Kajian perbandingan telah dijalankan antara kaedah DTC konvensional dan strategi yang dicadangkan di bawah keadaan operasi yang sama. Keputusan menunjukkan bahawa strategi yang dicadangkan mencapai peningkatan yang ketara, termasuk: 1) mengurangkan kejatuhan fluks stator sehingga 65.4%, 2) menstabilkan status ralat fluks, dan 3) gelombang arus yang lebih lancar dengan herotan yang berkurangan, menghampiri bentuk sinusoidal. Secara keseluruhannya, strategi putaran sektor yang dicadangkan membuktikan sebagai satu penambahbaikan praktikal dan berkesan kepada kaedah DTC konvensional, memberikan ketepatan kawalan yang lebih tinggi, operasi motor yang lebih lancar, serta ketahanan yang lebih baik pada kelajuan rendah, sambil mengekalkan beban pengiraan yang rendah dan struktur kawalan yang ringkas. Kemajuan ini amat relevan untuk aplikasi yang memerlukan kawalan tepat dalam keadaan dinamik atau kelajuan rendah seperti kenderaan elektrik dan sistem robotik.

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LIST OF ABBREVIATIONS

AC	-	Alternating Current
ADC	-	Analog-to-Digital Conversion
AI	-	Artificial Intelligent
DAC	-	Digital-to-Analog Conversion
DC	-	Direct Current
DSC	-	Direct Self-Control
DSP	-	Digital Signal Processing
DTC	-	Direct Torque Control
DFOC	-	Direct Field-Oriented Control
EMF	-	Electromotive Force
ENC	-	Encoder
EV	-	Electric Vehicle
EKF	-	Extended Kalman Filter
FOC	-	Field-Oriented Control
IFOC	-	Indirect Field-Oriented Control
GUI	-	Graphical User Interface
HIL	-	Hardware-in-the-loop
HMI	-	Human-Machine Interface
I	-	Current
IGBTs	-	Insulated Gate Bipolar Transistors
I/O	-	Digital Input/Output
kW	-	kilo Watt

LUT	-	Look-Up Table
MMF	-	Magnetomotive Force
MPC	-	Model Predictive Control
MRAS	-	Model Reference Adaptive System
PWM	-	Pulse-Width Modulation
PI	-	Proportional Integrator
rpm	-	Revolution Per Minute
SVM	-	Space Vector Modulation
V	-	Voltage
V/f	-	Voltage-to-Frequency
VSI	-	Voltage Source Inverter
Wb	-	Weber (unit of magnetic flux)
IGBTs	-	Insulated Gate Bipolar Transistors

LIST OF SYMBOLS

$\overline{v_s}$	-	Stator voltage
R_s	-	Stator resistance
$\overline{i_s}$	-	Stator current
$\overline{\varphi_s}$	-	Stator flux
v_x	-	Voltage vector
V_{dc}	-	DC voltage
${S_x}^+$	-	Switching state
$\Delta\varphi_s$	-	Stator flux angular velocity
δ_{sr}	-	Load angle
T_e	-	Torque
P	-	Pole
L_m	-	Motor inductance
L_s	-	Stator inductance
L_r	-	Rotor inductance
σ	-	Status
φ_r	-	Rotot flux
$\Delta\theta_{sh}$	-	Fixed angular shift
f_s	-	Switching frequency
ρ_s	-	Stator flux angle
ρ'_s	-	Flux sector
φ_d	-	Flux linkages
$\Delta\theta$	-	Shifted angle

ω_{m}	-	Motor speed
ΔT	-	Sampling time

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Journal Articles

Sabri, N.S.M., Tarusan, S.A.A., Zawawi, S.A.S.A., Jidin, A., Sutikno, T., 2025. Optimizing low-speed DTC performance for three-phase induction motors with sector rotation strategy. *International Journal of Power Electronics and Drive Systems*, 16(1), pp. 464–471. (Scopus)

Sabri, N.S.M., Tarusan, S.A.A., Zawawi, S.A.S.A., Jidin, A., Aihsan, M.Z., 2025. Mitigating Flux Droop in Low-Speed Steady-State DTC for Three-Phase Induction Motors. *IEEE 8TH International Conference on Electrical, Control and Computer Engineering, ECCE 2025*. (Scopus)

Zawawi, S.A.S.A., Jidin, A., Sabri, N.S.M., Tarusan, S.A.A., 2025. Enhanced torque control in high-speed DTC using modified stator flux locus. *International Journal of Power Electronics and Drive Systems*, 16(1), pp. 457–463. (Scopus)

CHAPTER 1

INTRODUCTION

This chapter presents an overview of the research, starting with the background that emphasizes the importance of induction motors across various applications and outlines key motor control techniques, including scalar and vector control. This research specifically focus on Direct Torque Control (DTC), highlighting its advantages and its limitations, as well as modern topologies developed to enhance its performance. The problem statement outlines critical challenges faced by conventional DTC especially at low speeds, which lead to the formulation of the research questions. In response, the research objectives define the specific goals of this study. The scope establishes the boundaries of the work, covering aspects such as modelling, simulation, and experimental validation. Finally, the thesis outline describes the structure of the thesis and detailing the content of each chapter.

1.1 Background

Induction motors are popular because of their durability, low cost, and low maintenance requirements (Zhang *et al.*, 2021; Sahoo *et al.*, 2022; KRIM and MIMOUNI, 2024). However, their performance is highly dependent on the employed control strategy. AC drive control is generally categorized into scalar control and vector control (Raja and Roy, 2024). Scalar control, presented by Bose in 1984, was one of the earliest methods. It used voltage-controlled Pulse-Width Modulation (PWM) to control induction motor (Bose, 1984). This approach performed well in steady-state circumstances but lacked dynamic