



Faculty of Electrical Engineering

FUZZY LOGIC CONTROLLED SPMSM DRIVES FOR LONG CABLE APPLICATIONS

Cheok Yong Seng

Master of Science In Electrical Engineering

2014

i

**FUZZY LOGIC CONTROLLED SPMSM DRIVES FOR
LONG CABLE APPLICATIONS**

CHEOK YONG SENG

**A thesis submitted
in fulfilment of the requirements for the degree of Master of Science
in Electrical Engineering**

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

ii

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.

Signature :

Supervisor : Assoc. Prof. Dr Zulkiflie Ibrahim

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 mengurangkan %THD bagi pemacu. Kajian prestasi keatas pemacu bolehubah kelajuan melawan panjang kabel yang berbeza boleh dilanjutkan kajiannya pada rujukan kelajuan motor yang sederhana dan tinggi.

ACKNOWLEDGEMENTS

No one can learn by themselves without the help of others in an attempt to seek knowledge from the time he was in the cradle to the grave, and I gladly would like to express gratitude for those who have helped me along the way of my studies in the successful completion of this thesis. I wish to express my sincere appreciation to my main thesis supervisor, Assoc. Prof. Dr Zulkifilie Ibrahim, for encouragement and guidance. Besides, I am very thankful to my lecturer Mrs. Jurifa, Mrs Nurazlin, and Mr. Hairol for their guidance and advices. Without their continued support and interest, this thesis would not have been same as presented here.

My group of postgraduate students Mrs. Normiza, Mr. Anggun, Mr. Musa and Mr. Ahmad Shukri should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members.

TABLE OF CONTENT

	PAGE
DECLARATION	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENT	iv
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF APPENDICES	xiii
CHAPTER	
1. INTRODUCTION	1
1.1 Background of High Performance AC Drives	1
1.2 Problem Statement	3
1.3 Research Objectives	4
1.4 Scope of Work	5
1.5 Contribution of the Research	6
1.6 Thesis Outline	6
2. LITERATURE REVIEW	9
2.1 Introduction	9
2.2 Vector Control of a Surface Mounted Permanent Magnet Synchronous Machine	11
2.2.1 Rotor Flux Oriented Control of Current-Fed SPMSM	12
2.2.2 Rotor Flux Oriented Control of Voltage-Fed SPMSM	13
2.3 Long Cable Drives Application	13
2.4 Conventional Speed Controller	19

2.5	Current Control Method for PWM Voltage Source Inverter (VSI)	22
2.6	Design of Fuzzy Logic Speed Controller	24
2.6.1	Fuzzy Control Rules	26
2.6.2	Membership Function	29
2.6.3	Defuzzification	30
2.6.4	Scaling Factor Calculation	30
2.7	Summary	33
3.	METHODOLOGY	35
3.1	Research Methodology	35
3.2	Mathematic Model of Sinusoidal Permanent Magnet Synchronous Motor (SPMSM)	38
3.2.1	Phase Variable Voltage Equation in the Original Reference Frame	38
3.2.2	Transformation to the d,q Reference Frame Fixed to the Rotor	42
3.2.3	Rotor Flux Oriented Control of SPMSM	46
3.3	Voltage Source Inverter	47
3.4	Hysteresis Current Controller	52
3.5	PI Speed Controller	56
3.6	Vector Controlled SPMSM Drives	57
3.7	Long Cable Model	59
3.7.1	Impedance measurement of 10 meter cable length	61
3.7.2	Circuit constant used for the simulation	66
3.8	Summary	68

4. DESIGN OF SPEED CONTROLLER	69
4.1 Design of PI Speed Controller	69
4.2 Simulation model of Rotor Flux Oriented Control (RFOC) with PI Controller	70
4.2.1 Initial Speed response for RFOC with PI Controller	70
4.2.2 Speed Response with Different Cable Length	72
4.3 Simulation Model of Rotor Flux Oriented Control (RFOC) with Fuzzy Logic Controller	79
4.3.1 Initial Speed Response for RFOC with Fuzzy Logic Controller	82
4.3.2 Comparative Study Between PI Speed Controller and Fuzzy Logic Speed Controller for Long Cable Application	83
4.4 Summary	88
5. EXPERIMENTAL INVESTIGATION	89
5.1 Introduction	89
5.2 Experimental Rig Setup	89
5.3 Software Configuration	91
5.4 Hardware Configuration	93
5.4.1 dSPACE System	93
5.4.2 Optocoupler	93
5.4.3 Voltage Source Inverter	94
5.4.4 SPMSM integrated with Resolver	94
5.4.5 Position Sensing with Resolver to Digital Converter (RDC)	95
5.4.6 Current Sensing with Hall Effect Sensor	96
5.4.7 High Voltage Differential Probe Calibration	101

