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Analysis of Fault Monitoring and Isolation of Induction Motor

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Abstract

The objective of this paper is to create a model based observer for the 3 phase induction motor to monitor the stator winding fault based on stator current and rotor speed using park's vector transformation. The healthy motor and fault motor models have been generated based on the rotating reference frame. Generally five types of fault occurs in stator winding which are Coil to coil, turn to turn, line to line, coil to ground, line to ground, if there is taking inter turn fault model based monitoring the fault
The stator winding *inter-turn* fault occurs due to change in voltage, current and stator resistance in a dynamic load when used in industrial application. Analysis of motor faults showed that the stator winding fault isa common fault which could result in damaging a motor and could stop the motor from running efficiently. If this stator winding fault can be detected and isolated early enough the life period of the motor can be increased and it is achieved using state space model.

Keywords: induction motor stator winding fault, inter-turn fault detection, fault motor

Introduction

This paper presents the induction motor stator winding fault diagnostic technique. There are three types of motor faults namely rotor, stator and bearing faults of which stator faults are considered here. [1] Additionally, this method is used to identify the severity of the fault in motor. The fault monitoring of the induction motor is performed when the induction motor is under operation and detects whether it is faulty or healthy [3]-[5]. The Induction motors are complex electro-mechanical devices used to convert electrical energy into mechanical energy in industrial processes worldwide.

Many industrial applications use motors to be implemented in pumps, fans, air compressors and conveyor belts, as well as many other applications. The power supply to induction motors may be provided directly from a constant frequency sinusoidal power supply or by an AC variable frequency drive. The stator winding-related breakdown can be segregated into five types of fault: turn-to-turn, coil-to-coil, line-to-ground, line -to-line, and open-circuit faults [1]. Among the five failure modes, turn-to-turn faults (stator turn fault) is supposedly the most puzzling one since the other forms of breakdowns are generally due to the result of turn faults[6]

Some of the causes for the stator winding failures are due to

- Change in resistance
- Change in voltage
- Changeincurrentand
- High temperature

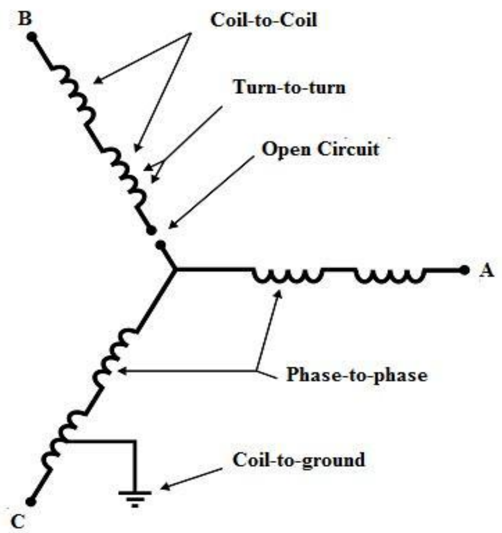

Figure 1: types of stator winding fault

The IEEE and Electric Power Research Institute reports that 37% of the failures in an induction motors are primarily because of the inter turn fault which in turn is due to turn insulation in stator winding. The motor model developed from per phase equivalent circuit of the mathematical equation can be expressed as following Circuits.

Healthy Motor Modeling

The modeling of equation can be generated from the per phase equivalent circuit of the three phase induction motor. The three phase voltage of an induction motor in balanced conditions can be expressed as follows [7].

$$V_{as} = \sqrt{2}\frac{V_l}{\sqrt{3}}\sin(wt) \tag{1}$$

$$V_{bs} = \sqrt{2}\frac{V_l}{\sqrt{3}}\sin\left(wt - \frac{2\pi}{3}\right) \tag{2}$$

$$V_{cs} = \sqrt{2}\frac{V_l}{\sqrt{3}}\sin\left(\omega t + \frac{2\pi}{3}\right) \tag{3}$$

