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Modeling, Digital Simulation and Diagnosis of Internal Fault of Induction Machine

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Abstract

The paper presents the modeling, simulation and diagnosis of an internal fault in stator windings of an induction motor. Common approach to inter-turn faults modeling in asynchronous machine is discussed and digital simulation of the model in MATLAB/SIMULINK is presented. Based on the presented simulation results of positive, negative and zero sequence currents one can correctly diagnose the motor stator fault. This diagnostic method helps in predicting and identifying the stator fault. A simple and step by step implementation of induction motor in MATLAB/SIMULINK is presented here for better understanding of the subject.

Keywords: Induction motor, Stator faults, MATLAB/SIMULINK, Inter turn faults.

Contents

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1. Introduction

Environmental, operation, and installation issues accelerate motor failure much earlier than the lifetime of the designed motor. Analysis and diagnosis of motor failures are very hot topic and essential area of research as motor-driven equipments are the backbone to business success and industrial development. Electric motors are one of the essential components of industrial processes and are often integrated with available equipment. Squirrel cage induction motors (SCIM) are more in use than the other motors reason being its low cost, low maintenance, ruggedness and operation with an easily available power supply sources. During the operation, motors has to go various stresses which leads to several failures [1-3]. So it is essential for IM in order to avoid disastrous/ permanent failures. Approximately 40 % of the failures in IM are caused by stator winding faults (for example, turn-turn, line to line and line to ground faults) [4, 5]. These faults in the rotor (which constitute approx. 10% of the faults) of IM include: i) faults in starting supply, ii) abnormal supply conditions, iii) mechanical overloads iv) rotor broken bar faults [6]. Many published techniques and many commercially available tools are available in literature to monitor induction motors to insure a high degree of reliability [7-12].

As the voltages become unbalanced, excessive heating occurs, and the motor should be de-rated. As undetected turn-to-turn winding faults grow the stator internal faults start and resulted in major faults. The recent advances in electronic and mechanical sensors provided the necessary technologies for effective incipient failure detection [13].

The available mechanical/electrical sensors should be used to measure stator currents and voltage, output torque, rotor position and speed, etc. [14]. The requirement of the present available techniques is to have some degree of expertise for user in order to distinguish a healthy system from a potential failure mode. The requirement is much more acute while analyzing the current spectrum (FFT analysis) of an IM since a multitude of harmonics exists due to both the design and construction of the motor and the several variations in the load torque [15]. Hence in this paper current-based monitoring has also been done and FFT analysis also performed to detect the internal faults.

In this Modeling, Digital Simulation and Diagnosis of Internal Fault of Induction Machine has been performed in SimPowerSystem blockset of MATLAB Simulink. Section II gives the detail regarding modeling of the induction motor. Section III presents results and discussion. Section IV concludes this paper.

