COMPUTER AIDED DESIGN OF THREE PHASE INDUCTION MOTOR

ONUH GODWIN

(2007/2/26400EE)

A PROJECT SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA.

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DECLARATION

I, Onuh Godwin declare that this work was done by me and has never been presented elsewhere for the award of a degree. I also hereby relinquish the copyright to the Federal University of Technology, Minna.
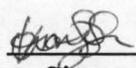
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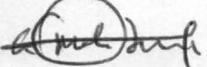
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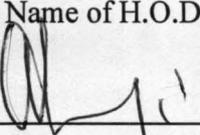
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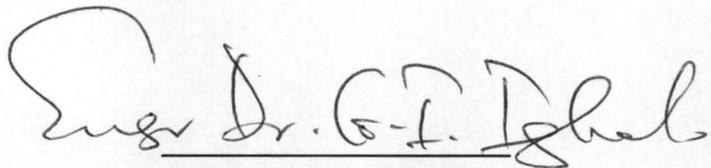
ENGR. TOLA OMOKHAFE

Name of Supervisor

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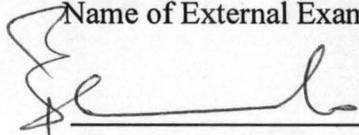
Signature and Date

ENGR. A.G RAJI

Name of H.O.D

_____ (March 15, 2012)

Signature and Date

Name of External Examiner

_____ 6/3/2012

Signature and Date

ii

DEDICATION

This project is dedicated to Almighty God the author and finisher of my Faith on whom my trust lies for His love, mercies and protection throughout my program.

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ABSTRACT

This work presents a computer aided design of a three phase induction motor. The software

design platform for the design is Java. A Java program will utilize the graphic user interface

(GUI) variation in the electrical parameter of the induction motor design, in response to variation

in the input parameters alteration. The GUI is designed in a way as to allow users enter the

specifications and the system response automatically calculated and can be printed out. This

would allow the designer to predict output of the induction motor at varying input specifications.

TABLE OF CONTENTS

Chapter One: General Introduction

Chapter Two: Literature Review

Chapter Three: Design of Three phase induction motor

Chapter Four: Test, Result and Discussion of Result

Chapter Five: Conclusion and Recommendation

LIST OF TABLES

LIST OF FIGURE

CHAPTER ONE

1.1 GENERAL INTRODUCTION

An AC motor is an electric motor that is driven by an alternating current.It consists of two basic parts,an outside stationary stator having coils supplied with alternating current to produce a rotating magnetic field, an outside rotor attached to the output shaft that is given a torque by the rotating field. There are two types of ac motors depending on the type of rotor used [1]. The first is the synchronous motor,which rotate exactly at the supply frequency or a sub multiple of the supply frequency. The magnetic field of the rotor is either generated by current delivered through slip rings or by a permanent magnet. The second type is the induction motor which runs slightly slower than the supply frequency. The magnetic field on the rotor of this motor is created by an induced current[2,3].

Ac induction motors are the most commonly used motors in industrial motion control systems as well as in main powered home appliances. Simple and rugged design, low cost, low maintainance and direct connection to an ac power source are the main advantages of an ac induction motor. Various types of ac induction motor are available in the market,different motors are suitable for different applications.

The induction motor operates by virtue of current induced from the stator field in the rotor. In this respect, its operation is similar to that of a transformer in that voltage in the stator (which is the primary coil) induces current in the rotor (acting as secondary coil)[4].

Computer aided design of three phase induction motor is a method by which three phase induction motor are designed with the use of programming software packages such as C++,

1

visual basic, java, matlab etc. The other method of designing induction motor is the Analytical method which is labourious and comparatively old too due to its long mathematical calculations which are very error prone, time consuming and less effective when compared to the computer aided design method.

1.2   AIMS AND OBJECTIVES OF THIS PROJECT

The aim of this project is to show a more efficient, cost effective, easy and fast method of designing a three phase induction motor by the use of computer programming software. The setbacks of other methods includes;

- Analytical method presents too lengthy process of arriving at the final design.

- Design calculations are error prone in the analytical method.

- The products final performance is slightly better than the analytical method.

1.3   METHODOLOGY:

Computer aided design of three phase induction motor is a method by which three phase induction motor are designed with the use of computer programming software such as C++, visual basic, matlab, java etc. In this project however, Java programming language is used. Several predetermined and assumed inputs(specifications), including all necessary mathematical formulae are fed into the program which is then run to give the values with which actual construction of the induction motor is done.

