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DIAGNOSIS OF INDUCTION MOTOR ROTOR FAULTS USING STATOR CURRENT SIGNAL ANALYSIS METHOD (MCSA)

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A B S T R A C T :

Rotor faults in induction motors, such as broken bars or damaged end rings, can degrade performance, increase vibration, and lead to serious failures if not detected early. This paper presents a non-invasive diagnostic method using Motor Current Signature Analysis (MCSA) to detect rotor-related anomalies by analyzing stator current signals in the frequency domain. The method is based on the appearance of characteristic sideband frequencies around the supply frequency, caused by magnetic field asymmetry when the rotor is damaged. By applying the Fast Fourier Transform (FFT) to the stator current signal, fault characteristics can be identified through the presence and amplitude of components at frequencies , where is the supply frequency and is the slip factor. Experimental results show that the MCSA method is highly effective in detecting broken rotor bar faults under various load conditions. The proposed method offers a low-cost, real-time motor condition monitoring solution that helps improve operational reliability in industrial systems.

Keywords: rotor fault, Motor Current Signature Analysis (MCSA), stator current, fault diagnosis, Fast Fourier Transform (FFT).

I. INTRODUCTION

In many modern industrial systems, three-phase induction motors play a crucial role in driving machinery and equipment. However, during extended operation, these motors can develop faults, particularly in the rotor section, such as broken bars or damaged end rings. If not detected and addressed promptly, these faults can severely impact performance, increase maintenance costs, and lead to system-wide downtime.

In this context, the development of fast, cost-effective, and non-invasive motor fault diagnostic methods has become an urgent need. Among the modern diagnostic techniques, Motor Current Signature Analysis (MCSA) has proven to be an effective tool for early detection of rotor faults.

MCSA is based on the principle that asymmetries in the rotating magnetic field caused by rotor faults will generate characteristic frequency components in the stator current, which can be observed in the frequency domain using Fourier transform. Monitoring the appearance and amplitude of sideband frequencies around the supply frequency allows for efficient diagnosis of broken rotor bars while the motor is still in operation.

This paper presents the principles and implementation procedures of MCSA, along with experimental results on actual motors to evaluate the effectiveness of rotor fault detection through stator current analysis.

II. THEORETICAL BACKGROUND

The squirrel cage three-phase induction motor is one of the most widely used types of motors in industry due to its simple structure and high reliability. However, the rotor—composed of conductor bars placed in slots and two short-circuit end rings—is particularly susceptible to mechanical faults such as broken bars or cracked end rings. When such faults occur, the current distribution in the rotor bars becomes uneven, resulting in magnetic field imbalances and torque oscillations.

Induction motors remain ubiquitous in industrial settings due to their simplicity, robustness, and cost-effectiveness. However, rotor-related faults—particularly broken rotor bars (BRB)—pose significant risks, potentially leading to imbalance, increased vibration, and reduced efficiency. Early fault detection is therefore vital to maintain reliability and avoid unplanned downtime [1], [2].

The synchronous speed of an induction motor is governed by the supply frequency and number of poles, expressed as:

$$n_s = \frac{120 f_s}{P} \quad (1)$$

Where:

n_s is synchronous speed (rpm)

f_s: is supply frequency (Hz)

P: is the number of poles.

The slip, defined by:

$$s = \frac{n_s - n_r}{n_s} \quad (2)$$

Where:

n_r: is the rotor mechanical speed in rpm, directly affects the frequency components observed in the stator current [1].

Under normal conditions, the rotor current frequency is:

$$f_r = sf_s \quad (3)$$

In the presence of rotor asymmetry such as broken bars, sideband frequencies emerge in the stator current spectrum around the fundamental frequency, described by:

$$f_{sb} = f_s \pm 2ks,\ k = 1, 2, 3\ldots \quad (4)$$

For k=1, this becomes $f_s(1\pm2s)$ a primary indicator of BRB faults [2], [3]. Modern approaches extend this by leveraging techniques such as successive variational mode decomposition (SVMD) for feature extraction and fault severity quantification using energy-based metrics [3].

Eccentricity faults also manifest characteristic spectral components:

$$f_{ecc} = f_s\left(1 \pm \frac{k(1-s)}{p}\right), \quad k = 1, 2, 3\ldots. \quad (5)$$

Where:

f_{ecc}: Fault-Related Eccentric Current Component

with $p = \frac{P}{2}$ representing pole pairs. These frequencies help distinguish mechanical eccentricity faults from electrical BRB issues [1].

To quantify fault severity, researchers often compute the amplitude ratio between sideband components and the fundamental frequency:

$$K_{brb} = \frac{A_{sb}}{A_{fs}} \quad (6)$$

where

A_{sb} : is sideband amplitude

A_{fs} : is fundamental amplitude.

K_{brb} : correlate with worsening rotor imbalance [2].

