Original Article

Applied Sci.

Design and Analysis of Three Phase Induction Motor using Computer Program

Eugene O AGBACHI *, James G AMBAFI, Omokhafe J TOLA, Henry O OHIZE

ABSTRACT [ENGLISH/ANGLAIS]

In the recent years it has been noticed that the induction motor has become the workhorse of the industrial sector of any economy. This is as a result of its easy means of construction and maintenance. Since the motor is being used for different purposes in the industries, the need to have an easy way of designing the machine arises. The basic design of an electrical machine, that is the dimensioning of the magnetic and electric circuits, is usually carried out by applying analytical equations. However, accurate performance of the machine is usually evaluated using computer aided design method. With this Computer aided design (CAD) method, the effect of a single parameter on the dynamical performance of the machine can be effectively studied by using a computer programming language. This paper presents a CAD approach (using java) in carrying out the design calculations which made the design of three phase induction easy.

Keywords: CAD, java, design, parameters, accurate performance

RÉSUMÉ [FRANÇAIS/FRENCH]

Dans les dernières années, il a été remarqué que le moteur à induction est devenue le cheval de bataille du secteur industriel de toute économie. C'est à la suite de ses moyens faciles de construction et d'entretien. Puisque le moteur est utilisé à des fins différentes dans les industries, la nécessité d'avoir un moyen facile de concevoir la machine se pose. La conception de base d'une machine électrique, qui est le dimensionnement des circuits magnétiques et électriques, est généralement effectuée en appliquant les équations d'analyse. Cependant, les performances exactes de la machine est généralement évaluée en utilisant la méthode de conception assistée par ordinateur. Avec cette conception assistée par ordinateur (CAO) la méthode, l'effet d'un seul paramètre sur la performance dynamique de la machine peut être efficacement étudiées en utilisant un langage de programmation informatique. Cet article présente une approche CAO (en utilisant java) dans la réalisation des calculs de conception qui ont fait la conception de trois phase d'induction facile.

Mots-clés: CAD, java, la conception, les paramètres, les performances exactes

INTRODUCTION

With the recent trend in Technology, most lengthy calculations and simulation of circuits are done with the use of computer programs designed to serve different purposes. Examples of such programs include Matlab, C++, java, etc.

Computer aided design (CAD) is the use of computer to assist in design processes. Specialised software packages exist for various types of design: architectural, engineering, electronics, highways and woven fabrics to mention but a few. It is generally possible to generate engineering drawings that gives detailed information on the final design to be constructed. CAD is also the modelling of physical systems on Computer, allowing both interactive and automatic analysis of design variants and the expression of design in a form suitable for manufacturing [1]. All CAD systems have potentials that could lead to many important benefits for organizations. For example, CAD systems can reduce the length of the product development cycle and improve relationships with both vendors and customers. Many literatures provide many descriptions of CAD applications that have helped to reduce the product development time [2, 3]. A shorter design cycle makes companies to respond more quickly to competitive challenges, incorporate newer technology into products, and charge higher prices for special features [4].

Three phase induction motor finds its application in almost all facets of life and thus its demand is high and it is thus advisable to design a program that aids in the

computation of the parameters required for the construction in order to save time and reduce the errors associated with the analytical method.

In this work we basically are concerned with the computer aided design of three phase induction motor using Java programming language since the analytical process is time consuming and so laborious. The language used for the development of this software is Java. Java is a general purpose, concurrent, class-based, object-oriented language that is specifically designed to have as few implementation dependencies as possible [5]. It is intended to let application developers "Write once, Run anywhere" [6]. The reason for our choice of java as a programming language is because it is robust, secure and portable; it also allows the programmer to create controls and then write codes for each control so that it could be executed at the press of a command button [5]. The program shall be presented in a graphical user interface (GUI).

MATERIALS AND METHODS

Design Specifications

The main specifications for the design of a three phase induction motor are: rated output power in H.p or KW, Frequency in Hz , Voltage in volts, Speed in rpm, Efficiency, Power factor, Full load Current, Type: Squirrel cage rotor or wound rotor [7, 8].

Design Equations

The design -was derived as follows:

Output Equation

We have to relate the output of the machine with its main dimensions.Let us use the following nomenclature:

E_{ph} = Induced emf per phase in volts.(induced emf/phase = applied voltage/phase)

I_{ph} = Current per phase,A.

T_{ph} = No. Of turns per phase.

φ = Flux per pole in the air gap.

P = No. Of poles.

