International Journal of Engineering Innovation & Research
Volume 3, Issue 5, ISSN: 2277 – 5668

Computer-Aided Performance Analysis of a Refurbished Three-Phase Induction Motor

Enyong P. M.
Auchi Polytechnic Auchi-Nigeria
Email: asumikenyong@gmail.com

Ike S. A.
University of Benin, Benin-City Nigeria
Email: sam.ike@uniben.edu

***Abstract* – In this work, a 20-kW, 48-slot, 4-pole, 3-phase, 380V, 50Hz, squirrel-cage induction motor was refurbished and subjected to a steady-state performance analysis. A computer-aided approach was adopted requiring the development of a software application package to that effect. In this paper the authors present the performance equations derived from the L-configured equivalent circuit of 3-phase induction motors. The equations enabled the generation of the necessary program using the MATLAB programming language. By means of open-circuit and short-circuit laboratory tests the six voltage, current and power quantities required as the major input variables to the software application package were obtained. Running the software package with these experimental quantities led to the determination of the machine equivalent circuit parameters in the first instance. And by using the parameters in the same running process the software package also produced the motor performance quantities and curves for analytical purposes. The analysis showed the motor as exhibiting satisfactory full-load values of torque, speed, output power, slip, power factor and efficiency.**

***Keywords* – Computer-Aided, Motor, Performance Analysis, MATLAB.**

I. INTRODUCTION

The induction motor as a rotating machine is one of the inventions of 1833 [1] and has been of immense significance to mankind especially in constant-speed drives [2,3]. When subjected to undesirable stresses arising from overload, insufficient lubrication, frequent starts/stops, inadequate cooling, etc., it develops fault and breaks down, [4, 5, 6] requiring to be refurbished. The induction motor in considered is a 20-kW, 48-slot, 4-pole, 380V, 50Hz, 3-phase, squirrel-cage type used in a quarry to drive a crushing machine. It became defective as a result of a discharge from thunder strike. In refurbishing this equipment a redesigning of the stator winding only was necessary being that the rotor system was still intact and hardlygoes bad. The focus in this circumstance is on the steady-state analysis of the performance of the refurbished motor using computer-aided design technique. To this end the work in this paper commences proper with the generation of the applicable performance equations as given in Section2.0. In Section 3.0 the authors present the computer program written in MATLAB

II. MOTOR PERFORMANCE EQUATIONS [7, 8, 9, 10, 11, 12]

The essential motor equations as derivable from the L-configured equivalent circuit of 3-phase induction motors are as summarized in the subsections that follow. In this treatment the motor is considered to have been delta-connected which is common in practice.

A. From Short-Circuit Test Results

For Short-Circuit Power Factor:

$$cos\emptyset_{sc} = \frac{P_{sc}}{\sqrt{3}V_{sc}I_{sc}}(lag.);\ \ \emptyset_{sc} = cos^{-\mathbf{1}}\left(\frac{P_{sc}}{\sqrt{3}V_{sc}I_{sc}}\right) \qquad (1)$$

For the Combined Stator/Rotor Resistances:

$$z_{sc} = \frac{V_{sc}}{\left(I_{sc}/\sqrt{3}\right)} = \quad \text{(short circuit impedance)} \ldots\ldots(2a)$$

$$r_1 + r_{21} = z_{sc}cos\emptyset_{sc}(theresistancesinohms).\ldots(2b)$$

For the Combined Stator/Rotor Reactances:

$$x_1 + x_{21} = z_{sc}sin\emptyset_{sc}(ohms);\ x_1{:}x_{21} = 1{:}1\ \ldots\ldots\ldots(3)$$

B. From Open-Circuit Test Results

i) For open-circuit power factor:

The experimental values of the open-circuit power and current must first be brought to those of the rated voltage, V_1,

$$P_{oc1} = \left(\frac{V_1}{V_{oc}}\right)^2 P_{oc}\ (full\ line\ input\ power)\ldots\ldots(4\text{a})$$

$$I_{oc1} = \left(\frac{V_1}{V_{oc}}\right) I_{oc}(line\ current, in\ amps)\ldots(4b)$$

$$cos\emptyset_{oc} = \frac{P_{oc1}}{\sqrt{3}V_1I_{oc1}}(lag.);$$

$$\emptyset_{oc} = cos^{-\mathbf{1}}\left(\frac{P_{oc1}}{\sqrt{3}V_1I_{oc1}}\right)\ldots\ldots\ldots(4c)$$

ii) For the Combined No-Load Resistances

$$z_{oc} = \frac{V_1}{\frac{I_{oc1}}{\sqrt{3}}}(open\ circuit\ impedance\ )\ \ldots.(5a)$$

$$r_{oc} = r_1 + r_m = z_{oc}cos\emptyset_{oc}\ ;$$

$$r_m = r_{oc} - r_1(the\ resistances\ ).(5b)$$

iii) For the Combined No-Load Reactances

$$x_{oc} = x_1 + x_m = z_{oc}sin\emptyset_{oc}\ ;$$

$$x_m = x_{oc} - x_1(the\ reactances\ )\ldots\ldots\ldots(6)$$

C) From the Complete Equivalent Circuit

i) Equivalent circuit impedances, total resistances & reactances:

