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Computational Design and Analysis of Three-Phase Induction Motor using Finite Element Method

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Abstract: The increment in the cost of electrical energy and relevant development in the material technology, operating cost and some other performance related items, promoted the designers to improve the performance of the induction motors. Three Phase induction motor plays key role in industrial and commercial sectors, because of their numerous advantages. This paper attempts to model an optimal three phase squirrel cage induction motor by changing the rotor winding configuration and keeping all other parameters i.e. stator/rotor slots area, number of stator/rotor slots, stator winding, stator/rotor core material etc. remains unchanged. This work investigates the influence of the rotor winding on the performance of the machine. Aluminum and Copper are simultaneously used as rotor winding material. A standard model of 3-phase induction motor has been taken and two different models are designed by changing the rotor winding configuration and simulated in Finite Element Method. The results have been compared to find out the best optimal model. The Finite Element Analysis software used is FEMM (Finite Element Method Magnetics).

Keywords: FEM, FEMM, 3-Phase Induction Motor, Motor Modeling, Motor Parameters

I. INTRODUCTION

After the increment in oil demand & cost of electrical energy and relative development in the material technology, designers of high efficiency induction motors have been paid more attention [2]. Electric motors are one of the most fundamental motion generation mechanisms in both industrial and household products. As such, they work often as noise and vibration generating sources as well. Although there are various types of electric motors, induction motors are most popular among them due to the low cost and ease of operation [5]. Three phase induction machines are commonly used in industrial and domestic applications because of its efficiency and cost effectiveness. These motors are easily portable. Proper and reliable operation of electrical machine results maximum financial benefit and highest energy efficiency in the industry. So parameter monitoring of the machine is very important in industry to detect and diagnosis the faults of an electrical machine at the earliest [6]. There are a lot of parameters on which the performance of induction motors depend. Small changes in these parameters make a big change in the performance of machine. These parameters are stator/rotor core, stator/rotor winding, stator/rotor slots, size & shape of slots, variation of slots etc. For a three phase squirrel cage induction motor, rotor bars shape optimization is frequently used to achieve certain working parameters or characteristics, such as increased starting torque, start-up current limitation, and higher efficiency for a specific speed. However, meeting all required specifications, in some cases, may be a very difficult and delicate operation, some compromises being necessary to be accepted [3]. The induction motor performance is affected by three types of faults such as electrical faults, mechanical faults and environmentally related faults.

Electrically related faults consist of unbalanced faults, under voltage faults, overload faults and earth faults. The rotor winding failure, stator winding failure and bearing faults are included in mechanically related faults. The external moisture, contamination in the ambient temperature also affects the induction motor performance. The faults due to these external variation and vibration faults are included in the environmentally related faults [6]. From the statistics, it is seen that about 10% of induction motor faults are located in rotor. Due to the rotor fault, the rotor is subjected too much lower voltage and higher temperature compared to the stator winding [6].

The total losses of induction motors may be taken as the sum of constant losses, which are core losses, friction and windage losses, and of load-dependent losses, which are stator/rotor winding losses and stray load losses [4]. The aim of this paper is to compare the results of two models with that of base model and investigate that which model is best optimal model. In the present paper, FEM is used as the main tool in the investigation of motor parameters and losses. FEMM (Finite Element Method Magnetics) software is used to analyze the performance of the induction motor with changing the rotor winding configuration.

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II. FINITE ELEMENT METHOD OF MAGNETICS

The finite element model of an induction motor is suitable in depth analysis of rotor fault condition. FEM is a numerical method for solving a differential or integral equation. It has been applied to a number of physical problems, where the governing differential equations are available. The method essentially consists of assuming the piecewise continuous function for the solution and obtaining the parameters of the functions in a manner that reduces the error in the solution. This powerful design tool has significantly improved both, the standard of engineering designs and the methodology of the design process in many industrial applications. The some benefits of FEM are increased accuracy, enhanced design and better insight into critical design parameters, virtual prototyping, fewer hardware prototypes, a faster and less expensive design cycle, increased productivity and increased revenue [6]. FEMM is a suite of programs for solving low frequency electromagnetic problems on two-dimensional planar and axisymmetric domains. The program currently addresses linear/nonlinear magneto static problems, linear/nonlinear time harmonic magnetic problems, linear electrostatic problems, and steady-state heat flow problems. By the use of FEMM we can easily find out the magnetic field distribution. The biggest advantage of FEMM is that it is free. Simplicity in control is another advantage. Unfortunately, the FEMM cannot work with complex three-dimensional models. It is only possible to extend or rotate around an axis of two-dimensional design. Work with the FEMM is similar to work with other finite elements method programs. Following steps have to be accomplished to complete solving problem successfully: geometrical model creation, materials definition, boundary definition and suitable mesh creation. Geometrical model can be created directly in FEMM, but drawing in FEMM is uncomfortable. Another possibility is to draw a geometrical model in a CAD program and download it into the FEMM. The FEMM contains a script language –the Lua script which could be very useful, hence it very simplifies solving of some complex problems [7].

