



UNIVERSITI PUTRA MALAYSIA

**SENSORLESS ADAPTIVE FUZZY LOGIC CONTROL OF PERMANENT
MAGNET SYNCHRONOUS MOTOR**

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MAGNET SYNCHRONOUS MOTOR**

By

MUTASIM IBRAHIM HAFZ NOUR

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

November 2007



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

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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

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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 cecap dengan anggaran sifar ralat pada kelajuan lingkungan tinggi, untuk menggantikan pengesanan 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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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.

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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.

MUTASIM IBRAHIM HAFZ NOUR

Date: 14 January 2008



TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	vi
ACKNOWLEDGEMENTS	ix
APPROVAL	xi
DECLARATION	xiii
LIST OF TABLES	xvii
LIST OF FIGURES	xviii
LIST OF ABBREVIATIONS	xxvi
CHAPTER	
1 INTRODUCTION	1.1
1.1 Background and Problem Statement	1.1
1.2 Aims and Objectives	1.6
1.3 Contribution	1.7
1.4 Overview of the Project and its Scope	1.8
1.5 Thesis Layout	1.10
2 LITERATURE REVIEW	2.1
2.1 Introduction	2.1
2.2 Speed Control of High Performance PMSM Drives	2.1
2.3 Fuzzy Logic Control	2.5
2.4 Why Use Fuzzy Logic	2.6
2.5 Hybrid Intelligent Systems	2.8
2.6 Adaptive Neuro Fuzzy Inference System (ANFIS)	2.9
2.7 Rotor Position Estimation	2.14
2.7.1 Back EMF Based Rotor Position Estimation	2.14
2.7.2 Signal Injection Based Rotor Position Estimation	2.15
2.8 Review of Related Work	2.18
2.9 Summary	2.24
3 THE ADAPTIVE FUZZY LOGIC SPEED CONTROLLER	3.1
3.1 Introduction	3.1
3.2 Modelling of Permanent Magnet Synchronous Machine	3.2
3.2.1 Space Vectors	3.3
3.2.2 Motor Equations in Stationary Reference Frame	3.6
3.2.3 Rotating Reference Frame	3.8
3.2.4 Equations of the Electromagnetic Torque	3.12
3.3 Vector Control Principle of PMSM	3.14
3.4 Design of the Speed FLC	3.19
3.4.1 Fuzzification and Fuzzy set Definitions	3.21
3.4.2 Knowledge Fuzzy Rule Base	3.29
3.4.3 Rule Evaluations and Implication	3.31
3.4.4 Aggregation of the Output Fuzzy Sets	3.32



3.4.5	Defuzzifications	3.32
3.5	Optimisation of the FLC	3.33
3.6	Fuzzy PD and PI Controllers	3.35
3.7	Hybrid Model Reference Adaptive Speed Controller	3.37
3.7.1	The Reference Model	3.39
3.7.2	The Adaptation Mechanism	3.41
3.8	Design and Optimisation of FLC Using Training Data	3.42
3.8.1	Modelling of Adaptive Fuzzy Logic System	3.44
3.8.2	Training Data	3.45
3.8.3	Structure of Adaptive Fuzzy Inference System	3.49
3.8.4	The Learning Algorithms	3.52
3.8.5	Construction and Tuning of the Adaptive FLC	3.58
3.9	On Line Adaptive FLC	3.60
3.10	PI Controllers Design	3.65
3.10.1	Current Controller Design	3.65
3.10.2	Speed Controller Design	3.70
3.11	Simulation Results	3.73
3.11.1	Step Change in Reference Speed Response for Rated and Increased Inertia at No Load Conditions	3.77
3.11.2	Step Change in Reference Speed at Full Load for Nominal and Increased Inertia	3.82
3.11.3	Step Change in Load at Constant Reference Speed	3.86
3.12	Summary	3.88
4	THE ESTIMATION OF ROTOR POSITION OF PMSM	4.1
4.1	Introduction	4.1
4.2	Signal Injection Based Rotor Position Estimation	4.2
4.2.1	Position Estimation Scheme	4.3
4.2.2	PI Controller Design and Tuning	4.10
4.2.3	Simulation Results	4.12
4.2.4	Discussion of the Simulation Results	4.19
4.2.5	Effect of the High Frequency Signal Injection	4.20
4.3	Back EMF Based Rotor Position Estimation	4.22
4.3.1	Parameters Sensitivity in Rotor Position Estimation	4.25
4.3.2	Tuning of the Stator Resistance	4.27
4.3.3	Phase Voltages Estimation	4.30
4.3.4	Simulation Results	4.33
4.4	Summary	4.40
5	REAL TIME PRACTICAL IMPLEMENTATION	5.1
5.1	Introduction	5.1
5.2	Experimental Setup Overview	5.3
5.3	Software Overview	5.8
5.4	TMSM320LF2407 DSP Controller Overview	5.12
5.4.1	PWM Waveforms Generation	5.13
5.4.2	Currents measurements	5.19
5.5	PI Controllers	5.21
5.6	Coordinates Transformations	5.26
5.7	Fuzzy Logic Speed Controller	5.27



