A Review of Voltage and Current Signature Diagnosis in Industrial Drives

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Abstract

With the industrial growth, it has become necessary to monitor the condition of the machine/system. Electrical machine being the most sensitive part has great importance for the researcher to monitor the faults diagnosis. Three phase squirrel cage motor is normally use for industrial purposes. Various techniques are used to control the speed such as DTC (Direct Torque Control), Vector Control, Close Loop Feedback Control etc. Small single phase Induction machine are used for home appliances hence the machine monitoring plays an important role for industrial as well as domestic appliances growth. Various fault detection method has been used in past two decades. Special attention is given to non-invasive methods which are capable to detect fault using major data without disassembly the machine. The Motor Current Signature Analysis (MCSA) is considered the most popular fault detection method now a day because it can easily detect the common machine fault such as turn to turn short ckt, cracked /broken rotor bars, bearing deterioration etc.This paper presents the review of identify the different types of faults in the induction motor during online condition by using current and voltage signature analysis. Special attention is focused on the effect of both space distribution of rotor breakage and rotor dissymmetry on the mechanism of generation of diagnosis signatures with the consideration of voltage supply unbalance and speed ripples. A comparison is made between the voltage signature analysis and current signature analysis of Induction motor.

1. Introduction

The AC induction motor is well suited to applications requiring constant speed operation. In general, the induction motor is cheaper and easier to maintain compared to other alternatives. The squirrel cage induction motor has been used in all kinds of electric drives more often than other electric motors because of its reliability, robustness and simplicity of bits construction. The classical theory of this electromechanical component is based on the assumption that the rotating mmf produced by stator winding excitation is sinusoidally distributed in space and that the rotor mmf due to the slip frequency induced currents is similarly distribute. In recent years, the problems of failure in large machines have become more significant and of concern in industrial applications. The desire to improve the reliability of industrial drive systems has led to concerted research and development activities in several countries to evaluate the causes and consequences of various fault conditions. In particular, ongoing research work is being focused on rotor bar faults and on the development of diagnostic techniques.[1-6]-Several diagnostic techniques have been proposed in the past to detect faults due to broken rotor bars. Most of them are based on the steady-state analysis of stator voltages and currents via fast Fourier transform (FFT). In [2], comparison and performance evaluation of different diagnostic procedures, to detect and quantify broken rotor bars of an induction machine supplied by the mains, are reported. The most well known method for the diagnosis of broken rotor bars in induction motors is based on the monitoring and the processing of the stator currents to detect some relevant frequencies. These one are the sidebands close to the fundamental frequency and other space harmonics present in the line current

2. Motor Current Signature Analysis

Motor Current Signature Analysis (MCSA) is a technique used to determine the operating condition of AC induction motors without interrupting production. MCSA techniques can be used in conjunction with vibration and thermal analysis to confirm key machinery diagnostic decisions. MCSA operates on the principle that induction motor circuits can, in essence, be viewed as a transducer. By clamping a Hall Effect Current sensor on either the primary or secondary circuit, fluctuations in motor current can be observed. [1] An idealized current spectrum is shown in Fig. 1. The two slip frequency sidebands due to broken rotor bars near the main harmonic can be clearly observed. Usually a decibel (dB) versus frequency spectrum is used in order to give a wide dynamic range and to detect the unique current signature patterns that are characteristic of different faults [2].
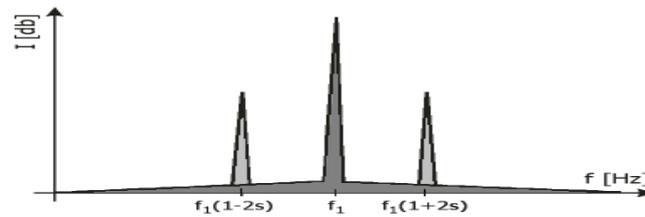
Fig .1. the Idealized current spectrum
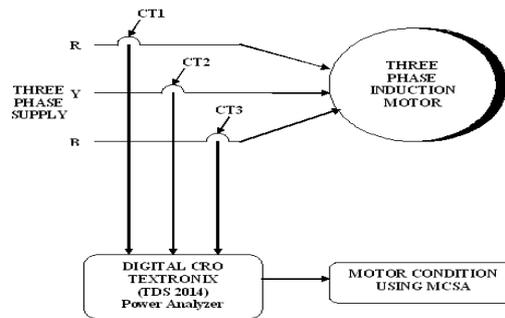
Fig.2. Block diagram of MCSA

