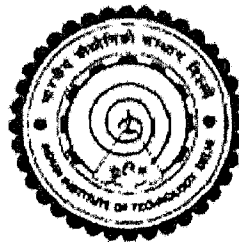


# **ANALYSIS AND DEVELOPMENT OF VECTOR CONTROL OF INDUCTION MOTOR DRIVE**

*by*

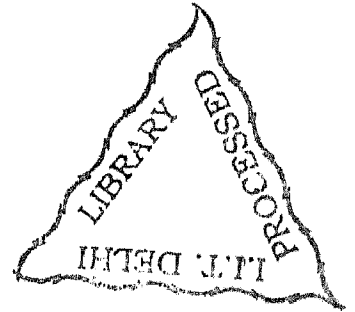
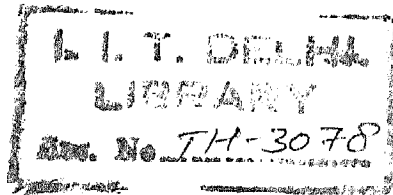
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Submitted  
in fulfilment of the requirements of the degree of Doctor of Philosophy  
to the



**Indian Institute of Technology, Delhi**  
**India**  
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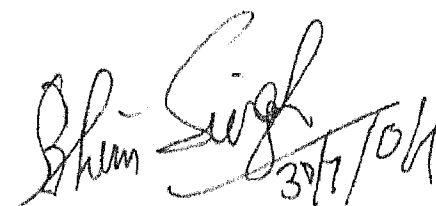
*Dedicated to*

*My Parents*

## CERTIFICATE

This is to certify that the thesis entitled, “**Analysis and Development of Vector Control of Induction Motor Drive,**” being submitted by **Mr. Sumit Ghatak Choudhuri** for the award of the degree of **Doctor of Philosophy** is a record of bonafide research work carried out by him in the Electrical Engineering Department of Indian Institute of Technology, Delhi.

Mr. Sumit Ghatak Choudhuri worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to my knowledge has reached the requisite standard. The results obtained here in have not been submitted in part or in full to any other University or Institute for the award of any degree.



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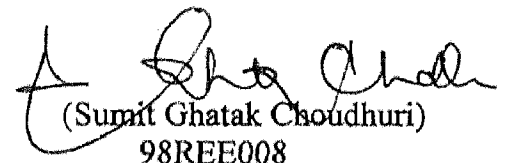
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(Sumit Ghatak Choudhuri)  
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## ABSTRACT

Ever since its development, the induction motor has been mainly used for constant speed applications. Three-phase squirrel cage induction motors have been widely preferred due to simplicity, robustness and maintenance free operation. However, for variable speed applications, preference is always given to dc motors. The main reason for using separately excited dc motor as a variable speed drive is the simplicity in control as the field and the armature currents are electrically decoupled from each other. However, the main problem with dc motors is the time to time maintenance of commutators, brushes and brushes holders. The rapid developments in power electronics and powerful digital signal processors (DSPs) have made the implementation of new control schemes possible to realise variable speed induction motor drives. Different control approaches such as scalar control, vector control, direct torque control etc. have used to realise adjustable speed drives through variable frequency control of squirrel cage induction motors.

In case of scalar control technique, the main disadvantage is the poor dynamic response of the induction motor drive. In case of vector control, the decoupled control of flux and torque makes its behaviour similar to a separately excited dc motor. However, the vector control technique can be further classified into direct vector control and indirect vector control differing in their method of implementation.

In the present investigation, the indirect vector control technique has been used with rotor flux orientation to realise variable speed induction motor drives. The voltage source inverter (VSI) is used to feed an induction motor in current control (CC) mode due to its merits over other variable frequency converters. The major contribution of this research work is on modelling, control, implementation, power quality improvement and sensor reduction in indirect vector control of induction motors.

A comprehensive mathematical modeling of vector controlled induction motor drive (VCIMD) system has been carried out to analyse and design the drive system. The dynamic response of the VCIMD under various operating conditions such as starting, speed reversal and load perturbation is simulated in MATLAB environment using simulink and power system blockset (PSB) toolboxes. The controller of the drive uses three feedback signals namely, currents in two of the motor phases ( $i_{as}$  and  $i_{bs}$ ) and the rotor speed ( $\omega_r$ ). The controller consists of the closed loop speed controller for generating the torque reference ( $T^*$ ), field weakening controller for providing the reference value of excitation current ( $i_{mr}^*$ ), the vector controller for generating two quadrature current signals for control of torque ( $i_{qs}^*$ ) and flux ( $i_{ds}^*$ ) and slip frequency ( $\omega_2^*$ ), the two-phase rotating to three-phase stationary converter to produce the three phase reference currents ( $i_{as}^*$ ,  $i_{bs}^*$  and  $i_{cs}^*$ ) and the sinusoidal pulse width modulated current controller which generates the gating signals for the solid state devices of the VSI.

The dynamic response of the VCIMD depends on the type of closed loop speed controller. In this work, the considered closed loop speed controllers are proportional integral (PI) speed controller, sliding mode (SM) speed controller, fuzzy logic (FL) speed controller, hybrid of PI and FL speed controllers and fuzzy pre-compensated proportional integral (FPPI) speed controller. A comparative study of response of the VCIMD is made of these speed controllers.

The real time implementation of VCIMD has been carried out in the laboratory environment on a 0.75kW, 415V, 1.75A, star connected, three-phase squirrel cage induction motor. The power circuit consists of three-phase, current controlled VSI feeding a three-phase squirrel cage induction motor. For implementation of the control algorithm, a dedicated digital signal processor (DSP) TMS320F240 is used to reduce system hardware to a great extent. The assembly language software of DSP facilitates the implementation of modern control techniques such as fuzzy logic based speed controllers.

Large current harmonics and poor power factor of ac mains are some of the common problems with variable frequency induction motor drives. In most cases, uncontrolled ac-dc converters are used leading to injection of harmonics into the ac mains. It also distorts the voltage at the point of common coupling (PCC) affecting other connected electrical loads. The present investigation also deals with power quality improvement employing some new topologies of ac-dc converters feeding VCIMDs. The proposed ac-dc converters feeding VCIMDs are classified into two major categories: (a) single phase ac-dc converters and (b) three-phase ac-dc converters. The single-phase ac-dc converters has been further classified into 1) single-phase uncontrolled converter with LC filter at the dc link, 2) single-phase improved power factor correction (IPFC) converter and 3) single phase voltage source converter (VSC). The three-phase ac-dc converters consists of 1) three-phase ac-dc converter with LC filter at the dc link, 2) three-phase ac-dc converter with LC filter at the dc link and with shunt passive filter at the PCC, 3) three-phase VSC, 4) twelve pulse ac-dc converter and 5) eighteen pulse ac-dc converter feeding VCIMD. A comparative study is also made of various ac-dc converters feeding VCIMDs on the basis of power quality indices. The obtained results of power quality indices demonstrate the enhanced performance of the improved power quality converters (IPQCs) over the conventional ac-dc uncontrolled converters feeding VCIMDs.

In the indirect vector control, the rotor flux vector position depends on the speed feedback signal and use of speed sensor causes an increase in the overall cost of the system. The estimation of speed signal is carried out using the sensed currents in two phases of the motor and the dc link voltage of the VSI. The elimination of the speed sensor results in further reduction of overall cost of the drive with improved performance of VCIMD.

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