In this project, system design will be based wholly on simulation in a java environment using Java programming language. The work presents program that utilizes a graphical user

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2

interface(GUI) to calculate electrical variation in the parameters of the induction motor. It is designed in such a way as to allow the user to enter the parameters under investigation.

The choice of java stem from its inherent mathematical orientation and easy GUI manipulation. Other software packages would have been used,however,none of these programs could handle the complex mathematical processes that may be encountered in this Engineering analysis.

The main reason for using GUI is because it makes things simple for the end users of the program. If GUI was not used, people will have to work from the command line interface which can be extremely difficult and frustrating.

1.4 SCOPE OF WORK

This project is basically concerned with the computer aided design of three phase induction motor using Java programming language since the analytical process is time consuming and so labourious.

1.5 SOURCES OF MATERIALS

The materials used for this project were sourced from Internet, textbooks, lecture notes, and other related past project materials in the department.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 THEORETICAL BACKGROUND

An electric motor uses electrical energy to produce mechanical energy through the interactions of magnetic fields and current carrying conductors. The reverse process, that is, producing electrical energy from mechanical energy is accomplished by an alternator, generator or dynamo.

Electric motor finds application as diverse as industrial fans, blowers and pumps, machine tools, power tools, diskdrive and household appliances. They may be powered by direct current (e.g a battery powered portable device or motor vehicle), or by alternating current from a central electrical distribution grid[5].

2.2 THE INDUCTION MOTOR

An induction motor is a type of asynchronous ac motor where power is supplied to the rotating device by means of electromagnetic induction. Another commonly used name is squirrel cage motor because the rotor bars with short circuit rings resembles a squirrel cage(hamster wheel). The field windings in the stator of an induction motor sets up a rotating magnetic field around the rotor. The relative motion between this field and the rotation of the rotor induces electric current in the conductive bars. In turn, these currents lengthwise in the conductors react with the magnetic field of the motor to produce force acting at a tangent orthogonal to the rotor, resulting in torque to turn the shaft. In effect, the rotor is carried around with the magnetic field but at a slightly slower rate of rotation. The difference in speed is called Slip and it increases with load[1].

4

The conductors are often skewed slightly along the length of the rotor to reduce noise and smooth out torque flunctuations that might result at some speed due to interactions with the pole pieces of the stator. The number of bars on the squirrel cage determines to what extent the induced emf/currents are fed back to the stator coils and hence the current through them. The constructions that offers the least feedback employs prime numbers of bars[7].

2.3 TYPES OF INDUCTION MOTOR

- Single phase
- Poly phase
- Three phase

2.31 THE THREE PHASE INDUCTION MOTOR

Three phase induction machines are asynchronous speed machines operating below synchronous speed when motoring and above synchronous speed when generating. They are comparatively less expensive to its equivalent size synchronous or Dc machine. There are of two types depending on the rotor construction.

2.32 SQUIRREL CAGE ROTOR TYPE

Most common AC motors uses the squirrel cage rotor which is found in virtually all domestic and light alternating current motors. The squirrel cage refers to the rotating exercise cage for pet animals. The rotor takes its name from the shape of its rotor windings – a ring at either end of the rotor with bars connecting the rings running the length of the rotor. It is typically cast aluminium or copper poured between the iron luminates of the rotor and usually only the end rings will be visible. The vast majority of the rotor currents will flow through the bars rather than the high

5

resistance and usually varnished laminates. Very low voltages and very high currents are typically in the bars and end rings. High efficiency motors will often use cast copper in order to reduce the resistance in the rotor[1].

In operation, the squirrel cage motor may be viewed as a transformer with a rotating secondary. When the rotor is not rotating in synchronism with the magnetic field, large rotor currents are induced. This large rotor current magnetises the rotor and interacts with the stator's magnetic field to bring the rotor almost into synchronisation with the stator's field.

An unloaded squirrel cage motor at rated no – load speed will consume electrical power only to maintain rotor speed against friction and resistance losses; as the mechanical load increases, so will the electric load. The electrical load is inherently related to the mechanical load. This is similar to a transformer where the primary's electrical load is related to the secondary's electrical load. This is why for example,a squirrel cage blower motor may cause the light in a home to dim as it starts, but doesn't dim the lights on startup when its fan belt(and therefore mechanical load) is removed. Furthermore, a stalled squirrel cage motor(overloaded or with jammed sharft) will consume current limited only by circuit resistance as it attempts to start. Unless something else limits the current(or cuts it off completely), overheating and destruction of the winding insulation is the likely outcome.

