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Design and Simulation of Dual Rotor Induction Motors for Core Loss Determination.

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Abstract

Dual rotor induction motors offer significant advantages in terms of torque density, efficiency, and power factor compared to conventional single rotor designs. However, the determination and minimization of core losses in such motors remain critical challenges, particularly as core losses directly impact overall motor performance and energy efficiency. This paper focuses on the design and simulation of dual rotor induction motors to accurately determine core losses under various operating conditions. Using advanced modeling techniques and simulation tools such as Finite Element Analysis (FEA) and the computational capacity of Ansys Maxwell 2D, the research had analyzed the effects of different design parameters, such as rotor geometry and material properties, on core losses. The goal is a developed optimized dual rotor induction motor design that minimizes core losses while maintaining high performance. The results showed that the core losses of the selected motor affected its performance at varied proportions. When the core losses were at 50%, the speed and output power of the motor was 92%. When the core losses were 100%, the motor overall performance dropped from 92% to 45%. This difference in performance index showed that when the core losses of three phase induction motor are not properly handled or eliminated, then the motor will not perform maximally to meet its expectations. These results have contributed to the development of more efficient dual rotor induction motors, with potential applications in industries requiring high-performance electric machines.

Keywords: Induction Motor, Dual Rotor, Fault Detection, Simulation and Core Losses.

I. INTRODUCTION

According to [1] in modern times the demand for smart output from industries cannot be underestimated hence the need for available machineries that are capable of performing its required task, thus, breakdowns or regular down times due to inefficient equipment and damages are avoidable factors but in most instances these challenges that appears to be avoidable are more or less very destructive in our industries. Unexpected down times and breakdowns are everywhere hence the required outputs are seriously affected. Induction machines have been in use over the years [2]. Commonly used are the single cage types due to its ruggedness, dust proof, portability and low cost of maintenance [3]. Considering the Induction Machine (IM) as a very common but robust machine used in our industries, though it is very rugged and strong, hence, other circumstances like rotor breakage, flux leakage, poor starting torque, high starting current and no speed regulation are the limitations of the single cage rotor induction motors, hence its continuous use is affected [3]. Trying to fix this problem commonly faced by the single rotor induction motor has resulted to the design and use of the Dual Cage Rotor Induction Motor. However, from available research recently carried out on modeling and simulating of induction motors, it is shown that the effectiveness of the induction motor depends on the ability to analyze and simulate for double cage rotor induction motor performance parameters [4]. The design of this motor is to solve the problem or limitations inherent with the single cage induction Motor (IM). Over a short period of usage, the DRIMs have proved to be more reliable and durable, hence unexpected leakages of flux and breakdowns are greatly reduced [5]. It is against this background that the need for the modeling and simulation of the dual cage rotor induction motor is birthed. This research will be investigating the transformational process that makes the dual cage rotor design more acceptable than the ordinary IM and its associated core losse [6]. This research had put into considerations the design and construction of the DRIM, the frequency and operating speed of the DRIM the comparison between the ordinary IM are the DRIM, as well as it cost and overall advantages. The transformational equation from the electrical

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angle to the dq parameters and its overall applications and limitations. Induction machines are divided into single phase, two phase or three phase induction and each of this category is subdivided into its various forms depending on its designs and modifications [7].

