Journal of Engineering and Sustainable Development

Vol. 24 No.02, March 2020
ISSN 2520-0917
https://doi.org/10.31272/jeasd.24.2.4

EFFECT OF DIFFERENT AMBIENT FACTORS ON TEMPERATURE DISTRIBUTION IN THREE-PHASE INDUCTION MOTOR

*Afrah Thamer Abdullah[1], Dr. Amer Majbel Ali[2]

1) M.Sc. Student, Electrical Engineering Department, Mustansiriyah University, Baghdad, Iraq.
2) Assistant Prof., Electrical Engineering Department, Mustansiriyah University, Baghdad, Iraq.

Received 14/3/2019 Accepted in revised form 25/ 4/2019 Published 1/3/2020

Abstract: This paper adopted a thermal network method (TNM) based on Motor-CAD software for investigating of temperature distribution inside different parts of a totally enclosed fan cooled (TEFC), squirrel cage, three-phase induction motor, with taking ambient considerations like ambient temperature, altitude, relative humidity, and contamination into account. The thermal model of the test motor was done according to its design documents. The results obtained from Motor-CAD were verified by comparing it with that obtained from the finite element analysis taken from Flux2D software with a good agreement.

Keywords: *Three-phase induction motor, thermal analysis, finite element analysis, thermal network method, Motor-CAD.*

تأثير العوامل البيئية المختلفة على التوزيع الحراري في المحرك الحثي ثلاثي الطور

الخلاصة: اعتمد هذا البحث طريقة الشبكة الحرارية (TNM) استنادا على برنامج Motor-CAD لاستقصاء توزيع الحرارة داخل مختلف أجزاء محرك حثي ثلاثي الطور نوع القفص السنجابي، المغلق تماما والمبرد بواسطة المروحة (TEFC)، مع مراعاة الاعتبارات المحيطة مثل درجة الحرارة المحيطة والارتفاع والرطوبة النسبية والتلوث في الحسبان. تم تنفيذ النموذج الحراري للمحرك الاختباري وفقًا للوثائق التصميمية الخاصة به. تم التحقق من النتائج التي تم الحصول عليها من Motor-CAD بعد مقارنتها مع تلك التي تم الحصول عليها من طريقة تحليل العنصر المحدد المأخوذة من برنامج Flux2D تتفق بشكل جيد.

1. Introduction

Heat has a negative impact on the electrical motor performance, so it's always better to eliminate the heat and reduce the temperature as low as possible inside the motor. Motor power losses are converted to heat inside it. Hot Spot means the most heated point in a motor, which often occurs on the conductors at the middle of the slot, and will be the highest temperature applies to the insulator. For the safe working of the motor, the hot spot temperature should be kept at a value adequately below the upper-temperature limit for the insulators.

*Corresponding Author: afrah.thamer@yahoo.com

Even though during steady state thermal conditions, there is different temperature distribution among different parts of the motor.

The temperature gradient means the difference in the steady state temperature between two given points. The capability of electric motors in withstanding the extreme temperatures often combined with intense humidity and corrosive environments, are crucial to many industrial processes. Standard motors are designed for operation in a 40°C ambient temperature and 1000 meter above sea level. [1][2]. An additional factor that affects the motor's ability to dissipate heat is the density of the surrounding air. With higher air density, more heat can be transferred, because at above sea level, air density decreases, meaning there is less oxygen on the intake. Furthermore, the air pressure decreases with altitudes, so less air generally make it into the machine.

Generally the air density at a specific location is very constant, but it is varying with altitude. The aim of this work is to study the effect of some ambient considerations like: ambient temperature, altitude, relative humidity, and contamination on the heat generation inside the induction motor, based on thermal network method software (Motor-CAD).

Although there are many research works concerning with study of thermal analysis of a three-phase induction motor, but the present work is unique (as seen from the reviewing of the relevant researches) in studying the effect of the above mentioned ambient considerations on the heat distribution inside the induction motor.

2. Methods of thermal analysis

2.1. Lumped Circuit Method

The principle of the thermal network method (TNM) is based on the division of motor into basic thermal elements representing a combination of conduction, convection, and radiation heat transfer operations. The thermal model of a TEFC induction motor is similar to an electrical network and it consists of [3]:

1- Thermal resistances rather than electrical resistances.
2- Power sources rather than current sources.
3- Thermal capacitances rather than electrical capacitors.
4- Nodal temperatures rather than voltage.
5- Power flow through resistances rather than current.
6- Geometry of motor components, so thermal resistances and thermal capacitances of all components can be calculated.

