UNIVERSITI PUTRA MALAYSIA

SIMULATION OF THREE-PHASE INDUCTION MOTOR CONTROL USING FUZZY LOGIC CONTROLLER

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BY

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Chairman: **Associate Professor Ir. Norman Bin Mariun, Ph.D.**

Faculty: **Engineering**

A fuzzy logic controller has been developed and simulated on an indirect vector control of an induction motor (IVCIM) drive system. The objective of the indirect vector control is to convert the three-phase induction motor into a linear device where the torque and the flux in the motor can be controlled independently. The induction motor is fed by a current-controlled PWM inverter. The proposed fuzzy speed controller block in a vector controlled drive system observes the pattern of the speed loop error signal and correspondingly updates its output, so that the actual speed matches the command speed.

The design of the fuzzy controller starts with identifying the inputs, performing the membership functions for the two inputs of the FLC and ends at manipulating the final command signal to the current regulator which triggers the inverter.

The fuzzy logic toolbox has been used to build the fuzzy inference system (FIS) which is the dynamo of the fuzzy logic controller. The proposed FLC controller has been designed to meet the speed tracking requirements under a step change in speed and load changes.

The proposed FLC drive dynamic performance has been investigated and tested under different operating conditions by simulation in the Simulink/Matlab software environment. In order to prove the superiority of the FLC, a conventional PI controller based IM drive system has also been simulated.

The simulation results obtained have proved the very good performance and robustness of the proposed FLC. It is concluded that the proposed fuzzy logic controller has shown superior performances over the conventional PI controller.

Abstrak tesis yang dikemukakan kepada Senat Unjiversiti Putra Malaysia sebagai
memenuhi Sebahagian keperluan untuk ijazah Master Sains.

SIMULASI KENDALI TIGA FASA MOTOR IMBASAN DENGAN MENGGUNAKAN PEGAWAL LOGIK TIDAK JELAS

Oleh

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Februari 2004

Pengerusi: **Profesor Madya Ir. Norman Bin Mariun, Ph.D**

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Pengawal Samar Logik (Fuzzy Logic) telah dibina dan disimulasi ke atas suatu pengawal vector tidak langsung bagi sebuah system pemacu motor aruhan (IVCIM). Objektif pengawal vector tidak langsung ini adalah untuk menukar motor aruhan tiga fasa kepada peranti linear dimana tork dan fluks di dalam motor boleh dikawal secara bebas. Motor aruhan disuap oleh penyongsang arus terkawal PWM. Blok pengawal kelajuan samara telah dicadangkan di dalam system pemacu vector terkawal memperlihatkan corak signal kesalahan lengkungan kelajuan dan serta merta menukar outputnya, oleh itu kelajuan sebenar sama dengan kelajuan arahan.

Rekabentuk pengawal samara bermula dengan pengenalan input, melaksanakan fungsi keahlian untuk 2 input FLC dan berakhir dengan manipulasi signal arahan terakhir kepada pengatur arus yang memetik penyongsang.

Kotak peralatan logic samara telah digunakan untuk membina system pemikiran samar (FIS) yang juga digelar dinamo pengawal logic samar. Pengawal FLC yang

Rekabentuk pengawal samara bermula dengan pengenalan input, melaksanakan fungsi keahlian untuk 2 input FLC dan berakhir dengan manipulasi signal arahan terakhir kepada pengatur arus yang memetik penyongsang.

Kotak peralatan logic samara telah digunakan untuk membina system pemikiran samar (FIS) yang juga digelar dinamo pengawal logic samar. Pengawal FLC yang dicadangkan telah direka untuk memenuhi cirri-ciri pengenalpasti kelajuan di bawah perubahan kelajuan dan perubahan beban.

Prestasi FLC pemacu dinamik yang dicadangkan telah disiasat dan diuji di bawah keadaan-keadaan operasi yang berbeza menggunakan Software Simulink/Matlab. Dalam usaha untuk membuktikan kelebihan FLC, sistem pemacu IM berdasarakn pengawal PI biasa telah disimulasi.

Keputusan simulasi telah membuktikan prestasi yang sangat baik dan ketegapan FLC yang dicadangkan. Oleh itu, boleh dibuat kesimpulan bahawa pengawal logic samara yang dicadangkan telah menunjukkan prestasi cemerlang jika dibandingkan dengan pengawal PI biasa.