Three phase voltage $V_{as}, V_{bs}, V_{cs}$is transferred to synchronously rotating reference frame in (dq0) transformation and the model can be generated from following equations

$$\begin{bmatrix} V_{\alpha s} \\ V_{\beta s} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & \frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} \tag{4}$$

Than the (dq0) axis voltage can be expressed as follows

$$\begin{bmatrix} V_{dS} \\ V_{qs} \end{bmatrix} = \begin{bmatrix} \cos(\gamma) & \sin(\gamma) \\ -\sin(\gamma) & \cos(\gamma) \end{bmatrix}\begin{bmatrix} V_{\alpha s} \\ V_{\beta s} \end{bmatrix} \tag{5}$$

The instantaneous valves of three phase induction motor stator and rotor current expressed as

$$\begin{bmatrix} I_{\alpha s} \\ I_{\beta s} \end{bmatrix} = \begin{bmatrix} \cos(\gamma) & \sin(\gamma) \\ -\sin(\gamma) & \cos(\gamma) \end{bmatrix}\begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} I_{as} \\ I_{bs} \\ I_{cs} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_{\alpha s} \\ V_{\beta s} \end{bmatrix} \tag{7}$$

The flux linkage can be expressed as the following four equations

$$\frac{dF_{qs}}{dt} = \omega_b\left[V_{qs} - \frac{\omega_m}{\omega_b}F_{ds} + \frac{r_s}{l_s}\left(F_{mq} - F_{qs}\right)\right] \tag{8}$$

$$\frac{dF_{ds}}{dt} = \omega_b\left[V_{ds} + \frac{\omega_m}{\omega_b}F_{qs} + \frac{r_s}{l_s}\left(F_{md} - F_{ds}\right)\right] \tag{9}$$

$$\frac{dF_{qr}}{dt} = \omega_b\left[V_{qr} - \frac{\omega_m - \omega_r}{\omega_b}F_{dr} + \frac{r_r}{l_r}\left(F_{mq} - F_{qr}\right)\right] \tag{10}$$

$$\frac{dF_{dr}}{dt} = \omega_b\left[V_{dr} - \frac{\omega_m - \omega_r}{\omega_b}F_{qr} + \frac{r_r}{l_r}\left(F_{md} - F_{dr}\right)\right] \tag{11}$$

Where

$$F_{mq} = x_{lm}\left[\frac{F_{qs}}{l_s} + \frac{F_{ds}}{l_r}\right] \tag{12}$$

$$F_{md} = x_{lm}\left[\frac{F_{qr}}{l_s} + \frac{F_{dr}}{l_r}\right] \tag{13}$$

$$x_{lm} = 1/\left(\frac{1}{xm} + \frac{1}{l_s} + \frac{1}{l_r}\right) \tag{14}$$

Then the (d q) current equation can be expressed as follows

$$I_{qs} = \frac{1}{l_s}\left(F_{qs} - F_{mq}\right) \tag{15}$$

$$I_{ds} = \frac{1}{l_s}\ (F_{ds} - F_{md}) \tag{16}$$

$$I_{qr} = \frac{1}{l_r}\ (F_{qr} - F_{mq}) \tag{17}$$

$$I_{dr} = \frac{1}{l_r}\ (F_{dr} - F_{md}) \tag{18}$$

The above equation can be expressed as torque and speed calculation

$$T_d = \frac{3}{2}\left(\frac{p}{2}\right)\ (F_{ds}I_{qs} - F_{qs}I_{ds}) \tag{19}$$

$$\frac{d_{\omega t}}{dt} = \frac{p}{2j}\ (T_d - T_o) \tag{20}$$

The Inter Turn Fault Model

The modeling of equation which is developed in (q-d-o) reference frame is used in the prediction of the inter turn fault in three phase induction motor. The four voltage equation can be expressed as inter turn short circuit fault of the proposed model. Due to sudden changes in three phase induction motor supply voltage, fault occurs in the stator winding after the ratted voltage and current and resistance of the motor.

