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Determination of Induction Machine Parameters by Simulation

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ABSTRACT*: A 38.1 Watt fractional horse power induction laboratory test motor model was created using MotorSolve 5.2; an electrical machine design application. Initial machine parameters such as voltage, speed, and main dimensions were selected and fed into the application and simulations ran. The simulated results were presented and analyzed. Unlike other induction machine parameter identification process, this method is simple, flexible and accurate since it does not involve rigorous mathematical manual computations and derivations and can be fine tuned to the best quality by adjusting precision accuracy algorithm embedded in the application. The (FE) finite element block of the machine design application performs all iteration internally and displays the result graphically as well as in discrete form.*

Keywords*: Simulation, Induction Motor, Parameter identification, Finite Element Analysis.*

I. INTRODUCTION

Induction motors are the power horse of industrial revolution and continuous process applications as well as automotive applications; hence various studies had been carried out on their structure, production controls and applications. In recent times the world population had grown beyond imagination despite natural and artificial disasters. These large numbers and the unwitting quest of man to explore the world to its fullest and attain perfection had placed unprecedented demand on design precision. To this effect, technology had continued to place emphasis on design accuracy, a challenge which had led engineers and scientist to develop high precision design applications which are capable of performing large number of mathematical computations within minutes, second or even milliseconds and with lofty accuracy.

Finite Element Applications (FEA) are widely used to arrive at high quality design parameters. Finite Element design application which incorporates 3D modeling interface dedicated to induction machine design was used to determine the parameters of the chosen design in this paper as described below. Other FE applications such as, AnsysMultiphysics, COMSOLMultiphysics, ElectNet, according to [1], Flux, SPEED etc can as well be used to perform induction machine parameter identification. It further described the use of Linear Time Harmonics Vector Field Potentials to determine motor parameters.

Traditionally, induction motor parameter was determined by three basic laboratory tests on prototype machine according to [2]. These tests; DC Resistance test, Locked Rotor Test, and No Load Test, were time consuming, expensive as prototype machines have to be constructed, and the laboratory equipments necessary to carry out the test and measure all the parameters of interest must be assembled, though the method proved resourceful before the advent of virtual simulators which are now capable of carrying out those task.

In finite element systems, the double cage model is found to give a better approximation of the parameters required to design and construct an induction motor fairly accurate [3]. [4] indentified inductions motor parameter using free acceleration and deceleration test results similar to the test described in [2] above. [5] and [6] estimated induction motor parameter by measuring transient stator current alone and applying varying degrees of mathematical optimization algorithms. [7] presented machine parameter identification by means of classical induction motor model used mostly in control applications and involves matrix vector formulation of machine parameters and minimizing them using least square methods. [8] applied modified particle swarm optimization theory to determine induction motor parameters. [9] in his dynamic model of induction motor parameters adopted the same principle of classical model to determine motor parameters as was used in [7]. [10] conventionally presented induction motor parameters using manual computations by specifying some initial parameters and working out induction motor parameters using conventional formulae.

All these models stated here and various others lists unending, that have been applied to induction motor parameter identification, non is as simple and straight forward as the simulations process described in this article.

II. MOTOR MODEL

Initial Parameter/ Rating

Voltage	=	100 Volts
Phase	=	3 Ø
Frequency	=	50Hz
No of Poles	=	4 poles
Synchronous Speed	=	1800 rpm
Power Rating	=	38.1 or 0.1 HP
R_1	=	Stator Resistance
L_1	=	Stator Inductance
R_2	=	Rotor Resistance
L_2	=	Rotor Inductance

A three dimensional as well as x-y view of the motor model is shown below.