In this paper the authors propose a new approach to investigate the diagnosis of the fault diagnosis in broken rotor bar in induction motor using an online method known as voltage signature analysis is shown in figure .2. The analysis of line neutral voltage signature conserves the advantage and simplicity of MCSA. Moreover, this one is more sensitive to motor failures. For instance, when broken-bar default is considered, one can find more extra harmonic frequencies with more significant amplitude to be detected as diagnosis signatures at least near the (3rd, 9th, 15th, and 21st) harmonics, and they are not too close to the principal frequencies in comparison to MCSA. This makes it more suitable for the diagnosis process, even in the[3] case of small slips or for incipient-failure detection. In addition to the characteristic components related to different types of faults in the machine, the line neutral voltage spectrum contains other higher harmonics known as rotor slot harmonics (RSHs) due to both space distribution of rotor bars and variation of the air-gap presence.[4] The detection of these harmonics in the line neutral voltage is also important from the viewpoint of motor related fault detection as well as sensor less speed estimation. The originality of this paper is the accurate formulas of different frequencies of these harmonics, from which one can analyze in a more efficient way the information related to the detection of machine faults. At the beginning, the harmonic frequencies of the line neutral voltage for a healthy machine are analytically calculated. In the second step, the proposed study is extended to calculate the harmonic frequencies of the line neutral voltage when the motor is running under unbalanced supply condition and presents rotor dissymmetry (constructional rotor bar or end ring defaults). The speed ripple effect is also considered. Simulation and laboratory tests demonstrate the effectiveness of the proposed study.[5]

3. Voltage Signature Analysis

The analysis of line neutral voltage signatures still remains far from being finished and efforts are in progress to improve the overall fault diagnosis of induction motors. The basis of any reliable diagnostic method is an understanding of the electric, magnetic, and mechanical behaviors of the machine in healthy or faulty state. [6] Therefore, in this paper, the authors propose an analytical investigation of the generation mechanism of different harmonics due to motor faults. Simulation of MVSA is mentioned in next section. The theoretical basis of this approach is based upon the consequential phase impedance variation (or imbalance) upon application of a turn fault in any of the stator phases. When considering only the fundamental component of electrical excitation, then the sum of the line–neutral voltages is given by the phasor relationship [7][8].

A. Basic Steps for Analysis

There are a number of simples steps that can be used for analysis using MCSA. The steps are as follow:
1. Map out an overview of the system being analyzed [9].
2. Determine the complaints related to the system in question. For instance, is the reason for analysis due to improper operation of the equipment, etc. and is there other data that can be used in an analysis [10].

3. Take data.

4. Review data and analyze:

4.1. Review the 10 second snapshot of current to view the operation over that time period.[11]

4.2. Review low frequency demodulated current to view the condition of the rotor and identify any load-related issues.

4.3. Review high frequency demodulated current and voltage in order to determine other faults including electrical and mechanical health.[12]

Most faults can be determined at a glance, with many rules being similar for both MCSA and vibration analysis. In addition, there are several rules that should be considered:

1. Pole pass frequency (ppf) sidebands around the line frequency indicate rotor bar faults. The higher the peaks, the greater the faults.

2. Harmonic pole pass frequencies often relate to casting voids or loose rotor bars.[13]

3. Non-ppf sidebands that cause a 'raised noise floor' around the line frequency peak normally relate to driven load looseness or other driven problems.

4. 'Raised noise floor' signatures relate to such things as looseness or cavitations.

5. Peaks that show in current and voltage relate to electrical issues, such as incoming power. Peaks that show in current only relate to winding and mechanical faults.