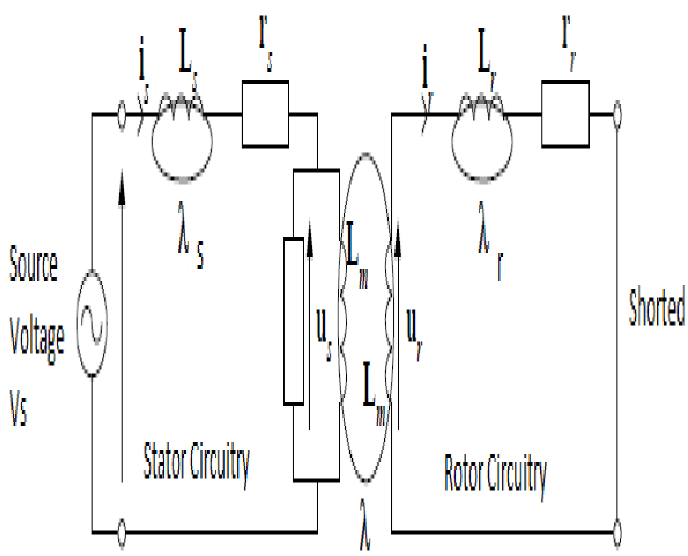

Fig-1. Equivalent electrical circuit of an induction motor

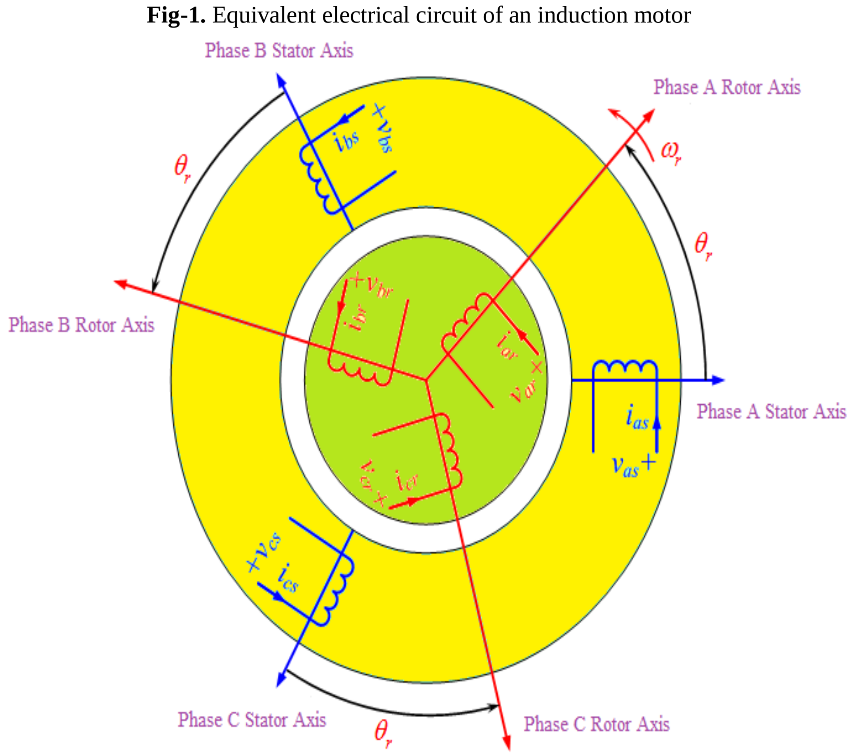

Fig-2. Circuit Model of a Three-Phase IM .

