CHAPTER I
INTRODUCTION

1.0 INTRODUCTION & LITERATURE REVIEW

Induction Motors are a critical component of many industrial process and are frequently integrated in commercially available equipment and industrial process. The operators of Electrical drives system are under continual pressure to reduce maintenance costs and prevent unscheduled downtimes, which result in lost production and financial income. Many operators now use on condition based maintenance strategies in parallel with conventional planned maintenance schemes. This has reduced unexpected failures, increased the time between planned shutdown for standard maintenance and reduced operational costs.

The operation of electrical machine in a unsafe condition can also be avoided. Since the incidence of unexpected failures is reduced the operator is able to exercise greater control in the prevention of incidents which may have environmentally damaging consequences. In hazardous installations this requires continuous online monitoring to prevent catastrophic failure.

During the past years there has been a substantial research into the creation of new condition monitoring techniques for induction motor drives. New methods have been developed which are now being used by the operators and research is continuing with the development of new and alternative online diagnostic techniques. However, it is still operator who have to make the selection of the most appropriate and effective monitoring system to suit their particular induction motor drive system. Due to the variety of diagnostic techniques now available this is not an easy task.

There are many published techniques and many commercially available tools to monitor induction motors to insure a high degree of reliability uptime which are reported in [1]. Inspite of these tools, many companies are still faced with unexpected system failure and reduced motor life time. Environmental, duty and installation issue may combine to accelerate motor failures far sooner that the designed motor life time. Critical induction motor applications are found in all industries and include all motor HP. It have been found that many of the commercial products to monitor induction motor are not cost effective when deployed on typical low to medium HP motors. Advances in sensors, algorithms and architectures should provide the necessary technologies for effective incipient failure detection.

In this context, a variety of sensors could be used to collect measurements from an induction motor for the purposes of failure monitoring. These sensors might measure stator voltages and current, air gap and external magnetic flux densities, rotor position and speed, output torque, internal and external temperature, case vibrations etc. In addition, a failure monitoring system could monitor variety of motor failures.

In general, online condition monitoring and diagnostics requires the sensing and analysis of signals that contain specific information, which is characteristics of the degradation process, problem, or fault to be detected. There are various factors that need to be considered when selecting the most appropriate monitoring technique for application in the industrial environment, these are

1) Sensor should be non invasive
2) Sensor and instrumentation system must be highly reliable
3) The diagnosis must be reliable
4) The severity of the problem should be quantified
5) Ideally, an estimation of remaining run life should be given

6) Ideally, a prediction of the fundamental cause of the problem/ fault should be provided via online information from sensors

Due to complexity of degradation mechanisms, problems and faults, it is extremely difficult and in most cases impossible to achieve all the above criteria. In many cases it is possible to achieve criteria 1 to 4. However, criteria 5 and 6 are extremely difficult to achieve due to the numerous variables that effect the determination of the causes of a problem.

It is not the aim to discuss in detail all the numerous failure mechanisms and their causes [4] in electrical machines since this has been adequately covered in number of previous reports and surveys such as the EPRI studies [2] and IEEE committee reports as in[3]. In the EPRI study [2], which focused on squirrel cage induction motors, the reported percentage failures by components for the samples was as follows

Bearing related: 41%
Stator Related: 37%
Rotor Related: 10%
Eccentricity and others: 12%

There can be significant variations on the above statistics, which will be unique to a particular group of induction motors operating in a specific installation and is due to the numerous causes of failures as reported in [1-2].

1. 1 BROKEN ROTOR BARS AND END RINGS IN SQUIRREL CAGE INDUCTION MOTORS

Failure surveys have reported that rotor winding problems in squirrel cage induction motors are considerably less frequent than stator winding failures [1-2]. With respect to detecting broken rotor barsin cage induction motors, signals such as airgap flux [6], axial flux[7], speed[8], torque[9-10], vibration[11] and current[12-13] have been reported.

G. B. Kliman, R. A. Koegl [6] have given the novel method to determine the presence of broken bars through theoritical analysis in induction motor. This detection is largely based on existing theories for the performance of induction motors with broken bars. The diagnosis from sensing only the current and its subsequent analysis is much more complex than it at first appears [14]. This is particularly true when a commercial diagnostic system has to cater for motors between a few kilowatts upto MWs of different designs, driving range of mechanical load. The accurate online prediction of slip, from only current analysis, to cope with such a range of induction motors drives operating at different load conditions is not a simple task. The accurate prediction of the slip is required for the diagnosis of the sidebands.

