INDUCTION MOTOR FAULT SIMULATION USING DIRECT PHASE QUANTITIES

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Abstract— The internal faults in stator winding of three phase induction motor occurs due to the breakdown of winding insulation which is the consequence of increased current in the winding due to a fault. This paper here presents the fault simulation of induction motor by making use of direct phase quantities. The simulation results showing the healthy condition currents and voltages along with turn to ground fault condition voltages and currents have been presented.

Index Terms— Direct Phase Quantities, Fault, Three-Phase Induction Motor, Simulation.

I. INTRODUCTION

Induction motors are widely used in industry due to their low cost, reliability and robustness and hence treated as back-bone of industry. But, it also subject to faults. Fault identification and diagnosis schemes are developed to provide advanced warnings of the faults so that appropriate actions can be taken for maintenance at an early stage [1]-[2]. This helps to prevent unscheduled maintenance of these machines and hence reduce the overall maintenance cost. Various surveys [3] concluded that bearing related failures are 40% of motor failures, stator inter-turn are 38% , rotor related failures are 10% and 12% affect other part of machine are treated as mixed failures. So, protection by condition monitoring of the induction motor has drawn a considerable attention in coming year's .Many condition monitoring techniques have been presented for different types of fault detection and localization in induction motor. Schoen et al [5] and Martelo [4] had studied bearing failures based upon the FFT analysis. Using same tool Cameron [6] and Benbouzid et al [7] studied other types of faults in rotor such as eccentricity, saturation and failure in rotor slot. By current Concordia pattern based and also a fuzzy decision system is given in [8] and using particle swarm optimization (PSO), stator inter-turn fault identification method is proposed in [9].

Recently, for fault identification, AI techniques such as expert systems, fuzzy inference system, neural network, SVM, genetic algorithm and adoptive neural fuzzy inference systems are being used. Bi-spectrum, high resolution spectral analysis, STFT, FFT and wavelet analysis are some time frequency domain techniques used for induction motor fault diagnosis. For broken rotor bars and inter turn short circuit in stator winding, stator current envelopes have been used for fault diagnosis are proposed in [10]. Thus, for motor protection, fault simulation of induction motor ought to be the prime motive.

The fault simulation of induction motor has been done in many ways using software like simulation in MATLAB Simulink, script file, pSPICE, symmetric component methods and others. Due to the inconvenience of the *dq0* model, internal faults of synchronous machines using direct phase quantities were adopted because it could only be used for steady state analysis not transient part which primarily occurs in case of fault. Stator winding of motor consists of insulated coil turns distributed in slots in the stator structure of the motor. An internal fault in the stator windings breaks the sinusoidal distributed characteristics of the windings. Hence, the symmetry in the machine windings is altered. So, the conventional *dq0* model is not suitable for internal fault analysis and simulation.

In this paper, the fault simulation of induction motor has been done by using direct phase quantities which give access to analyse all internal faults. Here, the healthy condition and turn to ground fault i.e. single line to ground fault has been considered. However, the analysis can be easily extended to different internal faults. The healthy and faulty condition of three phase induction motor stator windings has been simulated using script file in MATLAB R2013a.

II. INDUCTION MOTOR SIMULATION

A. *Healthy Condition:*

In normal condition i.e. the healthy condition, the phase equations using KVL can be written as:

$$V_s = R_s\, i_s + d\lambda_s/dt$$
(1)

$$V_r = R_r\, i_r + d\lambda_r/dt$$
(2)

where,

$V_s = [v_{as1} \;\; v_{bs} \;\; v_{cs}]^T$, Three-phase stator voltage

$i_s = [i_{as} \;\; i_{bs} \;\; i_{cs}]^T$, Three-phase stator current

$i_r = [i_{ar} \;\; i_{br} \;\; i_{cr}]^T$, Three-phase rotor current

$\lambda_s = [\lambda_{as} \;\; \lambda_{bs} \;\; \lambda_{cs}]^T$, Three-phase stator flux linkages

$\lambda_r = [\lambda_{ar} \;\; \lambda_{br} \;\; \lambda_{cr}]^T$, Three-phase rotor flux linkages

Also, flux linkages can be written in terms of inductance and current as current in inductor multiplied by its inductance value gives the flux values.

$$\lambda_s = L_{ss} i_s + L_{sr} i_r$$
(3)

$$\lambda_r = L_{rs} i_s + L_{rr} i_r$$
(4)

where,

L_{ss} is the stator winding self inductance matrix

L_{rr} is the rotor winding self inductance matrix

L_{sr} is the stator to rotor winding mutual inductance matrix

L_{rs} is the rotor to stator winding mutual inductance matrix

The resistance matrices for stator and rotor can be written as:

Stator resistance matrix:

$$R_s = r_s \,.\, I_{3\text{x}3}$$
(5)

Rotor resistance matrix:

$$R_r = r_r \,.\, I_{3\text{x}3}$$
(6)

where,

r_s = stator resistance value

r_r = rotor resistance value

The self- inductance and mutual-inductance matrices for both stator and rotor can also be written in the similar way:

$$L_{ss} = \begin{bmatrix} L_{ls} + L_{ms} & -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & L_{ls} + L_{ms} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} & L_{ls} + L_{ms} \end{bmatrix}$$
(7)

$$L_{rr} = \begin{bmatrix} L_{lr} + L_{ms} & -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & L_{lr} + L_{ms} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} & L_{lr} + L_{ms} \end{bmatrix}$$
(8)

$$L_{sr} = L_{ms} * \begin{bmatrix} cos(\theta r) & cos\left(\theta r + \frac{2\pi}{3}\right) & cos\left(\theta - \frac{2\pi}{3}\right) \\ cos\left(\theta r - \frac{2\pi}{3}\right) & cos(\theta r) & cos\left(\theta r + \frac{2\pi}{3}\right) \\ cos\left(\theta r + \frac{2\pi}{3}\right) & cos\left(\theta r - \frac{2\pi}{3}\right) & cos(\theta r) \end{bmatrix}$$
(9)

$$L_{rs} = {L_{sr}}^T$$
(10)

where,

L_{ls} = per-phase self-inductance (leakage inductance) value of stator-winding

L_{lr} = per-phase self-inductance value of rotor winding

L_{ms}= mutual-inductance value between stator and rotor

L_{ss} = stator winding inductance matrix

L_{rr} = rotor winding inductance matrix

L_{sr}= stator and rotor mutual inductance matrix

The electromagnetic torque can be expressed in machine variables as

$$T = \frac{P}{2} i_s^T \frac{\partial L_{sr}}{\partial \theta} i_r \quad (11)$$

where,

P = number of poles

L_{sr}= stator and rotor mutual inductance matrix

$i_s = [i_{as} \quad i_{bs} \quad i_{cs}]^T$, Three-phase stator current

$i_r = [i_{ar} \quad i_{br} \quad i_{cr}]^T$, Three-phase rotor current

The simulation results on the above equations and analysis are shown in Fig. 1.

B. Faulty condition (Turn- Ground Fault):

Assumptions:

Leakage inductance of shorted turns is μL_{ls}, where L_{ls} is per phase leakage reactance, and the fault impedance is resistive *(r_f)*.

Furthermost, the self inductances, mutual inductances, resistances of stator and rotor windings are considered as lumped parameters.

An induction motor with stator winding turn fault at phase A is shown in Fig. 2 where as_2 represents the shorted turns and u denotes the fraction of shorted turns.

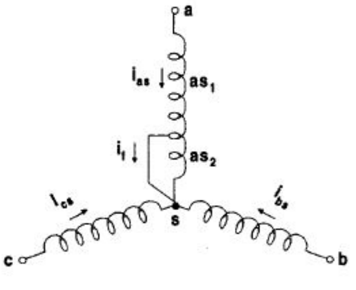

Fig.2 Stator winding turn fault

Derivation:

The stator and rotor equations for symmetrical induction machine with turn fault can be expressed as

$$V_s = R_s i_s + d\lambda_s/dt \quad (12)$$

$$0 = R_r i_r + d\lambda_r/dt \quad (13)$$

Where,

$V_s = [v_{as1} \quad v_{as2} \quad v_{bs} \quad v_{cs}]^T$

$i_s = \left[i_{as} \quad (i_{as-}i_f) \quad i_{bs} \quad i_{cs}\right]^T$

$i_r = [i_{ar} \quad i_{br} \quad i_{cr}]^T$

$\lambda_s = [\lambda_{as1} \quad \lambda_{as2} \quad \lambda_{bs} \quad \lambda_{cs}]^T = L_{ss} i_s + L_{sr} i_r$

$\lambda_r = [\lambda_{ar} \quad \lambda_{br} \quad \lambda_{cr}]^T = L_{rs} i_s + L_{rr} i_r$

