UNIVERSITI TEKNIKAL MALAYSIA MELAKA

# Faculty of Electrical Engineering

## FUZZY LOGIC CONTROLLED SPMSM DRIVES FOR LONG CABLE APPLICATIONS

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# FUZZY LOGIC CONTROLLED SPMSM DRIVES FOR LONG CABLE APPLICATIONS

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**in fulfilment of the requirements for the degree of Master of Science**
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**DECLARATION**

I declare that this thesis entitle Fuzzy Logic Controlled SPMSM Drives for Long Cable Applications 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 : Cheok Yong Seng

Date : .............................

## 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.

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| Signature | : ....................................................... |
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| Date | : ....................................................... |

**DEDICATION**

To my beloved mother, father and wife

## ABSTRACT

In many industrial Variable Speed Drives (VSD) applications require that the Voltage Source Pulse Width Modulation (PWM) Inverter and the motor be at separate locations, often resulting in long motor leads, high voltage oscillation at the motor terminal, increase harmonics content and affect the overall motor speed performance. To our knowledge, a detailed investigation of the impact of various cable lengths over speed response has not been reported in the literature. Therefore, the research focuses on investigation and evaluation of the performance of a Vector Controlled Sinusoidal Permanent Magnet Synchronous Motor (SPMSM) drive, controlled by PI speed controller and FL speed controller for different cable lengths conditions. Current control is performed in the stationary reference frame, using hysteresis current controllers. The scope of research is focusing on low speed operation based on simplified 9 rules Fuzzy Logic speed controller and tested for tested 100 meter maximum cable lengths and 1.1kW SPMSM. The drive is modeled, simulated and implemented using MATLAB, SIMULINK and FUZZY LOGIC Toolboxes. The experimental study is carried out based on dSPACE hardware platform for validating the simulation results. PI and Fuzzy Logic speed controllers are designed and tuned to obtain the best performance with criteria less than 0.72% overshoot and ±0.1 steady state error are acceptable. All the controller parameters are fixed based on designed case study for overall simulation and experimental studies. The overshoot/undershoot, settling time and rise time of the speed response are used to evaluate the controller performance. The simulation and experimental results have showed that the speed response and load rejection are degraded due to variation in cable length and increase of motor inertia. The proposed Fuzzy Logic has demonstrated better performance in term of step speed command, load rejection capability and THD compare with the results obtained from PI speed controller for different cable length conditions. The THD of the three-phase stator current is increased when motor is connected with longer cable. Fuzzy Logic speed controller shows better THD of stator currents as compare to PI speed controller where the THD was remain constant even cable length was increasing. When switching frequency of the Hysteresis PWM is increased, the stator currents will be closer to sinusoidal and indirectly reduced the %THD of the drives. Study on variable speed drive performance versus different cable length can be further investigated for medium and high motor speed commands operation.

## *ABSTRAK*

*Didalam kebanyakan aplikasi pemacu bolehubah kelajuan (VSD) memerlukan Penyongsang Modulasi Lebar Denyut dan motor berada pada lokasi yang terpisah, selalunya menyebabkan kabel motor yang panjang, ayunan voltan tinggi pada punca motor, kenaikan kandungan harmonic dan memberi kesan prestasi keseluruhan kelajuan motor. Berdasarkan pengalaman kami, penyiasatan yang terperinci bagi kesan pelbagai panjang kabel keatas sambutan kelajuan tidak pernah dilaporkan dalam kajian. Oleh itu, penyelidikan ini tertumpu pada kajian dan penilaian bagi pemacu Kawalan Vektor Motor Segerak Magnet Kekal (SPMSM) yang dikawal oleh pengawal kelajuan PI dan pengawal kelajuan Logik Kabur FL terhadap untuk keadaan panjang kabel yang berbeza. Kawalan arus dilakukan dalam kerangka rujukan pegun, menggunakan pengawal arus hysteresis. Skop penyelidikan tertumpu pada operasi kelajuan rendah berdasarkan kepada pengawal kelajuan Logik Kabur dimudahkan 9 aturan dan diuji untuk panjang maksima 100 meter dan 1.1kW SPMSM. Pemacu motor dimodel, disimulasi dan dilaksanakan menggunakan MATLAB, SIMULINK dan FUZZY LOGIC Kotakalat. Kajian ujikaji—dijalankan berdasarkan pelantar perkakasan dSPACE untuk mengesahkan keputusan simulasi. Pengawal kelajuan PI dan Logik Kabur yang telah direkabentuk dan tertala untuk mendapatkan prestasi yang terbaik dengan kriteria lebih kecil dari 0.72% lanjak dan ±0.1 –ralat keadaan mantap yang diterima. Kesemua parameter pengawal ditetapkan berdasarkan kepada kes rekabentuk bagi keseluruhan kajian simulasi dan ujikaji. Lajakan naik/lajakan turun, masa pengenapan dan masa naik bagi sambutan kelajuan digunakan untuk penilai prestasi pengawal. Keputusan simulasi dan ujikaji telah menunjukkan bahawa sambutan kelajuan dan penolakan beban adalah menyusut disebabkan perubahan panjang kabel dan pertambahan inersia motor. Logik Kabur yang dicadangkan telah menunjukkan prestasi lebih baik dari segi rujukan kelajuan langkah, kebolehan penolakan beban dan THD berbanding dengan keputusan yang diperolehi dari pengawal kelajuan PI untuk keadaan panjang kabel yang berbeza. THD bagi arus stator tiga-fasa adalah menaik apabila motor disambung kepada kabel panjang. Pengawal Logik Kabur menunjukkan THD lebih baik bagi arus stator berbanding kepada pengawal kelajuan PI dimana THD tetap malar walaupun panjang kabel ditambah. Apabila frekuensi pensuisan bagi PWM Histeresis dinaikkan, arus stator lebih mirip sinusoid dan secara tidak langsung akan mengurang %THD bagi pemacu. Kajian prestasi keatas pemacu bolehubah kelajuan melawan panjang kabel yang berbeza boleh dilanjukkan kajiannya pada rujukan kelajuan motor yang sederhana dan tinggi.*

