CHAPTER 1

INTRODUCTION

Induction motor drives are the most widely used electric drive in various industries because of their low cost, ruggedness, good efficiency and low maintenance. In recent years their use in specialized applications such as machine tool operations, etc. are extensive as more advanced control schemes such as field oriented control and direct torque control are being used which can give better dynamic performance and reliability of operation (Ajit Kumar 2010). This has become possible because of the availability of fast and cost effective digital signal processors (DSP) for the real-time implementation of these computationally intensive schemes.

Online estimation of state variables such as speed, rotor flux and parameters such as stator and rotor resistances of an induction motor without using physical sensors are essential to these advanced control schemes and non-invasive fault detection methods. Use of a speed encoder for velocity control is generally considered undesirable. The reason is that a speed sensor increases the closed loop response time and gives rise to shaft mounting related problems. This leads to poor reliability of operation, besides increasing the overall cost (Bose 2006). Model based estimators for induction motors use measured machine terminal voltages and currents to estimate state variables and parameters (Barut 2010, Gherram et al 2010, Guzinski and Abu-Rub 2011).
Though several deterministic methods like model reference adaptive system and speed adaptive observers are available, they generally suffer from inaccuracy due to noise in measurements. Unlike deterministic methods, stochastic estimators are more preferred because of their inherent capability to handle noise in available measurements. Moreover obtaining accurate measurement of winding parameters like rotor resistance and mutual inductance are difficult. Hence, the actual machine parameters and that of the model will never be the same. Also, parameters such as stator and rotor resistances and inductances change under different operating conditions (Bolognani et al 2008) mainly due to temperature variation, magnetic saturation, and change in supply frequency. Such conditions make design and implementation of estimators for accurate and reliable state and parameter estimation a difficult task.

To the best of our knowledge most of the works reported in literature are confined to estimation of state and parameters of induction motors under normal operating conditions. Hence there is a need for testing the performance of these estimators under wide variety of operating conditions of induction motor. Keeping the above objective in view, this work focuses on design and implementation of different nonlinear Kalman filters and a Neural network assisted nonlinear state filter for state and parameter estimation, more specifically speed and rotor resistance estimation of a squirrel cage type three phase induction motor. Further a critical evaluation on the performance of these filters under various operating conditions and rotor bar fault condition was carried out.

1.1 REVIEW OF STATE AND PARAMETER ESTIMATION OF INDUCTION MOTOR

Dan Simon (2006) has given a detailed introduction to optimal filtering techniques for state and parameter estimation of nonlinear systems.
The most popular stochastic filter used for wide range of tracking problem till date, is the Kalman filter (Kalman 1960). Mohinder et al (2001) have given a comprehensive account on Kalman filters, their properties and their implementation for state filtering of nonlinear systems. In recent years model based speed estimation schemes for induction motor has created wide interest because of its application to speed sensorless induction motor control technique (Barut 2010).

Numerous techniques based on model based deterministic schemes such as model reference adaptive systems (Madadi 2005) and adaptive observers (Lascu et al 2006, Forchetti et al 2009) were reported in the literature. Orlowska and Dybkowski (2010) reported a MRAS based scheme for speed estimation of induction motor and the authors have shown its robustness experimentally. Salmasi et al (2010) have proposed an adaptive observer for concurrent estimation of rotor flux and dc link voltage and tested its performance on the voltage source inverter based induction motor drive. Forchetti et al (2009) has developed a Luenberger observer based adaptive scheme for rotor position estimation and the authors have used the estimates in their field oriented control (FOC) scheme. Sliding mode observer based state estimation schemes for sensorless speed control of an induction motor are also reported (Rao et al 2009 and Lascu et al 2009). Khalil et al (2009) has reported a speed and flux observer and reduced order model based feedback controller design for a three-phase induction motor. Hadj Said et al (2011) has proposed an observer based online rotor and stator resistance estimation scheme.

Extensive work has been reported in literature with reference to state estimation using stochastic filters, specifically Extended Kalman filters and their implementation for induction motors. EKF based sensorless speed estimation using both extended order form of state space model (Shi

The Unscented Kalman filter was first introduced by Julier and Uhlmann (1997) and further developed by Wan and Van der Merwe (2000) for the state estimation of nonlinear systems. Van der Merwe and Wan (2001) have developed a square root Unscented Kalman filter algorithm for nonlinear systems. Bilal et al (2006) points out the various limitation in implementing EKF for state estimation of highly nonlinear systems and discussed the sensorless speed estimation of induction motor using Unscented Kalman filter. Jie Li and Yanru Zhong (2005) have analysed the merit and demerits of EKF and UKF for the state estimation of the three-phase induction motor and also pointed out the difficulty in the implementation of UKF for induction motor applications, because of its computational complexity.


