Induction Motor Faults and Artificial Intelligence Based Conditioning and Monitoring Techniques

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Abstract— Three phase induction motors have been intensively utilized in industrial applications, mainly due to their efficiency and reliability. These motors have good properties such as increased stability, robustness, durability, large power to weight ratio, low production costs and controllability easiness. All machines realize various stresses during operational conditions. These stresses might lead to some modes of failures or faults. Condition monitoring is necessary in order to prevent faults. These faults, are necessary to be identified and categorized, as soon as possible as they can end up in serious damages if not detected in due time. Different techniques of fault monitoring for induction motors are broadly classified as techniques based on model, signal processing, and soft computing. In recent years the monitoring and fault detection of electrical machines have moved from traditional techniques to Artificial Intelligence (AI). In this paper an attempt has been made to review different faults on induction motors and the applications of neural/fuzzy artificial intelligence techniques for induction motor condition monitoring. A brief description of various AI techniques highlighting the merits and demerits of each has been discussed. The futuristic trends on condition monitoring of induction motors are also indicated.

Keywords: Induction Motor (IM), Artificial Intelligence (AI), Fuzzy Logic (FL), Artificial Neural Network (ANN)

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I. INTRODUCTION

Modern industrial machines are mutual operation dependent with high cost of unexpected breakdowns. Thus condition monitoring techniques comprising of fault diagnosis and prognosis are of great concern in industry and are gaining increasing attention. Induction motor condition monitoring is a continuous motor serviceable life evaluation of the health of the motor. Protection and condition monitoring are closely related functions. Condition monitoring should be designed so as to pre-empt faults that can occur in the induction motor. Primary protection function is to recognize the occurrence of faults at an early stage. Warnings in advance are necessary to allow operator to schedule sequence in the safest manners. With proper condition monitoring of machines, we can reduce unexpected downtime and failures, to initiate standard maintenance procedures, and maintenance and operational cost reduction. Faults like rotor faults, short turn winding faults, gear faults, bearing faults and misalignment are general internal faults of IM. These general internal faults can be mainly classified in 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.

In recent years the monitoring and fault detection of electrical machines have moved from traditional techniques to Artificial Intelligence. AI based techniques have certain distinct advantages over traditional condition monitoring approaches. In the present paper an effort has been made to present a review of the application of AI techniques especially neural network and fuzzy logic for induction motor condition monitoring. These systems can be integrated together and also with other traditional techniques.

Fuzzy Logic (FL) has emerged as a profitable tool for the controlling of subway systems and complex industrial processes, as well as for household and entertainment electronics, diagnosis systems and other expert systems. FL is basically a multi-valued logic that allows intermediate values to be defined between conventional evaluations like yes / no, true / false, etc. Discrimination between rather warm or cold can be formulated and processed by computers. In this way an attempt can be made to apply a more human like thinking in the programming of computers. Fuzzy controllers are the application of fuzzy theory. They are different than conventional controllers; expert knowledge is used rather than differential equations to analyze a system. A FL based approach can help to diagnose faults in induction motors. FL is like a human thinking process and natural language based decisions to be made based on information. FL allows items to be categorized as having a certain membership degree in a particular set. During fault diagnosis, there are various situations in which an object is not "Good" or "Damaged", but may fall into some interior category. According to the fact that induction motor condition interpretation is a fuzzy concept, here the motor condition is described using linguistic variables. Fuzzy subsets and respective membership functions reflect amplitudes of stator current. A knowledge base, comprising rule base is built to support the fuzzy inference. The condition of induction motor is diagnosed using fuzzy inference rules. The obtained results indicate that the proposed FL approach is capable of highly accurate diagnosis. Humans express knowledge (like an electrical machine referred as "somewhat secure", "little overloaded"). This linguistic input can be represented by a fuzzy system.