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background of High Performance AC Drives

Variable-speed drives are continuously innovated. Their development is characterized by the progress made in various areas including power and microelectronics, control systems, magnetic materials, modern communication technologies (e.g. for ultra-fast bus communications), etc. The DC drives became an absolute selection in motion industry since their flux and torque can be controlled easily by the field and armature currents. The torque of the DC drives is controlled via the armature current while maintaining the field component constant, thus fast torque can be achieved easily. As the consequence, the DC drives extensively used in wide-ranging of applications which require speed and position control with high dynamic performance and high precision characteristics. The disadvantage of the DC drives mainly due to existence of the commutator and brushes in the DC motor which used to obtain the flux and torque components to be always perpendicular to one another, which require periodic maintenance. However, these problems can be overcome by the application of ac motors, which can have simple and rugged structure, high maintainability and economy. AC motors are more robust and immune to heavy overloading compare to DC motor (Rashid, 2001). Among the various ac drive systems, those which contain the squirrel cage induction motor have a particular cost advantage. At present the cage induction motor is the most frequently used motor in industry. This is due to the fact that it is simple, rugged, requires only low maintenance and is one of the cheapest machines available at all power ratings. However, permanent magnet synchronous motor (PMSM) drives are used in many applications and receiving increased attention because of their high torque density, high efficiency, and small size. The PMSM is preferable in industrial servo applications compare to the DC motor due to considerations of the cost, low maintenance, maximum speed capability, size and simplicity of design (Patil, Chile, & Waghmare, 2010).

With the rapid development in microprocessor, the high performance DSP chip becomes a popular research on digital control for ac drives due to their high-speed performance, simple circuitry, on-chip peripherals of a micro-controller into a single chip solution (Kung & Huang, 2004). The experimental results demonstrate that in step command response and frequency command response, the rotor position of SPMSM can fast track the prescribed dynamic response well. However, the whole system required a complicated operation of the proposed control algorithm, programming and difficulty on control design modification. However, in (Amamra, Barazane, Boucherit, & Cherifi, 2010) has shown the practical feasibility of the proposed approach that allows robust control of the induction. The control algorithm is built within Simulink environment combined with the Real- Time Interface (RTI) provided by dSPACE and is implemented by the main processor of the DS-1103 board in real-time. The combination of dSPACE DS1103 DSP and MATLAB/Simulink effectively created a rapid control prototype environment, in which the designer focused on control design rather than programming details or debugging control languages.

In recent years various speed and position sensorless control schemes have been developed for variable-speed ac drives. The main reasons for the development of these ‘‘sensorless’’ drives are : reduction of hardware complexity and cost, increased mechanical robustness and overall ruggedness, operation in hostile environments, higher reliability; decreased maintenance requirements, increased noise immunity, unaffected machine inertia, improvement of the vibration behaviour, elimination of sensor cables etc (Rashid, 2001).

Basic principles of vector control (field orientation), introduced in the early Seventies (Blaschke, 1972), showed that decoupled control of flux and torque was theoretically possible in three-phase AC machine. Since there are three flux vectors in an induction machine, three method of vector control can be distinguished: the stator-flux-oriented control, the air-gap-flux-oriented control and rotor-flux oriented control (Vas P. , 1990). The rotor-flux oriented control is the most popular method because of simple control system structure. All the vector controllers require accurate information about the instantaneous spatial position. The most popular alternative control method was direct torque control (DTC), was introduced by (Takahashi & Noguchi, 1986). The main feature of DTC is the absence of co-ordinate transformation and current controllers. DTC same as vector control require flux and torque estimates. However, the overall complexity of the control system is substantially reduced, compared with vector controlled drives.

