# Rotor Cage Fault Detection in Induction Motors by Motor Current Signature Analysis

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## ABSTRACT
Electric motors have revolutionized the way of human living and resulted in the modern life style. In every product that one consumes or uses today or in any service field that one benefits, it is for sure that there is an electric motor contributing to the production. These motors are playing important role in the industries called as horses of modern industry. Induction motors often operate in hostile environments such as corrosive and dusty places. These motors exposed to a variety of undesirable conditions and situations such as mal-operations. These unwanted conditions can cause the motor to go into a failure period, which may result in an unserviceable condition of the motor. The failure if not detected at its early stages, can result in a total loss of the machine itself, in addition to a likely costly downtime of the whole plant. More important, these failures may even result in the loss of lives, which cannot be tolerated. The method proposed, allows analyzing the operating conditions of induction motors. In this method Motor Current Signature Analysis (MCSA) is used particularly to detect loosening of broken rotor bars and end ring faults.

## General Terms
Induction Motor; Stator Current Spectrum

## Keywords
Motor Current Signature Analysis; Fast Fourier Transform

## 1. INTRODUCTION
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 [2]. 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 motors are key elements in assuring the continuity of the process and production chains of many industries. A majority of induction motors are used in electric utility industries, mining industries, petrochemical industries, and domestic appliance industries. Induction motors are often used in critical applications such as nuclear plants, aerospace and military applications, where the reliability must be at high standards. Induction motors often operate in hostile environments such as corrosive and dusty places. These motors may be exposed to a variety of undesirable conditions and situations such as mal-operations. These unwanted conditions can cause the induction motor to go into a failure period, which may result in an unserviceable condition of the motor. The failure of induction motors, if not detected at its early stages of the failure period, can result in a total loss of the machine itself, in addition to a likely costly downtime of the whole plant. More important, these failures may even result in the loss of lives, which cannot be tolerated. There are many types of maintenance techniques viz. preventive maintenance, proactive maintenance, default type, discard type, offline - online type. Thus, it is always a concern for the decision maker that which type of maintenance should be most appropriate or optimum. Decision makers, therefore, need to take into account the needs of their business, recommendations from the original equipment manufacturer, their own experience and that of other users of similar plant, and information on condition available from the plant offline or online. 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 [3, 4, 9, 10, 11, 12].

- Stator faults resulting in opening or shorting of one or more of phase winding.
- Abnormal connection of stator windings.
- Broken rotor bars or cracked rotor end rings.
- Static and /or dynamic air-gap irregularities.
- Bent shaft.
- Shorted rotor field winding.
- Bearing and gear box failures.

Percentage of fault distribution is shown in figure 1.


**Figure 1: 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 [9] into thermal, electrical, mechanical, and environmental. Thermal stresses might be due to thermal aging and thermal overloading. As a thumb rule, for every 10 $^{o}$C increase in temperature, the insulation life gets halved due to thermal aging. Unless the operating temperature is extremely high, the normal effect of thermal aging is to render the insulation system vulnerable to other influencing factors or stresses that actually cause the failure. If the insulation system loses its physical integrity, it fails to resist the other dielectric, mechanical, and environmental 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. Mechanical stresses might be due to coil movement and rotor striking the stator. The force on the coils due to the stator winding current ($I^2$) is maximum during the starting cycle, causing the coils to vibrate at twice the line frequency with movement both in the radial and tangential directions. This coil movement can cause damage to the coil insulation, loosen the top sticks, and cause damage to the copper conductors. 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, loose nuts and bolts 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, poor lead lugging of connections from the motor leads to the incoming line leads causing overheating and failure, 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. Most of the faults occurring in an induction motor produce one or more symptoms as given below [3, 4]:

- Unbalanced air gap voltages.
- Increased torque pulsations.
- Decreased average torque.
- Increased losses and reduction in efficiency.
- Excessive heating, leakage current in stator windings.
- Change in rotor time constant.