The stator current signal carries potential fault information. A three-phase induction motor may experience several types of fault conditions which include over load, ground fault, line to line fault, unbalanced supply voltage, over voltage, under voltage, single phasing, turn to turn fault. When one of the three-phases to the motor is open, single phasing situation occurs. This result increased positive and negative sequence currents and hence excessive heating. Negative sequence voltage is produced due to unbalance in supply voltage. It leads to increase in positive and negative sequence current components. Ground and line faults are prevalent in motors than other power system devices. These faults can be detected from the nature of the zero sequence current. Similarly turn to turn short and coil open faults can cause current unbalance. From the various literature analyses it is clear that various faults can be categorized with the help of stator current values. Stator currents are used because the sensors required for the purpose, usually present in the drive. The conventional monitoring systems have a number of drawbacks such as non flexibility, costlier, limitations of hardware which are mainly dependent upon application of instruments.

II. FAULTS IN INDUCTION MACHINES

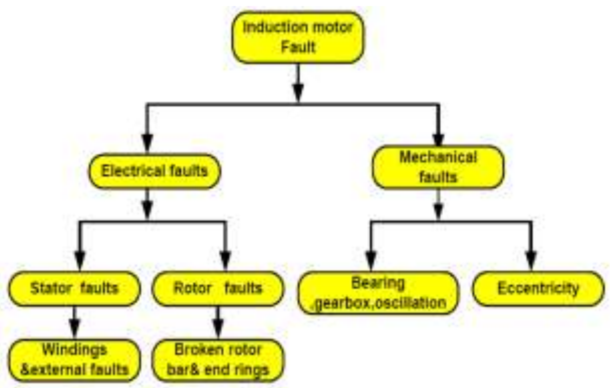

Figure 1: Fault classification in induction motors

A. Electrical faults:

The following electrical faults are very common in three-phase IM while operating in industries.

i) Rotor faults

Generally, low rated machines are manufactured by die casting whereas high rating machines are produced with copper rotor bar. Several related technological problems can be due to rotor manufacturing by die casting technology. It has been found that squirrel cage IMs show asymmetries in the rotor due to technological difficulties, or melting of bars and end rings. However, rotor failures may also result due to several other reasons. There are several main reasons of rotor faults.

- Due to brazing process in manufacture, non uniform metallurgical stresses may be produced into cage assembly and thus can also lead to failure during operation.
- A rotor bar may not be able to move longitudinally in the slot it occupies, when thermal stresses are produced during starting of machine.
- Heavy end ring results in large centrifugal forces, which can produce dangerous stresses on bars.

Due to the above mentioned reasons, rotor bar may get damaged and simultaneously rotor unbalance may occur. Rotor cage asymmetry results in the asymmetrical rotor currents. Due to this, damage of the one rotor bar can cause the damage of surrounding bar, thus damages can spread, leading to cascade bar fractures. In case of a crack, which occurs in a bar, the cracked bar may overheat, and can cause breaking of the bar. Thus, the surrounding bar will carry increased currents and hence are subjected to even larger mechanical and thermal 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. So, the increased thermal stresses can damage the rotor laminations. The rotor lamination temperature distribution is changed because of the rotor asymmetry. The cracking of the bar can be at various locations, including bars slot portion and end rings of bar joints. The possibility of cracking in the area of the end rings of bar joints is the highest when the start up time of the machine is long and when frequent starts are required.

