International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 3, Volume 2 (March 2015) www.ijirae.com

Condition Monitoring of Slip-ring Induction Motor

Dipti Agrawal[1]
[1]PG-Student,
Electrical Engg. Department,
HJD-ITER, Kera-Kutch

Mr.Naresh Yadav[2]
[2]PG-Student,
Electrical Engg. Department,
HJD-ITER, Kera-Kutch

Mr.Suresh Saini[3]
[3]PG-Student,
Electrical Engg. Department,
HJD-ITER, Kera-Kutch

HJD-Institute of Technical Education and Research, Kera- Kutch-370430 (India)

Abstract-** Condition monitoring of Slip-ring induction motor have been a challenging task for the engineers and researchers mainly in industries n organizations. There are many condition monitoring methods, including visual monitoring, vibration monitoring, thermal monitoring, chemical monitoring, acoustic emission monitoring but all these monitoring methods require expensive sensors or specialized tools whereas current monitoring out of all does not require additional sensors and analyzers. Current monitoring techniques are usually applied to detect the various types of Slip ring induction motor faults (Mechanical and Electrical) such as Rotor fault, short winding fault, air gap eccentricity fault, bearing fault, load fault etc.If any fault and failures occurs in the induction motor in any time can lead to excessive downtimes and causes a great losses in terms of revenue and mantainance.Therefore,condition monitoring for early fault detection of the motor is needed for the protection of the motor. It is indeed evident that this area is vast in scope. In the present paper, a very comprehensive survey of different types of induction motor faults and the signatures they generate and their diagnosis techniques and also different Artificial Intelligence techniques has been discussed.

Keywords-** Artificial intelligence techniques for fault diagnosis, Condition monitoring, Fault detection and diagnosis, Induction motor,.

I. INTRODUCTION

The studies of induction motor behavior during abnormal conditions due to presence of faults and the possibility to diagnose these abnormal conditions have been challenging topic for many electrical machine researchers. There are many condition monitoring methods including vibration monitoring, thermal monitoring, chemical monitoring, acoustic emission monitoring but all these monitoring methods require expensive sensors or specialized tools where as current monitoring out of all does not require additional sensors. This is because the basic electrical quantities associated with electromechanical plants such as current and voltage are readily measured by tapping into the existing voltage and current transformers that are always installed as part of the protection system. As a result, current monitoring is non-intrusive and may even be implemented in the motor control center remotely from the motors being monitored. [11,13]. In the research work, signal

Processing techniques are used for condition monitoring and fault detection of induction motors. The signal processing techniques have advantages that these are not computationally expensive, and these are simple to implement. Therefore, fault detection based on the signal processing techniques is suitable for an automated on-line condition monitoring system [7]. Signal processing techniques usually analyze and compare the magnitude of the fault frequency components, where the magnitude tends to increase as the severity of the fault increase. Therefore, the various signal processing techniques are used in present work for detection of common faults of induction motor. Signal processing techniques have their limitations. For example, the reliability of detecting the rotor fault using Fast Fourier Transform (FFT) depends on loading conditions and severity of fault. If the loading condition is too low or the fault is not too severe, Fast Fourier Transform may fail to identify the fault. Therefore, different techniques such as Wavelet Transform (WT) are investigated in the research work to find better features for detecting common faults under different loading conditions.

In order to perform accurate and reliable analysis on induction motors, the installation of the motors and measurement of their signal need to be reliable. Therefore, the first aim of this thesis is to design an experimental procedure and an experimental set up that can accurately repeat the measurements of signals and can introduce a particular fault to the motor in isolation of other faults. Stator current contains unique fault frequency components that can be used for detection of various faults of motor. The methods proposed in this research work allow continuous real time tracking of faults in induction motors operating under continuous stationary and non stationary conditions. Therefore, second aim of this research work is to investigate how the presence of common faults, such as rotor bar fault, short winding fault, air gap eccentricity, bearing fault, load fault, affect on different fault frequencies under different load conditions .

In this research work, condition monitoring and fault detection of induction motors is based on the signal processing techniques. The signal processing techniques have advantages that these are not computationally expensive and these are simple to

International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 3, Volume 2 (March 2015) www.ijirae.com

implement. Therefore, fault detection based on the signal processing techniques is suitable for an automated on-line condition monitoring system. Signal processing techniques usually analyze and compare the magnitude of the fault frequency components, where the magnitude tends to increase as the severity of the fault increase. Therefore, the third aim of this thesis is to utilize the various signal processing techniques for detection of common faults of induction motor.