In order to prevent the currents induced in the squirrel cage from superimposing itself back into the supply, the squirrel cage is generally constructed with a prime number of bars or atleast a small multiple of a prime number(rarely more than 2). There is an optimum number of bars in any design and increasing the number of bars beyound that point merely serves to increase the losses of the motor particularly when starting[5].

6

The speed of an AC motor is determined primarily by the frequency of the AC supply and the number of poles in the stator winding according to the relation;

$$Ns = \frac{120f}{P}$$

Where Ns = Synchronous speed in rev per minute(rpm).

F = Ac power frequency.

P = Number of poles per phase winding.

2.33 THE STATOR

The stator of a squirrel cage motor is in principle the same as that of a synchronous motor or generator. It is made up of a number of stampings which are slotted to recieve the windings.

The stator carries a three phase winding for a definite number of poles, the exact number of poles being determined by the speed requirement. The greater the number of poles, the lesser the speed and vice-versa. The stator winding, when supplied with three phase current, produces a magnetic flux which is of constant magnitude but which revolves at synchronous speed. This rotating magnetic flux induces an emf in the rotor by mutual inductance[1].

2.34 THE ROTOR

The rotor consist of a cylindrical lamination core with parallel slots for carrying the rotor conductors which should be noted clearly are not wires but consists of bars of copper or aluminium with one bar in each slot. The rotor bars are braced or electrically welded or bolted to

7

two heavy and stout-circuiting of same material known as end rings thus giving us what is picture sqarely called a squirrel-cage construction. In recent years, die-cast rotor construction made of silicon alloy with 6 - 12% silicon is used as pure aluminium does not cast well has become very popular because of ease in construction. There are no joints, so mechanically robust and good running performance as there is no possibility of high contact resistance[1].

2.35 WOUND ROTOR MOTOR

The wound rotor motor also called the slip-ring motor is a variation of the squirrel cage induction motor. While the stator is the same as that of the squirrel cage motor, it has a set of windings on the rotor which are not short-circuited nor brush lifted but rather terminated to a set of slip rings. This type of rotor is needed sometimes under specific requirement of speed control and high starting torque. The slip necessary to generate the maximum torque(pull-out torque) is directly proportional to the rotor resistance. In the slip-ring motor, the effective rotor resistance is increased by addding external resistance through the slip. Voltage is 100-400 for small machines using hand operated gear and maximum up to 1KV. for large machines[1,6].

$$\% \text{ Slip} = \frac{Ns - N}{Ns} \times 100$$

Where:

N_s= Synchronous speed

N= Actual speed

N_s–N is called the Slip speed.

Similarly, rotor(or motor) speed is given by:

$N = N_S(1 - S)$.

2.40 COMPUTER AIDED DESIGN

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, roadways and woven fabrics to mention but afew. Computer aided design programs usually allow a structure to be built up from several reusable 3 – dimensional components and the components(such as gears) may be able to move in relation to one another. It is generally possible to generate engineering drawings to allow 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[14].

2.41 HISTORY OF COMPUTER AIDED DESIGN

Computer aided design software would not be complete without the mention of Mathematician Euclid of Alexandria who in his 350BC treatise on mathematics "The element" expounded many of the postulates and axioms that are the foundations of the Euclidian geometry upon which todays CAD software are built. It was more than 2,300 years after Euclid that the first true CAD software, a very innovative system(although of course primitive compared to todays CAD software) called "Sketch pad" was developed by Ivan Sutherland as part of his PhD thesis at MIT in the early 1960s. Sketch pad was a specially innovative CAD software because the designer interacts with the computer graphically by using a light pen to draw on the computers monitor.

It was a tribute to Ivan Sutherland's ingenuity that even in 2004 when operations which took hours on 1960s computer technology can be executed in less than a millionth of a second and

9

touch sensitive TFT combination display/input devices are readily available. Sketch pad was the world's first CAD software but the first commercial computer aided machining(CAM) software system, a numerical control programming tool named PRONTO had already been developed by Dr. Patrick J. Hanralty who is most often referred to as "The Father of CADCAM"[14,15].

2.50   CHOICE OF PROGRAMMING LANGUAGE

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. It is intended to let application developers "Write once, Run anywhere" [12].