K_w=Winding Factor

B_{av}=Average value of flux density in the airgap

ac =Ampere conductor per meter of the armature periphery.

D = Armature diameter or stator bore diameter.

L = Stator core length in meter.

n_s=Synchronous Speed in r.p.s

η = Efficiency.

Cos Φ=Full load power factor

τ = Pole pitch=(πD)/P.

KVA rating of a three phase induction motor is given by:

$$KVA = 3 \times E_{ph} \times I_{ph} \times 10^{-3}$$ Or

$$KVA = 3 \times 4.44 \times K_w \times f \times \phi \times T_{ph} \times I_{ph} \times 10^{-3} \qquad (1)$$

If the rating is given in HP or KW,we convert it to KVA by the relation:

Thus,
$$KVA = \frac{HP \times 0.746}{\eta \times Cos\phi} \qquad (2)$$

Also
$$KVA = \frac{KW}{\eta \times Cos\phi} \qquad (3)$$

but specific magnetic loading   (B$_{av}$)

$$= \frac{\text{Total flux in the airgap}}{\text{Area of flux path in the airgap}}$$

specific magnetic loading (B$_{av}$)
$$= \frac{p\phi}{\pi DL} \qquad (4)$$

Specific electric loading (ac)

$$= \frac{\text{Total armature ampere conductor}}{\text{Armature at the airgap}}$$

$$= \frac{3 \times 2 \times I_{ph} \times T_{ph}}{\pi D} \qquad (5)$$

Also,
$$f = \frac{PN_s}{120} = \frac{Pn_s}{2} \qquad (6)$$

From equation (.4),
$$\phi = \frac{B_{av} \times \pi DL}{P} \qquad (7)$$

Also,from (.5),
$$T_{ph} \times I_{ph} = \frac{ac \times \pi D}{3 \times 2} \qquad (8)$$

Substitute (7) and (8) into (1) gives:

$$D^2 L = \frac{KVA}{C_0 n_s} \qquad (11)$$

Where $C_0 = 1.11 \times \pi^2 K_w \times B_{av} \times ac \times 10^{-3}$

Equation (11) is the output equation of an induction motor.

Calculation of the Main Dimensions

The armature diameter D (or stator core) and stator core length L, are known as the main dimensions.

$$D^2 L = \frac{KVA}{C_0 n_s}$$ in m³ which is also the volume   (12)

$$L = \frac{\pi D}{P}$$

(13)

It is advisable to design the three phase induction motor for best operating power factor [9]. To obtain the best power factor in an induction motor the following relationship can be assumed between D and L.

Pole pitch/ Core length = 0.18/ Pole pitch Or

$$\frac{(\pi D/P)}{L} = \frac{0.18}{(\pi D/P)}$$

Hence internal diameter of stator, $D = 0.135 P (L)^{\frac{1}{2}}$

(14)

Peripheral Velocity

The peripheral velocity $v = \pi D n$ m/sec   (15)

where n is in rps, v should not exceed 30m/sec for normal construction.

Stator Calculation

Turns per phase

Flux per pole $\phi = B_{av} \times \pi D L / P$

Stator voltage per phase, $E_s = 4.44 K_{ws} f \phi_m T_s$ (16)

Therefore Stator winding turns per phase is :

$$T_s = \frac{E_s}{4.44 K_{ws} f \phi_m}$$

(17)

where K_{ws} is the stator winding factor.

T_s is number of stator turns.

Stator Conductor

$$I_s = \frac{KVA \times 1000}{3 \times E_s}$$

Stator current per phase

(18)

Therefore, cross-sectional area of each conductor is

$$a_s = \frac{I_s}{\delta_s}$$

(19)

Where δ_s= Current density of stator conductor usually assumed between 3-5 A/mm².

Stator Slot

S_s = number of stator slot.

For a double lap winding,

S_s = 2MgP   (20)

Where M = The number of phases

g= number of slots per pole per phases.

P = the number of poles.

$$Y_{ss} = \frac{\pi D}{S_s}$$

The Slot pitch;   (21)

Where Y_{ss} is between 15-25mm

Total number of stator winding conductors = 3×2× Ts (22)

$$Z_{ss} = \frac{3 \times 2 \times T_s}{S_s}$$

Number of conductors per slot   (23)

Area of Conductor

Approximate area per slot = Copper section per slot/Space factor

$$= \frac{Z_{ss} a_s}{\text{Space factor}}$$

(24)

$$a_s = \frac{I_s}{\delta_s}$$

where

Where space factor varies from 0.25 to 0.4.