Signal processing techniques have their limitations. For example, some faults could be not diagnosed using Fast Fourier Transform, if the loading condition is too low or the fault is not too severe. Therefore, the final aim of this thesis is to investigate new features using different techniques such as Wavelet Transform (WT), to find better features for detecting common faults under different loading conditions.

It is possible to give vital diagnostic information to equipment operator before it catastrophically fails. The problem with this approach is that the results require constant human interpretation. To automate the diagnostic process, recently a number of soft computing techniques have been proposed. The use of soft computing techniques increases the precision and accuracy of the monitoring systems.

II. COMMON SLIP-RING INDUCTION MOTOR FAULTS

There are various faults in induction motors. This section describes different faults. The different faults classifications are based on the internal and external type of major faults occurring in the machine. The internal faults are placed under mechanical fault and electrical fault categories. While the external fault placed under electrical, mechanical and environmental fault.

A. Stator Faults

a. Stator faults resulting in the opening, shorting and grounding of one or more stator phase winding.
b. Rotor faults caused by the broken rotor bar or cracked rotor end rings.
c Mechanical failure due to bearing failure and air gap eccentricities.
d. External faults due to incorrect connection of stator and utility supply.

These faults produce mechanical vibration, unbalanced air gap voltages and line current, increased torque pulsation, decreased average torque, increased losses, reduction in efficiency and cause excessive heating.

Deterioration of winding insulation can lead to inter turn with very large circular currents; if left undetected, phase-phase or phase ground fault can occur leading to a catastrophic failure. Ground current flow leads to irreversible damage to the core due to excessive heating. Almost 25%-30% of all reported induction motor failure fall under this category. The asymmetry arising from turn faults in winding results in a negative and zero sequence (ground) components in the line current. However negative sequence current also caused by voltage unbalance, machine saturation etc.

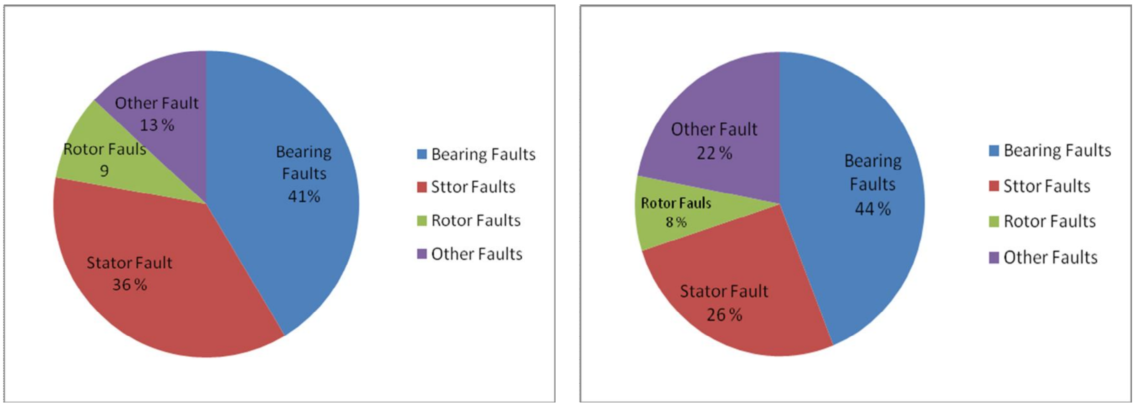


Fig 2.1 Percentage (%) of component of Induction Motor failure(IEEE &EPRI) [1]

B. Rotor faults

Rotor faults account for about 10% of total induction machine failures. The normal failure mechanism is a breakage or cracking of the rotor bars where they join the end-rings which can be due to thermal or mechanical cycling of the rotor during operation [14]. This type of fault creates the well-known twice slip frequency sidebands in the current spectrum around the supply frequency signal. The Main causes of the rotor faults are discussed below.

- Thermal stresses due to thermal overloaded and unbalance, hot spot or excessive losses rotor sparking (mainly fabricated rotor).
- Magnetic stresses caused by electromagnetic field, unbalance magnetic pull, electromagnetic noise and vibration.

