Faculty of Electrical Engineering

SPEED PERFORMANCE IMPROVEMENT OF THREE-PHASE INDUCTION MOTOR DRIVES USING ADAPTIVE SLIDING MODE CONTROLLER

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DECLARATION

I declare that this thesis entitled "Speed Performance Improvement of Three-Phase Induction Motor Drives Using Adaptive Sliding Mode Controller" 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	:	………………………………………..
Supervisor Name	:	Professor Ir. Dr. Marizan bin Sulaiman
Date	:	………………………………………..

DEDICATION

To my beloved mother and father

ABSTRACT

The induction motor is widely used in industrial applications. The most type of induction motor used in the industrial applications is three-phase squirrel cage AC induction motor. Several industrial applications use the induction motor because of its ruggedness, reliability and relatively low cost. However, more complexity control scheme is required for the induction motor because it is highly non-linear in a dynamic structure. In addition, the rotor currents and flux-linkage of induction motor also cannot be directly measured. The modified classical sliding mode control (SMC) algorithm is developed based on the conventional robust controller with the adaption of switching gain and discontinuous sigmoid functions to eliminate the undesirable chattering phenomenon. The main focus of this research is to design a sliding mode control strategy that provides speed performance improvement of delay time (t_d), rise time (t_r), peak time (t_p), maximum % overshoot (M_p), settling time (t_s) and steady-state error (e_{ss}) for the three-phase induction motor drives. More specifically, research objectives are to design a sliding mode controller by using an adaptive control strategy and compare with conventional SMC and PI speed controller. Then, the developed speed controller is implemented in an experimental rig based on indirect field-oriented control (IFOC) by using the digital signal processor (DSP) to achieve high performance control characteristics in controlling torque and rotor flux effectively. The PI or PID controllers are tuned to improve speed control issues of AC induction motor due to load variations and changes in parameters. However, the conventional strategy of the PI controller is realized cannot achieve better performance when the input of load variations are applied. Specifically, the algorithm to overcome these issues is proposed by using an ASMC and the speed control performances are tested in simulation by using PSIM software. Practically, the experimental works on hardware rigs are based on high voltage digital motor control (HVDMC) with power factor correction (PFC) from Texas Instruments (TI) that attached with the floating-point of TMS320F28335 DSP to analyze and validate the performance of an ASMC control algorithm. Moreover, the features of an ASMC are compared with conventional SMC and PI controller to improve the performance of an ASMC control algorithm. As a result, high-performance control of AC induction motor is achieved for different speed commands and loaded conditions as compared to conventional controllers. Technically, simulated results at 1400rpm with no-load conditions of maximum % overshoot (ASMC, M_p=14.4%), (SMC, M_p=24.42%), (PI, M_p=30.41%) and steady-state error (ASMC, e_{ss}=1.76rpm), (SMC, e_{ss}=6.02rpm), (SMC, e_{ss}=2.23rpm) are clearly summarized the ASMC is more superior performances compared with differences speed controllers of SMC and PI respectively. Supremely, experimental results for the ASMC at 1400rpm with no-load conditions of maximum % overshoot (M_p=0.28%) and steady-state error (e_{ss}=3.21rpm) are achieved comprehensive performances. Apart from this, the benefit of this research work is importantly desired for the non-linear of the AC motor to achieved dynamic performances such as fast response and also practically used at variable speed conditions.

