UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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AN OPTIMAL SWITCHING STRATEGY OF CASCADED H-BRIDGE MULTILEVEL INVERTER FOR HIGH-PERFORMANCE DIRECT TORQUE CONTROL OF INDUCTION MACHINES

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AN OPTIMAL SWITCHING STRATEGY OF CASCADED H-BRIDGE MULTILEVEL INVERTER FOR HIGH-PERFORMANCE DIRECT TORQUE CONTROL OF INDUCTION MACHINES

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
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DECLARATION

I declare that this thesis entitled "An Optimal Switching Strategy Of Cascaded H-Bridge Multilevel Inverter For High-Performance Direct Torque Control Of Induction Machines" 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.

Signature : ....

Name : ....

Date : ....

DEDICATION

Especially dedication is to my wife Wan Aida Mardiana Binti Wan Abdullah and my son Raisha Amani, not forgot to beloved mother Puan Che Rodiah Binti Che Ismail and my father En Zuber Ahmadi Bin Hassan Hilmi, my sister and brothers beloved

For taking care of me and educating me all these while. Also thank for their continuous prayers until I became what I'm now.

Also for my family

Dr Auzani Bin Jidin

Thank you very much

And not forgetting to all my relatives

Especially Power Electronics and Drives Group

The success belongs to us all

May God bless all of us…..Amin

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Master of Electrical Engineering (Power Electronics and Drives).

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ABSTRACT

Direct Torque Control (DTC) of induction machine has received wide acceptance in many adjustable speed drive applications due to its simplicity and high performance torque control. However, the DTC using a common two-level inverter poses two major problems such as higher switching frequency (or power loss) and larger torque ripple. These problems are due to inappropriate voltage vectors which are selected among a limited number of voltage vectors available in two-level inverter. The proposed research aims to formulate an optimal switching strategy using three-level Cascaded H-Bridge Multilevel Inverter (CHMI) for high performances of Direct Torque Control (DTC) of induction machines. By using three-level CHMI, it provides greater number of voltage vectors which can offer more options to select the most appropriate voltage vectors. The most appropriate voltage vectors are identified as the vectors that can produce minimum torque slope but sufficient to satisfy torque demands. The identification is accomplished by using an equation of rate of change of torque which is derived from the induction machine equations. The proposed strategy also introduces a block of modification of torque error status which is responsible to modify the status such that it can determine the most optimal voltage vectors from a look-up table, according to motor operating conditions. Some improvements obtained in the proposed strategy were verified via simulations and experimentations, as well as comparison with the conventional DTC using a two-level inverter. The improvements obtained are as follows; 1) minimization of switching frequency which is expected to reduce power loss, and 2) reduction of torque ripple. These two improvements are important requirements for excellent torque control in adjustable speed drive and high power applications.

ABSTRAK

Kawalan dayakilas langsung (DTC) bagi motor aruhan telah mendapat penerimaan yang luas di dalam kebanyakan aplikasi pemacu pelarasan laju disebabkan ianya ringkas dan kawalan dayakilas yang berprestasi tinggi. Namun begitu, DTC yang menggunakan sebuah dua peringkatan penyongsang yang biasa menimbulkan dua masalah besar iaitu frekuensi pensuisan yang tinggi (atau kehilangan kuasa) dan riak dayakilas yang besar. Masalah-masalah ini adalah disebabkan oleh vektor voltan tidak sesuai yang dipilih diantara bilangan terhad bagi vektor voltan yang terdapat dalam dua peringkatan penyongsang. Kajian yang dicadangkan bertujuan untuk memformulasi sebuah strategi pensuisan yang optimal menggunakan tiga peringkatan lata jejambat-H penyongsang berganda (CHMI) untuk prestasi tinggi bagi kawalan dayakilas langsung (DTC) motor aruhan. Dengan menggunakan tiga peringkatan CHMI, ia menyediakan bilangan lebih besar bagi vektor-vektor voltan yang mana boleh menawarkan lebih banyak pilihan untuk memilih vektor-vektor voltan yang sangat sesuai. Vektor-vektor voltan yang sangat sesuai tersebut dikenalpasti sebagai vektor-vektor yang boleh menghasilkan cerun dayakilas yang minimum tetapi mencukupi untuk memenuhi permintaan dayakilas. Pengenalpastian ini disempurnakan dengan menggunakan sebuah persamaan kadar perubahan dayakilas yang diterbitkan daripada persamaan-persamaan motor aruhan. Strategi yang dicadangkan juga memperkenalkan sebuah blok bagi pengubahsuaian status ralat dayakilas yang mana bertanggungjawab mengubah status tersebut supaya ia boleh menentukan vektor-vektor voltan yang sangat optimal daripada sebuah jadual carian, berpandukan keadaan operasi motor. Beberapa penambahbaikan yang diperoleh dalam strategi yang dicadangkan telah disahkan menerusi simulasi dan pengujian, begitu juga perbandingan dengan DTC konvensional yang menggunakan sebuah dua peringkatan penyongsang. Penambahbaikan yang diperoleh tersebut adalah seperti berikut; 1) meminimumkan frekuensi pensuisan yang dijangka akan mengurangkan kehilangan kuasa, dan 2) pengurangan riak bagi dayakilas. Kedua-dua penambahbaikan ini adalah keperluan penting bagi kawalan dayakilas berprestasi tinggi dalam aplikasi-aplikasi pemacu pelarasan laju dan berkuasa tinggi.