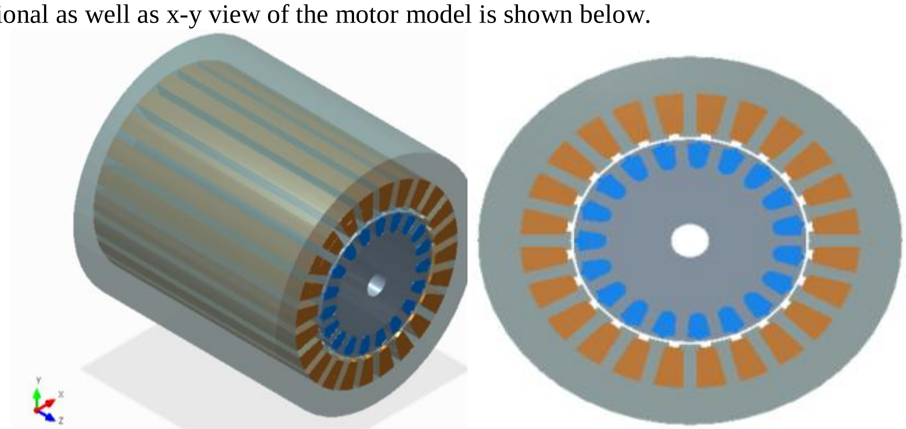

Figure 1: 3-D and x-y view of the induction motor model

The equivalent circuit model of the motor shown above is illustrated below. R_1, L_1, represents stator resistance and inductance respectively. R_2 and L_2 stands for rotor resistance and inductance. M represents the magnetizing inductance of the machine which may account for eddy current loss and the shunt resistor R_c is used to model the core (iron) loss as in the case of standard transformer model [3]. V_0 is the applied 3-phase voltages and I_1, I_c, I_M, and I_2 represents current distribution. *S* indicates slip as the rotor resistance varies with motor speed.

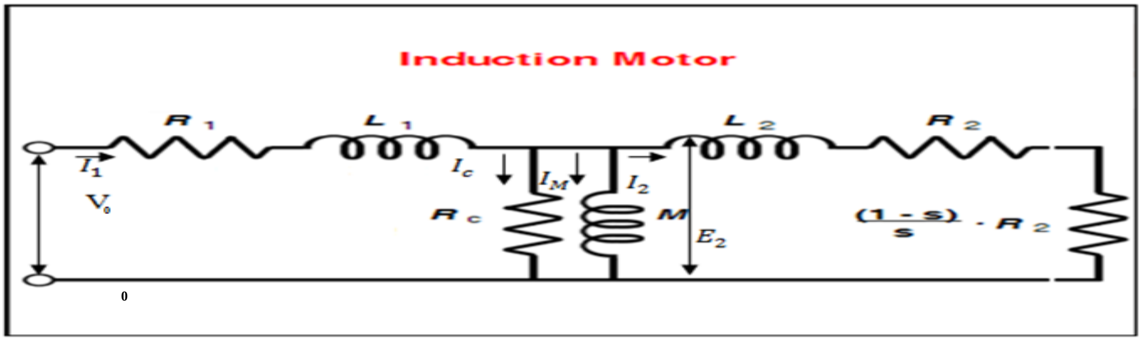

Figure 2: Equivalent circuit model of the induction motor.

III. MOTOR EQUATIONS

Input power;

$$P = 3VI\cos\emptyset \quad (1)$$

$$P = T\omega \quad (2)$$

Where $V, I, \cos\emptyset, T\ and\ \omega$ are voltage, current, power factor, Torque and rotor spindle speed respectively.

Impedance;

The parallel branch circuit impedance;

$$\frac{1}{Z} = \left(\frac{1}{R_C} + \frac{1}{R_2} + \frac{1}{(1-s)R_2/S}\right) + j\left(\frac{1}{M} + \frac{1}{L_2}\right) \quad (3)$$

Simplifying gives;

$$Z = \frac{\left(R_C + R_2 + \frac{(1-S)R_2}{S}\right) * j(M + L_2)}{\left(R_C + \frac{(SR_2 + R_2 + SR_2)}{S}\right) + j(M + L_2)} \quad (4)$$

$$Z = \frac{\left(R_C + \frac{R_2}{S}\right) * j(M + L_2)}{\left(R_C + \frac{R_2}{S}\right) + j(M + L_2)} \quad (5)$$

$$\therefore\ Z_T = R_1 + jL_1 + \left[\frac{\left(R_C + \frac{R_2}{S}\right) * j(M + L_2)}{\left(R_C + \frac{R_2}{S}\right) + j(M + L_2)}\right] \quad (6)$$

Normalizing to remove the complex variable j from the denominator yields,

$$Z_T = R_1 + jL_1 + \left[\frac{\left(R_C + \frac{R_2}{S}\right) * j(M + L_2)}{\left(R_C + \frac{R_2}{S}\right) + j(M + L_2)}\right] * \left[\frac{\left(R_C + \frac{R_2}{S}\right) - j(M + L_2)}{\left(R_C + \frac{R_2}{S}\right) - j(M + L_2)}\right] \quad (7)$$

$$Z_T = R_1 + jL_1 + \left[\frac{\left(j\left(R_C + \frac{R_2}{S}\right)^2 * (M + L_2)\right) - \left(j^2\left(R_C + \frac{R_2}{S}\right)(M + L_2)^2\right)}{\left(R_C + \frac{R_2}{S}\right)^2 + (M + L_2)^2}\right] \quad (8)$$

$$Z_T = R_1 + jL_1 + \left[\frac{\left(\left(R_C + \frac{R_2}{S}\right)(M + L_2)^2\right) + \left(j\left(R_C + \frac{R_2}{S}\right)^2 * (M + L_2)\right)}{\left(R_C + \frac{R_2}{S}\right)^2 + (M + L_2)^2}\right] \quad (9)$$

Starting torque in terms of machine parameters;

Let E_2 = Rotor e.m.f per phase developed at standstill

R_2 = Rotor resistance per phase

L_2 = Rotor inductance per phase at standstill.