AIRGAP LENGTH

$$L_g = 0.2 + 2(DL)^{\frac{1}{2}}$$

where L_g is in mm

Rotor Design
Rotor Slots

The first and most important thing to do here is to select the number of rotor slots in relation to the number of stator slots already selected.

$$Y_s = \frac{\pi D}{S_2}$$

Rotor slot pitch =   (31)

Where S_2 is the number of rotor slot.

The number of rotor slot per pole is expressed as :

$$g_2 = \frac{S_2}{2P}$$

(32)

Rotor Bar Current

If rotor mmf = 0.85 stator mmf,

Number of rotor bars (N_b) = Number of rotor slots (S_r), then:

Rotor mmf $= I_b \times S_r / 2$

Stator mmf $= 3 \times I_s \times T_s$

Therefore, $I_b \times S_r / 2 = 0.85(3 \times I_s \times T_s)$ or

$$I_b = 0.85(6 I_s T_s / S_r) \tag{33}$$

where I_b is the rotor bar current.

Rotor Bar Area

The rotor bar area is given by:

$$A_b = I_b / \delta_b \tag{34}$$

Where: δ_b = Current density, its value ranges between 4 to 7A/mm².

Copper Losses in the Rotor Bars

To do this, we calculate

Length of rotor bar l_b = L + Allowance for skewing.

Allowance for skewing = 5 to 8cm

Therefore, Resistance per bar, r_b = (0.021+l_b) m² /$A_b$mm²

$$\tag{35}$$

Hence, total copper losses in the rotor bars

$$= (I_b)^2 \times r_b \times \text{number of rotor bar} \tag{36}$$

End Ring Current

$$I_{e(\max)} = \frac{1}{2} \left(\frac{\text{Number of rotor bars}}{\text{Number of poles}} \right) I_{b(av)}$$

But for sine wave, $I_{b(av)} = I_b /1.11$. (1.11 is form factor for sine wave)

$$I_e = \frac{S_r I_b}{\pi P} \tag{37}$$

Area of End Rings

This is given by

$$A_e = \frac{I_e}{\delta_e} \text{ mm}^2 \tag{38}$$

Where end rings current density δ_e is between 5 to 8 A/mm²

Copper Losses in End Rings

Mean length of the current path $I_{me} = \pi D_{me}$

Where D_{me} =mean diameter of end ring between 4 – 6 cm less than rotor diameter.

Resistance of end Ring

$$r_e = \frac{0.021 \times I_{me}}{A_e}$$

where I_{me} is in m and A_e in mm².

Therefore, Total copper losses in the end rings is

$$L_e = 2 \times I_e^2 \times r_e \tag{39}$$

RESULTS

Previously, some parameters were derived equations 1-39, which aid in the design of three phase induction motor. This involves carrying out an analytical calculation or test using some given specifications. The specifications are presented as follows:

The Specifications

Rated Output = 10HP.
Voltage V = 415V.
Supply Frequency f = 50Hz.
Number of Phases m = 3.
Type of connection Δ = Delta.
Number of poles P = 4.
Full load Efficiency η = 0.87.
Full load power factor = 0.87.
Specific magnetic loading B_{av} = 0.45wb/m².
Specific electric loading ac = 23,000 A/m.
Gross core length L = 140mm.
Pole pitch τ_p = 129.59mm.
Winding type = Single layer mush.
Stator Winding factor K_{ws} = 0.955.
Number of stator slot S_s = 36.
Stator current density δ_s = 3.93 A/mm².
Stator slot per pole per phase g = 3.
Rotor diameter D_r = 164.3mm.
Number of rotor slots S_r = 44
Type of rotor winding = Cage.
Number of rotor bars per slot Z_{sr} = 1.
Rotor winding factor K_{wr} = 1.
Current density of rotor δ_b = 4.99A/mm².
Length of each bar L_b = 180mm.
Depth of end ring d_e = 12.5mm.
Thickness of end ring t_e = 10.26mm.

Analytical Method

The results of the analytical method using the given specifications are as shown in Table 1.

CAD Method

This method which involves the use of computer in design processes, provides a GUI platform in which the

design specifications can be provided to generate the desired output. Using the same specifications as in the analytical method, the obtained CAD output values are

shown in Table 1. Figure 1 shows the graphical user interface (GUI) of the CAD method.