Basically, there are two types of rotors commonly in use with induction motors [8]. These rotor types are the squirrel cage rotor and the wound type rotor. Laminated iron cores with slots uniformly placed are used for designing the squirrel cage rotor, but these slots are not made of iron like the rotor but of aluminum bars. This rotor is made up of two rings at each end with the aim to short circuit the bars [9]. These types of arrangement have some reasons which could be discussed much later in this work. On the other hand, instead of the wound rotor having aluminum bars in its slots, it has copper windings just like the stator 10]. There could be a reason behind this type of arrangement which may be discussed later. Slip rings are used to connect these windings from the motor brushes in order to create the machine output. Each of the connected winding is to each phase of the motor. The purpose of contacting the motor brushes is to enhance variable resistance control of the starting current and speed control of the machine [11]. Though both rotors are very essential in industrial use of the induction machine, the advantages of the squirrel cage rotor over the wound rotor makes it of more use frequently. It is very simple in design, slip rings and brushes are absent and it is very cheap for maintenance [12]. With the new revolution in the automobile industries globally, most manufacturers of cars started the massive production and sale of their electric vehicles (EV). This kind of car has a driving system which is powered by Electrical Machines instead of the conventional fossil fuel. Taking a look at the works of [13], this type of drive system has been published by many scientists globally stating the kind of electrical motor used in Electrical Vehicles. In the same vein, [14], also supported the claims. Single motor drive system mechanism is very common in nowadays automobiles associated with a mechanical differential (MD) gear system. Less frequently in use are the multi-motor (in-wheel hub motor). The electronic master controller is used to implement the mechanical differential of the multi-motor drive system as pointed out by [15]. The mechanical differential gear is applied as the dual rotor machine (DRM). Both induction machine and the synchronous machine can be possibly used to make the electrical mechanical differential (EMD) [16]. It is very common nowadays to see published papers on dual rotor induction motor showing the motor structure with its wound stator and its two rotors apparently [17]. The rotors would have been linked to each other but they are carefully separated from each other by two air gaps. This implies that each rotor has an accomplished air gap. But for the purpose of this research, the dual cage rotor induction motor presented here has only one air gap and two rotors (wound rotor and caged rotor) excluding the wound rotor [18-20].

II. METHODOLOGY

The method employed to make this paper a reality is the Finite Element Analysis with the integration of Ansys Maxwell 2D tools. It covers the design, modeling and simulation of double cage rotor induction motor with considerations to its specified motor parameters. Ansys Maxwell 2-D software is used to analyze double cage rotor induction motor. The simulated results are presented in different graphical plots corresponding the simulation time.

The following are the steps taken to achieve the objective of the study:

i. Development of the motor parameters for dual cage rotor induction motor
ii. Simulation of the double cage rotor induction motor parameters
iii. Simulation of the single cage rotor induction motor parameters
iv. Comparison of simulated results/plots between the single cage rotor and double cage rotor induction motors.

Model Equations

Electrical Model

$$\bar{V}_s = R_s\bar{\iota}_s + d\bar{\lambda}_s/dt + jwe\bar{\lambda}_s$$
$$O = R_{r1}\bar{\iota}_{r1} + d\bar{\lambda}_{r1}/dt$$
$$O = R_{r2}\bar{\iota}_{r2} + d\bar{\lambda}_{r2}/dt \qquad (1)$$

$$\bar{\lambda}_s = L_s i_s + L_{m1}\bar{\iota}_{r1} + L_{m2} i_{r2}$$
$$\bar{\lambda}_{r1} = L_{m1}\bar{\iota}_s + L_{r1} i_{r2} + M_{rr}\bar{\iota}_{r2}$$
$$\bar{\lambda}_{r2} = L_{m2}\bar{\iota}_2 + L_{r2} i_{r2} + M_{rr} i_{r2}$$
$$T = PL_{m1}(\bar{\iota}_{r1} \times \bar{\iota}_s) + PL_{m2}(\bar{\iota}_{rr} \times \bar{\iota}_s) \qquad (2)$$

This can be represented as electrical sub-model in (4).

$$\begin{bmatrix} Vd_s \\ Vq_s \\ Vdr_1 \\ Vqr_1 \\ Vdr_2 \\ Vqr_2 \end{bmatrix} = \begin{bmatrix} R_s & & & & & \\ & R_s & & & R_{rc} & \\ & & R_{r1}+R_{rc} & & & \\ & & & R_{r1}+R_{rc} & & R_{rc} \\ & R_{rc} & & & R_{r2}+R_{rc} & \\ & & & R_{rc} & & R_{r2}+R_{rc} \end{bmatrix} \begin{bmatrix} id_s \\ iq_s \\ idr_1 \\ iqr_1 \\ idr_2 \\ iqr_2 \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \lambda d_s \\ \lambda q_s \\ \lambda dr_1 \\ \lambda qr_1 \\ \lambda dr_2 \\ \lambda qr_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ -w_r\lambda qr_1 \\ w_r\lambda qr_1 \\ -w_r\lambda qr_1 \\ w_r\lambda dr_2 \end{bmatrix} \quad (4)$$

