Static Eccentricity Fault Analysis in Inverter Fed Induction Motor using Finite Element Method

B Hema Priya, R Karthick, B Lokprakash, S Vasanth and N Praveen Kumar

Department of Electrical and Electronics Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India -641112

E-Mail: bhemapriya248@gmail.com

Abstract. One of the common faults encountered in three phase induction motors (IM) is the eccentricity fault. In this work, a study on the electromagnetic characteristics of open-loop voltage source inverter fed IM is carried out for healthy and static eccentricity fault condition with the assistance of Finite Element Analysis. The importance of electromagnetic field analysis is it contains the data about the position of stator, rotor and mechanical parameters of IM. Thus the strategy of monitoring airgap magnetic fields and current are often used for the diagnosis of faults in IM. Detection of eccentricity fault at the incipient stage is difficult because the changes that the fault would introduce in the motor terminal quantities are negligible unless the severity is very high. A comparative study is carried out for healthy and eccentric fault motor with the help of ANSYS Maxwell Finite Element Analysis tool. Electromagnetic field parameters such as speed, current, flux distribution over the machine and in the air gap are analysed for healthy and faulty motor.

1. INTRODUCTION

Induction motors are generally utilized in the ventures for variable speed applications because of their ease of operation, high starting torque, and low maintenance cost and speed variation. Inverter fed induction motor is employed in the vicinity where there is a need for speed control. 80% of the mechanical faults occurring in the induction machines lead to eccentricity fault [1]. There are three sorts of eccentricity faults namely static, dynamic and mixed eccentricity fault. In static eccentricity the rotor hub is uprooted from the stator pivot; in any case the rotor pivots around its hub. The dynamic eccentricity, when the rotor pivot is dislodged from the stator hub, yet it turns around the stator hub. Blended issue happens when both the static and dynamic fault exist together in a machine.

The root cause of eccentricity faults are sudden increase or decrease in load when repetitively happens, manufacturing defects, stator core ovality and mechanical resonance. The eccentricity fault in electrical machine will lead to non-uniform air gap length. If the eccentricity fault is not diagnosed at the earlier stage, will have impact on the performance of the motor and finally damages the stator core, winding, and the rotor body which will result in huge financial loss. The mechanical fault occurs due to failure of mechanical parts in the motor which covers nearly 50-60% of overall faults in induction motor. The critical and severe among these is bearing and eccentricity fault. The analysis and detection of the air gap eccentricity is carried out with the help of stator line current spectrum in
The effects of eccentricity on stator and rotor core sheets get reflected in the windings as vibration. One of the popular methods to detect the eccentricity fault is Motor Current Signature Analysis (MCSA). In the practical scenario, the eccentricity fault gets transformed with the axial coordinate of the motor and leads to inclined eccentricity. The change in the axes are due to inappropriate position of the bearing, skewed rotor, bearing scraped area, skewed burden shafts, mechanical reverberation at basic speed and mechanical burden asymmetry which prompts the particular fault. The commonly occurring eccentricity fault has the axes stagnant in parallel with each other which also ensures that there is no much significant change in uniform air gap distribution. But if the parallelism is lost then it ends up in inclined eccentricity [2]. Even in completely perfect technical conditions, there might be a low percentage of eccentricity exists within tolerance level. The noteworthy change in static eccentricity fault is the direction of insignificant air hole length is time-invariant just as the worth and heading of the lopsided attractive draw. Unusualness shortcoming is likewise brought about by an inappropriate area of the stator and rotor at the assembling stage or by stator ovality[3]. The nearness of shifting air hole prompts outspread quality of electromagnetic beginning known as the uneven attractive force. Some different reasons for eccentricity fault are bowed shaft, bearing wear, misalignment, and mechanical reverberation. Infrequently in reality, a wide range of erraticism shortcoming that is static, dynamic and blended unpredictability issue will, in general, happen together at once. Indeed, even in another motor additionally has the eccentricity shortcoming because of getting together and development strategies. Plan circumstances and working qualities additionally add to unpredictability deficiency [5]. To distinguish the shortcoming precisely, the best possible and exact displaying should be set up [6].

Static eccentricity degree (SED) is the proportion between the separation of the hub of chambers of rings and air-gap length. Eccentricity shortcoming is depicted as far as SED as,

\[ \text{SED} = \frac{\text{Distance of hub of chambers of the internal eccentric ring}}{\text{air-gap length of the motor}} \]

The mentioned fault causes vibration and sounds in the present sign because of mechanical pressure, the rotor and stator impact when unconventional deficiency rate increments. The shortcoming in mains fed IM can be recognized utilizing FFT range of stator current [4]. Yet, when the machine is taken care of from an inverter, MCSA doesn't hold well in light of the fact that the inverter harmonics have impacts on the frequency spectrum.

This paper deals with the Finite Element Method (FEM) which is used to analyze the electromagnetic signatures of IM during static eccentricity fault condition and compared with healthy motor. The use of FEM for analyzing the electromagnetic parameters under healthy and faulty condition is a favored approach. Because FEM provides more accurate information during fault condition contrasted with the expository technique which utilizes direct properties[3]. FEM includes non-linearity such as magnetic saturation, actual properties of magnetic materials, windings placed in actual slots etc., FEM is used for analyzing IM faults such as stator winding faults [7] [8] [9], broken rotor bar faults [10] [11] and bearing faults [12].