5.8	Rotor Position Estimation	5.34
5.8.1	Signal Injection Based Algorithm	5.34
5.8.2	Back EMF Based Algorithm	5.36
5.9	DMC Developer PRO	5.38
5.10	Summary	5.40
6	EXPERIMENTAL RESULTS AND DISCUSSION	6.1
6.1	Speed Response	6.1
6.1.1	Response at No Load and Increased Inertia	6.2
6.1.2	Response at Load and Increased Inertia	6.8
6.1.3	Load Rejection Transient at Constant Reference Speed	6.12
6.2	Rotor Position Estimation using Signal Injection Algorithm	6.18
6.3	Rotor Position Estimation using Indirect Back EMF Algorithm	6.22
6.4	Discussion of Results	6.29
6.5	Summary	6.34
7	CONCLUSION AND FUTURE RESEARCH	7.1
7.1	Conclusion	7.1
7.2	Suggestions for Future Research	7.5
	REFERENCES	R.1
	APPENDICES	A.1
	BIODATA OF THE AUTHOR	B.1
	LIST OF PUBLICATIONS	B.2



LIST OF TABLES

Table	Page
2.1 Comparison Between Expert System Control (ESC), Fuzzy Logic Control (FLC), Artificial Neural Network (ANN). The Terms used for Grading are: □ Bad, ■ Rather Bad, ○ Rather Good and ● Good [32].	2.8
3.1 Rule Base Matrix	3.31
3.2 Optimised 21 Rule Base Matrix	3.34
3.3 Variations in Operating Conditions Adopted to Generate the Training Data	3.48
3.4 Final Distribution of the Singleton Output Membership Functions	3.60
5.1 Calculation of $\sin\theta_r$ using the Sine Lookup Table	5.28



LIST OF FIGURES

Figure		Page
1.1	Project's Overview	1.9
2.1	Simplified Schematic of the ANFIS Training Process	2.11
2.2	ANFIS Structure for a Sugeno Fuzzy Inference System	2.12
2.3	A typical Sensorless Motor Drive with HF Voltage Signal Injection.	2.17
2.4	Frequency Spectrum of the High Frequency Current of PMSM	2.18
3.1	Cross Sectional View of PMSM.	3.3
3.2	Stator Current Space Vector and its Projection	3.5
3.3	Two Axes Transformation	3.9
3.4	The Equivalent Circuit of PMSM in the dq Rotating Reference Frame	3.12
3.5	Stator Voltage, Current, and Flux Vectors in the dq Rotating Reference Frame	3.17
3.6	Vector Control Phasor Diagram	3.17
3.7	Block Diagram of PMSM Vector Controlled Drive.	3.19
3.8	Block Diagram of (a) Speed PD like FLC for PMSM, (b) Speed PI like FLC for PMSM	3.21
3.9	Input Membership Function Distribution for Both E and CE using (a) Triangle MF, (b) Bell Shape MF, (c) Gaussian MF.	3.26
3.10	Output Membership Functions Distribution	3.26
3.11	Speed Response of the PI Like FLC for Different Types of Membership Functions	3.27
3.12	Reference Torque Command Currents (I_q^*) Response	3.28
13	Optimised Membership Function for the Change of Error	3.34



