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Review Article

DETECTION OF BEARING FAULTS IN THREE PHASE INDUCTION MOTOR: A LITERATURE

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Abstract*:* Because of their immense points of interest over other electrical engines, a three phase Induction motor particularly assume a critical part in the modern applications. Subsequently, there is a solid interest for their steady and secured operation. On the off chance that whichever fault and failures occur in the engine it can prompt excessively downtimes and cause incredible losses as far as returns and upkeep. Along these lines, early blame introduction is required for the protection of the motor. The foremost kind of external fault experienced by these engines are over stacking; single phasing, unequal supply voltage, bolted rotor, and phase inversion, ground fault, under voltage and over voltage. In this paper, we exhibit the present literature study of researches done on induction faults.

Keyword*:* Induction motor, bearing faults, Ground fault

Introduction: The induction motor is one of the majority important motors used in industrial applications. It is used to transform electrical energy into mechanical energy. Its low cost and high performance in addition to its reliability make them the most popular alternating current motors used in the industrial and commercial fields [1]. These motors have the litheness of application fields; they can be employed in low power applications such as household appliances or in large power applications such as petroleum industry. Regardless of the fact of elevated reliability of induction motors, the operating conditions may represent the machine into dissimilar fault conditions. These faults may lead to machine shut down, thus causing industrial production losses. Avoiding the unexpected shutdowns is an imperative task for industries. In order to accomplish this task the induction motor has to be continually monitored to identify faults in early stages. Exposure of these faults in advance enables the protection engineers to take the indispensable corrective actions as quickly as possible. The main types of external faults experienced by an induction

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motor are over loading, single phasing, unbalanced supply voltage, locked rotor, phase reversal, ground faults, and under/over voltage. The history of fault monitoring and fault isolation started with the use of electromechanical relays to protect the motor against faults [2]. However, these electromechanical relays are slow in operation, consume significant power, and require periodic maintenance due to mechanical parts involved. The introduction of semiconductor technology had a positive impact on the induction motor protection field, and replaced the electromechanical relays by solid state relays as their operating speed is faster, consume less power, cheaper to manufacture and provide more reliability. Development of microprocessor technology in late 1970's enabled their application in the induction motor protective relays [3]. These relays allow the protection logic to be implemented by software programs.

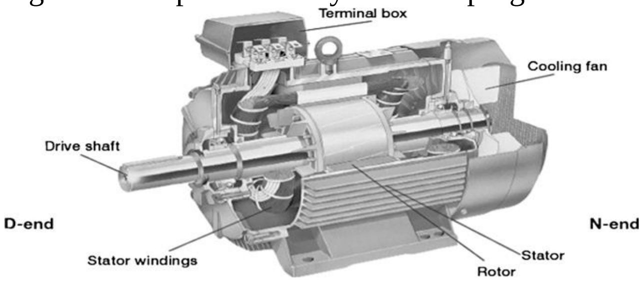

Fig. 1 Induction Motor

Faults In Induction Motor: The foremost faults of IM can broadly be classified as the subsequent:[4,5]

Three-phase induction motors are the most commonly used motors especially in industry because of their reliability and simplicity. These motors experience dissimilar types of faults during their operation [2]. These faults can be classified as intrinsic and extrinsic faults. The extrinsic faults include:

1. Over loading
2. Single phasing
3. Unbalanced supply voltage
4. Locked rotor
5. Phase reversal
6. Ground fault
7. Under voltage
8. Over voltage

A concise depiction of these faults and their characteristics is given below. Fortification of these motors is an imperative task which has been challenging to engineers. Protective relays were used to supervise these faults and detach the motor in case of a fault. Divergent relays used for protecting adjoining to these faults are also described below.

Overloading: Overload fault can take place when the mechanical torque exceeds the threshold point by applying mechanical load to the motor greater than full load rating. Overloading causes augment in phase currents, over heating the machine. In a conventional relay protection system (RPS), the over current relay trips the motor off-line when the current transformers (CT) encounter over current in the line.