2. CO-SIMULATION OF IM MODEL IN ANSYS MAXWELL WITH SIMPLORER

The investigation of eccentricity flaw is completed on a three-phase IM with the help of ANSYS Maxwell and Simplorer. The motor is taken care of from a three-phase PWM inverter. Figure 1 shows the IM model in ANSYS Maxwell FEA instrument, the structure subtleties of which are appeared in the Appendix.

Static eccentricity fault is incorporated in the IM model in ANSYS Maxwell for a fault degree of 0.15mm (43%). Figure 2 delineates the ANSYS Simplorer model of SPWM controlled inverter fed
IM. The IM model in ANSYS Maxwell is simultaneously simulated with Simplorer for winding excitation and load arrangements.

![Maxwell model of induction motor](image1)

**Figure 1.** Maxwell model of induction motor.

![Co-simulation between ANSYS Maxwell and Simplorer](image2)

**Figure 2.** Co-simulation between ANSYS Maxwell and Simplorer.

### 3. RESULTS

The study is completed on a 3φ, 380V, 7.5kW, 4 pole IM with 48 stator openings and 44 rotor spaces. The created FE model of IM is provided from a three-phase, PWM inverter with the switching frequency of 2 Khz in open circle condition. The motor is begun without any torque and at t=0.5s rated torque of 49 Nm is applied.

Figure 3 shows the speed of IM under healthy and eccentric fault condition. During eccentric fault condition, the oscillation in speed slightly increases while running at rated load compared to healthy motor as seen from Figure 3(b). Since the variations in speed ripples are very less, the oscillations alone cannot be treated as a fault parameter. Hence the static eccentricity with a high fault severity level of 43% induces slight oscillations in rotor speed.
Figure 3. Speed of Induction Motor. (a) Healthy Motor. (b) Eccentric Motor (43%).

Figure 4(a) delineates the winding current of the healthy machine and Figure 4(b) shows for the flawed machine (0.15 mm). It is difficult to see any distinction in flows among solid and the broken engine in any event, for a seriousness of 43%. Figure 5(a) delineates the FFT of the current for good machine and Figure 5(b) shows the FFT of the current for the faulty machine (0.15 mm). Contrasted with the FFT range of sound motor, the flawed motor current range shows a slight increment in clamour close to the crucial part. Henceforth for inverter fed IM, it is extremely hard to distinguish the static flightiness deficiency from stator current FFT range.
Figure 4. Winding currents of IM. (a) Healthy Motor. (b) Faulty Motor (43%).
Figure 5. FFT spectrum of Stator current. (a) Healthy Motor. (b) Faulty Motor (43%).

Figure 6 represent radial flux density in airgap for induction motor. Figure 6(a) shows the radial flux density distribution for healthy induction motor with respect to radial airgap distance at rated load condition. As indicated by Ampere circuital law, the result of the length of a component and attractive field power over a shut way gives the current encased in that surface. In the event that the current over a surface is thought to be steady, at that point attractive field power is contrarily relative to the length of a component. The attractive transition thickness is given as the result of relative porousness and attractive field force. Consequently, the air hole transition thickness experiences twisting when there is an adjustment in air hole length. The circulation of transition around the airgap is balanced with four half-cycles and the noise present in the waveform is expected stator and rotor spaces, non-sinusoidal winding dispersion and attractive immersion. Figure 6(b) portrays the outspread motion thickness of an acceptance engine with the flightiness of 0.15 mm. The twisting in the airgap motion thickness is because of flightiness shortcoming of 43% seriousness. Notwithstanding the above-said harmonics, more noise is initiated because of static eccentricity flaw. Figure 7 delineates the spatial FFT range of airgap outspread motion thickness for the solid and flawed motor. Aside from the central part, different noises in solid motor range are because of openings, windings and inverter harmonics. The expansion in consonant substance because of static erraticism can be seen from Figure 7(b) contrasted with solid motor range.
Figure 6. Radial airgap flux density of Induction Motor. (a) Healthy Motor. (b) Faulty Motor with 43% eccentricity.

Figure 7. Spatial FFT spectrum of radial airgap flux density. (a) Healthy Motor. (b) Faulty Motor with 43% eccentricity.

The flux distribution of a fine fettle IM appears in Figure 8. It is seen from Figure 8(a), the dispersion of magnetic lines over the solid motor is balanced over the post pitch and each shaft is found at an
attractive pivot of $360^\circ/p$ geometrical degrees, where $p$ is the number of posts. Whenever moment the bend of the periphery is $\pi D/p$ for all the shafts, where $D$ is that the inner distance across of the stator. Figure 9 shows the attractive field conveyance of IM under the static unusual condition with a seriousness level of 43%. It tends to be seen from Figure 9(a), asymmetry happens in the attractive field appropriation because of unpredictability flaw, the attractive tomahawks position of the posts become temperamental and each shaft length changes around $\pi D/p$ when arriving at the shortcoming district of the rotor during the pivot. The length of the attractive posts of the flawed machine experiences an intermittent variety round the rotor during motion turn. From the conveyance of attractive fixation in Figure 9(b) it is seen that the motion thickness becomes uneven bringing about immersion inside the rotor and stator teeth close to the dislodged position because of issue. At the point when the issue seriousness expands, the asymmetry in transition lines and motion thickness dispersion over IM increments.