- Residual stresses due to manufacturing problems.
- Dynamic stresses arise from shaft torque, centrifugal forces and cyclic stresses.
- Environmental stresses caused by contamination and abrasion.
- Mechanical stresses due to loose lamination, fatigued parts, bearing failure etc.

C. Bearing faults

The majority of electrical machines use ball or rolling element bearings and these are one of the most common causes of failure. These bearings consist of an inner and outer ring with a set of balls or rolling elements placed in raceways rotating inside these rings. Faults in the inner raceway, outer raceway or rolling elements produce unique frequency components in the measured machine vibration and other sensor signals. These bearing fault frequencies are function of the bearing geometry and the running speed. Bearing faults can also cause rotor eccentricity. A common cause for rolling element bearing failure is flaking, which occurs due to localized fatigue and results in the contamination of the lubricant oil with metal fragments. Other internal causes for bearing faults are vibration, inherent eccentricity and bearing current due to solid state drives. External causes are contamination and corrosion, improper lubricant and improper installation. About 40% of faults are bearing related.

Table 2.1 Percentage of failure by component

Field Components	**Percentage of Failure %(Approx)**	
	IEEE-IAS	EPRI
Bearing Related	44	41
Winding Related	26	36
Rotor Related	08	09
Others	22	13

III. CONDITION MONITORING AND NEED OF CONDITION MONITORING

Condition monitoring of Induction motor is the continuous assessment of performance and health of the machine throughout its useful operating life and diagnosing fault at their very inception. By condition monitoring, we simply mean that monitoring the overall parameters of the induction motor when it is running on its full load capacity through the effective measurement techniques so that the motor‘s life and its efficiency increases. In condition monitoring there are two major components one is the detection of fault through some effective and comprehensive techniques and the second one is the steps to reduce that effect which is lowering the efficiency of the induction motor, since we can‘t eliminate the existing error to the 100% extent [14,15].

A. Condition monitoring has great significance in the business environment due to the following reasons

- Increased machine availability and reliability
- Improved operating efficiency
- Improved risk management (less downtime)
- Reduced maintenance costs (better planning)
- Reduced spare parts inventories
- Improved safety
- Improved knowledge of the machine condition (safe short-term overloading of machine possible
- Extended operational life of the machine
- Improved customer relations (less planned/unplanned downtime)
- Elimination of chronic failures (root cause analysis and redesign)
- Reduction of post overhaul failures due to improperly performed maintenance or reassembly.
- It uses certain signal processing techniques to detect the faults related to different parameters which provides us a detail analysis of problem.
- The CM is a non invasive technique of measurement, i.e. the measurement is made outside the induction motor (the internal body measurement is not required).
- The Condition Monitoring (CM) is useful for the areas such as offshore oil industry, petrochemical industry, gas terminal and oil refineries where the induction motor is frequently installed in large no.

IV. CONDITION MONITORING OF INDUCTION MOTOR

It is required to detect, identify and then classify different kinds of failure modes that can occur within a machine system. Often several different kinds of sensors are employed at different positions to acquire vital signals from machine. These signals are 37 analyzed and features are extracted in order to gain information of different faults of the machine and ultimately the health of the machine [16].

V. CONDITION MONITORING TECHNIQUES

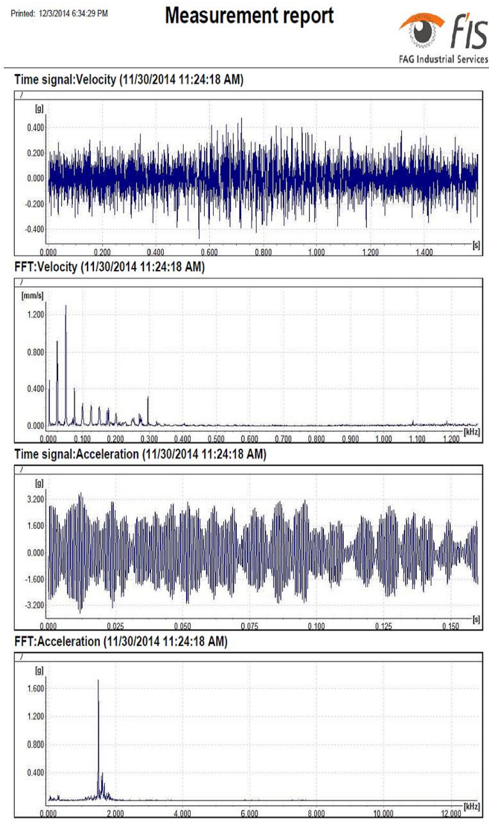
Most commonly used techniques are described below:

International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 3, Volume 2 (March 2015) www.ijirae.com

(A)Visual monitoring:-
This method ranges from a simple visual inspection by the unaided eye, through to the use of bore scopes for better access, microscopes to increase magnification, and closed circuit television cameras.