5.4.8	Fluke Power Quality Analyzer Calibration	102
5.5	Description of the Experimental Procedure	106
5.6	Experimental Result	107
5.6.1	Tuning for PI and Fuzzy Logic speed controller on standard cable length	109
5.6.1.2	Step speed command from standstill	112
5.6.2	RFOC with PI speed controller for 36 meter and 100 meter cable length	115
5.6.2.1	Step speed command from standstill for PI speed controller	115
5.6.2.2	Speed command step down by 20% for PI speed controller	117
5.6.2.3	Step load torque application for PI speed controller	118
5.6.3	Comparative study of PI and Fuzzy Logic speed controller for different cable length application	119
5.6.3.1	Step speed command from standstill for PI and FL speed controller	119
5.6.3.2	Speed command step down by 20% for PI and FL speed controller	121
5.6.3.4	Step load torque application for PI and FL speed controller	123
5.6.3.4	Over voltage comparison between PI and FL for different cable length	125
5.6.3.5	Total Harmonic Distortion of three phase stator voltage and current versus different cable length application	128
5.7	Summary	131
6.	CONCLUSION	134
6.1	Conclusion	134
6.2	Future Work	136
	REFERENCE	138
	APPENDIX A – Motor Data	158

APPENDIX B – Simulink Model in Simulation	160
APPENDIX C – Simulink Model in Experimental	166
APPENDIX D – Hardware Configuration	169
APPENDIX E – THD M-File Formula	172
APPENDIX F – Publications	173

LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1	: Matrix 49 rules table (Standard)	28
Table 2.2	: Matrix 9 rules table (Isa, Ibrahim, & Patkar, 2009)	28
Table 3.1	: Comparison between the Cyclo converter, LCI, and PWM VSI drives on dynamic performance and controllability (Rashid, 2001)	50
Table 3.2	: Principle of the hysteresis controller	53
Table 3.3	: Cable Constant per unit length	60
Table 3.4	: Cable parameters in differential mode when 10meter cable length was used (a) R_{Dif} (b) L_{Dif} (c) C_{Dif}	65
Table 3.5	: Cable parameters in common mode when 10 meter cable length was used. (a) G_{com} (b) C_{com}	65
Table 4.1	: Effects of increasing parameter K_p and K_i independently	70
Table 4.2	: Data of Fuzzy Logic Speed Controller	79

LIST OF FIGURES

FIGURES	TITLE	PAGE
Figure 2.1	: Rules editor from Fuzzy toolbox MATLAB	27
Figure 2.2	: Membership functions of 9 rules FL speed controller: (a) speed error; (b) change in speed error; (c) q-axis command current; (d) three dimensional control surface.	30
Figure 2.3	: Fuzzy logic speed controller	32
Figure 2.4	: Internal Structure of Fuzzy Logic Controller	33
Figure 3.1	: Research Methodology flow chart	37
Figure 3.2	: Stator and rotor winding magnetic axes, common rotor-fixed reference frame and current space vector.	38
Figure 3.3	: The electrical power conversion topology	48
Figure 3.4	: The basic structure of three-phase VSI	51
Figure 3.5	: Hysteresis current control scheme	53
Figure 3.6	: Hysteresis Current Control	54
Figure 3.7	: (a) Simulation result of phase current and (b) voltage for PI Speed controller	56
Figure 3.8	: PI Speed Controller based vector controlled SPMSM drive for long cable application	57
Figure 3.9	: Rotor flux oriented control scheme with PI speed controller and hysteresis current control (configuration used for simulation)	58
Figure 3.10	: Distributed parameter model per unit length for the long cable	59
Figure 3.11	: Cross section of the 4 conductor symmetric cable used in the experiment	60
Figure 3.12	: Simulation result of ringing frequency for Voltage line to line at terminal motor based on simulation model Figure 3.9 and Figure 3.10	62
Figure 3.13	: Parameter extracting method for 10 meter cable length	63
Figure 3.14	: Cable parameters in differential mode when the 10 meter cable length was used (a) R_{Dif} (b) L_{Dif} (c) C_{Dif}	64
Figure 3.15	: Cable parameters in common mode when the 10 meter cable length was used. (a) G_{com} (b) C_{com}	65
Figure 3.16	: Extraction of per-unit-length constants for the lossy long cable simulation	66
Figure 4.1	: Initial speed response for RFOC with PI Controller (a) Rated Speed 418rad/s (b) Rated load 3.6Nm applied and (c) Step command reduce 10%	71
Figure 4.2	: Comparison of speed responses obtained for different cable lengths during start-up (a) 100% rated speed 418rad/s (b) 50% of rate speed (c) 25% of rate speed (d) Rise time versus Cable length at rated speed (418rad/s)	73

