Core Loss Reduction In Induction Motor Using Finite Element Analysis

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***Abstract*— In this paper, we investigate the core losses of a 5.5kW induction motor under various operating conditions through Finite Element Simulation. The Finite Element Simulation of the motor was carried out in order to reveal the different indications of core losses. The core loss however is reduced by comparing the same motor in single layer configuration and double layer configuration. The result showed an improved core loss reduction in double layer winding configuration. It is clear that motor in double layer winding configuration, is more resistant to core loss, than the single layer winding.**

Keywords—— Core loss; Induction Motor; Finite Element; Single Layer; Double Layer

I. Introduction

Losses in electrical power generation, transmission and distribution as well as the accompanying appliances, such as electric motors demand significant attention from both power suppliers and users. The economic growth and development of any nation are intrinsically tied to the availability of energy [1]. Losses in power system and machines come in various forms. In [2], the input power to the stator windings is utilized in producing useful mechanical power which is exerted on the rotor, accounting for rotor copper losses. Availability of electricity is key for economic activities. Electricity power supply is the most important commodity for the development of a nation [3]. Access to a reliable electricity supply plays a pivotal role in empowering individuals and facilitating personal and economic development. Performance evaluation of asynchronous motor was conducted in [4]. However, it is imperative to consider and work on the structural analysis and geometry of Switched Reluctance Motors as discussed in [5].

The dynamic behaviour of six-phase induction motor was investigated in [6]. The core loss effect of the motor was considered in the investigation. Effect of Saliency and Core Losses on the Dynamic Behavior of Permanent Magnet Synchronous Motor as well as the Contingency Analysis for Improved Power System Stability, were carried out in [7,8]. Result showed an improved reduction in core loss and more stable power system. The Stability behaviour of Three Horse-Power Induction Motor by Eigenvalue. Also, Design and Implementation of Compliance Tests and Evaluation for a 37 kW Induction Motor based on International Standards was seen in [9,10]. Winding Reconfiguration of 5.5 kW Three-Phase Induction Motor for Improved Performance, in order to establish the effects of losses on both single-and double-layer configuration was analyzed in [11]. [12,13] worked on the dynamic analysis, computerization and response evaluation of both separately exited generator and permanent magnet synchronous motors. An impressive result was attained. Impact on structural dimensions as it affects induction motor performance, including losses was discussed in [14]. [15] opined that rotatory electrical machinery play vital role in industrial drive and economy. The paper developed strategy for optimization and future trends of field wound switching motors. FACTS controllers for power system compensation in order to drive industrial process, dominated by electric motors was successful [16]. Dynamic and computer simulation of induction motor for fault and performance analysis was of interest in [17]. Microgrid with focus on wind turbine and harnessing the potential of photovoltaic sources are important in losses consideration [18,19]. In [20], the accurate behavioral modelling of induction motor helps in designing controller for the machine and is also useful in detection of faults in machines. The rotor subsystem is expressed in qd coordinates and the stator subsystem is expressed in abc phase coordinates. Computer studies of an induction motor for Voltage-behind reactance model demonstrate the improvement in computational efficiency as compared with the qd or PD model. In this paper Voltage-behind-reactance model is developed in stationary reference frame using MATLAB-SIMULINK platform. The article also provided 3-phase induction motor design and VBR modelling of the induction motor. This model was helpful in estimating rotor flux connection, magnetizing flux connection, rear emf, thrust and machine speed. The recently proposed VBR model helps to achieve the required direct interface of the stator circuit with outside controllers also providing an improved numerical accuracy with reduced computational errors.

[21], specifically addressed the impact of induction motor load modeling. The paper proposes an induction motor dynamic modeling methodology based on advanced modeling capabilities. The goal is to

evaluate and determine the dynamic loading behavior. The article used d-q induction motor evaluation to describe the modeling strategy.

Implementation of modular Simulink model for induction machine simulation has been introduced. Unlike most other induction machine model implementations, with this model, the user has access to all the internal variables for getting an insight into the machine operation. Any machine control algorithm can be simulated in the Simulink environment with this model without actually using estimators. Individual parameter equations are solved in each block. Finally, the operation of the model is to simulate dynamic model of induction motor with torque and flux as independent quantities. The author believes that the Simulink will soon become an indispensable tool for the teaching and research of electrical machine drives.