$Z_{Tr} = \sqrt{(R^2{}_2 + L^2{}_2)}$ = Rotor impedance per phase at standstill.

Then;

$$I_2 = \frac{E_2}{\sqrt{(R^2{}_2 + L^2{}_2)}} \quad (10)$$

$$\cos\emptyset = \frac{R_2}{Z_{Tr}} = \frac{R_2}{\sqrt{(R^2{}_2 + L^2{}_2)}} \quad (11)$$

Therefore starting torque becomes;

$$T_{st} = k_1 E_2 I_2 \cos\emptyset \quad (12)$$

This implies that;

$$T_{st} = k_1 E_2 * \frac{E_2}{\sqrt{(R^2{}_2 + L^2{}_2)}} * \frac{R_2}{\sqrt{(R^2{}_2 + L^2{}_2)}} = \frac{k_1 E_2{}^2 R_2}{(R^2{}_2 + L^2{}_2)} \quad (13)$$

But;

$$k_1 = \frac{3}{2\pi N_s} \quad (14)$$

where N_s is the synchronous speed.

This implies that;

$$T_{st} = \frac{3}{2\pi N_s} * \frac{E_2{}^2 R_2}{(R^2{}_2 + L^2{}_2)} = \frac{3E_2{}^2 R_2}{2\pi N_s (Z_{Tr})^2} \quad (15)$$

Dynamic Torque in terms of machine parameters;

When the machine rotor is on motion, the induced emf and the rotor reactance or inductance is reduced by slip value represented by S [11]. Hence dynamic torque or torque under running condition will also be limited by slip as shown in the relation below.

$$T_D = \frac{3S{E_2}^2 R_2}{2\pi N_s (SZ_{Tr})^2} \tag{16}$$

At standstill, the motor draws double it's running current before starting known as the starting current and gradually reduces as the motor gathers speed, but is directly proportional to slip since slip action is opposite to that of speed. This is indicated in the relation and figure 5 below;

$$I \propto \frac{S}{N_s} \tag{17}$$

where s - slip and N_s synchronous speed.

Efficiency and torque relationship to speed and slip is a hyperbolic function stated below.

IV. MODEL PARAMETER COMPUTATION

With three built in model parameter calculation algorithms; the classical, the conventional and the inductance matrix algorithms, FE automatically computes the crucial parameters of the induction machine as represented in the equivalent circuit diagram redrawn in figure 3 below showing values.

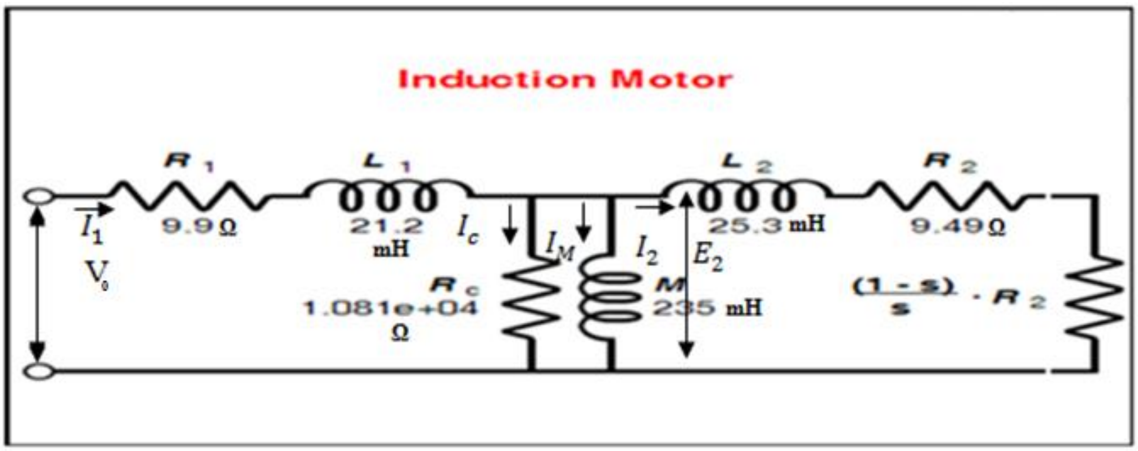

Figure 3: Equivalent circuit model of the induction motor after computation

When the model contains rotor bars with skew, inductance matrix method is usually used for parameter computation irrespective of the method selected by the machine designer. This is because it takes into cognizance the magnetizing and leakage inductances, thus producing a more accurate result. The table 1 below shows the parameter values computed to varying degrees of decimal approximation. Figure 4 and table 2 show the name plate data.