(B) Thermal Monitoring:-
Thermal monitoring can, in general, be used as an indirect method to detect some stator faults (turn-to-turn faults) and bearing faults. In a turn-to-turn fault, the temperature rises in the region of the fault, but this might be too slow to detect the incipient fault before it progresses into a more severe phase-to-phase or phase-to-neutral fault. In the case of detecting bearing faults, the increased bearing wear increases the friction and the temperature in that region of the machine. This increase in temperature of motor can be a detected by thermal monitoring.

(C) Vibration Monitoring:-
Vibration monitoring technique is widely used to detect mechanical faults such as bearing failures or mechanical imbalance.A piezo-electric transducer providing a voltage signal proportional to acceleration is often used.



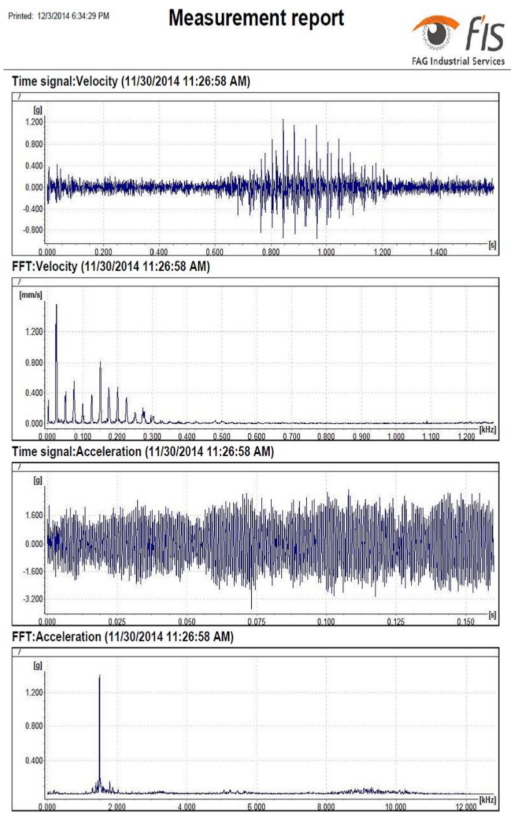


Fig. 5.1 Vibration Signal Analyzer on Drive End Side Fig. 5.2 Vibration Signal Analyzer on Non-Drive End Side

(D) By Using Thermographs instrument

- Modern thermal imaging cameras contain computers to directly indicate the temperature of the surfaces, as well as to provide the ability to compare past images with the present image, enabling changes in the thermal image to be easily detected.

VI. SIGNAL PROCESSING TECHNIQUES

There are several signal processing techniques which are very useful for fault diagnosis purpose. These are classified below [15,30,31]:

1. Frequency domain Fast Fourier Transform (FFT)
2. Time-Frequency techniques Short Time Fourier Transform (STFT)
3. Wavelet Transform (WT)

International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 3, Volume 2 (March 2015) www.ijirae.com

A. AI TECQNIQUES

1) ARTIFICIAL INTELLEGENCE TECHNIQUES-[1-2,8-10]

Artificial neural networks (ANNs), fuzzy, or neuro-fuzzy systems are now used extensively for speed, torque estimation, and solid-state drive control of both dc and ac machines. They are particularly suited for ac machines' applications where the relationships between motor current and speed are nonlinear. These AI techniques are now being extended as a decision making tool to MCSA results for condition monitoring and fault detection of machines [3,4]. A neural net-based fault diagnosis system utilizing the stator current spectra is described in Fig. 7.4. The preprocessor extracts the frequency components of the sampled current data. Using the rule-based frequency filters, these frequency components are classified into four categories with a decreasing level of importance. Based on these rules, a neural network, which has been trained for all possible operating conditions of the machine, is used to classify the incoming data. A spectral signature that falls outside the trained clusters is marked as a potential motor fault. In order to prevent false diagnosis, the postprocessor sends an alarm only when fault signatures are observed persistently. This function is performed by maintaining a time history of the motor being monitored. Such a scheme has been successfully implemented [4] to diagnose bearing and unbalanced rotor faults of induction motors. References [9] and [10] describe a neural-network-based fault prediction scheme that does not require any machine parameter or speed information. Speed is estimated from measured terminal voltage and current. Induction machines of different power ratings can be accommodated using minimal tuning of the neural network. Detection effectiveness of 93% or more is achieved.