[22], stated that the theory of reference frames has been effectively used as an efficient approach for analyzing the performance of the electrical machines. This paper presents a step-by-step Simulink implementation of an induction machine using stator and rotor equations in the stator reference frame. For this purpose, the relevant equations are stated at the beginning, and then a generalized model of a three-phase induction motor is developed and implemented. The main objective of this paper is to simulate the induction motor model in MATLAB/ Simulink and study the effect of speed, torque, stator and rotor currents on three phase induction motor performance characteristics. In the paper, an implementation and dynamic modelling of a three-phase induction motor with the use of MATLAB/Simulink are presented in step-by-step manner. The simulated result has given a satisfactory response in terms of the torque and speed characteristics. Further investigation will be on the simulation of induction motor model to determine the effect of saturation flux and effect of harmonics at supply side.

[23], provided a generic method created and explained in detail to investigate the dynamic behaviour of three-phase induction motor. Using basic function blocks found in MATLAB/SIMULINK software package, this model has been built up systematically. This model is described in similar but modular approach as in electrical machines theory. The motor model includes multi-level blocks solving equations for each motor part or component. This approach enables the researchers to calculate or investigate motor parameters like; voltage, current, flux, speed and torque. The model could also be used for a wide range of horse power needed in scientific research and numerical applications. A q-d axis-based model is proposed to analyze the transient performance of three-phase squirrel cage induction motor using stationary reference frame. Constructional details of various sub-models for the induction motor are given and their implementation in SIMULINK is outlined. Direct-online starting under different load conditions of a 3 hp induction motor (as a case study) is also studied. The motor stator voltage, the stator and rotor currents, the developed torque and rotor speed are numerically calculated and plotted for different operating conditions. Implementation of Simulink model for induction squirrel cage motor simulation was introduced. This model enables the users to have access to all the internal variables for getting an insight into the motor operation. It's available to investigate and predict the transient behavior of the three-phase induction motor using stationary reference frame. Using SIMULINK, the simulation systematically started from simple sub-models and blocks for the induction motor circuits and components.

II. METHOD

A. *FINITE ELEMENT*

Magnetic field is the principle upon which the design of electric machine is based and Maxwell equation gives the exact field distribution. Earlier the magnetic circuit or permeance (magnetic Ohms-law) method was used for calculating approximate magnetic fields in devices of simple geometry [20]. For more accurate calculations, however, finite element computer algorithms programs are necessary. The key limitation of the magnetic circuit method is that it requires assumption of the magnetic flux paths. The lengths and cross-sectional areas of all the paths must be known. Usually, the paths are assumed to consist of straight lines, which is erroneous to some extent. To calculate the effects of flux fringing, saturation, and leakage flux, one usually uses empirical correction factors. If a motor or other magnetic device has had essentially the same type of design for many years, then the empirical factors may be fairly well known.

Today's motor designers involve new design concepts, for which the flux paths and empirical factors are unknown. Even if the design is a well-understood older design configuration or concept, there is a great need for accurately determining the effects of geometric changes and saturation on motor efficiency and other performance parameters related to the magnetic field.

The Finite Element (FE) method is readily available in the laboratory in the form of a commercial computer software with the trade name "Ansys Maxwell". No flux routes or associated empirical variables are required for the software. This FE software correctly calculates magnetic fields and associated motor design parameters for complex machine geometry, with saturation, remarkable armature reactance, and with or without eddy currents.

B. *MATHEMATICAL PRINCIPLES OF MAXWELL 2D*

The technique of finite elements is focused on conservation of energy. It is well known that the flux density, B, the field intensity, H, the current density, J, the electric field, E, through the constitutive equations 1 to 3, are interrelated with each other [24].

$$B=\mu.H \quad (1)$$

$$H=v.B \quad (2)$$

$$J=\sigma E \quad (3)$$

Where σ is the material's magnetic permeability, v is the material's magnetic reluctivity and μ is the electrical conductivity of the apparatus in the conductive areas.

The law on energy conservation in electric motors can be obtained from Maxwell's laws as follows:

$$\nabla\times H=J+\partial D/\partial t \quad \text{(Ampere's law)} \tag{4}$$

$$\nabla \times E=-\partial B/\partial t+\nabla \times (vXB) \quad \text{(Faraday's law)} \tag{5}$$

$$\nabla . B=0 \tag{6}$$

Where D is the density/displacement vector of the electrical flux.

C. ANSYS MAXWELL SOFTWARE

Maxwell comes with various design types and the type is chosen based on the problem to be solved. These include;

(i) RMxprt: Rotating Machinery Expert, an integrated analytical instrument used in electrical machine design and analysis.

(ii) Maxwell 2D: Maxwell 2D simulates and solves 2D electromagnetic field problems in XY axis using Finite Element Analysis.

(iii) Maxwell 3D: Maxwell 3D utilizes Finite Element Analysis to analyze and resolve electromagnetic field problems in three dimensions.

