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**ABSTRACT**

This work studied the use of neural networks for model based fault diagnostics of induction motors. The idea was to use data provided by accurate FEM simulations of motor operation under different fault and load conditions to create identification based neural network model models which can be used for online fault diagnosis. The neural network models are created for each phase of the three phase induction motor, and each load condition is handled separately. Most of the faults cases have to be left out due to the unavailability of data for different fault conditions. The data is often a restriction for data-based models, because each different situation would require its own set of data, along with data for validation and testing. In literature in one of the work a FEM model of a 35 kW induction motor was simulated for cases of a healthy, rotor faulted and stator faulted motor. The parameters for the model were obtained from a real operational motor. No real measurement data was used, but studies with FEM simulations of induction motors show that the data is very realistic with respect to the data obtained from real motor measurements [Arkkio 1990]. Measurement data from a real motor was, however, used as an input to the FEM models in the data group that was used to build the time series models. Induction motors are one of the commonly used electrical machines in industry because of various technical and economical reasons. These machines face various stresses during operating conditions. These stresses might lead to some modes of failures/faults. Hence condition monitoring becomes necessary in order to avoid catastrophic faults.

**KEYWORDS:** Electrical Drives

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**INTRODUCTION**

Three-phase induction motors are the “workhorses” of industry and are the most widely used electrical machine. Because of its simple structure and high reliability, induction motor is used for many purposes such as: pumps, blowers, fans, compressors, transportation, etc. In an industrialized nation, they can consume between 40 to 50 % of total generated capacity of that country. However, owing to the thermal, electrical and mechanical stresses, mechanical and electrical failures are unavoidable in induction motors. Early detection of abnormalities in the motor will help to avoid expensive failures. Operators of electric drive systems are under continual pressure to reduce maintenance costs and prevent unscheduled downtimes that result in lost production and loss of financial income. The modern industry has widely used reliability-based and condition-based maintenance strategies to reduce unexpected failures and downtime. These techniques can increase the time between planned shutdowns for standard maintenance and reduce maintenance and operational costs. The operation of the machine in unsafe condition must also be avoided. Nevertheless, the failures are unavoidable, and failure statistics has reported that the percentage of failures in induction motor components is as follows:

- 1) Bearing related faults: 40%
- 2) Stator winding related faults: 38%
- 3) Rotor related faults: 10%
- 4) Other faults: 12%

It is important to note that even if the stator fault account makes up 38 % of the all faults, it is very important to spot them in time because they can lead to the total destruction of the motor. A reliable system for the detection of such a fault should be able to detect the fault at an early stage, monitoring the motor condition online.

## VARIOUS CAUSES/STRESSES LEADING TO STATOR FAULTS

The stator is subjected to various stresses such as thermal, electrical, mechanical, and environmental, which severely affects the stator condition leading to faults. The stator defects/faults can be broadly classified into the following two categories.

1) Laminations (Core hot spot, Core Slackening), frame (Vibration, Circulating currents, loss of coolants, earth faults).

2) Stator windings Defects/Faults: The most common defects/faults of stator windings are related to either the “end winding portion” or the “slot portion” as given below:

a) End-winding portion (local damage to insulation, cracking of insulation, turn-to-turn faults, discharge erosion of insulation)

b) Slot portion (fretting of insulation, displacement of conductors)

The various causes of stator failures have been identified. The majority of these faults are caused because of a combination of various stresses acting on the stator, which can be classified into thermal, electrical, mechanical, and environmental.

### ***Thermal Stresses:***

These stresses might be due to thermal aging and thermal overloading. As a thumb rule, for every 100C increase in temperature, the insulation life gets halved due to thermal aging. The effect of temperature on thermal aging can be minimized by using any of two approaches to ensure longer thermal life: either by reducing the operating temperature or by increasing the class of insulation materials used. Thermal overloading can occur due to the applied voltage variations, unbalanced phase voltage, cycling overloading, obstructed ventilation, higher ambient temperature, etc. As a thumb rule, for every 3.5% voltage unbalance per phase, the winding temperature increases by 25% in the phase with the highest current.

### ***Electrical Stresses:***

The electrical stresses leading to winding failures can be classified into dielectric, tracking, corona, and transient voltage conditions. The definite relationship between insulation life and the voltage stresses applied to the insulating materials has to be taken into consideration while selecting the materials and establishing the coil designs for adequate design life. These stresses can be classified into phase-to-phase, turn-to-turn, and turn-to-ground. If the insulation system is not completely protected from the environment, then in the motors with operating voltages over 600 V, a phenomenon known as tracking occurs in the windings leading to ground failures. Transient voltage conditions result in reduced winding life or premature failure (either turn-to-turn or turn-to-ground). These conditions can be caused by line-to-line, line-to-ground, multiphase line-to-ground, and three-phase faults, repetitive restriking, current-limiting fuses, rapid bus transfers, opening and closing of circuit breakers, capacitor switching, insulation failure, lightning, and variable frequency drives.

