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Analyzing and Detection of Rotor Faults in Squirrel Cage Induction Motor Drives Using MATLAB

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ABSTRACT: Induction motors are becoming familiar these days and is being employed in most of the industrial processes. This "Analyzing And Detection Of Rotor Faults In Squirrel Cage Induction Motor Drives Using Matlab" presents a simulation of detecting the rotor faults such as broken rotor bars or end rings in squirrel cage induction motor drives. It enables detection of those faults, which may arise during the lifetime of the motor, although special attention was given to identify broken rotor bars at an early stage of the fault propagation. This method is based on analysis of stator current frequency spectrum and the rotor speed approach, which can be measured without disturbing normal motor operation, therefore it is completely non-invasive and easy to implement in industrial environments. The stator current undergoes FFT analysis and the output of the analysis gives us the condition of the induction motor under operation. The possible outputs from the analysis can be either the motor running in healthy state or warning state or faulty state. The state of the motor is sent to the supervision station through GSM so that the operator can take necessary action.

KEYWORDS: Rotor faults, Broken rotor bar, FFT Algorithm , Spectrum analysis.

I.INTRODUCTION

Classic safety devices such as fuses, motor overload protection and circuit breakers are activated only after a significant faulty condition already occurs. If electric motors are used in critical duty drives, sudden failure can cause inadmissible safety risks and vast economic expenses. A diagnostic system which can predict such failures in advance is therefore of great importance. The main advantage of an on-line supervision and diagnostics of electrical machines is the ability to predict and foresee the type, position, probability and time of a possible fault. Such monitoring procedures allow for a prevention of sudden operation interruptions and improve the reliability of the drive system. Supervision of electrical drive systems using non-invasive condition monitoring techniques is becoming state-of-the-art method for improving the reliability of electrical drives in many branches of the industry.

The main advantage of such diagnostic system is prediction of possible breakdowns by on-line analysis of various parameters of the drive. Due to their simple construction, low cost and high reliability, three-phase cage induction motors are the most widely used type of electric motors. As a consequence of electrical or mechanical faults, which may arise during operation, many induction machines are operating at asymmetrical conditions. Most common rotor faults of induction motor are generally classified as electrical (asymmetry due to broken rotor bars and end-ring segments)and mechanical (static and dynamic eccentricity). Although mechanical faults are more frequent, electrical asymmetries of rotor cage are difficult to detect owing to inability of measuring rotor current during the operation of the motor. Failures of rotor cage (Fig. 1) are caused by combination of mechanical and thermal stresses due to the action of electromagnetic forces on bars of squirrel cage during starting, attraction forces between stator and rotor due to asymmetrical air-gap, centrifugal forces, forces caused by pulsating torque, and vibrations caused by unbalance of rotating masses. To identify such faults Motor Current Signature Analysis (MCSA) is today commonly adopted and reliable approach to perform the detection task at an early stage. Throughout the years, many upgrades of the basic MCSA scheme were proposed so as to improve the detection sensitivity.

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Fig 1 Broken rotor bars in induction motors.

II. EARLIER METHODS OF FAULT DETECTION

The history of fault diagnosis and protection is an archaic as the machine themselves the manufacturers and users of electrical machines initially relied on simple protections such as over current, over voltage, earth fault, etc. to ensure safe and reliable operations. However as the tasks performed by these machines grew increasingly complex; improvements were also considered in the field of fault diagnosis.
The common internal faults can be mainly categorized into two groups:
- Electrical faults
- Mechanical faults

Electrical faults include faults caused by winding insulation problems, and some of the rotor faults. Mechanical faults include bearing faults, air gap eccentricity, load faults and misalignment of shaft.
The following electrical faults are very common in three phase induction motor while operating in industries.

