

An Approach of Condition Monitoring of Induction Motor Using MCSA

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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. The present paper discusses the fundamentals of Motor Current Signature Analysis (MCSA) plus condition monitoring of the induction motor using MCSA.

I. INTRODUCTION

The operators of induction motor drives are under continual pressure to reduce maintenance costs and prevent unscheduled downtimes that result in lost production and financial income. Many operators now use online condition-based maintenance strategies in parallel with conventional planned maintenance schemes. However, it is still the operator who has to make the final decision on whether to remove a motor from service or let it run based on information from condition monitoring systems. A crucial point about motor current signature analysis (MCSA) is that it is sensing an electrical signal that contains current components that are a direct by-product of unique rotating flux components caused by faults such as broken rotor bars, air gap eccentricity, and shorted turns

in low voltage stator windings, etc. MCSA can detect these problems at an early stage and thus avoid secondary damage and complete failure of the motor [2, 4, 7, and 6]. It is true that broken rotor bars will result in a change to the vibration spectrum, but vibration is traditionally sensed at the bearings. And for each motor there is a different mechanical stiffness between the electromagnetic forces caused by broken bars and the position where the vibration is sensed. This adds an additional complexity when attempts are made to quantify the severity of the problem via vibration analysis. Electromagnetic forces are proportional to the flux density squared waveform in an induction motor [6, 7]. Hence, the vibration from unique electromagnetic forces from broken bars, etc., is a second order effect compared to current components directly induced from the specific rotating flux waves. In many cases, the fault severity (e.g., number of broken rotor bars) has to be serious before it can be detected by vibration analysis, and even then the prediction of fault severity is another order of magnitude more difficult. This is not the case with MCSA as has been proven via numerous industrial case histories. With respect to detecting airgap eccentricity problems, a similar reasoning applies as reported by Cameron, et al. [8], Tavner and Penman [9], and as demonstrated via industrial case histories by Thomson and Barbour, [10] and Thomson, et al. [11]. With respect to detecting shorted turns in low voltage stator windings then Thomson [12] has shown that MCSA can detect the fault before a phase-to-phase or phase-to-earth failure. It is therefore possible with a low voltage (LV) stator winding to have some lead time between shorted turns.

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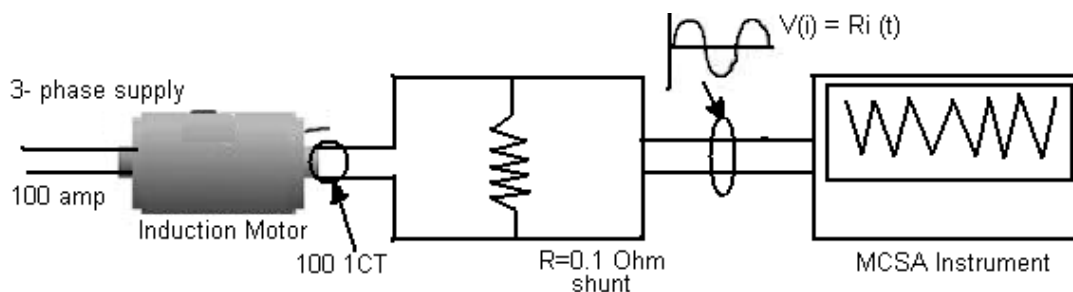


Figure 1: Basic MCSA Instrumentation System.

developing and actual failure. In comparison to a high voltage (HV, e.g., 4160 V and above) induction motor, the time to failure with an inter fault will be very short indeed

II. MOTOR CURRENT SIGNATURE ANALYSIS

Motor Current Signature Analysis (MCSA) is a system used for analyzing or trending dynamic, energized systems. Proper analysis of MCSA results will assist the technician in identifying:

1. Incoming winding health
2. Stator winding health
3. Rotor Health
4. Air gap static and dynamic eccentricity
5. Coupling health, including direct, belted and geared systems
6. Load issues
7. System load and efficiency
8. Bearing health

III. BASIC STEPS FOR ANALYSIS

There are a number of simple steps that can be used for analysis using MCSA. The steps are as follow:

1. Map out an overview of the system being analyzed.
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.
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.
 - 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.

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.
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 cavitation.
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.