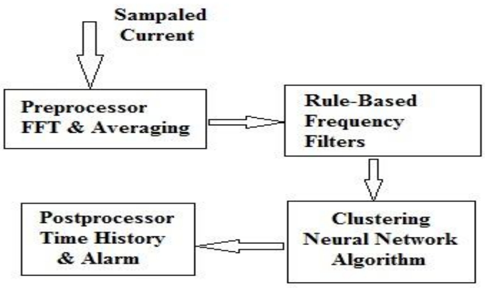


Fig. 6.1 ANN-based Fault Diagnosis

2) FUZZY LOGIC-

This involves making decisions based on classifying signals into a series of bands(fuzzy values) rather than simply as healthy or faulty based on a single threshold. For instance, based on the broken bar side band amplitude, a motor could be classified as healthy, marginal or faulty. Fuzzy logic allows combining fuzzy information from different signals together to make a more accurate judgment regarding the health of the motor [32,33].

fuzzy-logic-based systems have been used [9] to classify broken-bar-related faults by categorizing the two sideband components (6) around the fundamental of the induction motor line current by a set of nine rules. Denoting the sidebands as A1 and A2, which are the two inputs of the system, and n the number of broken bars as the output of the system, an example of these rules is " If A1 is small and A2 is large n, equals one broken bar." The fuzzy logic system considered is the Mamdani type. The fuzzy inference is obtained by using the fuzzy implication min–max methods and the centroid defuzzification technique. The membership functions for A1and A2 are small, medium, and large. Other examples of motor fault detection using neural networks and fuzzy-logic techniques can be found in [32,33].

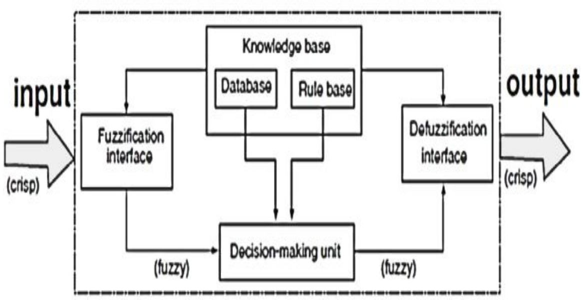


Fig.6.2 Fuzzy logic block diagram

3) EXPERT SYSTEMS - [1]

Expert systems seek to represent the knowledge of a human expert by defining a series of rules from which conclusions can be drawn. An example of a rule could be: if the broken bar side bands are greater than -45dB and the Park's current vector is a circular then it is likely that a broken bar fault is present.

C. LEAKAGE CURRENT ANALYSIS- THROUGH BEARING -[12]

What causes bearing damage?

Causes of bearing damage, for the most part, can be broadly classified within three categories:
(a) Lubrication
(b) Mechanical
(c) Electric Discharge Machining (EDM) or Bearing Currents

It is important to seek to identify the specific cause of failure in order to not repeat the failure, often within a short period of time. Bearing current failures, for example can occur in as short a time as one week after installation. Others, such as insufficient grease, can take several years to develop into a problem.
Further breaking down the leading causes of failure helps to identify the root cause and provide a guide for corrective action. Table 7.2 lists the primary causes of failure and evidence supporting the assumptions. Shaft currents are the fastest growing cause of bearing failure today, because of the rapid deployment of adjustable speed drives in industry, air conditioning and ventilating systems, plastic extruders, etc. Its root causes will be presented and analyzed to provide guidance for prevention of recurrence. Service centers play an important role in helping their customers identify and fix causes of premature motor failure. It helps to know the history of failures or repairs, but which are sometimes just not available or the piece of equipment transferred from one site to another.