A .Rotor faults:
Usually, lower rating machines are manufactured by die casting techniques whereas high ratings machines are manufactured with copper rotor bar. Several related technological problems can rise due to manufacturing of rotors by die casting techniques. It has been found that squirrel cage induction motors show asymmetries in the rotor due to technological difficulties, or melting of bars and end rings. However, failures may also result in rotors because of so many other reasons. There are several main reasons of rotor faults.
During the brazing process in manufacture, non-uniform metallurgical stresses may be built into cage assembly and these can also lead to failure during operation. A rotor bar may be unable to move longitudinally in the slot it occupies, when Thermal stresses are imposed upon it during starting of machine.

Heavy end ring can result in large centrifugal forces, which can cause dangerous stresses on the bars.
Because of the above reasons, rotor bar may be damaged and simultaneously unbalance rotor situation may occur. Rotor cage asymmetry results in the asymmetrical distribution of the rotor currents. Due to this, damage of the one rotor bar can cause the damage of surrounding bar and thus damage can spread, leading to multiple bar fractures. In case of a crack, which occurs in a bar, the cracked bar will overheat, and this can cause the bar to break. Thus, the surrounding bar will carry higher currents and therefore they are subjected to even larger thermal and mechanical stresses which may also start to crack . Most of the current which would have flowed in the broken bar now will flow in the two bars adjacent to it. Thus, the large thermal stresses may also damage the rotor laminations. The temperature distribution across the rotor lamination is also changed due to the rotor asymmetry. The cracking of the bar can be

presented at various locations, including the slot portion of the bars under consideration and end rings of bar joints. The possibility of cracking in the region of the end rings of bar joints is the greatest when the start-up time of the machine is long and when frequent starts are required.

B. Short turn faults:

According to the survey, 35-40 % of induction motor failures are related to the stator winding insulation. Moreover, it is generally believed that a large portion of stator winding-related failures are initiated by insulation failures in several turns of a stator coil within one phase. This type of fault is referred as a “stator turn fault” . A stator turn fault in a symmetrical three-phase AC machine causes a large circulating current to flow and subsequently generates excessive heat in the shorted turns. If the heat which is proportional to the square of the circulating current exceeds the limiting value the complete motor failure may occur. However, the worst consequence of a stator turn fault may be a serious accident involving loss of human life. The organic materials used for insulation in electric machines are subjected to deterioration from a combination of thermal overloading and cycling, transient voltage stresses on the insulating material, mechanical stresses, and contaminations. Among the possible causes, thermal stresses are the main reason for the degradation of the stator winding insulation. Stator winding insulation thermal stresses are categorized into three types: aging, overloading, and cycling. Even the best insulation may fail quickly if motor is operated above its temperature limit. As a rule of thumb, the life of insulation is reduced by 50 % for every 10 degree centigrade increase above the stator winding temperature limit. It is thus necessary to monitor the stator winding temperature so that an electrical machine will not operate beyond its thermal capacity. For this purpose, many techniques have been reported. However, the inherent limitation of these techniques is their inability to detect a localized hot spot at its initial stage.

A few mechanical problems that accelerate insulation degradation include movement of a coil, vibration resulting from rotor unbalance, loose or worn bearings, airgap eccentricity, and broken rotor bars. The current in the stator winding produces a force on the coils that is proportional to the square of the current. This force is at its maximum under transient overloads, causing the coils to vibrate at twice the synchronous frequency with movement in both the radial and the tangential direction. This movement weakens the integrity of the insulation system. Mechanical faults, such as broken rotor bar, worn bearings, and air-gap eccentricity, may be a reason why the rotor strikes the stator windings.

Therefore, such mechanical failures should be detected before they fail the stator winding insulation. Contaminations due to foreign materials can lead to adverse effects on the stator winding insulation. The presence of foreign material can lead to a reduction in heat dissipation. It is thus very important to keep the motors clean and dry, especially when the motors operate in a hostile environment.

