## Faculty of Electrical Engineering

# SENSORLESS SPEED DRIVES OF PERMANENT MAGNET SYNCHRONOUS MOTOR USING MODEL REFERENCE ADAPTIVE CONTROL

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**Master of Science in Electrical Engineering**

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# SENSORLESS SPEED DRIVES OF PERMANENT MAGNET SYNCHRONOUS MOTOR USING MODEL REFERENCE ADAPTIVE CONTROL

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**DECLARATION**

I declared that this thesis entitle "Sensorless Speed Drives Of Permanent Magnet Synchronous Motor using Model Reference Adaptive Control" 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 declared 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 Electrical Engineering (Power Electronics and Drives).

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| Signature | : | ………………………………… |
| Supervisor Name | : | Associates Professor Dr. Zulkifilie Bin Ibrahim |
| Date | : | ………………………………… |

**DEDICATION**

To my beloved father, mother, my little sister and family

**ABSTRACT**

In high performance drives, speed and torque controls of permanent magnet synchronous motors are usually attained by the application of position and speed sensors. However, speed and position sensors require the additional mounting space, reduce the reliability in harsh environments and increase the cost of the motor. Therefore, many studies have been carried out and reported to eliminate the speed and position sensors such as back electromotive force, signal injection, and others. However, these techniques have the drawbacks such as sensitive to machine parameter and others. The research focuses on investigation an evaluation of the sensorless speed control of surface mounted permanent magnet synchronous motor (SMPMSM) drives controlled by PI speed controller based on MRAC combined with V-I model and reactive power model. A Model Reference Adaptive Control (MRAC) has been chosen in this research based on its simplicity, good stability, and requires less computation. The SMPMSM is controlled using the principle of rotor flux orientation. Current control is performed in rotor reference frame based on SVPWM. The drives is simulated using SIMULINK/ MATLAB and the hardware implementation is based on dSPACE (DS1103). PI speed and current controllers are at first designed and the controller parameters are manually tuned to obtain steady state stability. A detailed investigation of the varies operating points; different speed command, forward-reverse speed operation, inertia variation and different speed command profiles. The overshoot/undershoot, settling time, and rise time of the speed response are used to evaluate the controller and speed estimation methods. The simulation and experimental with MRAC combined with V-I model speed estimation method results have proved that the drives is robust to the inertia variation, load rejection properties, speed variation and different initial speed profiles. Finally, the experimental investigation in MRAC combined with V-I model speed estimation method is performed in order to confirm the theoretical findings.

**ABSTRAK**

Didalam pemacu berprestasi tinggi, kelajuan dan kawalan daya kilas motor segerak magnet kekal kebiasaannya digandingkan dengan aplikasi sensor posisi dan kelajuan. Walau bagaimanapun, sensor tersebut memerlukan ruang pemasangan tambahan, malah ia mengurangkan kecekapan dalam persekitaran yang tidak mesra disamping meningkatkan kos motor. Oleh itu, banyak kajian telah dijalankan dan dilaporkan bagi tidak menggunakan sensor kelajuan dan posisi seperti kaedah daya gerak elektrik undur (BEMF), suntikan isyarat, dan lain-lain. Walau bagaimanapun, teknik ini mempunyai kelemahan seperti sensitif kepada parameter mesin dan lain-lain. Kajian ini memberi tumpuan kepada siasatan penilaian kawalan kelajuan tanpa sensor kelajuan bagi pemacu motor segerak yang permukaannya dipasang dengan magnet kekal (SMPMSM) yang dikawal oleh pengawal kelajuan PI gabungan kawalan adaptasi model rujukan (MRAC) model V-I dan model kuasa reaktif. MRAC telah dipilih dalam kajian ini berdasarkan strukturnya yang mudah, kestabilan yang baik, dan kurang memerlukan pengiraan. SMPMSM dikawal menggunakan prinsip orientasi fluk rotor. Pengawal arus dilakukan di dalam bingkai rujukan rotor berdasarkan SVPWM. Pemacu ini disimulasi menggunakan SIMULINK / MATLAB dan perlaksanaan perkakas adalah berdasarkan dSPACE (DS1103). Pengawal PI bagi kelajuan dan arus direkabentuk terlebih dahulu dan parameter pengawal diubah suai secara manual bagi mencapai keadaan kestabilan yang mantap. Penyiasatan yang terperinci dijalankan pada titik operasi yang berbeza; arahan kelajuan yang berbeza, operasi kelajuan ke hadapan-belakang, perubahan inersia dan profil arahan kelajuan yang berbeza. Lajak/lajak bawah, masa pengenapan, dan masa naik digunakan untuk menilai pengawal dan kelajuan melalui kaedah anggaran kelajuan. Simulasi dan keputusan eksperimen dengan penggunaan MRAC yang digabungkan dengan V-I model melalui kaedah anggaran kelajuan telah terbukti dengan keteguhan terhadap perubahan inersia, gangguan beban, perubahan kelajuan dan profil pendahuluan kelajuan yang berbeza. Kesimpulannya, kajian dan eksperimen dengan penggunaan MRAC yang digabungkan dengan V-I model melalui kaedah anggaran kelajuan telah dilakukan bagi mengesahkan penemuan teori tersebut.