Table 1: Equivalent circuit data table

Values	
R1	9.901026594 Ω
R2	9.489735585 Ω
Rc	10806.40833 Ω
L1	21.17636636 mH
L2	25.2633269 mH
M	235.0822367 mH

Phase	3	Hz	60
Volts	100	RPM	1710
Amps	0.641	HP	0.0508
Power Factor	0.477	Efficiency	71.6

Figure 4: Name plate data simulated from MotorSolve

Table 2: Nameplate data

Values	
Phase	3
Frequency	60 Hz
Voltage	100 V
RPM	1710 rpm
Current	0.640635467 A
Horsepower	0.050844399 hp
Power factor	0.477105111
Efficiency	71.61790111 %

V. SIMULATION RESULTS

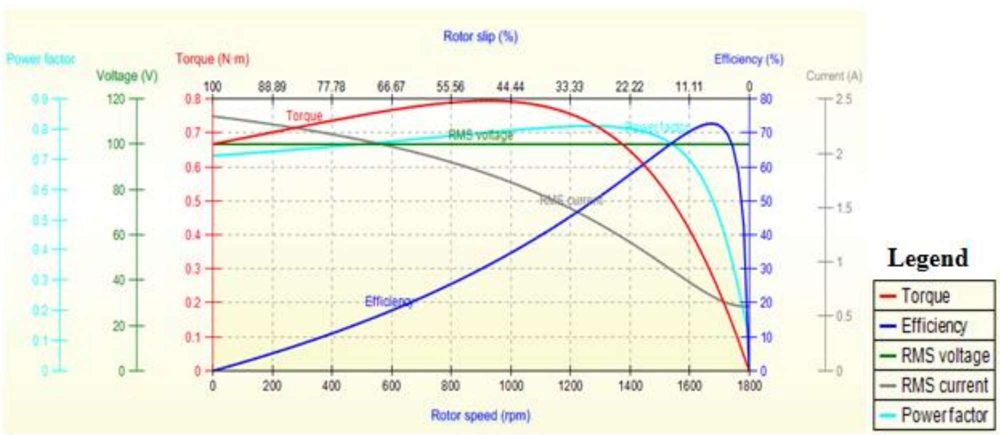

Figure 5: Composite plot of Power factor, Voltage, Torque, Efficiency and Current against Rotor speed and Slip in (%).

It can be seen from the torque curve above that when slip = 0%, torque also = 0%; hence the curve start from zero. At synchronous or close to synchronous speed, the term sL_2 is small compared to R_2. Therefore torque is directly proportional to slip(s) and inversely proportional to R_2. As slip increases, torque increases as well. If R_2 is kept constant, we obtain a straight line relation seen between zero and about 20% slip in figure 5 above. Increase in torque continues as slip increases (more motor load), until maximum torque, pull-out or breakdown is reached at about 44-55% slip. Any increase in motor load or slip beyond this point slows down the motor thereby reducing the torque developed by the motor.

The power factor curve shows that the motor has a power factor of 0.7-0.8 with maximum power factor achieved at synchronous speed or near synchronism. The efficiency of the motor increases as the motor accelerates and become maximum at synchronous speed as shown in figure 5 above. With the presence of drive circuit, the voltage used by the motor for its operation is constant as shown but the current wave form indicates high current at starting which is an indication that the motor resultant reactance is low at this stage but increases as the motor speed and temperature increases. It is also very clear that induction motor draws double the current required to run it normally during start up.