### ***Mechanical Stresses:***

These stresses might be due to coil movement and rotor striking the stator. The rotor can strike the stator due to a number of reasons like bearing failures, shaft deflection, rotor-to-stator misalignment, etc. If the strike happens only during startup, then the force of the rotor can cause the stator laminations to puncture the coil insulation, resulting in grounding the coil. If the rotor strikes the stator when the motor is running at full speed, then the result is very premature grounding of the coil in the stator slot caused by excessive heat generated at the point of contact. There might be many other causes for winding failures like rotor balancing weights coming loose and striking the stator, rotor fan blades coming loose and striking the stator, foreign particles/bodies entering the motor through the ventilation system and striking the stator, a defective rotor (e.g., open rotor bars) causing the stator to overheat and fail, and broken lamination teeth striking the stator due to fatigue. A part of broken bars may work itself into the air gap, causing immediate failure to copper-iron.

### ***Environmental Stresses/Contamination:***

The presence of foreign material could cause various ill effects on the functioning of the motor-like reduction in heat dissipation (which will increase operating temperature thereby reducing insulation life), premature bearing failure due to high-localized stresses, and breakdown of the insulation system (causing shorts and grounds). Every step should be taken to restrict/ minimize the moisture, chemicals, and foreign particles from interacting with the motor surface.

## CONDITION MONITORING ON INDUCTION MOTOR

Condition monitoring is an important issue in many fields, including railways, power delivery, and electrical machines and motors. Condition monitoring can be defined as a technique or process of monitoring the operating characteristics of a machine so that changes and trends of the monitored signal can be used to predict the need for maintenance before a breakdown or serious deterioration occurs, or to estimate the current condition of the machine. Considering an Example for Induction Motor Bearing Damage, it can be seen that Induction motors are a widely studied subject in condition monitoring. There are several different methods for recognizing failures. The most widely studied methods in bearing Condition monitoring is based on measurements of vibration, acoustic noise, or temperature. Vibration- and stator-current based methods seem to be some of the most popular. When monitoring bearing damage in induction motors, the characteristic frequencies of bearing damage are often used to monitor certain frequency components in either vibration or stator current signals.

### *Benefits Of Condition Monitoring*

Plant machineries are invaluable assets and are designed to operate under extremely harsh condition, where a failure may be catastrophic, both in safety and economic aspects.

- 1) Vibration Problem identification of rotating machines.
- 2) Exploring the cause of repetitive failure of machines
- 3) Ensuring the safety of the equipment against Vibration & Shock.
- 4) Dynamic balancing of Rotors and rotating components
- 5) Measurement of Natural frequency in static condition
- 6) Less downtime & more productivity
- 7) Reduced inventory for spares.
- 8) Enhancing the machine endurance limit
- 9) Greater safety to work force.

### *Monitoring Techniques*

These monitoring techniques have been classified into the following eight categories using different parameters is mentioned below.

#### *1) Magnetic Flux*

Any distortion in the air-gap flux density due to stator defects will set up an axial homopolar flux in the shaft, which can be sensed by a search coil fitted around the shaft. By using a minimum of four search coils located asymmetrically to the drive shaft, the location of shorted turn can be found out.

#### *2) Vibration*

The stator frame vibration is a function of inter turn winding faults, single phasing, and supply-voltage unbalance. The resonance between the exciting electromagnetic (EM) force and the stator is one of the main causes of noise production in electrical machines.

#### *3) Current*

The current drawn by an ideal motor will have a single component at the supply. The motor current signature analysis (MCSA) utilizes the results of the spectral analysis of the stator current of an induction motor to pinpoint an existing or incipient failure of the motor or the driven system. The diagnostic analysis has been reported by various researchers using the sequence components of current, radio-frequency (RF) component of neutral current, and shaft currents.

#### *4) Induced Voltage*

The voltage induced along the shaft of a machine (generator) is an indication of the stator core or winding degradation. Shaft voltage has not yet proved to be a useful parameter for continuous monitoring because it is difficult to measure in a reliable way. The maximum turn-fault sensitivity is obtained after band pass filtering around the fundamental frequency.

**5) Power**

The instantaneous electric power has definite advantages in comparison to current as a detection parameter. The characteristic spectral component of the power appears directly at the frequency of the disturbance, independent of the synchronous speed of the motor. The utilization of the instantaneous power enhances the reliability of the diagnostics of the induction motors.

**6) Surge Testing**

The surge testing is an established method for diagnosing winding faults. In the surge comparison test, two identical high voltages, high-frequency pulses are simultaneously imposed on two phases of the motor winding with third phase grounded. An oscilloscope is used to compare the reflected pulses indicating the insulation faults between windings, coils, and group of coils.

**7) Motor Circuit Analysis**

By measuring the EM properties of the electric motor as an electric circuit, the motor circuit analysis (MCA) determines the variations within the motor and identifies the defects. In MCA, a low amount of energy with amplified responses is applied. The responses help in evaluating the condition of both the windings and rotor through the comparative readings.

