International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 3, Issue 4 (November 2013) PP: 22-26

Various Techniques for Condition Monitoring of Three Phase Induction Motor- A Review

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ABSTRACT: *Now a days the use of Condition Monitoring of electrical machines are increasing due to its potential to reduce operating costs, enhance the reliability of operation and improve service to customers. Condition Monitoring of induction motors is a fast emerging technology for online detection of incipient faults. This paper includes a comprehensive review of different types of faults occur in induction motor and also point out the latest trends in condition monitoring technology.*

Keywords: *Condition Monitoring, Induction Motors, Fault Monitoring*

I. INTRODUCTION

Three phase induction motors are commonly used in the industry because of its robustness, simplicity of its construction and high reliability. Although induction motors are reliable we cannot avoid the possibility of failure. These failures may be very harmful to the motor and hence early detection of failure is needed before they affect the whole operational performance. This kind of early fault diagnosis can increase machinery availability and performance, reduce consequential damage and breakdown maintenance. To avoid the unwanted shutdown and increases the serviceable life of equipment, one must go for predictive maintenance instead of the conventional time based maintenance. This process reduces the possibility of motor failure during operation. By using this predictive maintenance one can get the higher reliability and low substantial cost.

The percentage of failures in induction motor component is as follows:
(1) Bearing related faults: 40%.
(2) Stator winding faults: 38%
(3) Rotor related faults: 10%
(4) Other faults: 10%
The major faults of electrical machines can broadly be classified as the following:
(1) Stator faults resulting in the opening or shorting of one or more of a stator phase winding;
(2) Abnormal connection of the stator windings;
(3) Broken rotor bar or cracked rotor end rings;
(4) Static and/or dynamic air gap irregularities;
(5) Bent shaft;
(6) Shorted rotor field winding;
(7) Bearing and gearbox failures.

II. VARIOUS TYPES OF FAULTS IN THREE PHASE INDUCTION MOTOR

A. Stator Faults

In induction motor the stator faults are occurs mainly due to inter turn winding faults caused by insulation breakdown. They are generally known as phase-to-ground or phase-to-phase faults. Almost 30%-40% faults are stator faults. It is very important to detect them in time because they can lead to the total destruction of the motor. Now a days stator current signal analysis is a popular tool to find out stator winding faults due to the advantage of cheap cost, operation and multifunction. Due to the faults in the induction motor the magnetic field in the air gap of the machine will be nonuniform and results in harmonics in the stator current which can be signatures of several faults. [1]

B. Rotor Faults

From the survey it has been showed that 10% faults of total induction motor failures are caused by rotor winding. Induction motor rotor faults are mainly broken rotor bars because of pulsating load and direct on line starting. It results into fluctuation of speed, torque pulsation, vibration, overheating, arcing in the rotor and damaged rotor laminations. [1]

Cage rotors are classified in two parts: cast and fabricated. Cast rotors were only used in small machines, but now a days due to the development of casting technology it can be used for the rotors of machines in the range of 3000 kW. While fabricated rotors are generally used in special application machines. [2]

The reasons for rotor bar and end ring breakage are as following:
1. Thermal stresses
2. Magnetic stresses
3. Residual stresses
4. Dynamic stresses
5. Environmental stresses
6. Mechanical stresses. [3]

C. Bearing Faults

This faults contains over 40% of all machine failures. Bearings are common elements of any electrical machines. The rotary motion of shaft is permitted by the bearings. As seen above the bearings are single largest cause of machine failures. Basically bearings consists of two rings which are known as the inner and the outer rings. A set of balls or rolling elements placed in raceways rotate inside these rings. A continuous stress on the bearing results into the fatigue failures. These failures are at inner or outer races of the bearings. This kind of failures results in rough running of bearings which results in detectable vibrations and increased noise levels. Contamination, corrosion, improper lubrication, improper installation and brinelling are the external factors which are also responsible for the bearing fault. Now when flux disturbance like rotor eccentricities occurs, it results in unbalanced shaft voltages and currents which are also the reason for bearing failures. [9]

Temperature is also a cause for bearing failure. So it is advisable that the temperature should not exceed beyond its predetermined limits at rated load condition. A fault in bearing imagined as a small hole, a pit or a missing piece of material on the corresponding elements. Now defecting rolling element bearings produces mechanical vibrations at the rotational speeds of each component. Consider the hole on the outer raceway. In this case the rolling element moves over the defect, it will stay in contact with the hole which produces an effect on the machine at a given frequency. [9]

D. Eccentricity related faults

Unequal airgap that exist between stator and rotor is known as machine eccentricity. When the eccentricity becomes larger, the resulting unbalanced radial forces can cause stator and rotor rub, and this can result in stator and rotor core damage. The eccentricity is divided into two parts: (1) Static eccentricity and (2) Dynamic eccentricity. In the case of static eccentricity the position of the minimal radial air gap length is fixed in space. Incorrect positioning of the stator or rotor core at the commissioning stage results into static eccentricity. [1] [2]

