Diagnosis of the Stator Fault in Inducation Motors Using Motor Current Signature Analysis

W.Z.Gandhare, Surekha Shivaji Bhalshankar

***Abstract*— Induction motors are critical components for most industries. Induction motor failures may yield an unexpected interruption at the industry plant. This paper presents a method for induction motor fault diagnosis based on stator current signal analysis. The condition monitoring of the electrical machines can significantly reduce the costs of maintenance by allowing the early fault detection, which could be expensive to repair. The applied method is called motor current signature analysis (MCSA) which utilizes the result of spectral analysis of the stator current. The diagnosis procedure was performed by using virtual instruments. The significant presence of some well-defined sideband frequencies in the harmonic spectrum of the measured line current clearly indicates the stator faults of the induction machines**

***Index Terms*— Current Signature Analysis (MCSA), Fault Detection, Condition Monitoring, Virtual Instuments, Stator Faults.**

I. INTRODUCTION

The studies of induction motor behavior during abnormal conditions due to presence of faults and the possibility to diagnose these abnormal conditions have been a challenging topic for many electrical machine researchers. There are many condition monitoring methods including vibration monitoring, thermal monitoring, chemical monitoring, acoustic emission monitoring but all these monitoring methods require expensive sensors or specialized tools where as current monitoring out of all does not require additional sensors[1]. This is because the basis electrical quantities associated with electromechanical plants such as current and voltage are rapidly measured by tapping into the existing voltage and current transformers that are always installed as part of protecting system. As a result, current monitoring is non-intrusive and may even be implemented in the motor control center remotely from the motors being monitored. It is observed that the technique called 'Motor Current Signature Analysis' (MCSA) is based on current monitoring of induction motor; therefore it is not expensive[2]. The MCSA uses the current spectrum of the machine for locating characteristic fault frequencies. When a fault is present, the frequency spectrum of the line current becomes different from healthy motor. Such a fault modulates the air-gap and produces rotating frequency harmonics in the and mutual inductances of the machine. It depends upon locating specific harmonic component in the line current. Therefore it offers significant implementation and economic benefits. In the research work, Motor Current Signature Analysis (MCSA) based methods are used to diagnose the common faults of induction motor such as broken bar faults, short winding fault, bearing fault, air gap eccentricity fault and load faults. The proposed methods in the research allow continuous and variable loaded conditions. The effects of various faults on current spectrum of an induction motor are investigated through experiments[2,3].

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II. MATHEMATICAL MODELING OF INDUCTION MOTOR

Different types of models have been proposed in the recent years to examine different problems associated with induction motors. These models are from the simple equivalent circuit to complex d, q models and abc models which allow the inclusion of different forms of impedance and/or voltage unbalance[4]. In the recent past, hybrid models have been developed which allow the inclusion of supply side unbalance but with the computational economy of the d, q models. Recently, there are so many applications in which induction motors are fed by static frequency inverters. Such applications are growing fast and a significant work in this field has already been done[5]. However, still there are a lot of scopes left which may be used in these applications. Induction motors are being used more than ever before in industry and individual machines of up to 10 MW in size are no longer a rarity. During start-up and other severe operations the induction motor draws large currents, produces voltage dips, oscillation torque and can even generate harmonics in the power system. It is therefore important to be able to model the induction motor in order to predict these phenomena. Various models have been developed, and the d, q or two-axis model for the study of transient behavior has been well tested and proven to be reliable and accurate[6,7]. It has been shown that the speed of rotation of the d, q axes can be arbitrary although there are three preferred speeds or reference frames as follows:

(a) *The stationary reference frame frame when the d, q axes do not rotate[5];*

(b) *The synchronously rotating reference frame when the d, q axes rotate at synchronous speed;*