Actual Stator Impedance

$$z_1 = \sqrt{r_1^2 + x_1^2}\ ;$$

$$\emptyset_1 = tan^{-1}\left(\frac{x_1}{r_1}\right)(impedance\ angle)\ldots.(7a)$$

Actual Magnetizing Circuit Impedance

$$z_m = \sqrt{r_m^2 + x_m^2}\,;\ \ \emptyset_m = tan^{-1}\left(\frac{x_m}{r_m}\right)(impedance\ angle) \ldots\ldots\ldots\ldots(7b)$$

Actual No-Load (Branch) Impedance

$$z_{oc} = \sqrt{r_{oc}^2 + x_{oc}^2}\,;$$

$$\emptyset_{oc} = tan^{-1}\left(\frac{x_{oc}}{r_{oc}}\right)(impedance\ angle) \ldots\ldots(7c)$$

Total Stator Leakage Factor for Short-Circuit Impedances

$$k_1 = 1 + \frac{x_1}{x_m} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots(8a)$$

Short- Circuit Equivalent Resistances

$$R_1 = k_1 r_1\ \ and\ \ R_{21} = k_1^2 r_{21}\ (equiv.resistances) \ldots\ldots\ldots(8b)$$

$$R_{sh} = R_1 + R_{21}\ (total\ short\ circuit\ resistance) \ldots\ldots\ldots\ldots\ldots(8c)$$

Short- Circuit Equivalent Reactances

$$X_1 = k_1 x_1\ \ and\ \ X_{21} = k_1^2 x_{21}(equiv.reactances) \ldots\ldots\ldots\ldots\ldots(8d)$$

$$X_{sh} = X_1 + X_{21}\ (total\ short\ circuit\ reactance) \ldots\ldots\ldots\ldots\ldots\ldots(8e)$$

Short-Circuit Equivalent Impedance

$$z_{sh} = \sqrt{R_{sh}^2 + X_{sh}^2}\,;$$

$$\emptyset_{\boldsymbol{sh}} = tan^{-1}(X_{sh}/R_{sh})(imped.\ angle) \ldots(8f)$$

Effective Load-Circuit Resistance and Impedance

$$R_e = R_{sh} + \left[R_{21}\frac{(1-s)}{s}\right]\ (effective\ resistance) \ldots\ldots\ldots\ldots\ldots(9a)$$

$$Z_e = \sqrt{\left(R_{sh} + \left[R_{21}\frac{(1-s)}{s}\right]\right)^2 + X_{sh}^2}\ (impedance) \ldots\ldots\ldots\ldots\ldots(9b)$$

$$\emptyset_{\boldsymbol{e}} = tan^{-1}(X_{sh}/R_e)\ (load\ cct.impedance\ angle)$$

Sum of No-Load and Load-Circuit Impedances

$$Z_{sm} = Z_e + z_{oc} = \sqrt{(R_e + r_{oc})^2 + (X_{sh} + x_{oc})^2} \ldots\ldots\ldots\ldots\ldots\ldots(10)$$

$$\emptyset_{\boldsymbol{sm}} = tan^{-1}[(X_{sh} + x_{oc})/(R_e + r_{oc})]\ (impedance\ angle)$$

Complete Motor Circuit Input Impedance

$$Z_{in} = \frac{(Z_{e)(z_{oc})}}{(Z_e + z_{oc})} = \frac{(Z_{e)(z_{oc})}}{Z_{sm}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

$$\emptyset_{in} = (\emptyset_{\boldsymbol{e}} + \emptyset_{oc} - \emptyset_{sm})\ \ (input\ impedance\ angle)$$

ii) Machine Input Power Factor:

$$pf = cos\emptyset_{in} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(12)$$

iii) Equivalent Circuit Currents (Per-Phase):

Total Motor Input Current

$$I_1 = V_1/Z_{in} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(13a)$$

Load Component of Input Current

$$I_{21} = \frac{z_{oc}}{(Z_e + z_{oc})}I_1 = \frac{z_{oc}}{Z_{sm}}I_1 = \frac{V_1}{\sqrt{\left(R_{sh} + \left[R_{21}\frac{(1-s)}{s}\right]\right)^2 + X_{sh}^2}} \ldots\ldots(13b)$$

iv)Machine Circuit Losses:

Open-Circuit (or No-Load) Stator Copper Loss

$$P_{occ} = 3\left(\frac{I_{oc1}}{\sqrt{3}}\right)^2 r_1 = I_{oc1}^2 r_1\ \ (watts)$$