Motor Current Signature Analysis (MCSA) remains the cornerstone of non-invasive rotor fault detection, relying on spectral techniques such as FFT, discrete wavelet transform (DWT), and Continuous Wavelet Transform (CWT) to reveal fault signatures in stator currents [3], [4]. Recent advances integrate AI and machine learning—including graph neural networks (GNNs), ensemble deep learning, and adaptive modal decomposition—to automatically detect and estimate fault severity with high accuracy and robustness, even under varying load and operational conditions [5], [6].

III. RESEARCH METHOD

An experiment was conducted to verify the capability of detecting rotor faults using the Motor Current Signature Analysis (MCSA) method. The test setup consisted of a three-phase squirrel cage induction motor with a rated power of 3 kW, voltage of 380 V, 4 poles, and operating at a frequency of 50 Hz. The motor was connected to a mechanical load in the form of an electromagnetic brake, which allowed for adjustable loading conditions.

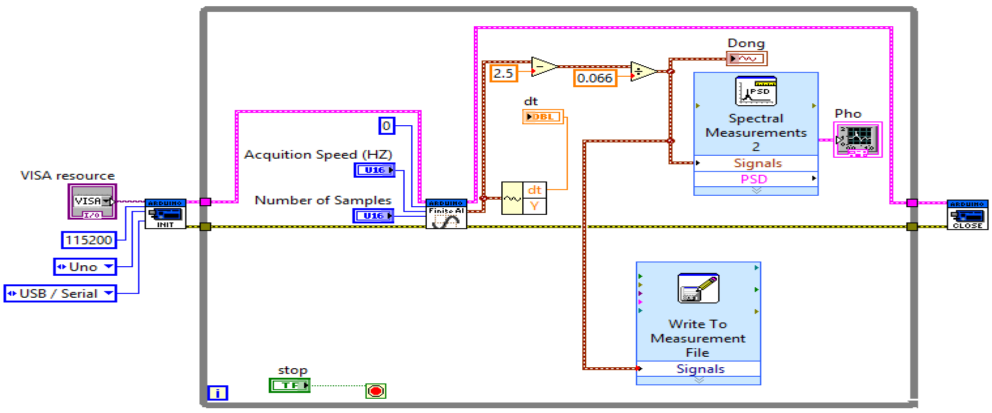

Figure 1. Spectrum analysis code using LabVIEW

The system uses UART communication (Arduino Uno) to acquire signal data via the USB/Serial port. Users input the sampling rate and number of samples to configure the data acquisition process. The collected data is then processed to calculate the Power Spectral Density (PSD) using the Spectral Measurements block. The results are displayed and saved to a data file using the Write to Measurement File block. The system operates within a while loop and can be stopped using a control button.

The stator current signal is measured using a Hall-effect current sensor and collected through a Data Acquisition (DAQ) device with a sampling rate of 10 kHz. The data is then processed to perform the Fast Fourier Transform (FFT) and analyze the frequency spectrum.

Figure 2. Motor Fault Diagnosis Model

Figure 2 illustrates the experimental model of a power generation and monitoring system using the Arduino platform. The motor drives a generator via a belt to produce electrical energy. The current is routed through a circuit breaker (CB closed) to a load consisting of three incandescent bulbs. The Arduino board collects voltage and current data, which is then transmitted to a computer for processing and storage. This model serves the purpose of real-time monitoring and evaluating power fluctuations in a small-scale system.

Two scenarios were established:

- **Scenario 1 – Normal motor:** The motor operates under fault-free conditions to collect baseline data.
- **Scenario 2 – Motor with rotor fault:** A fault is intentionally introduced by drilling a rotor bar to simulate a broken bar condition.

In each scenario, the current signal was recorded for a duration of 10 seconds under different load levels (0%, 50%, 100%). The frequency spectrum of the current was analyzed to detect characteristic sideband components appearing around the supply frequency (e.g., 48 Hz and 52 Hz for a 50 Hz supply with a slip of 0.02).

The results were compared in terms of the amplitude of these sideband components between the two scenarios. A significant increase in amplitude at these frequencies in the faulty case demonstrates the effectiveness of the MCSA method in diagnosing rotor faults.

