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A Comparative Analysis of Three Phase Induction Motor Performance Evaluation

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Abstract:

Induction motor is a veritable machine in the industries today, since is the most widely used electric motor in the industry. It offers a reasonable performance, manageable torque/speed characteristics and a better efficiency. The aim of this paper is to examine a comparative analysis of a three phase induction motor for performance evaluation. The computer simulation and experimental methods were used to carry out the investigations, validation and evaluation of the behavioural characteristics of the machine. The simulation and experimental results obtained were compared to validate the results obtained from the experimental method. It was shown that the results from the simulation and experimental methods were in agreement with the theoretical values of the three phase induction motor. Thus, the results indicated that the relative errors were negligible and the proposed simulation models accurately predict the equivalent circuit parameters of the induction motor.

Keywords — **Induction Motor, Experiment, Simulation, Evaluation, Characteristics and Performance.**

1.0 INTRODUCTION

Electricity is a particularly attractive form of energy that can be easily produced, transmitted and converted into other form of energy [1]. The commonest form of energy into which electricity can be converted is mechanical energy (driving energy) and, more than 60% of electrical energy produced is utilise in this way [1]. The conversion of energy from its electrical to mechanical form is achieved using electric motors, especially the induction motor in the industries [1]. The vast bulk of industrial electric motors are used to drive pumps, fans and compressors [1]. All the industrial installations, whether manufacturing units or complex process plant are driven by electric motors which often time is induction motor biased.

The induction motors are veritable devices in the industries today, as they are used to carry-out various tasks in the industries. The three phase induction motor has been the workhorse for industrial and manufacturing processes [2]. The induction motor is the most widely used type of electrical machine in the industries today because of its robustness, reliability, low cost, high efficiency and good self - starting capability [3]. The application of induction motor in the industries and manufacturing companies today cannot be overemphasize which range from food & beverages, metal processing, textiles and utilities to domestic appliances [4]. Consequently, induction motors are the wheel of industries and manufacturing companies. Hence, the selection of the right type of electrical machine for application and duty in the industries and the correct installation and maintenance of the machine are as important as the machine design itself [1]. For reliable performance, the exert motor must be selected for the right application, the choice of motor type is largely determined by the rating and whether fixed or variable speed is necessary [1]. Induction motors can be generally classified into two classes: (1). Alternating Current (A.C) supply motor and (2). Direct Current (D.C) Supply Motor. The A.C supply motor can be further classified into: (1). Single Phase Supply Induction Motor (2). Three Phase Supply Induction Motor.

Induction machines are mostly used in motoring mode. So detail information about equivalent circuit, losses and efficiency are available for motoring mode. There are many methods for calculating the efficiency of induction motor. The equivalent circuit parameters, losses and efficiency of induction motor can be calculated from the No load test, Blocked rotor test, DC test and Load test [5].

This paper will concentrate on the three phase supply induction motor to evaluate it performance characteristics in a comparative analysis method.

1.2 PERFORMANCE ANALYSIS OF THREE PHASE INDUCTION MOTOR

When new motor is purchased, complete tests can be conducted to verify their performance and integrity [6]. The user's experiences, motor size, motor voltage etc. There are many standards regarding testing of induction motors, standards such as NEMAMGI, IEEE 112, IEC 60034 - 01 and 02, API 541 and IEEE 841 make recommendation as to what tests are required and how they should be performed [6]. There are many different specified methods to performance test on induction motors, all requiring that the motor be loaded [6]. The different test methods do not necessarily produce the same results.

Induction motor is a classical asynchronous machine and mostly used due to its better performance than other electric motors [5]. Squirrel cage induction motors are used more due to some advantages like cheap, robust and low maintenance [5]. Induction motor performance depends on rotor resistance, air gap length, shape of both stator and rotor slots. One of the objectives of this paper is to discuss about the performance and operating characteristics of the induction motor and the factors affecting them [5].

1.3 MATERIALS AND METHODS

In this paper, two methods were adopted, the experimental method and the computer simulation method. In the experimental method, the stator winding resistance was measured with an Ohmmeter, the block rotor test and no load test were carried out. The equivalent circuit parameters obtained were use for the computer simulation method, the computer simulation method predict the circuit parameters of the machine. The models used for predicting the circuit parameters were used for simulating the load test and various operating characteristics of the machine and results were obtained.

1.3.1 MATERIALS

1 No. of Squirrel Cage Induction Motor, 1 No. of Three Phase Wattmeter, 3 No. of 5A Ammeter, 1 No. of 400V Voltmeter, 1 No. of Power Supply Module (Variac)

Machine Parameters:

Machine Rated Power: 1.1 kW, Machine Rated Voltage: 380V, Machine Rated Current: 2.6A, Machine Rated Frequency: 50Hz, Machine Rated Speed: 1400rpm, Number of poles: 4, Type of Connection: Y-connected.

1.3.2 METHODS APPLIED

1.3.2.1 EXPERIMENTAL METHODS

On the basis of the above method, it is clear that the performance evaluation for three phase induction motor is evaluated and these tests are carried out to give the correct informations regarding the induction machine, this gives the importance of these parameters to have certain characteristics that has been obtained to carried out the analysis of the machine performance [7].

1.3.2.2 EXPERIMENTAL DETERMINATION OF EQUIVALENT CIRCUIT PARAMETERS

For the purpose of this research paper, three tests would be conducted, DC Test, Block Rotor Test and No - Load Test.

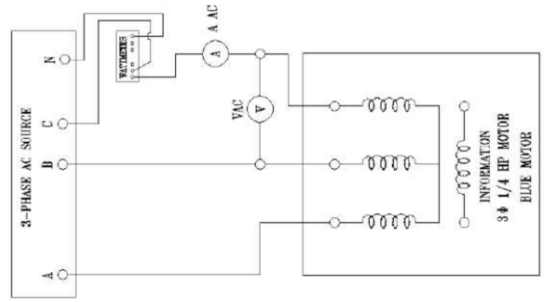


Figure 1: Connection Diagram for No - Load and Block Rotor Experiment

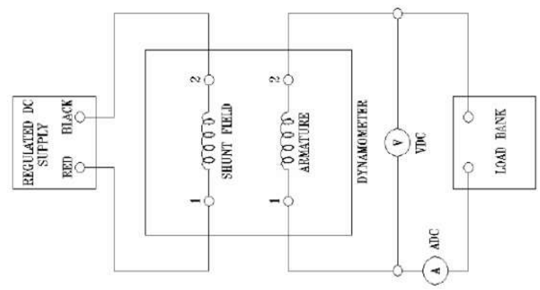


Figure 2: Connection Diagram for DC Test Experiment.