**8) AI-based fault monitoring approaches**

Despite the various techniques mentioned in the section, the monitoring and fault detection of electrical machines have moved from the traditional techniques to AI techniques in recent years. The main steps of an AI-based diagnostic mechanism are signature extraction, fault identification, and fault severity evaluation. The various AI techniques, expert systems, artificial neural networks (ANNs), fuzzy logic, fuzzy neural networks (NNs), genetic algorithms, etc. for the fault diagnostics of stator faults have been reported in the literature.

**DIFFERENT TYPES OF FAULTS IN AN INDUCTION MOTOR**

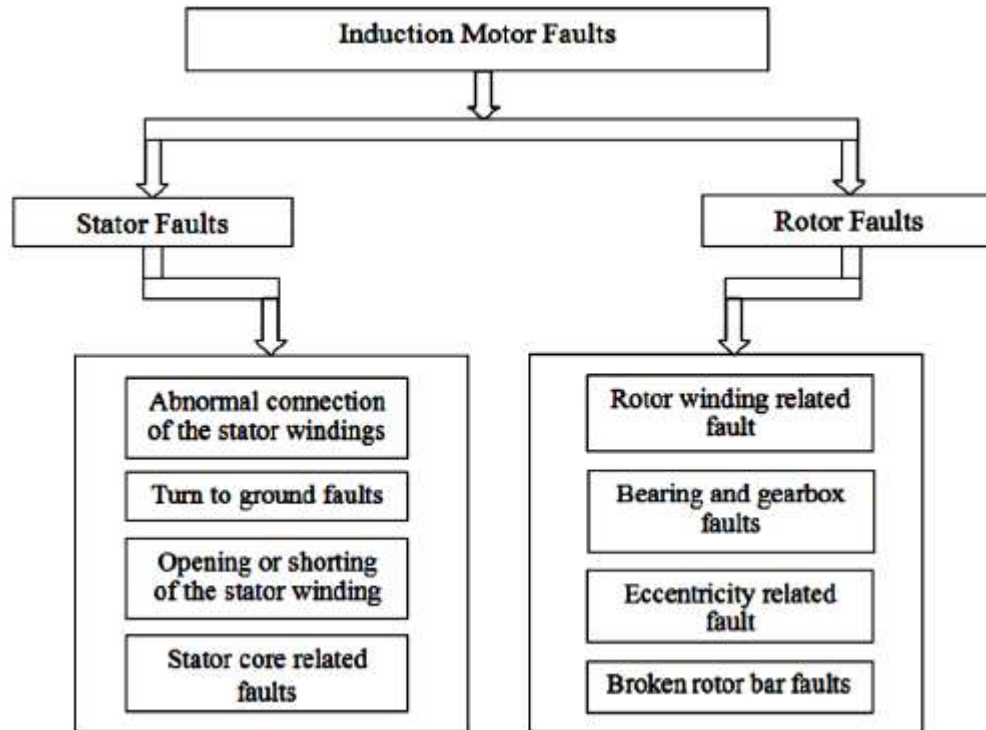
Induction motors are most commonly used electrical machines in industry because of their low cost, reasonably small size, ruggedness, low maintenance, and operation with an easily available power supply. Although these are very reliable, they are subjected to different modes of failures / faults. These faults may be inherent to the machine itself or due to operating conditions. The inherent faults may be due to the mechanical or electrical forces acting on the machine enclosure. If a fault is not detected or if it is allowed to develop further it may lead to a failure. The logical progression of the condition-monitoring technologies is the automation of the diagnostic process. To automate the diagnostic process, recently a number of soft computing diagnostic techniques have been proposed. Recently soft computing techniques such as expert system, neural network, fuzzy logic, adaptive neural fuzzy inference system, genetic algorithm etc. have been employed to assist the diagnostic task to correctly interpret the fault data. These techniques have gained popularity over other conventional techniques. These are easy to extend and modify besides their improved performance. The neural network can represent any non-linear model without knowledge of its actual structure and can give result in a short time. 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 above technique 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.

The most common faults to be found in induction machines are classified according to their location: stator and rotor which are as shown in Fig.1.

**Stator Faults**

Stator faults may be divided into two types these are as follows

1. Stator winding related faults
2. Stator core related faults



*Fig.1 Sources of Induction Motor Faults*

***Stator Winding related Faults***

According to an IEEE and Electric Power Research Institute motor reliability study, stator faults are mostly responsible for 37% of the failures in an induction motor. Many works have indicated that the majority of induction motor stator winding failures result from the destruction of the turn insulation. In most cases, this failure starts as a turn-to-turn (inter-turn) fault which finally grows and reaches in major ones such as coil-to-coil, phase-to-phase or phase-to-ground failures, and ultimately causing motor breakdown. Very often Stator winding of an induction machine is subjected to stresses induced by a variety of factors, such as thermal overloads, mechanical vibrations and voltage spikes caused by adjustable frequency drives. Some of the most frequent causes of stator winding failures are as follows.

