Induction Motor Thermal Performance Analysis

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Abstract: The objective of this research is to apply a mathematical model with the help of lumped parameter method and to conduct different test on induction motor using MATLAB to calculate temperature distribution in induction motor elements to maintain induction motor thermal stability and to find out if operating conditions is sufficient for insulation of copper windings, to discover induction motor hottest element as it has vital effect on performance and operation of motor. It was eminent from thermal model analysis that rotor bars and end winding are hottest element in the induction motor, and the reason is rotor bar losses and stator copper losses as this depend on stator current, this current of stator could be increased by decreasing the stator frequency or by increasing applied torque, which results in increase of each element temperature. The induction motor thermal model is validated by analytical values and result obtained from the MATLAB simulation model values and obtained results validate the correctness of the anticipated thermal model has uncertainties of about 4% ~ 6%.

Keywords: *Induction motor, thermal model, electromagnetic model, heat transfer method,* Lumped parameter thermal networks

1. Introduction

Heat transfer behavior is very vital to model in the case of induction motor because this model defines the cooling ability of induction motor and subsequently the machine nominal power. heat transfer modeling is practically problematic to model accurately without finite element analysis (FEA) the reason is the three-dimensional complex geometries. In spite of the fact as microprocessors with high speed are available, 3D Finite element analysis for dynamic thermal analysis consume time, however analytical method of different kinds can be practical to model easily heat transfer in the machine instead. In industries electrical machines majority run continuously in this situation steady-state temperature is reached.

Power plant generator, ac motors, conveyors of different types, propulsion motors are some applications of these types. Electrical machines heat transfer of the system is often studied in steady state, and machine heat capacitances are neglected in the system model. This model of the system is suitable enough for accurately guessing temperature rise steady-state for the machine, though this cannot model during loading variations heat transfer mechanisms. High over loadings in the system will have high losses, as a result temperature gradients of the system are high. Hence, in the present research paper heat transfer analytical model of the induction motor is built, focal interest in the current research paper study is engrossed on mechanism of transient heat transfer in the state of loading variations. The method used in the study predict average temperature of the model pretty accurately.

This present research gives attention to the three-phase induction motor thermal analysis. During the induction motor operation losses in the system occurs due to heat these losses due heat are rotor losses, stator copper losses, iron losses. These losses affect performance and efficiency of induction motor, as the losses in induction motor could raise the temperature of induction motor to a limit larger temperature than permissible limit of the operational temperature this will result in problems like (a) Winding resistance will Rise and as a result of this I2R losses will increase. (b) This result in rise of temperature in stator winding insulation, this results in the turn to ground or turn to turn short circuit might happen.(c) A motor break down may happen due to thermal stresses these thermal stresses exist in the rotor (end rings, bars). (d) This increased temperature rise has straight effect on model service life. Service life will decrease as temperature rise higher. Squirrel cage induction motor is the type of induction motor, it is known as 'squirrel cage' because it looks like it.

The rotor inside of it is a cylinder of steel laminations aluminum or copper which are highly conductive metals When AC is pass through stator windings this produces a rotating magnetic field. The reason for using squirrel cage motor is due to its advantage that its speed-torque characteristics can easily be changed. It is done by adjusting bars shape in rotor. A squirrel cage induction motor has parts like Rotor, Stator, Bearings, and fan. They are used a lot in industry because of their ease of adjust reliability, better heat regulation, low cost, self-starting, require less maintenance, high efficiency, lightweight and

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explosion proof (as no brushes are used this eliminates risk of sparking).

2. Lumped parameter thermal networks

Lumped parameter thermal networks for electrical machines temperature distribution calculation is generally used. The LPTN is an analytical approach that describes the temperature distribution in different points of the machine. It is simple in terms of implementation. Furthermore, it is rapid, when compared to the numerical methods. Lumped parameter modeling requires less calculation time compared to Finite Element Analysis which is numerical method specifically in dynamic simulations and 3D modeling. The developer of thermal model must consider heat flow paths, geometry of machine, thermal parameters and parameters which are dependent on time. So, the thermal network as to be elaborated in proper physical way. Complete machine is usually characterized by using 10 to 30 machine nodes. The component average temperature is calculated, hot-spot temperature is not calculated. When MATLAB is used setup time is much reduced, thermal network of the model is created in Simulink automatically. Temperature distribution is further discrete into component level, feedback is used in the circuit to accurate temperature losses, constant temperature is taken for simplicity for loss calculation.

1 To implement a statistical model by the use of a lumped parameter thermal approach.
2 Experimental test to evaluate the temperature profile inside that induction motor.
3 To determine induction motor thermal stability and to test whether it is necessary to insulate the copper windings under various loading conditions.
4 To figure out the hottest component that has the main impact on the function and output of the motor.

3. Methodology

3.1 Electromagnetic model

3-phase induction motor analysis is simplified with the help of per-phase equivalent circuits. This circuit of the pre-phase is shown in Figure 1, this pre-phase circuit is similar to transformer equivalent circuit. The inputs are voltage, torque and frequency for the electromagnetic motor model and outputs of model are voltages and currents, slip and the electromagnetic torque. Losses in the machine component are calculated from differences in the voltages and currents values, this loss calculation between thermal parts and electromagnetic of the model is compared. These losses depend on the stator voltage and motor parameters slip, induction motor complete equivalent circuit model and requires analysis of the model including stator and rotor, Figure 1 represent this model.

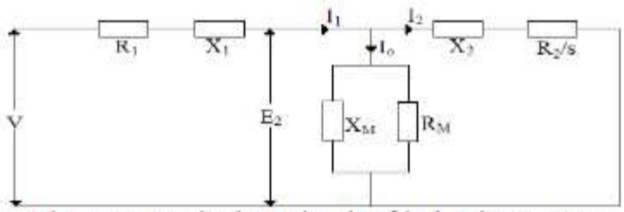


Figure 1- Equivalent circuit of induction motor

stator circuit in this equivalent circuit compromises of R_1 stator resistance, and as well as X_1 stator leakage reactance, resistance R_M ,this results for eddy current and hysteresis losses in the iron, X_M is the magnetizing reactance this is for the magnetizing element of exciting current. Whereas the rotor circuit in this equivalent circuit includes R_2 which is rotor resistance, and X_2 which is rotor leakage reactance. As shown in Figure 1 three currents are present in the circuit, one is the stator current represented byI_1 , other is the rotor current represented by I_2 , and the last is exciting current represented by I_0 these are divided two parts, core loss element of exciting current and magnetizing element of exciting current.