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TABLE OF CONTENTS

Page

DEDICATION
ABSTRACT ii
ABSTRAK iv
ACKNOWLEDGMENTS vi
APPROVAL vii
DECLARATION ix
LIST OF TABLES xii
LIST OF FIGURES xiii
ABBEVIATIONS/NOTATION/GLOSSARY OF TERMS xvi

CHAPTER

1 **INTRODUCTION** 1
- 1.1 Why Fuzzy Logic 3
- 1.2 Application of Fuzzy Logic 5
- 1.3 Research Objectives 5
- 1.4 Scope of Work 5
- 1.5 Thesis Layout 6

2 **LITERATURE REVIEW AND THEORITICAL BACKGROUND** 7
- 2.1 Literature Review on FLC Application in 3Φ Induction Motor 7
- 2.2 AC-Machine Motion Control Principle 12
- 2.3 Vector Control of 3-Phase AC Motors 13
  - 2.3.1 Induction Motor Dynamics and Control Structure 13
  - 2.3.2 Dynamic d-q Model 14
  - 2.3.3 Principle of Field Oriented Control (FOC) 18
- 2.4 Induction Motor Drives And Inverters 24
- 2.5 Fuzzy Logic Control (FLC) 26
  - 2.5.1 How Does FLC Different From Conventional Control? 27
  - 2.5.2 Fuzzy Logic Control Background 27
  - 2.5.3 Types of Fuzzy Controllers 28
  - 2.5.4 Principle of Fuzzy Logic Controller 29
  - 2.5.5 Fuzzy Inference System (FIS) 30
- 2.6 Fuzzy Logic And Control Principle in AC Motors 32

3 **METHODOLOGY** 39
- 3.1 Research Methodology And Design Procedure 40
- 3.2 Creating the Induction Motor Model Drive System 42
  - 3.2.1 Induction Motor Model (Electro-Mechanical Dynamics) 43
  - 3.2.2 Creating Vector Rotator Block 43
  - 3.2.3 Creating 2Φ to 3Φ Transformation Block 44
  - 3.2.4 Creating Slip Speed Block 45
  - 3.2.5 Unit Vector Generator 45
  - 3.2.6 Integrations of Blocks 46
- 3.3 Fuzzy Logic Controller Simulation Development Tools 51
  - 3.3.1 Modeling The Fuzzy Control of induction motor system 52

3.3.2 Fuzzy Controller Development for IFOC 54
3.3.3 Software Development and Matlab/Simulink Environment 60
3.4 Incorporating The FLC to The Drive Model 69
3.5 System Operation 72

4 **RESULTS AND DISCUSSION** 74
4.1 PI Controller Performance and Results 75
4.1.1 PI Controller Performance Under no-Load Condition 76
4.1.2 PI Controller Drive System Speed Tracking Performance 77
4.1.3 PI Controller Drive System With Variable Load Torque 79
4.1.4 PI Controller Performance With Load Disturbance 81
4.2 Fuzzy Logic Controller Performance And Results 82
4.2.1 Fuzzy Logic Controller I (FLC I) 84
4.2.2 Fuzzy Logic Controller II (FLC II) 86
4.2.3 Fuzzy Logic Controller Drive System Model 88
4.2.4 FLC Drive System Performance With no-Load Condition 89
4.2.5 FLC Drive System Speed Tracking Performance 90
4.2.6 FLC Drive System Performance W/ Variable Load Torque 92
4.2.7 FLC Drive System Performance With Load Disturbance 94
4.2.8 Minimum And Maximum Fuzzy Tool Rules 96
4.2.9 2-Loops FLC (Flux and Torque) for IVCIM 99
4.3 Results Comparison Between The PI And The FL Controllers 102
4.3.1 No-Load Condition Comparison 102
4.3.2 Speed Tracking Comparison 104
4.3.3 Variable Load Torque Performance Comparison 105
4.3.4 Stiff Load Torque Comparison 108

5 **CONCLUSIONS AND FUTURE WORK** 110
5.1 Conclusion 110
5.2 Future Work 111

REFRENCES R.1
APPENDICES A.1
BIODATA OF THE AUTHOR B.1

LIST OF TABLES

Table		Page
3.1	Rule matrix for fuzzy speed control	57

LIST OF FIGURES

FIGURE PAGE

2.1 Motor dynamic model (a) Coupling effect in three-phase stator and rotor windings of motor, (b) Equivalent two-phase machine 14