- Due to high stator core or winding temperatures
- Due to Loose bracing for end windings
- Due to Contaminations caused by oil, moisture etc
- Due to short circuits
- Due to starting stresses
- Due to electrical discharges
- Due to leakage of cooling systems

***Stator Core related Faults***

Stator core problems are rare compared to stator winding problems are not usually a major concern for small machines. However, the repair/rebuild process is more costly in the case of the stator core failure, since it usually requires the entire core to be replaced. Therefore, there has been interest in identifying the causes of core problems and finding ways of monitoring the core in order to detect and prevent stator core failure. The stator cores of induction machine are built from thin insulated steel laminations with a view to minimize the eddy current losses at higher operational efficiency. In the case of medium or large machines, the core is compressed after the core laminations are stacked in order to prevent the individual lamination sheets from vibrating and to maximize the thermal conductance in the core.

The main causes of stator core failures are as follows:



- Core end-region heating resulting from axial flux in the end winding region
- Core melting caused by ground fault currents
- Lamination vibration resulting from core clamping relaxation
- Loosening of core tightening at the core end resulting from vibration during operation
- Manufacturing defects in laminations
- Inter laminar insulation failure
- Stator-rotor rubs during assembly and operation
- Arcing from winding failure

### ***Rotor related Faults***

The most common rotor faults in an induction machine may be classified as:

1. Rotor winding related faults
2. Broken rotor bar fault
3. Bearing and gearbox faults
4. Eccentricity related faults

### ***Rotor Winding related Faults***

Short circuit turns in induction machine rotor windings cause operational problems such as high vibration levels; therefore early detection is essential. Normally the resistance of the windings on opposite poles is identical. The heat produced by Joule's effect is distributed symmetrically about the rotor forging. If the inter-turn insulation is damaged, then the rotor winding become short circuited. The resistance of the damaged coil diminishes and if the poles are connected in series, less heat is generated than in the symmetrical coil on the opposite pole. The rotor body thus experiences asymmetric heating, which produces a thermal bow in the rotor body, causing vibration. The unbalanced magnetic forces on the rotor produced by the change in the magneto motive force (MMF) from the winding contribute to increased vibration.

### ***Broken Rotor Bar Fault***

Under normal operating conditions, large mechanical and thermal stresses are presents, especially if the machine is being continually stopped and restarted or if the machine is heavily loaded. It is well known that the rotor current during starting can be as much as ten times the normal full load current and that the effects of these large currents are represented by very large thermal stresses in the rotor circuit. The starting period is also characterized by minimal cooling and maximum mechanical forces, which over stresses the rotor bars. The cracked bar will increase in resistance and will over heat at the crack. The bar will break completely and arcing will occur across the break. This arcing will then damage the rotor laminations around the faulted bar. The neighboring bars will carry an increased current and will be subjected to increased stresses, eventually causing these bars to fail. Finally the broken bars may lift outwards because of centrifugal forces and could damage the stator winding.

### ***Bearing and Gearbox Faults***

As reported in literatures, bearing faults may account for 42%-50% of all motor failures, motor bearings may cost between 3%-10% of the actual cost of the motor, but the hidden costs involved in downtime and lost production combine to make bearing failure a rather expensive abnormality. Ball-bearing related defects can be categorized as outer bearing race defects, inner bearing race defects and ball defects. Different stresses acting upon a bearing may lead to excessive audible noise, uneven running, reduced working accuracy, and the development of mechanical vibrations and as a result, increased wear. More than twenty years ago, few bearing failures were electrically induced but at the beginning of the 90's a study showed that bearing failures are about 12 times as common in converter-fed motors as in direct on-line motors. However mechanical issues remain the major cause of bearing failure.

### ***Eccentricity related Faults***

Machine eccentricity is defined as a condition of the asymmetric air-gap that exists between the stator and rotor. The presence of a certain level of eccentricity is common in rotating electrical machines; some manufacturers and users specify a maximum permissible level of 5%, where as in other cases, a maximum level of 10% of the air gap length is allowed by the users. However, manufacturers normally try to keep the total eccentricity level even lower in order to reduce vibration, noise and minimize unbalanced magnetic pull. Since the air gap of an induction machine is

considerable smaller than in other types of machines with a similar size and performance, this type of machine is more sensible to changes in the length of the air gap. There are two types of air gap eccentricity: static air gap eccentricity and dynamic air gap eccentricity. In the case of static air gap eccentricity the position of the minimal radial air gap length is fixed in space, while in the case of dynamic eccentricity the center of the rotor is not at the center of the rotation and the position of the minimum air gap rotates with the rotor. Unless detected early, the eccentricity becomes large enough to develop high unbalanced radial forces that may cause stator-to-rotor rub, leading to a major breakdown of the machine.

