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# Induction machine drive condition monitoring and diagnostic research—a survey

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**Abstract**

The subject of machine condition monitoring is charged with developing new technologies to diagnose the machinery problems. Different methods of fault identification have been developed and used effectively to detect the machine faults at an early stage using different machine quantities, such as current, voltage, speed, efficiency, temperature and vibrations. One of the principal tools for diagnosing rotating machinery problems has been the vibration analysis. Through the use of different signal processing techniques, it is possible to obtain vital diagnostic information from vibration profile before the equipment catastrophically fails. A problem with diagnostic techniques is that they require constant human interpretation of the results. The logical progression of the condition monitoring technologies is the automation of the diagnostic process. The research has been underway for a long time to automate the diagnostic process. Recently, artificial intelligent tools, such as expert systems, neural network and fuzzy logic, have been widely used with the monitoring system to support the detection and diagnostic tasks. This paper reviews the progress made in electrical drive condition monitoring and diagnostic research and development in general and induction machine drive condition monitoring and diagnostic research and development, in particular, since its inception. Attempts are made to highlight the current and future issues involved for the development of automatic diagnostic process technology.


*Keywords:* Induction machine; Fault; Health monitoring; Diagnostic; Artificial neural network

## 1. Introduction

Electrical motors are the majority of the industry prime movers and are the most popular for their reliability and simplicity of construction. Although induction motors are reliable, they are subjected to some mode of failures. These failures may be inherent to the machine itself or due to operating conditions. The origins of inherent failures are due to the mechanical or electrical forces acting in the machine enclosure. Researchers have studied a variety of machine faults, such as winding faults, unbalanced stator and rotor parameters, broken rotor bars, eccentricity and bearing faults. Different methods for fault identification have been developed and used effectively to detect the machine faults at different stages using different machine variables, such as current, voltage, speed, efficiency, temperature and vibrations. Thus, for safety and economic considerations, there is a need to monitor the behaviour of large motors, as well as small motors, working in critical production processes.

Traditional maintenance procedures in industry have taken two routes; the first is to perform fixed time interval maintenance, where the engineers take advantage of slower production cycles to fully inspect all aspects of the machinery. The second route is to simply react to the plant failure as and when it happens. However, making use of today's technology, a new scientific approach is becoming a new route to maintenance management. One of the key elements to this new approach is predictive maintenance through condition monitoring, which depends upon the condition of the plant. Condition monitoring is used for increasing machinery availability and performance, reducing consequential damage, increasing machine life, reducing

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spare parts inventories and reducing breakdown maintenance. An efficient condition-monitoring scheme is capable of providing warning and predicting the faults at early stages. There are many condition-monitoring systems installed in different types of engineering plants [1,2]. Monitoring system obtains information about the machine in the form of primary data and through the use of modern signal processing and analysis techniques, it is possible to give vital diagnostic information to equipment operator before it catastrophically fails. The problem with this approach is that the results require constant human interpretation. The logical progression of the condition-monitoring technologies is the automation of the diagnostic process. To automate the diagnostic process, intelligent diagnostic systems are used.

Recently artificial intelligent techniques, such as expert system, neural network, fuzzy logic and genetic algorithm, have been employed to assist the diagnostic task to correctly interpret the fault data. Neural network technique [3] has gained popularity over other techniques as it is efficient in discovering similarities among large bodies of data. Artificial neural network (ANN) is the functional imitation of a human brain, which simulates the human decision-making and draws conclusions even when presented with complex, noisy, irrelevant information [4]. The neural network can represent any non-linear model without knowledge of its actual structure and can give result in a short time during recall phase.

From the early stages of developing electrical machines, researchers have been engaged in developing a method for machine analysis, protection and maintenance. The use of advanced methods of technology increases the precision and accuracy of the monitoring systems. The area of condition monitoring and faults diagnostic of electrical drives is essentially related to a number of subjects, such as electrical machines, methods of monitoring, reliability and maintenance, instrumentation, signal processing and intelligent systems. This paper deals with a state-of-the-art discussion of the electrical drive condition monitoring and diagnostic research and development in general and induction machine drive condition monitoring and diagnostic research and development in particular, highlighting the analytical and technical considerations as well as various issues addressed in the literature towards practical realization of this new technology for health monitoring of the induction machine.

## 2. Modelling and analysis

A basic paper for induction machine analysis has been reported by Stanley [5]. The analysis made by Stanley is based on the direct three-phase model using phase variables and its presentation in shifted reference axis. Later on, many researchers made their contributions on the basis of the machine model given by Stanley with some modifications. However, since the main objective of this paper is not the machine modelling, only few selected papers from several papers that are reported in this area are discussed here.

Hughes and Alderd [6] have suggested a general model for the transient and unbalanced operation of two and three phase induction machine. The machine equations are expressed with respect to $\alpha\beta - dq$ coordinate. The model is simulated using an analogue computer and the obtained results are compared with practical results. Sarkar and Berg [7] have presented a direct three-phase model using phase variables and two axis models for a three-phase induction machine. The models are simulated using digital computer. The machine performance under rectangular waveform supply is also included. Jacovides [8] has reported the model of a drive consisting of a three-phase induction motor fed from a full bridge cycloconverter. The model based on phase variables and the Gaussian elimination method is used to reduce the order of the connecting matrix. Murthy and Berg [9] have presented a dynamic model based on instantaneous symmetrical components theory. The model is used to obtain the transient behaviour of thyristor-controlled three-phase induction motor. The model covers most of the operating modes and the analysis is carried out without reference to the rotor position. Krause and Lipo [10–13] and many other researchers have reported different analytical techniques based on phase variables and reference frame transformations for three-phase induction machine. Different machine and supply conditions have been included.

Fallside and Wortley [14] and Ueda et al. [15] have studied the effect of supplying the machine from variable frequency source from the point of view of stability. The effect of the machine parameter's variation on the machine stability has been discussed. Levi et al. [16,17] have reported the modelling of induction motor and synchronous machine considering sinusoidal and non-sinusoidal supply. The models are based on $d$–$q$ axes and the analysis includes the effect of machine saturation and core loss. Different control strategies of induction motor are also considered. Neto et al. [18] have presented a mathematical model of three-phase induction motor using phase variables. The model is based on the harmonic impedance concept and accordingly, the voltage and torque equations are derived. Two cases are included in the analysis, supplying the machine from sinusoidal and non-sinusoidal supply using PWM inverter. Toliyat et al. [19–21] have developed an analysis method for modelling the multiphase cage induction motor. The model considers the mmf harmonics using winding function approach. The model is used effectively to simulate different types of machine faults, such as asymmetry in the stator winding, air-gap