The diagnostic methods of identifying the above faults are given as [3, 4, 11, 12, 13, 14]:

- Electromagnetic field monitoring, search coils
- Temperature measurements
- Infrared recognition
- Radio-frequency (RF) emissions monitoring
- Noise and vibration monitoring
- Chemical analysis
- Acoustic noise measurements
- Motor current signature analysis (MCSA)
- Partial discharge measurements
- 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 like FT, FFT, STFFT, and WT. Review of the published research literature reveals that the analysis of rotor faults by motor current signature analysis for more broken rotor bars and for end ring faults is not published in the literature. In the paper, Motor Current Signature Analysis (MCSA) is used to detect more broken rotor bars and for end ring faults.

## 2. EXPERIMENTAL SETUP

As shown in figure 2 three round CTs (5A: 0.1A) are connected in star in three phases of the motor. Across the secondary of each CT, resistance of 100 ohm is connected to convert current into voltage. This signal is given to isolation (unity) amplifier. Output of this is connected to analog to digital converter ADC 0809 to convert analog input into digital output. The output channels of ADC 0809 are selected by using 89C52 microcontroller. Outputs of the channels are connected to COM1 through RS-232 port by serial communication. The real time data from COM1 is accessed into MATLAB 7.1 environment to find out the FFT of stator current. To vary the load on the motor it is coupled to dc generator to which resistive lamp bank in connected. The equipments used in the experimentation are:

- Induction Motor : 3 HP, 415 V, 4-pole, 50 Hz
- Data Acquisition Card
- Lamp bank- Resistive Load 10 KW
- Current Transformer 5A: 0.1A
- DC Generator: 3 KVA
- Rotor with different Faults

Different types of sensors can be used to sense the characteristic signals resulting from these faults. Various signal processing techniques can be applied to these sensor signals to extract particular features which are sensitive to the presence of faults. Finally, in the fault detection stage, a decision needs to be made as to whether a fault exists or not. On-line fault detection uses measurements taken while a machine is operating, to determine if a fault exists. Current transformer will sense the current from the one phase of stator winding which is given to signal conditioning circuit. The output of the signal conditioning circuit is given to PC with MATLAB 7.1 for the analysis purpose.

## 3. MOTOR CURRENT SIGNATURE ANALYSIS FOR ROTOR FAULTS

In squirrel-cage Induction motors around 5 to 10% of the faults are due to broken rotor or cracked bars and end-rings breakage. There are many reasons for such faults which include thermal stress due to over load, non-uniform heat distribution, hot spot and arc, magnetic stresses due to the electromagnetic force, unsymmetrical magnetic force, electromagnetic vibrations, residual stress from manufacturing stage, dynamic stress due to axial torque, environmental stress due to the contamination, materials wearing by chemical materials and humidity mechanical stress due to mechanical fatigue of different parts, fault ball-bearings and laminations loosing. Broken rotor bar and end ring fault are main causes of rotor failures. When there is a broken bar, no current flows through the broken rotor bar, thus, no magnetic flux is generated around the broken rotor bar. This generates an asymmetry in the rotor magnetic field. It is well known that a 3-phase symmetrical stator winding fed from a symmetrical supply with frequency $f_1$, will produce a resultant forward rotating magnetic field at synchronous speed and if exact symmetry exists there will be no resultant backward rotating field. Any asymmetry of the supply or stator winding impedances will cause a resultant backward rotating field from the stator winding. When applying the same rotating magnetic field fundamentals to the rotor winding, the first difference compared to the stator winding is that the frequency of the induced electro-magnetic force and current in the rotor winding is at slip frequency, i.e. $sf_1$, and not at the supply frequency. The rotor currents in a cage winding produce an effective 3-phase magnetic field with the same number of poles as the stator field but rotating at slip frequency $f_2 = s \cdot f_1$ with respect to the rotating rotor. With a symmetrical cage winding, only a forward rotating field exists. If rotor asymmetry occurs then there will also be a resultant backward rotating field at slip frequency with respect to the forward rotating rotor. As a result, the backward rotating field with respect to the rotor induces an e.m.f. and current in the stator winding at:

$$f_{sb} = f_1(1\text{-}2s)\ Hz \quad (1)$$

This is referred to as the lower twice slip frequency sideband. There is therefore a cyclic variation of current that causes a torque pulsation at twice slip frequency ($2s.f_1$) and a corresponding speed oscillation, which is also a function of the drive inertia. This speed oscillation can reduce the magnitude (amps) of the $f_1$ (1-2$s$) sideband but an upper sideband current component at $f_1(1+2s)$ is induced in the stator winding due to rotor oscillation [6].The upper sideband is enhanced by the third time harmonic flux. Broken rotor bars therefore result in current components being induced in the stator winding at frequencies given by:

$$f_{sb} = f_1(1 \pm 2s) Hz \quad (2)$$

## 3.1 Current Signature Due to Broken Rotor Bars

There are the classical twice slip frequency sidebands due to broken rotor bars. These side bands allow a clear identification of the rotor, the frequencies in which they appear are part of the rotor slipping and its amplitude strongly depends on the state of the load. An exact diagnostic requires the motor to be over half of its nominal load. The amplitude of this side band indicates the severity of rotor faults. The nature of the signatures is as shown in figure 3.

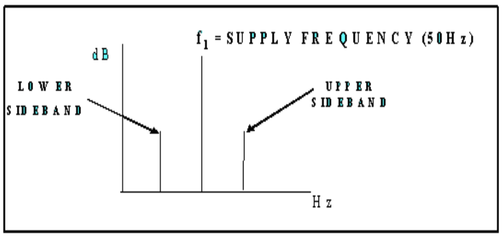


**Figure 3: Current Signature**

## 4 EXPERIMENTAL RESULTS

Initially motor is in the healthy condition. (i.e. rotor is healthy) and stator current spectrum is observed. Then another identical rotor with different rotor faults is taken and again stator current spectrum is observed. Then by using motor current signature analysis, analysis part is done to diagnose the type of rotor fault. FFT spectrum of stator current of induction motor under different rotor conditions is as shown in figure 4. Amplitudes of fundamental and sideband frequency components (dB) for different rotor conditions are shown in table 1.

**Table 1 Amplitudes of fundamental and sideband frequency components (dB)**

| | Fundamental Frequency 50Hz | Lower Frequency 26Hz | Upper Frequency 76Hz |
|---|---|---|---|
| Healthy | **180 db** | **2.2 db** | **3.25 db** |
| One Bar Broken | **146 db** | **0.8 db** | **1.2 db** |
| Three Bar Broken | **126 db** | **4.2 db** | **4.1 db** |
| Five Bar Broken | **104 db** | **3.2 db** | **3.4 db** |

From the above result table 1and figure 4 following observations are noted.

1. If the difference of magnitudes of fundamental components and any one side band frequency component is above 150 dB-Motor is healthy.
2. If the difference of magnitudes of fundamental components and any one side band frequency component is above 130 dB to 150 dB-Motor is normal (One bar broken).
3. If the difference of magnitudes of fundamental components and any one side band frequency component is above 110 dB to 130 dB-Motor is less critical (Three bar broken).
4. If the difference of magnitudes of fundamental components and any one side band frequency component is below 110 dB -Motor is critically damaged (Five bar broken).

## 5. CONCLUSION

In this paper Motor Current Signature Analysis is used to detect and diagnosis fault in induction motor. MCSA is a technique based on the study of frequency spectrum of the stator currents. This technique is more effective to point out faults in bars in rotors and for damaged end rings. The sidebands that appear in the FFT spectrum of the stator current allow identifying the fault easily. It is important to point out that diagnosis has to be done with the motor working at least with half of its nominal load and it is more effective when the load of the motor is bigger. This technique can be fairly simple, or complicated depending upon the system available for data collection and evaluation.

