Enhanced Algorithm For Motor Rotor Broken Bar Detection

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Abstract

Motor rotor broken bar is one of the predominant failure modes of squirrel cage induction motors. There are numerous researched methods for identifying rotor bar faults: motor current signature analysis, acoustic noise measurements, vibration monitoring, temperature monitoring, electromagnetic field monitoring, infrared recognition, radio frequency emissions monitoring, etc. The most frequently used method is called the Motor Current Signature Analysis (MCSA). It is based on a signal analysis of the motor current, obtained via a regular current transformer used for motor protection purposes. It is difficult to detect rotor bar failures by looking into the currents waveform-time domain analysis, however impact of rotor broken bars to the stator currents can be determined by analyzing spectrum of frequency distribution in the frequency domain.

Many factors affect reliable detection of the motor broken bar; motor load, system frequency and motor speed, construction of the motor etc. New algorithm takes into account all these factors to adapt to a changing operational condition of the motor. Also by learning healthy motor frequency spectrum signature, the detection of broken rotor bar can be made even more deterministic.

New algorithm was extensively tested on the induction motors with different system and motor conditions-results of this testing are presented. Lessons learned from the field installations are presented as well.

1 Introduction

Induction motors play an important role in the safe and efficient run in any industrial plant. The incipient fault detection or condition monitoring of the motors will help avoid expensive repairs or losses due to industrial process interruptions. Even though the motors are designed for a long fault-free time, usually 30 years, they are susceptible to failures and their sheer volume and high cost may result in an expensive maintenance. Various studies have shown that about 50 percent of motor failures are due to bearing failures, 35 percent due to insulation failures, 10 percent due to rotor cage failures, and 5 percent due to other causes [1].

This paper presents one method for an efficient detection of rotor related problems in a squirrel-cage induction motor.

2 Existing Methods

Numerous rotor failures detection methods have been proposed with a varying level of practicality and efficiency. Those methods often span several fields of science and technology. The most used methods for detecting the rotor bar problems are [2]:

- Motor current signature analysis (MCSA),
- Acoustic noise measurements,

- Model, artificial intelligence and neural network based techniques,
- Noise and vibration monitoring,
- Electromagnetic field monitoring using search coils, or coils wound around motor shafts (axial flux related detection),
- Temperature measurements,
- Infrared recognition,
- Radio frequency (RF) emissions monitoring,
- Chemical analysis, etc

The major limitation of most methods is that they require involvement of costly experts, or costly equipment, or both. Some methods are prone to false alarms, and others are simply not practical for deployment in an industrial plant environment.

Here, we present a practical method for detection of broken rotor bars, based on Motor Current Signature Analysis (MCSA) with no additional equipment needed beyond a motor protection relay, which is likely to be already present.

An ordinary MCSA detection algorithm is easy to implement and deploy. It needs one current transformer and a micro-controller capable of taking samples of one phase current and performing a Fast Fourier Transform (FFT). The decision algorithm is a different story. An expert (system) is needed to interpret the calculated level results; otherwise a false detection is inevitable.

Motor Current Signature Analysis (MCSA) Background

Under perfectly balanced conditions (source, motor and load) the stator phase currents are constant. For the purpose of analyzing rotor bar failures, it is sufficient to observe one phase current only, due to symmetry of a three-phase motor. A defect in a rotor bar of an induction motor causes the modulation of the stator current. This means that the current envelope will change according to the severity of the rotor failure. The current envelope is an imaginary curve connecting peaks of the phase current sinusoidal waveform.

It is difficult to analyze characteristics of rotor bar failures by looking into the current waveform - time domain analysis. The impact of broken rotor bars to the stator current can be determined by analyzing in the frequency domain. This approach in detecting rotor bar failures is called a Motor Current Signature Analysis (MCSA).