2.2 Dynamic $d^e - q^e$ model equivalent circuits of machine (a) q^e –axes circuit (b) d^e – axis circuit 16

2.3 Vector control principle a) Complex qds equivalent circuit in steady state b) Phasor diagram with i_{qs} and i_{ds} and peak values 19

2.4 Phasor diagram explaining indirect vector control 22

2.5 Typical inverter fed variable speed drive 24

2.6 A simplified diagram of a three-phase IGBT inverter 25

2.7 Input/Output mapping problem 29

2.8 Fuzzy logic controller main block diagram 32

2.9 Fuzzy speed controller in vector-controlled drive system 32

2.10 Single-rule fuzzy speed control principle 33

2.11 Two rule fuzzy control principle 35

2.12 Fuzzy inference system (FIS) 36

2.13 Structure of fuzzy control in feedback system 38

3.1 Induction motor in the simulink model 43

3.2 Vector rotator block and its subsystem 44

3.3 2-phase to 3-phase transformation (d-q to abc) 44

3.4 Slip frequency calculation block 45

3.5 Indirect vector control block diagram of induction motor drive with the slip calculation from the reference i_d^* and i_q^* 46

3.6 Simulink model of the PI control algorithm in the FOC of induction motor 50

3.7 Fuzzy control operation flow chart 51

3.8 General fuzzy controller in vector controlled induction motor drive system 52

3.9 Fuzzy speed controller in vector-controlled drive system under study 54

3.10 Membership functions for fuzzy speed control 56

3.11 The FIS editor for the field oriented control of IM 64

3.12 User interface for MF editor, input 1 membership functions 65

3.13 Rule editor using GUI 66

3.14 User interface for rule viewer for FLS 68

3.15 User interface to control surface viewer 69

3.16 Fuzzy controller block and it's under mask components 70

3.17 Indirect vector control based induction motor block diagram with fuzzy logic controller 71

4.1 The block diagram of indirect vector control of a variable frequency induction motor with PI speed controller 75

4.2 PI performance during simulation under no-load condition, a) Speed response b) Produced torque profile c) Stator currents profile 76

4.3 PI controller results during speed tracking simulation a) Speed response b) Produced torque profile c) Stator currents profile 78

4.4 PI controller performance when subjected to a sudden load Change a) Variable load torque b) Speed response c) Produced torque profile d) Stator currents profile 80

4.5 PI controller performance during stiff load torque profile, a) Speed response b) Stator currents profile 82

4.6 FLC.I (FIS) construction a) FLC block diagram b) Error MFS (input 1) c) Change of error MFs (input 2) d) Output MFs ΔT e) Rule editor f) Rule viewer g) Surface viewer 85

4.7 FLC.II (FIS) construction a) FIS block diagram b) Error MFS (input 1) c) Change of error MFs (input 2) d) Output MFs ΔT e) Rule editor f) Rule viewer g) Surface viewer 87

4.8 The fuzzy block with rule viewer used for the FLC 88

4.9 Simulink block diagram of the proposed fuzzy logic controller for IVCIM 88

4.10 FLC drive system results during no-load condition a) Speed response b) Torque profile c) Stator currents profile 89

4.11 FLC simulation results with speed tracking a) Reference speed signal & speed response of FLC b) FLC speed tracking performance c) Produced torque profile d) Stator currents profile 91

4.12 FLC controller results when subjected to a sudden load change a) Speed response with load change 50 Nm and 100 N.m b) Speed response) Produced torque profile c) Stator currents profile 94

4.13 FLC drive system results during load disturbance a) Speed response b) Produced torque profile c) Stator currents profile 96

4.14 FLC speed response results from a) 9 Rules FLC speed response and b) 49 Rules FLC speed response 97

4.15 FLC # I performance 98

4.16 FLC # II performance 98

4.17 Two loops fuzzy logic controllers (flux and torque) for IVCIM. 99

4.18 Two FLCs simulation results a) Speed response b) Produced torque profile c) Stator currents profile 100

4.19 2-Loops FLC and 1- loop FLC comparison 101

4.20 PIC and FLC performance comparison a) PI and FL speed response b) PI and FL produced torque c) PI and FL stator currents 103

4.21 PI and FL controllers results a) PI and FL speed tracking response b) PI and FL torque profile c) PI and FL stator currents 105