In the case of dynamic eccentricity, the centre of the rotor is not at the centre of the rotation and the position of minimum airgap rotates with the rotor. This misalignment caused due to the several factors such as bent rotor shaft, bearing wear or misalignment etc. An air gap eccentricity is permissible upto10%. An inherent level of static eccentricity exists even in newly manufactured machines due to manufacturing and assembly methods. [2]

III. VARIOUS TECHNIQUES OF CONDITION MONITORING

1. Thermal Monitoring

The thermal monitoring of electrical machines can be completed by measuring local temperature of the motor or by the estimation of the parameter. Due to the shorted turns in the stator winding the value of stator current will be very high and hence it produces excessive heat if proper action would not be taken and results into the destruction of motor. So some researchers have introduced thermal model of electric motor. Basically this model is classified into two parts:
(1) Finite Element Analysis based model
(2) Lumped parameter based model

FEA model is more accurate than the second model but it is a highly computational method and also time consuming. A lumped parameter based model is equivalent to the thermal network and made from thermal resistances, capacitances and corresponding power losses. 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 faults. [9]

2. Air gap torque monitoring

The airgap torque is produced by the flux linkage and the currents of a rotating machine. It is very sensitive to any unbalance created due to defects as well as by the unbalanced voltages. If the harmonic contains zero frequency that means the motor is operating in normal condition. The forward stator rotating field produces a constant while the backward stator field produces a harmonic torque. If we consider the speed of forward and backward rotating field as $+\omega_s$, $-\omega_s$, the speed of rotor as $\omega_s(1\text{-}s)$, and speed of rotor magnetic field as s ω_s then the value of the frequency will be -2 ω_s. Hence it indicates the gap in the stator winding and voltage. [2]

3. Noise Monitoring

By measuring and analyzing the noise spectrum we are able to do noise monitoring. Due to the air gap eccentricity the noise is produced. This noise is used for fault detection in induction motor. However it is not the accurate way to detect the fault by noise monitoring because of the noisy background from the other machines. Ventilation noise is associated with air turbulence, which is produced by periodic disturbances in the air pressure due to rotating parts. The noise is due to the Maxwell's stresses that act on the iron surfaces. These forces are responsible for producing the noise in the stator structure. [2] [9]

4. Vibration Monitoring

The vibrations are produced mainly due to the interturn winding faults, single phasing and supply voltage unbalance. It is also a parameter which is very useful for monitoring the health of induction motor. Vibrations in electric machines are caused by forces which are of magnetic, mechanical and aerodynamic origin. [2] [9]

5. Motor Current Signature Analysis

MCSA is a non-invasive, online monitoring technique for the diagnosis of problem in induction motor. A full mathematical analysis(with experimental verification) of a three phase induction motor operating with broken rotor bars was published by Williamson and Smith (1982)- this gives an excellent in-depth analysis. It is well known that a three phase symmetrical stator winding fed from a symmetrical supply will produce a resultant forward rotating magnetic field at synchronous speed, and, if exact symmetry exists,there will be no resultant backward rotating field. In most applications stator current is monitored for diagnosis of different faults of induction motor. [10]

The MCSA utilizes the results of spectral analysis of the stator current for the detection of air gap eccentricity, broken rotor bars and bearing damage. It is based on the behaviour of the current at the side band associated with the fault. For that the intimate knowledge of the machine construction is required. It is known that when the load torque varies with the rotor position, the current will contain spectral components, which coincides with those caused by the fault condition. Researchers conclude that Fourier analysis is very useful for many applications where the signals are stationary.

Any asymmetry of the supply or stator winding impedances will cause a resultant backward rotating field from the stator winding. Now apply the same rotating magnetic field fundamentals to the rotor winding the difference is that the frequency of the induced voltage and current in rotor winding is at slip frequency and not at the supply frequency and is given by $f_2=sf_1$, where f_2 is the rotor current frequency and f_1 is the supply frequency. [10]

6. Partial Discharge

Partial discharge can be described as an electrical pulse or discharge in a gas filled void or on a dielectric surface of a solid or liquid insulation system. This theory involves an analysis of materials, electric fields, arcing characteristics, pulse wave propagation and attenuation, sensor spatial sensitivity, noise and data interpretation. This is a small electric discharge, which occurs due to insulation imperfection. One of the main factor of partial discharge is poor manufacturing which results into voids or air pockets, which get discharged. A deteriorated winding has a PD activity approximately 30 times or even higher than a winding in good condition. So this is a very useful technique to monitor the effectiveness of the winding and also the health of the motor. [8]

7. Wavelet Analysis

Wavelets are functions that can be used to decompose signals, similar to how to use complex sinusoids in Fourier Transform to decompose signals. The wavelet transforms computes the inner products of the analyzed signal and family of wavelet. In general terms, mathematical transformations are applied to signals to obtain further information from that signal that is not readily available in the unprocessed signal. Most of the signals in practice are time domain signals. That is, whatever that signal is measuring, is a function of time. The frequency spectrum of a signal is basically the frequency components of that signal. It indicates what frequencies exist in the signal. [9]

Several transformations can be applied, but all amongst them the Fourier transformation is a best option and most popular one for signal decomposition. Although this transformation is widely used, it has some disadvantages. The Fourier transforms gives the frequency information of the signal, but it does not mark when in time these frequency components exist. [9]

This method works on principle that all signals can be reconstructed from the sets of local signals of varying scale and amplitude, but constant shape. In contrast with sinusoids, wavelets are localized in both the time and frequency domains, so wavelet signal processing is suitable for those signals, whose spectral content changes over time. Wavelet signal processing is different from other signal processing methods because of the unique properties of wavelets. For example, wavelets are irregular in shape and finite in length.