6. Peak pairs that do not relate to running speed or line frequency are most often bearing related problems. [14]

Motor current acts as an excellent transducer for detecting faults in the motor. Spectrum analysis of the motor's current and voltage signals disturbing its operation. Typical faults detectable by this are:

- rotor bar damage
- misalignment/unbalance
- foundation looseness
- static eccentricity
- dynamic eccentricity
- core damage
- loose wedges
- interterm shorts
- defective bearings

Electrical signature analysis is the procedure of acquiring the motor current and voltage signals performing signal conditioning and analyzing the derived signals to identify the various faults. The three signals are collected either directly through a CT. Thus, motors can be tested from the control panel, enabling easy testing or remote. A FFT(Fast Fourier Transform) analyzer is requires for converting the signals from the time domain to the frequency domain.[15 - 20]

4. Theory of Motor current signal

A motor current signal is ideally a perfect sinusoidal wave at 50 Hz .we can represent the current in terms of time as well frequency. her figure .3. Shows the current vs time while the second shows the current vs frequency.[21]

The amplitude of the peak in frequency is equal to the RMS amplitude of the sine wave. as this is a theoretical situation with no harmonics, we see only one peak in the frequency spectrum. the conversion of the current from time to the frequency domain is achieved using an algorithm called the fast Fourier transform[22] .
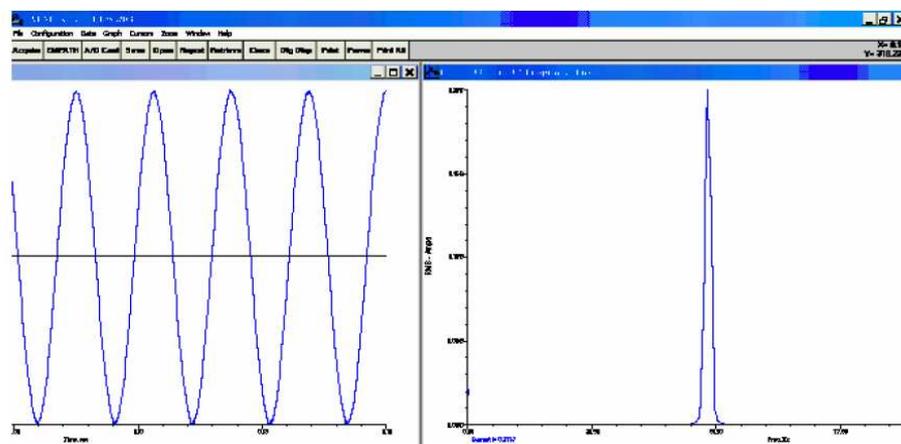
Fig.3. A perfect 50 Hz signal in both time & frequency domains.

During actual operation many harmonics will be present in the motor signal, thus an actual signal will show many peaks including line frequency and its harmonics is shown in figure.4. This is known as the motor's current signature. Analyzing these harmonics after amplification and signal conditioning will enable identification of the various motor faults [23].
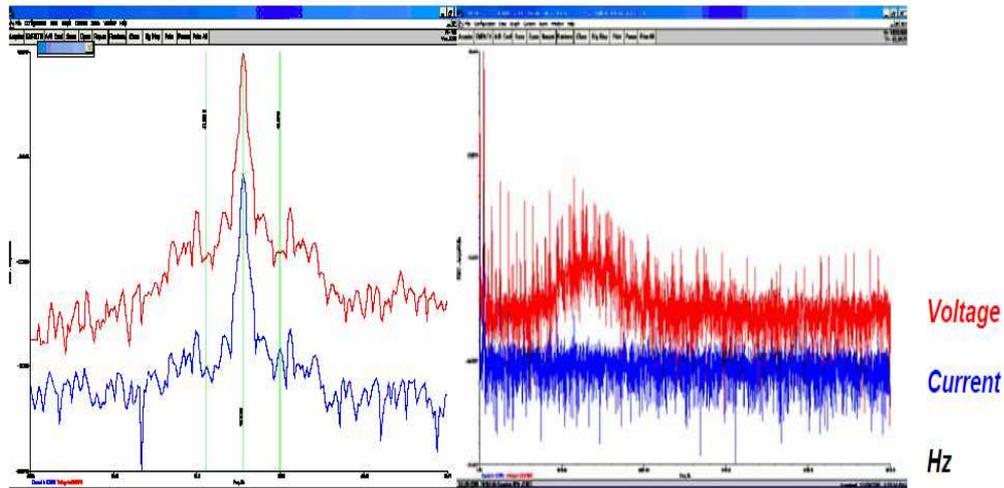
Fig.4. typical low and high frequency spectra of a good motor

Certain harmonics come in on the supply & these are of little consequence. However, harmonics are also generated due to various electrical and mechanical faults. All faults cause change in internal flux distribution thus generating t h e harmonics.