Losses of Induction motor can be easily calculated with the help of solving parameters of the equivalent circuit in Figure 1 for the E_2, I_1 and I_2 and by substituting these values in proper equations to calculate motor losses. To find the I_1 stator current, firstly stator impedance Z1 should be determine, as well as Z_2 rotor impedance and Z_0 magnetizing impedance.

Stator impedance is obtained in equation (1)

$$Z_1 = R_1 + jX_1 \tag{1}$$

Rotor impedance is obtained from equation (2)

$$Z_2 = \frac{R_2}{s} + jX_2 \tag{2}$$

Magnetizing impedance is obtained from equation (3)

$$Z_0 = \frac{R_m * jX_m}{R_m + jX_m} \tag{3}$$

Z_p which is equivalent impedance is calculated as in equation (4)

$$Z_p = \frac{Z_2 * Z_0}{Z_2 + Z_0} \tag{4}$$

At last total equivalent impedance is calculated as

$$Z_{in} = Z_1 + Z_p \tag{5}$$

By applying ohms law on figure 2 circuit magnitude of stator impedance is calculated as in equation (6)

$$I_1 = \frac{V}{Z_{in}} \tag{6}$$

Figure 2 - Equivalent circuit of induction motor with total impedance.

Voltage induced in in rotor in E2 rotor is determined as

$$E_2 = I_1 Z_p \quad (7)$$

I2 is rotor current is determined by applying ohms law on figure 2 circuit

$$I_2 = \frac{E_2}{Z_2} \quad (8)$$

3.2 calculation of heat losses

In the case of induction motor, when it is running for the moving weight associated on induction motor shaft, then losses occur, this acts as source for heat and is scattered through the entire induction motor and this differs in different operating conditions. The induction motor power losses comprise of central aspects represented in Figure 3.

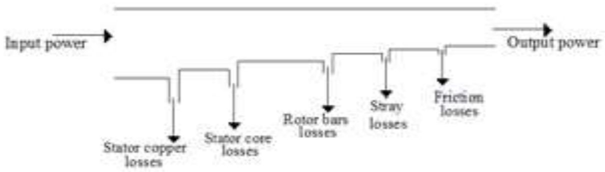


Figure 3- Flow chart of the heat losses

Losses of stator copper: heat generated when the current pass-through motor stator winding result in rise of temperature, this rise in temperature is because of stator copper losses. These losses of motor depend on square of stator current, and are calculated as below

$$P_{scl}=3I_1^2R_1 \quad (9)$$

Rotor bars losses: rotor bars losses formed when current pass-through rotor bars, these losses depend on rotor current square, as calculated in below equation:

$$P_{rol}=3I_2^2R_2 \quad (10)$$

Iron losses: these losses are formed due to eddy current and hysteresis, in the conducting core lamination. These losses are calculated as in below equation:

$$P_{core}=3\left(\frac{E_2^2}{R_m}\right) \quad (11)$$

3.3 Tests of induction motor

In our analysis induction motor of 1.5 KW three phase is used, to find this induction motor equivalent circuit parameters are essential to be identified, these parameters of an induction motor can be determined with the help of induction motor specific tests, these tests are DC test which is used to find the value of R_2, where as in the blocked rotor motor test is used to find the values of R_2 ,as well as the value of X_1 and X_2, and R2, the No-Load test, magnetizing reactance X_M determining test. In this research paper the 3-phase squirrel cage rotor type (Y 90S-2)induction motor is used. Information of the induction motor used is given in Table 1.

power	1.5 kW
Rotor speed	2840 r/min/3405 r/min
Phase number	3
Voltage	220-380/240-420 V
Current	5.9-3.4/5.4-3.08 A
frequency	50 Hz / 60 Hz

Table 1. The Characteristic Information Of The Used Induction Motor

Y series induction motors are AC asynchronous motors squirrel-cage totally-enclosed fan cooled, Y series has many advantages like low noise, excellent performance, high efficiency, large starting torque, energy saving, low vibration, convenient operation and high reliability. Also, the induction motors of Y series are suitable for use of common applications such as: transportation machineries, processing machineries, metal cutting machines, pumps, puddle mixers, blowers and agricultural machineries. Table 2 shows the parameters of equivalent circuit such as rotor resistance, magnetizing reactance, stator resistance, rotor reactance and stator reactance, these are calculated with the help of tests which are applied on induction motor. MATLAB is used for simulation as the parameters of induction motor are given to the setup, as this is used for calculation of power losses of induction motor like stator core losses stator copper losses and rotor bar losses.

Parameter	*Value (Ω)*
R_1	4.1667
R_2	3.33
X_1	4.72
X_2	7.08
X_M	111.3

Table 2. Equivalent Circuit Parameters Of Induction Motor

3.4 Variable-Frequency Induction Motor Drive

For variables peed operation induction motor needs a variable frequency drive (VFD). This VFD circuit comprises of components such as a SCR rectifier which is connected to an inverter with a DC link. Block diagram variable frequency drive of induction motor is given in the Figure 4.

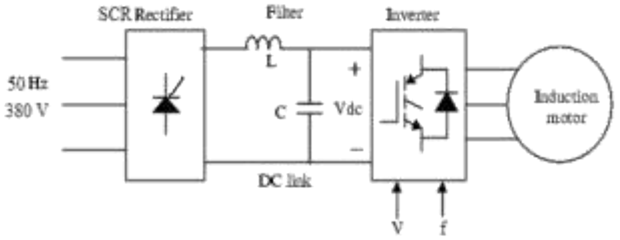


Figure 4 induction motor variable frequency drive block diagram.

The rectifier circuit in the block diagram is constructed with the thyristors, the function of thyristor is to covert AC supply voltage to DC voltage, by inserting a appropriate firing angle value of the supply voltage is controlled on the different values, the produced DC voltage signal is then filtered with the help of certain capacitor from noises before transferring it to IGBT inverter. The inverter is made of IGBT which consists of six power switches the IGBT inverter is used to alters the DC link voltage to a regulating three-phase AC voltage. inverter output frequency and voltage are control using different control techniques. pulse width modulation (PWM) is one of the most utilized technique to get 3-phase variable waveform of sinusoidal voltage with the help of modulating the on and off. Figure 5 shows the MATLAB Simulink of the inverter control circuit. volts/Hertz values is kept constant in this model, therefore once frequency is changed, the voltage value will be changed linearly with the help of SCR rectifier with appropriate firing angle with the aim to keep V/f constant.