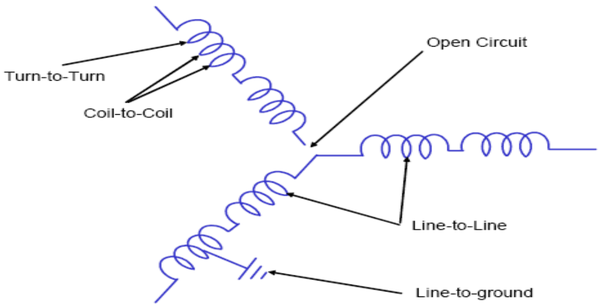

FIGURE 2: INTER TURN FAULTS

Regardless of the causes, stator winding-related failures can be divided into the five groups: turn-to-turn, coil-to-coil, line-to-line, line-to-ground, and open-circuit faults as presented. Among the five failure modes, turn-to-turn faults (stator turn fault) have been considered the most challenging one since the other types of failures are usually the consequences of turn faults. Furthermore, turn faults are very difficult to detect at their initial stages. To solve the difficulty in detecting turn faults, many methods have been developed.

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III. CAUSES FOR BREAKAGE OF ROTOR BARS

The reasons for rotor bar and end ring breakage are several.
a) Thermal stress due to thermal overload and unbalance, hot spots or excessive losses, sparking (mainly fabricated rotors).
b) Magnetic stresses caused by electromagnetic forces, unbalanced magnetic pull, electromagnetic noise and vibration.
c) Residual stresses due to manufacturing problems.
d) Dynamic stresses arising from shaft torques, centrifugal forces and cyclic stresses.
e) Environmental stresses caused, for example, contamination and abrasion of rotor material due to chemicals or moisture.
f) Mechanical stresses due to loose laminations, fatigued parts, bearing failure etc.

Existing condition monitoring techniques:

This research is focused on the condition monitoring and fault diagnosis of electric machines. Fault diagnosis is a determination of a specific fault that has occurred in system.
A typical condition monitoring and fault diagnosis process usually consists of four phases as shown in Figure 2 Condition monitoring has great significance in the business environment due to following reasons [1,2]
• To reduce the cost of maintenance
• To predict the equipment failure
• To improve equipment and component reliability
• To optimize the equipment performance
• To improve the accuracy in failure prediction.

IV CURRENT SIGNATURE ANALYSIS

Numerous applications of using MCSA in equipment health monitoring have been published among the nuclear-generation, industrial, defence industries. In most applications, stator current is monitored for diagnosis of different faults of induction motor. Randy R. Schoen addressed the application of motor current signature analysis for the detection of rolling-element bearing damage in induction machines. This study investigates the efficacy of current monitoring for bearing fault detection by correlating the relationship between vibration and current frequencies caused by incipient bearing failures. In this study,the bearing failure modes are reviewed and the characteristic bearing frequencies associated with the physical construction of the bearings are defined. The effects on the stator current spectrum are described and the related frequencies determined. Experimental results which show the vibration and current spectra of an induction machine with different bearing faults are used to verify the relationship between the vibrational and current frequencies. The test results clearly illustrate that the stator current signature can be used to identify the presence of a bearing fault. Randy R. Schoen [30] presented a method for on-line detection of incipient induction motor failures which requires no user interpretation of the motor current signature, even in the presence of unknown load and line conditions. A selective frequency filter learns the characteristic frequencies of the induction machine while operating under all normal load conditions. The generated frequency table is reduced to a manageable number through the use of a set of expert system rules based upon the known physical construction of the machine. This list of frequencies forms the neural network clustering algorithm inputs which are compared to the operational characteristics learned from the initial motor performance. This only requires that the machine be in "good" operating condition while training the system. Since a defect continues to degrade the current signature as it progresses over time, the system looks for those changes in the original learned spectra that are indicative of a fault condition and alarms when they have deviated by a sufficient amount. The combination of a rule based (expert system) frequency filter and a neural network maximizes the system's ability to detect the small spectral changes produced by incipient fault conditions. Compete failure detection algorithm was implemented and tested. An impending motor failure was simulated by introducing a rotating mechanical eccentricity to the test machine. After training the neural network, the system was able to readily detect the current spectral changes produced by the fault condition.