Induction motors are the most widely used electrical machines. Therefore, many researchers have studied motor diagnosis methods to prevent sudden stop in motor system.

If there are slightly damaged motors, which have been operating for a long time without symptoms, entire system including these motors can be very dangerous and these motor may be seriously damaged. Preventive measures should be periodically taken in order to protect motors and systems including motors. This is the most efficient way to keep motor operating continuously in healthy conditions.

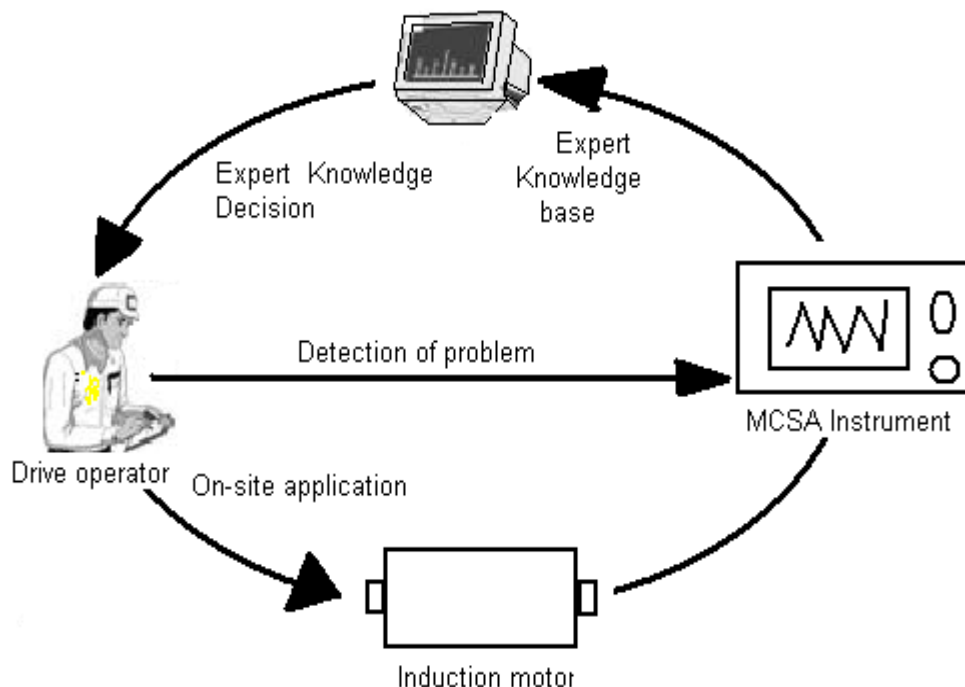


Figure 2: Overall MCSA Strategy.

IV. THEORY OF MCSA

A full mathematical analysis (with experimental verification) of a three-phase induction motor operating with broken rotor bars was published by Williamson and Smith (1982)—this gives an excellent in-depth analysis. A conceptual explanation is now presented to assist the reader in gaining a physical understanding of what happens in an induction motor with broken rotor bars. It is well known that a three-phase symmetrical stator winding fed from a symmetrical supply 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. Now apply 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 voltage and current in the rotor winding is at slip frequency and not at the supply frequency: s = per unit slip, f_1 = supply frequency Hz, $f_2 = sf_1$ Hz, f_2 = slip frequency of rotor currents Hz. The rotor currents in a cage winding produce an effective three-phase magnetic field, which has the same number of poles as the stator field but it is rotating at slip frequency (f_2) with

respect to the rotating rotor. When the cage winding is symmetrical, there is only a forward rotating field at slip frequency with respect to the rotor. If rotor asymmetry occurs, then there will be a resultant backward rotating field at slip frequency with respect to the forward rotating rotor. The result of this is that, with respect to the stationary stator winding, this backward rotating field at slip frequency with respect to the rotor induces a voltage and current in the stator winding at

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

This is referred to as a 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 that is also a function of the drive inertia. This speed oscillation can reduce the magnitude (amps) 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 time harmonic flux. Broken rotor bars therefore result in current components being induced in the stator winding at frequencies given by:

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

This gives $\pm 2sf_1$ sidebands around the supply frequency component f_1 . These are the classical twice slip frequency sidebands due to broken rotor bars.