Single phasing: Single phasing is a kind of unbalanced cases of the motor. It happens when one of the three lines are open. Complementary current flows through the other two lines and additional heat is generated in stator winding. In the traditional protection systems, a high-set instantaneous trip unit relay is used [2]. Single phasing also gives ascend to negative sequence current. A negative sequence relay can also be used to defend against this fault.

Unbalanced supply voltage: There are numerous causes of unbalance supply voltages for example unbalance loading, open delta transformers and unequal tap setting. This condition leads to reduction in motor efficiency, raises the motor temperature and excessive unbalanced full load current [6]. Three-phase voltages and currents during an unbalanced supply the protection design should detect over current condition during unbalanced supply [2].

Locked Rotor: Locked rotor takes place when the voltage is applied to a non-rotating motor. The stator current may be approximately six times its rated value during this situation [6]. There are various causes for this fault to happen for instance, if the rotor shaft is connected to heavy load the motor may experience locked rotor conditions. Locked rotor causes elevated current which leads to heating the rotor. Consequently locked rotor condition cannot be withstood for a long time. The permissible duration of the motor overloaded under locked rotor circumstance depends on the voltage applied to the motor terminals. Therefore, the protection system should be able to disconnect the motor when locked rotor condition exceeds the amount of allowed time. Traditional protective systems use over current relays with I-T characteristics [2].

Phase Reversal: Phase reversal take place when any of the two phases are reversed from the normal progression, which leads the motor to rotate in the reverse direction. When the motor starts to rotate in the opposite direction, it can cause intensive damage. Therefore, this condition should be corrected immediately. Reverse-phase relays and negative sequence relays are used for the protection [2].

Ground Fault: Ground faults occur when any of the phases touches the ground. Ground faults are further recurrent in motors than any other power system, since of their violent condition and frequent starts. The effects of this fault are intensive such as causing hazards to human safety and interference with telecommunication. It can be detected by measuring the ground leakage current [2].

Under Voltage: Under voltage fault is reducing the supply voltage on the three phases by specific percentage, which makes the motor from attaining rated speed in specified time, increases the current and overheats the machine. Low voltage protection relays are generally used in conventional systems. On the other hand, in order to avoid unwanted relay shutdowns due to momentary voltage drops, the AC contacts need a delay mechanism which delays the under voltage protection for a time period. This additional mechanism needs high sensitive devices and involves calibrations [2].

Over Voltage: Over voltage occur if the three phase voltages are greater than rated voltage. The consequence of this fault is increasing current flow which leads offensive stress on the motor insulation due to high heat dissipation. Conventional protection systems use the over voltage relays to protection the motor during this condition [2].

Related Work: For the diagnosis of induction motor fault different authors developed various techniques, in this section former work done for the detection of induction motor fault is presented below:

Sabouri and Ojaghi et al. [7] presented a novel technique based on evolutionary algorithms for identifying severity of ball bearing faults in three-phase induction motors. The proposed technique can be used to determine if the induction motor bearings are still in healthy condition or there is some defect at their inner or outer raceway. These defects cause basic motions on the air gap distribution that can be recognized as temporary air gap eccentricity. The particle swarm optimization algorithm is used to estimate severity of the resultant temporary air gap eccentricity. At this end, a rather exact model of the induction motor is required with the proposed bearing faults at variable severities. Winding function approach is extended to develop such model. This is a non-invasive technique because it uses only the line voltages and line currents of the stator. Other advantages of this method include: insensitive to unbalanced supply voltage, load level variation and temperature variation. The proposed technique is evaluated using simulation data obtained for a 2.2 kW three-phase induction machine. The simulation results demonstrated the effectiveness of the proposed technique for the diagnostics of the bearing faults.