Where

$$\begin{bmatrix} \lambda d_s \\ \lambda q_s \\ \lambda dr_1 \\ \lambda qr_1 \\ \lambda dr_2 \\ \lambda qr_2 \end{bmatrix} = \begin{bmatrix} Ll_s + L_m & 0 & L_m & 0 & L_m & 0 \\ 0 & Ll_s + L_m & 0 & L_m & 0 & L_m \\ L_m & 0 & Ll_{r1} & 0 & L_{mr} + L_m & 0 \\ 0 & L_m & 0 & Ll_{r1} + L_m & 0 & L_{mr} + L_m \\ L_m & 0 & L_{mr} + L_m & 0 & Ll_{r2} + L_m & 0 \\ 0 & L_m & 0 & L_{mr} + L_m & 0 & Ll_{r2} + L_m \end{bmatrix} \begin{bmatrix} id_s \\ iq_s \\ idr_1 \\ iqr_1 \\ idr_2 \\ iqr_2 \end{bmatrix} \quad (5)$$

Equation (1) represents the voltage performance in the rotor and stator of the dual cage rotor induction motor.

Flux linkage equation

$$\begin{bmatrix} \lambda_{qs} \\ \lambda_{ds} \\ \lambda_{0s} \\ \lambda_{qr} \\ \lambda_{dr} \\ \lambda_{0r} \end{bmatrix} = \begin{bmatrix} x_{ls} + x_m & 0 & 0 & x_m & 0 & 0 \\ 0 & x_{ls} + x_m & 0 & 0 & x_m & 0 \\ 0 & 0 & x_{ls} & 0 & 0 & 0 \\ x_m & 0 & 0 & x_{lr} + x_m & 0 & 0 \\ 0 & x_m & 0 & 0 & x_{lr} + x_m & 0 \\ 0 & 0 & 0 & 0 & 0 & x_{lr} \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{0s} \\ i_{qr} \\ i_{dr} \\ i_{0r} \end{bmatrix} \quad - (6)$$

System Modeling Process

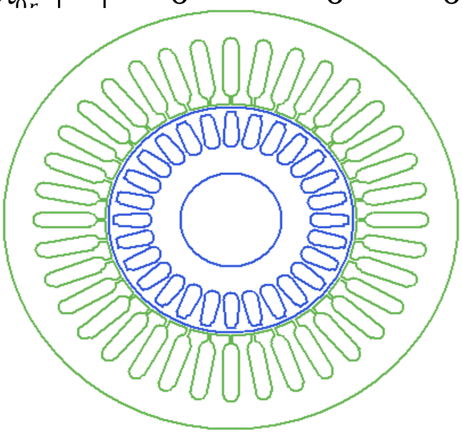

Figure 1: Motor Stator Model

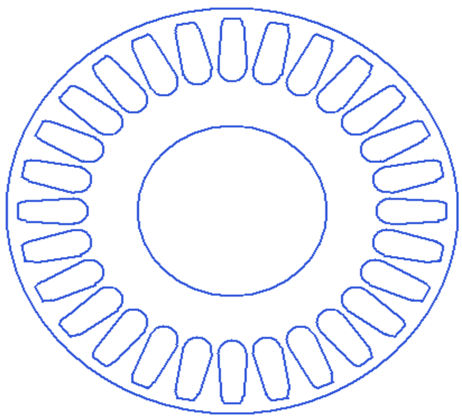

Figure 2: Motor Rotor Model

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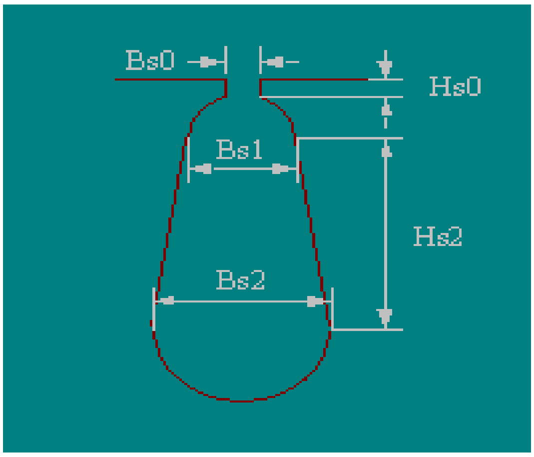