IV. RESULTS AND DISCUSSION

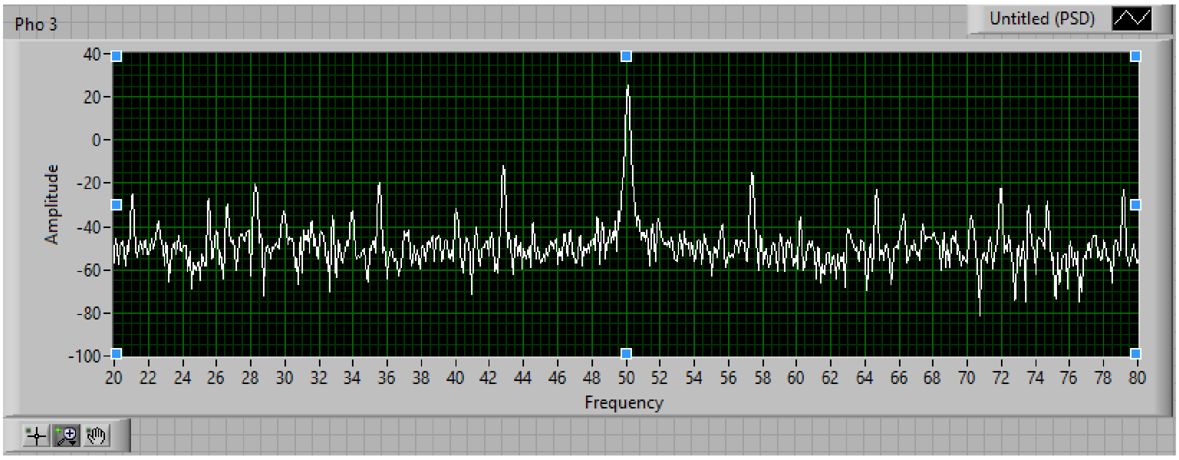

Figure 3. Frequency Spectrum of a Normal Motor Under Load

Figure 3 shows the frequency spectrum of the stator current obtained from a three-phase induction motor operating under normal load conditions. The supply frequency is 50 Hz, and the estimated slip is 0.02.

Observations from the spectrum include:

- The main component with the highest amplitude appears at 50 Hz, corresponding to the supply frequency.
- There are no significant sideband components observed at 48 Hz and 52 Hz (i.e., $f_s(1 \pm 2s)$), which are typically indicative of rotor faults.
- The remaining frequency components have much lower amplitudes and are distributed as background noise across the spectrum.

These results confirm that the motor is operating normally, without broken rotor bars or notable magnetic field asymmetries. The absence of sideband frequencies is a key criterion for verifying rotor health according to the MCSA method [1].

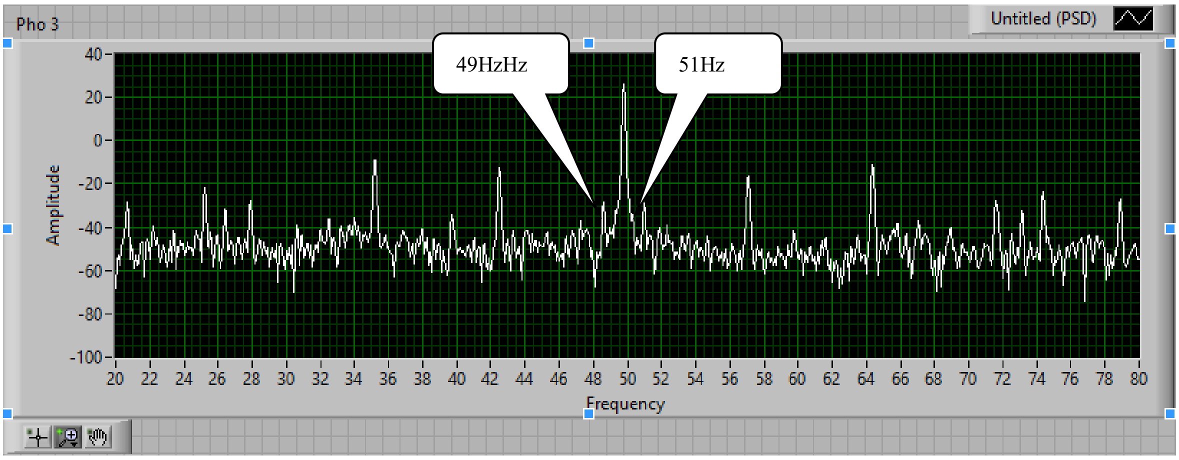

Figure 4. Frequency Spectrum of a Motor with a Broken Rotor Bar Under Load

In contrast, *Figure 4* presents the frequency spectrum of the stator current in the case of a motor with a rotor fault (a broken rotor bar). In addition to the dominant peak at the supply frequency of 50 Hz, clear sideband components appear around 48 Hz and 52 Hz with significantly increased amplitudes.

A comparison between the two spectra reveals that the amplitudes of the sideband components are substantially higher in the fault condition than in the normal condition. This confirms the effectiveness of the MCSA method in detecting rotor faults under load. In particular, the presence and magnitude of these peaks serve as direct indicators of broken rotor bars.

This analysis demonstrates that the frequency spectrum derived from the stator current signal can be reliably used as an indicator of rotor condition in industrial motor systems.

V. CONCLUSION

This paper has presented a method for diagnosing rotor faults in induction motors using Motor Current Signature Analysis (MCSA). By applying the Fast Fourier Transform (FFT) to stator current signals, characteristic frequency components associated with rotor faults were clearly identified in the frequency spectrum.

Experimental results showed that the appearance and increased amplitude of sideband components are typical indicators of broken rotor bars. The MCSA method proves to be effectively applicable in industrial environments due to its non-intrusive nature, low cost, and capability for online monitoring.

In the future, integrating MCSA with advanced signal processing techniques and artificial intelligence could further expand its potential in intelligent diagnostic systems and predictive maintenance applications.

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