Open-Circuit (or No-Load) Rotor Copper Loss

$$P_{ocr} = 0.5P_{ocs}(watts)$$

Total Open-Circuit (or No-Load) Copper Losses

$$P_{occ} = (P_{ocs} + P_{ocr})(watts) \ldots\ldots\ldots\ldots\ldots\ldots(14a)$$

Total Stator Full-Load Copper Losses

$$P_{sta} = 3I_{21}^2 R_1(watts) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(14b)$$

Total Rotor Full-Load Copper Losses

$$P_{rot} = 3I_{21}^2 R_{21}(watts) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(14c)$$

Total Mechanical Losses

$$P_{met} = P_{oc1} - P_{occ}(watts) \ldots\ldots\ldots\ldots\ldots(14d)$$

Friction & Windage Losses

$$P_{FW} = 0.01\ to\ 0.02P_{mN}(watts) \ldots\ldots\ldots\ldots(14e)$$

Total Iron Losses (hysteresis/eddy-current & rotational losses)

$$P_{ir} = P_{met} - P_{FW}(watts) \ldots\ldots\ldots\ldots\ldots\ldots(14f)$$

Total Machine Losses

$$P_{los} = P_{sta} + P_{rot} + P_{ir}(watts) \ldots\ldots\ldots(14g)$$

v) Mechanical Output Power Quantities:

Gross Mechanical Output Power

$$P_{mG} = 3I_{21}^2 R_{21}\left(\frac{1-s}{s}\right)(watts)\ldots\ldots(15a)$$

Net or Full-Load Mechanical Output Power

$$P_{mN} = P_{mG} - P_{met}(watts) \ldots\ldots\ldots\ldots\ldots(15b)$$

Maximum Mechanical Output Power

$$P_{mM} = \frac{3V_1(I_{sc1} - I_{oc1})}{2[1 + cos\emptyset_{sc}]} = \frac{\sqrt{3}V_1(I_{sc1} - I_{oc1})}{2[1 + cos\emptyset_{sc}]}\ (watts)\ldots\ldots\ldots\ldots\ldots(15c)$$

where I_{sc1} and I_{oc1} are line values in Δ winding connection.

vi)Mechanical Output Torque Quantities:

Gross Mechanical Output Torque

$$T_{mG} = \frac{P_{mG}}{2\pi n_r} = \frac{P_{mG}}{2\pi n_s(1-s)}(N.m) \ldots\ldots\ldots(16a)$$

Net or Full-Load Mechanical Output Torque

$$T_{mN} = \frac{P_{mN}}{2\pi n_r} = \frac{P_{mN}}{2\pi n_s(1-s)}(N.m) \ldots\ldots\ldots\ldots(16b)$$

Maximum Mechanical Output Torque

$$T_{mM} = \frac{P_{mM}}{2\pi n_r} = \frac{P_{mM}}{2\pi n_s(1-s)}(N.m) \ldots\ldots\ldots(16c)$$

Starting Mechanical Torque

$$T_{mS} = T_{mN}\left(\frac{I_{sc1}/\sqrt{3}}{I_{21}}\right)^2 s\ \ (N.m) \ldots\ldots\ldots\ldots(16d)$$

vii) Machine Slips

Actual Normal Full-Load or Rated Slip

$$s_f = \frac{P_{rot}}{P_{mN} + P_{rot} + P_{FW}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (17a)$$

Slip for Maximum Power/Torque

$$s_m = \pm \frac{R_{21}}{\sqrt{R_1^2 + X_{sh}^2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17b)$$

the +ve sign being for motoring whilst the –ve sign is for generating.

III. COMPUTER PROGRAMMING IN MATLAB

In order to produce the essential machine performance parameters and curves with the aid of a computer, the following programs written in MATLAB were necessary. MATLAB is the language of technical computing produced and licensed by Math Works Inc and made to provide a powerful matrix analysis environment for scientific and engineering computations *[11, 14]*. It is an acronym standing for Mathematical Laboratory *[15]*.

