Broken Rotor Bar Fault Detection of Induction Motors Based on Fast Fourier Transform

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***Abstract*— Induction motors play a key role in the industrial field. Therefore, continuous monitoring and online diagnostic system are essential to guarantee the seamless operation of modern industrial facilities. Condition monitoring and fault detection of induction motors are of great importance in production lines. It can significantly reduce the cost of maintenance and the risk of unexpected failures by allowing the early detection of potentially catastrophic faults. This paper proposes a study of broken rotor bar current signal analysis of motor using Fast Fourier Transform (FFT) algorithm for fault detection. The experimentations are implemented in a 1.5-kw, 2-Hp, 3-phase, 415-Volt, 1420-rpm, 4-pole, star connected squirrel cage induction motor. The experimental results show the variation of the fault indication signal while the motor is operated under the broken rotor bar conditions. Motor Current Signature Analysis (MCSA) is a condition monitoring technique used to detection problems in induction motors. It is the technique used to analyse and monitor the trend of dynamic energized systems.**

Keywords – FFT, broken rotor bar, Induction Motor, MCSA, algorithm.

I. Introduction

INDUCTION motors are inherently reliable and require minimum maintenance. However, like other motors, they eventually deteriorate and fail. This gives rise to the need for cost effective preventive maintenance based on condition monitoring, which can be addressed by monitoring and analysing the real-time signals of the induction motors. Induction motors are key components in the industrial environment, so it is essential to assure their proper condition guarantee the continuity of production processes. Motor current signal analysis (MCSA) has emerged as a widely used technique to perform condition monitoring of induction motors, in the field of on-line condition monitoring of electrical machines [1]–[5]. This methodology based on the measurement of the stator current signal has been developed. This can show the frequency and magnitude of each failure happen to occur in this kind of motor.

The FFT (Fast Fourier Transform) can be used for on-line failure detection of asynchronous motors. In this work a methodology is described for the most likely to broken rotor bars faults in induction motors. The electric motors in most cases are responsible for the proper functioning of the productive system. In this line, the corrective maintenance of equipment is very expensive since it involves unscheduled downtime and damage to the production process caused by equipment failures.

There are several techniques that can be used for detecting faults in induction motors. The MCSA (Motor Current Signal Analysis) is a non-invasive, on-line monitoring technique for diagnosing problems in induction motors. This method is based on the spectral decomposition of the steady state stator current which can be acquired with simple measurement equipment and under normal operation of the machine. In the MCSA method the current frequency spectrum is obtained and analysed aiming to find out specific components which can indicate an incipient fault in the machine. These frequencies are related to well-known machine faults. Therefore, after the processing of the stator current, it is possible to infer about the machine’s condition. A methodology with an accurate comprehension of the different influence of the variables is desired for the correct interpretation of the data acquired. In this work the frequency spectrum is obtained by the fast Fourier transform (FFT). For the case that the data acquisition is for a entire number of cycles of a certain component is easy to obtain its amplitude and frequency. In consequence we will have in the frequency spectrum certain components that could mask others of interest. This is commonly known as leakage. Another thing to take into account is the fact that the motor’s load condition is not always the same; this makes the fault signature characteristics different. The main objective of this methodology is to monitor these frequencies independently of the motor functioning and the data acquisition in order to determine the condition of the machine. To avoid the masking effect, the signal is multiplied by a function (window) reducing the discontinuity. In this opportunity we are not going to analyse the use of the different windows, but we focus in the acquisition of the signal’s amplitude introduced by the failure.

Here a methodology for monitoring and diagnosis of induction motors is presented, which monitors the motor without removing it from the production line, being this methodology: reliable, easy to apply and low cost.

The reasons for rotor bar breakage is several. They can be caused by the following:

1. Thermal overload causes thermal stresses mainly and unbalance the condition, hot spots, or excessive losses, sparking (mainly fabricated rotors).
2. Magnetic stresses generated through electromagnetic forces, un-balanced magnetic pull, electromagnetic noise, and vibration.
3. Due to manufacturing problems stresses reduces.