## 1.2 Problem Statement

In many industrial VSD applications require that the Voltage Source Pulse Width Modulation (PWM) inverter and the motor be at separate locations, often resulting in long motor leads of 15 – 150 meter (Matheson, Von Jouanne, & Wallace, 1999). Drive system used in oil exploitation, offshore platform drilling and mining industries usually required longer motor feeders longer than 1 km. Variable speed drive performance encounter significant overvoltage issue at motor terminal when apply on long cable application. This is due to the relative different between characteristic impedance of the cable and output impedance of the drive. The drive side voltage can have large amplitude oscillations, over twice its mean value and high THD content, mainly at the harmonic of the PWM signal, depending on the cable length and characteristic.

As reported in the literature review, overall motor drives performance degraded due to variation in voltage supply to the motor as well as the THD of the voltage and current (Buddingh, Dabic, & Groten, 2008). Variation in applied voltages and large oscillation in motor currents leads to variation in the operating point, result in increased Total Harmonics Distortion (THD) and degradation of the motor speed responses in term of oscillation, overshoot, settling time, steady state error else well as torque responses during motor acceleration and load disturbance operation.

## 1.3 Research Objectives

The research project investigates the effects of the cable length and the motor terminal voltage variation over speed response behaviour of the vector controlled variable speed drives with Sinusoidal Permanent Magnet Synchronous Motor (SPMSM) which is controlled by PI and Fuzzy Logic Speed controllers. The main objectives of the research can be summarised as follows:

i. To investigate the overall performances of the vector controlled SPMSM drives in terms of speed responses behaviour and load rejection capabilities controlled by PI and FL speed controllers for different cable length.

ii. To study the effect of overvoltage on THD of the motor current for different cable length.

iii. To compare the robustness of the Fuzzy Logic and PI speed controllers for different cable length and variation in motor inertia.

iv. To implement the developed Fuzzy Logic and PI speed controllers in an experimental rig for different cable length

## 1.4 Scope of Work

The work undertaken in this research consists of five stages.

1. To model three-phase Sinusoidal Permanent Magnet Synchronous Motor (SPMSM) into d-q motor model, three-phase Voltage Source Inverter (VSI), hysteresis current controllers, long cable, PI speed controller, FL speed controller and rotor flux oriented control of a voltage-fed SPMSM drives.
2. To investigate the SPMSM drives behaviour which is controlled by PI speed controller for different cable length. A detailed study of speed response characteristics between a motor drive connected with standard cable length (2 meter) and a motor drive connected with long cable length (200 meter and 400 meter) for standstill to rated speed application, load disturbance and robustness to the motor inertia change is carried out.
3. To investigate the SPMSM drives behaviour which is controlled by Fuzzy Logic speed controller for different cable length. The Fuzzy logic controller used in the research is based on the simplified Fuzzy Logic controller proposed in paper (Isa, Ibrahim, & Patkar, 2009). A detailed comparative analysis of speed response characteristics between a motor drive connected with standard cable length (2 meter) and a motor drive connected with long cable length (200 meter and 400 meter) for standstill to rated speed application, load disturbance and robustness to the motor inertia change is carried out.
4. To develop an experimental rig consists of PC installed with MATLAB/SIMULINK, DS1103 DSP of dSPACE, IGBT drivers and modules, Resolver Digital Converter (RDC), 300VDC power supply, 1.1kW SPMSM, DC generator and 4 conductors symmetric cable PVC insulated with maximum 100 meter.

5. In this research only focuses on the low speed drive (500rpm) due to low accuracy at the Resolver Digital Converter (RDC). A detailed comparative analysis between standard cable length (2 meter) and long cable length (36 meter and 100 meter) of speed response from standstill to below rated speed application (500rpm). This study also takes into consideration the effects of Total Harmonic Distortion (THD) of three-phase stator currents and overvoltage at motor terminal over speed response transient in term of rise time, load disturbance and robustness to the motor inertia change.

## 1.5 Contribution of the Research

The contribution of the research consists of:

1. A detailed investigation on the overall motor drives behaviour controlled by Fuzzy Logic and PI speed controllers under motor terminal voltage variation due to overvoltage reflection based on different cable length
2. A detailed simulation and hardware experimental investigation of the SPMSM drive which is controlled by PI and Fuzzy Logic under inertia variation condition for different cable length application. Also the correlation between THD, cable length and speed responses.

## 1.6 Thesis Outline

A brief overview of background high performance AC drives and its applications in industry such as aerospace actuators, robotics and industrial applications has been given in this chapter. High performance SPMSM drives and the concept of vector control are review in **Chapter 2**. This includes a detailed literature survey of long cable drive