PENAMBAHBAIKAN PRESTASI KELAJUAN PEMACU MOTOR ARUHAN TIGA FASA DENGAN MENGGUNAKAN PENGAWAL ADAPTIF MOD GELONGSOR

ABSTRAK

Motor aruhan digunakan secara meluas dalam aplikasi perindustrian. Jenis motor induksi yang paling banyak digunakan dalam aplikasi perindustrian ialah motor aruhan AU sangkar tupai tiga fasa. Beberapa aplikasi perindustrian menggunakan motor aruhan kerana ketahanan, kebolehpercayaan dan kos yang rendah. Namun, skim kawalan yang lebih kompleks diperlukan untuk motor aruhan kerana struktur dinamik yang tidak linear. Tambahan pula, arus pemutar dan pergerakan motor juga tidak boleh diukur secara langsung. Algoritma kawalan mod gelongsor (SMC) yang dibangunkan berdasarkan pengawal konvensional dengan adaptasi gandaan pensuisan dan fungsi sigmoid tak berterusan untuk menghapuskan fenomena tidak menentu. Tumpuan utama penyelidikan ini adalah untuk merekabentuk strategi kawalan mod gelongsor yang memberikan peningkatan prestasi kelajuan masa tunda (td), masa naikkan (tr), masa puncak (tp), % maksimum lajakan (Mp), masa penetapan (ts) dan ralat keadaan mantap (ess) untuk pemacu motor aruhan tiga fasa. Khususnya, objektif penyelidikan adalah merekabentuk pengawal mod gelongsor dengan menggunakan strategi kawalan adaptif dan membandingkan dengan pengawal SMC dan PI konvensional. Kemudian, pengawal kelajuan diimplementasi dalam rig ujikaji berorientasikan medan tidak langsung (IFOC) dengan menggunakan pemproses isyarat digital (DSP) untuk mencapai ciri-ciri kawalan prestasi tinggi. Pengawal PI atau PID ditala untuk meningkatkan kawalan kelajuan motor aruhan dengan variasi beban dan perubahan parameter. Namun, strategi pengawal PI konvensional tidak mencapai prestasi yang baik. Justeru, algoritma dicadangkan dengan menggunakan ASMC dan diuji dengan menggunakan perisian PSIM. Praktikalnya, kerja ujikaji adalah berdasarkan kawalan motor digital voltan tinggi (HVDMC) dengan pembetulan faktor kuasa (PFC) dari Texas Instruments (TI) yang dimuatkan menerusi TMS320F28335 DSP. Selain itu, ciri-ciri ASMC dibandingkan dengan pengawal SMC dan PI konvensional untuk meningkatkan prestasi algoritma kawalan ASMC. Hasilnya, kawalan kelajuan prestasi tinggi motor aruhan AU dicapai bagi kelajuan dan keadaan beban yang berbeza berbanding pengawal konvensional. Teknikalnya, keputusan simulasi pada kelajuan 1400rpm tanpa beban untuk % maksimum lajakan (ASMC, Mp=14.4%), (SMC, Mp=24.42%), (PI, Mp=30.41%) dan ralat keadaan mantap (ASMC, ess=1.76rpm), (SMC, ess=6.02rpm), (PI, ess=2.23rpm) secara jelas diringkaskan ASMC adalah pengawal yang lebih unggul berbanding dengan pengawal SMC dan PI. Sememangnya, keputusan ujikaji ASMC pada 1400rpm tanpa beban untuk % maksimum lajakant (Mp=0.28%) dan ralat keadaan mantap (ess=3.21rpm) adalah mencapai prestasi yang komprehensif. Sejajar daripada itu, faedah kerja penyelidikan ini amat penting kepada motor AU yang tidak linear bagi mencapai prestasi yang dinamik seperti tindak balas yang pantas dan juga praktikal digunakan pada keadaan variasi kelajuan.

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LIST OF ABBREVIATIONS

AC	-	Alternating Current
A/D	-	Analog to Digital
AFLC	-	Adaptive Fuzzy Logic Control
AFOC	-	Air Gap Flux Oriented Control
ANN	-	Artificial Neural Network
ASMC	-	Adaptive Sliding Mode Control
CCS	-	Code Composer Studio
CSI	-	Current Source Inverter
D	-	Derivative
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
FLC	-	Fuzzy Logic Control
GA	-	Genetic Algorithm
HOSM	-	High Order Sliding Mode
HVDMC	-	High Voltage Digital Motor Control
I	-	Integral