Table 3: Data used to plot composite characteristic of figure 5

S/N	Rotor speed (rpm)	Rotor slip (%)	Torque (N·m)	Efficiency (%)	RMS Voltage (V)	RMS current (A)	Power factor
1	1800	0	0	0	100	0.593999144	0.110797571
2	1782	1	0.045659935	42.74063487	100	0.592457956	0.194273015
3	1764	2	0.089677061	58.38708377	100	0.596857009	0.274448497
4	1746	3	0.132032725	65.79050517	100	0.606748708	0.349157791
5	1728	4	0.172717425	69.62868573	100	0.621556859	0.41694505
6	1710	5	0.211730067	71.61790111	100	0.640635467	0.477105111
7	1692	6	0.249077212	72.53566323	100	0.663323191	0.529572686
8	1674	7	0.284772315	72.784883	100	0.688985148	0.57473833
9	1656	8	0.31883498	72.59486396	100	0.7170396	0.613260862
10	1638	9	0.351290228	72.10544502	100	0.746971249	0.645915952
11	1620	10	0.382167796	71.40654511	100	0.778334676	0.673492389
12	1602	11	0.411501465	70.55844837	100	0.810751554	0.696730907
13	1584	12	0.439328437	69.60295065	100	0.84390453	0.716294332
14	1566	13	0.465688742	68.56983456	100	0.877529767	0.732757932
15	1548	14	0.490624692	67.48080747	100	0.911409354	0.746611365
16	1530	15	0.514180389	66.35199073	100	0.945364223	0.758266397
17	1512	16	0.536401265	65.19554565	100	0.979247856	0.76806685
18	1494	17	0.557333671	64.02076618	100	1.012940872	0.776298787
19	1476	18	0.577024517	62.83483157	100	1.046346444	0.78319996
20	1458	19	0.595520938	61.64333613	100	1.079386468	0.788968105
21	1440	20	0.612870013	60.45066936	100	1.111998384	0.793767997
22	1422	21	0.62911851	59.2602934	100	1.144132539	0.797737331
23	1404	22	0.644312675	58.0749487	100	1.175750015	0.80099157
24	1386	23	0.658498042	56.89680847	100	1.206820826	0.803627901
25	1368	24	0.671719282	55.72759628	100	1.237322425	0.805728468
26	1350	25	0.684020071	54.56867648	100	1.267238471	0.807362986
27	1332	26	0.695442983	53.42112449	100	1.296557796	0.80859088
28	1314	27	0.706029408	52.28578195	100	1.325273544	0.809463016
29	1296	28	0.715819485	51.16330034	100	1.353382459	0.810023117
30	1278	29	0.724852054	50.05417582	100	1.380884279	0.810308918
31	1260	30	0.733164623	48.95877711	100	1.407781226	0.810353115
32	1242	31	0.740793343	47.87736813	100	1.434077584	0.810184147
33	1224	32	0.747773004	46.81012633	100	1.459779338	0.809826838
34	1206	33	0.754137033	45.75715771	100	1.484893864	0.809302933
35	1188	34	0.759917499	44.71850917	100	1.509429674	0.80863154
36	1170	35	0.765145134	43.69417869	100	1.533396196	0.807829504
37	1152	36	0.76984935	42.68412376	100	1.556803585	0.806911721
38	1134	37	0.774058268	41.6882684	100	1.579662567	0.805891391
39	1116	38	0.777798748	40.70650904	100	1.601984301	0.80478025
40	1098	39	0.781096418	39.73871941	100	1.623780268	0.803588752
41	1080	40	0.783975716	38.78475468	100	1.645062169	0.802326233
42	1062	41	0.786459924	37.8444549	100	1.665841846	0.801001045
43	1044	42	0.788571207	36.91764798	100	1.686131207	0.799620674
44	1026	43	0.790330655	36.00415207	100	1.705942174	0.798191843

