**A REVIEW OF CONDITION MONITORING OF INDUCTION MOTORS**

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***Abstract-* the condition monitoring of induction means checking the health of the motor and detecting any fault which could happen over time. Induction motors are also known as industrial motors because of their wide range of usage in this modern industrial era. The various harmonic spectrum present in the line current can be detected by motor current signature analysis. The various types of faults occurring in the induction motors can be listed as stator, rotor, vibration, bearing and air gap eccentricity and the various techniques to detect and diagnose these fault are sought. The monitoring of the condition of electrical motor by human intervention is becoming obsolete and are reinstated by new age technologies such neural network, fuzzy logic systems, artificial intelligence wavelet analysis etc. This review paper presents the study of different fault detection and their diagnosis’ methods.**

 **Keywords-condition monitoring, induction motor, fault diagnosis, review**

1. INTRODUCTION

Before the revolution in industrial era the makers were troubled to protect the induction motors from faults like earth fault, overvoltage and overcurrent type uncomplicated faults. But as the time changed the duty of induction motors were also increased to keep up with the requirement of the market. And since the performance requirement of these motors were increased so the requirement to detect and diagnose the fault beforehand also increased to ensure the continuous, safe and reliable operation of induction motors. It is imperative to know the faulty condition and before any failure could happen its diagnosis is required because present day industrial mechanism is heavily interrelated and failure at one stage could lead to series of many more failures and may incur huge financial losses.



 fig. 1(a) sources of machine faults

The sources of machine faults are shown in fig. 1(a). In induction motor primary and secondary both types of fault can happen. One type of fault is rotor fault [1]. The categorization of various internal and external faults are shown in fig. 1(b) and fig. 1(c). the different type of fault occurring according to the different locations are rotor fault, stator fault [2], bearing fault [3], mechanical vibration fault, air gap eccentricity fault etc. The fault may be caused due to electrical condition or mechanical condition.

1. Different types of faults in induction motor



 Fig. 1(b) various types of internal faults



 Fig. 1(c) various types of external fault

Different types of faults are stated in literature and vigorous effort has been taken to classify them according to their origin. According to the occurrence of the faults in the induction motor they are primarily categorized into five types which are as under:

Stator fault which may happen because of the improper winding connection and short circuiting or opening of a stator phase winding;

Rotor fault may occur if a rotor winding is short circuited or because of broken rotor bars or rotor end-rings are broken;

Air gap differences- static or dynamic

Dynamic faults like bending of shaft which can cause the rubbing between the stator and rotor;

Bearing fault

1. *Stator faults*

Usually all the induction motors are put into high duty cycles of working conditions and they are subjected to various electrical, mechanical, thermal and also harsh environmental conditions. The very frequent types of stator faults occurring in an induction motor are phase to phase, coil to coil, coil to ground, open circuit and turn to turn faults etc. these faults are frequent in nature and can potentially harm the instrument.

Three different stator faults are as follows:

1. In frame: circulating currents, earth faults and coolant loss
2. In lamination: core slackening
3. Stator winding fault: damage to the connectors, damage to the insulations, displacement of conductors
4. *Rotor faults*

Rotor faults are basically the faults of rotor bars or damage of the bearing system. In the high capacity induction motor during the transient condition when the motor starts the defects in bar mainly occur due to the thermal stresses or fatigue. Due to the broken or damaged bar the torque of the induction motor is changed significantly and operating the machine in such conditions can be proved fatal and unsafe working environment.

1. *Bearing faults*

A bearing consist of concentric ring which is a set of roller balls which spins in the space between the outer ring and the inner ring. The faults in the bearing may be categorized as both distributed and local as presented in [1]. The distributed faults may be considered as rough surface, wave type motion, misaligned races etc. localized faults consists of the cracking on the surfaces which are rolling, pits and spalls etc. When a rolling element passes over the

faulty surface it creates a different type of vibrational impact at the very moment. With the help of anamoly’s position, rotation speed and the size of the bearing the amplitude and period of the vibrational impact can be obtained. The frequencies affiliated with the balls and rollers are determined by the rotational speed and the size of the bearing of induction motor. The condition of the bearing of the induction motor can be analyzed by the mechanical vibration analysis technique.