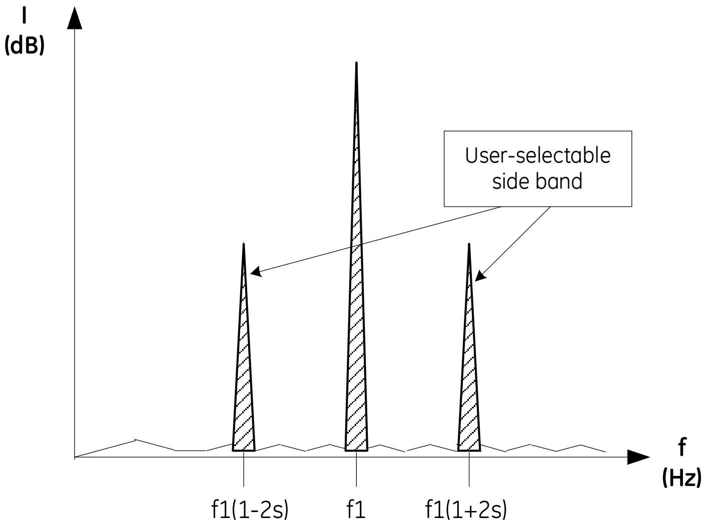

Figure 1. Simplified broken rotor bar current spectrum

Again, in perfectly balanced conditions, the stator current will be represented with a single spectral component in the current spectrum. It will be located at the frequency of the power source (i.e. 60 or 50 Hz, dependant on the power system). Let's label this frequency as "f_1". When a rotor bar failure is present, additional spectral components will be present too. The following analysis will try to explain them. Normally, in a real life situation, there will be many other components of various amplitudes – source harmonics, noise, components due to other imperfections (bearing faults, presence of gear boxes or belt drives, periodic changes of the motor load), etc.

In order to place spectral components caused by rotor bar failures on the current spectrum, let's review an induction motor slip properties. In a healthy motor operating in balanced conditions, there is a forward rotating magnetic field produced by stator. This field rotates at synchronous speed:

$$n_1 = f_1 / p \qquad \text{Eq. 1}$$

where "f_1" is the power source frequency and "p" is number of pole-pairs of the stator windings, per phase. The rotor of an induction motor always rotates at the speed "n", which is less than the synchronous speed "n_1". The slip is defined as:

$$s = \frac{(n_1 - n)}{n_1} \qquad \text{Eq. 2}$$

and it is a measure of how much the rotor slips back behind the rotating magnetic field. The slip speed "n_2" is the actual difference between the speed of the rotating field and the actual speed of the rotor: $n_2 = n_1 - n$. If we multiply both sides of slip definition by n_1, we get $s \cdot n_1 = n_1 - n$. By replacing $(n_1 - n)$ with n_2 in the slip speed definition per equation 2 above, the slip speed becomes $n_2 = s \cdot n_1$.

The frequency of rotor current is called the slip frequency and it is defined as:

$$f_2 = n_2 \cdot p = s \cdot n_1 \cdot p \qquad \text{Eq. 3}$$

The speed of the rotating magnetic field produced by the rotor bar current, with respect to the stationary stator winding is given by:

$$n + n_2 = n + n_1 - n = n_1 \qquad \text{Eq. 4}$$

This means that from the fixed stator perspective, the speed of rotating magnetic field caused by the rotor is equal to the stator caused rotating magnetic field. Therefore, both magnetic fields rotate at the synchronous speed. They appear to be locked to each other, and they produce a steady torque.

When there are broken rotor bars in a motor, there will be an additional magnetic field present. This magnetic field rotates backwards at the slip speed with respect to the rotor. From stator point of view this magnetic field rotates at speed $n_b = n - n_2$. It was determined earlier that $n + n_2 = n_1$, or $n = n_1 - n_2$, and $n_2 = s \cdot n_1$. By substituting these values above, the n_b becomes:

$$n_b = (n_1 - n_2) - s \cdot n_1 = n_1 - s \cdot n_1 - s \cdot n_1 = n_1 - 2 \cdot s \cdot n_1 = n_1 \cdot (1 - 2 \cdot s) \qquad \text{Eq. 5}$$

The equation above means that stationary stator “sees” the rotating magnetic field due to broken rotor bars at the speed:

$$n_b = n_1 \cdot (1 - 2 \cdot s) \qquad \text{Eq. 6}$$

By dividing left and right side by “p”, and keeping in mind that $f_b = n_b / p$ and $f_1 = n_1 / p$, the equation describing effect of broken rotor bars becomes:

$$f_b = f_1 \cdot (1 - 2 \cdot s) \qquad \text{Eq. 7}$$

Equation above is fundamental equation of the algorithm, using MCSA principle. The rotating magnetic field due to broken rotor bars induces the current in the stator windings at “f_b” frequency. In the stator current spectrum the component caused by broken rotor bars is located $2 \cdot s \cdot f_1$ down from f_1, which is the source frequency. The speed and torque oscillations occur at frequency $2 \cdot s \cdot f_1$, which means that there is a spectral component located at $f_1 + 2 \cdot s \cdot f_1$ as well. Therefore the spectral components due to broken rotor bars can be expressed as:

$$f_b = f_1 \cdot (1 \pm 2 \cdot s) \qquad \text{Eq. 8}$$

The lower component is due to broken bars, and upper one is due to a related speed oscillation. Since the broken rotor bar disturbances are of an “impulse nature” (not a pure sine wave), the broken rotor bar spectral components can be expressed more accurately as:

$$f_b = f_1 \cdot (1 \pm 2 \cdot k \cdot s) \qquad \text{Eq. 9}$$

where k = 1,2, 3...