Program for 3-Phase Induction Machine Performance Parameters

```
%This Program produces the Performance Parameters of a Redesigned
%and Refurbished 3-Phase Induction Motor using the Experimental
%Approach with the Motor being Delta- or Star-Connected
disp('PERFORMANCE ANALYSIS OF THE REDESIGNED/REFURBISHED');
disp('3-PHASE INDUCTION MOTOR BY THE EXPERIMENTAL METHOD');
disp(' ');
Psc=input('Enter the Short-Circuit Active Power Developed, Psc=')
Poc=input('Enter the Open-Circuit Active Power Developed, Poc=')
Isc=input('Enter the Short-Circuit Current Input, Isc=')
Ioc=input('Enter the Open-Circuit Current Input, Ioc=')
Vsc=input('Enter the Short-Circuit Input Voltage, Vsc=')
Voc=input('Enter the Open-Circuit Input Voltage, Voc=')
r1=input('Enter measured Stator Winding Resistance, r1=')
V1=input('Enter Motor Full Line Input Voltage, V1=')
s=input('Enter estimated Motor Slip, s=')
disp('Delta connection=7; Star connection=8');
Conn=input('Enter the Connection Type number, Conn=')
ns=f/p; nr=ns*(1-s); %synchronous & rotor speeds, respectively
z_sc7=1.732*Vsc/Isc;
z_sc8=Vsc/(1.732*Isc); %experi. short-cct. impedance
z_oc7=1.732*Voc/Ioc;
z_oc8=Voc/(1.732*Ioc); %experi. open-cct. impedance
if Conn==7
    z_sc=z_sc7; z_oc=z_oc7; Vph=V1;
elseif Conn==8
    z_sc=z_sc8; z_oc=z_oc8; Vph=V1/1.732;
end
Qsc=acos(Psc/(1.732*Vsc*Isc)); %short-circuit power factor angle
r_sc=z_sc*cos(Qsc); %combined short-circuit resistance in ohms
r21=(r_sc - r1); %rotor resistance referred to the stator (ohms)
x_sc=z_sc*sin(Qsc); %combined short-circuit reactance in ohms
x1=0.5*x_sc; %estimated stator winding reactance in ohms
x21=(x_sc - x1); %rotor winding reactance (in ohms) referred to the stator
Qoc=acos(Poc/(1.732*Voc*Ioc)); %open-circuit power factor angle
r_oc=z_oc*cos(Qoc); %combined open-circuit resistance
r_m=(r_oc - r1); %magnetizing circuit resistance
x_oc=z_oc*sin(Qoc); %combined open-circuit reactance
x_m=(x_oc - x1); %magnetizing circuit reactance
z1=sqrt((r1^2)+(x1^2)); %stator winding impedance
Q1=atan(x1/r1); %stator winding impedance angle
z_m=sqrt((r_m^2)+(x_m^2)); %magnetizing circuit impedance
Qm=atan(x_m/r_m); %magnetizing circuit impedance angle
Qoc=atan(x_oc/r_oc); %impedance angle of z_oc
Poc1=((V1/Voc)^2)*Poc; %open-circuit power developed on full voltage
Ioc1=(V1/Voc)*Ioc; %open- circuit (line) current input on full voltage
k1=(1 + (x1/x_m)); %total stator leakage factor
R1=k1*r1; R21=(k1^2)*r21; %equivalent stator and rotor resistances, resp.
Rsh=(R1 + R21); %total short-circuit equivalent resistance
X1=k1*x1; X21=(k1^2)*x21; %equivalent stator and rotor reactances, resp.
Xsh=(X1 + X21); %total short-circuit equivalent reactance
Zsh=sqrt((Rsh^2) + (Xsh^2)); %short- circuit equivalent impedance
Qsh=atan(Xsh/Rsh); %impedance angle of Zsh
```

```
Re=(Rsh + (R21*(1-s)/s)); %effective
load-circuit resistance
Ze=sqrt((Re^2) + (Xsh^2)); %effective
load-circuit impedance
Qe=atan(Xsh/Re); %impedance angle of Ze
Zsm=sqrt(((Re + r_oc)^2)+((Xsh +
x_oc)^2)); %sum of impedances in
%magnetizing branch and load-circuit
Qsm=atan((Xsh + x_oc)/(Re + r_oc));
%impedance angle of Zsm