$$\delta V_{qs} + V_{qs} = \frac{\mu}{3}(2\ \mu\ l_s + 3l_{ms})\cos(\gamma_s)\left(\frac{d}{dt}\right)i_f(\frac{\mu}{3}2\ r_s\cos(\gamma_s))\ i_f \tag{21}$$

$$\delta V_{ds} + V_{ds} = \frac{\mu}{3}(2\ \mu\ l_s + 3\ l_{ms})\sin(\gamma_s)\left(\frac{d}{dt}\right)i_f + \left(\frac{\mu}{3}\ 2\ r_s\sin(\gamma_s)\right)i_f \tag{22}$$

$$\delta V_{0s} = \mu^2 l_s\left(\frac{d}{dt}\right)i_f + \frac{\mu}{3}r_s i_f \tag{23}$$

$$\delta V_{qr} + V_{qr} = \mu\ l_{ms}\ (\cos(\gamma_s)\left(\frac{d}{dt}\right)i_f + (\omega_r\sin(\gamma_s)\ i_f \tag{24}$$

$$\delta V_{dr} + V_{dr} = \mu\ l_{ms}\ (-s\,in(\gamma_s)\left(\frac{d}{dt}\right)i_f + (\omega_r\cos\ (\gamma_s)(i_f) \tag{25}$$

Where

μ – is intensity of the fault and, If –is fault current number of shorted turn and total number of turns per phase in stator winding.

The developed torque can be expressed as following equation

$$T_d = \frac{3}{2}\frac{p}{2}\frac{1}{\omega_b}\left(F_{ds}I_{ds} - F_{qs}I_{qs}\right) + p\ \mu\ l_m\ if\ \left(I_{dr}\cos(\gamma_s) - I_{qr}\sin(\gamma_s)\right) \tag{26}$$

The Simulink model for the above mentioned equations is shown in fig (3)

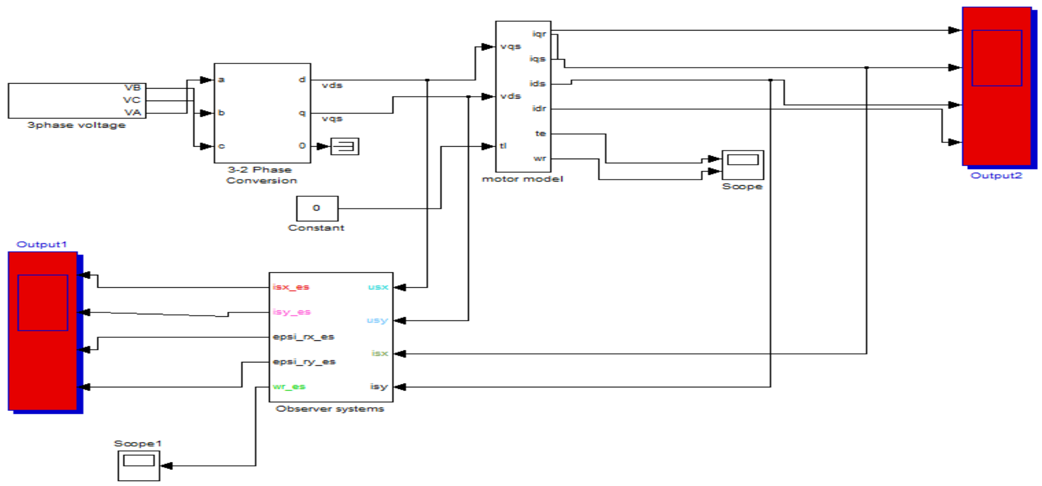

Figure 3: Motor Modeling

Fault Detection

The state space model based fault detection in three phase induction motor stator winding is obtained. Commonly motors operate at two modes namely, common mode and differential mode. Of which the healthy motor can be operated from common mode operation and faulty motor can be operated from differential mode operations. The faulty motor introduces two parameter in stator winding inter turn fault.