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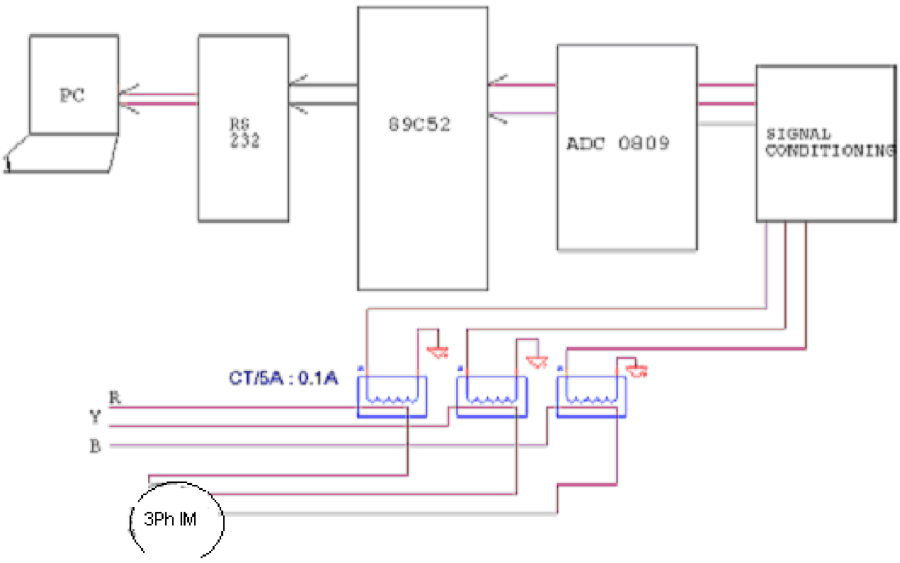
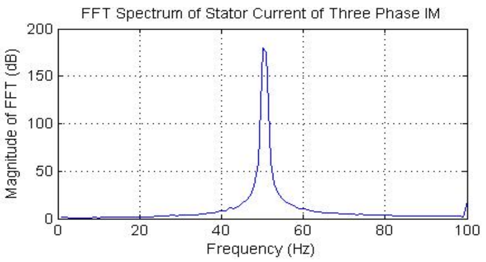
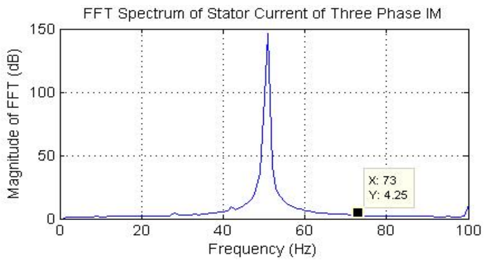


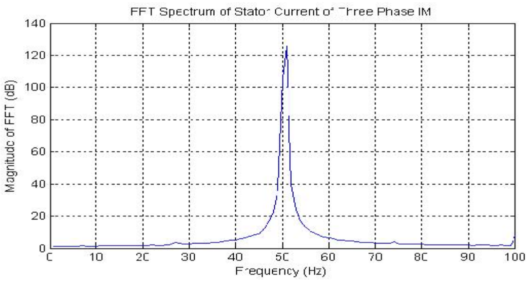

**Figure 2: Experimental setup**



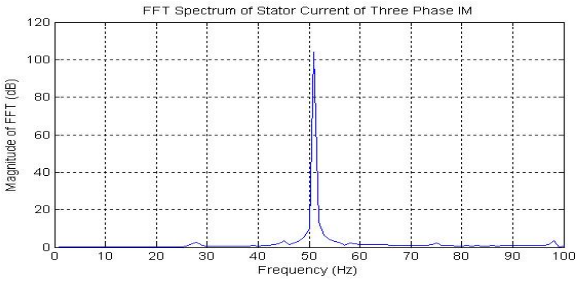

FFT Spectrum of stator current healthy condition




FFT Spectrum of stator current under one bar broken




FFT Spectrum of stator current under three bar broken




FFT Spectrum of stator current under five bar broken

**Figure 4: Signature Analysis**