ii) Stator turn faults

According to the survey, 35-40% of IM failures are related to the stator winding insulation. Also, it is generally true that a large portion of stator winding related failures are initiated by insulation failures in many turns of a stator coil within one phase. This type of fault is referred as a “stator turn fault”. A stator turn fault for a three phase symmetrical AC machine causes a large circulating current to flow and subsequently produces excessive heat in shorted turns. If the heat which is proportional to the square of the circulating current advances the threshold value, complete motor failure may occur. However, the worst consequence of a stator turn fault may be a serious accident resulting in loss of human life. The organic materials used for insulations in electric machines are subjected to deterioration from a combination of cycling and thermal overloading, mechanical stresses, transient overvoltage stresses on the insulating material, and contaminations. Among the possible causes, thermal stresses are the strong reason for the degradation of the insulation of stator winding. Stator winding insulation thermal stress is categorized into 3 types: aging, overloading and cycling. Even the best insulation may fail quickly if motor is operated above its temperature limit. As a thumb rule, the life of insulation is reduced by 50% for every 10^0C increase above the temperature limit of stator winding. It is hence necessary to monitor the stator winding temperature so that an electric machine will not cross its thermal capacity. For this purpose, several techniques have been reported. However, the inherent limitation of these techniques is that they are unable 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 warm bearing, air gap eccentricity and broken rotor bars. The stator winding current produces a force on the coils that is proportional to the current square. This force is at its maximum under transient overloads, causing the vibration of coils at twice the synchronous frequency with movement in both the radial and the tangential direction. This movement results in weakening of integrity of the insulation system. Mechanical faults, such as air-gap eccentricity, broken rotor bar, worn bearings, may be a reason for the rotor strikes the stator windings. Hence, such mechanical failures must be detected before they fail insulation of stator winding. Foreign materials contamination lead to adverse effects on the insulation of stator winding. The presence of foreign materials can lead to a reduced in heat dissipation. Hence it is important to keep the motors dry and clean, especially when the motors operate in a hostile environment. Regardless of the causes, stator winding various failures can be classified into the five groups: turn-to-turn, coil-to-coil, line-to-ground, line-to-line, and open-circuit faults as presented in figure 7. Among these failure modes, turn to turn faults (stator turn fault) have been considered the most challenging one since the other types of faults are the consequences of turn faults. Furthermore, turn faults are very difficult to detect at their initial stages.

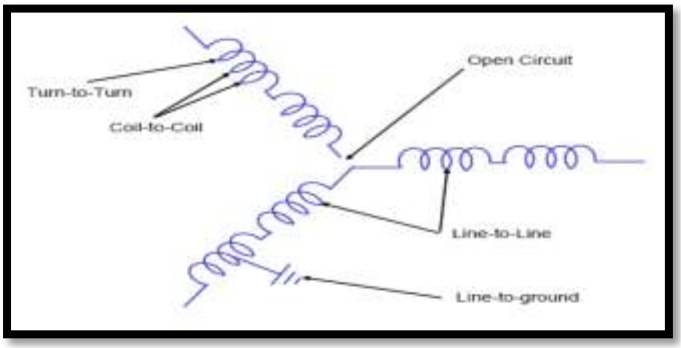

Figure 2: Different short and open stator winding turn faults

B. Mechanical faults

Common mechanical faults found in three phase IM are Air gap eccentricity, bearing faults and load faults.

III. AI BASED TECHNIQUES

Some of the AI based techniques for conditioning and monitoring of IM are discussed below

A. Artificial Neural Network (ANN)

The ANN tries to simulate a mathematical model of biological brain neural network. It is a set of simple processing unit, connected with each other and with weights assigned to the connections. According to a learning rule it is possible to modify these weights, so, the ANN is trained to acknowledge a pattern amongst the given training data. There are several transfer functions such as tan hyperbolic, sigmoid, etc. There are different kinds of neural network structures proposed. The most commonly used structure is the feed forward network. There are many hidden layers in the network. The figure 11 shows two hidden layer. In this network, the number of input nodes and output nodes are obtained by the number of patterns to be identified. The nodes in the hidden layer is selected for an application, generally uses a trial and error method. The neural network is to be trained to identify the output patterns corresponding to input pattern. There are many kinds of training algorithms suggested. The back propagation is one of the most popular algorithms.

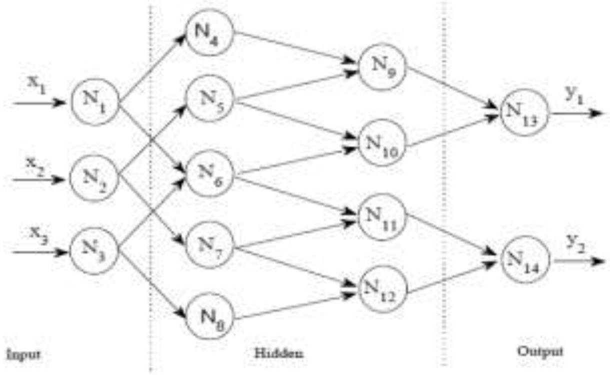

Figure 3: Feed-forward neural network.

Application of ANN:

In the use of ANNs some parameters are chosen by the user. One critical decision is to determine the appropriate architecture, that is, the number of layers, number of nodes in each layer.