Hamid A. Toliyat developed a new induction machine model for studying static rotor eccentricity. It is based directly on the geometry of the induction machine and the physical layout of all windings. The model can simulate the performance of induction machines during transients as well as at steady state, including the effects of static rotor eccentricity. Since the dynamic model of the motor includes the mechanical equation, any arbitrary time function of load torque can be specified from which the resulting stator current is calculated. To illustrate the utility of this method,

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a conventional three phase induction motor with 50% rotor eccentricity was simulated. Digital computer simulations have been shown to yield satisfactory results which are in close agreement with experimental results of previous studies.

M.E.H. Benbouzid and H. Nejjariet. al. stated that preventive maintenance of electric drive systems with induction motors involves monitoring of their operation for detection of abnormal electrical and mechanical conditions that indicate, or may lead to, a failure of the system. Intensive research effort has been for sometime focused on the motor current signature analysis. This technique utilizes the results of spectral analysis of the stator current. Reliable interpretation of the spectra is difficult, since distortions of the current waveform caused by the abnormalities in the drive system are usually minute. Their investigations show that the frequency signature of some asymmetrical motor faults can be well identified using the Fast Fourier Transform (FFT), leading to a better interpretation of the motor current spectra. Laboratory experiments indicate that the FFT based motor current signature analysis is a reliable tool for induction motor asymmetrical faults detection.

Benbouzid et. al. investigated the efficacy of current spectral analysis on induction motor fault detection. The frequency signatures of some asymmetrical motor faults, including air gap eccentricity, broken bars, shaft speed oscillation, rotor asymmetry, and bearing failure, were identified. This work verified the feasibility of current spectral analysis. Current spectral analysis was applied to other types of electrical machines too. For example, Thomson verified that the use of the current spectrum was successful in diagnosing air gap eccentricity problems in large, high-voltage, three-phase induction motors. Le Roux monitored the current harmonic component at the rotating frequency (0.5 harmonic) to detect the rotor faults of a permanent magnet synchronous machine.

Benbouzid made a review of MCSA as a medium for fault detection. This study introduces in a concise manner the motor signature analysis for the detection and localization of abnormal electrical and mechanical conditions that indicate, or may lead to a failure of induction motors. The MCSA utilizes the results of spectral analysis of the stator current for the detection of airgap 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, intimate knowledge of the machine construction is required. It is explained that when the load torque varies with rotor position, the current will contain spectral components, which coincide with those caused by the fault condition. The torque oscillation results in stator current harmonics Benbouzid made a review of MCSA as a medium for fault detection. This study introduces in a concise manner the motor signature analysis for the detection and localization of abnormal electrical and mechanical conditions that indicate, or may lead to a failure of induction motors . 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, intimate knowledge of the machine construction is required. It is explained that when the load torque varies with rotor position, the current will contain spectral components, which coincide with those caused by the fault condition. The torque oscillation results in stator current harmonics of compromise between time- and frequency-based views of a signal and provides information about both.

Mohamed El HachemiBenbouzid, and Gerald B. Kliman briefly presented signal (mainly motor current) processing techniques for induction motor rotor fault detection (mainly broken bars and bearing deterioration). The main advantages and drawbacks of the presented techniques are also briefly discussed. In many cases, the conventional steady state techniques may suffice. From the discussions, it appears that, for the most difficult cases, time-frequency and time-scale transformations, such as wavelets, provide a more optimal tool for the detection and the diagnosis of faulty induction motor rotors. On the one hand, they remedy the main drawbacks of motor current signal processing techniques for fault detection (i.e., nonstationarity). These techniques exhibit some interesting application advantages, such as for coal crushers, where speed varies rapidly and for deteriorated bearings where speed and and signatures may vary in an unpredictable manner.