$$(V / F_1) = 4.44 N_1 \phi_m \qquad (12)$$

N1 represents coil numbers

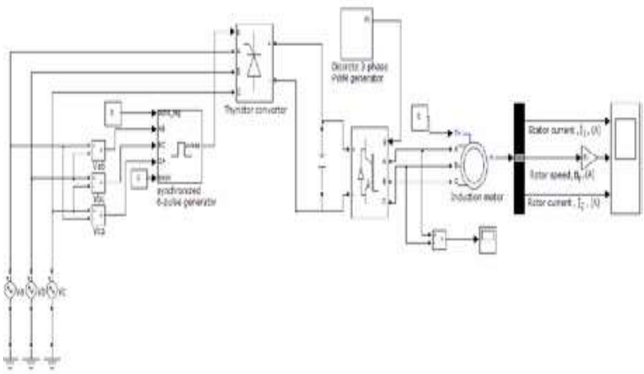


Figure 5 induction motor inverter control MATLAB simulation

3.5 induction motor thermal model

lumped-parameter thermal method is used to predict increase in the temperature of induction motor different parts. In making lumped method it should be supposed that induction motor geometry is divided into elementary elements because of different losses of these parts, and consequently different temperature rises as represented in Figure 6, Induction motor subdividing within the elementary components is a compromise between accuracy and simplicity for required results. accuracy of high level could be accomplished when induction motors is subdivided into geometrical parts.

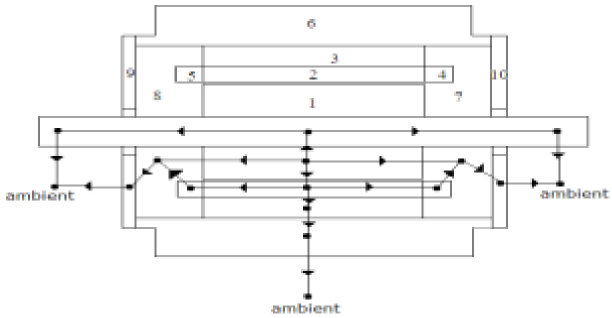


Figure 6 induction motor individual elements cross sectional longitude

In figure 6 Individual components of induction motor thermal model are:
1 is the Rotor bars, where is the 2 represents slot stator winding, 3 is the Stator core, 4 shows the right end winding, the 5 represents left end winding, 6 is the round frame, 7 shows the right end-cap air, 8 is the left end-cap air, 9 represents left side frame, 10 is the right side frame.
The built thermal model of induction motor is based on directions of the heat flow in induction motor as illustrated by Figure 7. Flow of heat in rotor bars, stator end-winding in the direction of end-cap air is due to convection and then to side frame. Heat flow rotor bars towards air gap and then to stator winding after that stator iron towards round frame at last by convection. The thermal model shown in figure 7 of the induction motor comprises of following components:

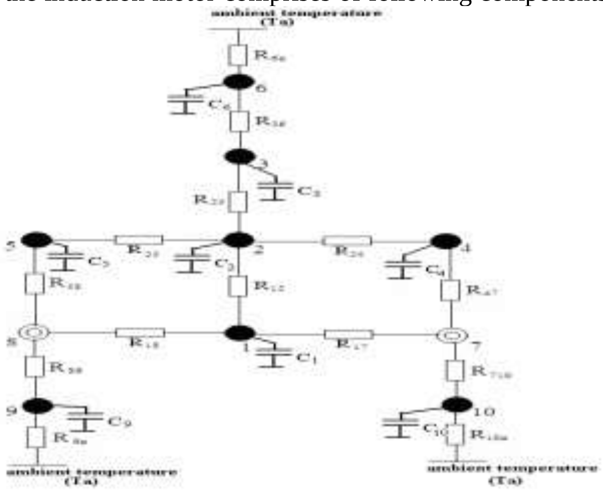


Figure 7 induction motor thermal model

The model consists of 14 thermal resistances and 10 nodes .induction motor stator comprises of end windings, stator winding and the stator iron. heat transfer of this structure is from rotor winding after that it goes to air gap and then it goes directly to stator winding. With the help of connection of frame, rotor and stator together with the thermal resistances, induction motor thermal network model is realized. Mathematical equations which is used to define induction motor thermal behavior are generally derived from basic energy balance equations, as represented in equation 13

$$\begin{pmatrix}\text{rate of energy}\\ \text{stored}\\ \text{within system}\end{pmatrix}=\begin{pmatrix}\text{heat flow}\\ \text{rate}\\ \text{into system}\end{pmatrix}-\begin{pmatrix}\text{heat flow}\\ \text{rate out of}\\ \text{system}\end{pmatrix}+\begin{pmatrix}\text{rate of heat}\\ \text{generated}\\ \text{within system}\end{pmatrix} \tag{13}$$

stationary system made with density ρ of material, having volume V which is constant, particular heat Cp, the balance equation becomes:

$$\rho C_p V\frac{dT}{dt}=Q_{in}-Q_{out}+Q_{gen} \tag{14}$$

When in system there is temperature distribution so equation (14) is used in this case.

4. Heat transfer methods:

In electrical components power dissipation is a complex process as it is the combination of(radiation, convection and heat conduction). Radiation is basically electromagnetic in nature which a body releases is solely on its temperature. convective heat occurs in gas or moving liquid. While heat conduction happens only through molecular communication. Three mechanisms (radiation, convection, conduction) in general dissipate heat energy which results in induction motor losses.

In Conduction heat transfers the heat flux Q this calculated from equation [20]:

$$Q_{th}=KA\frac{\Delta T}{\Delta x} \tag{15}$$

With the introduction of Rth thermal resistance due to conduction:

$$R_{th}=\frac{\Delta T}{Q_{th}}=\frac{\Delta x}{KA} \tag{16}$$

Heat transfer is modeled analogous to Ohm's law.

In convection heat transfer always from high temperature to low i.e., solid to gas or liquid with surface layer, this power dissipated because of convection is represented as,

$$Q=hA(T_s-T_\infty) \tag{17}$$

A in equation is area, temperature is represented by Ts, h is convection heat transfer coefficient.

Thermal resistance value which defines convective heat transfer is calculated as

$$R_{th,conv}=\frac{1}{Ah} \tag{18}$$

In radiation, Heat flux dissipated due to the radiation is represented with the help of Stefan-Boltzmann's equation:

$$Q_{th}=\in\sigma_{SB}(T_1^4-T_2^4) \tag{19}$$

5. Thermal model differential equations:

With the application of Equation (14)which is basic energy balance, on thermal model each node of induction motor which are defined in Figure 7, the formed differential equations are used to define induction motor thermal performance in transient and steady state in the firm operating conditions. In the steady state thermal analysis, the thermal circuit of a three-phase induction motor consists of thermal resistances and thermal sources connected between the motor component nodes. Each node is well-thought-out as lumped system, this system takes a control volume which defines heat entrance and leaves of the system. It is assumed that the in each part of induction motor temperature is distributed uniformly.