5. Application of MCSA for Induction Motor Fault Detection

In three phase induction motor under perfectly balanced condition (healthy motor), three phase supply is given to the stator winding, a forward rotating magnetic field is produced which rotates at synchronous speed,[24]

$$N_s = f_1 / p \qquad\qquad (1)$$

Where f_1 is the supply frequency
       p is the pole pairs of stator i.e., $p = P / 2$

The rotor rotates at N_r and Figure 5 illustrates that the rotor always rotates at a speed less than the synchronous speed. A measure of the slipping back of the rotor is termed the slip, defined as

$$\text{Slip } s = (N_s - N_r) / N_s \qquad\qquad (2)$$
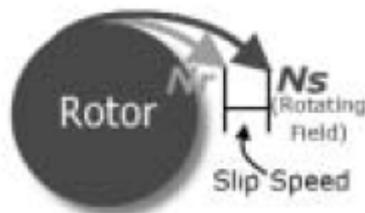
Fig 5.shows the Illustration of slip speed

The slip speed $N_2 = N_s - N_r = s \times N_s$ is the actual difference in between the speed of rotating magnetic field and actual speed of rotor .[25]
The frequency of rotor current is called the slip frequency and is given by

$$f_2 = N_2 \times p = s \times N_s \times p \tag{3}$$

Under normal operation, the speed of rotating magnetic field produced by the currents flowing in the rotor conductors moves faster than the actual speed N_r, as illustrated in Figure 6
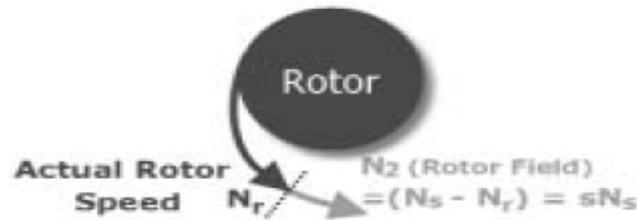
Fig 6 shows the Illustration of rotating field from rotor currents moving faster than rotor speed

Now the speed of rotating magnetic field produced by the current carrying rotor conductors with respect to the stationary stator winding is given by:

$$N_r + N_2 = N_r + N_s - N_r = N_s \tag{4}$$

With respect to a stationary observer on the fixed stator winding, then the speed of the rotating magnetic field from the rotor equals the speed of the stator rotating magnetic field, namely, the synchronous speed Ns [26].

A. Detection of broken rotor Bars

When a broken bar present or an eccentricity in the gap occurs, magnetic field is not longer constant between rotor and stator, creating slight deviation from the fundamental field. Those deviations induce current in the rotor and stator with a frequency slightly out of the fundamental frequency called sidebands. With broken rotor bars there is an additional rotating magnetic field produced. Broken rotor bar produce a backward rotating magnetic field at slip speed (-ve direction $(N_s - N_r) = s \times N_s$) with respect to rotor as illustrated in Figure 7.

Fig 7.shows the Illustration of forward and backward rotating magnetic fields from rotor currents when a Broken Bar exists.

Let N_b = backward rotating magnetic field speed produced by the rotor due to brokenbars

$$N_b = N_r - N_2$$
$$= N_r - s N_s$$
$$= N_s (1 - s) - s \times N_s$$
$$= N_s - 2 \times s \times N_s$$
$$N_b = N_s (1 - 2 s) \tag{5}$$

The stationary stator winding now sees a rotating field at:

$$N_b = N_s (1 - 2 s)$$

Or expressed in terms of frequency

$$f_b = f_1 (1 - 2 s) \tag{6}$$

This means that a rotating magnetic field at that frequency cuts the stator windings and Induce a current at that frequency (f_b). This in fact means that f_b is a twice slip frequency component spaced $2sf_1$ down from f_1. Thus speed and torque oscillation occur at $2sf_1$ and this induces an upper sideband at $2sf_1$ above f_1.