Choose the best architecture by testing three different architectures topology. For the mechanical faults we use 4x3x1, 4x5x1 and 4x10x1 (which represent input x hidden x output), and for the electrical faults we use 3x3x1, 3x5x1 and 3x10x1. Topology that showed better results was 4x5x1 for mechanical faults and 3x3x1 for electrical faults.

The maximum error was kept below 0.5%, the learning rate, the momentum and the maximum number of epochs, are assumed as 0.01, 0.9 and 1000, respectively, and the weights was initialized randomly. In input and hidden layer neurons, we considered a sigmoidal activation function and output layer neurons use linear function. We use an activation velocity of 0.001.

B. Fuzzy Logic

The concept of FL was introduced by Zadeh to present vagueness in linguistic terms and express human knowledge in a natural way. With the FL it is possible for control systems to evaluate concepts unquantifiable, as thermal sensation (hot, warm, cold, etc.). In other hand, the FL is an Boolean logic extension that admits intermediary values in between, FALSE (0) and TRUE (1), e.g., MAYBE with weight of 0.5. This means, a fuzzy value has any value in the range between 0 and 1.

In practice, a FL system can get certain knowledge, allowing taking decisions with a higher accuracy percentage. This knowledge is expressed in membership functions and rules are obtained from the study, in this case, of the IM, through engineer experience. From the point of view that sees IM condition as a fuzzy concept, there has been some FL approaches for diagnosis. The lack of accurate processing of fuzzy input data and construction of rules and membership functions, are presented as major difficulties.

Application of the Fuzzy Logic:

The output variables represent the different kind of faults, Unbalance (UB), Misalignment (MA), Mechanical Looseness (ML), Short Circuit (SC), Phase Unbalance (PU) and Broken Bars (BB) and health condition (HC).

The amplitudes of the vibration signals (inputs) are categorized using three linguistic variables for mechanical faults Small (S), Medium (M) and High (H) and two linguistic variables for electrical faults Small (S) and High (H). The IM condition (outputs) are categorized as No Fault (NF), Intermediate Level (IL) and Critical Level (CL) for mechanical faults and categorized as No Fault (NF) and With Fault (WF) for electrical faults.

The system was tested with triangular, trapezoidal and Gaussian membership functions. It was found that the combination of Gaussian and triangular membership function is the most appropriated for fault diagnosis of IMs using as input vibration signals.

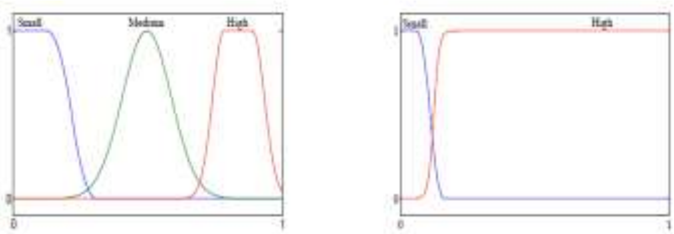

Figure 4. a) input membership functions for mechanical faults detection

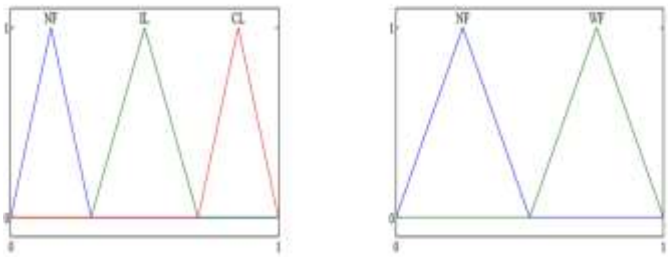

Figure 4.b) output membership functions for mechanical faults and electrical faults.

A fuzzy system can store certain knowledge, which allows it to make decisions with a high percent of accuracy. This knowledge is expressed in rules. Rules connect the inputs with the outputs to take the decision about the IMs condition.

CONCLUSION

Having reviewed the IM faults and techniques for fault diagnosis of an induction machine it is seen that accurate models of the faulty machine and model based techniques are essentially required for achieving a good fault diagnosis. It is difficult to obtain exact models of the induction motors and in application of model based techniques. While, soft computing approaches such as FL, artificial neural networks provide good tools for system analysis even though accurate models are not available.

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