D. Ansys RMxpt

The present study will lay emphasis on ANSYS RMxprt due to its efficiency in electrical machine design and analysis. Maxwell and RMxprt together generate a genuinely tailored machine design flow to satisfy market demand for greater effectiveness, and reduced motors cost. RMxprt can calculate motor efficiency, originate sizing decisions and replicate the device in a couple of seconds using classical analytical machines design and similar magnetic circuit techniques. RMxprt's capacity to build up a full Maxwell design (2D/3D) automatically includes design, content and boundary setting is a main advantage. The set-up includes the suitable symmetries and excitation for strict transient electromagnetic assessment with coupling circuit topology. In view of the nonlinearities and eddy current impact, RMxprt automatically produces a decreased model and transmits it to Maxwell 2D modeler, where further assessment of the electrical drive can be accomplished. RMxprt will be employed in this study to design and generate machine data.

E. Maxwell 2D

ANSYS Maxwell is an integrated software package with high performance that utilizes Finite Element Analysis (FEA) to fix electrical or magnetic issues. Finite components proved to be very solid and appropriate for the assessment of electromagnetics. Appropriate set of equations and their terms are used in the ANSYS Maxwell environment based on the selected solver such as electrostatics, magneto static, eddy current and magnetic transient.

F. Maxwell 3D

Maxwell 3D utilizes an assessment of finite elements to represent and fix electromagnetic field problem in three dimensions. When used, the end connections and leakage effect are considered. Maxwell 2D was used in this research work.

G. PARAMETERS OF 3-PHASE INDUCTION MOTOR

The machine data were extracted from an existing three phase squirrel cage induction machine. The pictorial view of the three-phase induction motor used for the research work is shown in fig.1.

Fig, 1: The Induction Motor [4]

For loss calculation, the total no load loss

$$P_o = P_{cu} + P_{rot} \tag{7}$$

$$P_{rot} = P_{FE} + P_{mech} \tag{8}$$

where P_{cu} = total copper loss

P_{rot}= rotational losses

P_{FE} = iron core loss

$P_{mech=}$ windage and frictional losses

III. RESULTS AND DISCUSSION

The results of this work are detailed under different conditions the machine was subjected to and these include no load condition, blocked rotor condition of the motor, rated load, asymmetrical fault on phase A and asymmetrical faults on phases A and B and these were performed on the single- and double-layer winding motors. The graphs are as generated during simulation in Maxwell 2D.

A. No load condition

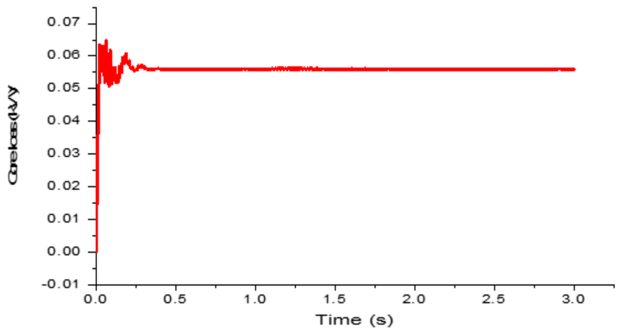

Figure 2: No load core loss of three-phase single layer winding

Figure 2 shows the core loss curve of the three-phase single layer winding induction motor. The core stabilizes at 57W on no-load.

B. Blocked Rotor Condition

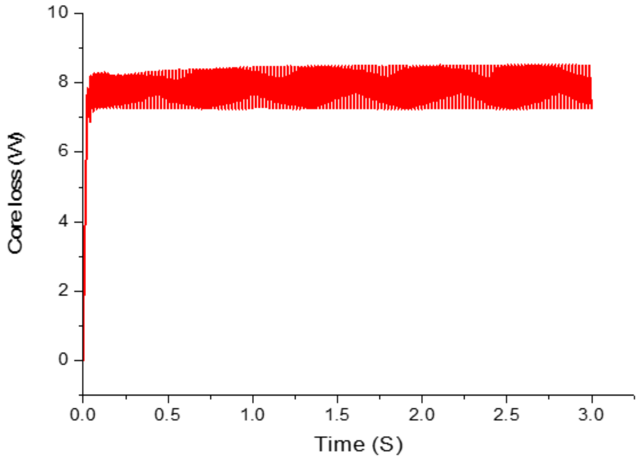

Figure 3: Blocked rotor core loss of three-phase single layer winding

Figure 3 shows the core loss curve of the three-phase single layer motor under blocked rotor condition. Since the rotor is blocked from rotating, core loss is approximately 8W.