V. RESULT AND DISCUSSION

. One of the simplest ways to detect the broken rotor bars or end-rings in squirrel cage induction motors is stator current approach. Here, the stator current is being measured by the stator current sensor and the stator current is being analysed for fault detection.

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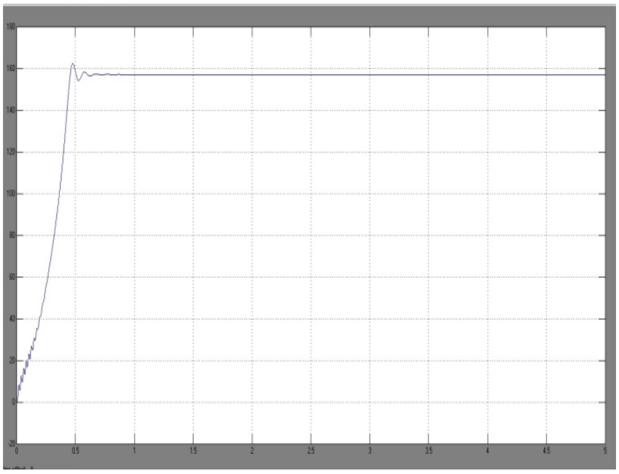

Fig 3. Output For An Induction Motor Without Fault (Speed Vs Current Characteristics)

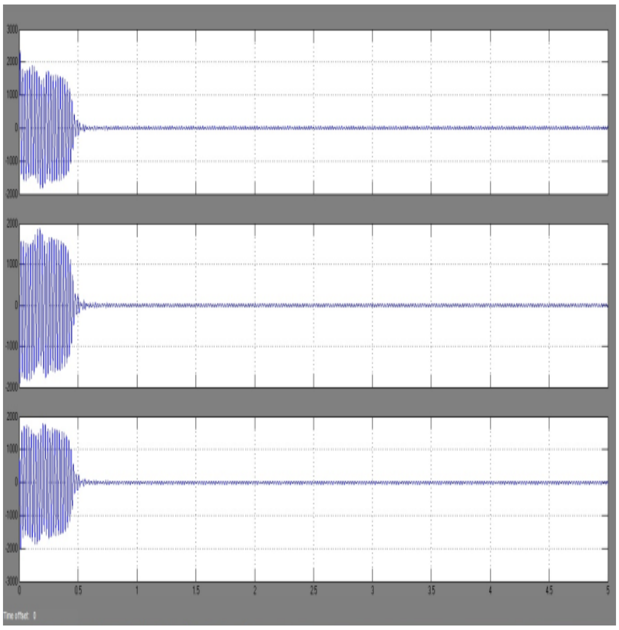

Fig 4. Stator Current In Healthy Motor

FFT Based Analysis:

Knowledge and experiences gained from modeling and testing of a few kW induction motors among others formed bases to design and develop an induction motor model using MATLAB. The stator current is being measured and the FFT is applied on it. The FFT converts the current spectrum into the frequency Spectrum. As a result of FFT Analysis, The condition of the motor can be found out. The monitoring goes for about a period of time and then a database is maintained over the entire period and the condition of the motor is being reported to the supervision station through GSM(to the operator in the station)

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An FFT output which shows the time history of the stator current and the spectral density of the stator current. A healthy induction motor will have distortions in the current spectrum when it is started. But it will not have any distortions above the fundamental frequency.

