Faculty of Electrical Engineering

MINIMIZATION OF TORQUE RIPPLE AND FLUX DROOP USING OPTIMAL DTC SWITCHING AND SECTOR ROTATION STRATEGY

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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MINIMIZATION OF TORQUE RIPPLE AND FLUX DROOP USING OPTIMAL DTC SWITCHING AND SECTOR ROTATION STRATEGY

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A thesis submitted
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2022

DECLARATION

I declare that this thesis entitled “Minimization of Torque Ripple and Flux Droop using Optimal DTC Switching and Sector Rotation Strategy” 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 Doctor of Philosophy.

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Date : 06/09/2022

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DEDICATION

Special Dedication to:

My Beloved Parents,

Ahmad Tarusan Bin Abu and Ros Binti Othman

For supporting and encouraging me to complete this research

Thank you for your both strong and gentle soul who making who I am today

My Respected Supervisor and Co-Supervisor,

Assoc. Prof. Dr. Mohd Luqman Bin Mohd Jamil and Dr Auzani Bin Jidin

Thank you for your both strong support, motivation, guidance and supervision to accomplish this research

May God bless and protect them with happiness

ABSTRACT

Direct Torque Control (DTC) is a well-known AC control scheme for its robustness and simplicity. Although DTC provides excellent dynamic torque control performance, but it has several drawbacks. The digital implementation of the hysteresis band controller, which causes a delay action, may result in huge ripple and switching frequency inconsistency for DTC torque performance. Since the torque slope is already disturbed in the hysteresis bandwidth in various operating conditions, the limiting voltage vector of the two-level inverter in the conventional DTC limits the control switching frequency in the hysteresis controller. Another drawback of conventional DTC is that the presence of voltage drop in a stator resistance at low operating speeds causes a droop in stator flux performance. This problem occurs as the voltage vectors deviate from the usual state, where it manifests itself as a change in the boundary sector of the circular flux locus. Therefore, an optimal DTC switching strategy and an optimal DTC sector rotation strategy to overcome the problems in a three-phase induction motor have been proposed. A five-level cascaded H-bridge (CHB) inverter was used in the optimal DTC switching strategy because it had many voltage vectors and could be used for a variety of speed operations. Its objectives were to propose the optimal switching vector in minimizing torque ripple and controlling switching frequency at the steady-state of various speed operations. A modification torque error status and a look-up table of a five-level CHB inverter were used to implement the specified optimal voltage vectors. Another objective was to formulate and evaluate the optimal DTC sector rotation strategy that can reduce stator flux droop in the variation of torque and speed in steady-state and dynamic response. The optimal sector rotation strategy is determined using an analytical model of shifted angle that incorporates speed and torque variables which is dynamically tuned. Both proposed strategies were compared with conventional method and verified through simulation and experimentation works. MATLAB/Simulink software is used to simulate the proposed strategies while a complete setup system consists of a DS1104 digital signal processor (DSP)-board (to implement the DTC algorithm), Field-programmable Gate Arrays (FPGA) (to implement the blanking circuit), two-level and five-level (CHB) inverter circuit, gate driver circuit, and a 1.1 kW induction motor with 2 kW DC generator as a load is developed for testing and verification purpose. A compromise between simulation and experimentation works resulted in significant improvements; 1) a reduction of torque ripple up to 50% and a reduction of switching frequency up to 40%, 2) an ability to maintain a similar magnitude of stator flux by eliminating the droops. In conclusion, the method introduced demonstrates the effectiveness of DTC performance which maintains its simple structure as well as offers ease in modification for a desired control purpose.

PENGURANGAN RIAK DAYAKILAS DAN KEJATUHAN FLUKS MENGGUNAKAN STRATEGI PENSUISAN DTC DAN PUTARAN SEKTOR YANG OPTIMUM

ABSTRAK

Kawalan Dayakilas Langsung (DTC) diakui sebagai satu keteguhan dan struktur kawalan AC yang ringkas. Walaupun DTC menyediakan prestasi cemerlang kawalan dayakilas yang dinamik, tetapi ia menyebabkan beberapa kekurangan. Pelaksanaan digital pengawal jalur histerisis, yang memicu tindakan lengah, boleh mengakibatkan riak besar dan ketidakseragaman pensuisan frekuensi untuk prestasi dayakilas DTC. Oleh kerana kecerunan dayakilas terganggu dalam lebar jalur histerisis dalam pelbagai keadaan operasi, vektor voltan penyongsang dua peringkat yang terhad dalam DTC konvensional telah menghadkan frekuensi pensuisan kawalan dalam pengawal histeresis. Satu lagi kelemahan DTC konvensional ialah penurunan voltan dalam rintangan pemegun pada operasi kelajuan rendah yang menyebabkan penurunan prestasi fluks pemegun. Masalah ini berlaku apabila vektor voltan menyimpang daripada keadaan biasa, di mana ia dipamerkan sebagai satu perubahan dalam sempadan sektor lokus fluks bulatan. Oleh itu, strategi pensuisan DTC dan strategi putaran sektor DTC yang optimum untuk mengatasi masalah dalam motor aruhan tiga fasa telah dicadangkan. Penyongsang tetimbang-H lima-peringkat (CHB) telah digunakan dalam strategi pensuisan optima DTC kerana ia mempunyai banyak vektor voltan dan boleh digunakan untuk pelbagai operasi kelajuan. Objektifnya adalah untuk mencadangkan pensuisan vector yang optimum dalam meminimumkan dayakilas riak dan mengatur freqkuensi pensuisan pada keadaan mantap pelbagai operasi kelajuan. Pengubahsuaian status ralat dayakilas dan jadual carian bagi penyongsang CHB lima-peringkat telah digunakan bagi melaksanakan penentuan vektor voltan yang optima. Satu lagi objektif adalah untuk merumus dan menilai putaran sektor DTC yang optimum yang boleh mengurangkan kejatuhan fluks pemegun dalam variasi dayakilas dan kelajuan dalam keadaan mantap dan tindak balas dinamik. Strategi putaran sektor optimum ditentukan menggunakan model analitik peralihan sudut yang menggabungkan pembolehubah kelajuan dan dayakilas yang ditala secara dinamik. Kedua-dua strategi yang dicadangkan telah dibandingkan dengan kaedah konvensional dan disahkan melalui kerja-kerja simulasi dan eksperimen. Perisian MATLAB/Simulink digunakan untuk mensimulasikan strategi-strategi yang dicadangkan manakala sebuah sistem binaan lengkap terdiri daripada papan pemproses isyarat digital (DSP) DS1104 (untuk melaksanakan algoritma DTC), Tatasusunan Gerbang Medan Terprogram (FPGA) (untuk melaksanakan litar padaman), litar penyongsang dua-aras dan lima-aras (CHB), litar pemacu get, dan motor aruhan 1.1 kW dengan penjana DC 2 kW sebagai beban dibangunkan untuk tujuan ujian dan pengesahan. Kompromi antara kerja-kerja simulasi dan eksperimen menghasilkan penambahbaikan yang ketara; 1) pengurangan riak dayakilas sehingga 50% dan pengurangan frekuensi pensuisan sehingga 40%, 2) keupayaan menyingkirkan kejatuhan untuk mengekalkan magnitud fluks pemegun yang serupa. Kesimpulannya, kaedah yang diperkenalkan menunjukkan keberkesanan prestasi DTC yang tetap mengekalkan struktur ringkasnya serta menawarkan kemudahan dalam pengubahsuaian untuk sesuatu tujuan kawalan yang dikehendaki.

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