These are sometimes referred to as the pole pass frequencies by condition monitoring practitioners, but this is not really an appropriate terminology and can cause confusion. The publications by electrical machine designers, researchers, and manufacturers always refer to the twice slip frequency sidebands due to broken bars, as can be verified by reading the references in this paper. Due to the variables that affect the frequency of these sidebands and their magnitude in amps (normally in dB in a MCSA system), the diagnostic strategy has to consider the following:

- Different rotor designs (effect of pole number and number of rotor slots, etc.).
- A wide range of power ratings.
- Different load conditions.
- Mechanical load characteristics.
- Mechanical components in the drive train.

These factors can significantly affect the diagnosis and need to be considered in the development of reliable MCSA instrumentation systems for three-phase induction motors.

V. LOW VOLTAGE STATOR WINDING FAULTS

The most common kind of faults related to stator winding of induction motors are: phase-to-ground, phase-to-phase and short-circuit of coils of the same or different phase. The last kind of fault is also called turn to turn fault. All these faults are classified as isolation faults and have several causes: hot spots in the stator winding (or stator core) resulting in high temperatures, loosening of structural parts, oil contamination, moisture and dirt, electrical discharges (in case of high voltage windings), slack core lamination, abnormal operation of the cooling system. Short-circuit related faults have specific components in the stator current frequency spectrum. Incipient faults can be detected sampling the stator current and analyzing its spectrum. This procedure is on the base of MCSA Method.

VI. ROTOR FAULTS

Motor current signature analysis (MCSA) is one of the most spread procedures to detect rotor faults. In fact, a rotor bar breakage introduces two anomalous lines in the current spectrum far

from the supply frequency line. The left-side component is caused directly by the fault, while the right-side component is caused by the consequent speed ripple. The sum of the amplitudes of these two components was proven to be a very good diagnostic index, suitably correlated to the fault severity for fabricated rotors. A drawback of this diagnostic procedure is the possible confusion with the motor current modulation produced by other events. As an example, pulsating load and particular rotor design also cause sideband current components. If the load variation frequency is near, the resulting current spectrum is similar to that of a faulted rotor, but the two causes can still be distinguished. A more difficult issue is that of the particular design of the rotor structure. In large motors, a spidered structure with the same number of legs and poles produces a magnetic asymmetry whose effect is the same of rotor electrical asymmetry.

VII. FAULT DIAGNOSIS AND FUZZY LOGIC

Fuzzy logic can systematically translate linguistic concepts to numbers and associate elements from a number set to concepts. This capability provides a simple method to analyze and interpret the frequency spectrum obtained for the stator current of induction machines. Fuzzy based algorithms and Fuzzy logic are well adapted to situations where no clear distinction between the concepts of true and false exists. Fuzzy logic can handle situations where the answer lies somewhere in-between. This is the typical case of machine fault diagnosis. In fact, in general it is a difficult task to establish the actual condition of a machine in terms of the existence or not of a defect. However, it makes more sense to classify a fault in terms of its degree of severity. Fuzzy logic permits to infer about the machine state and to establish its condition in different degrees of faulty condition. An important feature of Fuzzy based systems is that the human knowledge and experience can be integrated into the systems in a systematic way. This can be done when the Fuzzy sets and Fuzzy rules are being defined. This feature is even more important because the fault detection is in practice based on the human knowledge and experience, at least up to some degree.

VIII. CONCLUSION

Motor Current Signature Analysis is an electric machinery monitoring technology. It provides a highly sensitive, selective, and cost-effective means for online monitoring of a wide variety of heavy industrial machinery. It has been used as a test method to improve the motor bearing wear assessment for inaccessible motors during plant operation. This technique can be fairly simple, or complicated, depending on the system available for data collection and evaluation. MCSA technology can be used in conjunction with other technologies, such as motor circuit analysis, in order to provide a complete overview of the motor circuit. The result of using MCSA as part of motor diagnostics program is a complete view of motor system health.

A way forward is for the technology and intelligent diagnosis to be integrated into a technologically advanced hand-held instrument that is applicable to a diverse range of induction motor drives. It has to be appreciated that the operators requirements can be differ widely and an MCSA instrument must be able to cope with induction motor drives in power stations, Petrochemical refineries, offshore oil and gas production platforms, mining industry, paper mills and car industry.

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