![Figure 8](image)

**Figure 8.** Flux distribution over healthy Induction Motor. (a) Flux lines. (b) Flux density.
Figure 9. Flux distribution in faulty motor (43%). (a) Flux lines. (b) Flux density.

4. CONCLUSIONS

Thus, electromagnetic qualities of PWM inverter fed IM is broke down for solid and eccentricity flaw of degree 43% utilizing FEM model. Since the issue is exceptionally hard to recognize utilizing stator current range and speed for inverter took care of IM. An examination on the attractive field circulation (Flux Lines and Flux Density) of the solid and flawed motor model is completed. The examination shows the distortion in the hub of attractive posts prompting immersion in the rotor and stator teeth close to the dislodged locale. The spiral airgap transition thickness as for the airgap separation of sound and broken IM has been thought about. The examination shows the consonant substance in spatial FFT range of spiral airgap transition thickness is increased because of static unpredictability flaw.

5. APPENDIX

Three-Phase Induction Motor Design Parameters
5.1. General Data

Output Power (kW): 7.5
Rated Voltage (V): 380
Number of Poles: 4
Speed (rpm): 1420
Frequency (Hz): 50

5.2. Stator parameters

Number of Stator Slots: 48
Outer Diameter of Stator (mm): 210
Inner Diameter of Stator (mm): 148
Length of Stator Core (mm): 250
Type of Steel: M19_24G
Number of Parallel Branches: 2
Number of Conductors per Slot: 30
Number of Wires per Conductor: 2

5.3. Rotor parameters

Number of Rotor Slots: 44
Air Gap (mm): 0.35
Inner Diameter of Rotor (mm): 48
Length of Rotor (mm): 250
Type of Steel: M19_24G

5.4. Rated Load Operation

Stator Resistance (ohm): 0.550703
Stator Leakage Reactance (ohm): 0.615652
Rotor Resistance (ohm): 0.43119
Rotor Leakage Reactance (ohm): 0.823987
Stator Phase Current (A): 14.2959
Input Power (kW): 8.38835
Output Power (kW): 7.49976
Mechanical Shaft Torque (N.m): 49.317
Efficiency (%): 89.4069
Power Factor: 0.88757

References

[1] Faiz J, Ebrahimi M B, Akin B and Toliyat H A 2009 Comprehensive eccentricity fault diagnosis in induction motors using finite element method IEEE Transactions on Magnetics 45[3]1764- 67
[2] Ojaghi M and Mohammadi M 2016 Modeling eccentricity faults with axial asymmetry in three-phase induction motors IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society 1524-29
[3] Sobra J, Kavalir T, Krizek M and Skala B 2018 Experimental verification of the finite element analysis of an induction machine with implemented static eccentricity Fault18th International Conference on Mechatronics - Mechatronika (ME)1-5
[4] Benbouzid M E 2000 A review of induction motors signature analysis as a medium for faults detectionIEEE Transactions on Industrial Electronics47[5]984-93
[5] Polat A, Erturul Y D and Ergene L T 2015 Static, dynamic and mixed eccentricity of induction motor SDEMPED 2015 IEEE 10th International Symposium on Diagnostics for Electric Machines, Power Electronics and Drives 284–288

[6] Stoll R L 1997 Simple computational model for calculating the unbalanced magnetic pull on a two-pole turbo generator due to eccentricity IEEE Proc. Elect. Power Appl., 144[4] 263–270

[7] Praveen Kumar N, Isha T B and Balakrishnan P 2016 Radial electromagnetic field analysis of induction motor under faulty condition using FEM Biennial International Conference on Power and Energy Systems: Towards Sustainable Energy (PESTSE) 1-6

[8] Praveen Kumar N and Isha T B 2019 FEM based electromagnetic signature analysis of winding inter-turn short-circuit fault in inverter fed induction motor CES Transactions on Electrical Machines and Systems3[3] 309-315

[9] Prasob K, Kumar N P and Isha T B 2017 Inter-turn short circuit fault analysis of PWM inverter fed three-phase induction motor using finite element method International Conference on Circuit, Power and Computing Technologies (ICCPCT) 1-6

[10] Praveen Kumar N and Isha T B 2016 Electromagnetic field analysis of 3phase induction motor drive under broken rotor bar fault condition using FEM IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES) 1-6

[11] Praveen Kumar N and Isha T B 2019 Electromagnetic signature study of a closed loop speed controlled three-phase induction motor under broken rotor bar fault using finite element method Journal of Engineering Science and Technology14[5] 2731-45

[12] Praveen Kumar N, Vinothraj C and Isha T B 2018 Effect of wear and tear bearing fault in induction motor drives using FEM IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)1-6