UNIVERSITI PUTRA MALAYSIA

SENSORLESS ADAPTIVE FUZZY LOGIC CONTROL OF PERMANENT MAGNET SYNCHRONOUS MOTOR

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Dedication

This thesis is dedicated to Shatha and my family back in Palestine whose unconditional love made my journey possible.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

SENSORLESS ADAPTIVE FUZZY LOGIC CONTROL OF PERMANENT MAGNET SYNCHRONOUS MOTORS

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Chairman: Associate Professor Ishak Aris, PhD

Faculty: Engineering

Permanent Magnet Synchronous Motors (PMSM) require an electromechanical rotor position sensor to operate. The rotor position sensor has disadvantages, such as reliability, size, higher cost, and increased electrical connections. PMSM is used in many speed and position control industrial applications. Proportional integral (PI) and proportional integral derivative (PID) controllers have been widely utilised as speed controllers in PMSM drives. However, these controllers are very sensitive to step change of command speed, parameter variations and load disturbance.

In this work, an adaptive fuzzy logic speed controller is proposed. The main features of the proposed controller are; quick recovery of motor's speed from load disturbances and insensitivity to parameter variation over a wide speed range.

The proposed controller is a hybrid model reference adaptive speed controller (HMRASC) which mainly consists of two functional blocks. The first block is a direct FLC that has the error and the change of error as inputs. The error signal is measured between the actual motor speed and the desired speed and the output is the

change in the torque command. The second block implements a model reference adaptive controller. In the proposed system, the output speed of the reference model is compared with the actual speed of the motor and the resulted speed error is applied to a PI controller. The output signal of the PI controller is added to the direct FLC output to compensate any deviations in the motor speed from the reference speed due to parameters variation and disturbances in the load.

The design and optimisation of the FLC are carried out using an adaptive fuzzy inference system network that uses the backpropagation, least square and gradient algorithms. The fuzzy inference system is trained and designed using an adaptive network. The rules and the implication method used are also optimised and minimised in order to shorten the computation time. In addition, the effect of different types and distributions of the membership functions were investigated and presented.

This work also presents the estimation of the rotor position, which works effectively with nearly zero estimation error over wide speed range, to replace the electrometrical rotor position sensor. An estimation method based on the back EMF and flux estimation is presented to calculate the rotor position for medium to high speed. At low speed, the rotor position is calculated using signal injection where a high frequency low voltage signal is injected on the stator winding. In the proposed method, the measured motor's current and the estimated motor's voltage are processed through a signal processing block and a PI regulator to calculate the angle of the rotor position.

Finally the performance of the HMRASC and the rotor position angle estimation algorithms are evaluated by simulation and verified experimentally for two motors using MCK2407 kit and IMDM15 board which are based on the TMS320LF2407 fixed point Digital Signal Processor (DSP) for different operating conditions. The first motor is rated at 50W and the second is rated at 380W. Both experimental and simulation results obtained from the HMRASC and the position angle estimation algorithms showed superior results compared to other methods presented in the literature.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KAWALAN LOGIK SAMAR MUDAH SUAI TANPA PENGESAN UNTUK MOTOR SEGERAK MAGNET KEKAL

Oleh

MUTASIM IBRAHIM HAFZ NOUR

November 2007

Pengerusi: **Profesor Madya Ishak Aris, PhD**

Fakulti: **Kejuruteraan**

Motor Segerak Magnet Kekal (PMSM) memerlukan pengesan posisi pemutar elektro mekanikal untuk beroperasi. Pengesan posisi pemutar mempunyai banyak kekurangan seperti kebolehsandaran, saiz, kos yang lebih tinggi dan peningkatan sambungan elektrik. PMSM digunakan di dalam kebanyakan pengawal kelajuan dan posisi untuk aplikasi industri. Pengawal kesempurnaan berkadar langsung (PI) dan pengawal kesempurnaan terbitan berkadar langsung (PID) telah digunakan secara meluas sebagai pengawal kelajuan di dalam pemacu PMSM. Walau bagaimanapun, pengawal-pengawal ini sangat sensitif terhadap perubahan langkah dalam arahan kelajuan, perubahan parameter dan gangguan beban.