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4. Shaft torques arises dynamic stresses from centrifugal forces, and cyclic stresses.
5. Environmental stresses are generally caused due to contamination and abrasion of rotor material because of chemicals or moisture.
6. Mechanical stresses are caused due to loosing laminations, fatigued parts, bearing failure and many more.

II. BASIC PRINCIPLE OF ANALYSIS

A. Motor current signature analysis(MCSA)

Motor Current Signature Analysis is the technique used to analyse and monitor the trend of dynamic energized systems, [6]. MCSA is monitoring stator current (more precisely supply current) of the motor, [7]. Typical stator current monitoring system is illustrated in Figure 1. Single stator current monitoring system is commonly used (monitoring only one of the three phases of the motor supply current). Motor stator windings are used as transducer in MCSA, picking the signals (induced currents) from the rotor (but also revealing information about the state of the stator). Motor current is sensed by a Current Sensor (clamp probe, current transformer) with resistive shunt across its output, [8], and recorded in time domain. Picked current signal is then led to a spectrum analyser or specialized MCSA instrument. In ideal case motor current should be pure sinusoidal wave. In reality in motor current many harmonics are present.

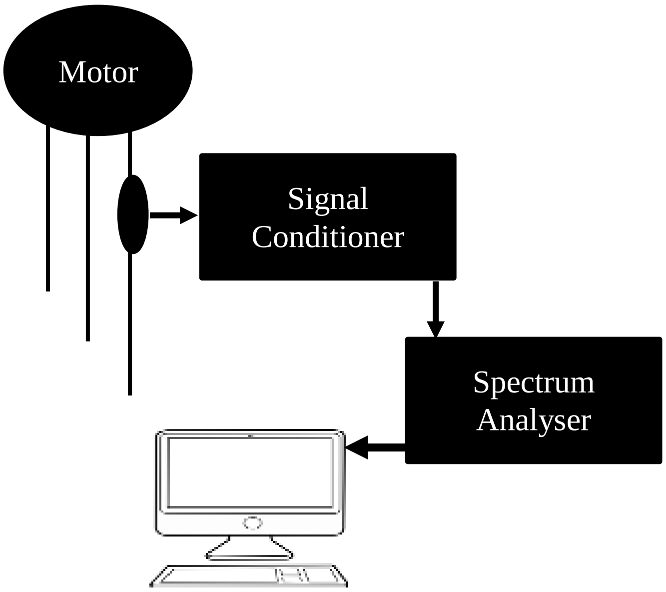

Fig.1 Stator current monitoring system

Various electrical and mechanical fault conditions present in the motor further modulate motor current signal and contributes to additional sideband harmonics. Faults in motor components produce corresponding anomalies in magnetic field and change the mutual and self-inductance of motor that appear in motor supply current spectrum as sidebands around line (supply, grid) frequency, [9].

B. Fast Fourier Transform (FFT)

Fast Fourier Transform (FFT) is an algorithm to compute the discrete current signal which are derived randomly from the motor through the data acquisition in term of

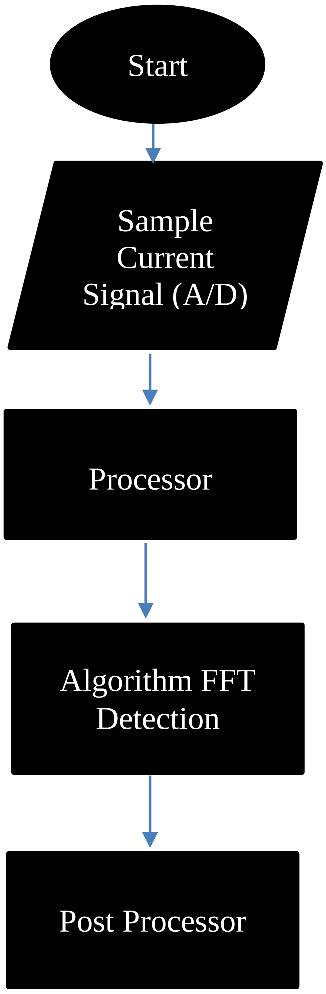

Fig. 2 Monitoring Scheme.