The thermal model linear deferential equations of induction motor from equation number 20 to 29 of above could be rewritten in the form of the matrix with the state space representation form as represented within Figure 8. For the calculation of an element temperatures in the induction motor, initially induction motor value of losses must be known consequently electromagnetic system model is required to determine these losses.

$$C_1\frac{dT_1}{dt}=P_{rol}-(G_{12}+G_{17}+G_{18})T_1+G_{12}T_2+G_{17}T_7+G_{18}T_8 \tag{20}$$

$$C_2\frac{dT_2}{dt}=P_{scl,sw}-(G_{23}+G_{24}+G_{25})T_2+G_{23}T_3+G_{24}T_4+G_{25}T_5 \tag{21}$$

$$C_3\frac{dT_3}{dt}=P_{core}-(G_{23}+G_{36})T_3+G_{23}T_2+G_{36}T_6 \tag{22}$$

$$C_4\frac{dT_4}{dt}=P_{scl,ew}-(G_{24}+G_{47})T_4+G_{24}T_2+G_{47}T_7 \tag{23}$$

$$C_5\frac{dT_5}{dt}=P_{scl,ew}-(G_{25}+G_{58})T_5+G_{25}T_2+G_{58}T_8 \tag{24}$$

$$C_6\frac{dT_6}{dt}=P_{r\text{-}frame}-(G_{36}+G_{6a})T_6+G_{36}T_3+G_{6a}T_a \tag{25}$$

$$C_7\frac{dT_7}{dt}=P_{capair}-(G_{47}+G_{17}+G_{710})T_7+G_{47}T_4+G_{17}T_1+G_{710}T_{10} \tag{26}$$

$$C_8\frac{dT_8}{dt}=P_{capair}-(G_{58}+G_{18}+G_{89})T_8+G_{58}T_5+G_{18}T_1+G_{89}T_9 \tag{27}$$

$$C_9\frac{dT_9}{dt}=P_{s\text{-}frame}-(G_{89}+G_{9a})T_9+G_{89}T_8+G_{9a}T_a \tag{28}$$

$$C_{10}\frac{dT_{10}}{dt}=P_{s\text{-}frame}-(G_{710}+G_{10a})T_{10}+G_{710}T_7+G_{10a}T_a \tag{29}$$

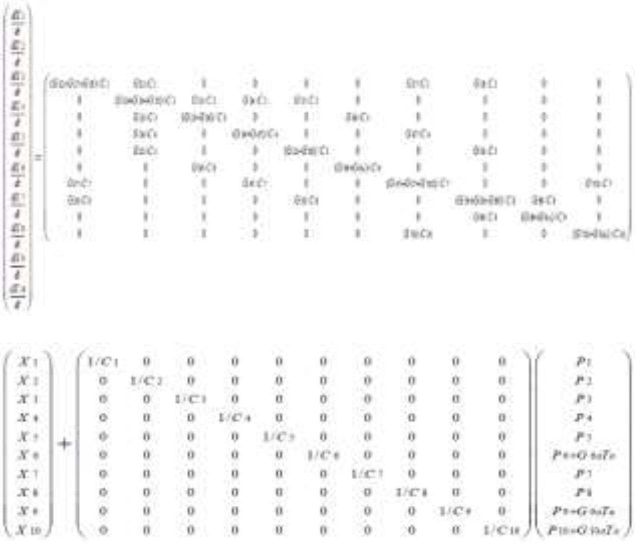


Figure 8 State space representation equation for the induction motor

Thermal capacitance and resistances of every component is found, these depend on physical properties of system as described in Table 4. These values are dependent also on induction motor geometrical dimensions as represented in Table 3.

Parameters	Value	Parameters	value
power	1.5 KW	Stator inductances	4.72 Ω
Rotor speed	2840 r/min/3405 r/min	Magnetizing inductance	111.3 Ω
Phase number	3	Rotor inductance	7.08 Ω
Voltage	220-380/240-420 V		
Current	5.9-3.4/5.4-3.08 A		
frequency	50 Hz / 60 Hz		
Stator resistance	4.167 Ω		
Magnetizing resistance	1187.48 Ω		
Rotor resistance	3.333 Ω		
Slot number	18	Stator length	82 mm
Stator diameter	131.5 mm	Rotor length	82 mm
Housing diameter	145 mm	Motor length	208.5 mm
Stator bore	72.5 mm	End winding extension	50 mm
Tooth width	5 mm	End winding inner diameter	72.5 mm
Slot depth	16 mm	End winding outer diameter	104.5mm
Air gap	0.5 mm	Bearing diameter	52 mm
Rotor diameter	71.5 mm	Bearing width	15 mm
Shaft diameter	29.5 mm		

Table 3. Dimensions and the specifications of the three phase induction motor typ

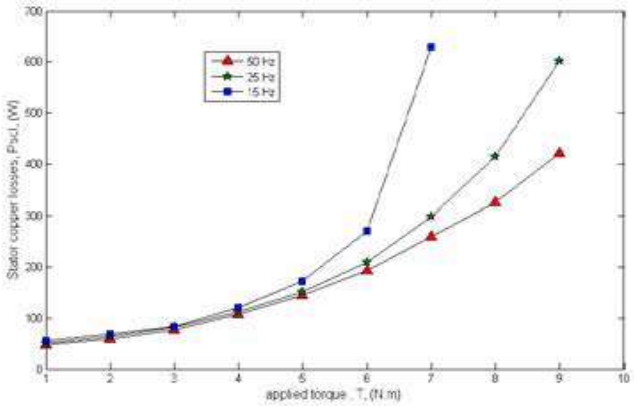
Material	Thermal conductivity (W/m.C)	Density (Kg/m^3)	Specific heat (J/Kg.C)
Iron	58	7850	420
Aluminum	222	2790	833
Steel	35	7770	460
copper	388	8933	385
Ambientair	0.02624	1.127	1007

Table 4. The physical properties of the materials in induction motor.