The motor thermal properties and heat losses are applied into the motor thermal model, to calculate temperature rises of all motor components at all operating conditions. In the steady state thermal analysis, the thermal circuit of a motor consists of thermal resistances and thermal sources connected between the motor component nodes.

2.2. Thermal Analysis by Finite Element Method

The finite element method (FEM) is a numerical method used to solve engineering problems such as electromagnetic, mass transport, heat transfer, and fluid flow. For solving the problem, it divides the big problem to smaller parts called finite elements. The equations that compose these finite elements are then assembled into a larger system of equations that constitute the whole problem. Although Motor-CAD uses TNM in motor thermal analysis, it has a finite element solution for the stator winding only. The thermal study of the test motor by FEM is achieved by using Flux2D software to determine the temperature distribution at any point of the induction motor in a steady-state condition. This method is particularly appropriate with large temperature gradients [4], but its taking a long process time to have a solution when comparing with TNM.

3. Mathematical Background

The heat transfer basics in the thermal network analysis of a three-phase induction motor are described as follows [5].

3.1 Heat Transfer by Conduction

The heat is transferred by conduction in solid material such as the stator and rotor, the general equation for heat conduction is given as in equation1.

$$\rho_c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda_x \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda_y \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda_z \frac{\partial T}{\partial z}\right) + Q \qquad (1)$$

Where ρ is the density of material in (kg/m^3), λ is the thermal conductivity (W/m ^{o} C), T is the temperature in (^{o} C), and Q is the dissipated power density in (W/m^2). In many cases only one-dimensional heat flux needs to be considered. Fourier's law is used to connect the heat flux and the temperature gradient, the heat flux q is given as in equation2.

$$q = -\lambda_x \frac{\partial T}{\partial x} \qquad (2)$$

3.2 Heat Transfer by Convection

In convection the heat is transfer from one place to another by the movement of fluids. The test motor is enclosed with an external fan, where the air is pushed by forced convection on the frame of the motor. The expression for the heat flux of forced convection is given as:

$$q = h A_s \Delta T \qquad (3)$$

Where h is heat transfer coefficient in ($W/m^2 °C$), A_s is surface area of material in (m^2).

3.3 Heat Sources (Power Losses)

The motor power losses are divided into five types:

1- Iron losses denoted by P_{Fe}.

2- Stator copper losses denoted by Pcu_1.
3- Rotor copper losses denoted by Pcu_2.
4- Friction and windage losses (mechanical losses).
5- Stray load losses.

These losses must be entered as a heat sources for the Motor- CAD model.

4. Modeling by Motor-CAD

A 2.2 kW, 2 poles, TEFC, class F, squirrel cage, three-phase induction motor is modeled by Motor-CAD at full load. All dimensions of the machine were entered in radial view, as shown in figure 1.