IDE	-	Integrated Development Enviroment
IFOC	-	Indirect Field Oriented Control
IGBT	-	Insulated Gate Bipolar Transistor
JTAG	-	Joint Test Action Group
MRAC	-	Model Reference Adaptive Control
P	-	Proportional
PC	-	Personal Computer
PCLPF	-	Programmable Cascaded Low Pass Filter
PI	-	Proportional Integral
PID	-	Proportional Integral Derivative
PWM	-	Pulse Width Modulation
QEP	-	Quadrature Encoder Pulse
RFOC	-	Rotor Flux Oriented Control
SFOC	-	Stator Flux Oriented Control
SISO	-	Single Input Single Output
SMC	-	Sliding Mode Control
SVPWM	-	Space Vector Pulse Width Modulation
TI	-	Texas Instrument
VSC	-	Variable Structure Control
VSI	-	Voltage Source Inverter

LIST OF SYMBOLS

A	-	Ampere
B	-	Friction coefficient, Nm/(rad/sec)
e	-	Position error
$e(t)$	-	Speed error, rpm
e_{max}	-	Maximum tracking error
e_{ss}	-	Steady-state error
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 self-inductance, H
L_r	-	Stator-referred rotor self-inductance, H
M_p	-	Maximun percentage overshoot
K	-	Linear feedback gain of sliding mode control
K_p	-	Proportional gain
K_i	-	Integral gain
K_c	-	Critical gain

K_u	-	Ultimate proportional gain
kg	-	Kilogram
m	-	Meter
N	-	Newton
P	-	Pressure
rad	-	Radian
s	-	Second
S	-	Sliding surface
t	-	Time
T	-	Torque
T_d	-	Derivative time constant
T_e	-	Electromagnetic torque
T_i	-	Integral time constant
T_L	-	Load torque
T_r	-	Rotor time constant
T_p	-	Peak time
T_s	-	Sampling time
T_{settle}	-	Settling time
V	-	Voltage
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

Journal:

1. Aziri, H., Patakor, F.A., Sulaiman, M., and Salleh, Z., 2017. Comparison Performances Of Indirect Field Oriented Control For Three-Phase Induction Motor Drives. *International Journal of Power Electronics and Drive Systems*, 8(4), pp.1682-1692.

Conference:

1. Aziri, H., Patakor, F.A., Sulaiman, M., and Salleh, Z., 2017. Simulation Of Three-Phase Induction Motor Drives Using Indirect Field Oriented Control In PSIM Environment. *AIP Conference Proceedings, International Conferences on Electrical and Electronic Engineering (IC3E 2017)*, pp.9-10.

CHAPTER 1

INTRODUCTION

1.1 Background

Over the last recent years, the application for induction motor in the industry cannot be denied. The use of induction motor applications are very wide such as for centrifugal pump, compressor, elevator, punching presses and many more. It is extensively used due to easy maintenance requirements, high reliability and lower cost for variable speed operation in wide areas (Bennassar et al., 2018). In addition, industrial applications become more attractive especially with advances of microprocessors and power electronics as a modern electrical drive for high performance characteristics such as robust to parameter variation of the system, inexpensive maintenance with free implementation operation, small overshoot and steady-state error with fast transient response (Saravanakumar et al., 2009).

Since the last few decades, the ease of control for variable speed drives was preferred by DC motor. However, the AC motor was replaced by the DC motor because of more privileges and reliable when compared to the DC motor (Jahns and Owen, 2001; Holtz, 2002). Traditionally, there are two major types of induction motor control in variable speed which are vector control and conventional volts per hertz (v/f) or scalar control. The vector control is achieved independent flux and torque that made AC drives equivalent to DC drives for a superior in dynamic performance. Thus, the scalar control gives a full load of torque over a wide range of speeds under steady-state conditions when the flux is constant except at low speed (Holtz, 2006; Mahato et al., 2019).