Faculty of Electrical Engineering

STATE-DEPENDENT SLIDING MODE CONTROL FOR THREE-PHASE INDUCTION MOTOR DRIVES

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PhD

2014

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A thesis submitted
in fulfilment of the requirements for the degree of Doctor of Philosophy
in Electrical Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

DECLARATION

I declare that this thesis entitle “STATE-DEPENDENT SLIDING MODE CONTROL FOR THREE-PHASE INDUCTION MOTOR DRIVES” is the results of my own research except as cited in the references. The thesis has not been accepted for any degree and is not currently submitted in candidature of any other degree.

Signature	:	....
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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in term of scope and quality for the award of Doctor of Philosophy (Electrical Engineering)

Signature	:...
Supervisor Name	:...
Date	:...

ABSTRACT

This research focuses on investigation and evaluation of the robust speed control for three-phase induction motor. A sliding mode control, which offers great potential to deal with uncertainties such as parameter variation and external load disturbances, is examined. The main obstacle of conventional sliding mode control is caused by discontinuous function of high control activity which is known as chattering phenomenon. In this research, this chattering phenomenon is significantly reduced by a newly developed algorithm. A fast sigmoid function with varying boundary layer algorithm is designed as a state-dependent to replace the discontinuous function in conventional sliding mode control as well as to avoid steady state error compare with the use of fixed boundary layer. It is known that the switching gain of sliding mode control is proportional to the chattering level, and normally a large switching gain is applied to handle the uncertainties. This research proposes a state-dependent sliding mode control which is the switching gain is proportional to the sigmoid function of the sliding mode controller. As a result, the boundary layer and the switching gain will change depending on uncertainties of the motor drives system. In this research, the induction motor is controlled by vector control strategy, using indirect field orientation and Space Vector Pulse Width Modulation technique. Simulation result have proved that the proposed state-dependent sliding mode control was able to deal with external load disturbances as well as effectively free from chattering phenomenon compared to conventional sliding mode control. Finally, experimental investigation is performed in order to confirm the theoretical and simulation findings. The proposed algorithm and the vector control strategy are developed in digital signal processing board. The experimental results have confirmed that the state-dependent sliding mode control is superior with regard to external load disturbances and variation in the reference speed setting when compared to PI speed control and conventional sliding mode control.

ABSTRAK

Kajian ini memberi tumpuan kepada penyiasatan dan penilaian kawalan kelajuan yang kukuh bagi motor aruhan tiga fasa. Kawalan mod gelongsor, yang menawarkan potensi yang baik untuk menangani ketidaktentuan seperti variasi parameter dan gangguan beban luaran, telah dikaji. Halangan utama kawalan mod gelongsor lazim adalah fungsi selanjar aktiviti kawalan yang tinggi yang dikenali sebagai fenomena gelugutan. Dalam kajian ini, fenomena gelugutan semakin berkurangan oleh algoritma yang baru dibangunkan. Satu fungsi algoritma sigmoid cepat dengan pelbagai lapisan sempadan direka bergantung kepada keadaan semasa untuk menggantikan fungsi selanjar pada kawalan mod gelongsor lazim untuk mengelakkan ralat keadaan mantap jika bandingkan dengan penggunaan lapisan sempadan tetap. Telah diketahui bahawa gandaan pensuisan kawalan mod gelongsor adalah berkadar langsung dengan tahap gelugutan, dan biasanya gandaan pensuisan besar digunakan untuk menangani ketidaktentuan. Kajian ini mencadangkan, kawalan mod gelongsor yang bergantung kepada keadaan semasa yang berkadar langsung dengan fungsi sigmoid pengawal mod gelongsor. Hasilnya, lapisan sempadan dan gandaan beralih akan berubah bergantung kepada ketidaktentuan sistem pemacu motor. Dalam kajian ini, motor aruhan dikawal oleh strategi kawalan vektor, menggunakan orientasi bidang tidak langsung dan Space Vector Pulse Width Modulation *teknik. Hasil simulasi telah membuktikan bahawa kawalan mod gelongsor yang bergantung kepada keadaan semasa yang dicadangkan mampu untuk menangani gangguan beban luaran dengan berkesan dan bebas dari fenomena gelutan berbanding kawalan mod gelongsor yang lazim. Akhirnya, siasatan ujikaji dilakukan untuk mengesahkan penemuan teori dan simulasi. Algoritma yang dicadangkan dan strategi kawalan vektor dibangunkan dalam papan pemprosesan isyarat digital. Keputusan eksperimen telah mengesahkan bahawa kawalan mod gelongsor bergantung kepada keadaan semasa adalah lebih berkesan dengan mengambil kira gangguan beban luaran dan perubahan dalam persekitaran kelajuan rujukan jika dibandingkan dengan kawalan kelajuan PI dan kawalan mod gelongsor lazim.*