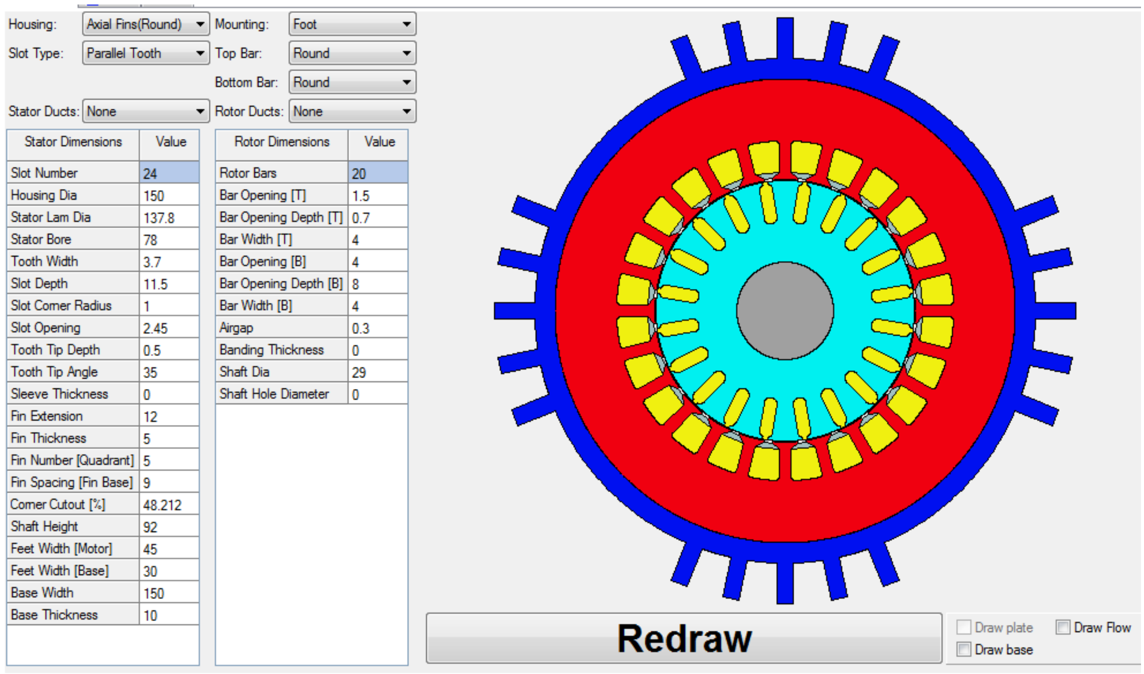

Figure1. Radial dimension of the test motor by Motor-CAD.

The winding pattern for the (slot/pole) combination of this machine is set up automatically by Motor-CAD software [6]. In the test motor, we have a single layer winding with 184 turns per phase, thermal resistance values are calculated automatically from motor dimensions and material data. The materials used in modeling the test motor are shown in figure2.

Component	Material from Database	Thermal Conductivity	Specific Heat	Density	Weight Internal	Weight Multiplier	Weight Addition	Weight Total
Units		W/m/C	J/kg/C	kg/m3	kg		kg	kg
Housing [Active]	Iron (Cast)	52	420	7272	3.232	1	0	3.232
Housing [Front]	Iron (Cast)	52	420	7272	2.296	1	0	2.296
Housing [Rear]	Iron (Cast)	52	420	7272	2.296	1	0	2.296
Housing [Total]					7.824			7.824
Endcap [Front]	Iron (Cast)	52	420	7272	0.7307	1	0	0.7307
Endcap [Rear]	Iron (Cast)	52	420	7272	0.7332	1	0	0.7332
Stator Lam (Back Iron)	M800-50A	30	460	7650	4.866	1	0	4.866
Inter Lam (Back Iron)	M800-50A	30	460	7650	0.1505	1	0	0.1505
Stator Lam (Tooth)	M800-50A	30	460	7650	0.8247	1	0	0.8247
Inter Lam (Tooth)	M800-50A	30	460	7650	0.02551	1	0	0.02551
Stator Lamination					5.866			5.866
Copper [Active]	Copper (Pure)	401	385	8933	0.7569	1	0	0.7569
Copper [Front End-Wdg]	Copper (Pure)	401	385	8933	0.7449	1	0	0.7449
Copper [Rear End-Wdg]	Copper (Pure)	401	385	8933	0.7449	1	0	0.7449
Copper [Total]					2.247			2.247
End Winding Ins. [Front]	Polystyrene (PS)	0.1	1350	1040	0	1	0	0
End Winding Ins. [Rear]	Polystyrene (PS)	0.1	1350	1040	0	1	0	0
Wire Ins. [Active]	Polystyrene (PS)	0.1	1350	1040	0.007823	1	0	0.007823
Wire Ins. [Front End-Wdg]	Polystyrene (PS)	0.1	1350	1040	0.008111	1	0	0.008111
Wire Ins. [Rear End-Wdg]	Polystyrene (PS)	0.1	1350	1040	0.007256	1	0	0.007256
Wire Ins. [Total]					0.02319			0.02319
Impreg. [Active]	Polystyrene (PS)	0.1	1350	1040	0.05613	1	0	0.05613
Impreg. [Front End-Wdg.]	Polystyrene (PS)	0.1	1350	1040	0.06473	1	0	0.06473
Impreg. [Rear End-Wdg.]	Polystyrene (PS)	0.1	1350	1040	0.05787	1	0	0.05787
Impreg. [Total]					0.1787			0.1787

Figure 2. Materials of the test motor selected by Motor-CAD

The thermal model is set up with housing type, materials, and cooling options etc. The model can be solved by click on the "solve thermal model", to calculate the temperatures at different motor regions as shown in the motor equivalent thermal model of figure 3.