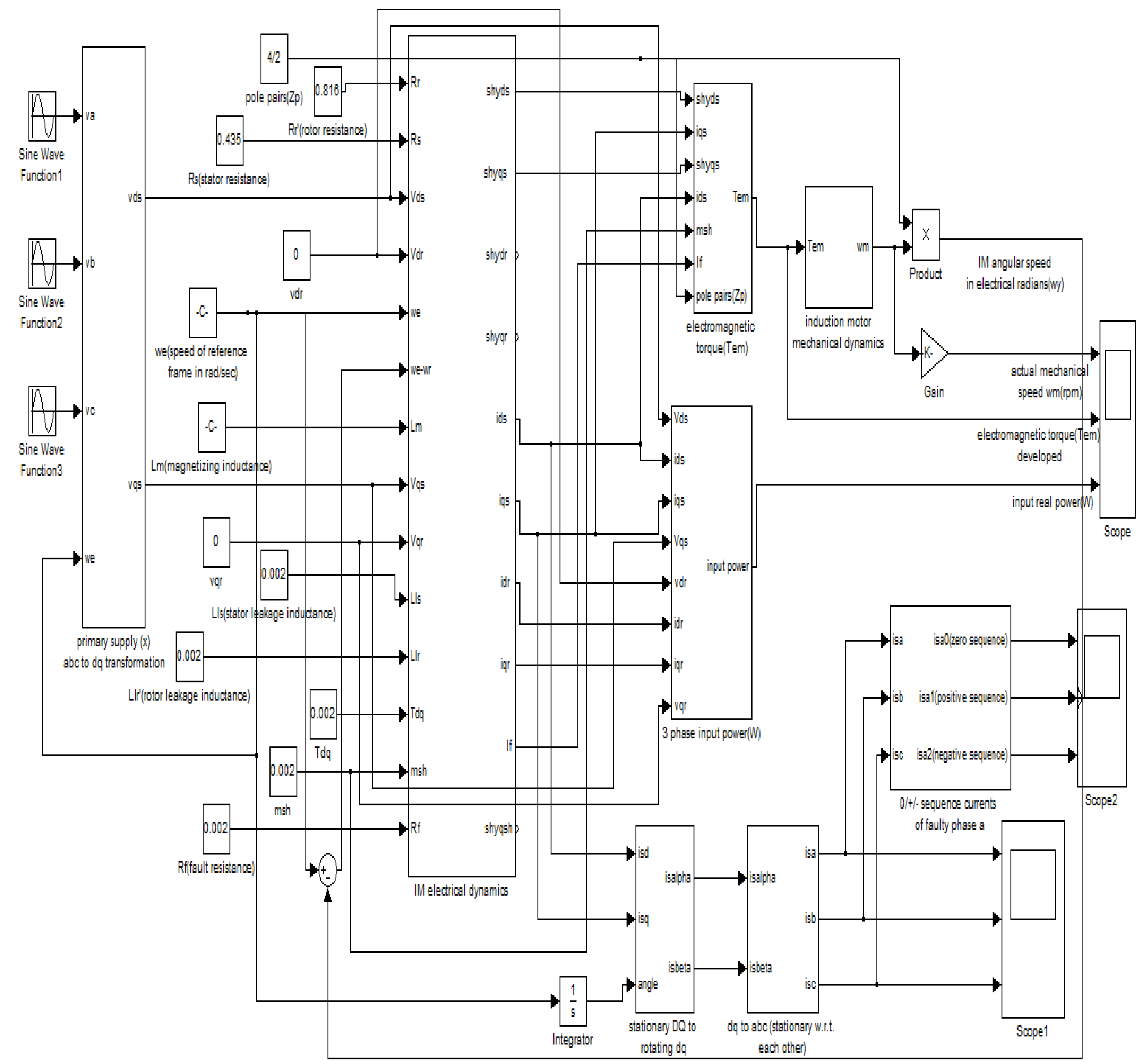

Fig-3. MATLAB Simulink model of Induction Motor.

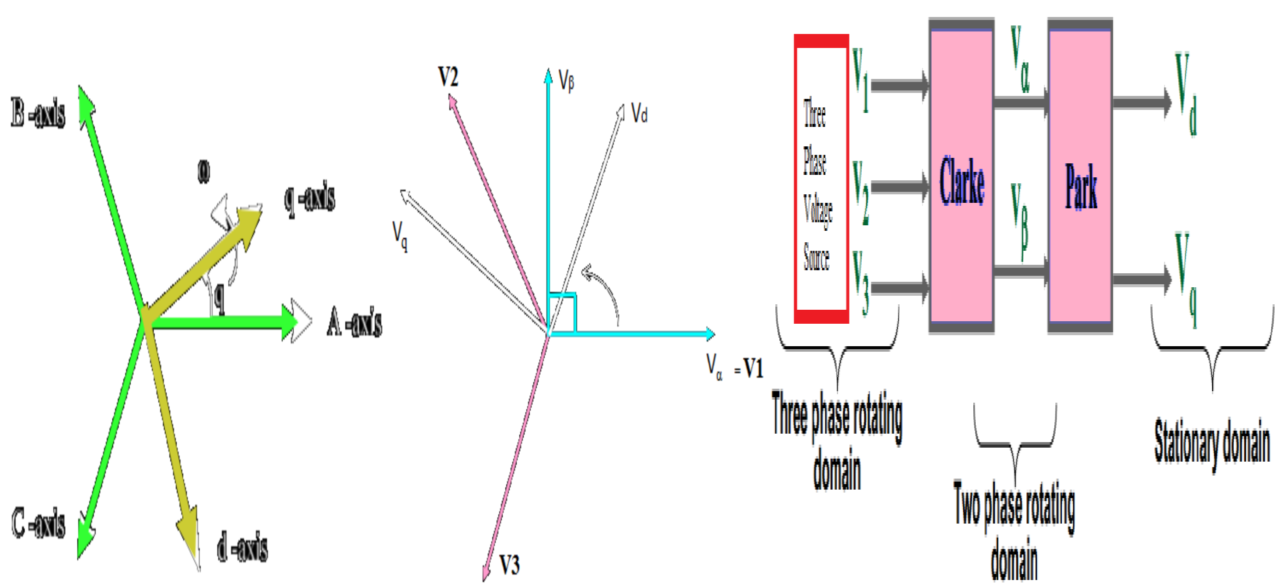

Fig-4. Vector and block diagram of axis transformation using Clarke and Park theories.

2. Modeling

The modeling of induction motor is discussed in this section. The modeling is done based on 2 axis theory in (d and q reference frame). The reason for doing the same is very clear and it has been already reported in the literature. Figure 1 shows the equivalent electrical circuit of an induction motor. It consists of stator and rotor circuitry. The equivalent electrical circuit is same as that of transformer model, difference being that the rotor circuit is shorted as squirrel cage induction motor is shorted by deep rotor bars. Figure 2 shows the circuit model of a three phase induction motor. In this figure three stator and three rotor axes are shown and their arrangements can be understood from this figure. Figure 3 shows the Simulink modeling of induction motor in MATLAB Simulink with the help of simpowersystem blockset. It has several subsystem to do the transformation of reference frame from abc to dq. The vector and block diagram of axis transformation using clarke and park theories are shown in figure 4. Using clark transformation three phase abc rotating reference frame is changed to two phase αβ rotating reference frame. From two phase αβ rotating reference frame, parks theory change it to two phase dq stationery reference frame. The second subsystem is for the winding which are shown in figure 5.