### Faults in induction motor

Of all the electrical machines, induction motors are the most common in industry due to their simplicity, rugged structure, cheapness and easy maintainability. A three phase induction motor is the most popular poly phase induction motor. There are several different types of faults that can manifest themselves in an induction motor. Faults are often classified according to where they occur in the motor. The most common faults are stator faults, rotor faults, bearing faults and eccentricity faults. These faults are mechanical in nature, but they have varying effect on the electrical signatures of the motor. The most common faults can be further classified according as follows:

- 1) Stator faults resulting in the opening of the phase winding
- 2) Rotor faults due to broken rotor bars or broken end rings.
- 3) Static or dynamic air-gap irregularities (eccentricity faults)
- 4) Bent shaft (dynamic eccentricity)
- 5) Misalignment
- 6) Bearing and gear box failures

Eccentricity faults can be static or dynamic in nature. Static eccentricity is such that the rotor has uneven air-gaps with respect to the stator but the positions and sizes of the air-gaps remain the same, i.e. the axes of the stator and rotor do not coincide. In case of dynamic eccentricity the rotational axis of the rotor is not in the centre of the rotor. Thus the air-gaps vary dynamically as the rotor rotates in the case of dynamic eccentricity. Faults can occur due to external effects, mistakes in production or assembly, or due to bad operating habits. Frequently faults occur due to several factors. For example, motor faults are frequently internal, such as bearing or winding faults, but the reason can be external, such as overheating caused by excessive dirt.

### FEM (FINITE ELEMENT METHOD) MODELING

The rotor-fault is studied with two different cases:

- 1) A motor with three broken rotor bars and an end ring
- 2) A motor with one broken rotor bar.

A stator fault is a motor with a turn to turn short circuit in the stator windings. In general faults do not cause large deviations in the stator current, but some higher harmonics do arise, which can be detected from the data to some degree.

The induction motor is fed with a supply voltage of 3Phase, 400V, which is divided into three phases. All of these voltages are used as inputs. Each voltage gives rise to a stator current with the same fundamental frequency and the same phase shift as the corresponding voltage. Thus each phase is considered here to represent a separate I/O relationship in the following manner:

$$\begin{aligned}
 i_1(t) &= M(\varphi_1, u_1(t-1), \dots, u_1(t-n), i_1(t-1), \dots, i_1(t-n)) \\
 i_2(t) &= M(\varphi_2, u_2(t-1), \dots, u_2(t-n), i_2(t-1), \dots, i_2(t-n)) \\
 i_3(t) &= M(\varphi_3, u_3(t-1), \dots, u_3(t-n), i_3(t-1), \dots, i_3(t-n))
 \end{aligned}$$

Where 1, 2 and 3 represent the different phases,  $u_j(k)$  is the voltage,  $i_j(k)$  the current and  $\Phi_j$  a set of model parameters for phase  $j$  at time  $k$ . Function  $M$  is a neural network function, specifically a Multilayer Perceptron Network. A three layer neural network model was chosen as the basic neural network structure. The number of nodes for the hidden layer was determined empirically. The fault detection and identification (FDI) scheme is based on a model bank of different models, each of which represents a given motor operating condition (Fig.2). The models are built using

neural network based time-series models, which are constructed for the motor based on the data of the motor in a given condition. Measured input is given to the models from the motor and the model outputs are then compared to the measured motor output signal. A residual is formed from these differences between the system and model outputs. The residual is then used by some form of classifier to obtain a motor condition classification. The classifier chooses a model, which represents the data most accurately. Assuming valid and accurate model, this model should then be the model for the condition in which the system is operating at that moment. This is then used as the system fault classification result. Here a Bayesian classifier for classifying the motor condition from the residuals is used.

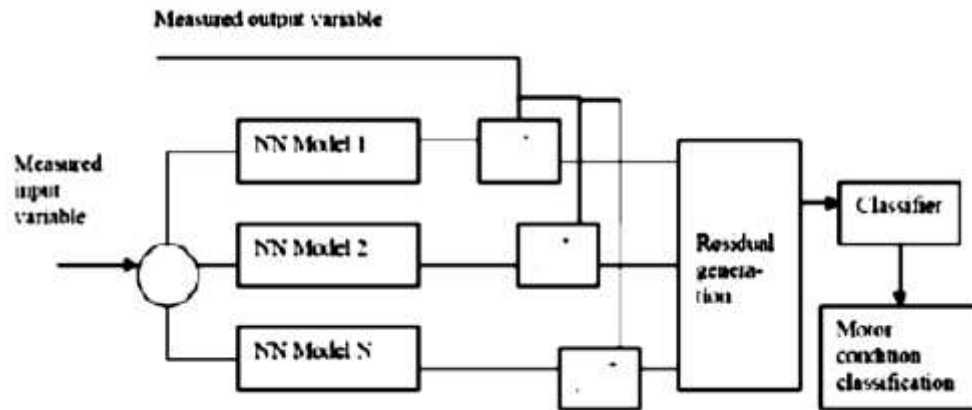
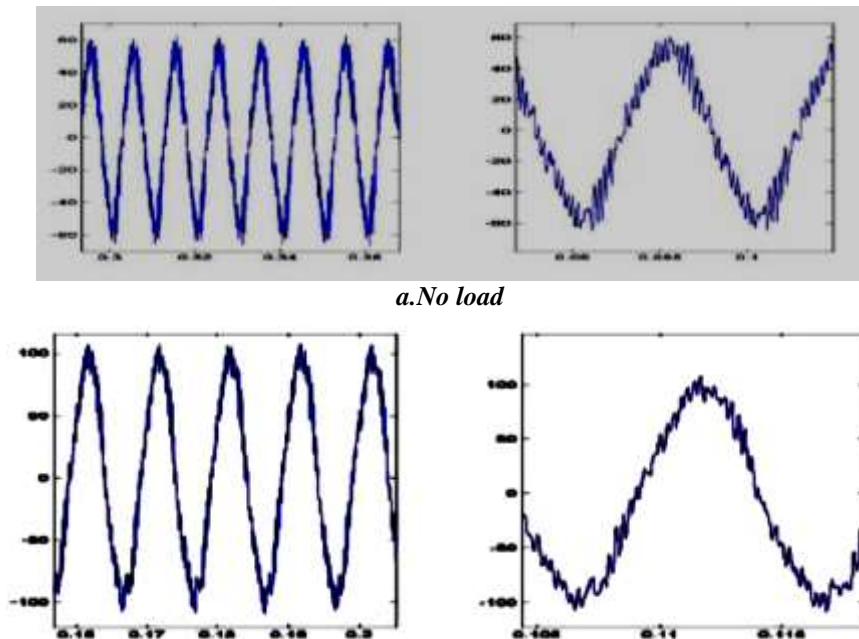