Figure 3: Motor Slot Model

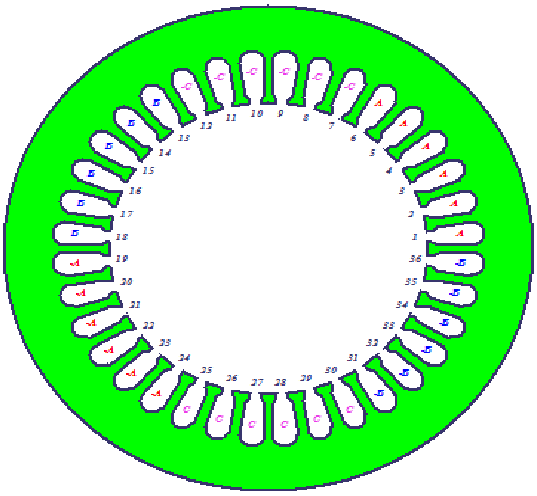

Figure 4: Motor Windings Model

III. Results and Discussion

The simulated results from the Maxwell 2-D for dual cage rotor induction motor. The emphasis is laid on the core losses in the windings of the motor. The parameters of the motor were used for the simulation. The Finite Element Analysis were done with the aid of Maxwell 2-D from Ansys systems. Different parameters were considered in the simulation. Plots of motor winding core losses, operating torque, motor speed, phase current, motor flux, output power performance, motor reactance, power factor are presented.

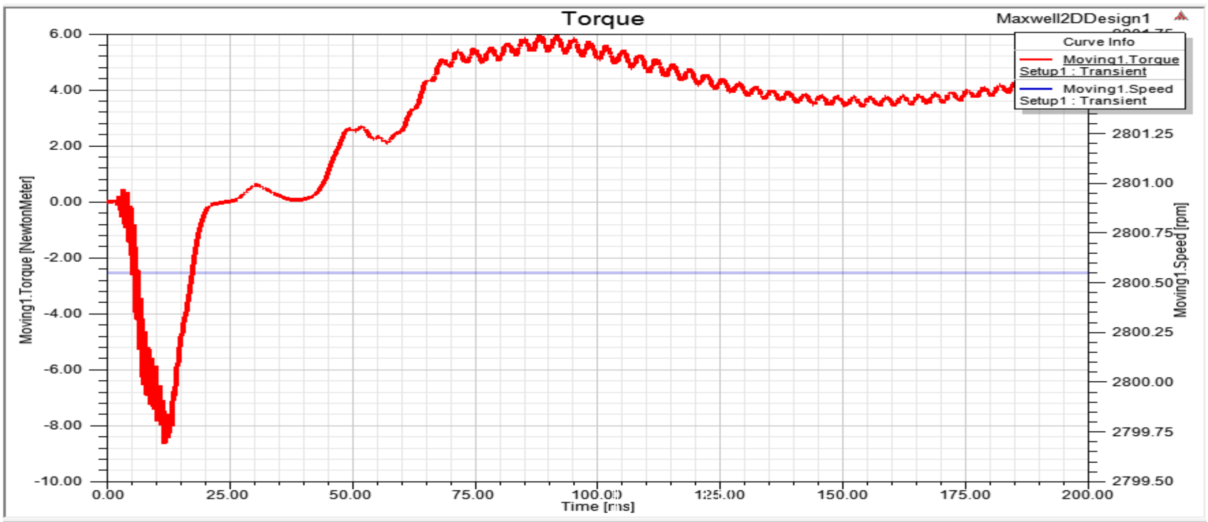

Figure 5: Motor Torque

In figure 5 the simulated torque of the dual cage rotor. The torque started at point 0.0 and retrogressed to point -8.00 and picks progressively to point 6.00 and thus maintain stability throughout the entire process. This movement of the torque clearly indicates the physical property that distinguishes the dual cage rotor induction motor that it has a high starting torque with low starting current. This torque took 200ms to build up. This time frame is ideal.