The resistance and inductance matrix are given by

$$R_s = r_s . diag[(1-\mu) \quad \mu \quad 0 \quad 0] \quad (14)$$

$$R_r = r_r . I_{3x3} \quad (15)$$

$$L_s = L_{ls} . diag[(1-\mu) \quad \mu \quad 0 \quad 0] + L_{ms} \begin{bmatrix} (1-\mu)^2 & \mu(1-\mu) & \frac{-(1-\mu)}{2} & \frac{-(1-\mu)}{2} \\ \mu(1-\mu) & \mu^2 & \frac{-\mu}{2} & \frac{-\mu}{2} \\ \frac{-(1-\mu)}{2} & \frac{-\mu}{2} & \frac{-1}{2} & 1 \\ \frac{-(1-\mu)}{2} & \frac{-\mu}{2} & 1 & \frac{-1}{2} \end{bmatrix} \quad (16)$$

$$L_{sr} = L_{ms} * \begin{bmatrix} (1-\mu)\cos(\theta_r) & (1-\mu)\cos(\theta_r + \frac{2\pi}{3}) & (1-\mu)\cos(\theta_r - \frac{2\pi}{3}) \\ \mu cos(\theta r) & \mu cos\left(\theta r + \frac{2\pi}{3}\right) & \mu cos(\theta r + \frac{2\pi}{3}) \\ cos\left(\theta r - \frac{2\pi}{3}\right) & cos(\theta r) & cos\left(\theta r + \frac{2\pi}{3}\right) \\ cos\left(\theta r + \frac{2\pi}{3}\right) & cos\left(\theta r - \frac{2\pi}{3}\right) & cos(\theta r) \end{bmatrix} \quad (17)$$

$$L_{rs} = {L_{sr}}^T \quad (18)$$

$$L_{rr} = \begin{bmatrix} L_{lr} + L_{ms} & -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & L_{lr} + L_{ms} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} & L_{lr} + L_{ms} \end{bmatrix} \quad (19)$$

The electromagnetic torque can be expressed in machine variables as

$$T = \frac{P}{2} i_s^T \frac{\partial L_{sr}}{\partial \theta} i_r \quad (20)$$

Similarly, turn fault equations for phases B and C and rotor open condition has been analysed. The results for faulty conditions have been shown in Fig. 3.

III. SIMULATION RESULTS

The motor parameters used for simulation is given in Table 1.

Table 1

Three Phase Induction Motor Parameters

Input Voltage And Frequency	230 V, 50 Hz
Power, no. of poles	5.5 kW, 2
Stator Resistance	1.5 ohm
Rotor Resistance	2 ohm
Stator self inductance	3.5
Rotor self inductance	3.5
Mutual Inductance	55
Inertia	0.296

The results of healthy condition are shown in Fig. 1. Which includes stator voltage Fig. 1(a), rotor voltage Fig. 1(b), stator current Fig. 1(c), rotor current Fig. 1(d) and speed Fig. 1(e).

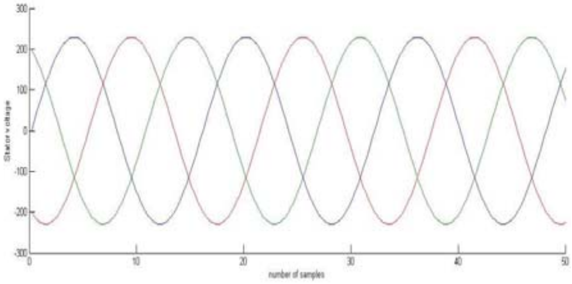

Fig. 1(a) Stator voltage (Healthy)

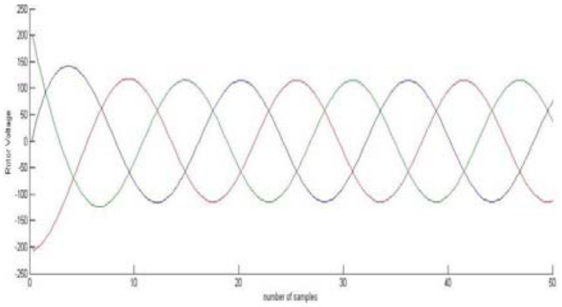

Fig. 1(b) Rotor voltage (healthy)

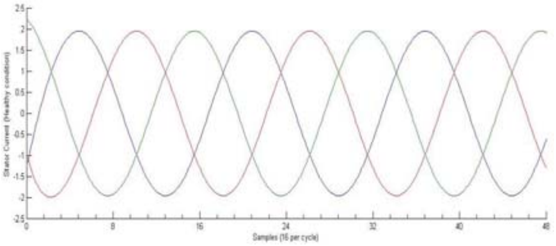

Fig. 1(c) Stator Current (healthy)