4.22 PI and FL controller results current response a) Speed response b) Produced torque profile c) Stator currents profile 107

4.23 PI and FL controllers results a) Speed response b) Produced torque profile c) Stator currents profile 109

LIST OF ABBREVIATIONS

Symbols	**Stands for**
ac	Alternating current
B_m	rotor damping coefficient
ce,	Change of error
CSI	Current source inverter
dc	Direct current
Defuzz	Defuzzification
d, q (subscript)	direct and quadrature axes for motor
e,	Error
e (subscript)	the quantity is referred to synchronously rotating reference frame.
FIS	Fuzzy inference system
FLC	Fuzzy logic controller
FL	Fuzzy logic
Fuzz	Fuzzification
FOC	Field oriented control
G1, G2, G3	Gains of error, gains of change of error and the output gain some times called K1, K2, K3
GTO	Gate turn off thyristors
i_s, v_s, ψ_s	stator current, voltage and flux vectors
i_r, v_r, ψ_r.	rotor current, voltage and flux vector
IFOC	Indirect field oriented control
IGBT	Insulated Gate Bipolar Transistor

IM	Induction Motor
IVCIM	indirect vector controlled induction motor
J	rotor inertia
L_m	magnetizing inductance
L_r	rotor self inductance
L_s	stator self inductance
MFs	Membership functions
P	the number of poles
PI	Proportional Integral
PID	Proportional integral differential
PWM	Pulse width modulation
3-phase	Three phase currents or voltages
R_r	Rotor resistance per phase
R_s	Stator resistance per phase
r (subscript)	The quantity is referred to the rotor reference frame.
s (subscript)	The quantity is referred to the stator reference frame.
T_e	Electromagnetic developed torque
T_L	Load torque
VSI	Voltage source inverter
ω_r	Rotor angular velocity (mechanical) in (rad/sec)
ω_{sl}	Slip angular velocity (rad/sec)
ωe	Synchronously rotating reference frame angular velocity = $\omega sl + \omega_r$

CHAPTER ONE

INTRODUCTION

Nowadays, AC motors, in particular squirrel cage induction type, are widely used in industry due to their simple and rugged structure. Moreover, they are economical and immune to heavy overloads. However the use of induction motors also has its disadvantages, mainly the controllability, due to its complex mathematical model and its nonlinear behavior during saturation effect. Induction motor (IM) require complex control algorithms, because there is no linear relationship between the stator current and either the torque or the flux. This means that it is difficult to control the speed or the torque. So the development of high performance motor drives to control such motor is very important in industrial applications [1].

High performance control and estimation techniques for induction motor drives are very fascinating and challenging subjects and recently many techniques have been developed for induction motor drives and hence very good control performances have been achieved. Generally, a high performance drive system must have good dynamic speed command tracking and load regulating responses, and the performances are insensitive to the drive and load parameter variations [1].

Among the existing techniques, the most commonly used is the proportional-integral (PI) controller. The PI controller is very easy to be implemented, but the PI controller cannot lead to good tracking and regulating performance simultaneously. Moreover, its control performances are sensitive to the system parameter variation and load disturbances. Recently, the modern controls, such as optimal control, variable structure system control, adaptive control, etc., have been applied to yield better performance. However, the desired drive specifications still cannot be perfectly satisfied by these methods.

In many motor control applications, direct control of torque is highly desirable as a system with a fast response to changes in torque is very beneficial. The field oriented control (FOC) or vector control theory is the base of a special control method for induction motor drives. With this control method, induction motors can successfully replace expensive dc motors.

The invention of vector or field-oriented control, and the demonstration that ac motor can be controlled like a separately excited dc motor, brought renaissance in the high performance control of induction motor drives. In fact, with vector control, induction motor drive outperforms the dc drive because of higher transient current capability, increased speed range and lower rotor inertia [2].

The most important aspect of the field-oriented control of induction motor is the transformation of the stator currents into a torque producing component (the quadrate q) and a flux-producing component (the direct path d). To enable the flux producing current component to align with the rotor magnetic flux, the accurate estimation of a transformation parameter called the unit vector is required. However, if this unit vector can be correctly determined, then the ac drive performance will depend on the effectiveness in producing the appropriate torque command. This control technique is very sophisticated in implementation using the conventional controllers [2].