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**LIST OF PRINCIPAL NOTATION**

| | | |
|---|---|---|
| $V_d$ | - | d-axis stator voltages |
| $V_q$ | - | q-axis stator voltages |
| $i_d$ | - | d-axis stator currents |
| $i_q$ | - | q-axis stator currents |
| $V_\alpha$ | - | α-axis stator voltages |
| $V_\beta$ | - | β-axis stator voltages |
| $i_\alpha$ | - | α-axis stator currents |
| $i_\beta$ | - | β-axis stator currents |
| $L_d$ | - | d-axis stator currents |
| $L_q$ | - | q-axis stator currents |
| $\theta_r$ | - | rotor electrical position |
| $\omega_e$ | - | rotor electrical angular velocity |
| $\Psi_m$ | - | flux linkage |
| $\Psi_d$ | - | d-axis stator flux linkages |
| $\Psi_q$ | - | q-axis stator flux linkages |
| $R_s$ | - | stator winding resistance |
| $\omega_r$ | - | rotor electrical speed |
| $\omega_m$ | - | rotor mechanical speed |
| P | - | pole pairs |
| $V_{ab}, V_{bc}, V_{ca}$ | - | line voltages |

| | | |
|---|---|---|
| $V_{dc}$ | - | DC supply voltage |
| $f$ | - | fundamental frequency |
| $\tau_i$ | - | integral time constant |
| $U_{(t)}$ | - | control output |
| $K_p$ | - | proportional gain |
| $K_i$ | - | integral gain |
| e(t) | - | tracking error |
| $\rho$ | - | $d/dt$ |
| $J$ | - | total mechanical inertia |
| $B$ | - | total damping coefficient |
| $\varepsilon$ | - | estimation error |
| $i_{abc}$ | - | phase currents |
| $V_{abc}$ | - | phase voltages |
| $V_{ref}$ | - | Reference voltage |
| $T_{em}$ | - | Torque electromagnetic |
| PC | - | Computer |
| $T_L$ | - | Load torque |
| $I_s$ | - | Supply current |
| $P_{in}$ | - | Instanteneous power |
| $T_s$ | - | Settling time |
| P | - | Proportional |
| PI | - | Proportional-Integral |
| PID | - | Proportional-Integral-Derivative |
| PD | - | Proportional-Derivative |

| | | |
|---|---|---|
| $K_t$ | - | Torque constant |

## LIST OF SUPERSCRIPT

| | | |
|---|---|---|
| '*' | - | Commanded value |

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## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| AC | - | Alternate Current |
| AI | - | Artificial Intelligence |
| ANN | - | Artificial Neural Networks |
| ADC | - | Analog-to-Digital Control |
| DAC | - | Digital-to-Analog Control |
| DC | - | Direct Current |
| DSP | - | Digital Signal Processor |
| DTC | - | Direct Torque Control |
| EKF | - | Extended Kalman Filter |
| ELO | - | Extended Luenburger Observer |
| EMF | - | Electromagnetic Force |
| FPGA | - | Field Programmable Gate Array |
| FLC | - | Fuzzy Logic Control |
| IGBT | - | Insulted Gate Bipolar Transistors |
| IPMSM | - | Interior Permanent Magnet Synchronous Motor |
| I/O | - | Input/Output |
| LPF | - | Low Pass Filter |
| MRAC | - | Model Reference Adaptive Control |
| MOSFET | - | Metal Oxide Semiconductors Field Effect Transistors |
| PMSM | - | Permanent Magnet Synchronous Motor |