3.14	Speed Response Using 49 and 21 Rules	3.35
3.15	Speed Response of PI and PD Fuzzy Controllers for PMSM Drive	3.37
3.16	HMRASC PMSM Drive	3.38
3.17	Reference Model for PMSM	3.40
3.18	Simulink Reference Model of Vector Controlled PMSM	3.40
3.19	Speed Response of the PMSM Using HMRASC for Two Different Reference Model	3.41
3.20	The Vector Controlled Dynamic Model of PMSM Used to Generate the Training Data	3.46
3.21	Structure of Adaptive Fuzzy Inference System	3.51
3.22	Flowchart of the Learning Algorithm	3.54
3.23	Initial Distribution of the Membership Functions	3.59
3.24	Final Distribution of the Membership Functions	3.59
3.25	Block Diagram of On Line Adaptive FLC with the PMSM Drive	3.62
3.26	q-axis PI Current Controller Loop	3.67
3.27	Current Controller Loops with Feed-Forward Compensation	3.67
3.28	Simplified q-axis PI Current Controller Loop	3.68
3.29	Step Response for i_{sq} Current Loop	3.69
3.30	PI Speed Control Loop	3.70
3.31	Simplified PI Speed Control Loop	3.71
3.32	Simulink PI Controller Model	3.73
3.33	Simulink Model of the Adaptive FLC Vector Controlled PMSM Drive.	3.75
3.34	Adaptive FLC Shown in Figure 3.33	3.76
3.35	Speed and Torque Command Current Responses to 600 rad/s Step Speed Command from Standstill at No Load and Rated Inertia	3.78



3.36	Speed and Torque Command Current Responses to 600 rad/s Step Speed Command from Standstill at No Load and Increased Inertia	3.79
3.37	Speed and Torque Command Current Responses to 200 rad/s Step Speed Command from Standstill at No Load and Rated Inertia	3.79
3.38	Speed and Torque Command Current Responses to 200 rad/s Step Speed Command from Standstill at No Load and Increased Inertia	3.80
3.39	Speed and Torque Command Current Responses to 30 rad/s Step Speed Command from Standstill at No Load and Rated Inertia	3.80
3.40	Speed and Torque Command Current Responses to 30 rad/s Step Speed Command from Standstill at No Load and Increased Inertia	3.81
3.41	Speed and Torque Command Current Responses for ± 100 rad/s Repetitive Step Reference Speed at No Load and Increased Inertia	3.81
3.42	Speed Response and Torque Command Current for a 600 rad/s Step Reference Speed at Full Load and Rated Inertia	3.83
3.43	Speed Response and Torque Command Current for a 600 rad/s Step Reference Speed at Full Load and Increased Inertia	3.83
3.44	Speed Response and Torque Command Current for a 200 rad/s Step Reference Speed at Full Load and Rated Inertia	3.84
3.45	Speed Response and Torque Command Current for a 200 rad/s Step Reference Speed at Full Load and Increased Inertia	3.84
3.46	Speed Response and Torque Command Current for a 30 rad/s Step Reference Speed at Full Load and Rated Inertia	3.85
3.47	Speed Response and Torque Command Current for a 30 rad/s Step Reference Speed at Full Load and Increased Inertia	3.85
3.48	Speed Response and Torque Command Current for ± 100 rad/s Repetitive Step Reference Speed at Full Load and Increased Inertia	3.85
3.49	Speed and Torque Command Current Responses to Step Load Torque Applications at 600 rad/s Reference Speed	3.87
3.50	Speed and Torque Command Current Responses to Step Load Torque Applications at 200 rad/s Reference Speed	3.87



