International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 1 Issue 5, July - 2012

Induction Motor Noninvasive Fault Diagnostic techniques: A Review

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Abstract

This paper reviewed non-invasive diagnostic techniques utilized for electrical machines with special reference to induction motors. Induction motors come across various abnormalities and faults consider as external and internal faults. This Review mainly focussing on recent fault detection methodologies, based on soft computing, Signal processing and hybrid approaches.

Key words: soft computing, Artificial Intelligence (AI), Motor current signature analysis (MCSA), Artificial Neural Network (ANN), Fuzzy Logic, Expert Systems (ES), RMS (Root Mean Square value), Self Organizing Map(SOFM), Rotor Slot harmonics (RSH)

1. Introduction

Induction motor is a most widely used industrial load and consumes a major part of overall electrical consumption. Area of fault diagnosis in electrical machines and power systems is increasing interest area for academicians as well as for industry. The wide variety of environments and conditions motor exposed to, misoperations and manufacturing defects can make it subject to incipient faults or gradual deterioration and can lead to motor failure if left undetected. Most electric motor failures interrupt process, reduce production and may damage related machinery. Sometime a small HP motor failure can also create hours of plant stoppage in continuous processing industries. Reliable and healthy operation of induction motors is the major need of industries. There many ways used by the industry to tackle the problem like preventive and corrective maintenance, keeping spare motors, protective system etc;. In some industries very expensive scheduled maintenance performed in order to prevent sudden motor failures. Therefore there is considerable demand to reduce maintenance cost and prevent unscheduled downtime for electric motors and drive systems. Early fault detection or correct fault detection and classification allows scheduling maintenance which reduces the maintenance efforts by reducing failure and downtime and improves the overall availability of motor driven system. It increases the revenue by reducing failures.

Still in many industries the lower hp motors are protected by fuses and overload relay which is not sufficient to protect the motor from all kind of failures. A comprehensive cost effective protection technology is a major need. Induction motors appears to different kind of faults or abnormalities which can majorly divided in two parts external and internal faults. Undervoltage, overvoltage, phase failure, unbalance supply, mechanical overload, locked rotor, Earthfault between supply feeder and motor terminals and three phase fault at the terminals are considered as external failure and short circuit Stator interturn failure, bearing, rotor faults, eccentricity consider as internal faults.

There are invasive and noninvasive methods for fault detection. The traditional electromechanical and static relay based protection technologies in industry are invasive methods as require insertion of temperature sensors for example bearing and winding temperature RTD. As in [3] the location of the temperature detection device used to measure temperature impact significant on degree of protection. The noninvasive methods are more preferable because they are based on easily accessible and inexpensive measurements to diagnose the machine conditions without disintegrating the machine [1, 5]. These schemes are suitable for on-line monitoring and fault detection purposes [5].

For the investigation in the area of fault diagnosis and protection some important issues are

1) A comprehensive noninvasive protection scheme which covers all external and internal faults and also provide operator heuristic knowledge incorporation depend upon the condition or trending.

2) Applicability of artificial intelligence to solve the problem like stalling, excessive start time, frequent start etc;

3) Quantitative fault detection in order to state an absolute threshold, independent of operating conditions [45, 27]

4) Fault detection in inverter-driven motors [45, 27]

Noninvasive Methods which can be utilized for the fault diagnosis in induction machine discussed here are classified in three categories, Soft computing methods which include mainly ANN, Fuzzy logic and expert systems based diagnosis, Signal processing based Approaches and Hybrid approaches. The use of combination of induction motor model and ANN, Model and fuzzy logic, Neurofuzzzy approach, Model and any signal processing method etc; are considered here as hybrid approaches. There are some others approaches also like thermal measurements, chemical analysis, axial flux, noise and vibration monitoring, infrared recognition etc; for the problem solution worked upon.