Zin=Ze*z_oc/Zsm; %total input impedance
of motor circuit
Qin=(Qe + Qoc - Qsm); %impedance angle
of Zin
pf=cos(Qin); %machine input power
factor
I1=Vph/Zin; %per-phase motor total
input current (in amps)
I21=I1*(z_oc/Zsm); %per-phase load
component of the total input current
(amps)
Isc1=Isc*(V1/Vsc); %short-circuit
(line) current on full voltage (amps)
Pocs=(Ioc1^2)*r1; %open-circuit stator
copper loss (watts)
Pocr=0.5*Pocs; %open-circuit rotor
copper loss (watts)
Pocc=(Pocs + Pocr); %total open-circuit
copper losses (watts)
Psta=3*(I1^2)*R1; %stator copper loss
(watts)
Prot=3*(I21^2)*R21; %rotor copper loss
(watts)
Pmet=(Poc1 - Pocc); %total mechanical
losses (watts)
Pmg=3*(I21^2)*(R21*(1-s)/s); %gross
mechanical output power (watts)
Pmn=(Pmg - Pmet); %net mechanical
output power (N.m)
Pfw1=0.017*Pmn;Pfw2=0.014*Pmn;Pfw3=0.01
2*Pmn;Pfw4=0.01*Pmn;
%friction/windage losses(watts)
if Pmn<=5600
Pfw=Pfw1;%friction & windage losses
(watts)
elseif Pmn>5600 && Pmn<=25000
Pfw=Pfw2;%friction & windage losses
(watts)
elseif Pmn>25000 && Pmn<=56000
Pfw=Pfw3;%friction & windage losses
(watts)
else
Pfw=Pfw4;%friction & windage losses
(watts)
end
Pir=(Pmet - Pfw); %total iron losses
(watts)
Plos=(Psta + Prot + Pir + Pfw); %total
motor losses (watts)
```

```
eff=(Pmn/(Pmn + Plos))*100; %efficiency
(percentage)
Pmm=(3*Vph^2)/(2*(Rsh+Zsh)); %maximum
output power (watts)
Tmg=(Pmg/(2*pi*nr)); %gross mechanical
output torque (N-m)
Tmn=(Pmn/(2*pi*nr)); %net mechanical
output torque
Tmm=(3*Vph^2)/(4*pi*ns*(R1+sqrt(R1^2+Xs
h^2))); %max mech output torque (N-m)
I17=1.732*I1; I217=1.732*I21; I18=I1;
I218=I21;
if Conn==7
    I_1=I17; I_21=I217;
elseif Conn==8
    I_1=I18; I_21=I218;
End
Tms=Tmn*(Isc1/I_21)^2*s; %mech starting
torque on delta conn
sf=Prot/(Pmn + Prot + Pfw); %full-load
machine slip p.u.
sm=R21/(sqrt((R1^2)+(Xsh^2))); %siip at
maximum torque
sp=R21/(R21+Zsh); %siip at maximum
power
disp('FIND BELOW CADTECH DETAILS OF THE
MOTOR PERFORMANCE');
disp(' ');
disp('1] THE MOTOR CIRCUIT CURRENTS:');
Rated_Motor_Input_Line_Current_in_Amps=
I_1
Load_Component_of_Input_Line_Current_in
_Amps=I_21
No_Load_Input_Line_Current_in_Amps=Ioc1
Full_ShortCircuit_Line_Current_in_Amps=
Isc1
disp('2] THE MOTOR POWER LOSSES:');
Total_Copper_Losses_in_Watts=Psta+Prot
Total_Iron_Losses_in_Watts=Pir
Friction_and_Windage_Losses_in_Watts=Pf
w
disp('3] THE MOTOR POWER FACTORS:');
Rated_Motor_Input_Power_Factor_in_PerUn
it=pf
No_Load_Power_Factor_in_PerUnit=cos(Qoc
)
Short_Circuit_Power_Factor_in_PerUnit=c
os(Qsc)
disp('4] THE ACTIVE POWER
QUANTITIES:');
Gross_Mechanical_Output_Power_in_Watts=
Pmg
Net_Mechanical_Output_Power_in_Watts=Pm
n
Maximum_Mechanical_Output_Power_in_Watt
s=Pmm
disp('5] THE DEVELOPED TORQUE
DETAILS:');
Gross_Mechanical_Output_Torque_in_Nm=Tm
g
```

```
Net_Mechanical_Output_Torque_in_Nm=Tmn
Maximum_Mechanical_Output_Torque_in_Nm=
Tmm
Mechanical_Starting_Torque_in_Nm=Tms
disp('6] THE MOTOR EFFICIENCY:');
Machine_Percentage_Efficiency=eff
disp('7] THE MOTOR SLIP DATA:');
Machine_Full_Load_Slip_in_PerUnit=sf
Slip_for_Maximum_Output_Torque_in_PerUn
it=sm
Slip_for_Maximum_Output_Power_in_PerUni
t=sp
```