III. FINITE ELEMENT MODEL

The particular motor of interest i.e. reference model is 2 HP motor running of a 220 Vrms line-to-line, 50 Hz, 3-phase supply. It is a 4-pole machine, implying that it will be running at slightly less than 1500 RPM. The winding configuration for one pole of the machine is shown in figure 1. There are 36 stator slots and 28 rotor slots. There are 44 turns inside each slot (*i.e.* so that a phase current of 1 A would place a total of 44 Amp*Turns in a slot). The rotor's diameter is 80 mm, and the air-gap between the rotor and stator is 0.375 mm. The stack length is 100 mm.

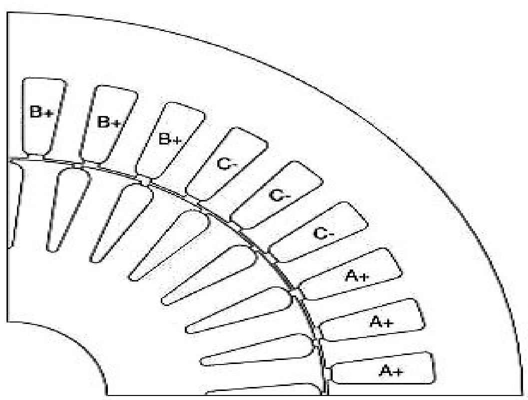

Fig.1. Example Induction Motor Winding configuration

Two types of models named model-1 & model-2 are simulated by changing the rotor winding configuration. The work is carried out to investigate the influence of the rotor winding on the performance of the machine. In the simulation work, two materials aluminum and copper are simultaneously used in the rotor winding to analyze the effects on the performance of the machine.

IV. SIMULATION WORK

In this work, two different types of the rotor winding configuration of the three phase squirrel cage induction motor are examined. The other specification like number of slot of stator and rotor, length and diameter of stator and rotor core, stator and rotor slot area, current and core material etc. are remain unchanged as in base model. The rotor slot area is 39.23 mm2. By changing rotor winding configurations, new models have been designed. There complete geometry is explained further.

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A. Dimension of slot configurations

The configurations of rotor slot for reference model, model-1 and model-2 are shown in figure 2.

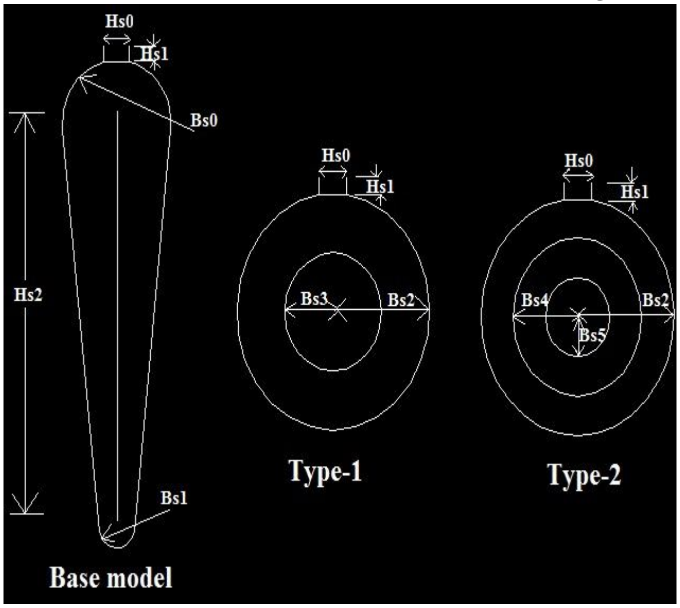

Fig. 2. Rotor slot configurations

The geometric parameters of rotor slots are given in Table 1.

TABLE I. ROTOR SLOT PARAMETERS

Parameter	Dimension(mm)
Hs0 (mm)	0.944
Hs1 (mm)	0.497
Hs2(mm)	12.046
Bs0 (mm)	2.00
Bs1 (mm)	0.63
Bs2 (mm)	3.532
Bs3 (mm)	1.767
Bs4 (mm)	2.356
Bs5 (mm)	1.178

B. Geometric parameters

Area is same in model-1 and model-2 as of reference model. However the slot configuration is changed. In model-1, the slot is of circular shape with two regions. The area of inner region is 9.7965 mm^2 and the area of outer region is 29.434 mm^2. In model-2, the rotor slot is circular with three regions. The area of inner region is 4.354 mm^2, area of middle region is 13.062 mm^2 and the area of outer region is 21.814 mm^2.

