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Fault Diagnosis Of Induction Motor Under Various Fault Conditions Of Stator Winding At Different Loading Level

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Abstract— Stator inter turn faults are a standout amongst the most well-known faults happening in induction motors. Around 30– 40% of faults of induction motors are stator faults. Stator faults are caused by a blend of thermal, electrical, mechanical, and environmental stresses. Early recognition of inter turn short circuit is imperative to lessen repair costs. In this paper, execution of induction motor under various failure's of stator windings are inspected using FEM approach. Maxwell Transient solver is used for separating the lead of motor under solid and diverse broken conditions.

Keywords: Stator Winding Faults, Induction Motor, Fault Monitoring, Maxwell2D

I. INTRODUCTION

Three phase induction motors are the principle work horse of the industries and along these lines they are focus of the vast larger part of the industrial processes. Similar to all other pivoting machines, the induction motors are also exposed to a wide range of stringent conditions like thermal and environmental stresses and mechanical damages [1-2]. Induction motors are a noteworthy key piece of industry and have an essential part in the processes and creation lines in numerous areas of industry. Thus, startling failures in these motors may make real problems.

The Institute of Electrical and Electronics Engineers (IEEE), the Electric Power Research Institute (EPRI) and Allianz have done definitive studies on this issue. The level of failures by segment are given in Figure 1. Stator faults have 26% rates as indicated by IEEE and 36% rates as indicated by EPRI and 63% as per Allianz. Sudden failures for the most part happen because of inward and outer motor faults.

Table 1 : Comparison of IEEE, EPRI and Allianz surveys

Components	Fault Percentage Distribution		
	IEEE	EPRI	Allianz
Bearings	44	41	13
Stator	26	36	63
Rotor	8	9	13
Others	22	14	8

A comparative fault distribution informed by [3] is shown in Table 1; this comparison was carried out in several surveys of faults of large induction motors, conducted by the Institute of Electrical and Electronics Engineers (IEEE) [4–6], Electric Power Research Institute (EPRI) [7], and Allianz [8]. differences in distributions are because survey conducted by IEEE and EPRI focuses on medium-sized induction machines, while Allianz survey focuses more on medium- to high-voltage large induction machines.

II.CLASSIFICATION OF STATOR FAULTS AND CAUSES

The stator is subjected to various stresses such as thermal, electrical, mechanical, and environmental [9]–[11], which severely affects the stator condition leading to faults [12].

a. Classification of Stator Faults

The stator defects/faults can be broadly classified into the following two categories.

1) Laminations (core hot spot, core slackening), frame (vibration, circulating currents, loss of coolants, earth faults).

2) Stator Windings Defects/Faults: The most common defects/ faults of stator windings are related to either the “end winding portion” or the “slot portion” as given below:

- End-winding portion (local damage to insulation, fretting of insulation, contamination of insulation by moisture, oil or dirt, damage to connectors, cracking of insulation, discharge erosion of insulation, displacement of conductors, turn-to-turn faults).
- Slot portion (fretting of insulation, displacement of conductors).

b. Causes/Stresses Leading to Stator Faults

The various causes of stator failures have been identified [9] - [12]. The majority of these faults are caused because of a combination of various stresses acting on the stator, which can be classified into thermal, electrical, mechanical, and environmental.

- **Thermal Stresses :** These stresses may be because of thermal maturing and thermal over-burdening. As a thumb administer, for each 10□C increase in temperature, the insulation life gets divided because of thermal maturing. Unless the working temperature is greatly high, the ordinary impact of thermal maturing is to render the insulation system powerless against other affecting factors or stresses that really cause the failure [9]. On the off chance that the insulation system loses its physical honesty, it fails to resist the other dielectric, mechanical, and environmental stresses. The impact of temperature on thermal maturing can be limited by using any of two approaches to ensure longer thermal life: either by

- decreasing the working temperature or by increasing the class of insulation materials used.