IV. LABORATORY TEST RESULTS

The laboratory test results of the 3-phase 48-slot, 4-pole induction motor, which are the primary input data to the computer program, are as given in Table 1.

Table 1: Open-Circuit and Short-Circuit Test Results

Type of Test	**Applied Voltage**	**Current Drawn**	**Power Consumed**	**Remarks**
Open-Circuit	V_{oc} = 307V	I_{oc} = 6.0A (line value)	P_{oc} = 510W	Motor connected in DELTA.
Short-Circuit	V_{sc} = 100V	I_{sc} = 38.0A (line value)	P_{sc} = 2115W	
D.C. Resistance	$r_{1a} = 0.72\Omega$, $r_{1b} = 0.72\Omega$ and $r_{1c} = 0.72\Omega$; Thus, $r_1 = 0.72\Omega$			Taken @ 35^0C
NB: *The supply voltage as measured was 307V (Line-to-Line, 3-phase).*				

V. RESULTS OF THE PROGRAM

I) Performance Parameters

Values of the performance parameters for the 48-slot 3-phase motor as obtained from MATLAB Workspace are given here for the perusal of the reader.

1) Rated Motor Input Line Current in Amps = 38.7520
2) Exciting No Load Line Current in Amps = 7.4267
3) Load Component of Input Line Current in Amps = 35.2336
4) Full Short-circuit Line Current in Amps = 144.4000
5) Total Copper Losses in Watts = 2.0805e+003
6) Total Iron Losses in Watts = 443.1615
7) Friction and Windage Losses in Watts = 278.6469
8) Rated Motor Input Power Factor in Per Unit = 0.9133
9) No Load Power Factor in Per Unit = 0.1599
10) Short Circuit Power Factor in Per Unit = 0.3214
11) Gross Mechanical Output Power in Watts = 2.0625e+004
12) Net Mechanical Output Power in Watts = 1.9903e+004
13) Maximum Mechanical Output Power in Watts = 3.4637e+004
14) Gross Mechanical Output Torque in Nm = 137.4910
15) Net Mechanical Output Torque in Nm = 132.6793
16) Maximum Mechanical Output Torque in Nm = 261.1644
17) Mechanical Starting Torque in Nm = 100.2849
18) Machine Percentage Efficiency = 87.6581
19) Machine Full Load Slip in Per Unit = 0.0459
20) Slip for Maximum Output Torque in Per Unit = 0.1724
21) Slip for Maximum Output Power in Per Unit = 0.1419

II) Performance Curves

The performance curves plotted using MATLAB were as follows.