C. Rotor winding materials

Aluminum and Copper are used simultaneously in the rotor winding to analyze the effects on the performance of the machine. In base model, the material used is Aluminum. Whereas in model-1 the inner region is filled with Copper and outer region is filled with Aluminum. In model-2, the inner region is filled with Aluminum, middle region is filled with Copper and outer region is filled with Aluminum.

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V. FEMM MODEL

The base model, model-1 and model-2 are imported in FEMM software. Materials are assigned in the models. After run the mesh, the flux distribution can be seen as in figure 3, figure 4 and figure 5 respectively.

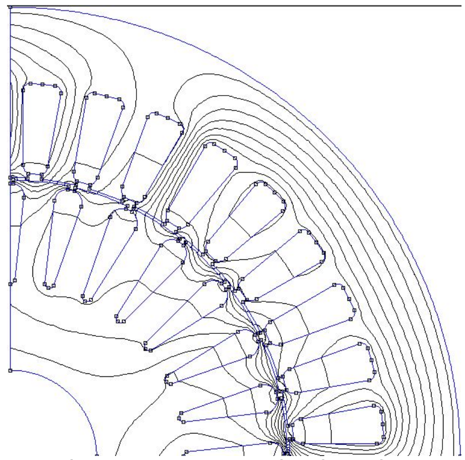

Fig.3. Plot of Real component of A for reference model

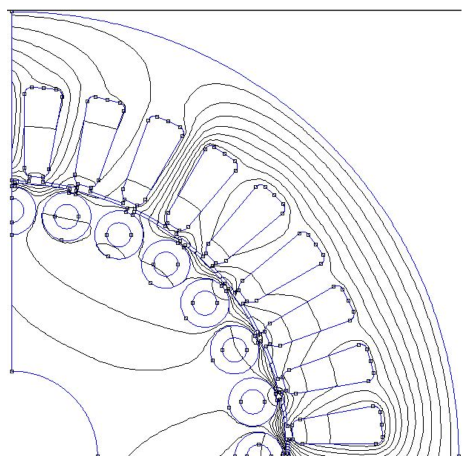

Fig.4. Plot of Real component of A for model-1

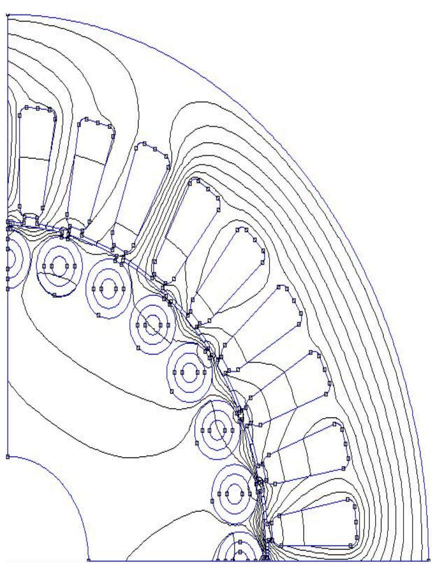

Fig.5. Plot of Real component of A for model-2

As shown in figure 3, figure 4 and figure 5 the flux distribution is differ model to model. The distribution of flux is sinusoidal between stator and rotor i.e. in the air-gap. Flux is as much as more sinusoidal the harmonics will be less and when harmonics are low then the loss will also be low.

VI. SIMULATION RESULTS

The performance of all three models is different to each other. The results are calculated in FEMM for one-fourth symmetry of the proposed model. In this paper, one-fourth symmetry is used for simplicity. So, the results are of one-fourth part of the machine. The results are shown in Table 2.

TABLE II. CALCULATED RESULTS

Parameters	Reference model	Model-1	Model-2
Total Losses	0.783 Watts	0.633 Watts	0.605 Watts
Total loss density	0.0285 W/mm^2	0.02313 W/mm^2	0.02209 W/mm^2
Voltage drop	1.456 V	1.271 V	1.264 V
Real power	0.266 W	0.214 W	0.205 W
Reactive power	0.677507 VAr	0.598115 VAr	0.59864 VAr
Apparent power	0.728 VA	0.635 VA	0.632 VA
Power factor	0.9306	0.9419	0.9472