The amplitude of harmonic spectral components due to rotor bar defects, where k >= 2, are dependant of the geometry of the fault. Their amplitude is significantly lower than the “main” sidebar component and they can be ignored in this analysis. It is sufficient to measure the ratio of amplitudes one of the “main” sideband components versus the amplitude of the source frequency component, in order to “judge” the effect of the rotor bar defects. This ratio is directly proportional to the failure severity (the number of cracked or broken rotor bars). The upper and lower “main” sideband components are equal and it is irrelevant which one is used for calculation the ratio.

The position of sideband components, with respect to the source frequency component, is proportional to the motor slip. Due to frequency resolution of the detection method and presence of a source frequency "jitter", it may not be possible to detect sideband components while motor is idling, or running at light loads, i.e. while the slip is very small and the sideband components are very close to the source frequency.

3 Field Experience with MCSA Based Fault Detection

The method described above was incorporated many years ago and has a field experience history. At one facility, with approximately 110 medium voltage motors, three (3) motors have been identified with broken rotor bars in the past 10 years. A motor with a broken rotor bar is usually detected by an operator who reports high motor noise or vibration, or during routine maintenance of the motor by using current signature analysis that checks the motor phase current sideband component frequency magnitude versus the fundamental frequency. The protective relay is used to provide confirmation that a motor has broken rotor bars. The suspect motor sideband value is compared to an identical motor under the same loading. The relay confirms that the suspect motor has a broken rotor bar when the magnitude of sideband current is higher.

The relay also provides a maximum value of percent sideband current. During a motor start the percent sideband current is very high and usually this value is recorded in the maximum value field.

But field experience prompted improvements in the next generation relays with a broken rotor bar detection, which should include the following:

- An alarm set point with an adjustable value.
- If frequency tracking is not implemented in the motor protective relay, then additional error is possible-therefore it's desirable to have robust frequency tracking mechanism in the relay.
- Disable broken rotor bar detection readings during motor starting and load changes.
- Learn trends in motor slip frequency at different operating conditions, including different load, operating voltage, etc.
- Measure broken rotor bar component level in decibels to quantify probability of having this kind of motor failure.

The picture bellow is from a coal-fired power plant with three turbine generators. It shows the damaged rotor of a medium voltage motor, rated for 6600 V, 1500 HP, used as primary air fan motor.

Figure 2. 6600 V, 1500 HP fan motor with broken rotor bars (field picture)

4 Algorithm Implementation Description

The implementation of the algorithm for detection of the rotor bar damage, based on the current signature analysis, as a standalone device carry many risks of a false detection. A human expert operator is usually employed, in order to minimize false detections. Since the standalone devices are not suitable for a continuous monitoring without a costly expert operator, damage to the rotor may go undetected for a period longer than necessary. Often the rotor damage is suspected only when the motor is slow to accelerate, or even cannot be started successfully.

The algorithm for detection rotor bar damage, based on the motor current signature analysis, consists of series of digital signal processing steps necessary for evaluating the current spectral components attributed to the presence of damaged rotor bars. This steps include signal sampling, digital filtering, Fast+ Fourier Transform, sample decimation, anti-aliasing filtering, etc. In order to work in a "non-operator assisted mode", this algorithm needs to be hardened with a series of measures to avoid false alarms.

In order to achieve a proper frequency resolution and accuracy a sample of motor current spanning at least 10 seconds is required for the relay sampling 64 samples per cycle. This results in 2048 length of FFT. A synchronous amplitude demodulation is applied before a series of up to 30 FFTs are performed. It takes approximately 30 seconds to acquire data and calculate the ratio of side-band component versus the fundamental. In the implementation discussed in this paper, the dynamic range of 65 dB, with accuracy of +/- 1.5 dB was achieved. This turned out to be sufficient, since the typical value of interest is in the range of –60 to –40 dB.

This conclusion is based on the published experimental data on the Broken Rotor Bar spectral component level, relative to the fundamental level. It indicated that [5]:

- If the BRB component level is around –60 dB or more, there is probably, no fault.

- If the BBR component level is at least at –54 dB, there is, very likely, a cracked rotor bar.
- If the BRB component level is greater than –50 dB, there is probably a broken bar.

The implementation of the broken rotor bar detection algorithm in a motor protection device, and equipping it with necessary supervision conditions readily available in a motor protection device, which allows early detection of the rotor problems with substantially reduced risk of false alarms.

