UNIVERSITI PUTRA MALAYSIA

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

OMAR SAID ALGAYASH BENNANES.

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BY

OMAR SAID ALGAYASH BENNANES

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DEDICATION

To

Mufida, Hanin and Moad

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the partial requirements of the degree of Master of Science

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February 2004

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

OMAR SAID ALGAYASH BENNANES

Februari 2004

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

Fakulti: **Kejuruteraan**

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

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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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I certify that an Examination Committee met on 4th February 2004 to conduct the final examination of Omar Said Bennanes on his Master of Science thesis entitled "Simulation of Three-phase Induction Motor Control Using Fuzzy Logic Controller" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Ishak Bin Aris, Ph.D.
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Senan Mahmod Abdullah, Ph.D.
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Sudhanshu Shekhar Jamuar, Ph.D.
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Che Mat Hadzir Bin Mahmud, Ph.D.
Associate Professor
School of Electrical and Electronic Engineering
Universiti Sains Malaysia
(Member)

GULAM RUSUL RAHMAT ALI, Ph.D.
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 23 MAR 2004

This thesis submitted to the Senate Universiti Putra Malaysia, has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the supervisor committee are as follows:

Norman Bin Mariun Ph.D, PEng.
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Samsul Bahari Mohd. Noor, Ph.D.
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Jasronita Jasni M.S.c
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

AINI IDERIS, Ph.D
Professor/ Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 9 APR 2004

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 Universiti Putra Malaysia or other institutions.

OMAR SAID ALGAYASH BENNANES

Date 05 MAR 2004

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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.