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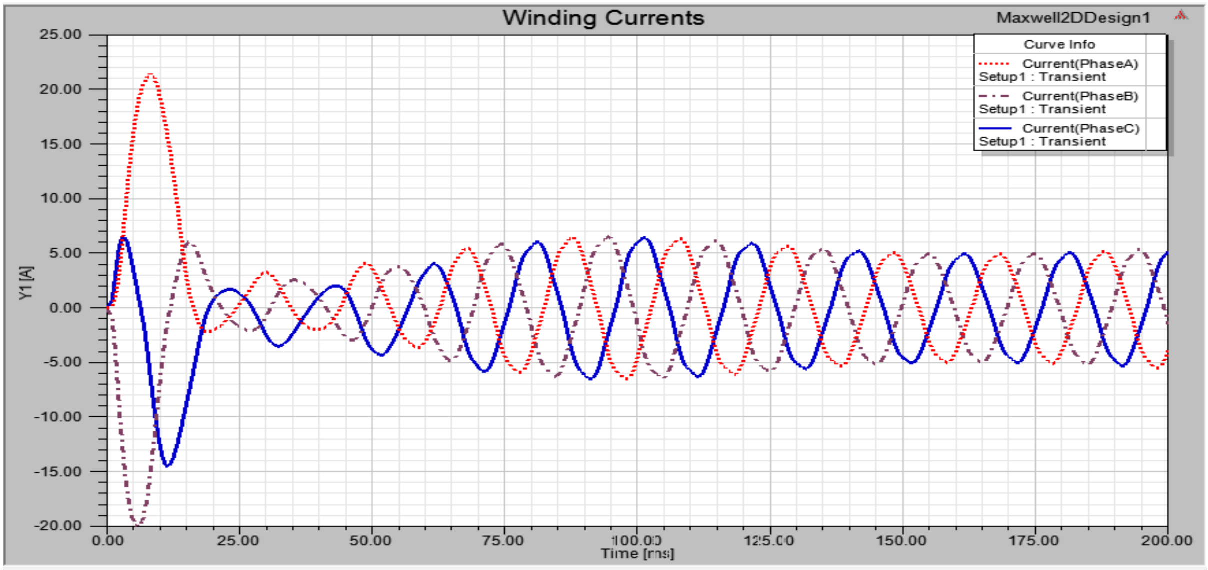

Figure 6: Transient Currents

In figure 6 the simulated transient winding current of phase A,B&C for the dual cage rotor induction motor. The three phase winding currents are in electrical angle of 120 degrees to each other at a frequency of 50Hz. The currents started at point 0.0 and progressed stuntedly to point 5.00. From this point, the current gained stability and progressed uniformly to the end of the running process.