It is possible to find the parameters of the equivalent circuit of the three phase induction motor experimentally as shown in Figure 3 below.

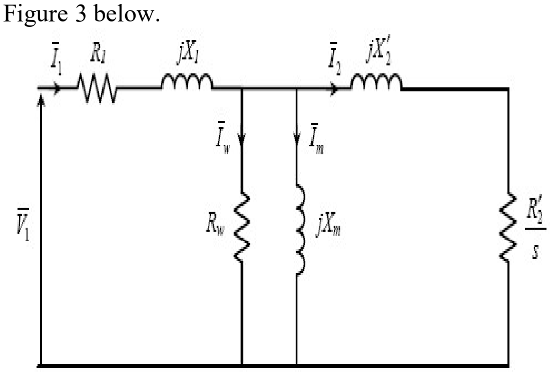


Figure 3: Equivalent circuit of three phase Induction Motor.

1.3.2.3 The DC Experimental Test:

The DC resistance of the stator can be measured by applying DC current to the terminals of the winding of each phase and taking the reading of the voltage and the current (or using ohmmeter), and determine the DC resistance as follows:

$$R_{iDC} = \frac{V_{iDC}}{I_{iDC}}, \qquad \text{.........................} \ 1$$

Where i represents the number of winding i (i = 1, 2, 3). After that, the average of the readings can be calculated as:

$$R_{DC} = \frac{R_{1DC} + R_{2DC} + R_{3DC}}{3} \quad \text{......... 2}$$

Then, the AC resistance is given by:

$$R_1 = 1.15\ R_{DC} \quad \text{............. 3}$$

1.3.2.4 The Locked Rotor Test

When the rotor is locked (i.e. prevented from running), *S (slip)* is equal to 1. The secondary impedance becomes much less than the magnetizing branch and the corresponding equivalent circuit becomes that of Figure 4. The readings that were obtained from this test are as follows:

a) Three phase power $P_{3\phi\_BL}$ 4

b) Line voltage: V_{L_BL} 5

c) Line current: I_{BL} 6

From these readings, the per phase values of the power P_{BL} and phase voltage V_{BL} can be obtained as follows:

$$P_{BL} = \frac{P_{3\phi\_BL}}{3} \quad \text{........................ 7}$$

$$V_{BL} = \frac{V_{L\_BL}}{\sqrt{3}} \quad \text{......... ....8}$$

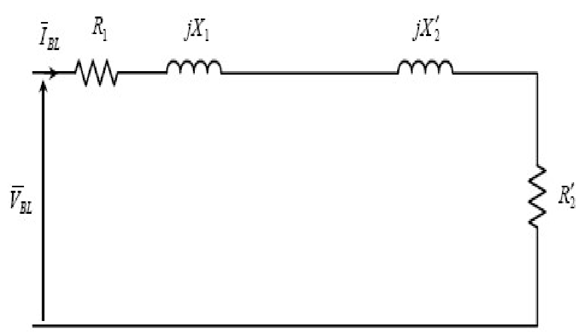


Figure 4: Approximate Equivalent Circuit for the Locked Rotor Condition

Then, R_{eq}, Z_{eq} and X_{eq} can be obtained using the following equations:

$$R_{eq} = \frac{P_{BL}}{I_{BL}^2} \quad \text{............. 9}$$

$$Z_{eq} = \frac{V_{BL}}{I_{BL}} \quad \text{............10}$$

$$X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2} \quad \text{......... 11}$$

The separation of X_1, X_2^1, R_1 and R_2^1 can be done as follows:

$$X_1 = X_2^1 = 0.5Xeq \quad \text{........ 12}$$

1.4.2.3 Experimental Test of No Load

When the induction motor runs at no load, the rotor speed approaches the synchronous speed. The slip becomes very small in this case. Accordingly, the secondary impedance becomes high compared with the magnetizing branch; the equivalent circuit can be approximated by that of Figure 5.

The readings to be obtained from this test are as follows:

a) Three phase power $P_{3\Phi\_NL}$

b) Line voltage V_{NL_L}

c) Line current I_{NL}

From these readings, the per phase values of the power P_{NL} and phase voltage V_{NL} can be obtained using equation 7 and equation 8.

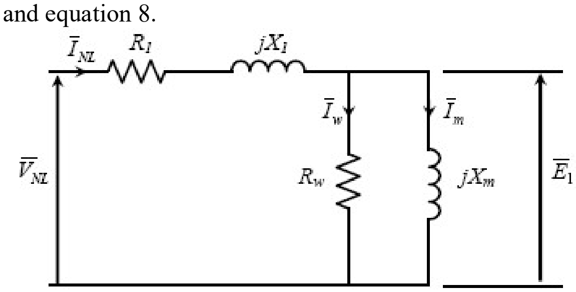


Figure 5: Approximate Equivalent Circuit for the No Load Condition.

Then, R_w and X_m, can be obtained as follows:

$$P_{core+mechanical} = P_{NL} - I_{NL}^2 R_1 \quad \text{..................... 13}$$

$$\bar{E}_1 = \bar{V}_{NL} - \bar{I}_{NL}(R_1 + jX_1) \quad \text{...................... 14}$$

$$(\bar{I}_{NL} = I_{NL}\angle -\theta,\ \theta = \cos^{-1}\frac{P_{NL}}{V_{NL}\, I_{NL}}) \quad \text{................ 15}$$

$$R_w = \frac{|E_1|^2}{P_{core+mechanical}} \quad \text{.................................. 16}$$

$$I_w = \frac{|E_1|}{R_w} \quad \text{.................................. 17}$$

$$I_m = \sqrt{I_{NL}^2 - I_w^2} \quad \text{.............................. 18}$$

$$X_m = \frac{|E_1|}{I_m} \quad \text{.................................. 19}$$

1.4.2 COMPUTER SIMULATION METHOD

The computer simulation test carried out in this paper was done using Matlab/Simulink software, the induction motor tests using the Simulink program was implemented by designing models for the various tests. This part of the paper will consider the following simulations:

1. DC Test for Stator Resistance (**DC-test**)
2. No Load Test (**No-Load**)
3. Blocked Rotor Test (**Blocked-Rotor**)
4. Load Test (**Load-Test**)

Simulations are designed to follow the actual hardware experiments as closely as possible that will give a chance to compare the simulation results to those of the actual experiment (experimental method). For the tests, we use the Matlab Power System Blockset and Simulink which provide models of power systems such as induction motors, transformers, etc. A Simulink diagram for each test is provided during the experiment.