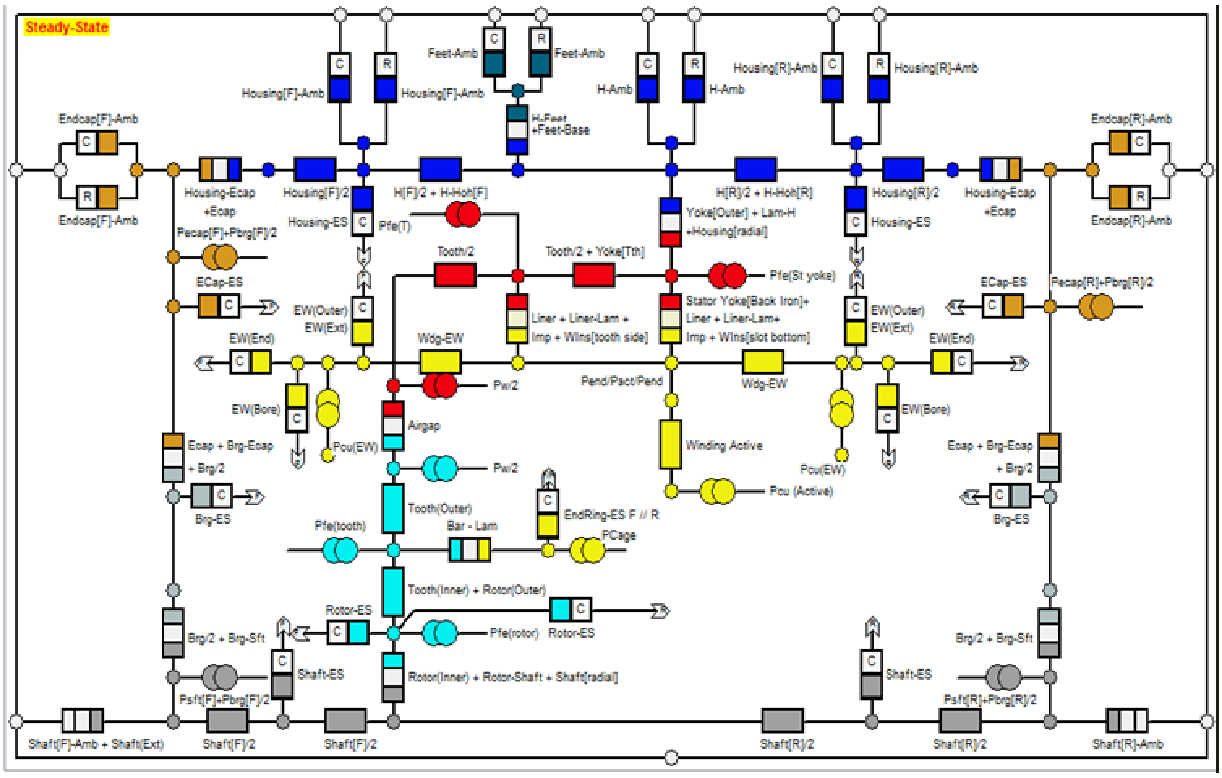

Figure 3. Equivalent thermal network of the test motor by Motor-CAD

5. Modeling by Flux2D

The finite element method model for the test motor is done by using Flux2D software [7], as shown in figure 4.We used software sketcher to draw the motor geometry according to its design documents. The machine consists of five different materials: shaft steel type CK45, electrical steel type M800-50A, cast iron for frame, pure cast aluminum for rotor bars, and copper wires for stator winding.

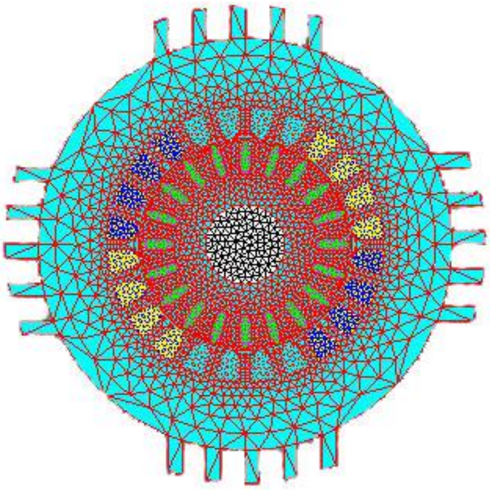

Figure 4. FEM model for the test motor by Flux2D

6. Results and discussion

Simulations were performed by Motor-CAD to obtain the temperatures in six regions of the motor: frame, stator windings, stator yoke, rotor yoke, rotor bars, and shaft as illustrated in figure 5. Four case studies were simulated to study the effect of changing ambient temperature, altitude, relative humidity, and contamination upon the heat generated inside the motor.