Steady state model available in literature for IM neglects the transients (electrical) arising because of change in load and variation in stator frequency. These variations are very common in applications involving variable-speed drives (VSD). VSD are converter-fed from finite power sources, which are limited by the ratings of the switch and size of the filter, i.e. it means they have a limitation in supplying large transient power. Hence, a need was there to evaluate and analyze the dynamics of

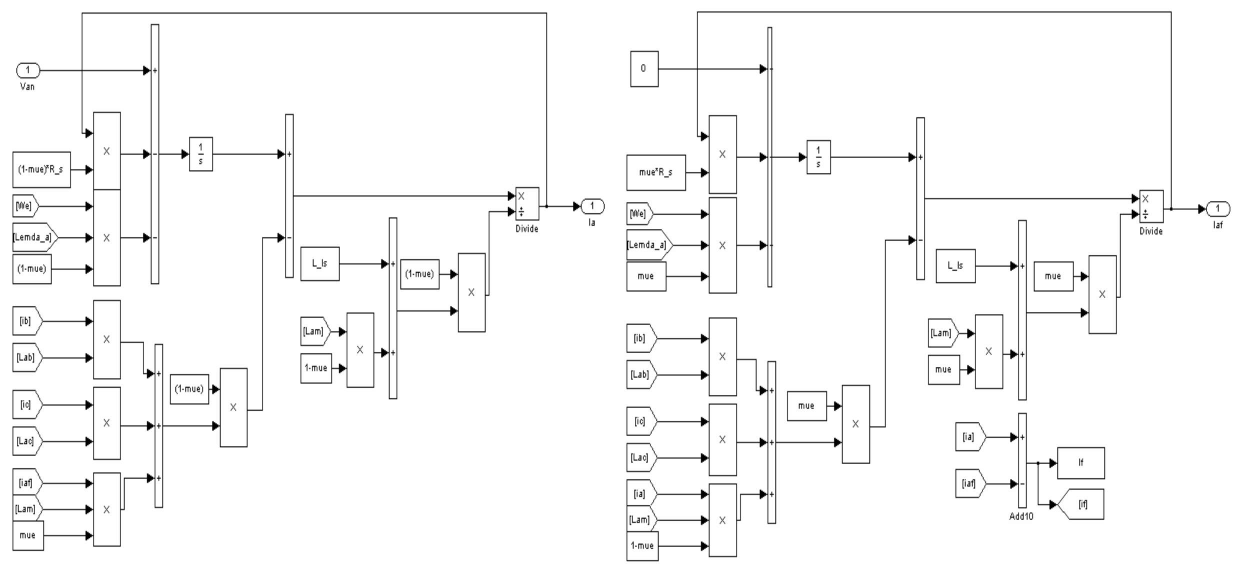

Fig-5. Subsystem of Induction Motor, showing the winding details of IM.

converter-fed VSD so as to assess the adequacy of the converter switches and the converters for a given motor application and their interaction to determine the excursions of torque and currents in the converter and motor combined system. Thus, the dynamic model built in MATLAB Simulink environment shown in figure 3 and based on equations no 1 and 2 considers the instantaneous effects of varying currents/ voltages, stator frequency and torque disturbance. Equation 1 shows the flux linkages matrix and equation 2 shows the transformation in dq reference frame.

$$\begin{bmatrix} \lambda_{as} \\ \lambda_{bs} \\ \lambda_{cs} \\ \lambda_{ar} \\ \lambda_{ar} \\ \lambda_{ar} \end{bmatrix} = \begin{bmatrix} L_{ss} & 0 & 0 & & & \\ 0 & L_{ss} & 0 & & L_{sr} & \\ 0 & 0 & L_{ss} & & & \\ & & & L_{rr} & 0 & 0 \\ & L_{sr}^{T} & & 0 & L_{rr} & 0 \\ & & & 0 & 0 & L_{rr} \end{bmatrix} \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \\ i_{ar} \\ i_{br} \\ i_{cr} \end{bmatrix} \quad \begin{bmatrix} \lambda_{ds} \\ \lambda_{qs} \\ \lambda_{0s} \\ \lambda_{dr} \\ \lambda_{qr} \\ \lambda_{0r} \end{bmatrix} = \begin{bmatrix} L_{ss} & 0 & 0 & 3/2M_{sr} & 0 & 0 \\ 0 & L_{ss} & 0 & 0 & 3/2M_{sr} & 0 \\ 0 & 0 & L_{ss0} & 0 & 0 & 0 \\ 3/2M_{sr} & 0 & 0 & L_{rr} & 0 & 0 \\ 0 & 3/2M_{sr} & 0 & 0 & L_{rr} & 0 \\ 0 & 0 & 0 & 0 & 0 & L_{rr0} \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{0s} \\ i_{dr} \\ i_{qr} \\ i_{0r} \end{bmatrix}$$