2. AI based approaches

The Noninvasive Parameter estimation technique, require mathematical model and elaborate understanding of system dynamics based on system parameters. The parameters are usually chosen to reflect the motor conditions and usually difficult to obtain. In addition, as in [5] the interpretation of the fault conditions-which is a fuzzy concept using rigorous mathematical formulations is generally impractical and inaccurate. ANN is proposed for fault identification and other power system applications [10, 31] & is emerging technologies promising for future widespread industrial usage [5, 8]. Artificial Neural Network are used to implement the incipient fault detection scheme no modelling of the machine is necessary. As in [6] With proper monitoring and fault detection schemes, the incipient faults can be detected; thus, maintenance and down time expenses can be reduced while also improving safety. Many of the conventional methods used to determine these faults are either very expensive to implement, performed off-line, require the need of an expert, or impractical for small machines, ANN have been proposed and have demonstrated the capability of solving the motor monitoring and fault detection problem using an inexpensive, reliable, and noninvasive procedure An overview of feedforward nets and the backpropagation training algorithm, along with their respective pseudocodes, and a general methodology for the design of feedforward artificial neural networks to perform motor fault detection is discussed in [5]. Neural network design considerations such as network performance, network implementation, size of training data set, assignment of training parameter values, and stopping criteria discussed and a fuzzy logic approach to configure the network structure has been presented to automate the network design in [8]. A Neural Network fault detector composed of two parts one for filtering noise and disturbance while retaining steady state measurements and other to detect fault developed for single phase motor. Neural network trained using controllable data sources developed using a computer programme for initial design and training of ANN for bearing and stator turn fault detection[9]. Feedfoward layered network structure and backpropogation algorithm used in ANN technique applied for identification of external faults of induction motor. Three phase current and voltages from the induction motor are used in approach. RMS value calculated using DFT [10]. Radial basis function utilized to train ANN for the detection of bearing and stator interturn fault. Instantaneous current and angular velocity depending upon rotor speed are utilized in the approach [12]. PC based monitoring and fault detection scheme for 3 phase I.M using ANN developed in [11]. A scheme for detection of stator turn consists of a FF neural network combined with a SOFM is shown in [14] to display the operating condition of the machine on two dimensional grid. The operating point moves as faults start developing and can be used to alert motor protection system to incipient fault but SOFM not able to reliably detect a fault when autotransformer added to create unbalance supply in different phase. A diagnosis of three phase induction motor stator fault carried out with Hebbian based unsupervised NN and using Principal component analysis based algorithm by deriving α and β component of line current. The direction of NN eigenvector obtained from this component used to discern motor healthy or not in [7].

An Artificial Neural Network used to learn characteristic of good operating motor may contain harmonics due to load in [30] and a frequency filter is employed to passes only harmonics importance to fault detection. After sufficient training period, neural network signals a potential failure condition when a new cluster formed if persists for some time for online fault prediction possible. Fault detection comparison between support vector machine and back propagation algorithm using experiment data in [28] and the training patterns are obtained using MCSA and spectral Park's vector. A experiment test were conducted in [31] by varying thermal induced stress between ambient and maximum rated temperature of winding and online sequence components were calculated, monitored by previously offline trained neural network act as negative sequence model of induction motor to detect the turn fault.

Simulated RMS values of parameters are taken for ANN training for external faults classification and Applicability of NN for fault detection and protection discussed in [38]. Using simulated faults and radial basis function Neural network train for external fault detection. Instantaneous values of faults are taken and shown network classified the faults correctly in [39].]. A filter bank of Neural network time series models are created for normal and faulty motor, Bayesian classifier is used for correct classification of fault and tested with different types of FEM simulated fault data in [46].

Conventional ANN can correctly detect the faults but cannot provide heuristic interpretation of the solution due to its numerically oriented structures. Some Engineers prefer the accurate fault detection as well as the heuristic knowledge behind the fault detection process. Fuzzy logic is a technology that can easily provide heuristic reasoning while being difficult to provide exact solutions. Methodology behind a novel hybrid Neurofuzzy system which merges the neural network and fuzzy logic technologies to solve fault detection problems and training procedure for Neurofuzzy fault detection system is discussed for single phase induction motor bearing and stator turn fault detection in [6]. This procedure will be used to determine the correct solutions by constructing the fault detector using fuzzy membership function module and fuzzy rule module. In [19] trained Neurofuzzy fault detector provide accurate fault detector performance; also provide the heuristic reasoning behind the fault detection process and the actual motor fault conditions through the fuzzy rules. A knowledge base is built in [36] to support the fuzzy inference for the detection of external fault like voltage unbalance and open phase wherein fuzzy subset and corresponding fuzzy membership function describe stator current amplitudes.

3. Signal processing based approaches

One of the most frequently used fault detection methods is the MCSA. This technique depends upon locating faults according to the position of specific harmonic components in stator current spectrum like broken rotor bars, air-gap eccentricity, bearing fault, faults in stator windings, etc. As advantage of the method only a single current transducer is required for its classical method and can also be applied on-line. Signal processing techniques are applied to the measured sensor signals in order to generate features or parameters (e.g. amplitudes of frequency components associated with faults) which are sensitive to the presence or absence of specific faults. Calculation of simple statistical parameters such as the overall RMS value of a signal can give useful information. For instance, the RMS value of the vibration velocity is a convenient measure of the overall vibration severity [4, 27]. In the same way, the RMS value of the stator current provides a rough indication of the motor loading. Some of the main stator current signature based techniques discussed in [41,27] are frequency analysis based Classical FFT & Instantaneous FFT, Bispectrum periodic with a period of 2π and preserves both magnitude and phase information, High Resolution spectral analysis and Wavelet analysis. The other frequency analysis technique can also be well associated for MCSA are Park's vector approach. Fourier analysis is useful for stationary signals while in transitory signal Short time Fourier Transform and Wavelet analysis. STFT represents a sort of compromise between time and frequency based view of signal but used with limited precession as fixed size of window. Wavelet transform overcome this limitation. A windowing technique with variable-size region is then used to perform the signal analysis, which can be the stator current. Wavelet analysis allows the use of long time intervals where we want more precise low-frequency information, and shorter regions where we want high-frequency information [41]. Park vector approach is based on the locus of the instantaneous spatial vector sum of three stator currents. This locus is affected by stator winding faults and air gap eccentricity. Park's vector monitored in [48] for identifying stator interturn fault whose ellipticity increased with the severity of the fault and its major axis orientation is associated to faulty phase.