  Thermal over-burdening can happen because of the connected voltage variations, unequal phase voltage, cycling overloading,obstructed ventilation, higher surrounding temperature, and so on. As a thumb run, for each 3.5% voltage unbalance for each phase, the winding temperature increases by 25% in the phase with the highest current [9]. The physical specifications of the heap (dormancy, weight, starting burden speed, torque bend, starting cycle, and so forth.) are to be mulled over while selecting a motor for a specific purpose because the motor draws five to eight times the ordinary current amid startup. On the off chance that the motor is subjected to rehashed starts inside a small span of time, the winding temperature will quickly increase. Cycling also gives rise to another debilitating impact of expansion and constriction of the insulation system. It is estimated that the winding temperature increases directly with the heap so the motors should be designed to work beneath the ordinary limits for a specific insulation system or using an insulation system with a rating that is well over the working temperature. The motor should be kept clean inside and outside to ensure that the stream of air is not restricted; otherwise, winding temperature will increase because of warmth created in the stator and the rotor. On the off chance that keeping the motor clean is impracticable, at that point this factor has to be mulled over amid design stage, which can be accomplished by restricting the winding temperature and updating the insulation system.
- **Electrical Stresses :** The electrical stresses prompting winding failures can be classified into dielectric, following, crown, and transient voltage conditions. The distinct relationship between insulation life and the voltage stresses connected to the insulating materials has to be thought about while selecting the materials and establishing the curl designs for sufficient design life. These stresses can be classified into phase-to-phase, swing to-turn, and swing to-ground.

  On the off chance that the insulation system is not totally shielded from the earth, at that point in the motors with working voltages more than 600 V, a wonder known as following occurs in the windings prompting ground failures.

  Transient voltage conditions result in lessened winding life or untimely failure (either swing to-turn or swing to-ground). These conditions can be caused by line-to-line, line-to-ground, multiphase line-to-ground, and three-phase faults, dreary restriking, current-constraining fuses, quick bus transfers, opening and closing of circuit breakers, capacitor switching, insulation failure, lightning, and variable frequency drives
- **Mechanical Stresses :** These stresses may be because of loop development and rotor striking the stator. The power on the coils because of the stator winding current ($F \propto I^2$) is most extreme amid the starting cycle, causing the coils to vibrate at double the line frequency with development both in the spiral and distracting directions. This loop development can cause harm to the curl insulation, loosen the best sticks, and cause harm to the copper conductors.

  There may be numerous different causes for winding failures like rotor adjusting weights coming loose and striking the stator, rotor fan blades coming loose and striking the stator, loose nuts and bolts striking the stator, remote particles/bodies entering the motor through the ventilation system and striking the stator, a deficient rotor (e.g., open rotor bars) causing the stator to overheat and fall flat, poor lead carrying of connections from the motor leads to the approaching line leads causing overheating and failure, and broken cover teeth striking the stator because of weariness. A piece of broken bars may work itself into the air hole, causing prompt failure to copper-press.
- **Environmental Stresses/Contamination :** The presence of remote material could cause various sick effects on the working of the motor-like decrease in warm dissipation (which will increase working temperature in this way lessening insulation life), untimely bearing failure because of high-confined stresses, and breakdown of the insulation system (causing shorts and grounds). Each step should be taken to restrict/limit the moisture, chemicals, and outside particles from connecting with the motor surface.

III. SIMULATION SETUP

We are utilizing Finite Element Method (FEM) to deal with the induction motor under different conditions. It is a numerical method for unraveling a differential or integral condition. It has been connected to various physical issues, where the overseeing differential equations are accessible. The method basically comprises of expecting the piecewise persistent capacity for the arrangement and getting the parameters of the functions in a way that diminishes the blunder in the arrangement.

Table :2 Specifications of modeled three phase induction motor used

Parameters	Value
Phase	3 Phase IM
Rated Power	5kW
Rated Voltage	415V
Frequency	50Hz
Number of poles	4

Rmxpert and Maxwell is used for FEM analysis.The proposed model of induction motor is shown in Fig. 1.

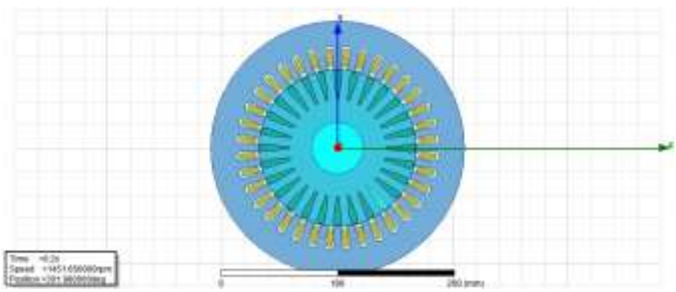

Fig. 1 Proposed model of induction motor

The simulation work was conducted using a three phase 5kW, 415V rated induction motor.Detailed Specification of induction motor used for the simulation work is given in Table 2.