3. Results and Discussion

The Simulink model shown in figure 2 was run for 0.2 seconds in the MATLAB Simulink environment. The winding modeled are shown in figure 5. The Simulink model was tested for fault as well as without fault. The results obtained are shown in figure 6 to 17. Figure 6 and figure 7 shows the sequence current namely zero, positive and negative for faulty and without fault induction motor. It can be observed from these two figures that when there is no fault in the system comprising induction machine the negative sequence current will be zero. Whereas when there is a fault in induction machine then current will have negative sequence component as well. The symmetrical and periodical zero sequence current in the system without fault will also get disturbed and the unsymmetrical and non periodical zero sequence current will flow in the faulty induction machine as clearly seen from the figure 7.

Figure 8 and figure 9 shows the mechanical speed, the electromagnetic torque, and the real input power required for induction machine with fault as well as without fault. It can be observed from these two figures that the transients in the induction motor with internal fault are very high. The mechanical speed of IM with internal fault is much lower and the transients in the torque do not settle. Figure 10 and 11 shows the output three phase current of induction motor.

Figure 12 and 13 shows the transformation of voltage from three axes to two axes. The voltages are transformed using park's transformation. The equations used are given in equation 1 and 2.

FFT analyses were also performed to analyze the total harmonic distortion (THD) for a healthy system as well as for a faulty system. The FFT obtained with the help of "powergui" block in MATLAB Simulink are shown here in figure 14 to figure 17. Figure 14 and 15 shows FFT of a healthy system. Figure 14 shows THD for phase A Voltage and figure 15 for phase A current. THD of phase A voltage as seen from the figure 14 is 4.10% which is much lower than the specified limit of IEEE standards. Where as in figure 15 THD of phase A current is 7.03%. Figure 16 and 17 shows FFT of a faulty system. Figure 16 shows THD for phase A Voltage and figure 17 for phase A current. THD of phase A voltage as seen from the figure 16 is 8.45% where as in figure 17 THD of phase A current is 13.39%. Hence one can clearly observe that the THD value of faulty system is much higher than the THD of a healthy system. Table 1 gives the value of THD for current and voltage for both the healthy and faulty systems.

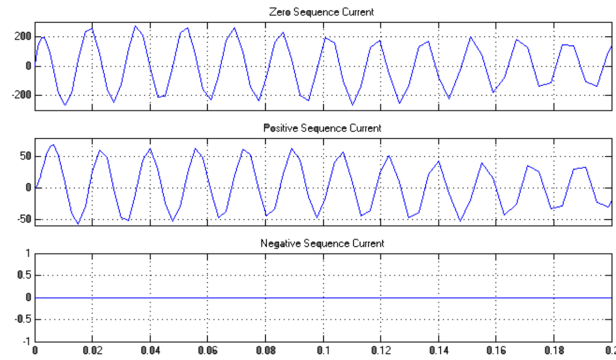

Fig-6. Zero, positive and negative sequence of currents for healthy (Unfaulty) system