1. *Vibration faults*

The oscillations happening in the mechanical parts of the machines are also known as vibrations and these vibrations can be observed by attaching an external observation tool to the mechanical shaft of the induction motor. For a normal motor a different spectrum of the frequency is observed which changes with the different types of the faults and these spectrum observed in the faulty conditions can be compared with one working in normal condition.

1. *Eccentricity faults:*

Whenever there is an uneven air gap between the stator and the rotor it results in air gap eccentricity. The two different eccentricity faults are namely static air gap eccentricity and dynamic air gap eccentricity. Inclined air gap eccentricity is caused due to the axial unevenness in the air gap. There can also be mixed air gap eccentricity faults which is a combination of both type of faults. Static eccentricity can be a result of faulty positioning of stator or rotor at the time of commissioning of induction motor while dynamic eccentricity may be a result of wear and tear of bearing, bending of shaft or mechanical resonance at critical speed.

1. Different types of fault and their detection technique

Various types of fault detection techniques have been developed related to detect and diagnose the signals related to the fault. The various methods to diagnose the fault encompass the following fields of science and technology:

1. Motor current signature analysis(MCSA);
2. Neural network;
3. Artificial intelligence;
4. Infrared recognition;
5. Temperature analysis;
6. Radio frequency emission monitoring;
7. Vibration monitoring;
8. Electromagnetic field monitoring;
9. Acoustic noise monitoring;
10. Chemical analysis;

|  |  |
| --- | --- |
| Fault detection techniques | Detected faults |
| MCSA  | Rotor, bearing, stator and vibration faults |
|  Artificial neural network | Stator, bearing faults |
| Parks transform  | Bearing, stator faults |
| Wavelet analysis | Stator, rotor, bearing and vibration faults |
| Concordia transform | Bearing fault |
| Finite element method  | Stator, rotor and vibration faults |
| External magnetic field analysis | Rotor faults |
| Multiple reference frame theory | Eccentricity faults  |
| KU transformation | Stator faults |
| Power decomposition technique | Stator faults |
| Vibration testing analysis | Bearing and vibration faults |
| Zero crossing time method | Stator faults |
| Model analysis method | Vibration fault |

Table 1. Comparison of various fault detection technique

1. *Stator faults*

Whenever there is fault in induction motor it will cause the change in the electrical parameters of the motor. These parameters can be analyzed to detect and diagnose the faults.

In recent times, many techniques have been developed by the researchers for detecting the fault in stator winding. Some of the technique include the artificial neural network and wavelet analysis based stator faults [4, 5]. In [6] the third harmonic component is utilized to show the turn to turn insulation failure faults with axial flux monitoring. Because of the asymmetries in the stator impedance there is a zero sequence component of current. In [7] presented a method for the detection of stator winding faults. Stator faults can be detected by analyzing the voltage and current from the power supply terminals. The vector controlled induction motor drives used in the industry have the ability to run even on shorted turns in coils [8]. If the fault in stator winding is detected early and field is reduced the vector controlled induction motor can operate optimally for shorter period of time. An offline technique which employs the method of observing the residual saturation harmonic in which the fault is diagnosed by measuring the odd multiple of third harmonic components present in the voltage just after the switch-off [9]. The stator winding fault in a three phase induction machine can be diagnosed by Hebbian- based neural network algorithm which is an automatic unsupervised neural network algorithm [10]. In this method first the alpha- beta components of stator current are utilized to obtain the principal components of the machine. When these components are projected into new vector space severity index can be calculated. With the directions of the vector obtained from projecting the neural network indicate the faulted phase and the relation between the eigen vector space components shows if the induction motor is in normal condition or faulted condition.