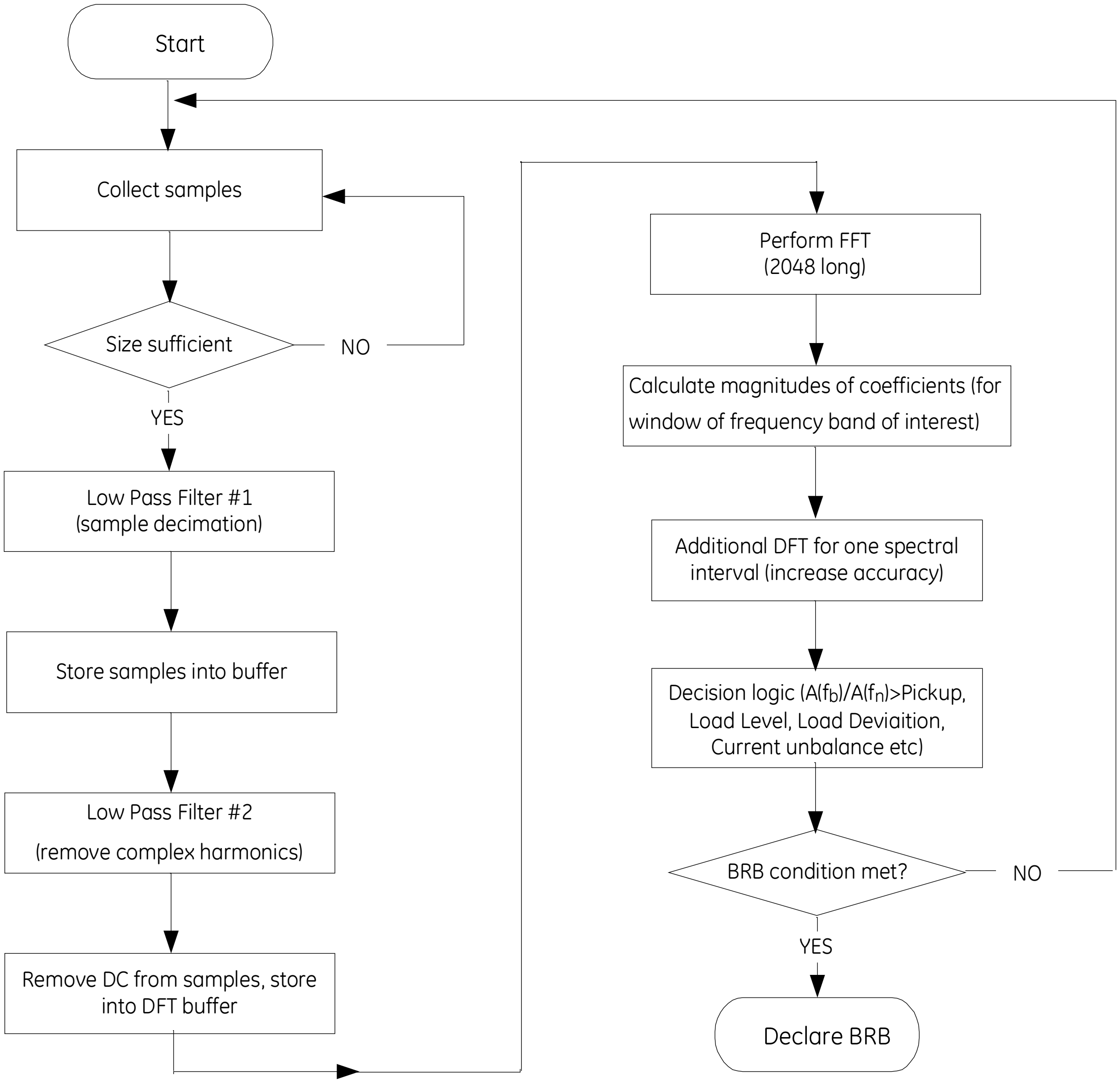

Figure 3. Flowchart of algorithm processing

The current signature analysis method requires a relatively long data set in order to provide a sufficient frequency resolution that is necessary for accurate fault detection. This data set is approximately 10 seconds long. During that period various disturbances can create a false detection scenarios. The following text enumerates those conditions and describes a practical solution for each of them.

System Frequency Deviation from Nominal

The frequency deviation from a nominal value is a major risk for a false detection since the applied algorithm uses a synchronous envelope demodulation.

This issue is being resolved by employing a frequency-tracking algorithm, normally used on an advanced protection device for accurate phasor components calculations. The frequency-tracking algorithm plays a role in the carrier frequency recovery - the essential step for synchronous demodulation accuracy.

4.1 Motor Load Variation

The load variation could be the source for a false detection of a spectral component attributed to a damaged rotor bar. Knowing or estimating the motor slip can result in a narrower window where the broken rotor bar component may reside, effectively reducing probability of a false detection. Even better results are achieved by monitoring the motor load variations during the data acquisition algorithm. The motor load is readily available on a motor protection device for other purposes. For the supervision of the detection algorithm for rotor bar faults, it is sufficient to calculate the standard deviation of the motor load every several power cycles. If the standard deviation of the motor load exceeds a preset value, the data set is discarded and the data acquisition starts from the beginning. The algorithm will effectively search and find an interval of a steady motor load required for the detection of rotor damage.