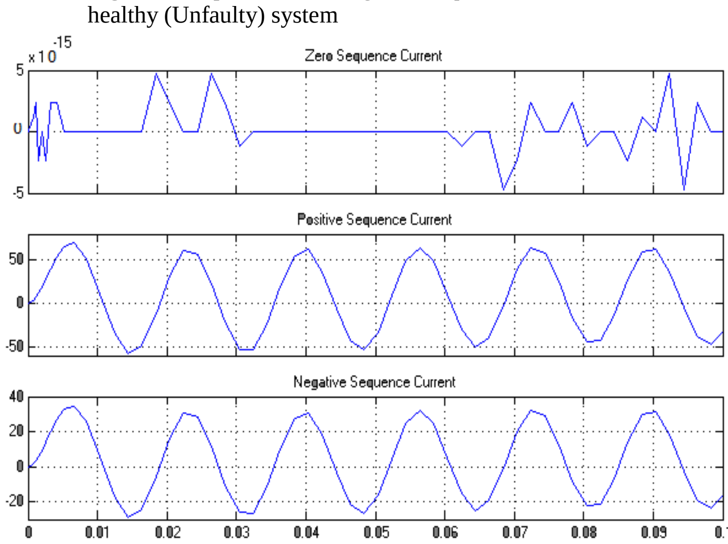

Fig-7. Zero, positive and negative sequence of currents for faulty system

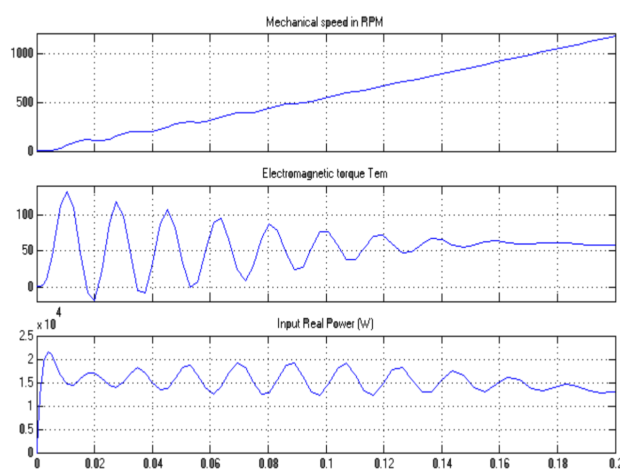

Fig-8. Mechanical speed, electromagnetic torque and input real power for healthy (Unfaulty) system

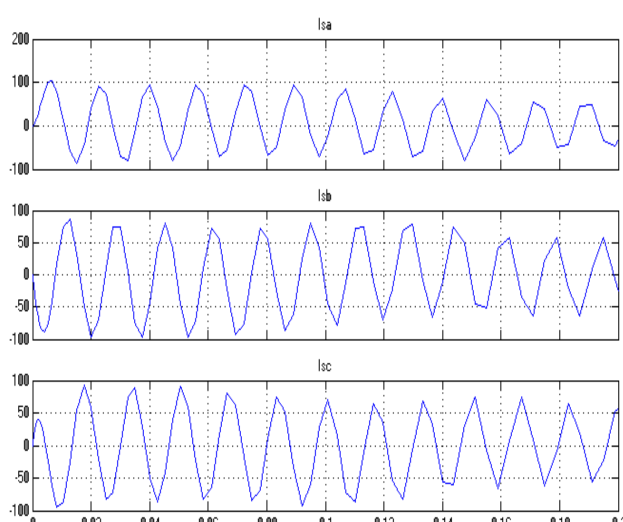

Fig-10. The output three phase current of induction motor for healthy (Unfaulty) system

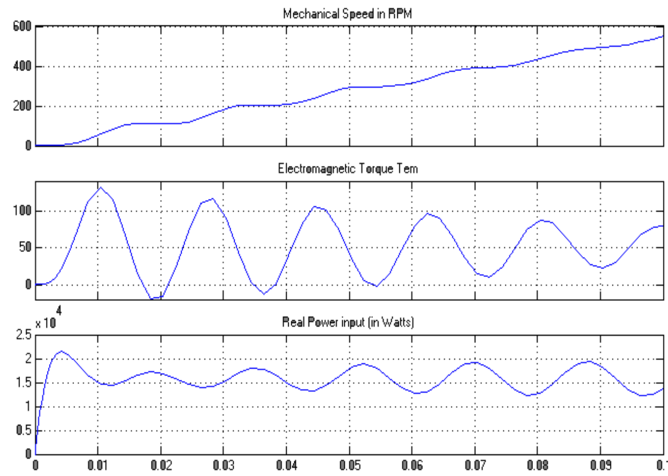

Fig-9. Mechanical speed, electromagnetic torque and input real power for faulty system