(c) *The rotor reference frame when the d, q axes rotate at rotor speed*

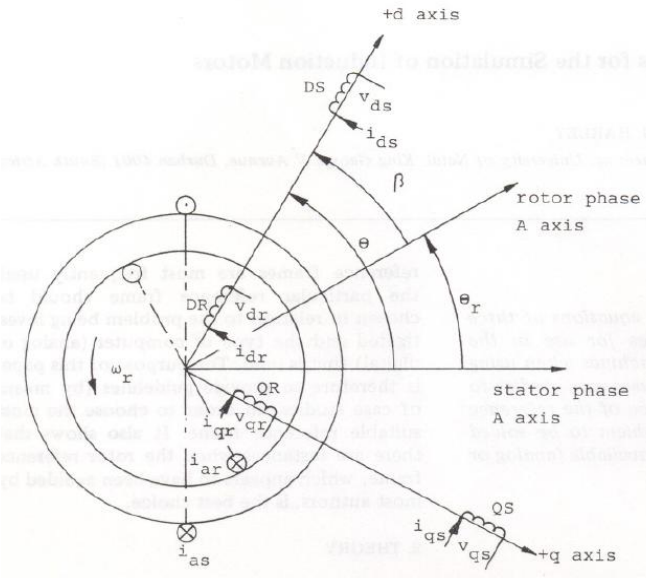

Figure 1: Idealised Current Spectrum

Let, line to line voltages be (V_{ab}, V_{bc}, V_{ca}) and line to neutral voltages be (V_{an}, V_{bn}, V_{cn})

$V_{ab} = V_{aN} - V_{bN}$;

$V_{bc} = V_{bN} - V_{cN}$;

$V_{ca} = V_{cN} - V_{aN}$;

$V_{an} = {}^2/_3 V_{aN} - {}^1/_3 V_{bN} - {}^1/_3 V_{cN}$;

$V_{bn} = {}^{-1}/_3 V_{aN} + {}^2/_3 V_{bN} - {}^1/_3 V_{cN}$;

$V_{cn} = {}^{-1}/_3 V_{aN} - {}^1/_3 V_{bN} + {}^2/_3 V_{cN}$;

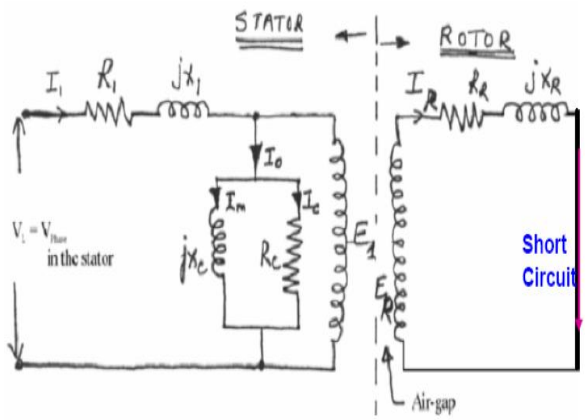

Figure 2: Equivalent Circuit Diagram of Induction Motor

$$V_D = R_1 i_D + L_1 p i_D + L_M . p i_D \quad (1)$$

$$V_Q = R_1 i_Q + L_1 p i_Q + L_M . p i_D \quad (2)$$

$$V_d = L_M . p i_D + \omega_r L_M i_Q + R_2 i_d + L_2 p i_d + \omega_r L_2 i_q$$

(3)

$$V_q = -\omega_r L_M i_D + L_M p i_Q + R_2 i_q + L_2 p i_q - \omega_r L_2 i_d$$

(4)

The torque equation is expressed as,

$$T = J\, p\omega_r + B\omega_r - L_M\left(i_Q i_d - i_D i_q\right) \quad (5)$$

Simplifying above equations stated above we get the algebraic differential equations for the motor as,

$$\frac{di_{ds}}{dt} = \frac{L_r}{L_sL_r - L_m^2}V_{ds} - \frac{L_rR_s}{L_sL_r - L_m^2}i_{ds} + \frac{L_mR_r}{L_sL_r - L_m^2}i_{dr} + \frac{L_m^2}{L_sL_r - L_m^2}\omega_r i_{qs} + \frac{L_mL_r}{L_sL_r - L_m^2}\omega_r i_{qr}$$

$$\frac{di_{qs}}{dt} = \frac{L_r}{L_sL_r - L_m^2}V_{qs} - \frac{L_rR_s}{L_sL_r - L_m^2}i_{qs} + \frac{L_mR_r}{L_sL_r - L_m^2}i_{qr} - \frac{L_m^2}{L_sL_r - L_m^2}\omega_r i_{ds} - \frac{L_mL_r}{L_sL_r - L_m^2}\omega_r i_{dr}$$