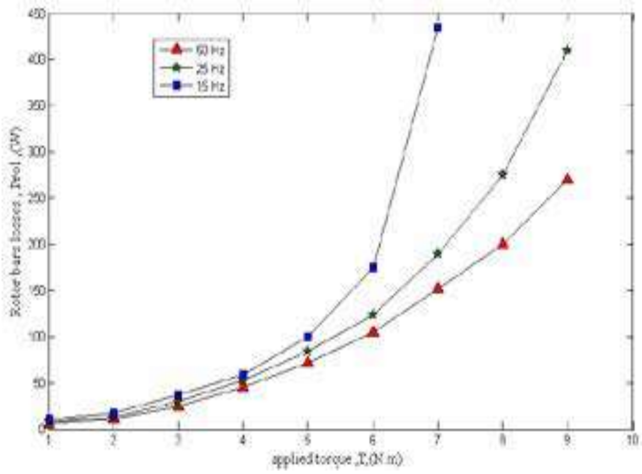
6. Simulation of electromagnetic model in MATLAB

After the calculation of parameters of induction motor with the help of induction motor tests these are represented in Table 2 ,induction motor parameters are introduced as inputs to MATLAB, the simulation of the process is represented in Figure 7, to discover induction motor features like rotor speed, rotor current and stator current these are given to power losses block as in Figure 6, to calculated power losses (Pcore), (Pscl) and (Prol) with of change in applied torque with different stator frequency values of 15 Hz, 50 Hz, and 50 Hz.

power losses values of induction motor are dependent on stator current value. if stator current increase in the induction motor power losses increases and vice versa. It is observed that rotor bars losses and stator copper losses in Figure 10 (a and b) increases with the increasing applied torque.



(a)



(b)

Figure 9 (a) stator copper losses (b) rotor bar losses at different values of the applied torque and stator frequencies.

6.1 Determining induction motor each element temperature by running it continuously at evaluated conditions with stator frequency different values:

Initially, each element temperature is determined in induction motor equal to 30 C, at valued conditions (stator current=3.8A,line to line voltage =380V, rated load =5 N.m at, stator frequency frequency=50Hz, output power = 1500W, star connection, 2poles). rotor and stator resistances and reactance are calculated from tests applied to induction motor.

Secondly, induction motor is run at small values of the stator frequencies of 15 Hz and of 25 Hz with equal valued load, to notice effect of the stator frequency on temperature the deviations of stator frequency is taken according to the V/f ratio, this value is essential to be constant during the operation. Figure 10 shows the MATLAB simulation of the thermal model, This MATLAB simulation can calculate induction motor heat losses at rated conditions after that these losses in second step are injected in thermal model to determine induction motor each element temperature at rated conditions, and with stator frequency small values.

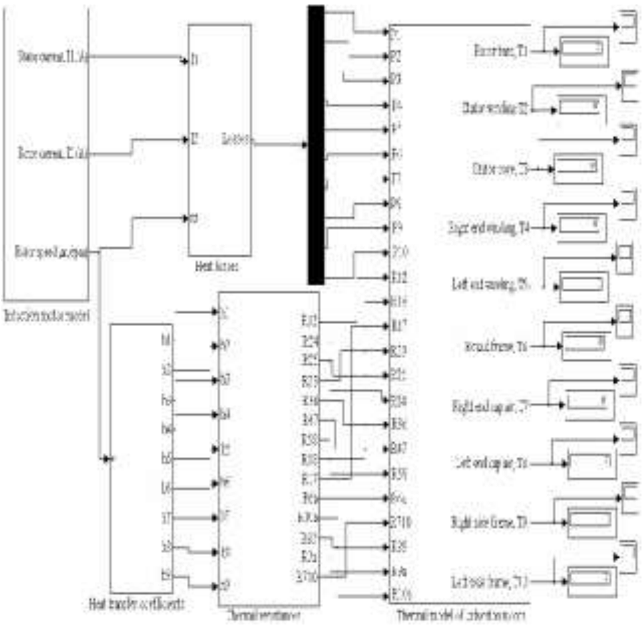


Figure 10 Matlab simulation of thermal model of induction motor for determining the temperature distribution

6.2 Determining induction motor each element temperatures by running it discretely at different stator frequency and torque values:

applying different torque values on induction motor at different stator frequency values of 15, 25 and 50 Hz rendering to the signals as illustrated in the Figure 11. When induction motor is run value of the torque is changed at different interval periods of time. From Figure 10, value of applied torque is changed at different time intervals as represented in Figure 11. At first motor ran at frequency of 50 Hz Then to 25 Hz and at last at 15Hz. using the Pulse width modulation into consideration, ratio V/f is kept constant, firing angle value is changed to obtain the desired supply voltage, and to see how temperature of motor elements changes.

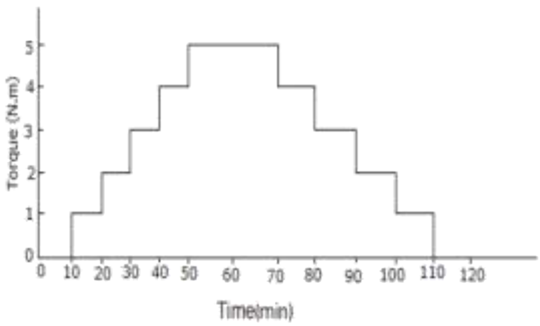
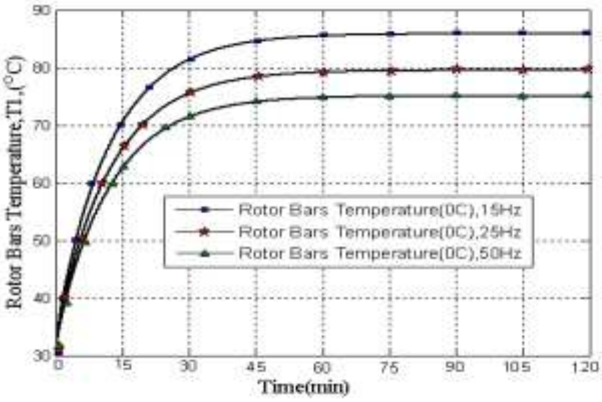
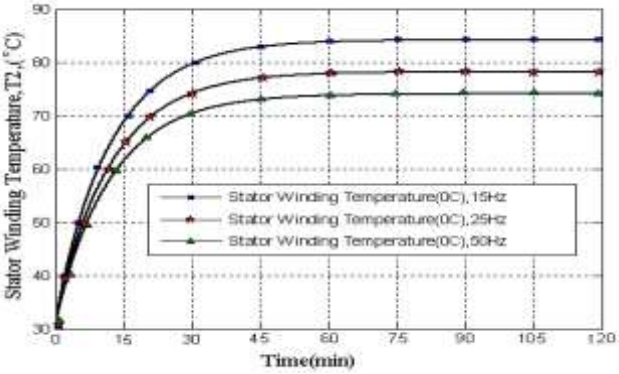


Figure 11 The applied torque signal at different values

temperatures change when stator frequency decreased with same rated load, Figure 12 (a and b) represents this.