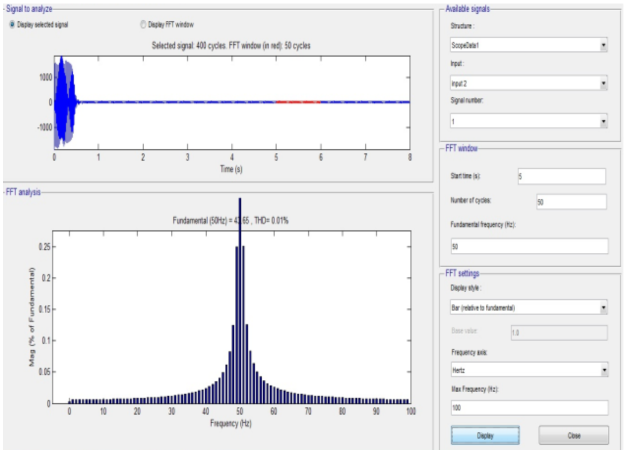

Fig. 5 FFT Output In A Healthy Motor

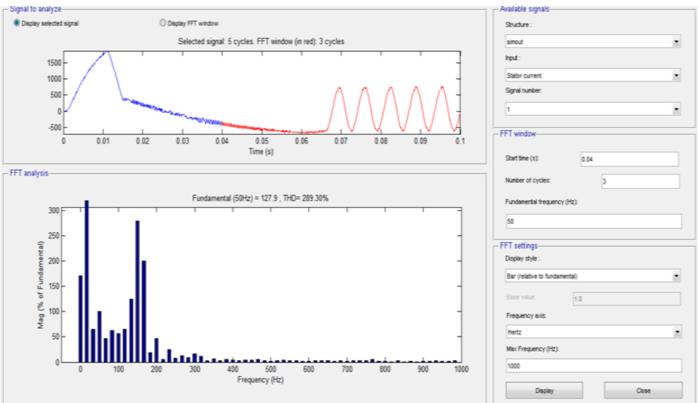

Fig. 6 FFT Output In A faulty Motor

The comparison output of speed and torque characteristics of fault and healthy motor

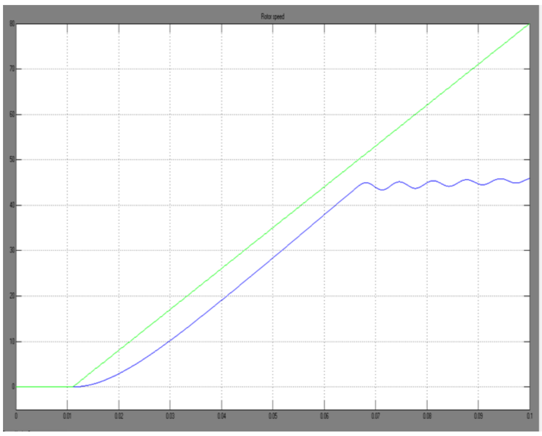

FIGURE 7 .,Speed And Torque Characteristics Of Healthy And Faulty Motor

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STATE OF THE MOTOR	THD VALUE (IN %)		METHOD USED
	HEALTHY	FAULTY	
HEALTHY	0.01	0.81	STATOR CURRENT APPROACH
FAULTY	0.01	289.30	ROTOR SPEED APPROACH

Table 1 Shows The Threshold Value In Health And Faulty Of Stator Current And Rotor Speed

VI.CONCLUSION

The proposed system owes to detect the rotor faults in squirrel induction cage induction motors at a very early stage and it prevents any hassles in the operation of the motor. The broken rotor bars in the squirrel cage induction motor was early found using the stator current analysis alone. The necessity of various sensors like torque sensor, temperature sensor, vibration sensor are eliminated. The result analysis in TABLE-I clearly shows the state of both the healthy and faulty motor and its THD values. By using this method, the reliability of operation gets improved. It is completely a non-invasive strategy and it does not require any manual operation nearer to the induction motor. Everything can be monitored and recorded from the supervision station. The necessity of early detection of broken rotor bars in induction motors gained importance since it is very difficult to measure the rotor current due to its constructional features. So this proposed method detects the broken rotor bars using the stator current measurement alone while the previous experiments were based on measurement of vibration, noise, temperature, etc.,

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