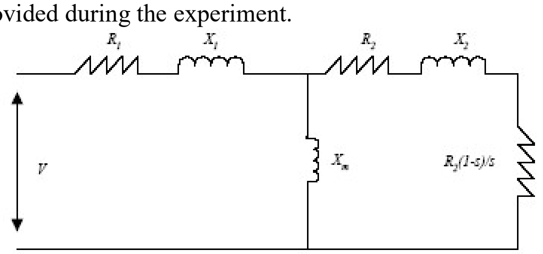


Figure 6: Per-Phase Equivalent Circuit of an Induction Motor.

1.4.2.1 DC TEST FOR STATOR RESISTANCE SIMULATION

The DC test will provide data that enables us to compute the stator winding resistance R_1 as shown in Figure 4. The simulation diagram for the DC test stator resistance is depicted in Figure 7. A voltage source is applied to the phase A and B of the induction motor through a series RC branch, while the phase C is grounded. The diagram has an induction motor block, this block contains the parameters that are needed to determine the induction motor tests and compare it to hardware experimental method results. In this test, the DC voltage and DC current were recorded and R_1 value was calculated as follows;

$$R_1 = \frac{V_{DC}}{2I_{DC}} \quad \text{...................... 20}$$

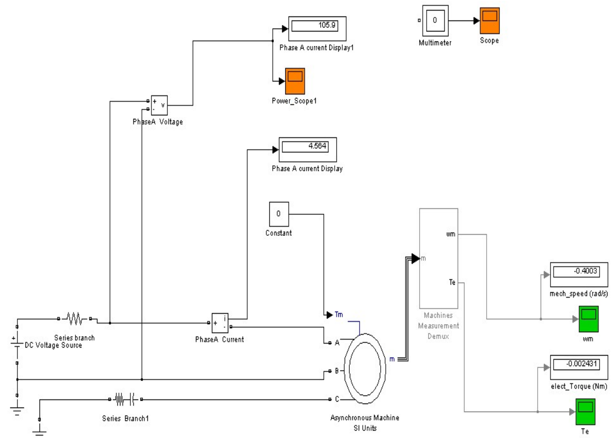


Figure 7: Simulink Diagram for the DC Test

1.4.2.2 SIMULATION OF BLOCKED ROTOR TEST

The blocked rotor test (locked rotor test) was performed to determine the equivalent circuit parameters of an induction motor. This test corresponds to the short-circuit test on a transformer. In this test, the rotor is blocked so that it cannot move more than a voltage less than the rated voltage that was applied to the motor. The resulting current, voltage and power measurements enables us to compute the induction motor parameters. Figure 8, shows the Simulink diagram for the blocked rotor test. We used the same induction motor parameters as the no-load test. However, in order to simulate blocked rotor condition, we set the inertia of the rotor to infinite. In this test, the rotor is locked. A three-phase AC voltage was applied to the motor and adjusted to an appropriate value so that the current flow of each phase is equal to its rated value. Recall that the rated current is **2.6**Amps, the simulation was run at various frequencies and data obtained on phase A current ($\mathbf{I_A}$), phase A RMS voltage ($\mathbf{V_A}$) and phase A input real and reactive powers ($\mathbf{P_A}$, $\mathbf{Q_A}$).

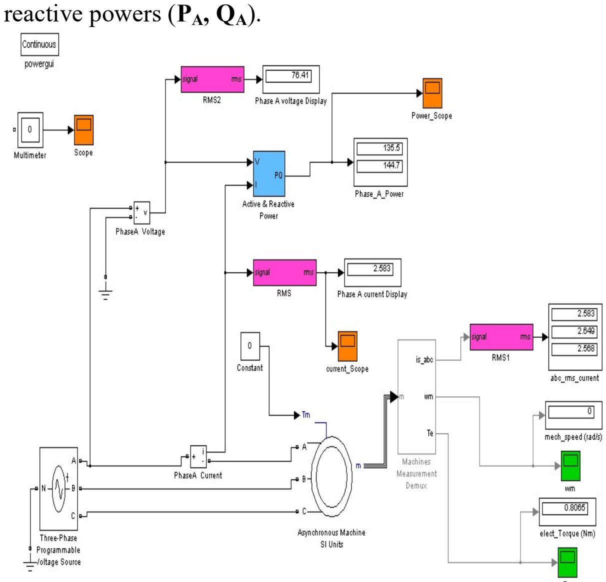


Figure 8: Simulink Diagram for Blocked Rotor Test

At each frequency, R_{LR} and X_{LR} were computed using the following equations:

$Z_{LR} = V_A/I_A$ 21

$PF = \cos\theta = P_A/V_AI_A$ 22

$Z_{LR} = R_{LR} + j X'_{LR} = Z_{LR}\cos\theta + jZ_{LR}\sin\theta$ 23

OR

$R_{LR} = P_A/I^2_A$ 24

$X'_{LR} = Q_A/I^2_A$ 25

$X_{LR} = X_1 + X_2 = (f_{rated}/f_{test})\, X'_{LR}$; 26

f_{rated} = 50Hz and the average of X_{LR} and R_{LR} were taken.

$R_2 = R_{LR} - R_1$ 27

$X_1 = X_2 = 0.5X_{LR}$ 28

1.4.2.3 SIMULATION TEST FOR NO-LOAD

The no-load test on the induction motor measures the rotational losses of the motor and it is able to evaluate its magnetizing current. In this test, a rated balanced AC voltage **of 220Vrms per-phases** with a rated frequency **of 50Hz** was applied to the stator and rotor runs without any load. The Simulink diagram of the no-load test is given in Figure 9. We also used the same induction motor for the DC test. The Y-connected 3-phase ideal voltage (**phase A, phase B and phase C**) source is connected to the stator windings. A zero mechanical load was applied to the rotor of the induction motor (input terminal **Tm**) to simulate the no-load condition. Some measurement blocks have been added to the diagram to measure some of the electrical and mechanical quantities, which are the Real and reactive power for the phase A (**phase-A-power**), the rms currents of the phases (**abc_rms_currents**), mechanical speed (**mech-speed**, **Wm**), electrical torque (**elect-torque, Te**) etc.

Using the data, the rotational losses of the motor and the sum of the stator leakage reactance and magnetizing reactance ($X_m + X_1$) were computed as follows:

$X_m + X_1 \approx V_A/I_A$ or $X_m + X_1 = Q_A/I^2_A$ 29

The three phase total input power: $P_{3\Phi} = 3P_A$ 30

The stator copper losses: $P_{SCL} = 3I^2AR_1$ 31

The rotational losses: $P_{rot} = 3P_A - P_{SCL}$ 32

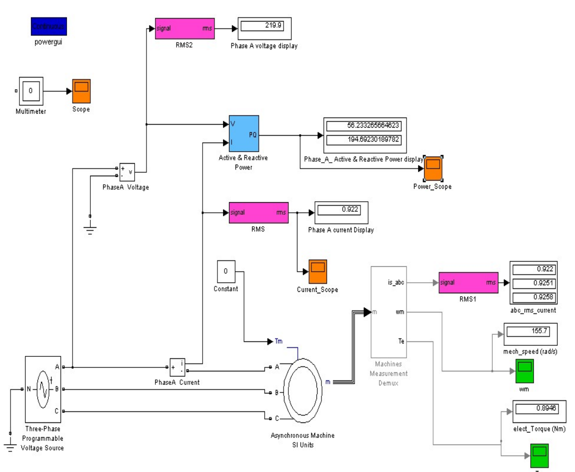


Figure 9: Simulink Diagram for No-Load Test.