- γ_{cc} (Location of parameter) the angle between the stator winding inter turn short circuit fault. The taking a parameter values $[0, \frac{2\pi}{3}, \frac{4\pi}{3}]$ is corresponding to [Vas Vbs Vcs] respectively.
- μ_{cc}(Detection parameter) the number of inter turn short circuit and the total number on inter turn in healthy per phase.

$$\mu_{cc} = \frac{number\ of\ inter\ turn\ short\ circuir\ winding}{total\ numer\ of\ inter\ turn\ in\ healthy\ phase}$$

The state space model of induction motor can be given by

$$\dot{X} = Ax + Bu \tag{27}$$

$$Y = Cx + Du \tag{28}$$

Where

$$x = [I_{qs} I_{ds} F_{qs} F_{ds}]^T$$

$$u = [\delta V_{ds}\ \delta V_{qs}]^T$$

$$A=\begin{bmatrix} -\frac{r_r+r_s}{ls} & \omega & \frac{r_r}{l_m l_s} & \frac{\omega}{ls} \\ -\omega & -\frac{r_s+r_r}{ls} & -\frac{\omega}{ls} & \frac{r_r}{l_m l_s} \\ r_r & 0 & -\frac{r_r}{l_m} & 0 \\ 0 & r_r & 0 & -r_r \end{bmatrix} \tag{29}$$

$$B = \begin{bmatrix} \frac{1}{l_s} & 0 \\ 0 & \frac{1}{l_s} \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \tag{30}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \tag{31}$$

$$D = \frac{2}{3r_s}\sum_{k=1}^{3} \mu_{cck}\, p(-\gamma_s)(\theta_{cck})p(\gamma_s)\, i_f \tag{32}$$

The matrix equation D is inter turn fault location angle is $p(\gamma) and (\theta_{cck})$

Results

The induction motor for the stator winding faulty as well as the healthy condition are simulated as per the equations from(1) –(20) and (21) –(34) respectively using Simulink in mat lab. The fault that is occurring in the model is detected using the state space observer.

Simulation Results

The above stated equation are simulated step by step and the result is shown in figures for faulty and healthy condition