Here we have simulated a 3 phase induction motor under various configuration of coils of stator winding. All the setups for simulation that we have used for simulation are

A. Under normal condition
B. Under faulty conditions
i) Fault condition with one coil of phase A open of stator winding
ii) Fault condition with two coils (one of phase A and one of phase B) open of stator winding
iii) Fault condition with three coils (one - one each of phase A, phase B and phase C) open of stator winding

A. INDUCTION MOTOR UNDER NORMAL CONDITION

Under normal conditions, the induction motor without having any fault in stator winding coil is simulated at loading level of 1451.65 rpm and the performance characteristics are plotted below.

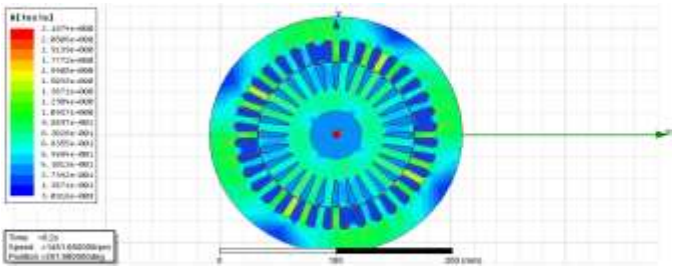

Fig.2 Flux density distribution of induction Motor during normal condition

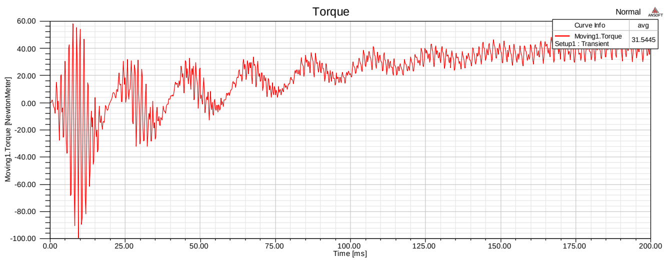

Fig. 3 Torque response of Induction Motor over period of Time during normal condition

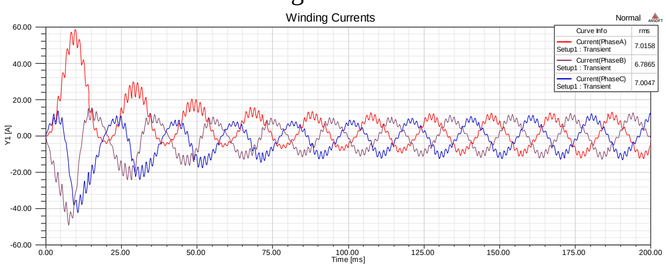

Fig. 4 Current response of Induction Motor during normal condition

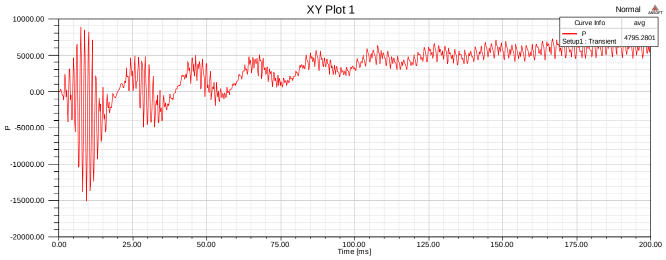

Fig. 5 Output Power response of Induction Motor during normal condition

B. INDUCTION MOTOR UNDER FAULTY CONDITIONS

Overheating is one of the main cause of stator winding insulation deterioration and even failure of it. The insulation degrading or failure is mainly caused by poor ventilation, problem in cooling circuit or overload condition, contamination in air and/or humidity etc. These erroneous conditions are possibly causing shorted turns, shorted coils (same phase, it is the most common fault), phase to phase, phase or coil to ground and single phasing. Such failures cause stator electrical imbalance as well as variations in the current harmonic content. Mechanical problems can also occur in the stator such as loosen edges, but this is statistically less frequent [1,2].

i. Faulty Condition in Induction Motor having One Coil Open of Stator Winding.

Here, a 3 phase induction motor is modeled with one coil open of phase A of stator winding of 3 phase induction motor to analyze the harmonic content of the motor at 1451.65 rpm.