C. Rated Load Condition

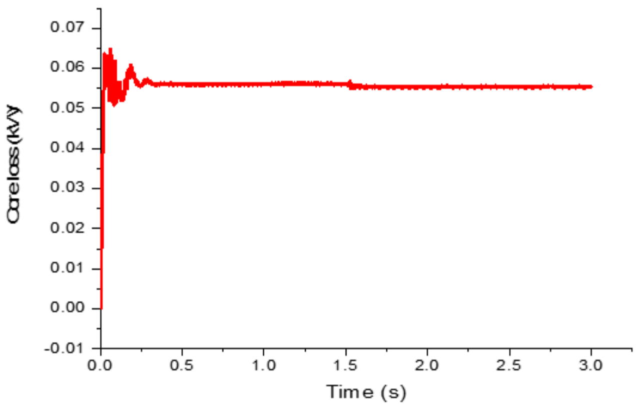

Figure 4: Rated load core loss of three-phase single layer winding

Figure 4 shows the core loss curve of the machine when rated load is applied at 1.5s. there is a reduction of core loss from 57W to 55W as the load is introduced.

D. Asymmetrical Faults Condition at Phase A

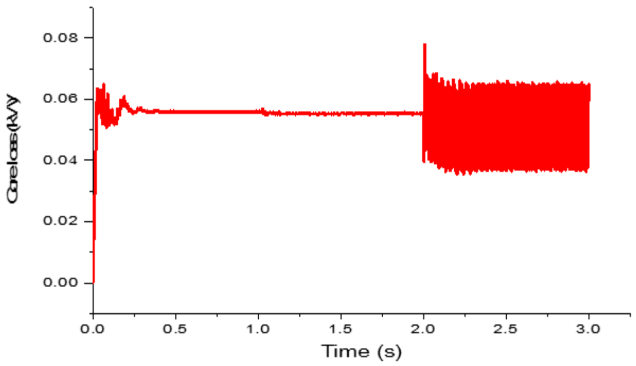

Figure 5: Core loss of three-phase single layer winding with asymmetrical fault at phase A

The core loss of the machine drops on loss of excitation as seen in figure 5.

E. Asymmetrical Faults Condition at Phase A and B

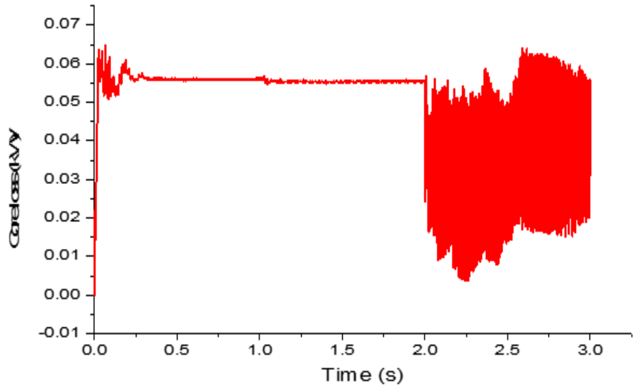

Figure 6: Core loss of three-phase single layer winding with asymmetrical fault at phases A and B

Figure 6 shows the core loss of the machine under the condition of loss of phases A and B voltage excitations.

F. No load condition

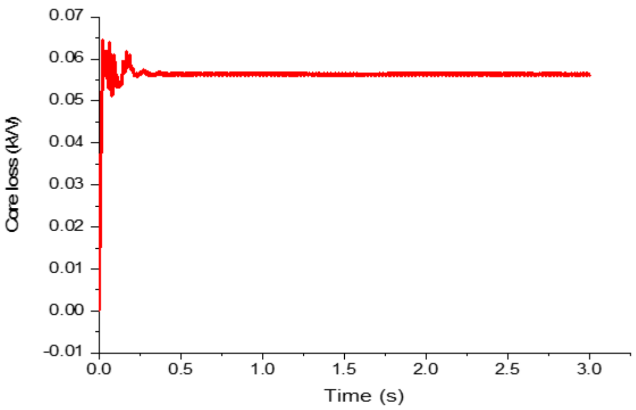

Figure 7: No load core loss of three-phase double layer winding

Figure 7 shows the core loss of the three-phase double layer winding motor. The no-load core loss is 56.6W.