Figure 4.3 : Comparison of speed responses to step rated load torque application obtained for different cable lengths: (a) at rated 418rad/s (b) at 50% of rate speed (c) at 25% of rate speed (d) Load disturbance recovery time versus cable length at rated torque	75
Figure 4.4 : FFT frequency comparison between standard cable (2 meter) and long cable (100 meter) for phase 'A' stator current	76
Figure 4.5 : THD of 3 phase stator voltage and current versus cable length based on PI speed controller	77
Figure 4.6 : Comparison of speed responses for increased 20% of rated inertia for different cable length (a) at rated speed 418rad/s (b) at rate torque	79
Figure 4.7 : Simulink model of Fuzzy logic speed controller with scaling factors and limiter	81
Figure 4.8 : Initial speed response for RFOC with F.L Controller (a) Rated Speed 418rad/s (b) Rated load 3.6Nm applied and (c) Step command reduce 10%	82
Figure 4.9 : Comparison between PI speed controller and Fuzzy logic controller to step speed command and rated load applied for standard length cable.	84
Figure 4.10 : Comparison between PI and Fuzzy logic speed controller to step speed command for 100 and 200 meter cable length at different step speed command	86
Figure 4.11 : Comparison between PI and Fuzzy logic speed controller at rated torque applied for 100 and 200 meter cable length at step load command applied	87
Figure 5.1 : Motor Speed Control System Block Diagram	90
Figure 5.2 : Experimental rig	91
Figure 5.3 : RTI board library for the DS1103	92
Figure 5.4 : Calibration speed of RDC	96
Figure 5.5 : Output signal from resolver	96
Figure 5.6 : Hall Current Sensor calibration on 3 phase current (Phase A, B and C)	98
Figure 5.7 : Hall Current Sensor calibration setup	99
Figure 5.8 : Hardware configuration	100
Figure 5.9 : High Voltage Differential Probe calibration	101
Figure 5.10 : Fluke Power Quality Analyzer meter calibration circuit.	103
Figure 5.11 : Fluke 435 power Quality Analyser meter calibration hardware setup	104
Figure 5.12 : Setup of the Power Quality Analyzer meter	104
Figure 5.13 : Results of current measurement by Power Quality Analyzer meter	105
Figure 5.14 : Rotor flux oriented control scheme with PI speed controller and hysteresis current control (Simulink/Matlab Configuration used for experimental)	108
Figure 5.15 : Experimental setup of PI Speed Controller	109
Figure 5.16 : Experimental setup of Fuzzy logic speed controller with scaling factor and limiter	110
Figure 5.17 : Experimental setup of membership functions of 9 rules FL speed controller: (a) speed error; (b) change in speed error; (c) q-axis command current; (d)three dimensional control surface.	111
Figure 5.18 : Reference speed profile used for whole experimental for PI and FL speed controller	113
Figure 5.19 : Experimental responses at 500rpm for standard cable length a) speed at 500rpm b) reference stator q-axis currents c) Actual stator phase 'a' current	113

Figure 5.20 : Experimental results of Phase Voltage and current for PI and FL speed controllers	115
Figure 5.21 : Experimental responses comparison between 2 meter, 36 meter and 100 meter cable length at 500rpm with PI speed controller a) speed at 500rpm b) reference stator q-axis currents c) Actual stator phase ‘a’ current	116
Figure 5.22 : Experimental responses comparison between 2 meter, 36 meter and 100 meter cable length at step down 20% speed command with PI speed controller a) speed at 500rpm b) reference stator q-axis currents c) Actual stator phase ‘a’ current	117
Figure 5.23 : Experimental responses comparison between 2 meter, 36 meter and 100 meter cable length at step load torque applied with PI speed controller a) sudden load torque 7.36Nm is applied b) reference stator q-axis currents c) Actual stator phase ‘a’ current	118
Figure 5.24 : Experimental responses comparison between PI and FL speed controller for 36 meter and 100 meter cable length at step speed command from standstill (a) and (b) speed at 500rpm (c) and (d) reference stator q-axis currents (e) and (f) Actual stator phase ‘a’ current	121
Figure 5.25 : Experimental responses comparison between PI and FL speed controller on different cable length at speed command step down by 20% (a) and (b) speed at 400rpm (c) and (d) reference stator q-axis currents on (e) and (f) Actual stator phase ‘a’ current	122
Figure 5.26 : Experimental responses comparison between PI and FL speed controller on different cable length at step load torque applied (a) and (b) sudden load torque 7.36Nm is applied (c) and (d) reference stator q-axis currents (e) and (f) Actual stator phase ‘a’ current	124
Figure 5.27 : Experimental results for V_{L-L} at motor terminal based with PI speed controller.	127
Figure 5.28 : Experimental results for V_{L-L} at motor terminal based on FL speed controller.	128
Figure 5.29 : Overvoltage at motor terminal comparison between PI and FL speed controllers for 2 meter, 36 meter and 100 meter cable lengths.	128
Figure 5.30 : THD current stator of PI speed controller versus FL speed controller for different cable length application.	130
Figure 5.31 : THD current stator of 0.1 versus 0.5 hysteresis band.	131

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Motor Data	158
B	Simulink Model in Simulation	160
C	Simulation Model in Experimental	166
D	Hardware Configuration	169
E	THD M-File Formula	172
F	Publications	173

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