VII. CONCLUSION

By applying the data collected through different Condition Monitoring Techniques preferably Vibration and Temperature Monitoring to the different Fault Detection Techniques such as MCSA &AI ,we can find out the Faults of the slip ring Induction Motor before it will be existed in the Motor.

- Once we find out the Faults before it will be existed in the Motor, we can rectify or can take precautions. so we can reduces the Motor failure and also increases the availability,reliability,performance of the Motor.
- In different Fault Detection Techniques we observe that in the AI Techniques using the FUZZY LOGIC we find out more accurate result about uncertainty or vagueness in the motor well functioning parameters than other Techniques, because through FUZZY LOGIC more flexible sense of membership is possible.
- FUZZY LOGIC also allows combining fuzzy information from different signals together to make a more accurate judgment regarding the health of the motor.

REFERENCES:

[1] Khadim Moin Siddiqui, Kuldeep Sahay, V.K.Giri, 'A survey of Health Monitoring and Fault Diagnosis in Induction Motor', ISSN (Print): 2320 – 3765 ISSN (Online): 2278 – 8875 Vol. 3, Issue 1, January 2014.
[2] Partha Sarathee Bhowmik, Sourav Pradhan and Mangal Prakash 'A survey of Fault Diagnostic And Monitoring Methods Of Induction Motor', International Journal of Applied Control, Electrical and Electronics Engineering (IJACEEE) Volume 1, Number 1, May 2013.
[3] Neelam Mehala, Ratna Dahiya.'Condition monitoring methods, failure and analysis for Induction machines' International Journal of Circuits, Systems and Signal Processing.
[4] Sulekha Shukla, Manoj Jha, M. F. Qureshi, 'Motor Current Signature Analysis for Fault Diagnosis and Condition Monitoring of Induction Motors using Interval Type-2 Fuzzy logic' ISSN 2348 – 7968, IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 1 Issue 5, July 2014.
[5] K. K. Pandey,P.H.Zope, S.R.Sarulkar,'Review on Fault Diagnosis in Three-Phase Induction Motor', Proceedings published by International Journal of Computer Applications® (IJCA), MEDHA – 2012.
[6] Ehsan Tarkesh Esfahani, Member, IEEE, Shaocheng Wang and Sundararajan V, 'Multi-Sensor Wireless System For Eccentricity And Bearing Fault Detection In Induction Motors' IEEE /ASME Transactions On Mechatronics, VOL. X, NO.X'.
[7] M.E.H. Benbouzid, 'Bibliography on Induction Motors Faults Detection and Diagnosis' IEEE Transactions on Energy Conversion, Vol. 14, No. 4, December 1999.
[8] MO-yuen Chow, Sui Oi Yee, 'Methodology For On-Line Incipient Fault Detection In Single-Phase Squirrel-Cage Induction Motors Using Artificial Neural Networks, IEEE Transactions on Energy Conversion, Vol. 6, No. 3, September 1991.