(a)

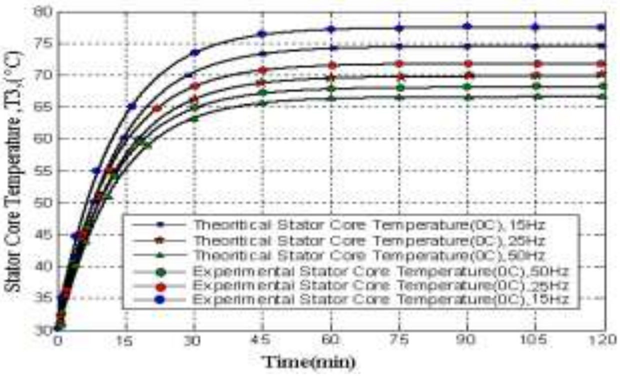


(b)

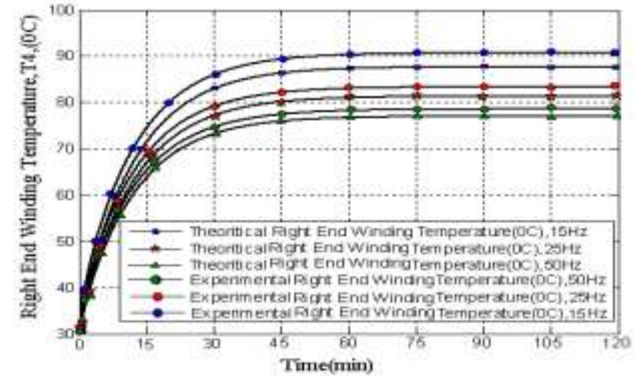
Figure 12 (a) Temperature of the Rotor bars (b) temperature of stator winding at the rated load at different values of the stator frequency.

7. Results

It is eminent from simulation results of induction motor thermal model that rotor bars and stator end winding is the hottest element in induction motor Figure 12(a) and figure 13(b) illustrate this point, this might be due to rotor bars losses and stator copper losses .because these losses are reliant on value of stator current, this stator current is considered as central aspect in induction motor heating.

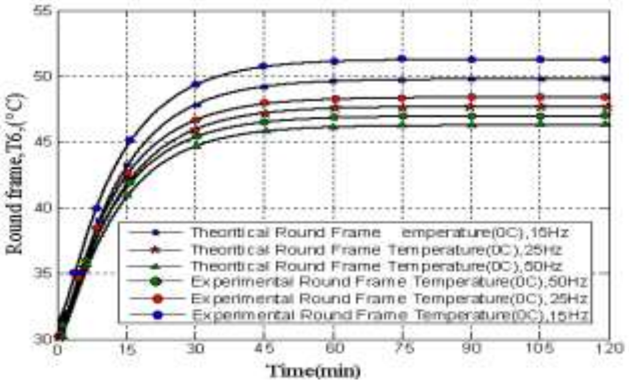


(a)

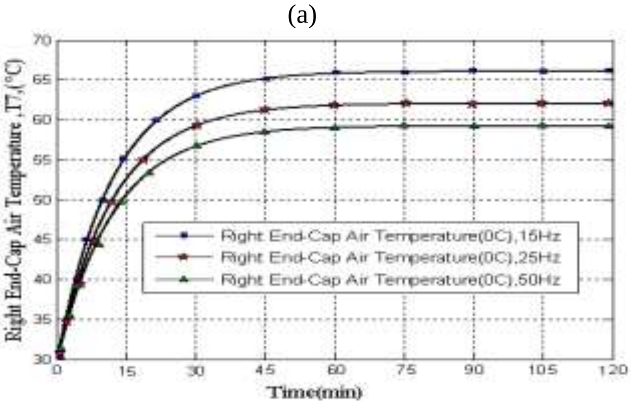


(b)

Figure 13 (a) Temperature of the stator core (b) temperature of right end winding at the rated load at different values of the stator frequency



(a)



(b)

Figure 14 (a)Temperature of the round frame (b) Temperature of the Right end cap air at the rated load at different values of the stator frequency.

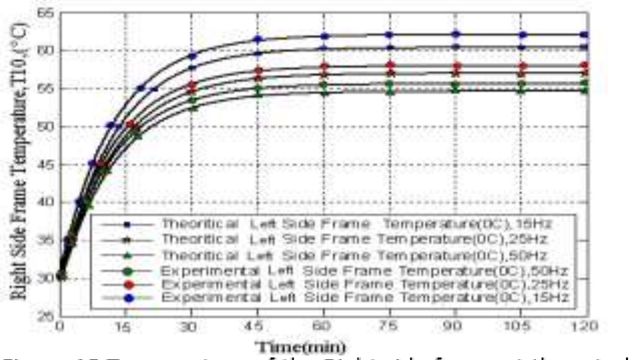


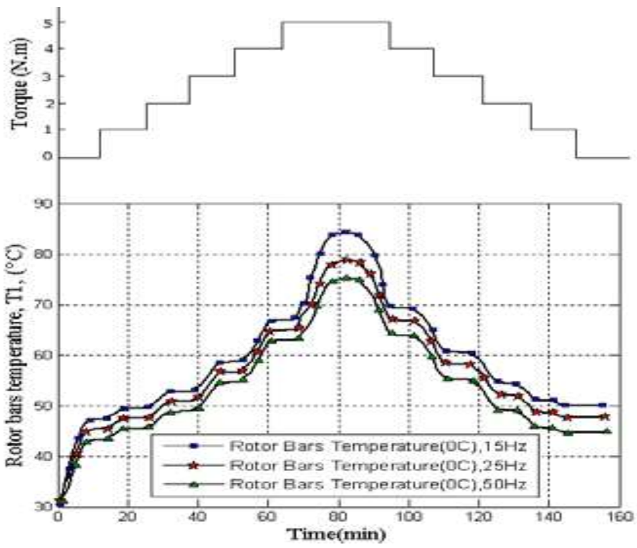
Figure 15 Temperature of the Right side frame at the rated load at different values of the stator frequency.

end winding element temperature at stator frequency of 50 Hz is 77 C at rated load, it is smaller than 120 C which is tolerable temperature. But when stator frequency is kept at less values of 15 or 25 Hz, the induction motor will start to draw large stator current, this means that rotor and stator copper losses will increase, which results in increased temperature specially the end winding sometimes it increases to acceptable level of temperature. This high temperature will result in the burnout and damage the insulation of windings of induction motor, at 25 Hz frequency value the temperature value is 82 C and at frequency of 15 Hz is 90 C value, as represented in Figure 18.