The detection of faults in a dynamic system can help to avoid severe damage where system reliability and safety are essential. Detection and monitoring of rotor bar breakage in squirrel cage induction motors has been a well studied problem. The widely studied and reported method (Jung et al 2006, Kumar et al 2009) is the motor current signature analysis (MCSA) in which certain side band frequencies of current spectrum are used to identify broken rotor bars. Recent studies by Kim and Seok (2010) have shown that the MCSA method generally suffers from load disturbance and speed variation. Neural network classifiers for stator current signature analysis are also reported in the literature (Arabaci and Bigin 2009, Moradian et al 2006) for broken rotor bar detection. Armaki and Roshanfekr (2010) suggested the use of support vector machine classifier to identify the different signatures in the stator current which are indicative of broken rotor bar in squirrel cage induction motor. Ahmed et al (2006) have shown that side band of instantaneous angular speed (IAS) spectrum can be used to identify the broken rotor bar faults.

Model based deterministic methods for broken rotor bar detection is also widely reported in literature (Rodriguez-Cortes et al 2004, Bachir et al 2006, Santos et al 2006). Filippetti et al (1992) proposed a multilevel knowledge base for rotor fault detection in which the authors have developed different rotor bar models including a simplified model. Successful application of Joint Extended Kalman filters for simultaneous state and parameter estimation applied to an induction motor have been reported in literature (Besancon 2001, Besancon and Ticlea 2003, Ticlea and Besancon 2006). Karami et al 2010 has discussed Joint UKF based simultaneous state and parameter estimation approach for detection and diagnosis of broken rotor
bars. Dual estimation of state and parameter of a nonlinear system was first explored by Wan and Nelson (1996) and has been gaining popularity in recent years for combined state and parameter estimation (Wan et al 2000, Gove and Hollinger 2006).

Many literatures are available (Peter Vas 1998, Krause et al 2002, Bose 2006) which discuss in detail the modeling and advanced control of induction motor drives.

1.2 OBJECTIVES OF THE RESEARCH WORK

The objectives of this research work are as follows

- To select a suitable state space model of a three-phase induction motor for the purpose of filter design and to carry out simulation studies.

- To develop algorithm for EKF, UKF, and NSF for state and parameter estimation using the chosen machine model.

- To implement EKF, UKF and NSF on the simulated machine model using MATLAB and to test their effectiveness under various simulated machine operating conditions.

- To analyze the results obtained from simulation studies and assess the relative performance of these filters.

- To verify the practical usability of the filters designed using the real time data collected from ac drive setup (ACS 800, ABB)
• To verify the agreement of results and conclusions drawn on the filters performance under simulation studies with that of real time data based results.

• To develop algorithms for JEKF, JUKF, DEKF and DUKF specifically for detection of broken rotor bars in three-phase squirrel cage induction motor.

• To implement JEKF, JUKF, DEKF and DUKF for the rotor bar fault detection on the simulated machine model.

• To test the efficacy of JEKF, JUKF, DEKF and DUKF for the rotor bar fault detection under load disturbance in simulated environment.

1.3 ORGANISATION OF THE THESIS

The work reported in this thesis is organized in 6 chapters. Introduction Chapter gives an overview on the necessity and methods of state and parameter estimation of a three phase induction motor. A comprehensive review on the model based nonlinear estimation schemes with specific application to induction motor is presented. Objectives of the research work carried out are also reported.

Chapter 2 explains the basics of various nonlinear state and parameter estimation schemes used in this work. The various steps to implement nonlinear Kalman filters are presented in this chapter.

Chapter 3 discusses briefly the structure, equivalent circuit representation and dynamic model of a three phase squirrel cage induction motor. The state space models used in various filters are also reported in this chapter.
Chapter 4 elaborates the design and implementation of EKF, UKF and NSF for speed estimation of a three-phase induction motor. Critical analyses of their performance for various machine operating conditions based on Monte Carlo simulation study are presented. The chapter also gives an overview of the experimental setup used in this work. Experimental data based offline validation of filter design and verification of simulation results are also presented in detail.

Chapter 5 describes briefly the modeling of induction motor rotor with broken rotor bars. Design and implementation under simulated environment of joint and dual nonlinear Kalman filters for detection of broken rotor bar under various fault condition are discussed. The results and analysis of Monte Carlo simulation studies are also presented.

Chapter 6 summarizes the research work carried out, its contribution and discusses the scope for further research in this direction.