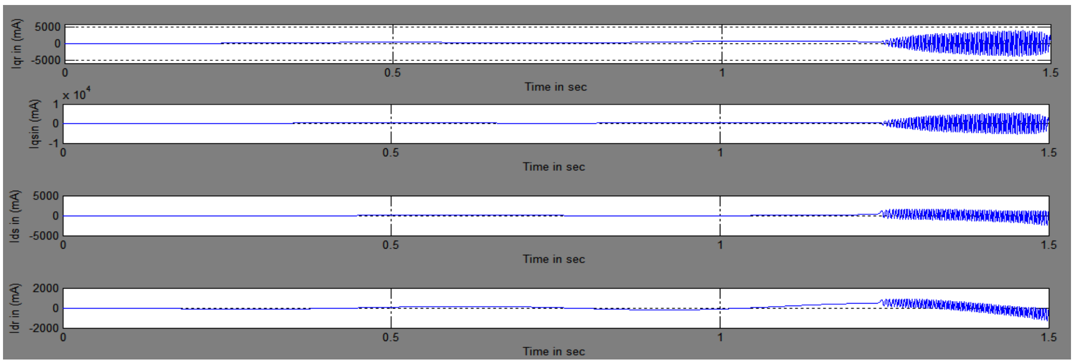

Figure 8: faulty motor d q axis current

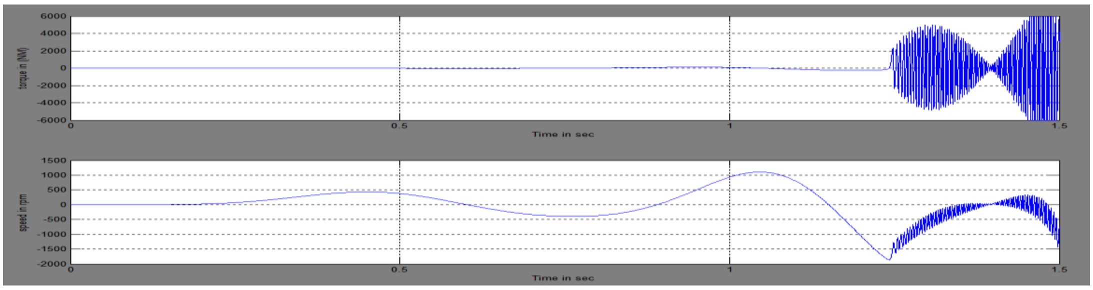

Figure 9: faulty motor speed and torque

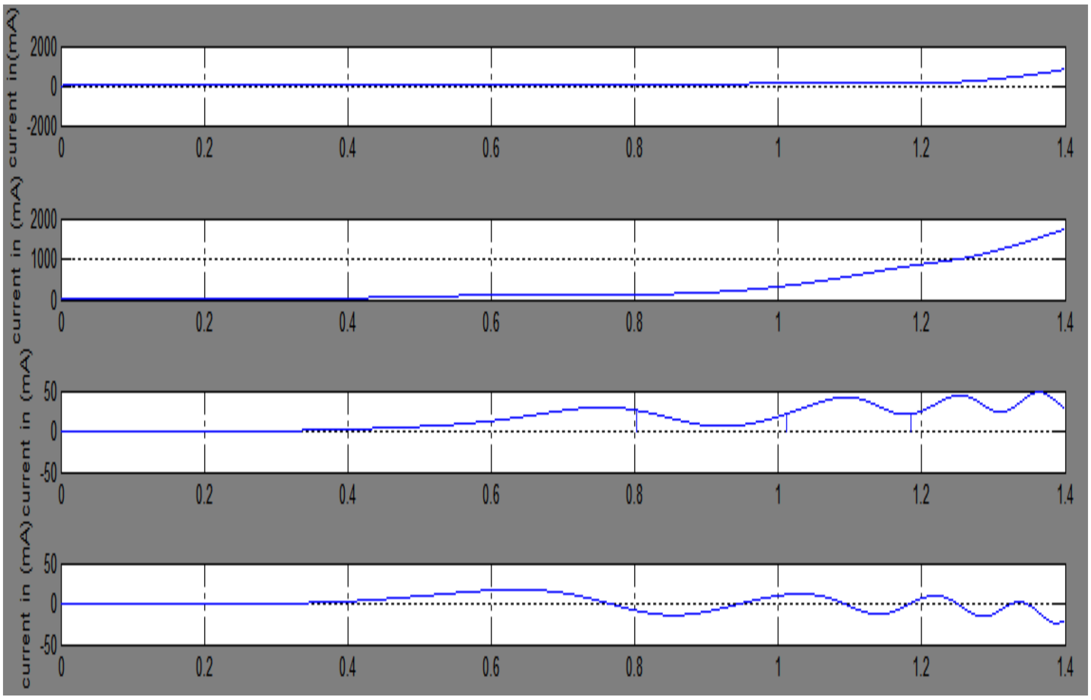

Figure 10: (q d) axis current observers

Conclusion

Mathematical modeling of healthy and faulty conditions of the motor are obtained and the estimation of stator winding faults are performed using observer model.

In this paper a methodology by which induction motors stator winding inter-turn faults can be monitoredby observer model based on the stator current has been proposed. The technique used was based on the Park’s vector transformation. Stator current vector patterns are employed to distinguish between 'healthy' and' faulty' induction motors. The results are derived from building Simulink models in MATLAB. The current from park's vector approach of healthy motor was found to be of non-faulty output while current from park's vector based faulty motor lies in faulty condition since short circuit current increases ten times more than the normal rating current. Using the above, inter-turn faults in the windings of induction motor can be easily determined. In future, laboratory experiments can be conducted and by method of changing resistance, the output current can be determined in healthy and faulty approaches.

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