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LIST OF ABBREVIATIONS AND SYMBOLS

$d\ ,q$	-	Direct and quadrature of the stationary reference frame
d^r, q^r	-	Real and imaginary and real of the rotor
$i_s\ ,\ i_r$	-	Stator and rotor current space vector in stationary reference frame
$R_r\ R_s$	-	Rotor and stator resistance
L_s	-	Stator self-inductance
L_r	-	Rotor self-inductance
L_m	-	Mutual inductance
$\bar{\varphi}_{s,}\bar{\varphi}_r$	-	Stator and rotor flux linkage space vector in reference frame
$i_{rd}\ ,\ i_{rq}$	-	d and q components of the rotor current in stationary reference frame
$i_{sd}\ ,\ i_{sq}$	-	d and q components of the stator current in stationary reference frame
$v_{sd}\ ,\ v_{sq}$	-	d and q-axis of the stator voltage in stationary reference frame
$\varphi_{sd,}\varphi_{sq}$	-	d and q components of the stator flux in stationary reference frame
$\bar{v}_s$	-	Voltage vectors
n	-	Numbers of phase
$i_{a,}i_b\ i_c$	-	Current phase a,b and c
L	-	Self-inductance
T_e	-	Electromagnetic Torque
T_e^*	-	References of torque

ε_T	-	Output torque error
σ_T	-	Output torque status
θ_r	-	Angle with respect to rotor axis
θ_s	-	Angle with respect to stator axis
δ_{sr}	-	Different angle between stator flux linkage and rotor flux linkage
V_{dc}	-	DC link voltage
$S_a^+ \ S_b^+ S_c^+$	-	Switching states of phases a,b and c
P	-	Pairs of pole
θ_{sec}	-	Angle of sector definition
ω_r	-	Rotor electrical speed in rad/s
ν_{dc}	-	DC link voltage
ε_φ	-	Output flux error
φ_s^*	-	References of flux
φ_s	-	Flux estimate
σ_φ	-	Output flux status
σ	-	Total flux leakage factor
$\bar{v}_{xN}$	-	Inverter phase voltage
v_{xN}	-	Phase stator voltages
DTC	-	Direct Torque Control
IM	-	Induction Motor
VSI	-	Voltage Source Inverter
FOC	-	Field Oriented Control
DSC	-	Direct Self Control

DT	-	Sampling period
AC	-	Alternating Current
DC	-	Direct current
DSP	-	Digital Signal Processor
ADC	-	Analog Digital Converter
DAC		Digital Analog Converter
FPGA	-	Field Programmer Gate Array
SVM	-	Space Vector Modulated
UB	-	Upper Band
LB	-	Lower Band
IGBT	-	Insulated Gate Bipolar Transistor
CHMI	-	Cascaded H-Bridge Multilevel Inverter
NPCMI	-	Neutral Point Clamp Multilevel Inverter
FCI	-	Flying Capacitor Inverter

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