3.51	Speed and Torque Command Current Responses to Step Load Torque Applications at 30 rad/s Reference Speed	3.88
4.1	Estimated and Actual Rotating Reference Frame	4.3
4.2	Position Estimation Signal Processing Block Diagram	4.8
4.3	(a) PI Controller Block Diagram for Rotor Position Estimation, (b) PI Like FLC Block Diagram for Rotor Position Estimation	4.9
4.4	Closed Loop Block Diagram for Tuning the PI Position Estimation Controller	4.11
4.5	Sensorless Vector Controlled PMSM Drive Based Signal Injection	4.11
4.6	Simulink Model of the High Frequency Signal Injection and the Current Controllers	4.12
4.7	Rotor Position Estimation at Reference Speed of 12.566 rad/s ($f = 2$ Hz)	4.14
4.8	Rotor Speed Estimation at Reference Speed of 12.566 rad/s ($f = 2$ Hz)	4.14
4.9	Rotor Speed Estimation at Reference Speed of 12.566 rad/s ($f = 2$ Hz)	4.15
4.10	Rotor Position Estimation at Reference Speed of 6.28 rad/s ($f = 1$ Hz)	4.16
4.11	Rotor Speed Estimation at Reference Speed of 6.28 rad/s ($f = 1$ Hz)	4.17
4.12	Motor Currents at Reference Speed of 6.28 rad/s ($f = 1$ Hz)	4.17
4.13	Rotor Position Estimation at Reference Speed of 3.14 rad/s ($f = 0.5$ Hz), Full Load is Applied at $t=5$ s	4.18
4.14	Rotor Position Estimation at Reference Speed of 1.57 rad/s ($f = 0.25$ Hz), Full Load is Applied at $t=10$ s	4.18
4.15	Rotor Position Estimation at Reference Speed of 0.785 rad/s ($f = 0.125$ Hz), Full Load is Applied at $t=10$ s	4.19
4.16	Stator Current without Signal Injection and its Corresponding THD	4.21



4.17	Stator Current with Signal Injection and its Corresponding THD	4.22
4.18	Implementation of Rotor Position Estimation Algorithm in Simulink	4.25
4.19	Stator Resistance Estimation Scheme	4.28
4.20	Simulink Model of the Stator Resistance Estimation Algorithm Integrated to the Vector Controlled PMSM Drive	4.29
4.21	Estimation of the Stator Resistance	4.30
4.22	Three Phase VSI Driving a Three Phase PMSM Load	4.32
4.23	Equivalent Circuit of the VSI Connected to the Stator of the PMSM	4.33
4.24	Rotor Position Estimation at 60 Hz (377 rad/s) Reference Speed. Full Load Torque ($T_L=0.8$ Nm) is Applied at $t=0.1$ s	4.35
4.25	Rotor Speed Estimation at 60Hz (377 rad/s) Reference Speed. Full Load Torque ($T_L=0.8$ Nm) is Applied at $t=0.1$ s	4.36
4.26	Three Phase Stator Current at 60 Hz (377 rad/s) Reference Speed. Full Load Torque ($T_L=0.8$ Nm) is Applied at $t=0.1$ s	4.36
4.27	Rotor Position Estimation at 30 Hz (188.5 rad/s) Reference Speed. Full Load Torque ($T_L=0.8$ Nm) is Applied at $t=0.1$ s	4.37
4.28	Rotor Position Estimation at 10 Hz (62.83 rad/s) Reference Speed. Full Load Torque ($T_L=0.8$ Nm) is Applied at $t=0.25$ s	4.37
4.29	Rotor Position Estimation at 2 Hz (12.566 rad/s) Reference Speed. Full Load Torque ($T_L=0.8$ Nm) is Applied at $t=1.5$ s	4.38
4.30	Rotor Position Estimation Error at 10 Hz (62.83 rad/s) Reference Speed. Full Load Torque ($T_L=0.8$ Nm) is Applied at $t=0.25$ s	4.38
4.31	Rotor Position Estimation Error at 5 Hz (31.4 rad/s) Reference Speed. Full Load Torque ($T_L=0.8$ Nm) is Applied at $t=0.5$ s	4.39
4.32	Rotor Position Estimation Error at 2 Hz (12.566 rad/s) Reference Speed. Full Load Torque ($T_L=0.8$ Nm) is Applied at $t=1.5$ s	4.39
5.1	The Block Diagram of the MCK2407 and PM50 Boards	5.5
5.2	The Block Diagram of the IMDM15 Board	5.6