1.4.2.4 SIMULATION FOR LOAD TEST

This simulation, a rated voltage was applied to the stator through a Y-connected AC voltage source. Recall that the per phase rms voltage is **220V**. Therefore; we choose the peak amplitude as **310V** for each AC voltage source. Figure 10 shows the Simulink diagram for the load test. The induction motor block has an input terminal labelled as $\mathbf{T_m}$ through this terminal different mechanical load were put to the shaft of the motor. The mechanical load **Tm** is specified in terms of torque **(N.m).** The simulations for various values of Tm were done and the **mechanical speed, slip speed, output power, and motor efficiency** changes with the load were also recorded. From the data obtained, the following calculations were made:

Output power at each load level: $P_{OUT} = T_m w_m$ 33

Total input power at each load level: $P_{IN} = 3P_A$ 34

Efficiency of the motor at each load level:

$\eta\% = P_{OUT}/P_{IN} \times 100$ 35

Slip at each load level: $s = (1500 - n_m)/1500$ 36

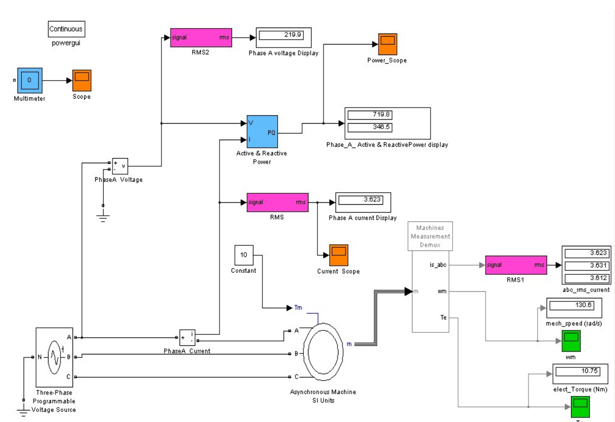


Figure 10: Simulink Diagram for Load Test.

1.5 RESULTS ANALYSIS AND DATA PRESENTATION

The various tests for the machine for both the laboratory experiment and the simulation method were conducted and the data obtained are presented below.

1.5.1 EXPERIMENTAL RESULTS FOR STATOR RESISTANCE TEST

The value of stator winding resistance measured with an ohmmeter, R_{DC} = 10.1Ω. The AC resistance is calculated as $R_1 = 1.15R_{DC}$ = 11.6Ω

1.5.2 EXPERIMENTAL RESULTS FOR BLOCK ROTOR TEST

The values obtained from block rotor test are shown in Table 1 below.

Table 1: Blocked Rotor Test Record

$V_{L\ L}$	I_R	I_Y	I_B	$P_{3\Phi}$
120	2.5	2.5	2.7	400

Hence, $P_{BL} = P_{3\Phi}/3$ =133.33W , $V_{BL} = V_L/\sqrt{3}$ = 69.3V,

$I_{BL} = (I_R + I_Y + I_B)/3 = 2.6A$
$R_{eq} = P_{BL} / I^2_{BL} = 19.72\Omega$, $Z_{eq} = V_{BL} / I_B = 26.65\Omega$, $X_{eq} = \sqrt{(Z^2_{eq} - R^2_{eq})} = 17.92\Omega$.
From our calculations $X_1 = X_2^1 = 8.96\Omega$, $R_2^1 = R_{eq} - R_1 = 8.12\Omega$.

1.5.3 EXPERIMENTAL RESULTS FOR NO LOAD TEST

The values obtained from the experiment are shown in Table 2 below.

Table 2: No Load Test Record

$V_{L L}$	I_R	I_Y	I_B	$P_{3\Phi}$
380	1.0	1.1	1.0	360

Hence the equivalent circuit parameters for the machine under test are: $R_1 = 11.6\Omega$, $R_2 = 8.12$, $X_1 = X_2 = 8.96\Omega$, $X_m = 233\Omega$, $Rm = 390\Omega$

1.5.4 SIMULATION RESULTS FOR DC TEST

The recorded DC voltage, $V_{DC} = 105.9V$ and the DC current recorded, $I_{DC} = 4.564A$.
Using the equation 20 as shown below:

$$R_1 = \frac{V_{DC}}{2I_{DC}}$$

$R_1 = 11.6\Omega$

1.5.5 SIMULATION RESULTS FOR BLOCKED ROTOR TEST

The records obtained are recorded in Table3 below;

Table 3: Blocked Rotor Simulation Record

Test Frequency(Hz)	VArms(V)	IA(A)	PA(W)	QA(Var)	Wm (rad/second)
40	64.65	2.6	140.90	101.70	1.250
50	71.68	2.6	130.50	126.40	1.018
60	75.22	2.6	130.80	146.20	0.807

At each frequency R_{LR} and X_{LR} are computed using the following formulas:
$Z_{LR} = V_A/I_A$; $PF = \cos\theta = P_A/V_AI_A$, $Z_{LR} = R_{LR} + j X'_{LR} = Z_{LR}\cos\theta + jZ_{LR}\sin\theta$
Hence, $R_{LR1} = 20.84\Omega$, $R_{LR2} = 19.30\Omega$, $R_{LR3} = 19.35\Omega$, $R_{LR} = 19.83\Omega$, $X'_{LR1} = 15\Omega$, $X_{LR1} = 18.75\ \Omega$, $X'_{LR2} = 18.70\Omega$, $X_{LR2} = 18.70\Omega$, $X'_{LR3} = 21.63\Omega$, $X_{LR3} = 18\Omega$, $X_{LR} = 18.48\Omega$, $R_2 = R_{LR} - R_1 = 8.2\Omega$, $X_1 = X_2 = 0.5X_{LR} = 9.2\Omega$

1.5.6 SIMULATION RESULTS FOR NO LOAD TEST

The records obtained are provided in the Table 4 above.
From the results, the followings are calculated as follows;
$X_m + X_1 \approx V_A/I_A$ or $X_m + X_1 = Q_A/I^2_A$
$I_A = 0.92A$, $X_m + X_1 = 240\Omega$
Recall $X_1 = 9.2\Omega$
Hence $X_m = 231\Omega$

The three phase total input power: $P_{3\Phi} = 3P_A = 3\times56.23 = 169W$, the stator copper losses: $P_{SCL} = 3I^2AR_1 = 30W$, the rotational losses: $P_{rot} = 3P_A - P_{SCL} = 139W$.