Dalam kajian ini, pengawal kelajuan logik samar mudah suai telah dicadangkan. Ciri-ciri utama bagi pengawal yang telah dicadangkan adalah; pemulihan pantas daripada gangguan beban dan ketidak pekaan terhadap variasi parameter pada lingkungan kelajuan yang tinggi.

Pengawal yang dicadangkan adalah model rujukan pengawal kelajuan mudah suai hibrid (HMRASC) yang secara asasnya terdiri daripada 2 blok fungsi. Blok yang pertama adalah FLC terus yang mempunyai ralat dan perubahan ralat adalah sebagai masukan. Isyarat ralat yang diukur di antara kelajuan motor sebenar dan kelajuan motor yang dikehendaki dan keluaran adalah perubahan di dalam arahan tork. Blok yang kedua melaksanakan model rujukan pengawal mudah suai. Di dalam sistem yang dicadangkan, kelajuan keluaran model rujukan dibandingkan dengan kelajuan sebenar motor dan ralat kelajuan yang dihasilkan digunakan di sebuah pengawal PI. Isyarat keluaran daripada pengawal PI ditambah kepada keluaran FLC langsung untuk menggantikan sebarang sisihan di dalam kelajuan motor daripada kelajuan rujukan yang disebabkan oleh perubahan parameter dan gangguan di dalam beban.

Rekabentuk dan pengoptimuman FLC dilaksanakan menggunakan rangkaian sistem penarikan samar mudah suai yang menggunakan perambatan balik, kuasa dua terkecil dan algoritma kecerunan. Sistem inferen samar dilatih dan direkabentuk menggunakan rangkaian mudah suai. Peraturan-peraturan dan kaedah implikasi juga dioptimumkan dan dikurangkan untuk memendekkan masa pengiraan. Selain daripada itu, kesan daripada kepelbagaian jenis dan taburan oleh fungsi-fungsi yang berkaitan telah disiasat dan dibentangkan.

Kajian ini juga membentangkan anggaran posisi pemutar, yang berfungsi secara cekap dengan anggaran sifar ralat pada kelajuan lingkungan tinggi, untuk menggantikan pengesan posisi pemutar elektro mekanikal. Kaedah anggaran berdasarkan EMF balik dan anggaran fluks dibentangkan untuk mengira posisi pemutar untuk kelajuan sederhana sehingga tinggi. Pada kelajuan rendah, posisi

pemutar dikira menggunakan suntikan isyarat di mana isyarat voltan rendah berfrekuensi tinggi disuntik kepada lilitan stator. Di dalam tatacara yang telah dicadangkan, arus motor yang diukur dan anggaran voltan motor telah diproses melalui satu blok pemprosesan isyarat dan sebuah pengaturcara PI untuk mengira sudut posisi pemutar.

Akhir sekali, prestasi HMRASC dan algoritma penganggaran sudut posisi pemutar dinilai dengan menggunakan simulasi dan disahkan secara eksperimen untuk kedua-dua motor menggunakan kit MCK2407 dan papan IMDM15 yang berdasarkan pada Pemproses Isyarat Digital (DSP) TMS320LF2407 bertitik tetap untuk keadaan operasi yang berbeza. Motor yang pertama dikadarkan pada 50W dan yang kedua dikadarkan pada 380W. Kedua-dua keputusan yang didapati secara eksperimen dan simulasi yang didapati daripada HMRASC dan algoritma penganggaran sudut posisi telah menunjukkan keputusan yang lebih baik berbanding kaedah-kaedah lain yang telah dibentangkan di dalam kajian literatur.

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Above all, I want to give thanks to ALLAH for upholding me by His hand, comforting me through His Word and sustaining me by His strength throughout the time I have been working on accomplishing this project. Truly, Apart From Him, I can do nothing, and I am nothing, but through Him, all things are possible according to His will.

I certify that an Examination Committee has met on 26th November 2007 to conduct the final examination of Mutasim Ibrahim Hafz Nour on his Doctor of Philosophy thesis entitled "Sensorless Adaptive Fuzzy Logic Control of Permanent Magnet Synchronous Motor" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the degree of Doctor of Philosophy.

Members of the Examination Committee are as follows:

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Date: 21 February 2008

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of **DOCTOR OF PHILOSOPHY**. The members of the Supervisory Committee were as follows:

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Date: 21 February 2008

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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MUTASIM IBRAHIM HAFZ NOUR

Date: 14 January 2008

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