Fig.2 The structure of the model-based FDI system used.

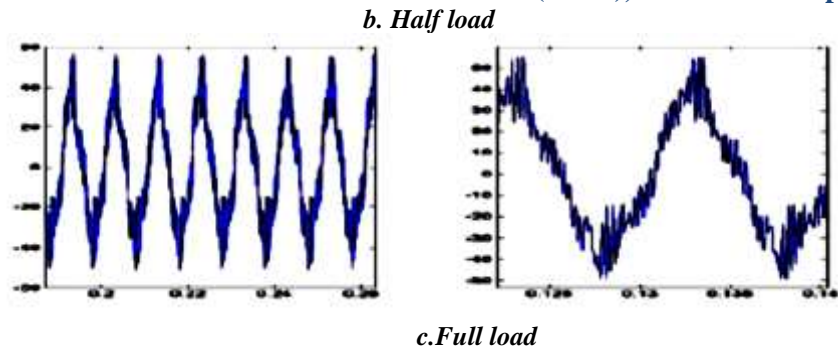
**DATA**

The data used in the study is generated using a FEM (Finite Element Method) model of an induction motor. The data is generated for three different load conditions: no load, half load and full load. The load is determined with respect to the nominal load present in the motor nameplate. The voltages used to feed the motor are obtained from a voltage converter. In some cases the motor can be fed with sinusoidal input voltage, but this study centers on motors with converter feed.

*Healthy motor*



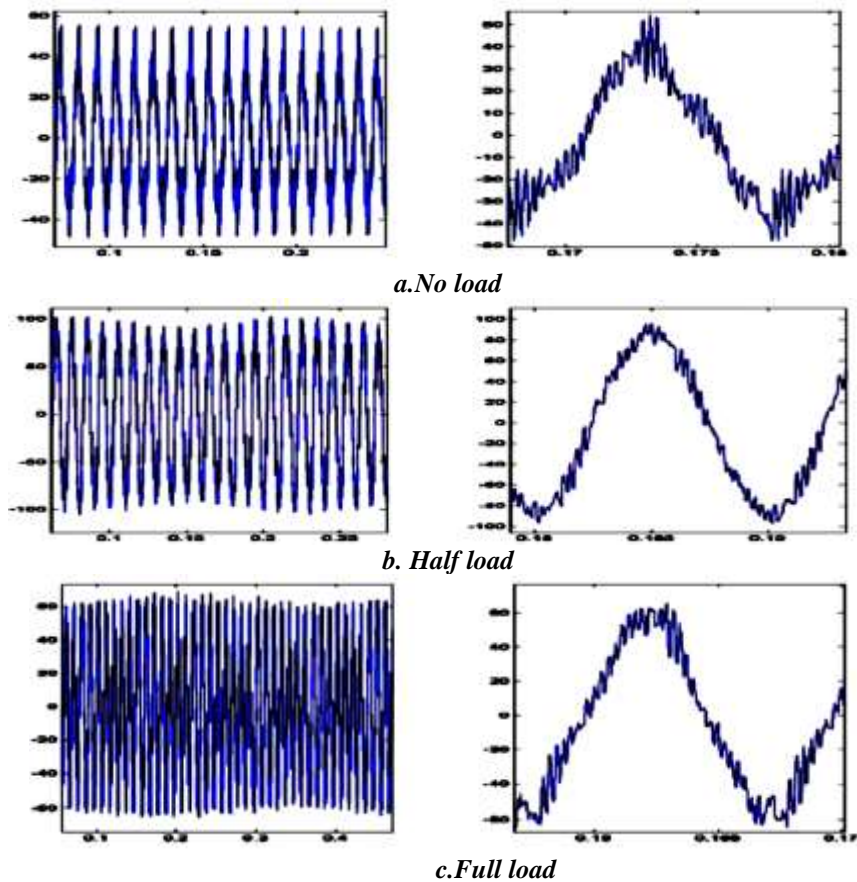




**Fig.3 Healthy stator current  $i_l$  with no load, half load and full load**

The figures above show the stator current ( $i_l$ ) when a healthy motor is under different load conditions. The right hand side picture on each figure is an up close zoom of the data on the left hand side. The figures show clearly that the amplitude of the stator current increases as the load increases. In no-load condition the amplitude maximum is 50 A, for half a load 60A and for full load 100A, approximately. The figures also indicate that the form of the stator current changes with respect to load. Hence it is suitable to model the different load conditions separately.