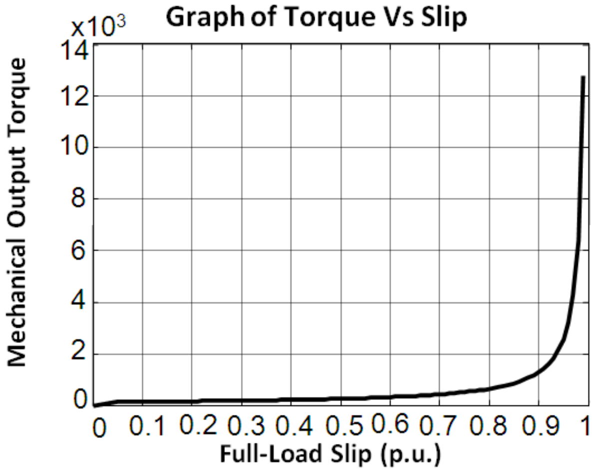

Fig.1. Torque Vs Slip Curve of the 48-Slot 3-Phase Motor

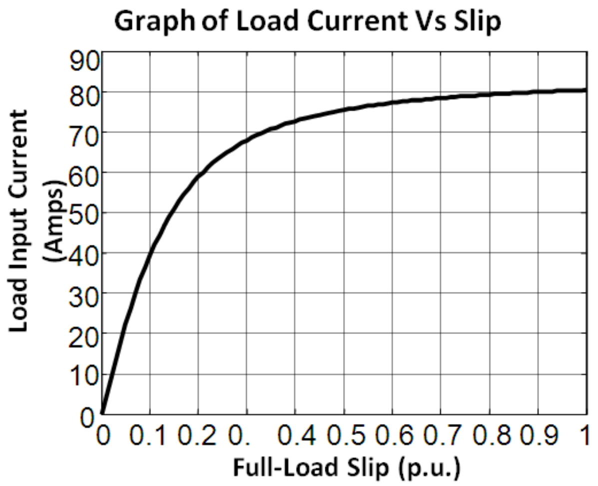

Fig.2. Current Vs Slip Curve of the 48-Slot 3-Phase Motor

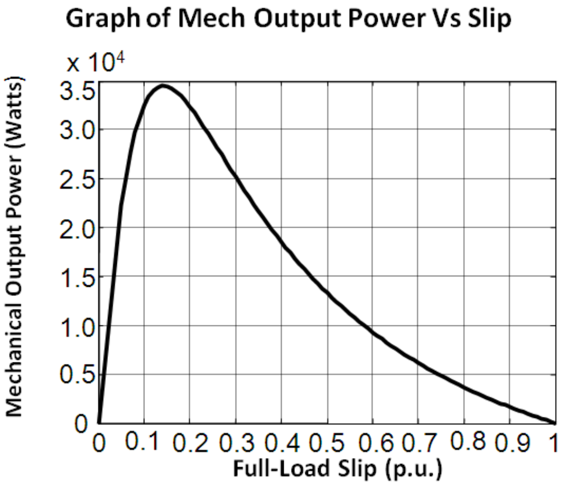

Fig.3. Output Power/Slip Curve of the 48-Slot 3-Phase Motor

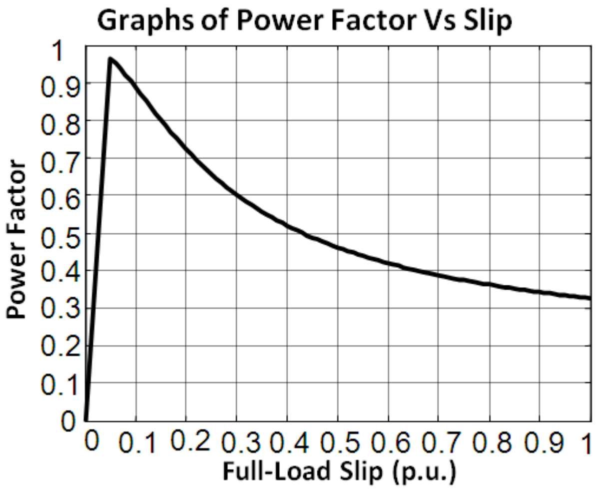

Fig.4. Power Factor/Slip Curve of the 48-Slot3-Phase Motor

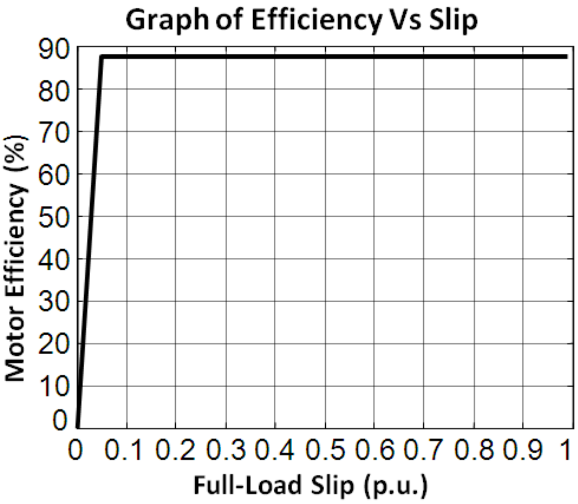

Fig.5. Efficiency Vs Slip Curve of the 48-Slot 3-Phase Motor

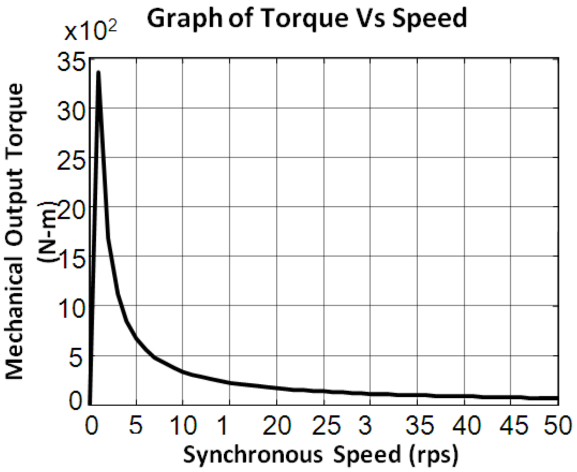

Fig.6. Torque Vs Speed Curve of the 48-Slot 3-Phase Motor

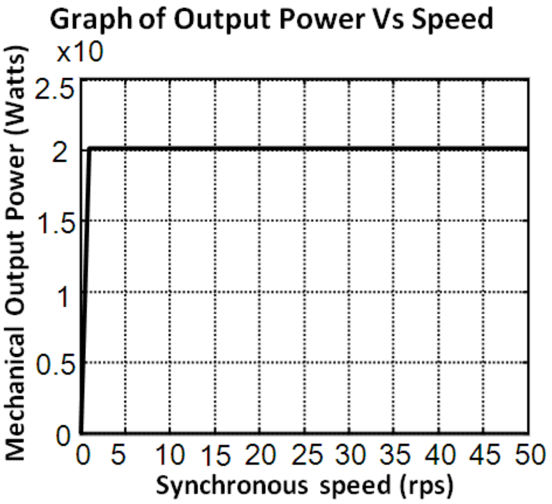

Fig.7. Output Power/Speed Curve of the 48-Slot 3-Phase Motor

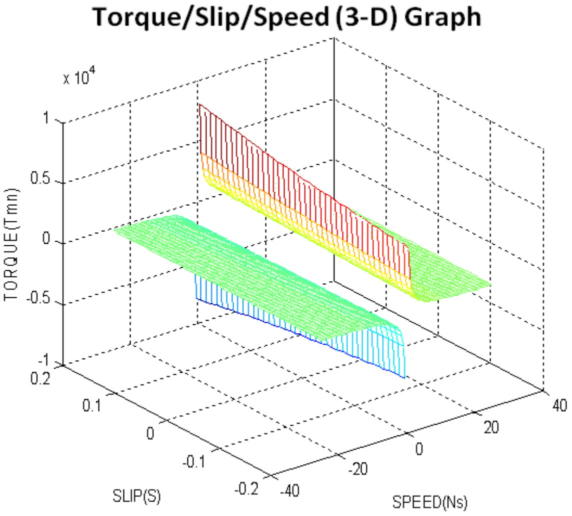

Fig.8. Torque/Slip/Speed (3-D) Curves of the 48-slot3-Phase Motor

VI. ANALYSIS AND CONCLUSION

1. Performance Analysis

A) Starting Performance:

The starting torque is 100.28N-m (i.e. 75.6% of full-load Net Mechanical Output Torque, T_{mN}). It ought to be up to 65.5%T_{mN} according to *[16, p.238]*. Clearly, a good starting torque is exhibited by this machine.