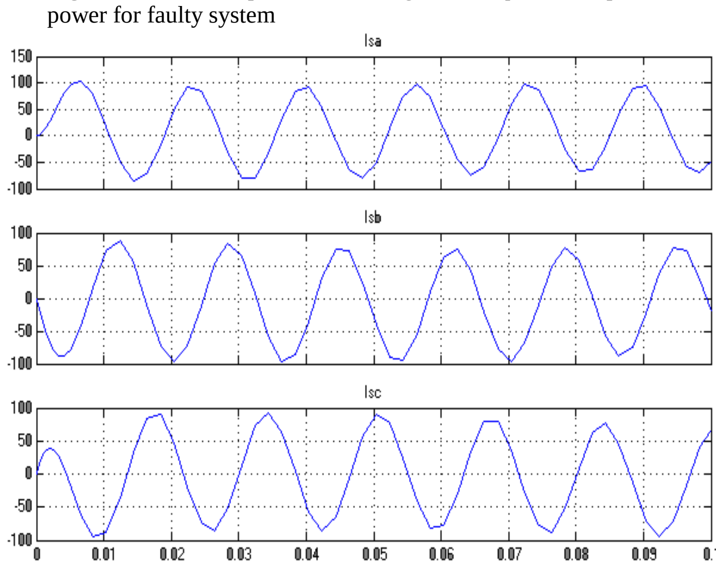

Fig-11. The output three phase current of induction motor faulty system

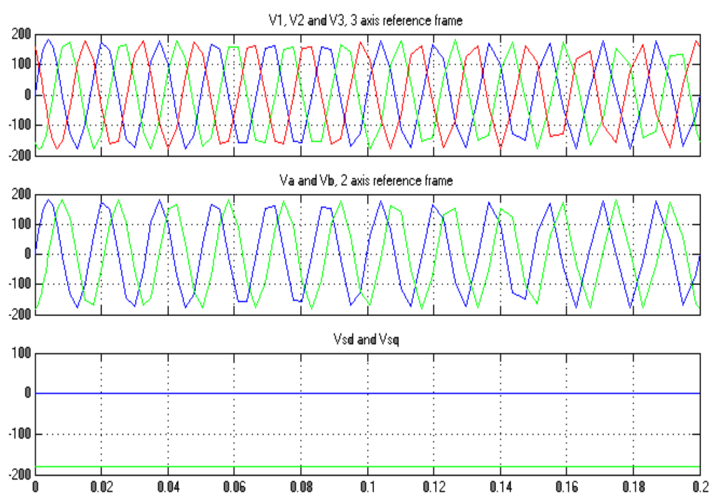

Fig-12. The transformation of voltage from three axes to two axes for healthy (Unfaulty) system

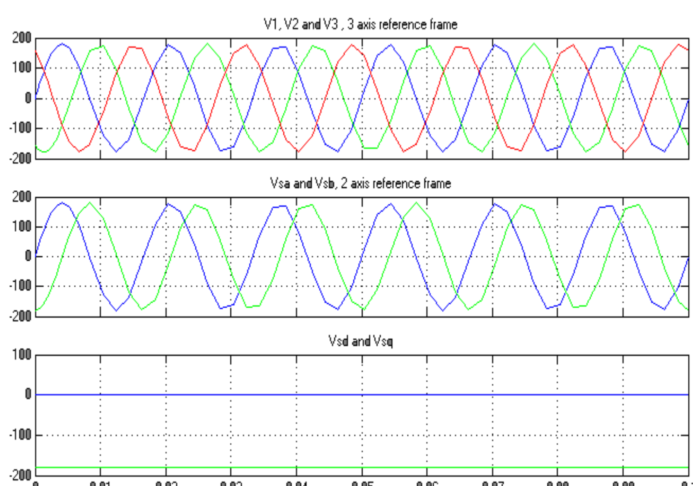

Fig-13. The transformation of voltage from three axes to two axes for faulty system