$$\frac{di_{dr}}{dt} = \frac{-L_m}{L_sL_r - L_m^2}V_{ds} + \frac{L_mR_s}{L_sL_r - L_m^2}i_{ds} - \frac{R_rL_s}{L_sL_r - L_m^2}i_{dr} - \frac{L_sL_m}{L_sL_r - L_m^2}\omega_r i_{qs} - \frac{L_sL_r}{L_sL_r - L_m^2}\omega_r i_{qr}$$

$$\frac{di_{qr}}{dt} = \frac{-L_m}{L_sL_r - L_m^2}V_{qs} + \frac{L_mR_s}{L_sL_r - L_m^2}i_{qs} - \frac{R_rL_s}{L_sL_r - L_m^2}i_{qr} + \frac{L_sL_m}{L_sL_r - L_m^2}\omega_r i_{ds} + \frac{L_sL_r}{L_sL_r - L_m^2}\omega_r i_{dr}$$

$$\frac{d\omega_r}{dt} = \frac{3}{4}N_p\frac{L_m}{J}(i_{qs}i_{dr} - i_{ds}i_{qr}) - \frac{B}{J}\omega_r - \frac{T_l}{J}$$

$$\begin{bmatrix} \frac{di_{ds}}{dt} \\ \frac{di_{qs}}{dt} \\ \frac{di_{dr}}{dt} \\ \frac{di_{qr}}{dt} \\ \frac{d\omega_r}{dt} \end{bmatrix} = \begin{bmatrix} \frac{-L_rR_s}{y} & \frac{L_m^2}{y}\omega_{r0} & \frac{L_mR_r}{y} & \frac{L_mL_r}{y}\omega_{r0} & \frac{L_m^2}{y}i_{qs0} + \frac{L_mL_r}{y}i_{qr0} \\ \frac{-L_m^2}{y}\omega_{r0} & \frac{-L_rR_s}{y} & \frac{-L_mL_r}{y}\omega_{r0} & \frac{L_mR_r}{y} & \frac{-L_m^2}{y}i_{ds0} - \frac{L_mL_r}{y}i_{dr0} \\ \frac{L_mR_s}{y} & \frac{-L_sL_m}{y}\omega_{r0} & \frac{-R_rL_s}{y} & \frac{-L_sL_r}{y}\omega_{r0} & \frac{-L_sL_m}{y}i_{qs0} - \frac{L_sL_r}{y}i_{qr0} \\ \frac{L_sL_m}{y}\omega_{r0} & \frac{L_mR_s}{y} & \frac{L_sL_r}{y}\omega_{r0} & \frac{-R_rL_s}{y} & \frac{L_sL_m}{y}i_{ds0} + \frac{L_sL_r}{y}i_{dr0} \\ \frac{3}{4}\frac{L_mN_p}{J}(-i_{qr0}) & \frac{3}{4}\frac{L_mN_p}{J}(i_{dr0}) & \frac{3}{4}\frac{L_mN_p}{J}(i_{qs0}) & \frac{3}{4}\frac{L_mN_p}{J}(-i_{ds0}) & \frac{-B}{J} \end{bmatrix} *$$

$$\begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ di_{qr} \\ \omega_r \end{bmatrix} + \begin{bmatrix} \frac{L_r}{y} & 0 & 0 \\ 0 & \frac{L_r}{y} & 0 \\ \frac{-L_m}{y} & 0 & 0 \\ 0 & \frac{-L_m}{y} & 0 \\ 0 & 0 & \frac{-1}{J} \end{bmatrix} \begin{bmatrix} V_{ds} \\ V_{qs} \\ T_l \end{bmatrix}$$

The flux equations are given by :

$$\lambda_{qr} = L_m i_{qs} + L_r i_{qr}$$
$$\lambda_{dr} = L_m i_{ds} + L_r i_{dr}$$
$$\lambda_{qs} = L_s i_{qs} + L_m i_{qr}$$
$$\lambda_{ds} = L_s i_{ds} + L_m i_{dr}$$

In the three-phase induction motor under perfectly balanced conditions (healthy motor) only a forward rotating magnetic field is produced, which rotates at synchronous speed , $n_1 = f_1/p$, where f_1 is the supply frequency and p the pole pair of the stator windings. The rotor of induction motor always rotates at a speed (n) less than the synchronous speed.