B) Running Performance:

The machine also have a goodand normal running capability judging from the value of the full-load torque T_{mN} (= 132.68N-m) which on the rated speed is 50.8%T_{mG} (gross mechanical output torque). For a standard, T_{mN} should not be less than 40%T_{mG}*[11, p.482]*.

C) Efficiency Consideration:

The efficiency on full load is 87.66%. This is satisfactory according to *[17, p.372]* medium size induction motors such as this should have efficiencies of 85 to 88%.

2. Conclusion

A comparison of the values of starting torque, running torque and efficiency obtained from the machine (as key performance parameters) with standard performance values as sourced from standard text, it is clear that the computer software application technique developed was satisfactory.

REFERENCES

[1] Say M. G. and Taylor E. O. (1980): *Direct Current Machines*, 1st Ed., London, Pitman Publishing Ltd.

[2] Krause P. C. (1986): *Analysis of Electric Machinery*; New York; McGraw-Hill Book Publishing Co. Ltd.; p.181-208.

[3] Buchingham H. and Price E. M. (1959): *Electro-Technology for National Certificate Courses*, Vol.111, London, English Universities Press Limited; p.227-228.

[4] Mehala N. (2010): *Condition Monitoring & Fault Diagnosis of Induction MotorUsing Motor Current Signature Analysis;*PhD Thesis, Electrical Engineering Department; National Institute of Technology, Kurukshetra, India; pp.10-35.

[5] Robinson J., Whelan C. D. and Haggerty N. K. (2004): *Trends in advanced motor protection and monitoring;* IEEE Transaction on Industry Applications, Vol. 40, No. 3, pp.853-860.

[6] Stefani A. (2010): *Induction Motor Diagnosis in Variable Speed Drives,* PhD Thesis in Electrical Engineering, University of Bologna, XXII Cycle; p.3-22.

[7] Shepherd J. Morton A. H. & Spence L. F. (1970): *Higher Electrical Engineering*, 2nd Ed., London, Pitman Publishing Limited; pp.435-483.

[8] Liwschitz-Garik M. and Whipple C. C. (19--): *Alternating Current Machines*, 2nd Ed., Princeton, New Jersey, D. Van Nostrand Co. Inc.

[9] Daniels A. R. (1976): *Introduction to Electrical Machines*, Maiden Ed.,London, Macmillan Press Limited; p.75-111.

[10] Say M. G. (1976): *Alternating Current Machines*, 4th Ed., London, Pitman Publishing Limited; p.250-365.

[11] Kostenko M and Piotrovsky L. (1977): *Electrical Machines*, vol. 2, Moscow, Mir Publishers; p.413-482; 519-534; 577-585.

[12] IEC 60034-1(2004): *Rotating Electrical Machines Part 1: Rating and Performance*; Geneva; International Electrotechnical Commission.

[13] Saadat H. (1999): *Power System Analysis*, New Delhi, Tata McGraw-Hill Co.; p.586-637.

[14] Okoro O. I. (2005): *Introduction to MATLAB/SIMULINK for Engineers and Scientists*, Nsukka-Nigeria, John Jacob's Classic Publishers Ltd.; p. 01.

[15] Hahn B. D. (1997): *Essential MATLAB forScientist and Engineers*, 1st Ed., London, Arnold Publication.

[16] Murthy K. M. V. (2008): *Computer-Aided Design of Electrical Machines*; Sultan Bazar; BS Publishers; p.223-318.

[17] Mittle V. N. & Mittal A. (1996): *Design of Electrical Machines*, 4th Ed., NaiSarak, Delhi, Standard Publishers Distributors; p.321-472.

AUTHORS' PROFILE

Ike Samuel Amaechi holds a Ph.D. in Electrical Power and Machines Engineering of the University of Benin, Benin City, Edo State, Nigerian. He is an associate professor and currently the Acting Director of Advance Digital Engineering Centre, University of Benin, Benin City, Edo State, Nigeria. He has published several research papers in both local, national and international peer reviewed journals. He is a registered member of Nigerian Society of Engineers (NSE) and Council for the Regulation of Engineering in Nigeria (COREN).
Email: sam.ike@uniben.edu

Enyong Peter Michael is a Chief Lecturer in the Department of Electrical/Electronic Engineering of Auchi Polytechnic, Auchi.He hails from Uruan LGA via Uyo Capital City of Akwa-Ibom State,Nigeria. He was born on 15th January, 1955; had his B.Eng. (Electrical/Electronic Engineering) in 1982 from University of Nigeria, Nsukka; obtained an M.Eng.(Power/Machines) in 2008 from University of Benin, Benin-City, Nigeria; and currently on his Ph.D. programme. He is a registered member of Nigerian Society of Engineers (NSE), and Council for the Regulation of Engineering in Nigeria (COREN).