The reason for my 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 code for each control so that it could be executed at the press of a command button.

2.51   AN OVERVIEW OF JAVA PROGRAMMING LANGUAGE

Java is an object-oriented programming language introduced in 1995 by Sun Microsystems, the feel of the java program is fairly similar to that of C++.

The fundamental structural component of a Java program is the class. All data and methods are associated with some class; there is no global data or function as in C++. Classes can be members of packages; packages and class membership help determine scope and visibility of data and methods.

Its advantages include scalability, reusable codes, platform independence, shorter codes and its safe as it avoids CPU corruption.

Java applications are typically compiled to byte code (class file) that can run on Java Virtual Machine (JVM) regardless of computer architecture [13].

2.52 SYSTEM REQUIREMENT

This refers to the necessary requirements to achieve a successful software development.

Hardware Requirement

Hardware refers to the physical components of the computer. Below are the hardware requirements of this project;

1) At least Pentium 2-class processor with a speed of 450MHz.

2) Random Access Memory (RAM) size of 512MB and above.

3) Hard disk storage capacity of 1GB and above.

4) VGA of 800 × 600, 256 colors or as recommended: high color 16-bit.

5) Mouse and Keyboard.

Software Requirement

Software refers to the set of instructions to be executed by a computer. The software requirements for this project include:

1) Windows XP/Vista/7 operating system.

2) Java development kit (JDK).

3) Java runtime environment (JRE).

4) Net beans 6.5 and above compiler.

5) Any suitable antivirus.

2.53   SOFTWARE MAINTENANCE

Software should not be abandoned as soon as it becomes operational because it has to be monitored to ensure that it meets the user and management requirements and to see if it can accommodate any feasible additional changes. It is a well known fact that system depreciates over time. If such cases occur, the system designer could be called upon to perform any of the following tasks:

- Preventive maintenance: changes to change the existing system so as to reduce the risk of failure while operating.

- Corrective maintenance: correcting the problem that arises while using the system.

- Perfective maintenance: Enhancements or modifications to improve the safety, reliability, efficiency or cost-effectiveness of operation.

- Adaptive maintenance: Adaptations to address requirements that arises due to changes in the environment.

CHAPTER THREE

3.0 DESIGN OF A THREE PHASE INDUCTION MOTOR

3.1 DESIGN SPECIFICATIONS

The main specifications for the design of a three phase induction motor are:

1. Rated output in H.P or KW.

2. Three phase

3. Frequency in Hz

4. Voltage in volts

5. Speed in rpm

6. Efficiency

7. Power factor

8. Connections

9. Full load Current

10. Type:Squirrel cage rotor or wound rotor

3.2 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} = Number Of turns per phase.

φ = Flux per pole in the air gap.

P = Number 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,m.

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 = $(\pi D)/P$.

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

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

Or

$$KVA = 3 \times 4.44 \times K_w \times f \times \varphi \times T_{ph} \times I_{ph} \times 10^{-3} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.1)$$

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

$$KVA = \frac{H.P \times 0.746}{\eta \times \cos \Phi} \quad \text{... (3.2)}$$

Also,

$$KVA = \frac{KW}{\eta \times \cos \Phi} \quad \text{... (3.3)}$$

but specific magnetic loading (B_{av}) = $\frac{\text{Total flux in the airgap}}{\text{Area of flux path in the airgap}}$

$$Bav = \frac{P\varphi}{\pi DL} \quad \text{... (3.4)}$$

And

Specific electric loading (ac) = $\frac{\text{Total armature ampere conductor}}{\text{Armature at the air gap}}$

$$ac = \frac{3 \times 2 \times I_{ph} \times T_{ph}}{\pi D} \quad \text{... (3.5)}$$

Also,

$$f = \frac{PN_s}{120} = \frac{Pn_s}{2} \quad \text{... (3.6)}$$

From equation (3.4),

$$\varphi = \frac{B_{av} \times \pi DL}{P} \quad \text{... (3.7)}$$

Also, from (3.5),

$$T_{ph} \times I_{ph} = ac \times \pi D/3 \times 2 \quad \text{... (3.8)}$$

15

Substitute (3.7) and (3.8) into (3.1) gives:

$$KVA = 3 \times 4.44 \times K_w \times (Pn_s/2) \times (B_{av} \times \pi DL/P) \times (ac \times \pi D/3 \times 2) \times 10^{-3} \quad ....(3.9)$$

$$KVA = 1.11 \times \pi^2 \times K_w \times B_{av} \times ac \times 10^{-3} \times D^2 Ln_s$$

$$= 1.11 \times \pi^2 \times K_w \times B_{av} \times ac \times 10^{-3} \times D^2 Ln_s \quad .... (3.10)$$

$$KVA = C_o \times D^2 Ln_s$$

$$D^2 L = \frac{KVA}{C_o n_s} \quad ....(3.11)$$

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

Equation (3.11) is the output equation of an induction motor.