However Since Manufacturing asymmetries and misalignment may cause confusion at detect of broken bars, some of magnitude of these components are found even in healthy and hence this requires further processing to detect the fault. The user requires to have some degree of expertise in order to distinguish a normal operating condition from a potential failure mode. This is because of monitored spectral components can result from number of sources, including those related to normal operating conditions. This requirement is even more acute when analyzing the current spectrum of an induction motor since the multitude of harmonics exist due to both the design and construction of the motor and the variation in the load torque. Hence the effect of the load inertia, speed fluctuation also need to be studied for accurate detection of the fault. The actual load operating condition of the motor also needs to be taken into account for the prediction of the severity of broken rotor bars. For a given number of broken bars the magnitude of the side bands can change , if load is varied. This is not true for all motors since it is a function of the motor rating, design and load characteristics. Thus the intelligent diagnosis of the fault sidebands due to broken rotor bars is therefore required.

1.2 AIR GAP ECCENTRICITY

Various methods have been proposed for the online diagnosis of air gap Eccentricity in three phase induction motors. These include the monitoring and spectrum analysis of air gap flux[6], axial flux[7], stator core vibration[18] and current[19-20]. Of particular importance in the analysis is to take into account of the combined influence of static and dynamic eccentricity since both will always occur simultaneously in an electrical machine[23]. The changes in the signal (Current, flux or vibration) are a function of the interaction between static and dynamic eccentricity flux waves[24].

For reliable diagnosis, several sections of the current spectrum should be interpreted. This is required to establish whether the particular flux components will actually induce a voltage and current in the stator winding. Hence a compatibility analysis between the pole pairs of respective flux waves and harmonic pole pairs for the stator winding of the particular motor being monitored must be carried out[24]. A subsequent theoretical analysis was carried out to explain the experimental phenomenon [25] that proved due to modulation effects between static and dynamic eccentricity waves that flux components at frequencies given in [25] occurred with p±1 pole pairs. Hence these flux waves can induce currents in the stator windings.

However these components are also function of load and hence intelligent diagnosis is required to detect the presence of air gap eccentricity, so also for commercial equipment, it requires the threshold values of components to reliably detect the presence of air gap eccentricity.

1.3 BEARING DAMAGE

It is universally accepted that vibration monitoring and analysis can be highly successful at detecting mechanical problems in electrical drives. However the online current monitoring method can be used to detect problem related to bearing failures. There is evidence, via laboratory tests, that faults in roller element bearings causes change in current spectrum [26, 27]. Again these components are function of load and hence intelligent diagnosis is required to detect the bearing faults. However, there is a distinct lack of case histories of current monitoring being applied in industry to detect mechanical faults.

1.4 STATOR WINDING FAULTS

It is shown that the sensing and analysis of airgap flux or axial/ stray leakage flux can identify components indicative of shorted turns in stator windings [6-7, 28]. Studies carried out in laboratories have shown that axial flux monitoring can detect shorted turns, however, there is a still a distinct lack of industrial case histories to fully assess the reliability of the technique when applied to a wide range of LV induction motors of different designs and ratings.

It should be also be noted that to ensure high quality signals the axial flux coil should be inside the sensors. The use of air gap search coils is highly invasive and is not a practical option for machines already installed and it is not popular in new machines. Operators do not like the invasive transducers. Axial flux monitoring via a search coil around the shaft can be used to identify the shorted turns, although it is less invasive than airgap search coil, it is still invasive to the motor's environment.

Since the fact the CT is a non invasive, the same signal can be analysed to diagnose stator winding faults in LV Induction motors. *Frederict C* at [30] and Andreas Stavrou, Howard G. Sedding [29] have shown that certain current components can be identified that are functions of shorted turns in stator coils. However these components are not visible in all types of configuration of Induction motors. So also the variation of these components is not same in different configuration of Induction motors.