Table 4: Simulation for No-Load Record

VA (V)	VB (V)	VC (V)	IA (A)	IB (A)	IC (A)	PA (W)	QA (Var)	Te (Nm)	Wm (rad/second)
220	220	220	0.922	0.925	0.925	56.23	194.69	0.895	155.7

Table 5: Equivalent Circuit Parameters with Corresponding Errors

1.5.7 SIMULATION RESULT FOR LOAD TEST

The records obtained are shown in the table 6 below;

Table 6: Simulation Record for Load Test

Mechanical Load(Torque),Tm(Nm)	VA rms (V)	IA (A)	PA (W)	QA (Var)	Wm (rad/second)
5	220	1.85	352.40	213.00	146.50
6	220	2.14	412.40	226.90	144.10
7	220	2.46	486.10	245.70	141.50
8	220	2.80	550.60	270.40	138.50
9	220	3.19	637.40	303.00	134.90
10	220	3.62	719.80	346.50	130.60
11	220	10.05	1282	1820.00	-1388.00
12	220	10.07	1269	1830.00	-1604.00
13	220	10.10	1283	1836.00	-1797.00
14	220	10.10	1276	1841.00	-1985.00
15	220	10.14	1239	1845.00	-2165.00

From the data obtained, the following calculations were made and tabulated in Table 7 below:
Output power at each load level: $P_{OUT} = T_mw_m$, Total input power at each load level: $P_{IN} = 3P_A$, Efficiency of the motor at each load level: $\eta\% = P_{OUT}/P_{IN} \times 100$, Slip at each load level: $S = (1500 - n_m)/1500$, Speed at each load level: $N_m = (W_m/2\pi)\times60$ rpm.

Figure 11: Active and Reactive Power Waveform

Parameters	R_1	R'_2	X_1	X_2	X_m
Experimental Values	11.6	8.12	8.96	8.96	233
Simulation Values	11.6	8.20	9.20	9.20	231
Error(%)	0.000	0.935	2.678	2.678	0.858

for Blocked Rotor Test Simulation.

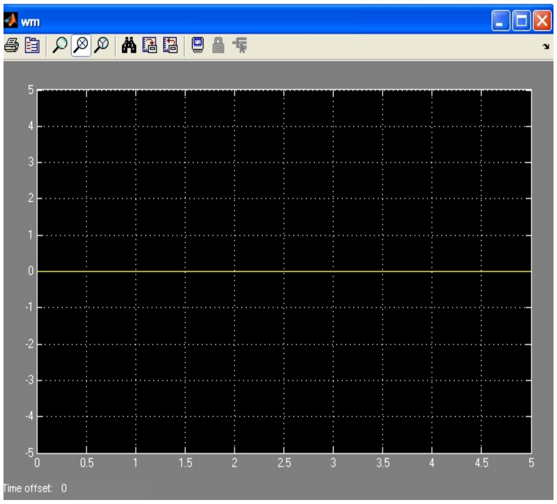
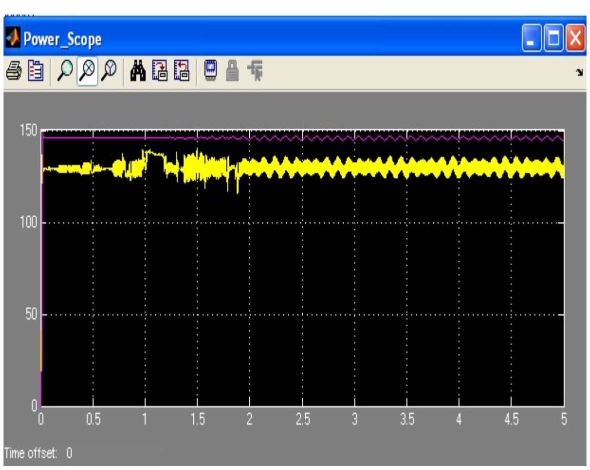


Figure 12: Mechanical Speed Waveform for Blocked Rotor Test Simulation.

Table 7: Calculated Values from Measured Values for Load Test Simulation

P_{out} ($T_m W_m$)w	P_{in} ($3P_A$)w	N_m ($W_m/2\pi$) (rpm)	η % (P_{out} / P_{in})	s (1500 - N_m)/1500
732.50	1057.20	1398.97	69.29	0.067
864.60	1237.20	1376.05	69.88	0.082
990.50	1459.80	1351.22	67.85	0.099
1108.00	1651.80	1322.58	67.08	0.118
1214.10	1912.20	1288.20	63.49	0.141
1306.00	2159.40	1247.14	60.48	0.169
-15268.00	3846.00	-13252.70	-397.00	8.195
-19248.00	3807.00	-15315.10	-506.00	9.342
-23387.00	3849.00	-17176.90	-608.00	10.376
-27790.00	3828.00	-18952.90	-726.00	11.363
-32475.00	3717.00	-20691.50	-874.00	12.329



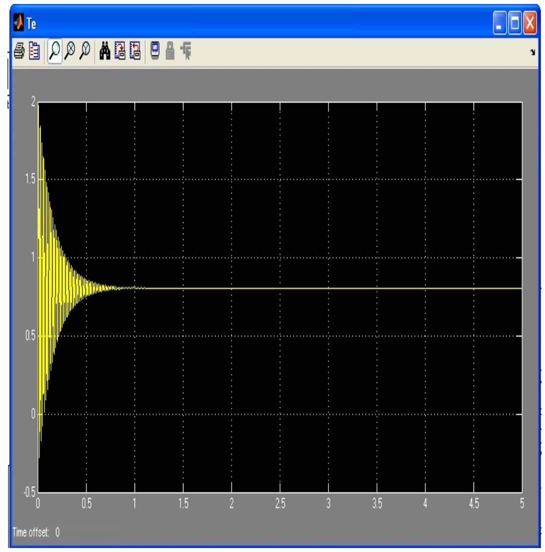


Figure 13: Electromagnetic Torque Waveform for Blocked Rotor Test Simulation.