4.2 Motor Current Unbalance

An unbalance power source, or internal unbalances in the motor itself, is causing the motor current unbalance. The current unbalance can possibly impact the broken bar algorithm results. Since the current unbalance is readily monitored on a modern protection device, the broken bar algorithm is blocked when the current unbalance crosses a preset value. This value should be set somewhat below the level for the current unbalance alarm.

4.3 Motor Starting and Overloaded Conditions

The motor start phase and any overload situation are also excluded form the broken rotor bar detection based on the motor load level. This is in order to eliminate any possibility of a changing motor current having the spectral components in the window of interest for the broken rotor bar detection.

4.4 Dynamic Measuring Range

A protection device metering system is normally designed to handle medium and high signal levels necessary for protection functions. The metering of very small values, associated with the broken rotor bar, is compromised when the motor is lightly loaded. For that reason the broken rotor bar detection is blocked while the motor load is below a preset value. In addition to that, a sliding window based filter is applied to the calculated spectral components in order to further reduce the likelihood of a false alarm.

4.5 Broken Rotor Bar Components Dependency on Motor Load Level

The practical measurements of the current spectral components attributed to the damaged rotor bars are somewhat proportional to the motor load level, even though the theoretical values are not. In order to prevent a false alarm for higher load levels, a simple restraining algorithm is applied. This restraining algorithm dynamically modifies the rotor bar alarm level based on the motor load level at the time of measurement.

4.6 Delay in Declaring Rotor Damage Alarm

The slow progressing rotor damage does not require an instantaneous response. As a final step in the prevention of a false detection, a delay of an arbitrary length is applied to the decision-making. The alarm level has to be present for a preset time before the alarm is actually declared. This step helps filtering out any false detection not being caught by other supervision measures.

5 Test Results and Analysis

Various lab tests on a 3 kW induction motor, under different load conditions (hence different slip) and with different number of rotor broken bars, are carried out to validate the described algorithm and to check the performance of the motor BRB detection function in the relay.

Figure 4. Lab testing of the new algorithm

5.1 Fault Sensitivity Test

This test is performed to measure the sideband component levels for different degrees of rotor broken bars at a given load condition. The component level is expected to increase with the severity of rotor broken bar. The experiment result may be used to set the minimum pick up level for the algorithm to indicate the presence of the broken bar in the rotor so as to avoid any false alarms.

Test Procedure:

a) The load on the motor is kept constant
b) The rotor broken bar frequency is estimated based on the supply frequency and rotor speed for the given load.
c) Start of BRB sideband and end of BRB sideband is set such that the estimated BRB frequency is within the band.
d) For different rotors namely healthy, 1 broken bar, 2 broken bars and 3 broken bars, the component level and component frequency is tabulated as below.

Rotor Case	Supply Frequency (Hz)	Load FLA	Rotor Speed	Estimated BRB frequency (Hz)	Start of BRB sideband (Hz)	End of BRB sideband (Hz)		Component Frequency (Hz)
Healthy	49.13	0.81	1456	47.93	-1.63	-0.63	-	47.77 to 47.96
1BRB	48.6	0.78	1446	47.74	-1.66	-0.66	-	47.54 to 47.65
2BRB	49.2	0.78	1460	48.13	-1.7	-0.7	-	48.13 to 48.2
3BRB	49.5	0.79	1467	48.3	-1.5	-0.5	-	47.95 to 48.28

Table 1. Component levels change for different number of broken bars

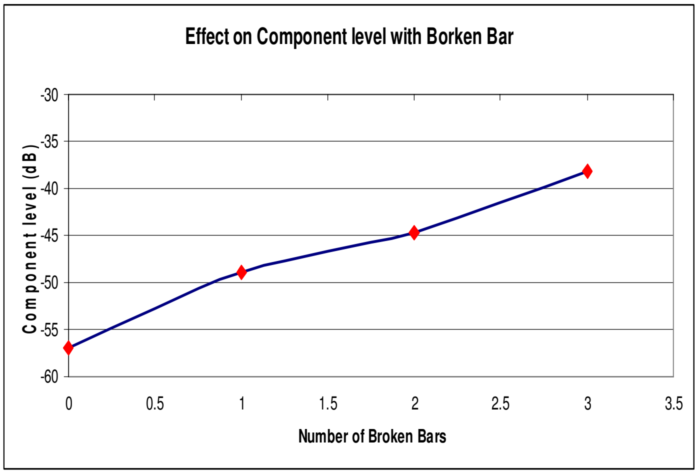

Figure 5. Relationship between number of broken bars and component levels

The test result clearly indicates that the sideband component level increases as the number of broken rotor bars increases. The minimum pickup level can be set between –55 and –50 dB for this motor.