45	1008	44	0.79175832	35.10377776	100	1.725286625	0.7967206
46	990	45	0.79287326	34.21632976	100	1.744176357	0.795212391
47	972	46	0.793693577	33.34160846	100	1.76262305	0.793672128
48	954	47	0.794236457	32.47941117	100	1.780638236	0.792104246
49	936	48	0.79451821	31.62953322	100	1.798233276	0.790512755
50	918	49	0.794554308	30.79176885	100	1.815419342	0.788901283
51	900	50	0.794359423	29.96591203	100	1.832207398	0.787273112
52	882	51	0.793947465	29.15175705	100	1.84860819	0.785631221
53	864	52	0.793331615	28.34909913	100	1.864632234	0.783978305
54	846	53	0.79252436	27.55773486	100	1.880289811	0.782316812
55	828	54	0.791537528	26.77746258	100	1.895590961	0.780648963
56	810	55	0.790382318	26.00808274	100	1.910545479	0.778976771
57	792	56	0.789069335	25.24939812	100	1.925162912	0.777302065
58	774	57	0.787608613	24.50121411	100	1.939452562	0.775626504
59	756	58	0.786009648	23.76333884	100	1.953423483	0.773951593
60	738	59	0.784281427	23.03558336	100	1.967084484	0.772278697
61	720	60	0.782432447	22.31776173	100	1.980444132	0.770609054
62	702	61	0.780470748	21.60969114	100	1.993510752	0.768943785
63	684	62	0.778403931	20.91119193	100	2.006292434	0.767283907
64	666	63	0.776239183	20.22208771	100	2.018797036	0.765630336
65	648	64	0.773983299	19.54220531	100	2.031032185	0.763983904
66	630	65	0.771642701	18.87137484	100	2.043005288	0.762345359
67	612	66	0.769223458	18.20942971	100	2.05472353	0.760715375
68	594	67	0.766731306	17.55620656	100	2.066193884	0.759094558
69	576	68	0.764171664	16.91154533	100	2.077423113	0.757483454
70	558	69	0.761549652	16.27528915	100	2.088417778	0.755882549
71	540	70	0.758870105	15.64728439	100	2.09918424	0.754292278
72	522	71	0.756137591	15.02738057	100	2.109728671	0.752713028
73	504	72	0.753356421	14.41543033	100	2.12005705	0.751145141
74	486	73	0.750530668	13.8112894	100	2.130175178	0.749588918
75	468	74	0.747664176	13.21481657	100	2.140088678	0.748044626
76	450	75	0.744760574	12.62587358	100	2.149803	0.746512495
77	432	76	0.741823287	12.04432516	100	2.159323429	0.744992724
78	414	77	0.738855544	11.47003886	100	2.168655088	0.743485484
79	396	78	0.735860396	10.90288513	100	2.177802942	0.741990918
80	378	79	0.732840718	10.34273716	100	2.186771806	0.740509148
81	360	80	0.729799221	9.789470857	100	2.195566346	0.73904027
82	342	81	0.726738462	9.242964818	100	2.204191089	0.737584361
83	324	82	0.723660854	8.703100241	100	2.21265042	0.736141481
84	306	83	0.720568666	8.169760881	100	2.220948593	0.73471167
85	288	84	0.717464041	7.642832992	100	2.229089733	0.733294954
86	270	85	0.714348994	7.122205277	100	2.237077837	0.731891343
87	252	86	0.711225425	6.60776883	100	2.244916784	0.730500836
88	234	87	0.708095123	6.099417082	100	2.252610335	0.729123418
89	216	88	0.704959769	5.59704575	100	2.260162139	0.727759064

90	198	89	0.701820949	5.100552783	100	2.267575732	0.726407738
91	180	90	0.69868015	4.609838311	100	2.274854547	0.725069395
92	162	91	0.695538773	4.124804593	100	2.282001915	0.723743984
93	144	92	0.692398135	3.645355972	100	2.289021065	0.722431442
94	126	93	0.689259471	3.171398817	100	2.295915133	0.721131702
95	108	94	0.686123943	2.702841486	100	2.30268716	0.71984469
96	90	95	0.68299264	2.23959427	100	2.309340099	0.718570327
97	72	96	0.679866583	1.781569353	100	2.315876816	0.717308528
98	54	97	0.676746731	1.328680762	100	2.322300092	0.716059203
99	36	98	0.673633981	0.880844328	100	2.328612629	0.714822259
100	18	99	0.670529173	0.437977639	100	2.334817049	0.713597598
101	0	100	0.667433094	0	100	2.340915897	0.712385121

VI. HEAT CAPACITY MODEL

Every matter has a certain amount of heat it can withstand over a given period of time before changing state; known as the heat capacity. If the temperature of the body is not exceeded far beyond acceptable limit within the operating time, the heat capacity of the body remains constant.

Let C = heat capacity in Joules per Kg per ^{0}C

θ = Maximum temperature the body can withstand in time t.

t = Operating time

The heat capacity can be related to the temperature and operating time as follows;

$$\mathrm{C} \propto \theta t; \Rightarrow \mathrm{C} = h\theta t \qquad (20)$$

where h is a constant of proportionality known as specific heat capacity. A plot of C against time t figure 6 below, show constant range of values provided maximum permissible temperature and operating time are not exceeded beyond acceptable limit for each individual motor part.