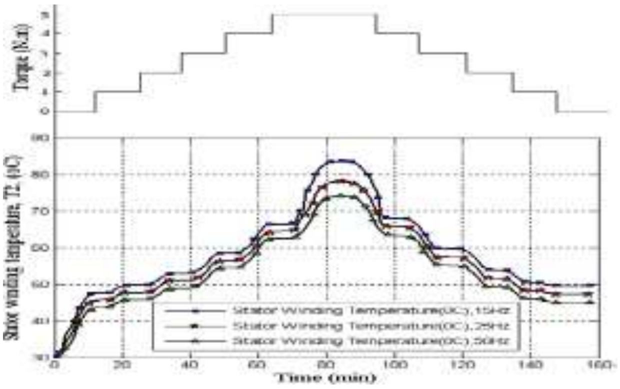
At different stator frequencies and at different torques is tested. From observation it is notice that induction motor each element temperature has increased when stator frequency is decreased. Temperatures are plotted against time as represented from figure 16, 17 and figure 18.

The results present that end winding and rotor bars are hottest temperature elements, hence from Figure 22 and 26 the temperature of end winding at 50 Hz and no load firstly increased to 44 C then it increased to 47 C with applied torque 1 Nm, 50 C with torque 2 Nm, 57 C with torque 3 Nm, 65 C with torque 4 Nm and 77 C with applied torque 5 N. It is eminent that temperature increases when the applied torque is increased. Temperature will decrease when applied torque is decreased. when the applied torque reduces from value of 5 Nm to the applied torque value of 4 Nm, end winding temperature is higher than 65 C, the reason is the heat capacitance at end winding which is accountable of storing heat in end winding, consequently end winding do not lose all heat.

In Figure 13 (b)left end and right end winding is represented, as larger stator current is drawn from induction motor which is the reason that of increased heat losses to a larger value this results in that induction motor quick heating to levels might be greater than acceptable temperature level, this will cause induction motor damage to speed up.

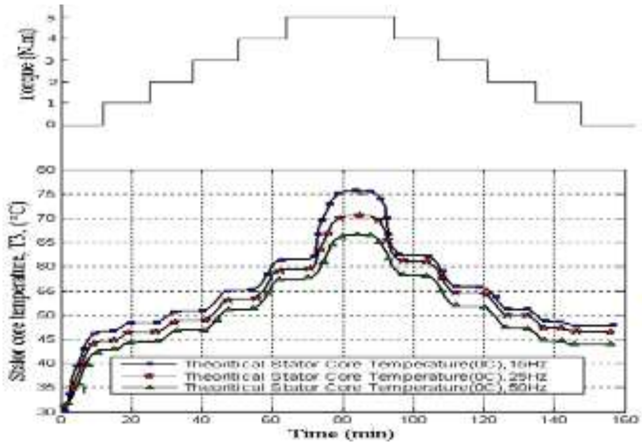


(a)

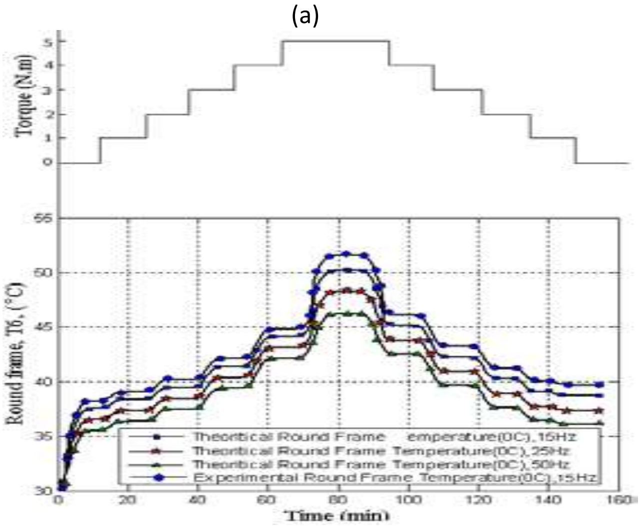


(b)

Figure 16 (a)temperature of the Rotor bars (b) temperature of the Stator winding at different values of the applied torque and at different values of the stator frequency.

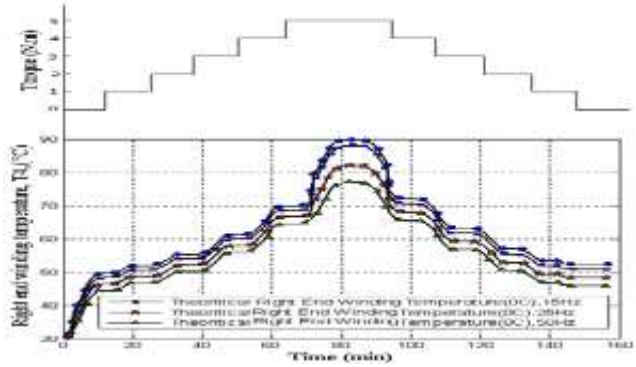


(a)

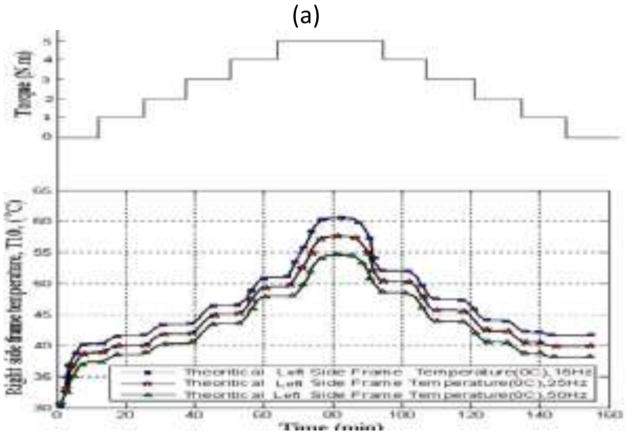


(b)

Figure 17 (a) temperature of the stator core (b) temperature of the Round frame at different values of the applied torque and at different values of the stator frequency.



(a)



(b)

Figure 18 (a) temperature of the Right end winding (b)temperature of the Right side frame at different values of the applied torque and at different values of the stator frequency.

Temperature of round frame, stator end winding and rotor bars, versus applied torques is plotted in Figures 19, 20 and figure 21, with applied torques at different frequencies the induction motor temperature changes, induction motor torque is in continuous form, till the temperature of elements got to condition of steady state.