$$X_k = \sum_{n=0}^{n=1} X\, n\, e^{-i2\pi \frac{n}{N}}$$

X_k= transform values.
Xn = Sample values.
N = Number of sample

There are total N outputs and the value of $\underline{\boldsymbol{X}}_k$ is derived from summation of such N outputs. FFT algorithm is a method to compute the summation of the results in term of N log N composes of four main processes as demonstrated in Fig. 2.

Sampler: Sample signal of the stator current signature is sent through a low pass filter in order to remove undesired

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high frequency components that produced an aliasing, and then, an analogue to digital converter A/D is employed to converting the input signal.

Processor: The sample signal is converted into the frequency domain by using Fast Fourier Transform (FFT) algorithm.

Fault Detection Algorithm: In order to reduce a number of spectrum information into a usable level, an algorithm employs a frequency filter to eliminate those components that provides non-useful failure information. The algorithm keeps only the components that are particularly interested which inform specified characteristic frequencies of the current spectrum that are coupled to the particular motor faults.

Post Processor: Since the fault is not spurious event but degrading the motor continuously. The post processor diagnoses the frequency component and then classifies them.

C. Detection of broken bars

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. $s.f_1$, 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 $f_2= s.f_1$ 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:

$$F_{sb}=f_1\ (1-2s)\ HZ$$

This is referred to as the lower twice slip frequency sideband due to broken rotor bars. There is therefore a cyclic variation of current that causes a torque pulsation at twice slip frequency ($2sf_1$) and a corresponding speed oscillation, which is also a function of the drive inertia. This speed oscillation can reduce the magnitude (amps) of the $f_1\,(1\text{-}2s)$ sideband but an upper sideband current component at $f_1\,(1+2s)$ is induced in the stator winding due to rotor oscillation. 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 [9].

$$f_{sb} = f_1(1\pm2s)\ Hz$$

These are the classical twice slip frequency sidebands due to broken rotor bars.

III. HARDWARE DESCRIPTION

Tests related to experimental work were conducted on two similar squirrel cage induction motor, all with the same rating of 1.5-kW (2 hp), 3-Φ, 50 Hz, 415V, 1420rpm.