**Motor with rotor fault**



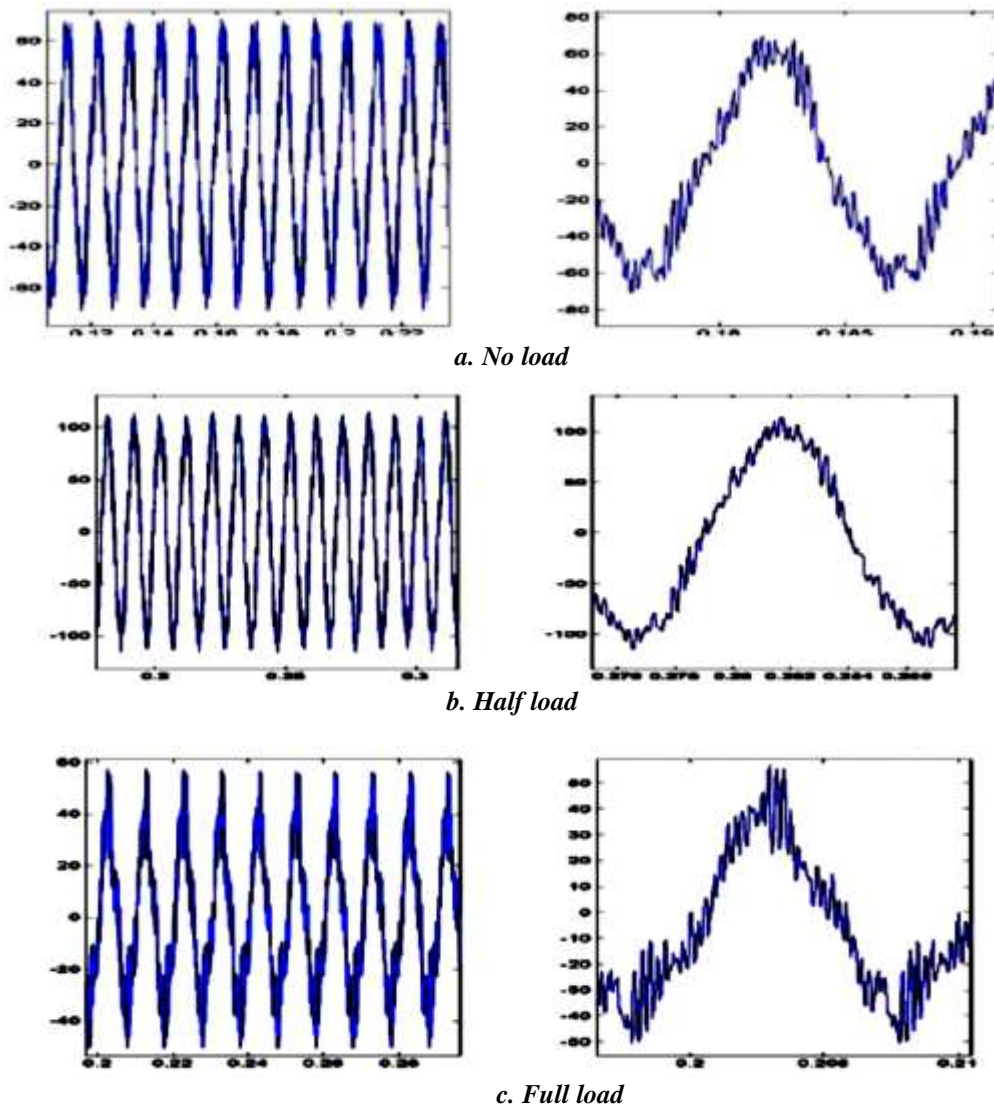
**Fig.4 Stator current  $i_l$  of a rotor faulty motor with no load, half load and full load**

Again the figures show that the amplitude increases with respect to the load. A rotor fault causes low frequency oscillation in the stator current which is more apparent in the higher load conditions. This can be seen from the figure

on the left hand side. The amplitudes of the data are at the same level as in the healthy case, i.e. a rotor fault does not seem to cause an increase in amplitude by itself. There are, however, subtle changes in the shape of the data but no obvious characteristics of faults can be seen by eye.

**Motor with a stator turn fault**

The analysis of currents shows that load is a significant factor in the shape of the stator current; hence it is necessary to obtain measurements in a steady state with a known load. The load can be estimated using the slip, because it is known that slip increases as a function of load. The figures also show that adequate data for fault diagnosis can be obtained in a short time interval.