G. Blocked Rotor Condition

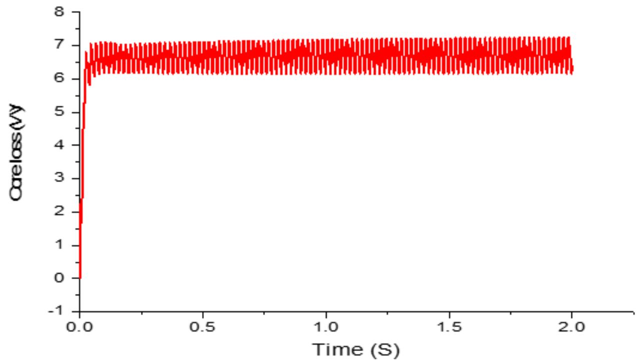

Figure 8: Blocked rotor core loss of three-phase double layer winding

The blocked rotor core loss is shown in figure 8. Since the rotor is not rotating, the core loss is 6.5W.

H. Rated load condition

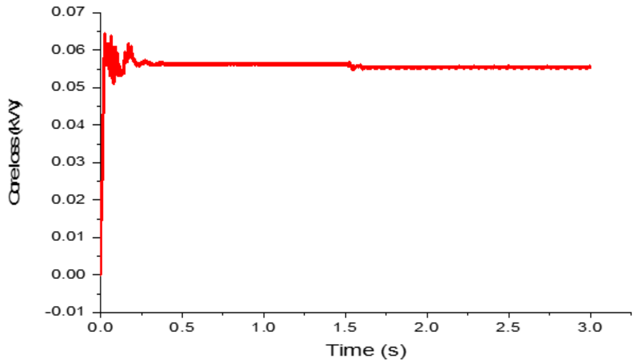

Figure 9: Core loss of three-phase double layer winding on rated load

Core loss as shown in figure 9, indicates a reduction from 56.63W to 55.4W on introducing the load at 1.5s.

I. Asymmetrical fault Faults Condition at Phase A

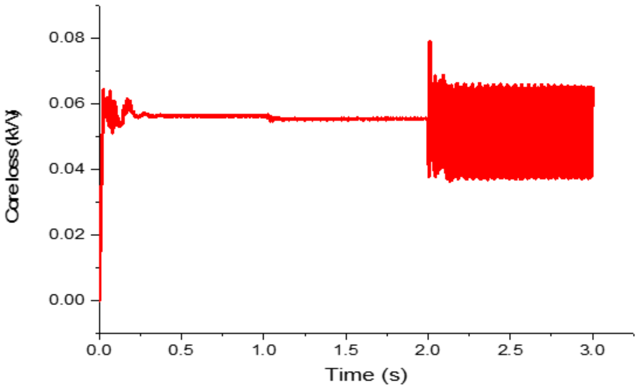

Figure 10: Core loss three-phase double layer winding with asymmetrical fault on phase A

The effect of loss of excitation of phase A on core of the motor is presented in figure 10. It shows further reduction with more ripples

J. Asymmetrical fault Faults Condition at Phase A and B

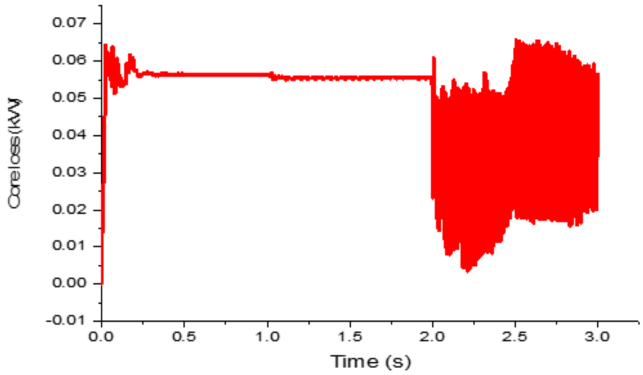

Figure 11: Core loss of three-phase double layer winding with asymmetrical fault on phase A and B

Figure 11 shows the curve of the core loss of the three-phase double layer winding motor on loss of phases A and B excitation voltage at 2.0s. The curve is unstable, though reducing. The summary of the performances of the core loss is shown in table 1. It has the induction motor in the two configurations and core loss analysis at their transient conditions.

Table 1: Core loss Performance at Different Condition

Condition	Single layer winding	Double layer winding
No load	57W	56.6W
Blocked rotor	8W	6.5W
Rated load	55W	55.4W
Asymmetrical fault at phase A	45W	45W with less ripples
Asymmetrical fault at phase A and B	35W	34W with less ripples

CONCLUSION

In the study, it was seen that the core loss analysis is performed under different condition of the three-phase motor. The three-phase induction motor was analyzed in its single layer winding and double layer winding configurations. The no load, blocked rotor, rated load, asymmetrical faults at phase A and asymmetrical faults at phases A and B were considered in both configurations. The result showed improvement in double layer winding configuration than single layer winding configuration.

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