5.3	50 W PMSM Hardware Experimental Set-up	5.7
5.4	380 W PMSM Hardware Experimental Set-up	5.7
5.5	General Software Flowchart	5.9
5.6	The Flowchart of the Interrupt Functions	5.10
5.7	Computation of Compare Values for PWM Generation from Reference Voltage (Phase a).	5.14
5.8	Representation of One Leg of the VSI	5.15
5.9	Sinusoidal PWM Reference Signals and Phase to Mid Point Voltages	5.17
5.10	Waveforms of Three Phase PWM Line Voltage	5.18
5.11	Waveforms of Three Phase PWM Phase Voltage	5.18
5.12	Block Diagram of the Current Measurements Interface	5.20
5.13	Block Diagram of the Discrete PI Controller	5.22
5.14	Digital PI Current Controller Loop	5.24
5.15	FLC Software Implementation Flowchart	5.29
5.16	Fuzzification Implementation of Triangle Membership Functions	5.30
5.17	C Code of Long Division of two Numbers	5.31
5.18	Project Files Window in the DMC Developer Environment	5.39
5.19	Output Menu of the Project in the DMC Developer PRO Environment	5.40
6.1	Speed and Torque Command Current Responses at 600 rad/s Step Reference Speed (50 W PMSM)	6.3
6.2	Speed and Torque Command Current responses at 200 rad/s Step Reference Speed (50 W PMSM)	6.3
6.3	Speed and Torque Command Current responses at 30 rad/s Step Reference Speed (50 W PMSM)	6.4
6.4	Speed and Torque Command Current Responses for ± 200 rad/s Repetitive Step Reference Speed at No Load and Increased	



	Inertia (50 W PMSM)	6.4
6.5	Speed and Torque Command Current Responses at 500 rad/s Step Reference Speed (380 W PMSM)	6.6
6.6	Speed and Torque Command Current Responses at 200 rad/s Step Reference Speed (380 W PMSM)	6.6
6.7	Speed and Torque Command Current Responses at 30 rad/s Step Reference Speed (380 W PMSM)	6.7
6.8	Speed and Torque Command Current Responses for ± 100 rad/s Repetitive Step Reference Speed at No Load and Increased Inertia (380 W PMSM)	6.7
6.9	Speed and Torque Command Current Responses at 600 rad/s Step Reference Speed at Load (70% Full Load) and Increased Inertia (50 W PMSM)	6.9
6.10	Three Phase Stator Current Response at 600 rad/s Step Reference Speed at Load and Increased Inertia (50 W PMSM)	6.9
6.11	Speed and Torque Command Current Responses at 200 rad/s Step Reference Speed at Load (70% Full Load) and Increased Inertia (50 W PMSM)	6.10
6.12	Three Phase Stator Current Response at 200 rad/s Step Reference Speed at Load and Increased Inertia (50 W PMSM)	6.10
6.13	Speed and Torque Command Current Responses at 30 rad/s Step Reference Speed at Load (40% Full Load) and Increased Inertia (50 W PMSM)	6.11
6.14	Speed and Torque Command Current Responses at 200 rad/s Step Reference Speed at Load and Increased Inertia (380 W PMSM)	6.11
6.15	Speed and Torque Command Current Responses at 30 rad/s Step Reference Speed at Load and Increased Inertia (380 W PMSM)	6.12
6.16	Speed Response to Step Load Torque Applications at 600 rad/s Reference Speed (50 W PMSM)	6.14
6.17	Current Response to Step Load Torque Applications at 600 rad/s Reference Speed (50 W PMSM)	6.14
6.18	Speed and Torque Command Current Responses to Step Load Torque Applications at 200 rad/s Reference Speed (50 W PMSM)	6.15
6.19	Speed and Torque Command Current Responses to Step Load	