1.5 MOTIVATION

Owing to large nos of induction motors used in power plants, process plants and utilities, there is need of an online condition monitoring system. The sensor of this system should be non invasive and diagnostic must be reliable. This can be achieved by motor current signature analysis. However this technique is still in R & D stage and as such no commercial system is available to perform the online condition monitoring of motors through motor current signature analysis.

Various researcher have attempted to detect different types of faults through motor current signature analysis[1 to 39]. However each researcher has attempted single fault detection through motor current signature analysis. However in actual system any type of fault can occur in the Induction Motor. Hence diagnostic system should be able distinguish between each type of fault.

Even though researcher have attempted to detect each fault individually through Motor Current Signature Analysis, however this still needs to be refined for problems such Source abnormalities, effect of Load inertia and speed fluctuations, different configuration of motors etc.

In a view of above, there is lot of potential to develop motor current signature analysis for online condition monitoring of motors. This motivated the author to develop this technique so that it can be readily applied for online condition monitoring of motors and develop a commercial system based on motor current signature analysis for online condition monitoring of motors.

1.6 OBJECTIVE & SCOPE OF THESIS

The application and advantages of online current monitoring i.e current signature analysis have been brought out. It proves whorthwile if this techniques are applied for the fault detection within induction motors. However this requires the proper modeling and instrumentation to detect the various faults within induction motors.

The major objective of this thesis work is

1) To study the various types of techniques available for online detection of the different types of faults within induction motor and to develop defined procedure for carrying out current signature analysis.

2) To develop the single instrumentation for recording of voltage and current and detection of all types of faults within induction motor.

3) To develop the suitable software for detection of different faults.

4) Laboratory simulation of faults.

5) Field Trials at Nuclear Power Station (KAPS).

The above objective were met by modeling the different faults, carrying out detailed experimentation and then development of algorithms, Hardware and Software. The system was validated with the laboratory and Field Trials. The brief description of the chapters included in the thesis are given below.

1.7 THESIS ORGANIZATION

Chapter II deals with detail about the concepts of condition monitoring and Online techniques available for the condition monitoring of motors, such as Vibration analysis, Flux Monitoring, Motor current signature analysis, Induced voltage in stator. It also introduces the concept of Motor Current Signature Analysis.

Chapter III deals with detail about the various faults within the Induction Motors & their causes. It also describes the modeling of various faults such as Rotor faults, Bearing faults, Eccentricity faults and Stator Electrical faults. This chapter also gives details about the diagnostic techniques developed to detect the individual fault.

Chapter IV deals with detail about the algorithm developed based on the fault detection technique developed in above chapter and how it can be implemented for online condition monitoring of Induction motors.

Chapter V describes the process of hardware development required to detect the fault online. It also describes the different hardware components used to detect the fault online.

Chapter VI describes the process of Software development. It also describes the different modules developed for the fault detection.

Chapter VII gives the details of the laboratory trials conducted to simulate the different faults in the laboratory and detecting them through the system developed. It also gives the Field trials carried out to validate the system performance in field.

Chapter VIII gives the conclusion derived in the whole study. This chapter discuss in details about the various findings of this theisis

Chapter IX gives the list of References refered for whole development and thesis.

Appendix A gives the details of analysis carried out on different motors at various sites to validate the system.

Annexure I gives the list of publication in various National and International Conferences.

1.8 CONCLUSION

Online Condition Monitoring and diagnostic of motors can be achieved using Motor curent signature analysis and can be effectively applied for early detection of

- broken rotor bars,
- air gap eccentricity ,
- bearing degradation and
- Stator windings faults.
- Misalignment

Based on the literature survey the various techniques were studied and examined. The detailed experimentation was carried out to formulate the fault detection algorithm for each individual fault. The instrumentation based on requirements of the fault detection algorithm was developed succesfully alongwith the software. The instrumentation alongwith the software was able to detect all above faults when simulated in the laboratory. The instrumentation was also subjected to field trials at different units. The instrument was able to perform satisfactorily under different operating condition in the different units. It succesfully detected the misalignment which seems to be major problem in indian conditions. This instrument also detected the torque pulsation observed in various application of motors through VFD in bearing manufacturing plants. Hence giving indication that it can effectively differentiate the operating conditions and possible fault. This instrument has also detected the rotor fault in one of the motors of thermal power plant, showing the capability of instrument to detect effectively the faults at site.