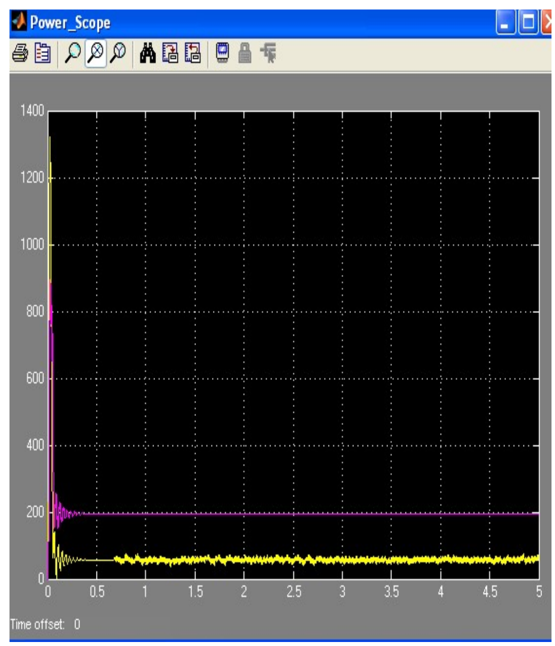


Figure 14: Active and Reactive Power Waveform for No Load Test Simulation.

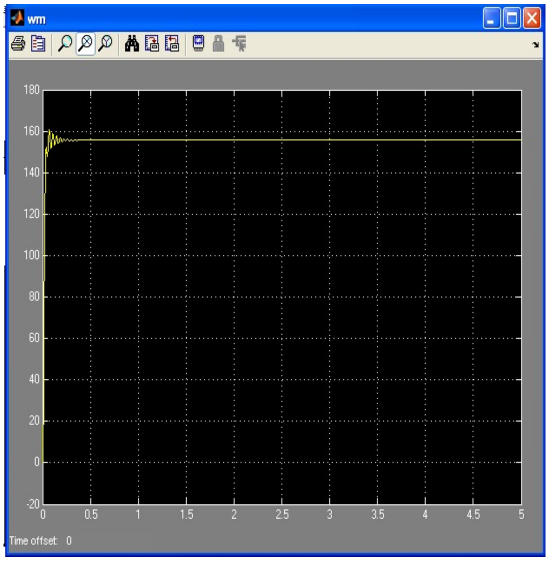


Figure 15: Mechanical Speed Waveform for No-load Test Simulation.

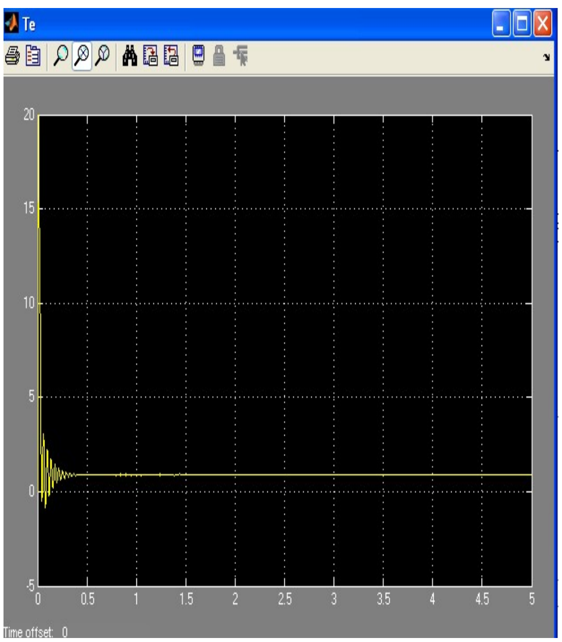


Figure 16: Electromagnetic Torque Waveform for No Load Test Simulation.

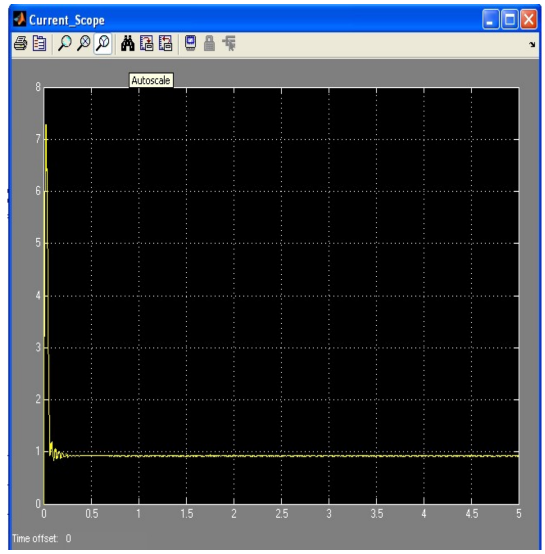


Figure 17: Current Waveform at for No Load Test Simulation.

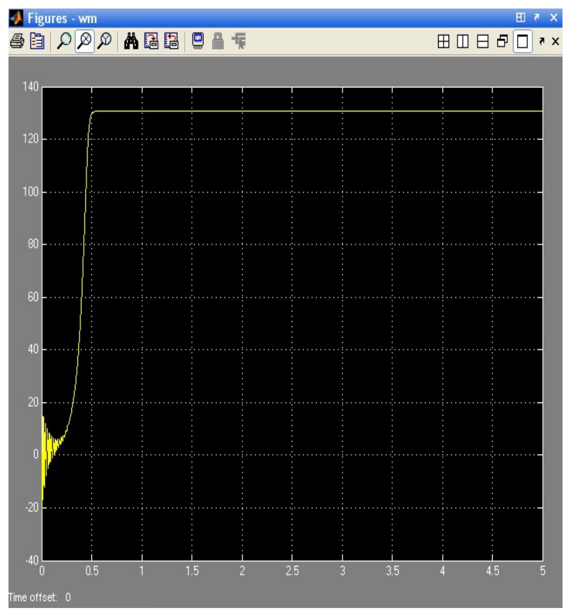


Figure 18: Mechanical Speed Waveform at Full Load Test Simulation.

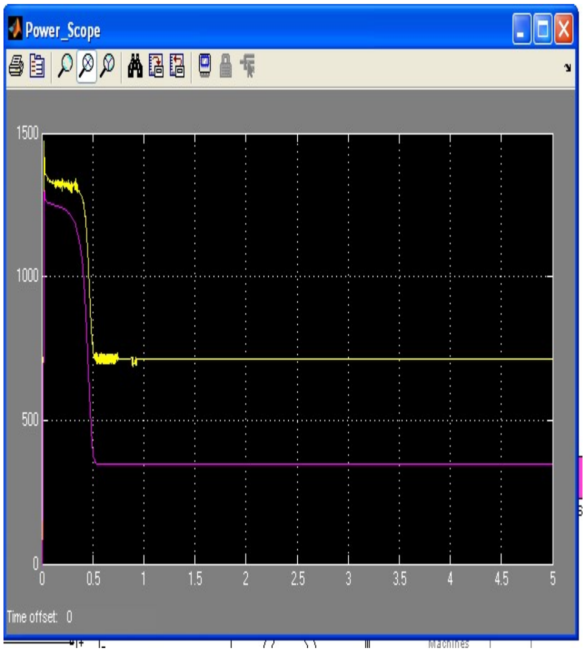


Figure 19: Active and Reactive Power Waveform at Full Load Test Simulation.