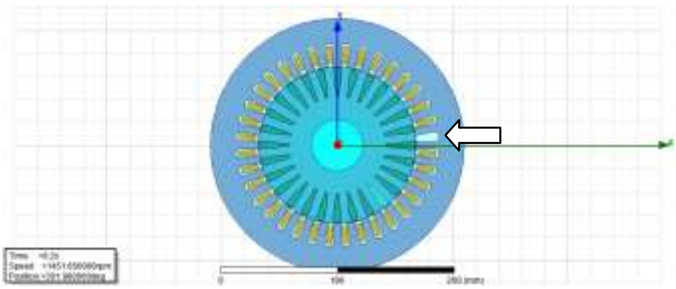

Fig. 6 Model of Induction Motor with one coil of phase A open of stator winding

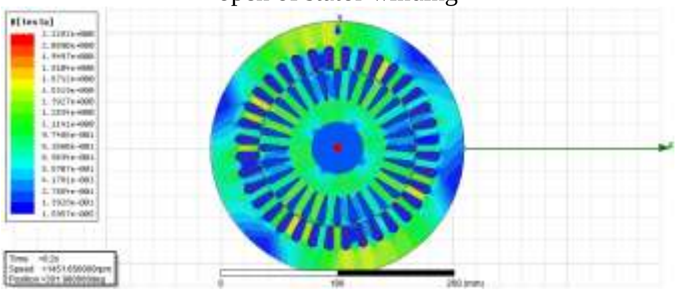

Fig. 7 Flux density distribution of Induction Motor during fault condition with one coil open of stator winding

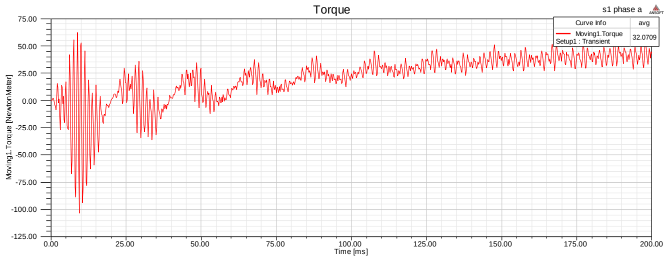

Fig. 8 Torque response of Induction Motor over period of Time during fault condition with one coil open of stator winding

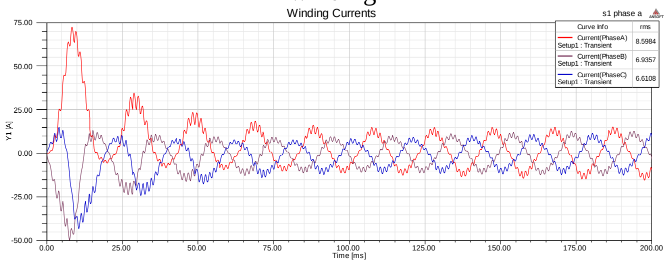

Fig. 9 Current response of Induction Motor during fault condition with one coil open of stator winding

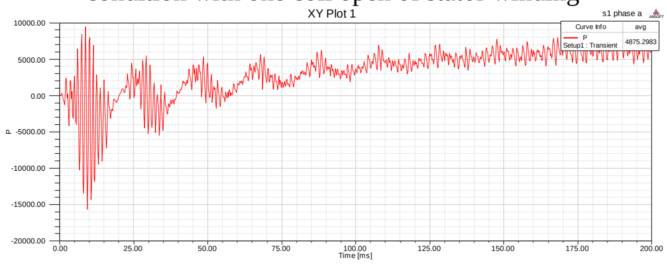

Fig. 10 Output Power response of Induction Motor during fault condition with one coil open of stator winding

ii. Faulty Condition in Induction Motor having two Coil Open of Stator Winding.

Here, a 3 phase induction motor is modeled with two coil open(one one each from Phase A and Phase B) of stator winding of 3 phase induction motor to analyze the harmonic content of the motor at 1451.65 rpm.

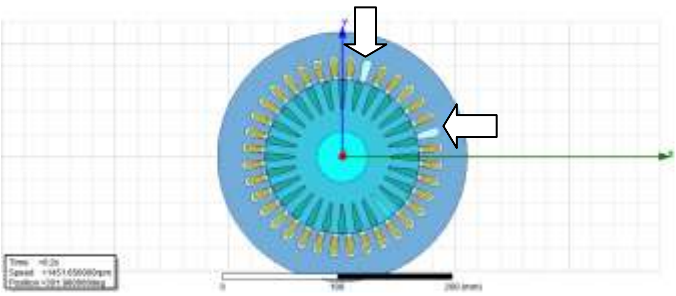

Fig. 11 Model of Induction Motor with two coils open of stator winding

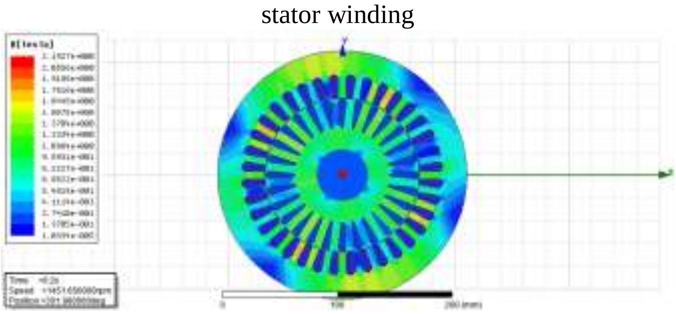

Fig. 12 Flux density distribution of Induction Motor during fault conditionwith two coils open of stator winding