The sleep, s= $(n_1–n) / n_1$, is the measure of the slipping back of the rotor regarding to the rotating field. The slip speed ($n_2 = n_1 –n=s\ n_1$) is the actual difference in between the speed of the rotating magnetic field and the actual speed of the rotor[5]. The common technique for online detection of motor faults is known as motor current signature analysis (MCSA). The objective of this technique is to detect certain components in the stator current spectrum that are only a function of specific fault. However, it has been shown mathematically and experimentally by that the spectral components due to shorted turns are not a reliable indicator of stator winding fault. The interaction between a faulted stator winding and healthy rotor cage is studied, the faulted asymmetry stator winding may produce spatial harmonics of any wave number into the air-gap field. However, all these harmonics vary at single frequency, *i.e* .the supply frequency of the sinusoidal voltage source. The stator harmonics induce current in the rotor cage and reflect back from the rotor as new air-gap field harmonics. Seen from the stator, the air gap harmonics caused by the induced rotor currents vary at frequencies[4]:

$$f_{rf} = f_1\left[1 \pm \frac{\lambda n}{p}(1-s)\right]$$

Where $\lambda = 1,2,3….$

Modeling of Stator Fault for Inducation Motor

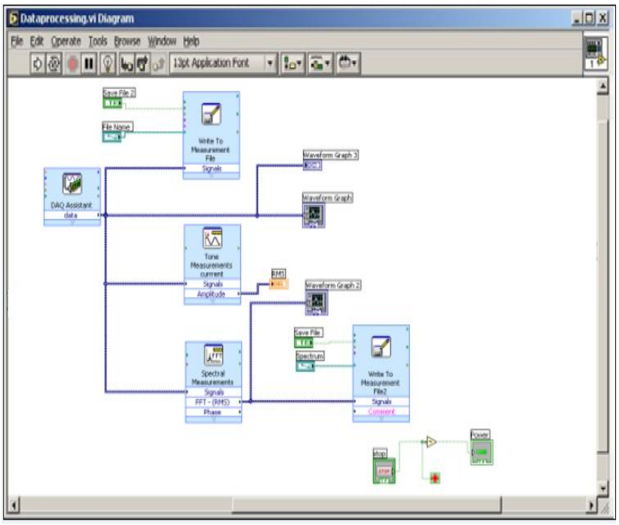

Figure 3: Induction Motor LABVIEW Simulink Model

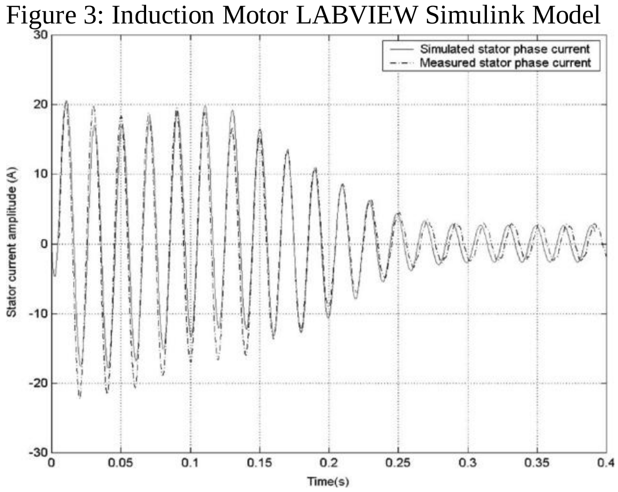

Figure 4: Stator Current Spectrum for Simulated and Measured Results During Healthy Motor Condition