5.2 Sweeping Frequency Test

This test is performed to determine the effect of sweeping the frequency window setting on the component level measured at a given load for a constant degree of rotor broken bars failure.

Test Procedure:

a) The load on the motor is kept constant

b) The rotor broken bar frequency is estimated based on the supply frequency and rotor speed for the given load.

c) For a given rotor fault, the start of BRB sidebands and end of BRB sidebands are swept with a given width of 1Hz

d) The actual parameters for each test are recorded in the table below

Number of BRB	Load (FLA)	Sweeping Frequency Window Width (Hz)	Supply Frequency (Hz)	Motor Speed (RPM)	Estimated BRB Frequency (Hz)
Health	0.9	1	49.03	1430	46.3
1	0.89	1	49.05	1430	46.28
2	0.89	1	49.35	1445	46.98
3	0.91	1	49.15	1436	46.58

Table 2. Sweeping frequency test

e) The component level versus sweeping frequency at different fault levels is plotted as below.

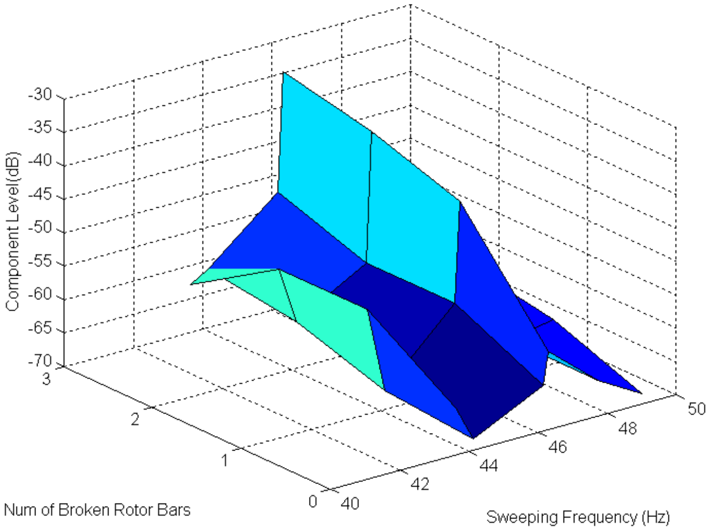

Figure 6. Sweeping frequency test illustration

It can be seen from this plot that the component level reaches the maximum value when the sweeping frequency window reaches the estimated sideband component frequency, $f_b = (1 - 2 \cdot s) \cdot f_1$.

5.3 Effect of Steady Load

This test is performed to determine the effect of load on the component level measured for a constant degree of rotor broken bars failure. It is known that the component frequency of the rotor broken bar signal is slip dependent. Now, whenever there is a rotor with a broken bar in the induction machine, the algorithm may not indicate its presence because of the very low slip under no load conditions. This experiment aims at determining the minimum load required so that the algorithm can detect the fault.

Test Procedure:

a) The width of the sideband window is kept constant for a given rotor fault.
b) The load on the motor is varied.
c) For each load on the motor, the rotor broken bar frequency is estimated based on the supply frequency and rotor speed.
d) The start of BRB sidebands and end of BRB sidebands are set according to the estimated rotor broken bar frequency.
e) The component level and component frequency is plotted as below.

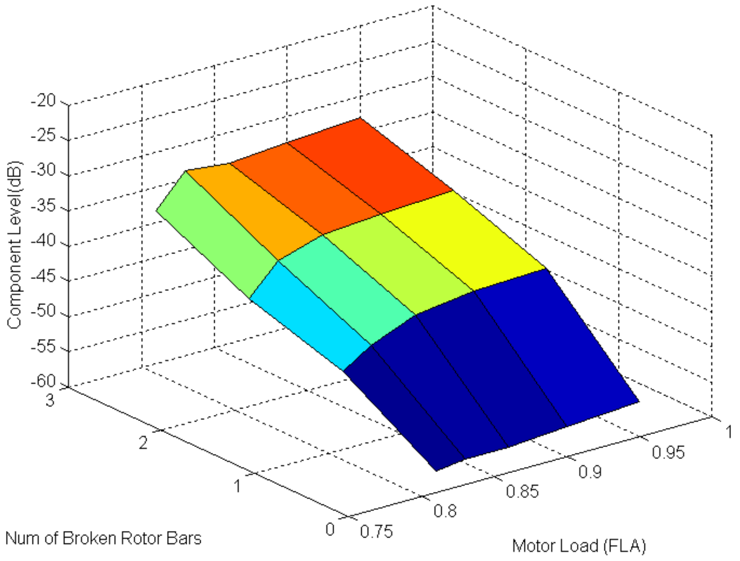

Figure 7. Steady load frequency test illustration

It can be seen that the measured sideband component level decreases as the load decreases. For the test we have carried out in the lab, i.e. the load varied from 0.78-0.99 FLA, the BRB component level was discriminative to detect the BRB condition.