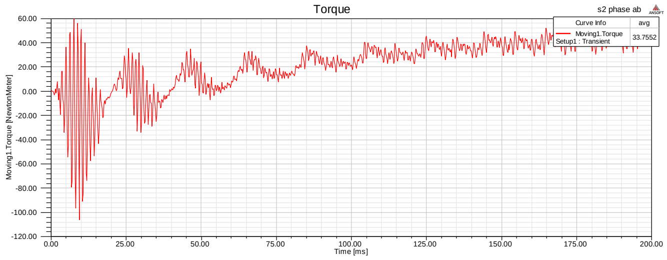

Fig. 13 Torque response of Induction Motor over period of Time during fault condition with two coils open of stator winding

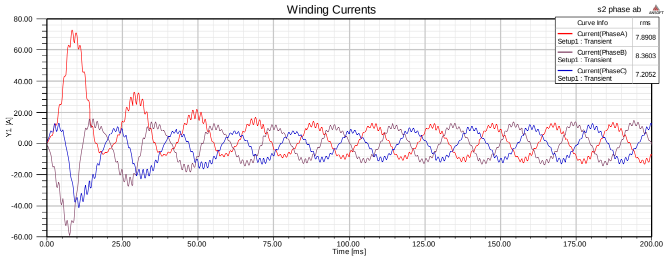

Fig. 14 Current response of Induction Motor during fault conditionwith two coils open of stator winding

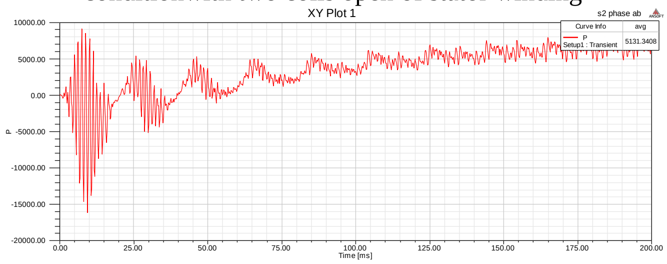

Fig. 15 Output Power response of Induction Motor during fault condition with two coils open of stator winding

iii. Faulty Condition in Induction Motor having three Coils Open of Stator Winding.

Here, a 3 phase induction motor is modeled with three coils open(one one each from Phase A, Phase B and Phase C) of stator winding of 3 phase induction motor to analyze the harmonic content of the motor at 1451.65 rpm.

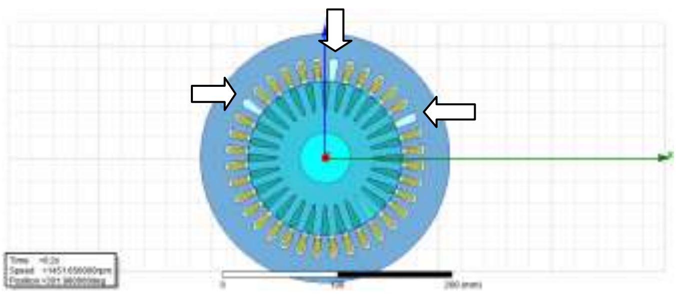

Fig. 16 Model of Induction Motor with three coils open of stator winding

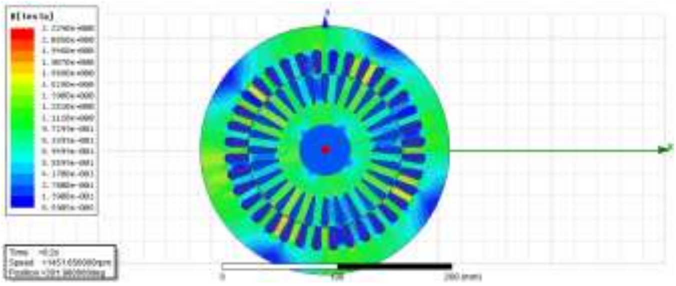
Fig. 17 Flux density distribution of Induction Motor during fault condition with three coils open of stator winding