Fuzzy control has emerged over the years to become one of the most active and fruitful areas of research in the application of fuzzy set theory. In recent years, fuzzy logic has been successfully applied in many control applications including the control of ac induction motors. Furthermore, fuzzy logic controller has been shown to be insensitive to external disturbance and small unknown or erroneous information.

A conventional PI controller requires accurate sensor inputs and appropriate values of the PI constants to produce high performance drive. Therefore the unexpected change in load conditions or environmental factors would deteriorate the drive performance. In contrast, fuzzy logic controllers use heuristic input-output relations to deal with vague and complex situations. The sensor input does not need to be very precise and theoretically it is more robust to fluctuations in operating conditions. Hence fuzzy controllers offer the benefits of low cost and higher reliability.

1.1. Why Fuzzy logic?

One of the main advantages of using fuzzy logic (FL) is to overcome the need for a precise mathematical model of the controlled system. Furthermore in this application the FL has many advantages include short development times, easy transfer to different motor sizes, and a strong tolerance for electrical motor parameter oscillations. FL offers several unique features that make it a particularly important and good choice for many control problems and here are the main features [1,2,4]:

- Fuzzy control can incorporate linguistic knowledge: In order to make a good controller, one should utilize prior knowledge and physical insight about the system.

If mathematical model is hard to get, then the most important information comes from the sensors, which provide the linguistic description of the system and the control instructions. Fuzzy controllers can systematically convert this linguistic knowledge into control action, whereas, conventional controllers fail short of that. If in some situations the most important information comes from human experts, then fuzzy control is the best choice.

- It is easy to understand because it emulates human control strategy. The numbers of practical engineers who understand these systems increases.
- It is simple to implement: Fuzzy logic systems, which are at the heart of fuzzy control, admit a high degree of parallel implementation. Many fuzzy VLSI chips have been developed to make the implementation of fuzzy controllers simple and fast.
- It is inexpensive to develop where cost is one of the most important criteria for a successful product. Furthermore there are software tools available for designing fuzzy controllers.
- It is inherently robust since it does not require precise, noise-free inputs and can be programmed to fail safely if a feedback sensor quits or is destroyed. The output control is a smooth control function despite a wide range of input variations.
- Fuzzy controllers are nonlinear controllers: FL can control nonlinear systems that would be difficult or impossible to model mathematically. This opens doors for control systems that would normally be deemed unfeasible for automation.

1.2. Applications of Fuzzy logic

Fuzzy logic has been widely applied in power electronics and systems. Applications include, speed control of dc and ac drives, feedback control of converter, off line PI and PID tuning, non-linearity compensation, on-line and off-line diagnostics, modeling, parameter estimation, performance optimization of drive systems based on on-line search, estimation for distorted waves, and many other variety of applications [1,4].

1.3. Research Objectives

The objective of this research work is to:

1. Investigate the implication of fuzzy logic controller in conjunction with the conventional control systems in the indirect field oriented control of a three-phase induction motor.
2. Develop a fuzzy logic controller that would be capable to improve the time response of the system understudy.
3. Prove the successful application of FLC in IM control by comparing the results obtained with the results of the respective conventional PI controller algorithms.

1.4. Scope of Work

A model representing the induction motor in the indirect field oriented (vector) control was built using the related equations using Simulink blocks in the Matlab software environment. This system was tested and its performance was proved first, using conventional PI speed controller. Then using fuzzy logic toolbox in the Matlab/Simulink environment a fuzzy logic controller suitable for the application understudy was built and embedded in the control system circuit of the above mentioned model instead of the PI model. The performance of the proposed FLC was compared with an established conventional PI controller. Furthermore a comparison with a very well known work was carried out.

1.5. Thesis layout

This thesis starts with Chapter One, which gives an introduction to the principals of this work, the reasons and motivation for it. It also discusses the objectives of this work.

Chapter Two discusses briefly the principle and the theory of ac motor control, in particular the indirect field oriented control (IFOC) of 3-phases induction motors, then with more details the fuzzy logic control theory, and in particular the fuzzy control of induction motor, and finally presents some of the literature review for papers, journal, and some works related to this application.

Chapter Three focuses on the methodology and the implementation of various control algorithms, in particular PI controllers and FLC for the AC induction motors.

Chapter Four presents the results and the discussion. Then a comparison between different control techniques is outlined.

Finally, Chapter Five consists of the conclusion from the implementation and some suggestions for future implementation.