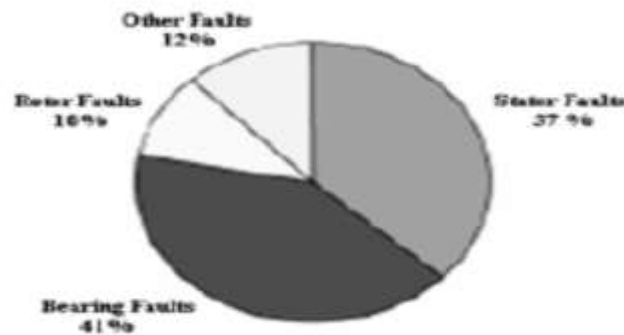


**Fig.5 Stator current  $i_1$  of a motor with a stator turn fault, with no load, half load and full load**

A data set from a time interval of 0.25s to 0.5s is enough to capture the low frequency oscillations. Most of the fault information is present in the higher order harmonics of the currents, thus it is necessary to have a high enough sampling frequency. Here sampling frequency of 40 kHz is used.

## ROTOR CAGE FAULT DETECTION IN INDUCTION MOTORS BY MOTOR CURRENT SIGNATURE ANALYSIS

Electric motors have revolutionized the way of human living and resulted in the modern life style that one used to. Induction motors have dominated in the field of electromechanical energy conversion by having 80% of the motors in use. Induction machine, with power ranging from few KW to several MW, are the most used electric actuators in industrial applications to drive pumps, fans, elevators, and conveyor systems. 75 % of the electrical energy generated in India is utilized for running industrial and domestic motors. These motors are playing important role in the industries, called as horses of modern industry. Induction motor failure surveys have found the most common failure mechanisms in induction machines. These have been categorized according to the main components of a machine i.e. stator related faults, rotor related faults, bearing related faults and other faults. Percentage of fault distribution is shown in fig.6.



*Fig.6 Fault distribution in Induction Motor*

The various causes of induction motor faults have been identified. The majority of these faults are caused because of a combination of various stresses acting on the stator and rotor, which can be classified into thermal, electrical, mechanical, and environmental. Most of the faults occurring in an induction motor produce one or more symptoms as given below:

1. Unbalanced air gap voltages.
2. Increased torque pulsations.
3. Decreased average torque.
4. Increased losses and reduction in efficiency.
5. Excessive heating, leakage current in stator windings.
6. Change in rotor time constant.

The diagnostic methods of identifying the above faults are given as:

1. Electromagnetic field monitoring, search coils
2. Temperature measurements
3. Infrared recognition
4. Radio-frequency (RF) emissions monitoring
5. Noise and vibration monitoring
6. Chemical analysis
7. Acoustic noise measurements
8. Motor current signature analysis (MCSA)
9. Partial discharge measurements
10. Current sequence detection

The history of fault diagnosis & protection of electrical machine is as old as such machine themselves. There are many published techniques to ensure a high degree of reliability and many available tools to monitor induction motors. In last 10 years, much has been written about condition monitoring of electrical machines and numerous studies have been conducted in this field. Many papers have been written concerning condition monitoring of induction motor.

Most of the research has been directed towards the emphasis on inspecting stator current. The advantage of stator current monitoring is that one can get the fault information without requiring access to the motor. There are so many available techniques for data processing have been used in induction motor monitoring. There are various techniques based on main stator winding current signature. Motor Current Signature Analysis (MCSA) is used to detect more broken rotor bars and for end ring faults.

## CONCLUSIONS

This work studied the use of neural networks for model based fault diagnostics of induction motors. The idea was to use data provided by accurate FEM simulations of motor operation under different fault and load conditions to create identification based neural network model models which can be used for online fault diagnosis. The neural network models are created for each phase of the three phase induction motor, and each load condition is handled separately. Most of the faults cases have to be left out due to the unavailability of data for different fault conditions. The data is often a restriction for data-based models, because each different situation would require its own set of data, along with data for validation and testing. In literature in one of the work a FEM model of a 35 kW induction motor was simulated for cases of a healthy, rotor faulted and stator faulted motor. The parameters for the model were obtained from a real operational motor. No real measurement data was used, but studies with FEM simulations of induction motors show that the data is very realistic with respect to the data obtained from real motor measurements [Arkkio 1990]. Measurement data from a real motor was, however, used as an input to the FEM models in the data group that was used to build the time series models. Induction motors are one of the commonly used electrical machines in industry because of various technical and economical reasons. These machines face various stresses during operating conditions. These stresses might lead to some modes of failures/faults. Hence condition monitoring becomes necessary in order to avoid catastrophic faults. Various fault monitoring techniques for induction motors can be broadly categorized as model based techniques, signal processing techniques, and soft computing techniques. In case of model based techniques, accurate models of the faulty machine are essentially required for achieving a good fault diagnosis. Sometimes it becomes difficult to obtain accurate models of the faulty machines and also to apply model based techniques.

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