VII. CONCLUSION

In present days, requirement of efficient motors is increasing day by day. Efficient motors save the energy and resources. The importance of efficiency and the race to improve efficiency remains important factor for the performance of the machine. In the present work, rotor geometry has paid attention on the performance improvement in the three-phase induction motor. Two types of models are simulated by changing the rotor winding configuration in base model and compare the results of these two models with that of base model. Keeping the parameters like as Stator/Rotor slot area, Stator/Rotor size, core material, stator winding unchangeable. Only slot configuration changed with winding material. Total losses are recorded less in case of model-2. Total loss density is recorded low in model-2 as compared to other models. Voltage drop is also low in model-2. Power factor is improved a little bit in case of model-2. So, by these comparisons it can be concluded that model-2 is best model compared to other. So, the efficiency will be improved by using the model-2 model configuration. Thus we can save a lot of energy by using these efficient models.

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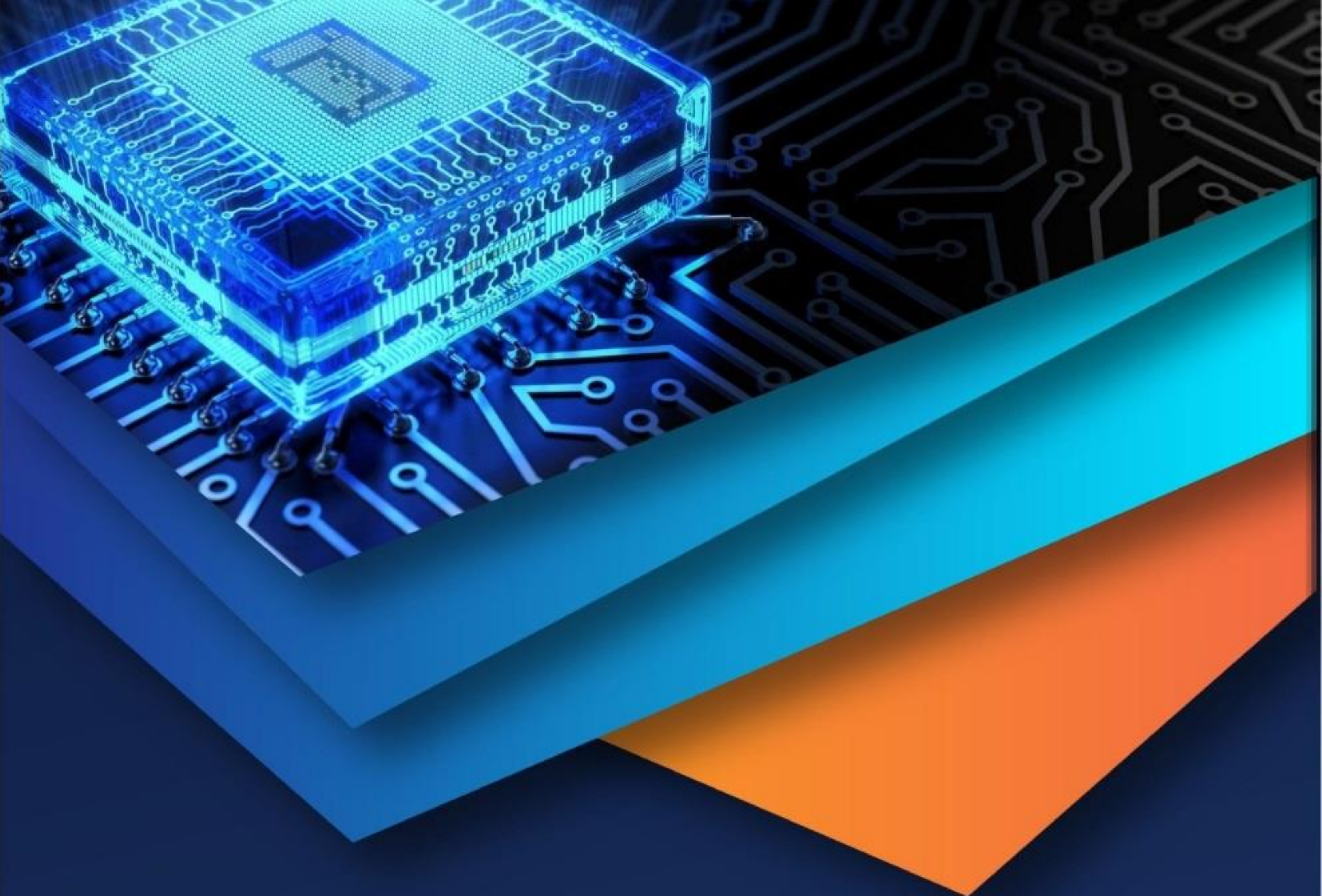

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