ACKNOWLEDGEMENT

First and foremost, grateful thanks to Allah S.W.T for guiding and helping me in completion of this thesis.

I would like to express gratitude to my supervisor Engr. Professor Dr. Marizan bin Sulaiman for his help, encouragement, patient and strong command throughout the period of this work. Also to my co-supervisor, Associate Professor Dr. Zulkifilie bin Ibrahim for giving invaluable assistance and guidance.

This thesis was made possible by *Hadiah Latihan Persekutuan* Scholarship. I gratefully acknowledge the funding received towards my PhD from Ministry of Higher Education of Malaysia.

Words cannot express my appreciation and gratefulness to the closest people to my heart, my parents Hj Patakor bin Hj Hussein, Hjh Siti Hafizah binti Rohani, father and mother in-law Hj Salleh bin Ali, Hjh Zaharah binti Ahmad, my husband Zulhisyam bin Salleh, my daughter Irdina Zulhisyam and son Afiq Zulhisyam and all my family members for their love, support and encouragement as well as their perpetual support and blessing prayer.

Last but not least, I am very grateful to my peers and colleagues at the Electrical Machines and Drives laboratory at Universiti Teknikal Malaysia Melaka, thanks to all my friends and colleagues inside and outside of the research group for their friendship, assistance and support.

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LIST OF ABBREVIATIONS

AC	Alternating Current
A/D	Analog to Digital
AFOC	Air-Gap-flux-Oriented Control
CCS	Code Composer Studio
CSI	Current Source Inverter
DC	Direct Current
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
GA	Genetic Algorithm
IDE	Integrated Development Environment
IFOC	Indirect Field Oriented Control
IGBT	Insulated Gate Bipolar Transistor
JTAG	Joint Test Action Group
MRAC	Model Reference Adaptive Control
PI	Proportional plus Integral (controller)
PID	Proportional, Integral plus Derivative (controller)
PWM	Pulse Width Modulation
QEP	Quadrature Encoder Pulse
RFOC	Rotor-Flux-Oriented Control
SFOC	Stator-Flux-Oriented Control
SMC	Sliding Mode Control
SDSMC	State-Dependent Sliding Mode Control
SVPWM	Space Vector Pulse Width Modulation

TI	Texas Instrument
VSI	Voltage Source Inverter

LIST OF SYMBOLS

B	Friction coefficient, Nm/(rad/sec)
$e(t)$	Speed error, rpm
d	lumped uncertainties
i_{ds}, i_{qs}	d and q axis stator currents, A
$i_{dr,}$ i_{qr}	Rotor current in d and q axis, A
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	Magnetizing inductance, H
L_s	Stator selfinductance,H
L_r	Stator-referred rotor selfinductance, H
K	Linear feedback gain of 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_d	Derivative time constant
T_e	Electromagnetic torque
Ti	Integral time constant
T_L	Load torque
T_r	Rotor time constant
V_{dc}	DC link voltage
V_{ds}, V_{qs},	d and q axis stator voltage, V
ω_r	Rotor speed, rpm

ω_r^*	Rotor speed reference, rpm
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
β	Switching gain

LIST OF PUBLICATIONS

Paper published

- Lazi, J.M., Ibrahim, Z., Isa, S.N.M, Anugerah, A., **Patakor, F.A**.,Mustafa, R "Sensorless speed control of PMSM drives using dSPACE DS1103 board" *PECon 2012 - 2012 IEEE International Conference on Power and Energy*
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  doi: 10.1109/SCOReD.2011.6148752

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