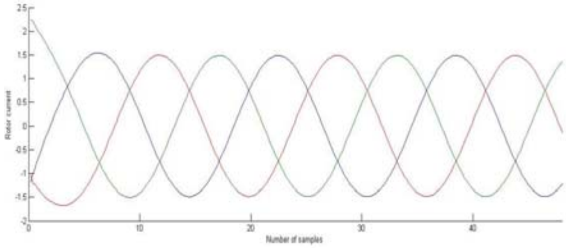

Fig. 1(d) Rotor Current (healthy)

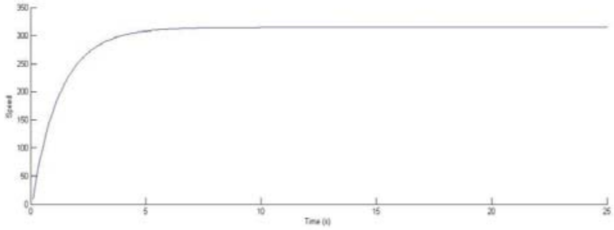

Fig. 1(e) Speed (healthy)

As it can be observed, the continuous signals of voltages and currents are taken in form of samples i.e. 16 samples per cycle to maintain frequency of 800 Hz. The number of samples per cycle can be varied according to one’s convenience. They could be 8 samples per cycle also.

The various results of fault simulation have been shown in Fig. 3 which includes stator voltage Fig. 3(a), stator current with a-phase turn-ground fault Fig. 3(b), rotor current Fig. 3(c), stator current with b-phase turn-ground fault Fig. 3(d).

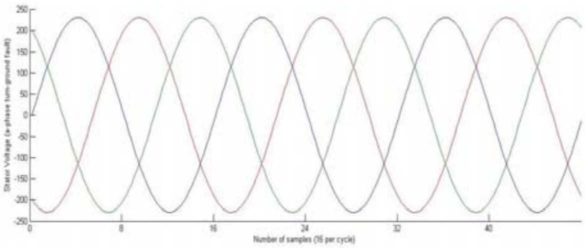

Fig. 3(a) Stator voltage (a-phase turn-ground fault)

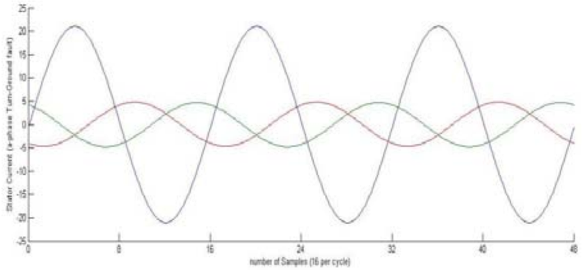

Fig. 3(b) Stator current (a-phase turn-ground fault)

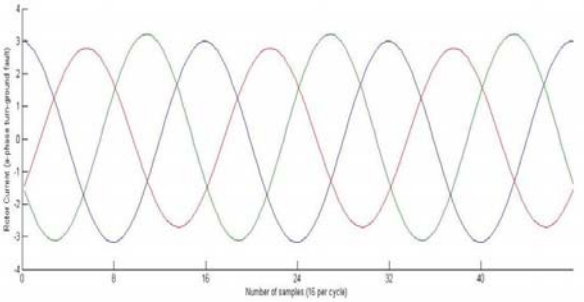

Fig. 3(c) Rotor Current (a-phase turn-ground fault)

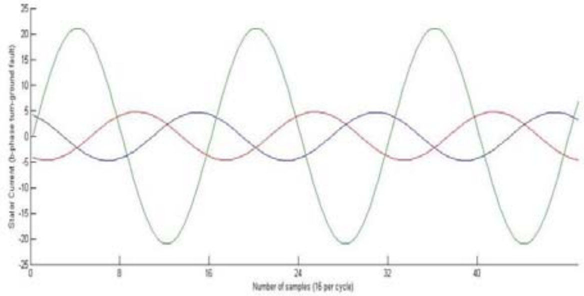

Fig. 3(d) Stator current (b-phase turn-ground fault)

CONCLUSION

In this paper, another way to induction motor fault simulation using direct phase quantities has been presented. Here, motor electrical parameters have been used for calculation of inductances rather than the machines geometrical parameters which are comparatively difficult to obtain. However, the result is still approximate because the actual windings are never perfectly sinusoidal in space and also lumped parameters are considered. But, the analysis gives a way to investigate any type of internal fault in the stator winding.

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