CERTIFICATE

This is to certify that the thesis entitled "**Efficiency Optimization in Induction Motor Drives**" which is being submitted by **Mr. Rajinder** for the award of degree of **Doctor of Philosophy in Electrical Engineering**, Delhi Technological University, Delhi, is a record of student's own work carried out by him under our supervision and guidance. The matter embodied in this thesis has not been submitted in part or full to any other university or institute for award of any degree or diploma.

Dr. Mini Sreejeth
Associate Professor
Department of Electrical Engineering
Delhi Technological University
Delhi-110042, India

Prof. Madhusudan Singh
Professor
Department of Electrical Engineering
Delhi Technological University
Delhi-110042, India

ACKNOWLEDGEMENT

It has been a pleasure for me to work on this thesis. First and foremost, I would like to express my sense of gratitude and indebtedness to my supervisors Dr. Mini Sreejeth and Prof. Madhusudan Singh, Electrical Engineering Department, Delhi Technological University for their inspiring guidance, valuable suggestions, encouragement, untiring effort throughout the course of this work and help in providing necessary facilities and resources during the entire period of my research work. Their wide knowledge and logical way of thinking have helped me to complete my research work. They always made themselves available for me despite of their busy schedules and I consider it as a great opportunity to carry out my research work under their guidance and to learn from their research expertise.

I am indebted to my wife Mrs. Sunita Devi, daughters Riya Sharma and Yashvi Sharma for their unconditional support, patience throughout my study period. They encouraged me all the time, no matter what difficulties I encountered. I would like to express my deepest regards and gratitude to my parents for their unmitigated love. I would like to express my greatest admiration to all my family members and relatives for their positive encouragement that they showered on me throughout this research work. I extend my personal thanks to my friends and colleagues for their valuable support and reminding me to complete my work at the earliest. Sincere thanks to Delhi Technological University, Guru Nanak Dev Institute of Technology faculties and authorities for providing me necessary facilities for the smooth completion of my work.

Above all, I would like to thank The Almighty God, who has blessed me strength and support throughout my life and always provides me with a path to acquire knowledge and learning.

RAJINDER
(2K14/PhD/EE/09)

ABSTRACT

The induction motor is most widely used motor in industrial and domestic applications due to its high reliability and lower cost. The variable speed operation of the induction motor with the help of power electronics is the most common way of improving energy efficiency in electric drives. The energy efficient drives in modern processes results in high quality and cheaper products, lower production cost and energy saving and hence reducing of global pollution. Recent development in the area of digital signal processing and microprocessors has made the implementation of high performance IM drives cost effective and viable solution to adjustable speed applications in industries. The aim of the present thesis work is to deal with the advance control methods for variable speed induction motor drives with improved energy efficiency. This is achieved by optimal control of the flux producing current component using loss model and search control methods of the IM drive. The performance analysis of scalar control and vector controlled of induction motor drive is being studied. Modeling and simulation of volts-hertz (V/f) and indirect field oriented control (IFOC) have been carried out by using MATLAB/Simulink and full spectrum simulator (FSS). Full spectrum simulator provides both offline and real time simulation with hardware in loop (HIL) facility. Results obtained from both MATLAB and FSS offline simulator are compared with the FSS online simulator.

Sensitivity analysis of machine performance variables is carried out to predict the motor performance affected by parameter variations through mathematical and computational methods. To design robust drive many control techniques with online parameter estimation have been described. The model reference adaptive system based stator resistance and motor speed estimation methods in a sensorless induction motor drive is analyzed in detail. The MRAS based control is applicable for zero and low speed applications and found stable in all four quadrants of operations of drive. The stator resistance estimation adaptive mechanism utilizes adaptive neuro-fuzzy inference system (ANFIS) and the estimated stator resistance is used for making the rotor speed estimation system independent of stator resistance and makes the system robust against the temperature variation. The sensorless IM drive system with MRAS estimator shows robust feature concerned with parameter variation for stator resistance from its initial value during working condition of IM.

A simple and easily realizable loss model technique for implementation of a PI and fuzzy logic controller based efficiency optimization algorithm for a vector controlled induction motor drive is also presented. A new approach to optimize the efficiency based on optimal control of iron losses only is introduced and compared with the optimal control of the total losses under different operating conditions.

A novel algorithm of searching the flux current component for efficiency optimization of vector controlled induction motor drives through search control (SC) approach is also investigated and dynamic performance of the drive system is analyzed in detail. This new algorithm called “deep valley search algorithm” and can be considered as an alternative to the search control problems. This approach uses the optimal control of the flux producing current component for efficiency improvement by reducing the core losses and to minimize the measured dc-link power to the inverter at light load conditions.