Patole and Bhagwat [8] presented three phase induction motor model has been designed in LabVIEW. It has been modeled in such a way that it can be simulated as an ideal or healthy motor as well as a faulty motor having faults such a stator winding fault, rotor fault and bearing or eccentricity fault. It can be simulated for various ratings of induction motors and the values of current, voltages and different waveforms associated with the faults can be obtained which can be used in any application where faults in induction motors need to be detected.

Hui-Wei et al. [9] presented an adaptive fault tolerant control (FTC) of nonlinearly parameterized systems with uncontrollable linearization. The progress was made due to the development of a novel feedback design technique called adding a power integrator, which was motivated by homogeneous feedback stabilization and was proposed initially for global stabilization of nonlinear systems with uncontrollable linearization.

SENOL et al. [10] scrutinized the application of induction motor stator current signature analysis (MCSA) using Park's transform for the exposure of rolling element bearing damages in three-phase induction motor. This chief discussed bearing faults and Park's transform, and after that gives a concise overview of the radial basis function (RBF) neural networks algorithm. In end, system information and the experimental results are presented. Data acquisition and Park's transform algorithm are dexterous by means of LabVIEW and the neural network algorithm is accomplished by using MATLAB programming language. Experimental consequences demonstrate that it is feasible to perceive bearing damage in induction motors using an ANN algorithm.

Singh and Kumar [11] presented the study; motor current signature analysis technique has been used to detect the faulty bearing installed in load machine (coupled to an induction motor). It has been seen that faulty bearings installed in load machines don't directly alter air-gap eccentricity of an induction motor. In fact, these bearing faults affect the resultant torque of an induction motor. As modulating fault components show very low amplitude, these are usually masked by noise. Present paper is devoted towards extracting features of faulty components efficiently from stator current using continuous wavelet transform. Present methodology is assessed for detecting outer race faults in bearings installed in load machines using motor current signature analysis.

Ergin et al. [12] faults in induction motors were diagnosed using the Common Vector Approach (CVA). In order to verify the performance of CVA, a database including stator current signals for normal and faulty cases with 1.5A loading condition was used. The current signals belong to six identical induction motors one of which is normal and remaining ones are faulty motors. The 2-step One-Dimensional Discrete Wavelet Transform (1D-DWT) is applied on the current signals in order to construct feature vectors of each class in the database. While performing CVA, the leave-30-out strategy was followed to test all feature vectors in the database. Substantially satisfactory recognition results were obtained for wavelet energy component-based features.

Kompella et al.[13] presented an approach to detect the bearing faults experienced by induction machine using motor current signature analysis (MCSA). At the incipient stage of bearing fault, the current signature analysis has shown poor performance due to domination of pre fault components in the stator current. Therefore, in this paper domination of pre fault components is suppressed using noise cancellation by Wiener filter. The spectral analysis is carried out using discrete wavelet transform (DWT). The fault severity is estimated by calculating fault indexing parameter of wavelet coefficients. It is further proposed that, the fault indexing parameter of power spectral density (PSD) based wavelet coefficients gives better results. The proposed method is examined using simulation and experiment on 2.2 kW test bed.

Altaf et al. [14] presented an efficient supervised Artificial Neural Network (ANN) learning technique that is able to identify fault type when situation of diagnosis is uncertain. Significant features are taken out from the electric current which are based on the different frequency points and associated amplitude values with fault type. The simulation consequences illustrate that the projected technique was able to diagnose the target fault type. The ANN architecture worked well with selecting of significant number of feature data sets. It seemed that, to the outcomes, precision in fault detection with features vector has been achieved during classification performance and confusion error percentage is acceptable among healthy and faulty condition of motor.

Monitoring Technique: There are a lot of methods which have already been used in the last four decades for health monitoring of the machine but most commonly used techniques are described below:

Magnetic Flux Monitoring: Abnormal harmonics which materialize in the stator current are functions of a number of variables due to Magneto Motive Force (MMF) allocation and permeance-wave representation of the air-gap. Consequently a few distortions in the air-gap flux density due to stator insufficiency sets up an axial flux in the shaft. The axial magnetic leakage flux of an induction motor is voluntarily measured using a circular search coil which is positioned on the non-drive (rear) end of the machine, concentric with the shaft. The seek coil fabricates an output voltage which is proportional to the rate of change of the axial leakage flux. This signal surrounds many of the identical frequency components which are present in the stator current. It is particularly useful for estimating the speed as it contains a strong component at the slip frequency [15-16].