Figure 1: This figure shows the GUI platform for CAD computation.
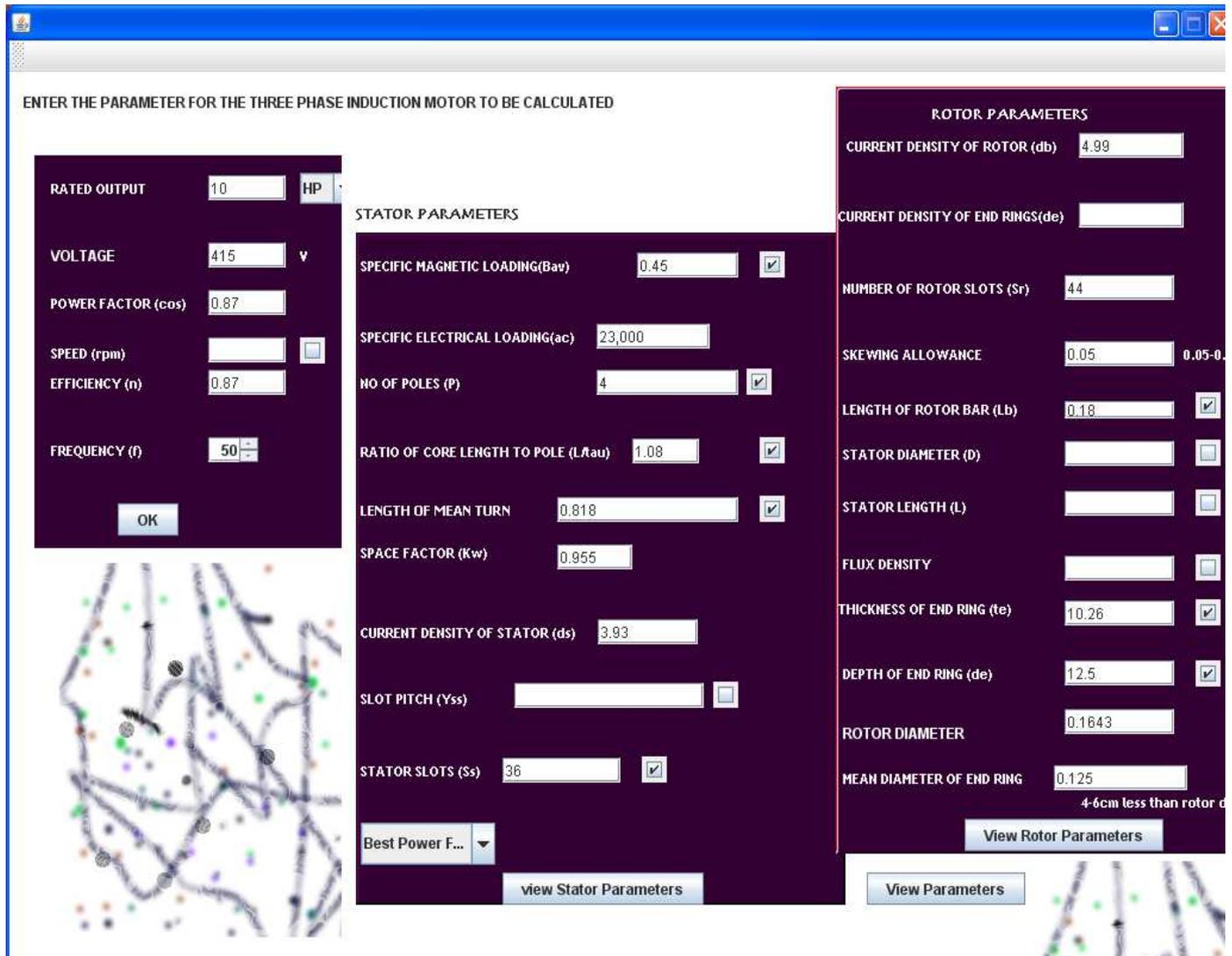
DISCUSSION

The computer aided design of three phase induction motor slightly varies in the values obtained for some parameters when compared to the analytical calculations. This is because these parameters are either assumed or chosen from a table of approximate values or calculated. The variance may occur due to the fact that the analytical calculations are full of approximations, time consuming, laborious and hence very prone to errors when compared to the computer aided design method. These slight differences are however negligible and most times they do not have significant effect on the design.

The CAD method when compared with the analytical method offers many advantages. As can be seen in table 1, there is a slight variation in the result by the two approaches which even made the CAD method superior to the analytical method.

These advantages include:

  i.   The CAD method is easy and avoids all sources of computational errors.

  ii.   The machine designed using the CAD method will definitely be more efficient than the one designed using analytical method. This can be seen in the losses and resistances offered by both machine conductors.

iii.   The time spent in computation is much less than the time spent using analytical method.