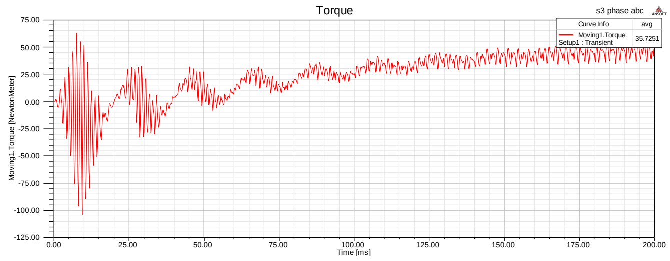

Fig. 18 Torque response of Induction Motor over period of Time during fault condition with three coils open of stator winding

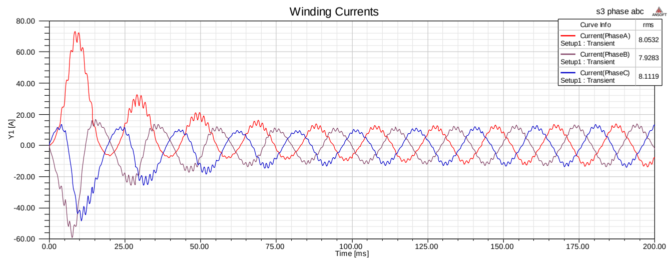

Fig. 19 Current response of Induction Motor during fault condition with three coils open of stator winding

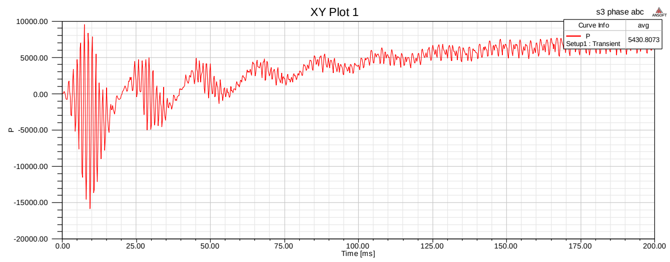

Fig. 20 Output Power response of Induction Motor during fault condition with three coils open of stator winding

So above all conditions have been simulated at 1451.65 rpm and results have been obtained after that simulation is carried out at different loading level at 1151.65 rpm.

IV. RESULTS AND CONCLUSION

The results of Induction Motor under various fault conditions are calculated and compared in the table below where Table 3 compares Average Magnetic Torque at two different speeds i.e.1451.65rpm and 1151.65rpm

Table :3 Average Magnetic Torque at two different speeds

Speed	1451.65 rpm	1151.65 rpm
Condition	Magnetic torque Nm (Average)	Magnetic torque Nm (Average)
Healthy	31.5445	19.0220
One Coil Open	32.0709	18.6354
Two Coil Open	33.7552	19.4465
Three Coil Open	35.7251	20.7028

Here below in Table 4, it compares Stator Current at two different speeds i.e.1451.65rpm and 1151.65rpm.

Table :4 Stator Current at two different speeds

Speed	1451.65 rpm	1151.65 rpm
Condition	Magnetic torque Nm (Average)	Magnetic torque Nm (Average)
Healthy	31.5445	19.0220
One Coil Open	32.0709	18.6354
Two Coil Open	33.7552	19.4465
Three Coil Open	35.7251	20.7028

Here below in Table 5, it compares Average Mechanical Power at two different speeds i.e.1451.65rpm and 1151.65rpm.

Table :5 Average Mechanical Power at two different speeds

Speed	1451.65 rpm	1151.65 rpm
Condition	Magnetic torque Nm (Average)	Magnetic torque Nm (Average)
Healthy	31.5445	19.0220
One Coil Open	32.0709	18.6354
Two Coil Open	33.7552	19.4465
Three Coil Open	35.7251	20.7028

In this paper the Induction Motor is being operated under various healthy and faulty conditions. And to design and foresee the conduct of the Induction Motor, RM-Xpert and ANSYS MAXWELL is being utilised. The main objective of the paper is to address the conduct of the 3 phased induction motor under these various conditions which includes different combinations of the Stator Winding. The Flux density and current density plot have been obtained that help to analyse the condition of induction motor under various faulty conditions. From the analysis of the results we can conclude that more the severity of fault i.e. number of stator coils are open the different parameters that we have calculated such as Magnetic Torque, Static Current and Average Mechanical Power are increasing.

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