Vibration Monitoring: Vibration monitoring approach is the oldest health monitoring approach of the induction motor. It is broadly used to discover mechanical faults such as bearing failures or mechanical imbalance. A piezo-electric transducer providing a voltage signal proportional to acceleration is regularly used. This acceleration signal can be integrated to furnish the velocity or position [17].

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. Because of the shorted turns in the stator winding the value of stator current will be extremely high and thus it generates extreme heat if proper action would not be taken and consequences into the destruction of the motor. Thus, some researchers have introduced thermal model of electric motor. Basically this model is classified into two parts:

a) Finite element analysis (FEA) based model

b) Lumped parameter based mode

Air Gap Torque Monitoring: The air gap torque is produced by the flux linkage and the currents of a rotating machine. It is extremely sensitive to several unbalance created due to deficiencies as well as by the unbalanced voltages. Since, all types of motor faults generate the side bands at special frequencies in the air gap torque. Though, it is not probable to determine the air gap torque openly. The discrepancy between the estimated torques from the model gives an indication of the subsistence of broken bars. From the input terminals, the immediate powers consist of the charging and discharging energy in the windings. For that reason, the instantaneous power can not represent the instantaneous torque. Since the output terminals, the rotor shaft and mechanical load of a rotating machine comprises a tensional spring system that has its own natural frequency. The attenuates of the components of air gap torque transmitted through the tensional spring system are different for different harmonic orders of torque components. But by using this method it is not easy to diagnose all faults.

Noise Monitoring: By measuring and analyzing the acoustic noise spectrum we are able to do noise monitoring. Because of the air gap eccentricity the noise is formed. This noise is used for fault detection in induction motor. On the other hand, it is not the precise way to perceive the fault by noise monitoring because of the noisy background from the other machines. Ventilation noise is connected with air turbulence, which is fashioned by periodic disturbances in the air pressure due to rotating parts. The noise is caused by the Maxwell's stresses that act on the iron surfaces. These forces are responsible for producing the noise in the stator structure [18].

Stator Current and Voltage Monitoring

- The stator current is usually measured using a clip-on hall-effect current probe. It contains frequency components which can be related to a variety of faults such as mechanical and magnetic asymmetries, broken rotor bars and shorted turns in the stator windings. Most of the published research work in current years has examined the utilization of the stator current for health monitoring. Particularly using frequency analysis [19-20].
- This can be securely measured using high frequency differential voltage probe or isolation amplifier. It has been used to determine the instantaneous power, instantaneous torque and negative sequence impedance.

Induction Motor Fault Detection Method: The faults of induction motor can be identified by using different such as SVM, ANN, Fuzzy logic, Expert system etc. some of them is describing below:

Multi-Dimensional Space Techniques: Multiple fault parameters can be taken into account by representing each fault parameter as one dimension of a multiple-dimensional space. A given set of parameters corresponds to a point in this space. Points for healthy operation are located in different regions in this space from points for faulty operation. Fig. 2 A Hyper Plane is Chosen to Separate Data for Healthy and Faulty Machines [21]. The support vector classification approach [22] tries to find a linear combination of parameters (geometrically represented by a hyper plane) that will separate the healthy data from that faulty data as shown in fig 2. Another approach is to try to define geometric regions in the space which correspond to healthy operation and to faulty operation [22].