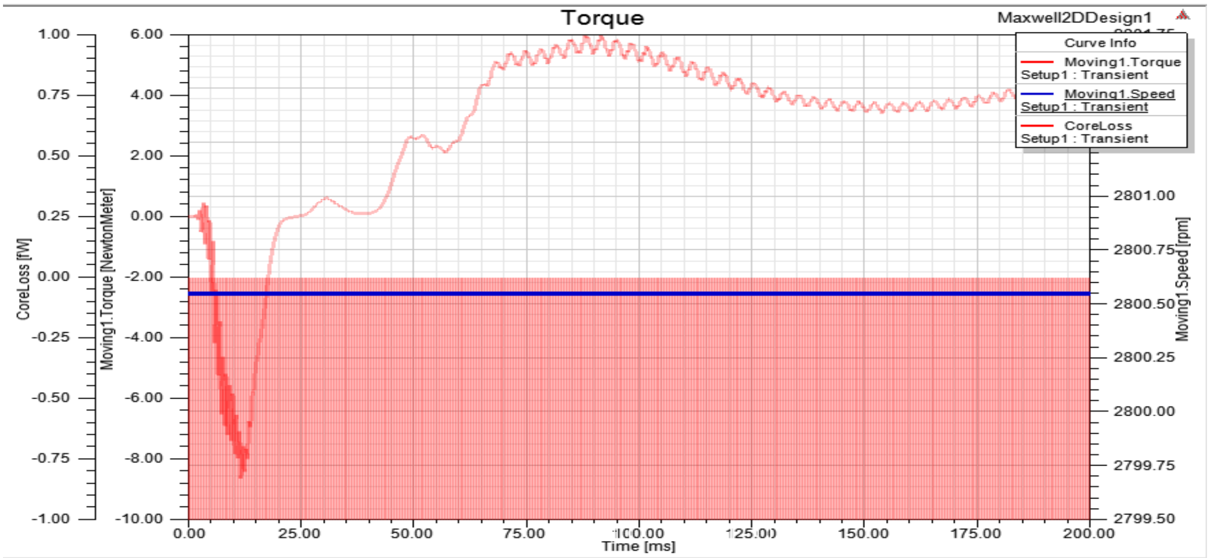

Figure 7: Speed, Core Losses and Transient Response

In figure 7, the simulated core losses of dual cage rotor induction motor. The losses occurred at point 0.00 and progresses down to -1.00. This is due to the armature resistance at the windings of the motor. The minus sign indicate losses in the system. At this affected region, the effect is only 50%. This core losses at this point are still manageable and easily detected while the motor is in operation.

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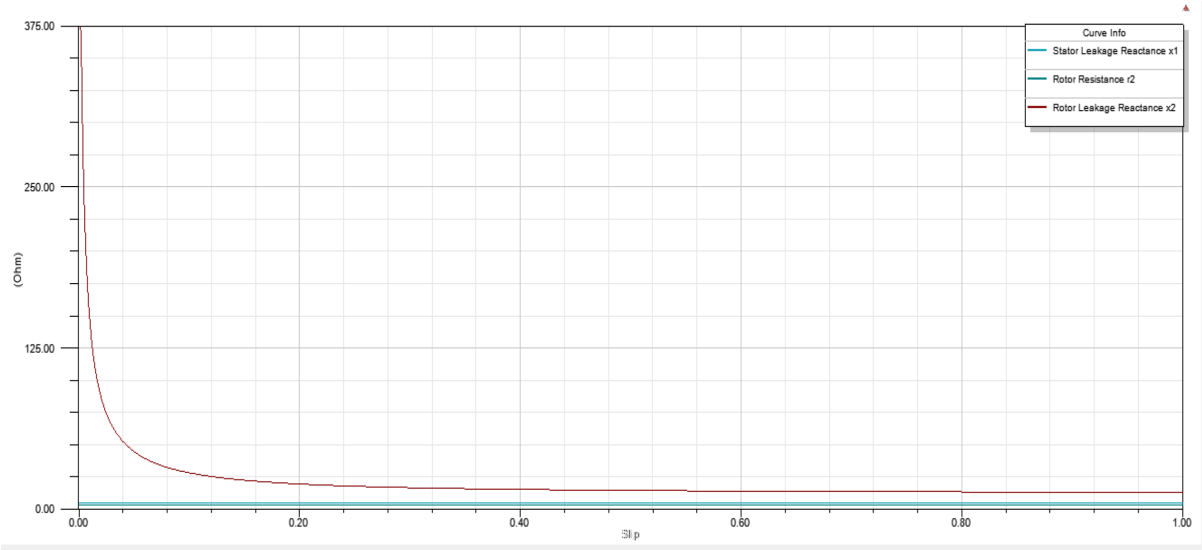

Figure 8: Motor Reactance

In figure 8 the reactance of the double cage rotor induction motor. It shows the three phase reactance. Due to the balanced operational condition for the double cage rotor induction motor, the reactance in phase A, reactance in phase B and reactance in phase C all are mutually distributed in the motor windings.

IV. CONCLUSION

The finite elements analysis (FEA) method was used to implement it. Simulation tools used are Ansys Maxwell software. The simulation results of the ordinary induction motor model and that of the dual cage rotor model were compared, From the Simulation results verification, it is discovered that DRIMs offer high starting torque and low starting current and there is consistency between the DRIM model and the selected Single cage rotor induction motor parameters in terms of the torque response, changes uniformly over the range, the phase current maintained stability as torque changes and then drops completely, the output power performance increases uniformly all through the operation of the motor , the operating current windings decreases during the process and across phase A, B and C. From the results, it can be ascertain that simulating induction motors especially the dual cage rotor type of motor is more precise with the use of the Ansys Maxwell 2-D tools due to its electromagnetic influence. This more reliably when it is modeled to obtain core losses of the motor. The plots are best obtained and interpreted to indicate the effect of core losses in a three phase induction motor.

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