TABLE OF CONTENTS

CHAPTER – I: INTRODUCTION

CHAPTER – II: LITERATURE REVIEW

CHAPTER – III: CONTROL OF INDUCTION MOTOR DRIVE USING FULL SPECTRUM SIMULATOR (FSS)

CHAPTER – IV: SENSITIVITY ANALYSIS OF INDUCTION MOTOR PERFORMANCE

CHAPTER – V: SPEED AND STATOR RESISTANCE ESTIMATION OF SPEED SENSORLESS IM DRIVE

CHAPTER – VI: EFFICIENCY OPTIMIZATION IN IFOC IM DRIVE BASED ON LOSS MODEL CONTROL

CHAPTER – VII: EFFICIENCY OPTIMIZATION IN IFOC IM DRIVE BASED ON SEARCH CONTROL

CHAPTER – VIII: MAIN CONCLUSIONS AND FUTURE SCOPE OF WORK

LIST OF ABBREVIATIONS

The principal abbreviations used in this thesis are listed below. Other abbreviations not defined in this list are defined locally.

AC	: Alternating Current
ANFIS	: Adaptive Neuro-Fuzzy Inference System
ANN	: Artificial Neural Network
CSI	: Current Source Inverter
DC	: Direct Current
DFOC	: Direct Field Oriented Control
DSP	: Digital Signal Processor
DTC	: Direct Torque Control
EKF	: Extended Kalman Filter
EMF	: Electro Motive Force
FIS	: Fuzzy Inference System
FLC	: Fuzzy Logic Controller
FOC	: Field Oriented Control
FSS	: Full Spectrum Simulator
GA	: Genetic Algorithm
IFOC	: Indirect Field Oriented Control
IGBT	: Insulated Gate Bipolar Transistor
IM	: Induction Motor
IMD	: Induction Motor Drive
LMC	: Loss Model Control
MF	: Membership Function
MRAS	: Model Reference Adaptive System

NN	: Neural Network
PC	: Personal Computer
PI	: Proportional Integral
PSO	: Particle Swarm Optimization
PWM	: Pulse Width Modulation
RPM	: Revolution Per Minute
SC	: Search Control
SEQUEL	: Solver for Circuit Equations with User Defined Element
SVM	: Space Vector Modulation
SVPWM	: Space Vector Pulse Width Modulation
VC	: Vector Control
VSD	: Variable Speed Drive
VSI	: Voltage Source Inverter

LIST OF SYMBOLS

The principal list of symbols used in this thesis is listed below. Other symbols not defined in this list are defined locally.

i_{ds} : Flux producing current component

i_{ds}^{*} : Reference flux producing current component

i_{qs} : Torque producing current component

i_{qs}^{*} : Reference torque producing current component

i_{dr} : *d* axes rotor current

i_{qr} : *q* axes rotor current

I_1 : Stator current

I_2 : Rotor current

k_e : Eddy current coefficient

k_h : Hysteresis coefficient

k_m : Mechanical loss coefficient

k_p : Proportional gain

k_i : Integral gain

L_m : Mutual inductance

L_{lr} : Rotor leakage inductance

L_{ls} : Stator leakage inductance

L_r : Rotor inductance

L_s : Stator inductance

P : No. of poles

P_{cu} : Copper losses

$\mathrm{P(n)}$: DC link power at instant n

$\Delta\mathrm{P(n)}$: Change of dc link power

$P_{mec\,h}$: Mechanical losses

P_{Fe} : Iron losses

P_{Total} : Motor total losses

R_2 : Rotor resistance referred to the stator

R_1 : Stator resistance

s : Slip

T_e : Electromagnetic torque

φ : Flux linkage.

φ_{ds} : *d* axes stator flux linkage

φ_{qs} : *q* axes stator flux linkage

φ_{dr} : *d* axes rotor flux linkage

φ_{qr} : *q* axes rotor flux linkage

v_{ds} : *d* axes stator voltage

v_{qs} : *q* axes stator voltage

v_{dr} : *d* axes rotor voltage

v_{qr} : *q* axes rotor voltage

ω : Angular speed of synchronously rotating reference frame

ω_r : Angular speed of the rotor

σ : Leakage coefficient

ω_{sl} : Slip frequency

V_o : Boost voltage

CL : Constant losses

P_{in} : Input power

P_{out} : Output power

Pg : Air gap power

pf : Power factor

I_m : Magnetizing current

I_1 : Stator current

I_{st} : Starting current

T_{st} : Starting torque

R_c : Core loss equivalent resistance

LIST OF FIGURES

LIST OF TABLES