Figure 6 shows a notable increase of motor temperatures with each increase of ambient temperature of 20 °C in 4 steps, while figure 7 shows a little increase in motor temperatures for each increase of motor altitude in each step of 1000 meter, figure 8 shows the increasing of relative humidity from 20% to 100% has a little effect on the increase of motor temperatures, lastly figure 9 shows the increasing of dioxide carbon contamination level will cause a reduction in heat dissipation from motor and raise the motor temperature.

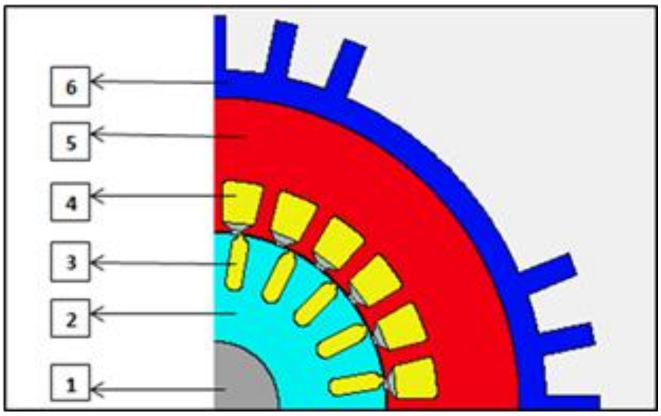

Figure 5. Motor six regions for temperature estimation

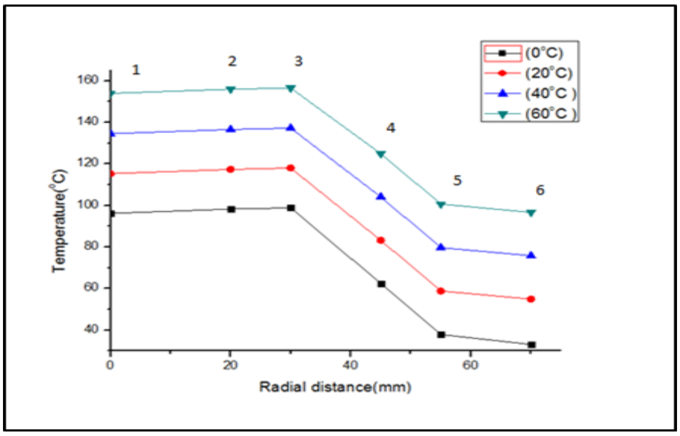

Figure 6. Temperature of each motor part at different ambient temperature

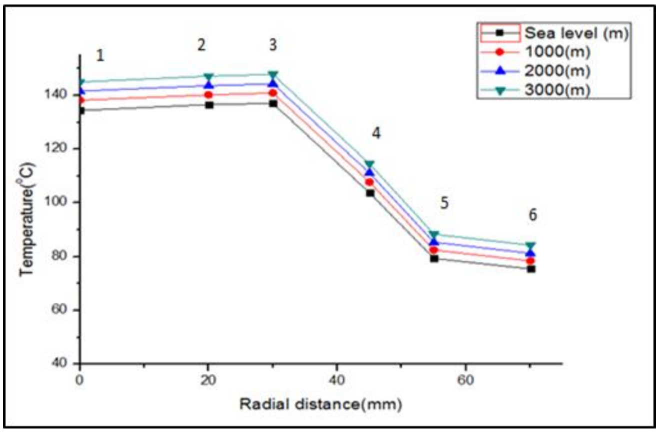

Figure 7. Temperature of each motor part at different altitude

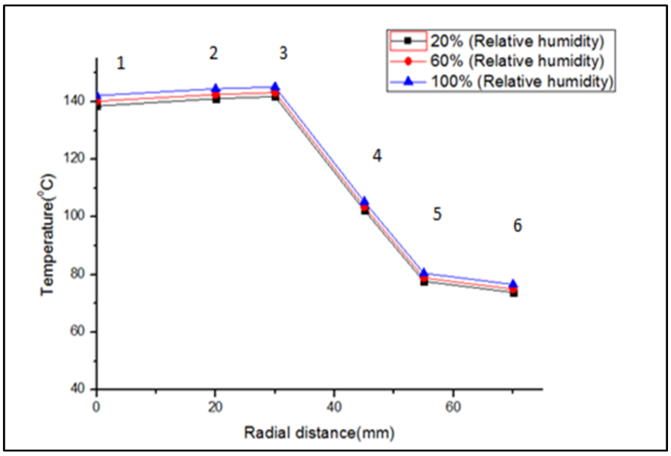

Figure 8. Temperature of each motor part at different relative humidity

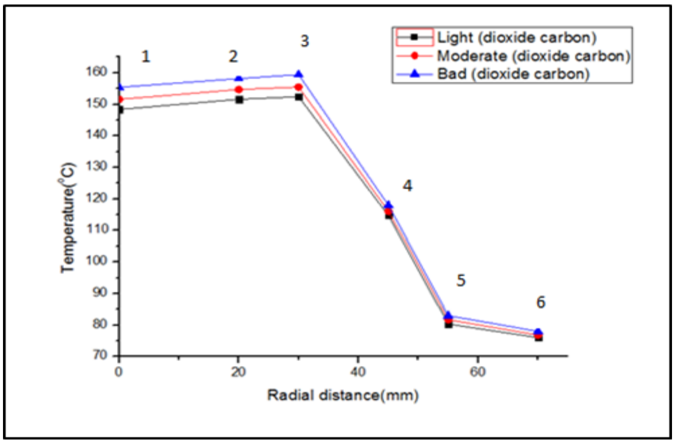

Figure 9. Temperature of each motor part at different contamination levels.

To verify the Motor-CAD results, we compared its results of stator winding temperatures at different ambient temperatures with that taken from finite element analysis software (Flux2D) as shown in figure 10.

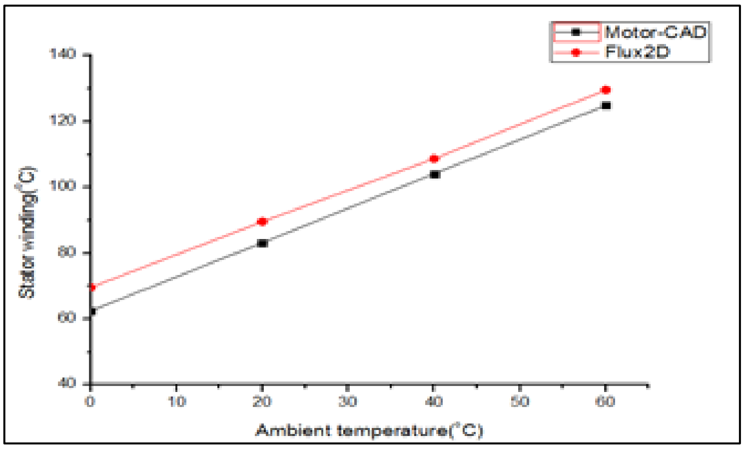

Figure 10. Comparison of stator winding temperature estimated by Motor-CAD and Flux2D.

6. Conclusions

