

## **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.

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## 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.

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## 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
$P(n)$	: DC link power at instant $n$
$\Delta P(n)$	: Change of dc link power

$P_{mech}$	: 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
$\varphi$	: Flux linkage.
$\varphi_{ds}$	: $d$ axes stator flux linkage
$\varphi_{qs}$	: $q$ axes stator flux linkage
$\varphi_{dr}$	: $d$ axes rotor flux linkage
$\varphi_{qr}$	: $q$ 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
$\omega$	: Angular speed of synchronously rotating reference frame
$\omega_r$	: Angular speed of the rotor
$\sigma$	: Leakage coefficient
$\omega_{sl}$	: Slip frequency
$V_o$	: Boost voltage
CL	: Constant losses
$P_{in}$	: Input power
$P_{out}$	: Output power
$P_g$	: 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

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