CONCLUSION

It is concluded that in this research work it is seen from the analytical calculations carried out and the computer aided design method used that there are a slight differences in the results obtained when compared. It can be concluded that both methods gave almost the same result; but, the analytical method past through some long and tedious process of arriving at the final design parameters which were error prone hence resulted in slight differences. The slight differences in the output result are very negligible. Finally, the product final performance is better in the computer aided design than the analytical method and the computer aided design is less time consuming and highly recommended.

Table 1: This table shows both analytical results and CAD results

Induction Motor Parameter Stator	Analytical results Output	Computer aided design results Output
The revolution per minute	1500	1500
The revolution per seconds	25	25
The power in KVA is	9.86	9.86
The Coefficient Co is	108.31	108.31
The value of D^2L is	$0.0036414m^3$	$0.003640m^3$
The value of D is	0.1625m	0.1625m
The value of L is	0.1379m	0.1379m
The flux per pole is	7.9209mwb	7.918mwb
Turns per phase	247.125	247.22
Stator current	7.92A	7.916A
Area of each conductor	$2.01mm^2$	$2.01mm^2$
Stator slots	36	36
Conductors per slots	41.19	41.2
Area per slot		86.91
Air gap length	0.3497m	0.3497m
Slot pitch	0.014180m	0.014182m
Stator Resistance	2.11ohms	2.108ohms
Stator copper loss	397.06w	396.375w
Rotor		
Rotor Slot pitch	11.730mm	11.733mm
Rotor bar current	226.86A	226.85A
Rotor bar area	$45.46mm^2$	$45.46mm^2$
End ring current	794.36A	794.19A
End ring area	$128.25mm^2$	$128.25mm^2$
Resistance per bar	0.00008315ohms	0.00008300ohms
Resistance in the end ring	0.00006431ohms	0.0000640ohms
End ring losses	81.60w	81.13w
Copper losses in the rotor bar	188.31w	188.27w
Total losses in the rotor bar	269.47w	269.40w

REFERENCES

[1]   CAD software history. 2008. Retrieved from www.cadazz.com/cad-software-history.htm .

[2]   Bull RJ. Concept to Protocol of Using Computing Techniques. Proceedings of the Institute for Mechanical Engineers Conference on Effective CADCAM '87/Towards Integration, 1987.

[3]   Calkins DE, Ishimaru J. Computer Graphics and Animation Come to Ship Designing. Computers in Mechanical Engineering 1984;3:33-42.

[4]   Robertson DC, Allen TJ. Evaluating the Use of CAD Systems in Mechanical Design Engineering. Massachusetts Institute of Technology. Massachusetts, USA. 1999. p.2-7.

[5]   Liang D. Introduction to Java Programming; Comprehensive Version, 6th Edition, Pearson Prentice Hall, Upper Saddle River, 2007 p.491–521.

[6]   Dietel PJ, Dietel HM. Java; How to Program, 7th Edition, Prentice Hall 2007.

[7]   Agarwal RK. Principles of Electrical Machines Design, Fourth Edition, S.K Kataria and Sons, Delhi. 2007.

[8]   Mittle VN, Mittal A. Design of Electrical Machines, Fourth Edition, New Delhi. 1996.

[9]   Forgiel M. The Electrical Machine Problem solver, Second Edition, New Jersey 08854,West Pis Cataway,2005;Pp.553–660.

How to Submit Manuscripts

Since we use very fast review system, and since we are dedicated to publishing submitted articles with few weeks of submission, then the easiest and most reliable way of submitting a manuscript for publication in any of the journals from the publisher Research, Reviews and Publications (also known as Research | Reviews | Publications) is by sending an electronic copy of the well formatted manuscript as an email attachment to rrpjournals@gmail.com or online through http://www.rrpjournals.com/ .

Submissions are often acknowledged within 6 to 24 hours of submission and the review process normally starts within few hours later, except in the rear cases where we are unable to find the appropriate reviewer on time

Manuscripts are hardly rejected without first sending them for review, except in the cases where the manuscripts are poorly formatted and the author(s) have not followed the instructions for manuscript preparation which is available under the Instruction for Authors link at http://www.rrpjournals.com/InstructionsForAuthors.html .

Research | Reviews | Publications and its journals have so many unique features such as rapid and quality publication of excellent articles, bilingual publication, some of which are available at http://www.rrpjournals.com/uniqueness.html .