In this paper, the effect of ambient temperature, altitude, relative humidity, and contamination on a three-phase induction motor temperature was investigated. Thermal network method based on Motor-CAD software and finite element method based on Flux 2D software were adapted successfully to do this work. The results obtained show the increase in motor temperature with increase in ambient temperature, altitude, relative humidity, and contamination level. The Motor-CAD results were compared with finite element analysis results of Flux2D with a good agreement.

Abbreviation

h	heat transfer coefficient
A_s	surface area
q	the heat flux
ΔT	temperature gradient

7. References

1. Gnacinski, P., (2008) *"Windings temperature and loss of life of an induction machine under voltage unbalance combined with over-or under voltages,"* IEEE Trans. on Energy Conversion, Vol. 23, No. 2, June.
2. Mellor, P. H., Roberts, D., and Turner, D. R,(1991)*" Lumped Parameter Thermal Model for Electrical Machines of TEFC Design",* IEE Proc. B, Vol. 138, No. 5, pp. 205–218.
3. A. Boglietti, A. Cavagnino, and D. A. Staton., (2005) *"TEFC induction motors. Thermal models : Aparameter sensitivity analysis,"* IEEE Trans. Ind. Appl., vol. 41, no. 3, pp. 756–763, May/Jun.
4. J P Holman., (1986)*"Heat Transfer",* McGraw-Hill Book Company, New-York,(6th).
5. Gunnar Kylander, (1995) *"Thermal modeling of small cage induction motors",*PhD dissertation,Chambers university of technology.
6. Motor-CAD v7.4.7Motor Design Ltd
7. Flux2D software – www.cedrat.com.