3.21 CALCULATION OF THE MAIN DIMENSIONS

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

From $KVA = C_o D^2 Ln_s$,

$$D^2 L = \frac{KVA}{C_o n_s} \text{ in m}^3 \text{ which is also the volume} ....(3.12)$$

$$L = \frac{\pi D}{P} \quad ....(3.13)$$

The ratio of gross core length to pole pitch can be assumed as given below for various design consideration.

I.   To achieve minimum over all cost   - 1.5 to 2.0

II.   To obtain good efficiency   - 1.4 to 1.6

III. To achieve good over all design   - 1.0 to 1.1

IV.   To obtain good power factor   - 1.0 to 1.3

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

$$\frac{\text{Pole pitch}}{\text{Core length}} = \frac{0.18}{\text{Pole pitch}}$$

Or

$$\frac{\pi D}{PL} = \frac{0.18P}{\pi D}$$

Hence internal diameter of stator, $D = 0.135P\sqrt{L}$ .... (3.14)

3.22 PERIPHERAL VELOCITY

The peripheral velocity $V = \pi Dn$ m/sec...(3.15)

V should not exceed 30m/sec for normal construction.

3.30 STATOR DESIGN

Turns per phase

Flux per pole,

$$\varphi = \frac{B_{av} \times \pi DL}{P}$$

Stator voltage per phase,

$$E_s = 4.44 \times K_w \times f \times \varphi \times T_s \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.16)$$

Therefore Stator winding turns per phase is :

$$T_s = \frac{E_s}{4.44 \times K_w \times f \times \varphi} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.17)$$

Where

K_w is the stator winding factor.

T_s is number of stator turns.

3.31 STATOR CONDUCTOR

Stator current per phase

$$I_s = \frac{KVA \times 1000}{3E_s} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.18)$$

Therefore, cross-sectional area of each conductor is

$$a_s = \frac{I_s}{\delta_s} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (3.19)$$

Where :

δ_s= Current density of stator conductor usually assumed between 3-5 A/mm^2.

3.32 STATOR SLOT

S_s = number of stator slot.

For a double lap winding,

$$S_s = 2MgP \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(3.20)$$

For single lap winding,

$$S_s = MgP$$

Where   M = The number of phases

g= Number of slots per pole per phases.

P = The number of poles

The Slot pitch

$$Y_{ss} = \frac{\pi D_s}{S_s} \quad \text{..} \quad (3.21)$$

Where Y_{ss} is between 15-25mm

Total number of stator winding conductors

$$= 3 \times 2 \times T_s \quad \text{..} \quad (3.22)$$

Number Of conductors per slot

$$Z_{ss} = \frac{3 \times 2 \times T_s}{S_s} \quad \text{..} \quad (3.23)$$

3.33 AREA OF CONDUCTOR

Approximate area per slot

$$= \frac{\text{Copper section per slot}}{\text{Space factor}}$$

$$= \frac{Z_{ss} a_s}{\text{Space factor}} \quad \text{..} \quad (3.24)$$

Where: space factor varies from 0.25 to 0.4.

3.34   STATOR WINDING RESISTANCE

$$r_s = \rho \frac{L_{mts}T_s}{a_s} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.25)$$

Where:

ρ = resistivity = 0.021

L_{mts} = Length of mean turns.

a_s = Stator Area.

T_s = Stator turns

3.35   STATOR COPPER LOSSES

$$L_s = 3 \times I_s \times r_s \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.26)$$

Where:

I_s = Stator current.

r_s = Stator resistance

3.36   AIRGAP LENGTH

$$L_g = 0.2 + 2\sqrt{DL}$$

Also,

$$L_g = 0.2 + D \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (3.27)$$

Where: L_g is in mm

3.40 ROTOR DESIGN.

3.41 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. This can be done using the following rules:

1. $S_r \neq S_s$ either may be greater than the other by 15 to 30 percent.