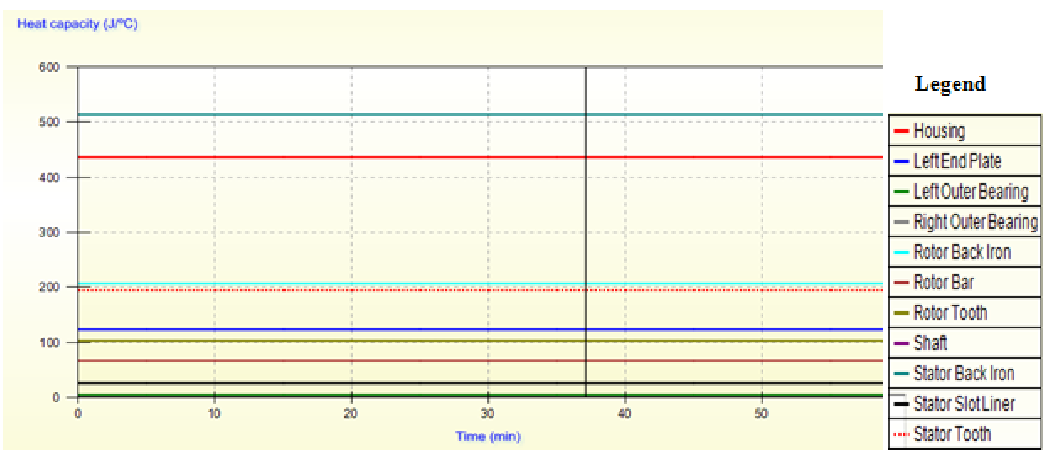

Figure 6: Composite plot of motor material Heat Capacity against operation time.

VII. THERMAL MODEL OF THE MOTOR

A simple thermal model, assuming a homogeneous body of motor can be obtained as follows [12]:

At time't', let the motor has following parameters

Q_1 = Heat developed, Joules/sec or watts,

Q_2 = Heat dissipated to the cooling medium, watts,

W = Weight of the active parts of the machine.

h = Specific heat, Joules per Kg per ^{0}C.

S = Cooling Surface, m^2

d = Co-efficient of heat transfer, Joules/Sec/m^2/^{0}C

θ = Mean temperature rise ^{o}C

At time dt, let the temperature rise of the machine be dθ, Therefore, heat absorbed by the machine = (Heat generated inside the machine – Heat dissipated to the surrounding)
Where,

$$d\theta = [Q_1 - Q_2]dt \qquad (21)$$

Since,

$$Q_2 = \theta dS \qquad (22)$$

Substituting (ii) into (i), gives

$$C\frac{d\theta}{dt} = Q_1 - D\theta \qquad (23)$$

Where $C = hW$ and $D = dS$.
C is the thermal heat capacity of the machine in watts/ºC and D is the heat dissipation constant in watts/ºC.
The first order differential equation of the equation – above is stated below

$$\theta = \nexists_{ss} + Ke^{-t/\tau} \qquad (24)$$

Where

$$\nexists_{ss} = {Q_1}/{D} \ and\ \tau = {C}/{D} \qquad (25)$$

To solve for K we put t = 0 in equation (iii) and the solution becomes

$$\theta = \nexists_{ss}\left[1 - Ke^{-t/\tau}\right] + \theta_1 e^{-t/\tau} \qquad (26)$$

Represented in the graph of figure 7 is the graph of temperature characteristics of selected machine parts which are based on the relation of equation (23) above.

Table 4: Data used to plot composite heat capacity of figure 6

S/N	Time (min)	Housing (ºC)	Hub (ºC)	Rotor Back Iron (ºC)	Rotor Bar (ºC)	Rotor Tooth (ºC)	Shaft (ºC)	Stator Back Iron (ºC)	Stator Slot Liner (ºC)	Stator Tooth (ºC)
1	0	20	20	20	20	20	20	20	20	20
2	7.5	20.740134	20.3807291	20.64631764	20.6665051	20.66546463	20.109777	21.1768267	21.38872508	21.33542628
3	15	22.450405	21.8623245	22.35690022	22.3782412	22.37720516	21.1214619	23.1334383	23.36895788	23.30476687
4	20	23.158608	23.0355191	23.32452769	23.3275363	23.32767126	22.439803	23.48923	23.53543385	23.52585457
5	27.5	23.761875	23.7065358	24.03986358	24.0597062	24.05866093	23.2487472	24.2850971	24.52369239	24.47184459
6	35	25.32079	25.0155945	25.54548377	25.5656691	25.56459815	24.186265	26.1140327	26.38119709	26.31932709
7	40	25.913213	26.0676885	26.3931432	26.3947021	26.39480143	25.3721243	26.3426564	26.41543533	26.40818598
8	47.5	26.356402	26.5716218	26.93924441	26.9582899	26.95721161	26.027432	26.9806371	27.25002905	27.20002642
9	55	27.773216	27.7302135	28.29500587	28.3142131	28.3131145	26.809709	28.663394	28.95823003	28.89838841
10	60	28.256897	28.6628241	29.02222061	29.022477	29.02254214	27.877551	28.7777325	28.8756689	28.87055665