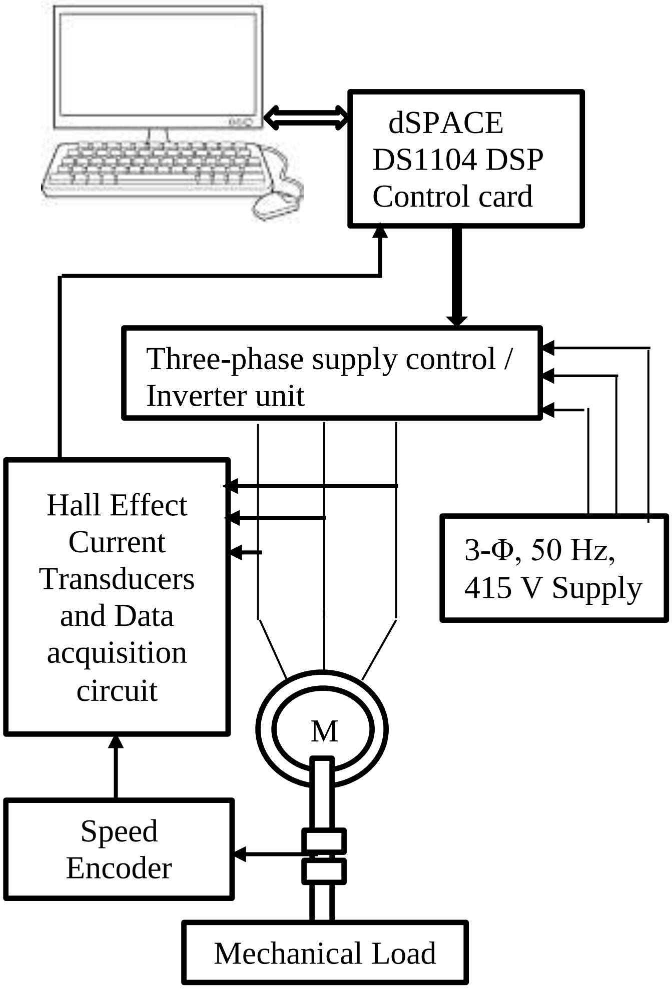

Fig. 3 Schematic of the experimental set-up.

First motor was considered as healthy and its current waveforms was used as reference base line to detect fault in the other motor. The other motor considered as faulty. The faulty motor tested under fault was seeded with rotor fault created by cutting across the rotor bar. The fault condition of unbalanced supply in a single or more stator phases was seeded by controlling the relevant phase supply though a three-phase auto-transformer. The motor seeded with faults were tested to acquire corresponding current data in time domain that could further be processed and analysed to detect and identify the induction motor fault condition. In figure 3, Simulink, dSPACE-Controldesk and dSPACE DS1104DSP controller board were employed during this research work as a multi-channel data acquisition system for the initial collection

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of data. Its use in this research has been adapted as a means of procuring, accumulation and presenting the time-domain records of the stator current acquired through the current sensors.

The induction motor set-up was loaded through a mechanical load arrangement that is depicted in the physical layout of the experimental apparatus in Figure1. The data for current, voltage and speed were acquired though three hall-effect current sensors, Hall-effect voltage sensor and a speed encoder.

The cage induction motor that is put under test is made to run either as a direct fed constant speed induction motor drive when it is supplied with 3-Φ, 50 Hz, 415 V supply or as a Adjustable Speed Induction Drive (ASID) when fed from PWM inverter. In this work, a low pass filter has been employed to filter out the high frequency noise components.

The stator current in each of the three phases is measured using three hall-effect current transducers. The line voltage is measured using a single hall-effect voltage transducer. The sampling frequency of 10 KHz was used to sample the stator current signals. This sampling frequency is sufficient enough to avoid any aliasing in the frequency domain. A rotary type shaft encoder was used as speed sensor for measurement of motor speed. The speed encoder was mounted to the motor at its non-coupling end and special provision for fixing and aligning the speed encoder with motor shaft was made.

IV. Results

The experiments have been performed to detect the broken rotor bar faults in three phase induction motor using Simulink software. The results obtained from these experiments are given below.

1. Healthy Motor Condition

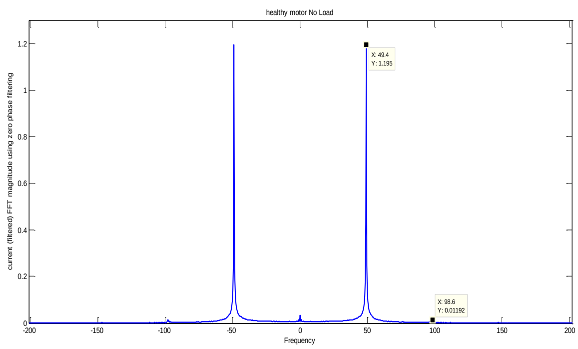

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Fig.4 FFT of the stator current for a healthy induction motor at no load condition.