5.4 Offline FFT Analysis on Captured Waveforms

Some current waveforms have been captured during the test and the frequency spectrums of these waveforms were analyzed offline using FFT to compare with the online measurement of the sideband components.

One of these waveforms is shown below, in which the motor load was 0.97FLA, supplied frequency was 49.1 Hz, motor speed was 1427 rpm and with 3 rotor bars broken.

It can be seen that the current waveform amplitude was clearly modulated with an approximate 3 Hz signal. Based on the MCSA theory, the modulated signal frequency can be calculated as below:

$$\text{slip} = \frac{49.1 \times 30 - 1427}{49.1 \times 30} = 0.031228747 \qquad \text{Eq. 10}$$

The sideband frequency=(1-2*0.031228747)*49.1=46.03Hz. So the modulated signal frequency was 49.1-46.03=3.07 Hz, which agrees with what we have observed from the current waveform.

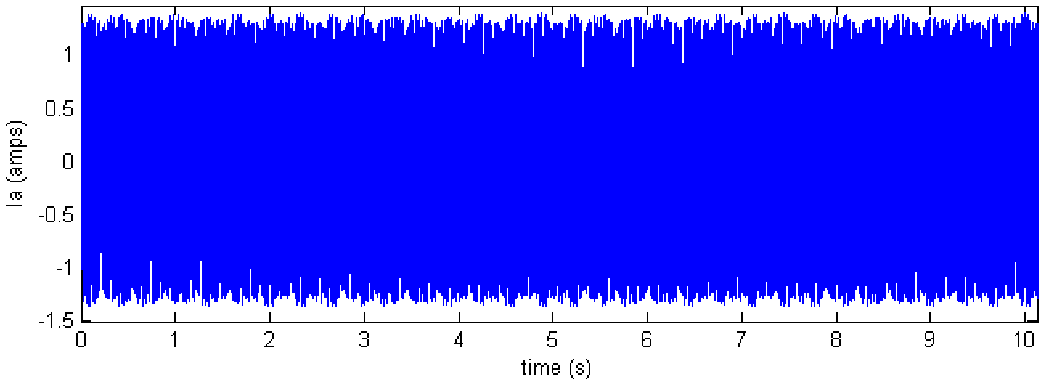

Figure 8. Captured waveform for FFT analysis

The frequency spectrum of this captured current waveform from FFT is shown in the following figure. The sideband component frequency and the sideband component level from the offline FFT is 46.09 Hz and –35.17 dB respectively. This is very close to the online measurement values: 46.09 to 46.17 Hz and –33.68 dB.

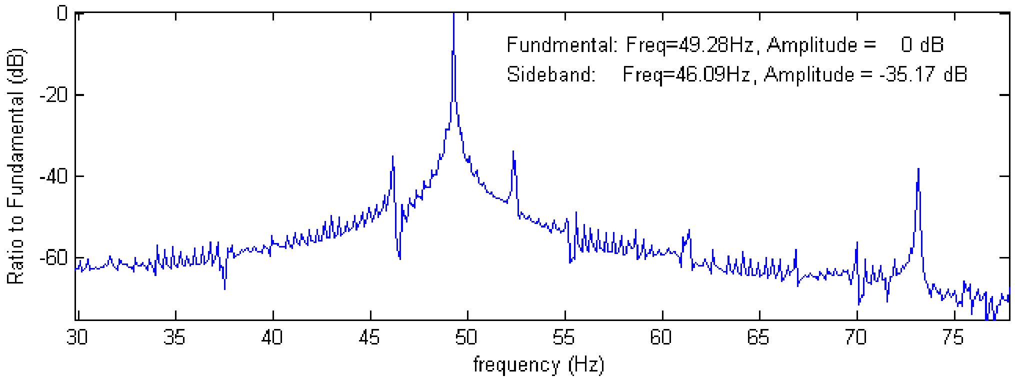

Figure 9. Result of off-line FFT analysis

In summary, various tests have been performed with different levels of faults and different load level on the motor, the component levels and the corresponding component frequencies shown by the relay are observed which are in accordance with the expected values as per the theory.

6 Setting Example

This section explains which typical settings are required in a motor protective relay to accomplish a motor broken bar detection and how these setting are selected

START OF BRB OFFSET

This setting defines the beginning of the frequency range where the spectral component due to a rotor bar failure, will be searched. The beginning of the frequency range is defined as: $f_{start} = f_1 + f_{start\_offset}$ where "f_1" is system frequency, and f_{start_offset} is this setting.