[16] measures current spectra to detect faults in three phase induction motors but does not distinguish supply voltage unbalance condition. [20] analyzed motor current spectrum under faulty conditions (inter-turn short circuits) and illustrated that RSH in the motor current are amplified under stator winding fault conditions. In [22] RSH in the motor spectrum are sensitive to supply voltage unbalance. They have presented a method using the RSH in the terminal voltage spectrum just after switch off so it does not have aforementioned problem but is included in off line methods. A method proposed in [15] based on motor current signature analysis for detection of inter-turn short circuits in the stator winding of I.M. utilizes three phase current spectra to overcome the problem of distinguishing stator interturn fault form voltage unbalance as in case of classical MCSA where only one transducer used in one phase. Although the magnitude of these harmonics depends upon the level of voltage unbalance, they have the same magnitude in three phase in these conditions, While in short circuit the magnitudes differ from each other. However machine asymmetry is not considered while supply unbalance voltage condition occurs. Using high resolution spectral analysis of stator current spectrum through experiment the voltage unbalance and open phase external fault condition identified [32]. In [33] two approaches based on discrete wavelet transform utilized for the induction motor fault detection wherein first fault detection criteria is the comparison between threshold determined experientially during healthy condition of motor and DWT coefficients of fault currents using selected mother wavelet 'db3' at the sixth level of resolution utilized and second based on comparison of modulus maxima of the DWT coeffiecients. Wavelet packet transform based protection system developed in [40] coefficients of the Wavelet Packet Transform line currents compared experimentally decided threshold for detecting and diagnosing various disturbance occurring in induction motor. Single phasing, phase to earth and short circuit faults.

4. Hybrid Approaches

Combination like I.M Model and any signal processing method, Model and soft computing method etc; are considered here as a hybrid approach for the fault detection of induction motor. Induction machine model have been simulated in [17, 18, 26] for its behaviour analysis in Matlab/Simulink using symmetrical I.M d-q model. As in [17] dynamic simulation of small induction motor based on mathematical modelling is one of the key steps in the validation of the design process of motor drive system and [34] discussed induction machine model wherein all parameter are accessible for control and verification purposes. d-q model provides guide lines for dynamic simulation of induction motor, which can also applied for some faults data generation. [26] Shows the results of studies under acceleration, variable load and open phase using this model. Conventional d-q model and development of its current, torque and power relationships are based on the assumptions that MMF produced by stator winding excitation is sinusoidally distributed in space and that the rotor MMF due to the slip frequency induced currents is similarly distributed. Space harmonic are not considered which may exist due to motor asymmetry. The existence of space harmonics creates detrimental effect on the steady state and transient characteristic of the machine.

[1,34] developed a transient model using winding function approach and magnetic coupled circuit theory, model [34] can extended for the solution of rotor bar, end ring and stator faults. Rotor fault cause-effect relationships studied in [1] using stator current and frequency signature. [2] suggested way for formulate the suitable model using the decomposition of mutual inductance matrix into Fourier series and

presentation of induction motor in park frame and extend the model for solution of rotor bar fault. Winding function approach is used which accounts for all space harmonics in the machine and analysis of induction motor under stator or rotor asymmetries is presented in [24]. A generalized two axis model of a sq. Cage induction motor based on winding function approach and magnetic coupled circuit theory developed in [25] and a dynamic model in [43] developed which takes into account stator and rotor faults. Induction Motor stator current Concordia patterns are computed under different load and fuzzy logic approach used to find the stator fault in [47]. [21] Proposes fault detection based on signal processing as predictive filter and soft computing fuzzy logic. Finite Element Method used to generate virtual data that allow testing the technique and foreseeing the change in current under different motor conditions like broken bar, eccentricity and interring turn short circuit. In [23] a faulty model using park d-q model developed assumed that one of the phase has two windings in series, represent the unaffected portion and shorted portion and then used fuzzy system to identify the motor stator condition with high accuracy for stator interturn fault. Stator open phase identified using d-q model and fuzzy logic. [29] uses neural/expert system to solve fault detection. Protection scheme for incipient faults using Microcontroller established in [37] using dynamic modelling of induction machine. Limit values are entered for incipient faults and when unexpected situation occurs it trip contactor. Fuzzy logic systems lack ability of self learning and fuzzy membership functions and fuzzy rules cannot be guaranteed to be optimal. Fusion of neural network and fuzzy logic like Adaptive network based fuzzy inference system and fuzzy adaptive learning control/decision network partly overcome the problem with reducing convergence time. Genetic Algorithm can also be used to optimize the parameter and structure of neural network and fuzzy logic systems [42]. An overview of complete current based noninvasive monitoring and protecting techniques for stator rotor, bearing and thermal overload related failure is presented in [44]

5. Conclusion

This paper discuses the importance of induction motor in field application and need of fault detection and classification techniques This paper attempted to review internal and external fault noninvaisve detection methodologies considering recently utilized AI based, Signal Processing based and hybrid approaches. Model based approach also covered in hybrid approach.

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