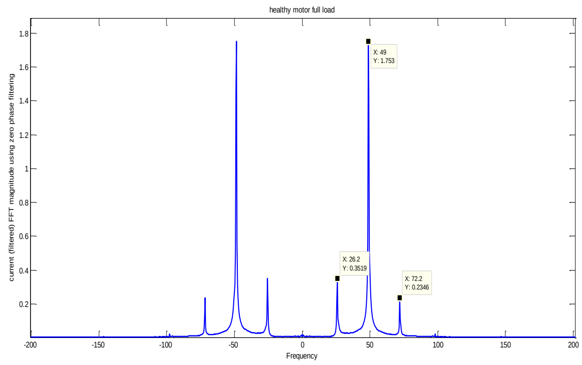

Fig.5 FFT of the stator current for a healthy induction motor at full load condition

In this section of work analysis is done by using FFT for no load & full Load of healthy condition to extract the features which are sensitive to the presence of fault. Knowing the nominal power of the motor, it can be deduced from the current consumption during the test that speed will be very close to that of synchronism. In Fig 4 and Fig 5, there are handy a sidebands.

2. Broken rotor bar condition

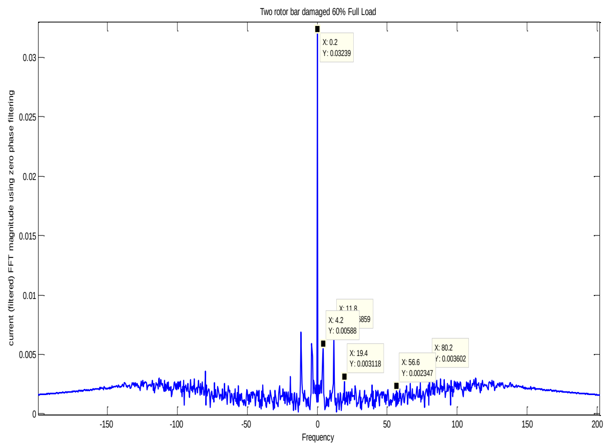

Fig.6 FFT of the stator current for a faulty induction motor at no load condition.

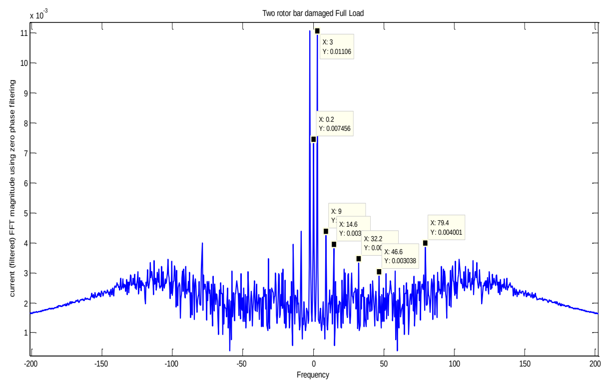

Fig.7 FFT of the stator current for a faulty induction motor at Full load condition.

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We clearly understand how side lobes are sharply increase with the fault severity of broken bars in induction motor. The frequencies of the upper sideband harmonic (USH) and the lower sideband harmonic (LSH) have been used to detect the fault. It has already been stated that when the fault is occur then the stator current shows the side bands around the fundamental frequency. The amplitude of the side lobes are increased that's clearly indicate of the broken rotor bar fault. It has been observed from the results that the side bands around the fundamental frequency are increased from 20 Hz to 60 Hz compare to healthy motor frequency. So it is clearly shows that the motor has broken rotor bar fault.

V. Conclusions

The aim of this work is condition monitoring and fault detection of induction motors which can be applied at the industrial level. The work show that FFT can efficiently use for detecting broken rotor bars faults. This system is able to produce the exact value of the harmonics in study of the sampling time. This method gives impressive and accurate results. It is possible from this technique to determine the exact extent of the defect and the associated frequency. In this way, the study of the growth tendencies of failure is easier. This method requires minimum sensitization and no need to remove the motor while doing the test. This paper discuss the fundamental of FFT and demonstrates through industrial case studies, how motor current signature analysis can reliably diagnose rotor bar problems in induction motor drives.

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