One other method is parks transform which is based on the spectral analysis of the current [11]. In [12] a technique is presented which is a combination of discrete wavelet transform, artificial neural network (ANN), genetic algorithm (GA) and feature extraction. Motor current signature analysis (MCSA) is a sensitive and cost effective method of online conditioning of induction motor. The results obtained from MCSA provide the clear view of the health of the induction motor [13].

1. *Rotor fault*

By decomposing the transient current the broken rotor faults can be identified. Wavelet analysis is used for the decomposition of the current [14]. When numerous bars of rotor are broken the fault caused deteriorates the steady state torque slip characteristics of the induction motor. Global fault index method is one such new method for the detection and diagnosis of the fault in the induction machine. By analyzing the line current and the instantaneous supply of power, this method gives quite significant result to detect the broken rotor fault [15]. In electromagnetic theory a corrosion model of the rotor is developed to simulate the broken rotor faults. Especially for squirrel cage induction motor the finite element method is incorporated to detect the rotor bar faults [16].

Analyzing the state space vector of the stator voltage which are induced after disconnecting it from the mains the broken rotor faults can be detected. The state space vector of the induced voltages after disconnecting it from the mains can be computed by MUSIC and STMUSIC algorithm. The results obtained from the above two mentioned algorithm are then compared against the standard FFT and STFFT algorithms.

1. *Bearing fault*

Bearing faults can be majorly classified into two types. The first one is single point defect and the second one is general roughness defect.

The main advantage of classifying the two defects is that it gives which defect is causing the problem. The technology is mainly focused on the identification of single point defect rather than the general roughness defect. This gives a clear insight on how the technology should be planned and developed. By examining the stator current the bearing fault can be detected [16].

Adaptive neural fuzzy interference system (ANFIS) is a new technology to detect the bearing fault and inter-turn short circuit fault of the motor [17]. In this method the incoming current and the rotational speed of the induction motor is examined and then at later stage the temperature of the bearing, noise produced by the induction motor are also added. Frequency response analysis is also a method to detect and diagnose the rolling bearing fault [18]. This method requires the vibrations produced from the motor and then it compares with the standard frequency of the vibration obtained from the healthy condition of a motor.

Motor current spectral analysis (MCSA) is also one available method to detect the bearing fault [19]. By using the vibration and current frequency the efficiency this method is first calculated. DWT can well be utilized for feature extraction for classifying the data available and this allows the early detection of the faults that could happen over time if not prevented. There are six different types of the bearing faults are described in the paper of which some are single point defect, combined single point defect and general roughness of the induction motor. Vibration and current frequency are tested under external vibration [19].

1. *Eccentricity*

In [20] the park’s vector of stator current is first computed and then by observing the split park’s vector pattern the severity of the fault is detected. Using the winding function theory simulation of squirrel cage induction motor is performed and the air gap eccentricity faults can be detected. The presence of the two different side band frequency in current spectra can be used to detect the static as well as the dynamic air gap eccentricity faults [21]. This method is largely used for the high voltage, high capacity induction motors.

1. *Vibration*

In an induction motor system the presence of air gap eccentricity of the rotor and torsional vibration can create lateral oscillations of the rotor which should not be permitted. The simulation of these kind of fault in an induction motor is presented in analytic way in [22]. In this paper the technique is provided to measure and analyze the acoustic noise spectrum, current spectrum and overall noise in dB of inverter fed induction motor drive.

1. CONCLUSION

There are different kind of faults are stated in literature such as stator fault, rotor faults, bearing fault, eccentricity and vibration faults which are reviewed in this paper. By studying the different methods and technology presented in various literatures it is concluded that the motor current signature analysis (MCSA) is the most preferred method for detecting and diagnosing the incipient faults in induction motor. Along with these methods it is also required to have the knowledge of theoretical analysis and modeling of induction motor to differentiate between the frequencies produced because of the fault and general harmonics present in the induction motor system. In this paper other techniques which are based the fuzzy logic system, neural network system, wavelet analysis and genetic algorithm have also been discussed.

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