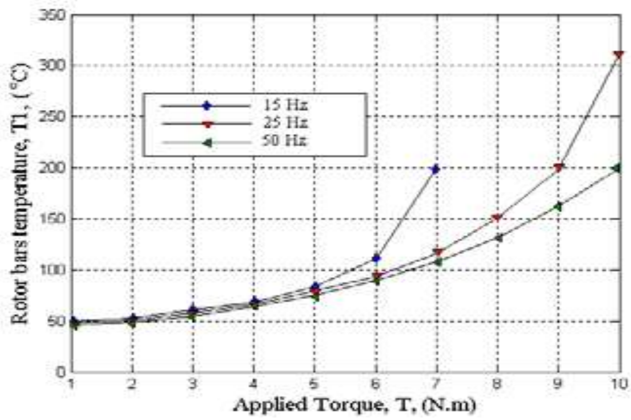


Figure 19 the temperature of the rotor bars versus the applied torque.

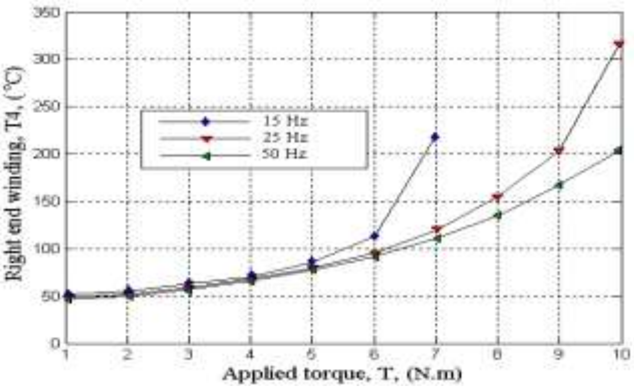


Figure 20 the temperature of the End winding versus the applied torque

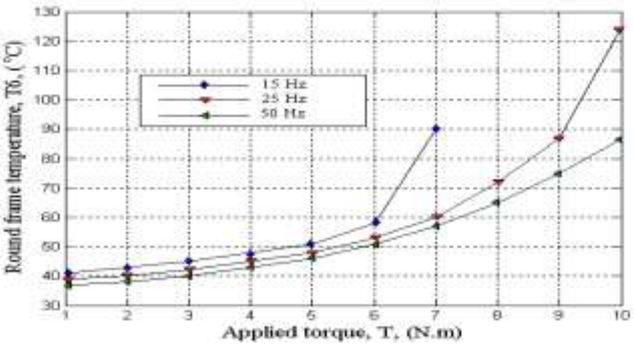


Figure 21 the temperature of the round frame versus the applied torque.

To confirm the present induction motor thermal model results is compared the results with results of different researcher's models [1], [2], and [3], to realize the core variances in value of temperature change with respect to diverse studies.

[1]has used 7.5-kW squirrel-cage induction motor operation at rated load, study is focused on transient and Steady states thermal analysis of a the end winding temperature in this model the result of this study is near to our results of end winding temperature. [2]has focused on induction motor thermal performance with changed synchronous speeds, this study curves of temperature are similar to temperature curves of our research, when synchronous speed of induction motor is reduced, temperature parameter increases with same load, his result is similar to our results. [3]has calculated rotor and stator temperatures with different torque values, our thermal model result is close to their end winding temperature curves, this similarity in result support thermal model proposed our research.

in Figure 22, Figure 23 result of our study and the previous research studies were consistent on induction motor. The differences in our study and other research values is maybe because of use induction motor of different power rating of our study.

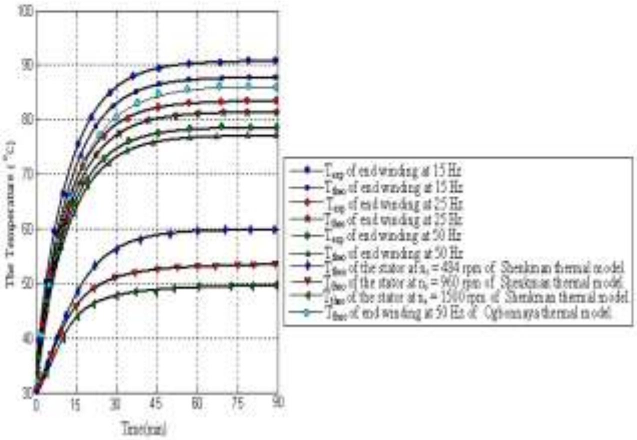


Figure 22 The comparison between the present thermal model and different thermal models for other researchers at rated load

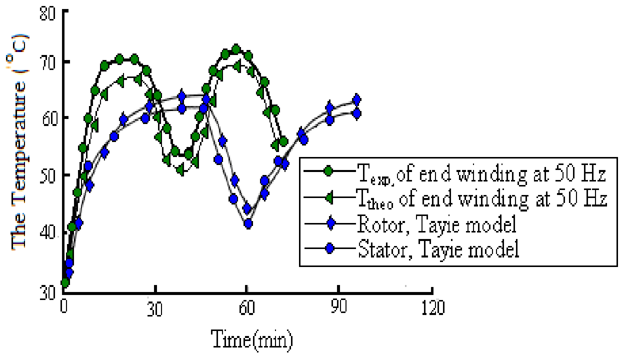


Figure 23 The comparison between the present thermal model and Tayie thermal model at different torques

5. Conclusion

This study is based on induction motor thermal analysis with the help of lumped parameter thermal method the model of thermal is applied to calculate induction motor temperature in changed operating conditions in rated load and different values of stator frequency and different values of applied torque. Used thermal model has given the strong representation of induction motor temperature distribution in different parts, it has given us precaution in case of problems occurring in operating condition of induction motor, like insulation of the induction motor, if induction motor internal temperature surpassed motor's insulation thermal class it will result in reduced motor life, if motor operating temperature increase by 10-deg C this will decrease in half the motor's useful service.

Analytical solution is used to predict heat losses in induction motor, stator copper losses of induction motor have a substantial part in total losses of motor, stator copper losses are dependent on the stator current, these losses are the main reason for the induction motor heating. This stator current value could be increased with the help of increased applied torque value or by small values of stator frequency at constant applied torque, at small rotational speed of induction motor, values of heat transfer coefficients of induction motor inside and outside are decreased, and cooling efficiency is affected by this.

At rated conditions temperature of each element of induction motor is obtained, then these temperatures at constant load were changed by reducing the stator frequency, then it was noticed that limiting thermal factor is temperature of copper winding, this could damage slot liners of the plastic.

The tentative results are presented for round frame, right end winding, stator core, left end winding, right side frame, left side frame, from results it is clear that proposed induction motor thermal model is able for calculation of temperatures in different elements of induction motor at decent accuracy in different operating condition sit have 3% to 5% percentage error. These errors between calculated and measured values of temperatures are probably from thermocouples this obtain only stator core, frame and outside temperature of stator windings, also due to calculation of model heat capacitances and thermal resistances, which is because of induction motor material properties and geometrical dimensions. However, these errors in the proposed model are within acceptable range for practical purposes.

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