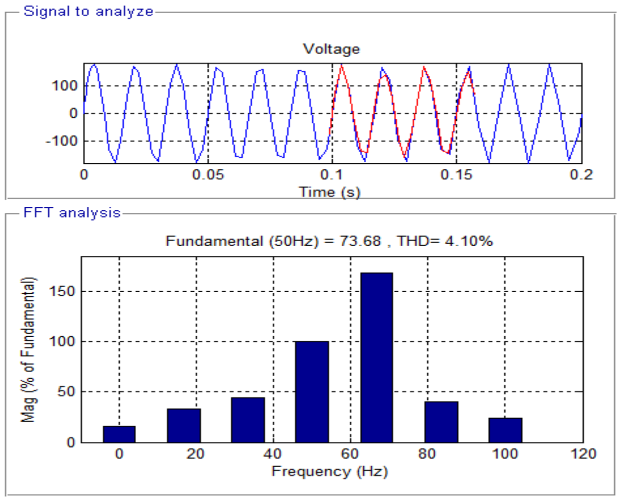

Fig-14. The THD for phase A Voltage for healthy (Unfaulty) system

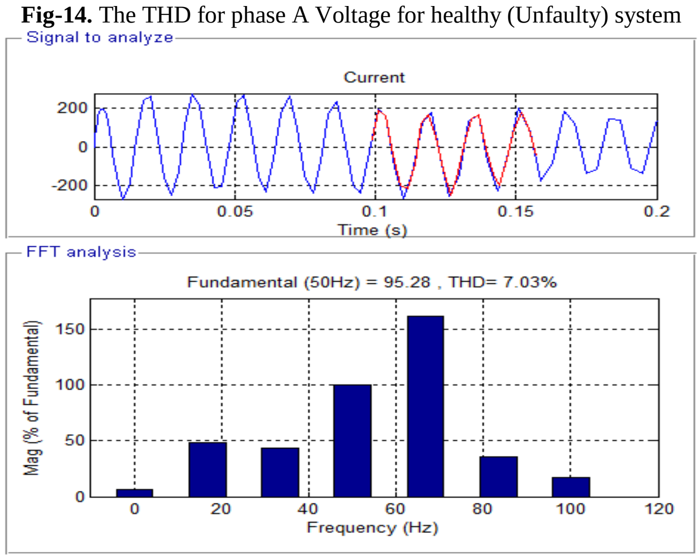

Fig-15. The THD for phase A Current for healthy (Unfaulty) system

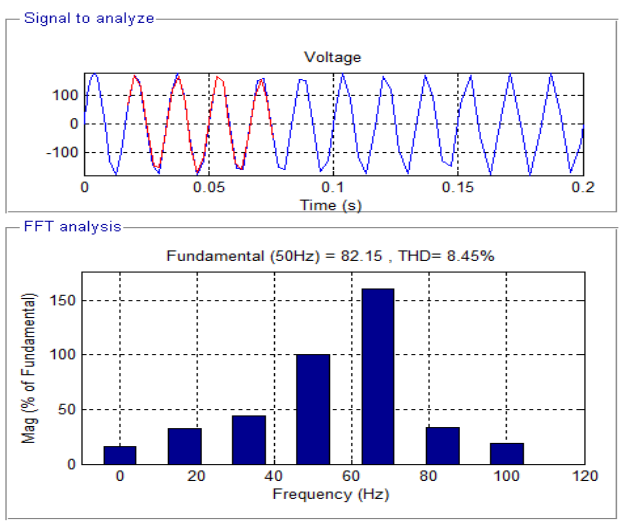

Fig-16. The THD for phase A Voltage for faulty system

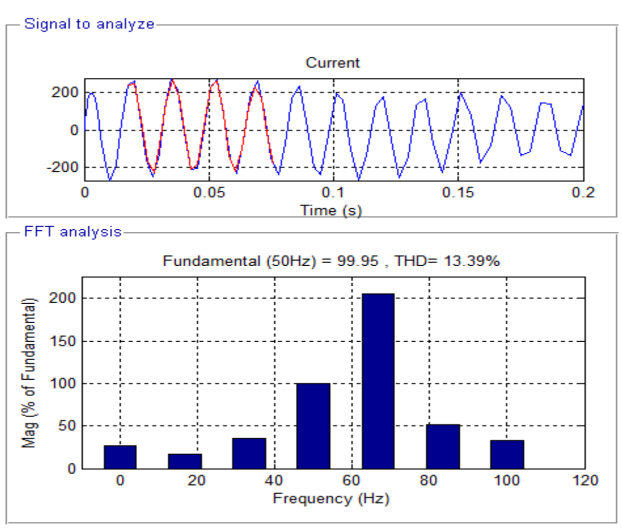

Fig-17. The THD for phase A Current for faulty system

Table-1. THD results for current and Voltage

Total No. of Level	THD
Va of healthy system	4.10%
Ia of healthy system	7.03%
Va of faulty system	8.45%
Ia of faulty system	13.39%

4. Conclusion

This paper has modeled an induction motor. The induction motor was modeled in dq reference frame. The model was simulated with healthy as well faulty system. The results for both have been presented and compared. The results very clearly shows that how one can diagnose the fault in the induction motor by observing the positive sequence, negative and zero sequences. The result for faulty system clearly shows an output for negative sequence. Hence online monitoring is possible and fault can be detected online by observing the sequence current. Total harmonic distortion of healthy and faulty system also shows that THD of faulty system is much higher than that of healthy system. Hence it can be concluded that diagnosis of fault in induction motor is possible and it can be done as well online.

Appendix

The Assumptions and Definitions are stated here:-

i. Space mmf and flux waves are considered to be sinusoidal distributed, hence neglecting the effect of teeth and slots.
ii. The induction machine is regarded as group of linear coupled circuits, hence permitting superposition to be applied, whereas neglecting saturation, hysteresis, and eddy currents.
iii. L_s: self inductance per phase of the stator windings.
iv. M_s: mutual inductance per phase of the stator windings.
v. r_s: resistance per phase of the stator windings.
vi. L_r: self inductance per phase of the rotor windings.
vii. M_r: mutual inductance per phase of the rotor windings
viii. r_r: resistance per phase of the rotor windings.
ix. M_{sr}: maximum value of mutual inductance between any stator phase and any rotor phase.

5. Acknowledgements

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