If the upper sideband is to be measured, this setting should be set to a value equal to $f_{start\_offset} = 2 \cdot s \cdot f_1 - \max(0.3, \min(2 \cdot s \cdot f_1 - 0.4, 1.0))$, where "$f_1$" is system frequency, "s" is the motor slip at full load, and 0.3, 0.4 and 1.0 are fixed values; "max" returns the largest of its arguments and "min" returns the smallest of its arguments. For example, if the full load slip is 0.01, set this setting to: 2·0.01·60 – 0.8 = 0.40 Hz, for a 60 Hz power system.

If the lower sideband is to be measured, this setting should be set to a value equal to $f_{start\_offset} = -2 \cdot s \cdot f_1 - \max(0.3, \min(2 \cdot s \cdot f_1 - 0.4, 1.0))$. Using the same values from previous example, this value should be set to –1.2 -0.8 = -2.00 Hz.

END OF BRB OFFSET

This setting defines the end of the frequency range where the spectral component due to a rotor bar failure, will be searched. The end of the frequency range is defined as: $f_{end} = f_1 + f_{end\_offset}$, where "$f_1$" is system frequency, and f_{end_offset} is this setting.

If the upper sideband is to be measured, this setting should be set to a value equal to $f_{end\_offset} = 2 \cdot s \cdot f_1 - \max(0.3, \min(2 \cdot s \cdot f_1 - 0.4, 1.0))$, where "$f_1$" is system frequency, "s" is the motor slip at full load, "max" returns the largest of its arguments and "min" returns the smallest of its arguments. For example, if the full load slip is 0.01, set this setting to: 2·0.01·60 + 0.8 = 2.00 Hz, for a 60 Hz power system.

If the lower sideband is to be measured, this setting should be set to a value equal to $f_{end\_offset} = -2 \cdot s \cdot f_1 - \max(0.3, \min(2 \cdot s \cdot f_1 - 0.4, 1.0))$. Using the same values from previous example, this value should be set to –1.2 +0.8 = -0.40 Hz.

BRB START BLOCK DELAY

This setting is used to block Broken Rotor Bar detection function for a time defined by this setting, when motor is starting. This element is active only when the motor is running and will be blocked upon the initiation of a motor start for a period of time defined by this setting. For example, set it to 60 seconds to avoid false alarm during motor starting.

MINIMUM MOTOR LOAD

This setting is used to block the data acquisition of the Broken Rotor Bar detection function, as log as the motor load is below this setting. The Broken Rotor Bar detection algorithm cannot accurately determine the BRB spectral component when a motor is lightly loaded. For example, set it to 0.7 FLA.

MAX. LOAD DEVIATION

This setting is used to block the data acquisition of the Broken Rotor Bar detection function, as log as the standard deviation of the motor load is above this setting. The Broken Rotor Bar detection algorithm cannot accurately determine the BRB spectral component when the motor load varies. For example, set it to 0.1 FLA.

MAXIMUM CURRENT UNBALANCE

This setting is used to block the data acquisition of the Broken Rotor Bar detection function, as log as the current unbalance is above this setting. The Broken Rotor Bar detection algorithm cannot accurately determine the BRB spectral component in a current unbalance situation. For example, set it to 15% unbalance level.

BROKEN ROTOR BAR PICKUP

This setting specifies a pickup threshold for this element. The pickup threshold should normally be set to a level between –54 dB (very likely, a cracked rotor bar) and –50 dB (probably a broken rotor bar). For example, set it to –52 dB.

BRB BLOCK
This setting specifies an operand blocking this function. Typically, a panel cut-off switch or other user specified conditions blocks this function.

7 Conclusions

This paper describes an algorithm for detection of broken rotor bars based on Motor Current Signature Analysis (MCSA) enhanced with a set of motor conditions, collected by a protection relay in order to avoid a false declaration of an alarm due to rotor problems. This approach greatly reduces a need for a human expert involvement in the results interpretation and the decision making process.

The proposed algorithm is implemented in a motor protection relay, and extensively tested for consistency and accuracy of alarms due to damage of rotor bars of an induction motor, both in simulated environment and in the electrical machine lab, involving real motors with various degree of rotor damage. The test results prove that the algorithm is capable of detecting abnormalities in the motor early, before they turn into expensive-to-repair failures. This algorithm detects problems of the rotor while motor is online. Based on an alarm from this algorithm, it may be possible to prevent problems on the next motor start, for example, by scheduling maintenance at a more convenient time, or providing a backup motor. A more severe rotor bar fault may result in a significant torque reduction while the motor is starting next time, and an overload element trip at that time, may be significantly costlier to the process. The presence of broken rotor bars causes torque and speed oscillations in the rotor, provoking premature wear of bearings and other driven components. There is also a possibility of turning a non-detected rotor bar breakage into a catastrophic stator failure.

The future studies will include further enhancements in order to increase algorithm's robustness in case of pulsating motor load conditions.

8 References

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