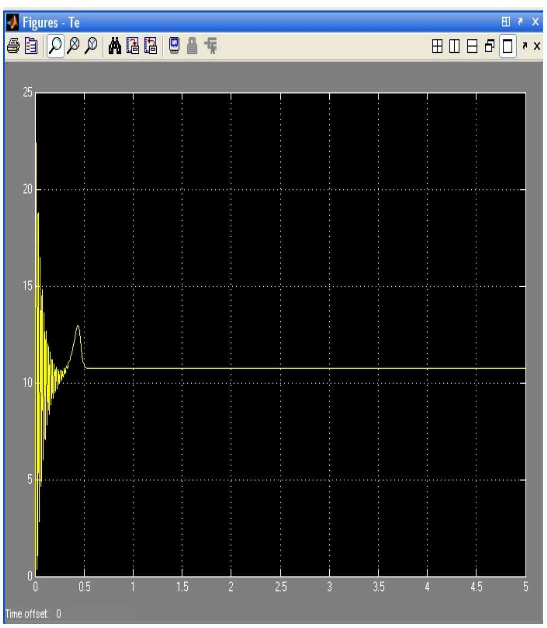


Figure 20: Electromagnetic Torque at Full Load Test Simulation.

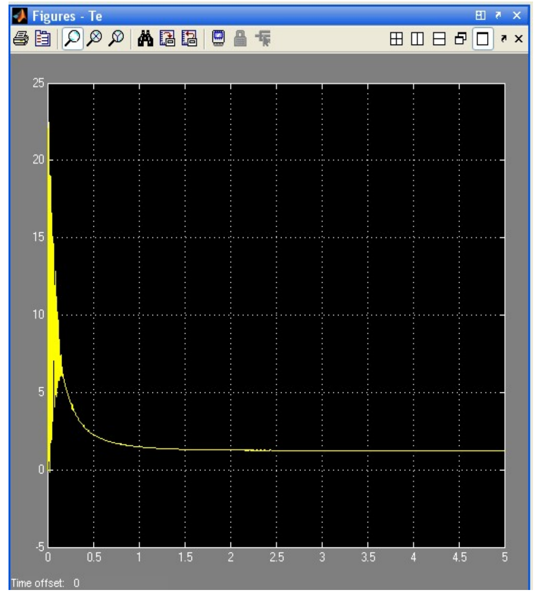


Figure 21: Elecromagnetic Torque Waveform at Overload Simulation.

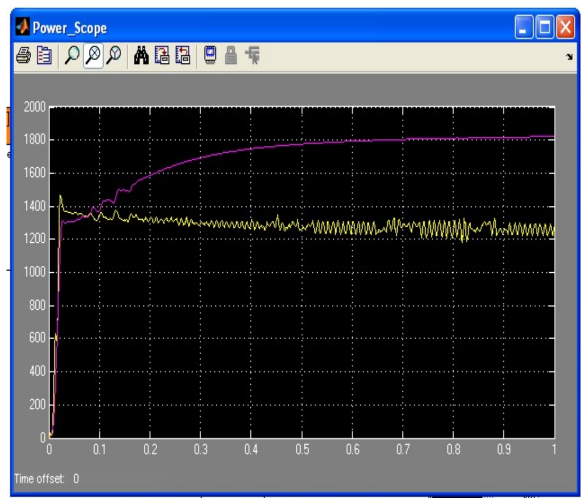


Figure 22: Active and Reactive Power Waveform at Overload Simulation.

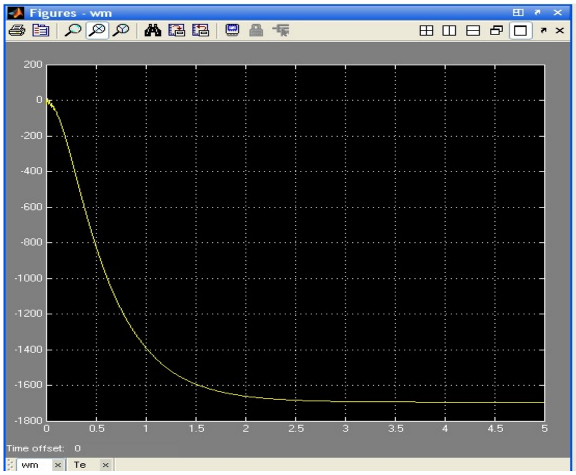


Figure 23: Mechanical Speed Waveform at Overload Simulation.

The following graphs were constructed to show the relationships between the various parameters obtained, as shown in the following figures 24, 25, 26, 27, 28, 29 and 30 below: (1). T_m vs S, (2). T_m vs η, (3). P_{OUT} vs T_m, (4). N_m vs P_{OUT}, (5). I_A vs P_{OUT}, (6). T_m vs N_m (7). I_A vs N_m