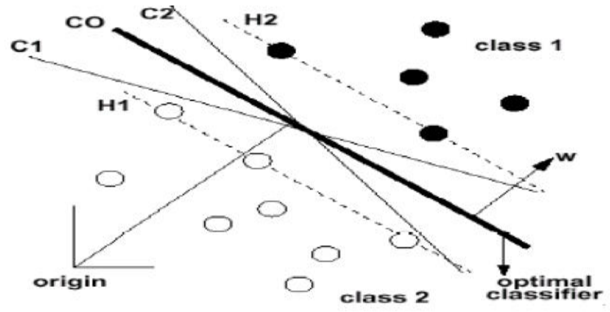

Fig.2 Hyperplane to separate data for healthy and faulty machine

Neural Networks: Artificial neural networks are modeled on the neural connections in the human brain. Every artificial neuron accept several inputs, applies preset weights to each input and generates a non-linear output based on the result. The neurons are connected in layers between the inputs and outputs [23]. The training of the neural network is performed by feeding in selected sets of parameters corresponding to known healthy and faulty machines and adjusting the input weights of the neurons to give the required output in each case [22].

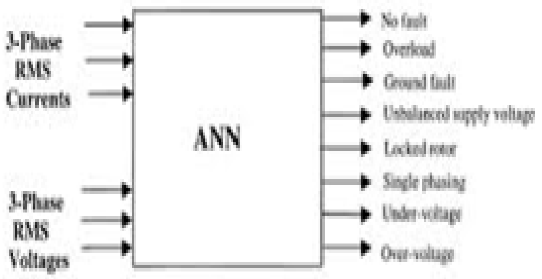

Fig.3 : Induction motor fault condition detection using ANN

Fuzzy Logic: This engross 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[24].

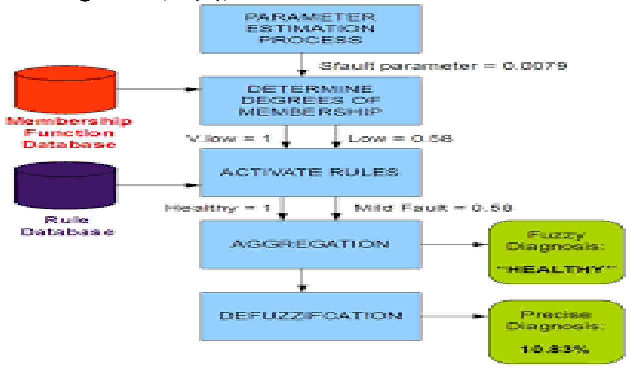

Fig.4 : Induction motor fault condition detection using Fuzzy Controller

Expert Systems: 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 [25].

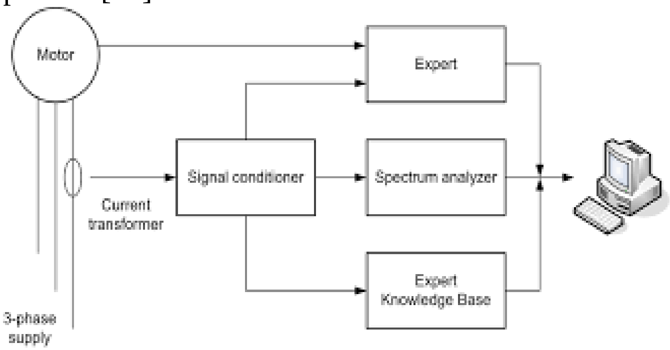

Fig.5: Expert system for IM fault detection

Conclusions: Induction motor assumes a huge part in Industrial application however in these different faults can likewise happen. To enhance the reliability and execution of induction motor constant observing is basic and it likewise decreases its maintenance cost. In this paper a comprehensive literature review of the fault diagnosis in induction motor is introduced and furthermore fault detection methods, for example, neural system, expert system, support vector machine and so forth. There are different technique has been developed to analyze the fault however the vast majority of the strategy is useful for consistent speed of induction motor. Wavelet transform is one of the image processing techniques which additionally help to analyze the fault than neural system, fluffy rationale and master framework. The greater part of the strategies are single sensors with particular signal processing technique so in future develop such technique which can utilize multiple sensors to analyze the fault of induction motor.

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