Table 5: Data used to plot composite temperature characteristics of figure 7

S/N	Time (min)	Housing (J/ºC)	Left End Plate (J/ºC)	Left Outer Bearing (J/ºC)	Right Outer Bearing (J/ºC)	Rotor Back Iron (J/ºC)	Rotor Bar (J/ºC)	Rotor Tooth (J/ºC)	Shaft (J/ºC)	Stator Back Iron (J/ºC)	Stator Slot Liner (J/ºC)	Stator Tooth (J/ºC)
1	0	436.1886443	123.7089235	4.524155629	4.524155629	206.5332797	67.047453	102.8832267	2.9667789	514.1745189	25.9614234	194.3538751
2	5	436.1886443	123.7089235	4.524155629	4.524155629	206.5332797	67.047453	102.8832267	2.9667789	514.1745189	25.9614234	194.3538751
3	10	436.1886443	123.7089235	4.524155629	4.524155629	206.5332797	67.047453	102.8832267	2.9667789	514.1745189	25.9614234	194.3538751
4	15	436.1886443	123.7089235	4.524155629	4.524155629	206.5332797	67.047453	102.8832267	2.9667789	514.1745189	25.9614234	194.3538751
5	20	436.1886443	123.7089235	4.524155629	4.524155629	206.5332797	67.047453	102.8832267	2.9667789	514.1745189	25.9614234	194.3538751
6	25	436.1886443	123.7089235	4.524155629	4.524155629	206.5332797	67.047453	102.8832267	2.9667789	514.1745189	25.9614234	194.3538751
7	30	436.1886443	123.7089235	4.524155629	4.524155629	206.5332797	67.047453	102.8832267	2.9667789	514.1745189	25.9614234	194.3538751
8	35	436.1886443	123.7089235	4.524155629	4.524155629	206.5332797	67.047453	102.8832267	2.9667789	514.1745189	25.9614234	194.3538751
9	40	436.1886443	123.7089235	4.524155629	4.524155629	206.5332797	67.047453	102.8832267	2.9667789	514.1745189	25.9614234	194.3538751
10	45	436.1886443	123.7089235	4.524155629	4.524155629	206.5332797	67.047453	102.8832267	2.9667789	514.1745189	25.9614234	194.3538751
11	50	436.1886443	123.7089235	4.524155629	4.524155629	206.5332797	67.047453	102.8832267	2.9667789	514.1745189	25.9614234	194.3538751
12	55	436.1886443	123.7089235	4.524155629	4.524155629	206.5332797	67.047453	102.8832267	2.9667789	514.1745189	25.9614234	194.3538751
13	60	436.1886443	123.7089235	4.524155629	4.524155629	206.5332797	67.047453	102.8832267	2.9667789	514.1745189	25.9614234	194.3538751

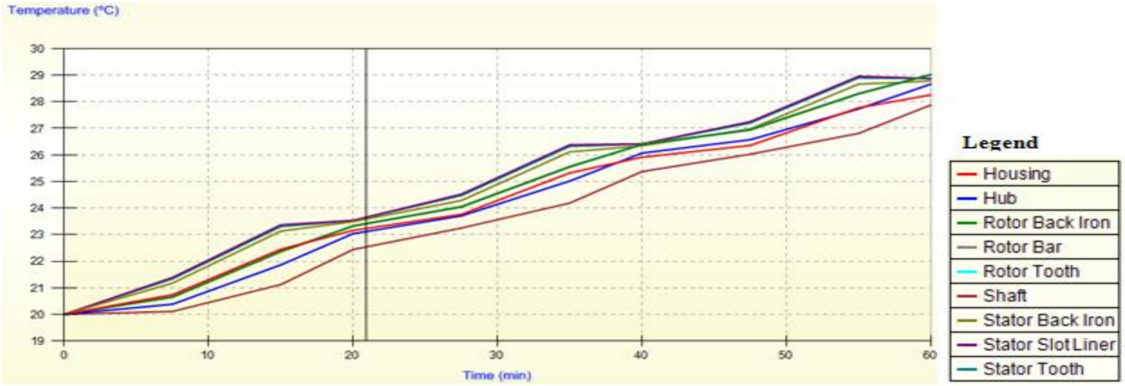

Figure 7: Plot of Temperature variation of selected motor parts against time

VIII. CONCLUSION

Various authors had written on induction motor parameter identification process and model, majority of which are highly complex and time consuming but this paper presented a model based on simulation using finite element analysis application. (FEA). The method is highly efficient in terms of time and value precision utilizing direct and easily discernible mathematical models to plot performance characteristics graphs. It is highly flexible as it offers means for model initial parameter variation and consequent re-calculation of required motor parameter with just click of a button. This method is suitable for laboratory experiments and tutorials with an insight into industrial experiments with moderate improvement in design.

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