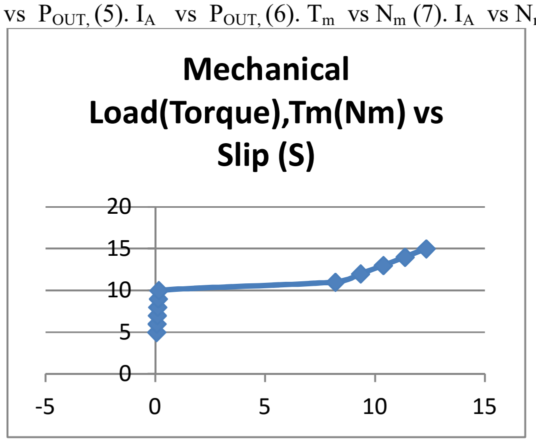


Figure 24: Torque vs Slip

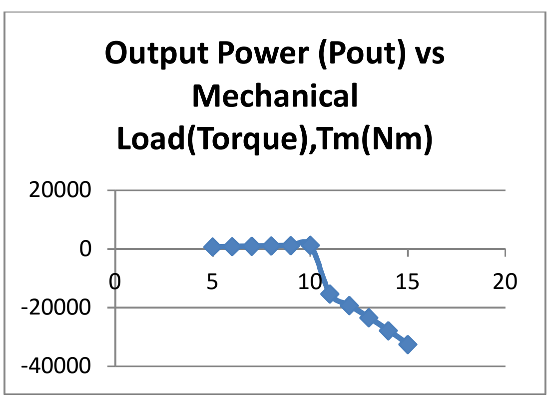


Figure 25: Output Power vs Torque

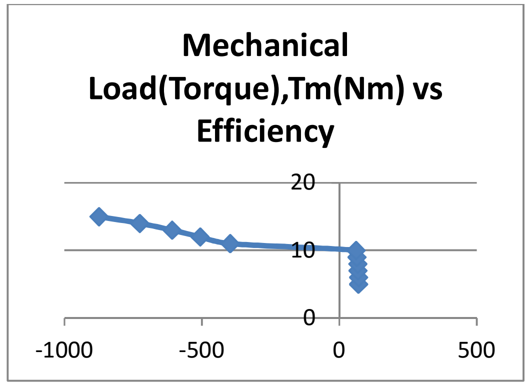


Figure 26: Torque vs Efficiency

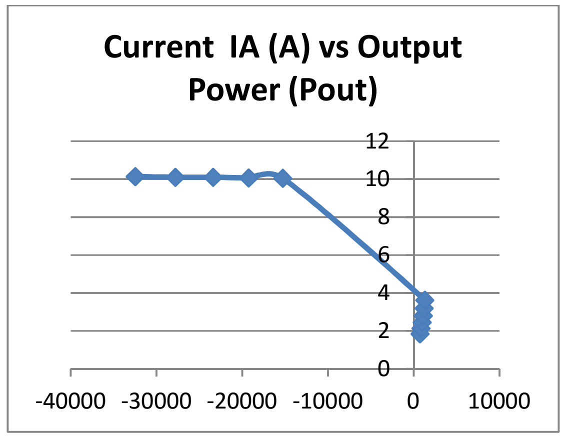


Figure 27: Current vs Output Power

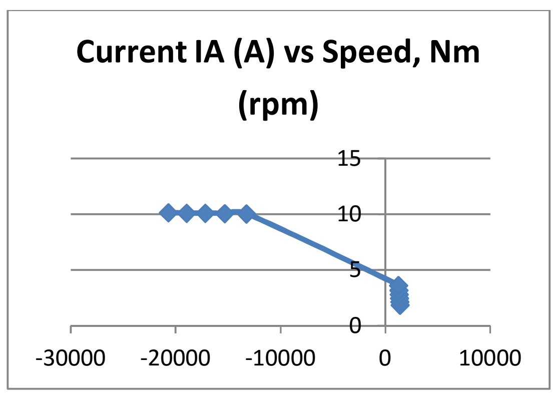


Figure 28: Current vs Speed

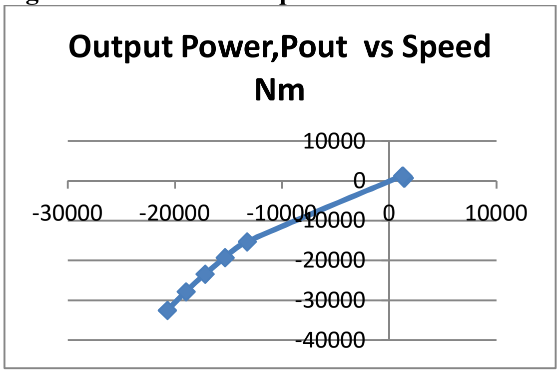


Figure 29: Output Power vs Speed

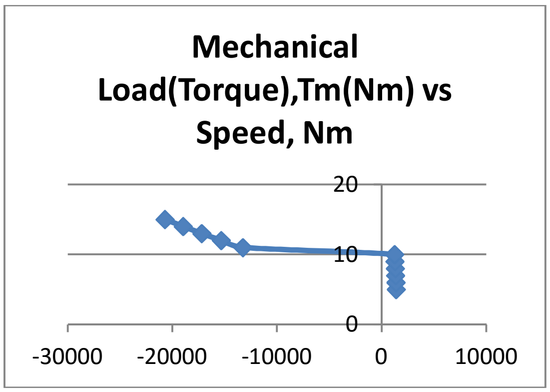


Figure 30: Torque vs Speed

1.6 CONCLUSION

The effectiveness of the proposed simulation models have been illustrated in this work. We compared the equivalent circuit parameters determined by simulation method with those obtained from the experimental method. A set of hardware experiments were first performed (i.e. dc test, load test and blocked rotor test) on the induction motor to obtain appropriate equivalent circuit parameters with the simulation software. The data obtained were shown in Table 1 & 2. The resulting parameters were $R_1 = 11.6\Omega$, $R_2 = 8.12\ \Omega$, $X_1 = 8.96\ \Omega$, $X_2 = 8.96\ \Omega$ and $X_m = 233\ \Omega$.

For the motor tested, the simulink/power system blocked models of the dc no-load; load test and the blocked rotor test were shown in Table 3 & 4, where various quantities such as voltage, current and power required to compute the equivalent circuit parameters were presented. The dc test simulation data for the motor were as follows V_{DC} = 105.9V and I_{DC} = 4.564A. The starting current was 7.2A while the running current was 0.922A under no load simulation test; this shown that the starting current of the induction motor was about 8 times the running current.

The equivalent circuit parameters computed using the simulation data were $R1 = 11.6\Omega$, $R_2 = 8.2\Omega$, $X_1 = 9.2\Omega$, $X_2 = 9.2\Omega$ and $X_m = 231\Omega$. The corresponding errors in relative to those obtained experimentally were shown in Table 5.

The results indicated that the relative errors were negligible and the proposed simulation models accurately predict the equivalent circuit parameter. The largest errors occur in the stator and rotor leakage reactance, since one assumes that the two reactance have equal contributions to the blocked rotor reactance which might not be the real case. Haven known the accuracy of the simulation model, the load test simulation was carried out. The data obtained was shown in Table 6, where quantities such as current, voltage, active and reactive power, mechanical speed and electromagnetic torque required to compute various operating characteristics of the motor under steady state were presented. The power output, power input, efficiency, speed in rpm and slip of the motor were computed from the load test simulation data. The simulation was done using different mechanical load ranging from 5 to 15Nm in terms of torque.

The graphs of speed/output power, mechanical load/output power, mechanical load/slip, mechanical load/speed, current/speed and efficiency/slip were constructed. From the graphs, it is obvious that as the power output of the motor increases the speed decreases; the mechanical load also increases as the power output increases; the power output increases as the current increases; the slip increases as the power output increases; the slip increases as the load increases too, and the speed decreases as the load increases. All the characteristics behaviour of the machine plotted were shown in figures 24, 25, 26, 27, 28, 29 and 30 to show the behaviour of the machine. The various waveform under no load, blocked rotor and load tests, the combination of the various waveform and the graphs shows that the experimental and simulation analysis of the motor agree with the theoretical values of the three phase induction motor.

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