[9] Subhasis Nandi, Hamid A. Toliyat, Xiaodong Li, 'Condition Monitoring and Fault Diagnosis of Electrical Motors—A Review' Ieee Transactions On Energy Conversion, Vol. 20, No. 4, December 2005.
[10]G.K. Singh a, Sa'ad Ahmed Saleh Al Kazzaz b, 'Induction machine drive condition monitoring and diagnostic research a survey' Electric Power Systems Research 64 (2003) 145_/158.
[11]P.J. Tavner 'Review of condition monitoring of rotating electrical machines' Published in IET Electric Power Applications Received on 23rd June 2007, doi: 10.1049/iet-epa:20070280.
[12]Har Prashad, Review of Diagnosis and Cause Analysis of Rolling Element Bearing Failure in Electrical Power Equipment due to Current Passage.Paper at ASME/STLE Tribology Conference in Torento, Onario Canada,on April12,1998.
[13]Peter Vas, "Parameter estimation, condition monitoring, and diagnosis of electrical machines", Clarendon Press Oxford., 1993.
[14]Jeevanand S, Bhim Singh, B K Panigrahi and Vaibhav Negi, "State of Art on Condition Monitoring of Induction Motors",IEEE 2010.
[15]Xiaoli Li, Shiu Kit Tso, and Jun Wang,"Real-Time Tool Condition Monitoring Using Wavelet Transforms and Fuzzy Techniques", IEEE Transactions On Systems,Man, And Cybernetics—Part C: Applications And Reviews, vol. 30, no. 3, August 2000.
[16]Frederick C. Trutt, Joseph Sottile and Jeffery L. Kohler, "Online Condition Monitoring of Induction Motors", IEEE Transaction On Industry Applications Transactions, vol. 38, no. 6, Nov-Dec 2002 pp.1627-1632.
[17]Xin Xue, V. Sundararajan, Luis Gonzalez-Argueta , "Sensor Fusion for Machine Condition Monitoring" , Asme International Mechanical Engineering Congress And Exposition Imece November 11-15, 2007, Seattle, Washington, USA.
[18]Alberto Bellini, Fiorenzo Filippetti, Carla Tassoni and Gérard-André Capolino, "Advances in Diagnostic Techniques for Induction Machines", IEEE Transactions On Industrial Electronics, vol. 55, no. 12December 2008 , pp. 4109-4126 .
[19]P. H. Mellor, D. Roberts, and D. R. Turner, "Lumped parameter thermal model for electrical machines of TEFC design," IEEE Pro. Electric Power Application, Vol. 138, pp. 205-218, 1991.
[20]O.I.Okoro, "Steady and transient states thermal analysis of a 7.5-kW squirrel cage induction machine at rated-load operation", IEEE Transactions on Energy Conversion, Vol. 20, No. 4, pp. 730-736, December, 2005.
[21]Z. Gao, T. G. Habetler, and R. G. Harley, "An online adaptive stator winding temperature estimator based on a hybrid thermal model for induction machines," in Conf. Rec. IEEE IEMDC'05, pp. 754-761, San Antonio, Texas, USA, May, 2005.
[22]J.F.Moreno, F. P. Hidalgo, and M. D. Martinez, "Realization of tests to determine the parameters of the thermal model of an induction machine," IEEE Proc. Electric Power Application, Vol. 148, No. 5, pp.393-397, September, 2001.
[23]P. Milanfar and J. H. Lang, "Monitoring the thermal condition of permanent-magnet Synchronous motors," IEEE Transactions on Aerospace and Electronic Systems, vol.l. 32, No. 4, pp. 1421-1429, October, 1996.
[24]Dorrell, D. G. and Smith, A. C, "Calculation and measurements of unbalance magnetic pull in cage induction motors with eccentric rotors, part 2: experimental investigation", IEEE Proceedings Electric Power Applications, Vol. 143, No. 3, May, pp. 202-210, 1996.
[25]Belahcen, A., Arkkio, A., Klinge, P., Linjama, J.,Voutilainen and V., Westerlund, J., 1999, "Radial forces calculation in a synchronous generator for noise analysis", Proceeding of the Third Chinese International Conference on.
[26]Electrical Machines, Xi'an, China, pp. 199-122, August 1999. [26] Li, B., chow, M. Y., Tipsuwan and Y., Hung, J. C., "Neural-Network-Based Motor Rolling Bearing Fault Diagnosis", IEEE Transactions on Industrial Electronics, Vol. 47, No. 5, October, pp. 1060-1069, 2000.
[27]L. B., and Nandi, A. K., "Genetic algorithm for feature selection in machine Condition monitoring with vibration signals", IEE Proceedings Vision, Image and Signal Processing, Vol. 147, June, pp. 205-212, 2000.
[28]Dorrell, D. G., Thomson W. T., and Roach, S., "Analysis of air-gap flux, current, and vibration signals as function of a combination of static and dynamic eccentricity in 3-165 phase induction motors", IEEE Transactions on Industry Applications, Vol. 33, Jan./Feb., pp. 24-34, 1997.
[29]Wu, S., and Chow, T. W. S. "Induction machine fault detection using SOM based RBF neural networks", IEEE Transactions on Industrial Electronics, Vol. 51, No. 1, February, pp. 183-194, 2004.
[30]Boashash B., "Time frequency signal analysis" in: Advances in spectrum estimation and array processing, Ed. S. Haykin, Printice Hall, 1990.
[31]Richard G. Lyons, "Understanding digital signal processing", Pearson Education, 2009.
[32]M.Y. Chow, "Methodologies of Using Neural Network and Fuzzy Logic Technologies for Motor Incipient Fault Detection", World Scientific, Singapore, 1997.