Classical twice slip frequency sidebands therefore occur at $\pm 2sf_1$ around the supply frequency.

$f_b = (1 \pm 2s) f_1$ Hz

While lower side band is specifically due to broken bar and upper side band is due to consequent speed oscillation.

The speed oscillation can reduced the magnitude of the $f_1 (1-2s)$ sideband , but an upper sideband current component at $f_1(1+2s)$ is induced in the stator winding due to the rotor oscillation. This upper sideband is also enhanced by the third harmonic flux.

Broken rotor bars therefore result in current components being induced in the stator winding at frequencies given by

$$f_b = f_1(1 \pm 2s) \text{ Hz} \tag{7}$$

In fact, several papers shows that broken bars actually give rise to a sequence of such sidebands given by

$$f_b =(1\pm 2ks)f_1, \qquad k = 1, 2,3\ldots \tag{8}$$

Therefore the appearance in the harmonic spectrum of the sidebands frequencies Given by (6) or (7) clearly indicates a rotor fault of the induction machine.

B. Detection of Air gap eccentricity

Air gap eccentricity problems can be detected by identifying the characteristic current signature pattern which is indicative of abnormal levels of air gap eccentricity and to then trend that signature. The specific frequencies of the current components indicative of air gap eccentricity may be calculated from:

$$f_{ac} = f_1 \{(R\pm n_d) (1-s/p)\pm n_{ws}\} \tag{9}$$

Where

f_{ac}= frequency components which are a function of air gap eccentricity, Hz

$n_d =\pm 1$

n_{ws}, = 1, 3,5, 7 ..... Etc

With $n_d = 0$ in "(3)" gives the classical rotor slot passing frequency components - a series of components spaced at twice the supply frequency, $2.f_1$, apart. The signature pattern of specific rotor slot passing frequencies and the two components from "(3)" with $n_d = \pm 1$ can be used to identify abnormal levels of air gap eccentricity [27].

C. Detection of Mechanical Influences

Changes in air gap eccentricity result in changes to the air gap flux waveform any mechanical disturbance to the rotor of the induction motor can result in changes to the air gap flux waveform. Consequently this can induce stator current components given by:

$$f_e= f_1\pm mfr \tag{10}$$

Where

f_r = rotational speed frequency of the rotor, Hz

m = 1, 2, 3 .... harmonic number

f_e = current components due to air gap disturbance, Hz

This means the effects of mechanical disturbances from, for example, slow speed gearboxes, fluid couplings, belt drives, and recycling in compressors can induce current components. In addition, problems such as shaft / coupling misalignment, bearing wear, roller element bearing defects and mechanical problems that result in dynamic rotor disturbances can be potentially detected due to changes in the current spectrum.

D. Detection of Shorted Turns in Stator winding

The objective is to reliably identify current components in the stator winding that are only a function of shorted turns and are not due to any other problem or mechanical drive characteristics. The diagnosis of shorted turns via CSA is based on detecting the frequency components given by equation (11) in that these rotating flux waves can induced corresponding current components in the stator windings.[28-30]

$$f_{st} = f_1\{n/p(1-s)\pm k\} \tag{11}$$

Where

f_{st} = components that are a function of shorted turns.

f_1= supply frequency,

n =1,2,3..

p = pole pairs
s = slip

6. Conclusions

This paper described about the comparison of motor current signature analysis and voltage signature analysis in induction motor. This method is a highly versatile and proven technology for condition monitoring and fault analysis of motors. It solves the biggest hurdle of any plant manager, which is to prove obtain a shutdown for testing his machines. The advantage of using the Motor current Signature Analysis method can detect these problems at an early stage and thus avoid secondary damage and complete failure of the motor. Another advantage of this method is that it can be also applied online. These results have clearly demonstrated that MCSA is a powerful technique for monitoring the health of three phase induction motor rotor.

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