The decomposition of the signal into different frequency bands is simply obtained by successive highpass and lowpass filtering of the time domain signal. The original signal x[n] is first passed through a halfband highpass filter g[n] and a lowpass filter h[n].

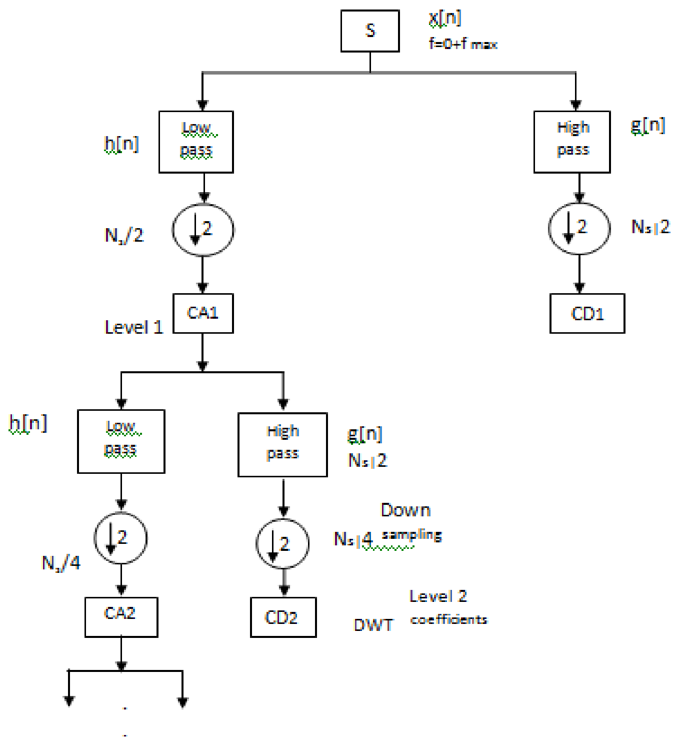

Fig.1 The DWT decomposition of a signal

After the filtering, half of the samples can be eliminated according to Nyquist's rule. Simply discarding every other sample will subsample the signal by two, and signal will then have half the number of points. The scale of the signal is now doubled. Note that the filtering removes a part of the frequency information, but leaves the scale unchanged. Only the sub sampling processes change the scale. [7]

8. Expert Systems

It is a computer program for performing a suitable data acquisition and a FFT is to be activated for stating the stationary condition of the machine. By using this technique the harmonic contents are eliminated and perform the reduction of the large amount of spectral information to a sutable level. The system can detect the health of the motor by using signature extraction and fault identification from the various harmonic component and from the condition of the motor. [4]

9. Fuzzy Logic System

For induction motor fault detection, the machine condition is described by linguistic variables. Basic tools of fuzzy logic are linguistic variables. Their values are words or sentences in a natural or artificial language, providing a means of systematic manipulation of vague and imprecise concepts. Fuzzy subsets and the corresponding membership function is constructed for any one parameter for example stator current amplitude. A knowledge base consisting of rule and databases is formed to support the fuzzy inference.

Fuzzy rules and membership functions are constructed by observing the data set. Once the form of the initial membership functions has been determined, then fuzzy if-then rules can be derived. [4] [5]

10. Artificial Neural Network

The architecture of the neural network indicates the arrangement of the neural connection as well as type of units characterized by an activation function. The processing algorithm specifies how the neuron calculates the output vector for any input vector and for a given set of weights. The adjustment of weights is basically known as the training of the neural network. The fault severity evaluation can be done by the supervised neural network, which can synthesize the relationship between the different variables. The neural network can acquire knowledge through the training algorithm and store the knowledge in syneptic weights.

The objective of training the network is to adjust the weights so that application of a set of inputs produces the desired set of outputs. [6] [4]

11. Neural Fuzzy System

By combining ANN techniques and fuzzy logic, a neural-fuzzy system is created. The neural-fuzzy is an ANN structured upon fuzzy logic principles, which enables this system to provide qualitative description about the machine condition and the fault detection process. Fuzzy parameters of membership functions and fuzzy rules provide the knowledge. [4]

IV. CONCLUSION

A brief review of most frequent electric faults in case of induction motor has been described over here along with their detection techniques. This paper also contains the different monitoring methods of three phase induction motor which are used previously and also important for now a days like AI based detection techniques.

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