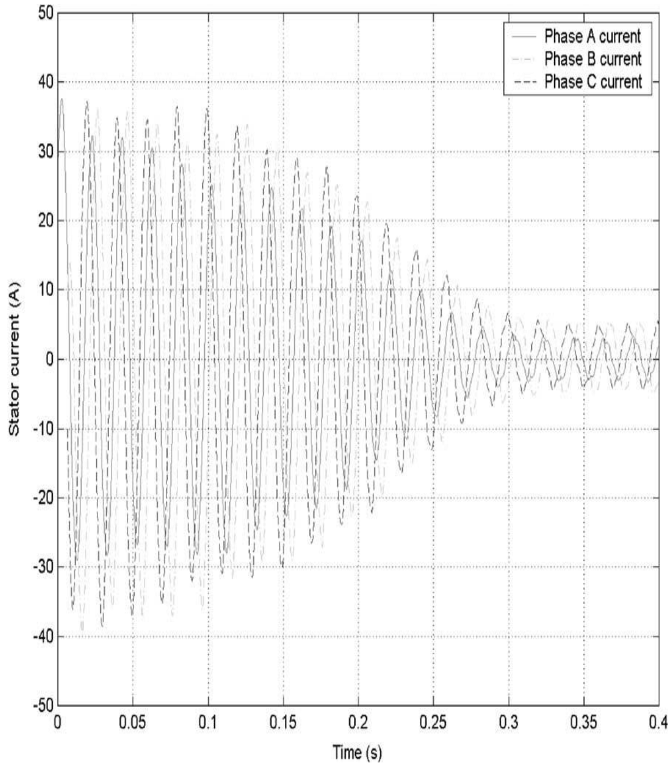

Figure 5: Stator Phase Current Spectrum 20 V Drop in One Phase of Voltage Supply

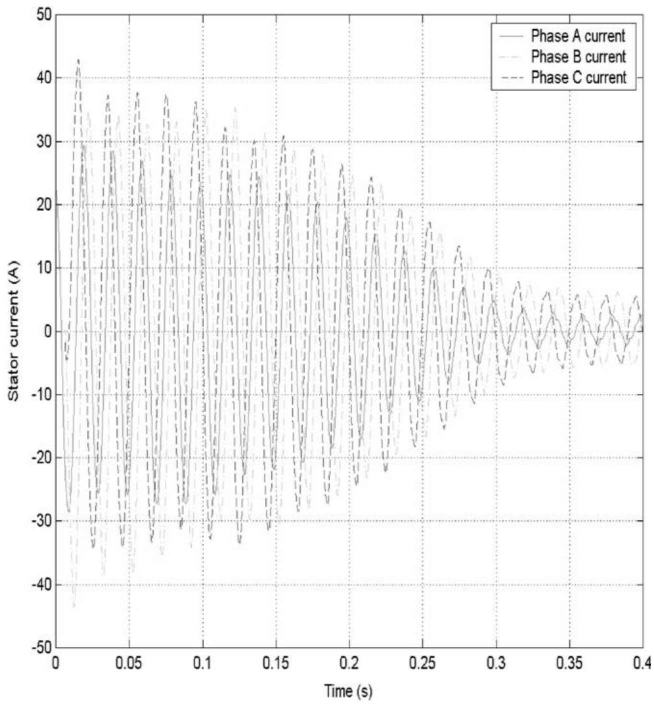

Figure 6: Stator Phase Current Spectrum 40 V Drop in One Phase of Voltage Supply

The stator currents of phase-A, phase-B and phase-C are very high initially as the motor tries to overcome the inertial forces to attain speed. From about 7-8 amperes, stator currents settle down to about 0.5-1 ampere at steady state.

Stator current contains unique fault frequency components that can be used for detection of various faults of motor. Therefore, this research work investigates how the presence of common fault, load fault, affects on different fault frequencies under different load conditions. The ripple amplitude increases with increasing asymmetric stator supply.

III. CONCLUSION

This paper presented successful simulation and condition monitoring of induction motor with traditional electrical machine model. It has been demonstrated that a generalized motor model can be used to simulated induction motor faults to a high degree of accuracy. The ripple amplitude increases with increasing asymmetric stator supply. Stator current contains unique fault frequency components that can be used for detection of various faults of motor. Therefore, this research work investigates how the presence of common fault, load fault, affects on different fault frequencies under different load conditions.

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