2. To limit harmonic induction torques,

    a) S_r is not greater than $1.25 S_s$

    b) The difference between S_s and S_r should not be equal to P, 2P, or 5P.

3. To avoid magnetic locking, the difference between S_r and S_s should not be equal to 3P.

4. To avoid noise and vibration, the difference between S_r and S_s should not be equal to 1, 2, P±1, P±2.

Rotor slot pitch

$$Y_{rs} = \frac{\pi D_r}{S_r} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (3.31)$$

Where:

S_r is the number of rotor slot

D_r is the rotor diameter

The number of rotor slot per pole is expressed as:

$$g_r = \frac{S_r}{2P}$$ .... (3.32)

3.42 ROTOR BAR CURRENT

Rotor bar current can be found out by assuming that the rotor mmf is approximately equal to the stator mmf. The difference is of the order of about 15 percent. The stator mmf is about 15 percent greater because of the magnetizing mmf.

Thus,

Rotor mmf = 0.85 stator mmf,

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

$$\text{Rotor mmf} = \frac{I_b S_r}{2}$$

$$\text{Stator mmf} = 3 \times I_s \times T_s$$

Therefore,

$$\frac{I_b \times S_r}{2} = 0.85 \times 3 \times I_s \times T_s$$

23

$$I_b = 0.85 \left(\frac{6I_s \times T_s}{S_r} \right) \quad \text{...} \quad (3.33)$$

Where I_b is the rotor bar current.

I_s and T_s are stator current and turns respectively.

3.43 ROTOR BAR AREA

The rotor bar area is given by:

$$A_b = \frac{I_b}{\delta_b} \quad \text{...} \quad (3.34)$$

Where δ_b = Current density and it's between $(4 - 7)$ A/mm^2

3.44 COPPER LOSSES IN THE ROTOR BARS

To do this, we calculate

Length of rotor bar,

$l_b = L + \text{Allowance for skewing.}$

Allowance for skewing = $(5 - 8)$ cm

Therefore, Resistance per bar is,

$$r_b = \frac{(0.021 \times l_b) \text{m}^2}{A_b \text{mm}^2} \quad \text{...} \quad (3.35)$$

Hence, total copper losses in the rotor bars is,

24

$$L_r = I_b^2 \times r_b \times \text{number of rotor bar} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(3.36)}$$

3.45   END RING CURRENT

$$I_{emax} = \frac{1}{2} \times \left(\frac{\text{Number of rotor bars}}{\text{Number of poles}} \right) I_{bav}$$

But for sine wave,

$$I_{bav} = \frac{I_b}{1.11}$$

Where: 1.11 is form factor for sine wave

Thus,

$$I_{emax} = \frac{1}{2} \times \frac{S_r}{P} \times \frac{I_b}{1.11}$$

$$I_e = \frac{1}{2\sqrt{2}} \times \frac{S_r}{P} \times \frac{I_b}{1.11}$$

$$I_e = \frac{1}{\pi} \times \frac{S_r}{P} \times I_b$$

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

$$\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(3.37)}$$

3.46   AREA OF END RINGS

This is given by

$$A_e = \frac{I_e}{\delta_e} \, mm^2 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(3.38)}$$

Where:

δ_e = Current density and is between $(5 - 8)$ A/mm^2

3.47   COPPER LOSSES IN END RINGS

Mean length of the current path $l_{me} = \pi \, D_{me.}$

Where D_{me} = mean diameter of end ring between $(4 - 6)$ cm less than rotor diameter.

Resistance of end Ring

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

$$\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(3.39)}$$

Where l_{me} is in m and A_e in mm^2.

Therefore,

Total copper losses in the end rings are:

$$L_e = 2 \times I_e^2 \times r_e \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(3.40)}$$

3.48 TOTAL ROTOR COPPER LOSS

L_{rt} = Copper losses in the rotor bar + Copper losses in end rings.

$$L_{rt} = L_r + L_e \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (3.41)$$

CHAPTER FOUR

4.0   TEST, RESULT AND DISCUSSION OF RESULT

In the previous chapter, some parameter where derived which aids in the design of three phase induction motor. This chapter simply involves carrying out an analytical calculation or test using some given specifications and afterwards, the result of the analytical calculations be compared with the result generated by the computer aided design software using same specifications as shown below.

4.10   THE SPECIFICATIONS ARE:

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/m^2.

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/mm^2.

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/mm^2.

Length of each bar L_b = 180mm.

Depth of end ring d_e = 12.5mm.
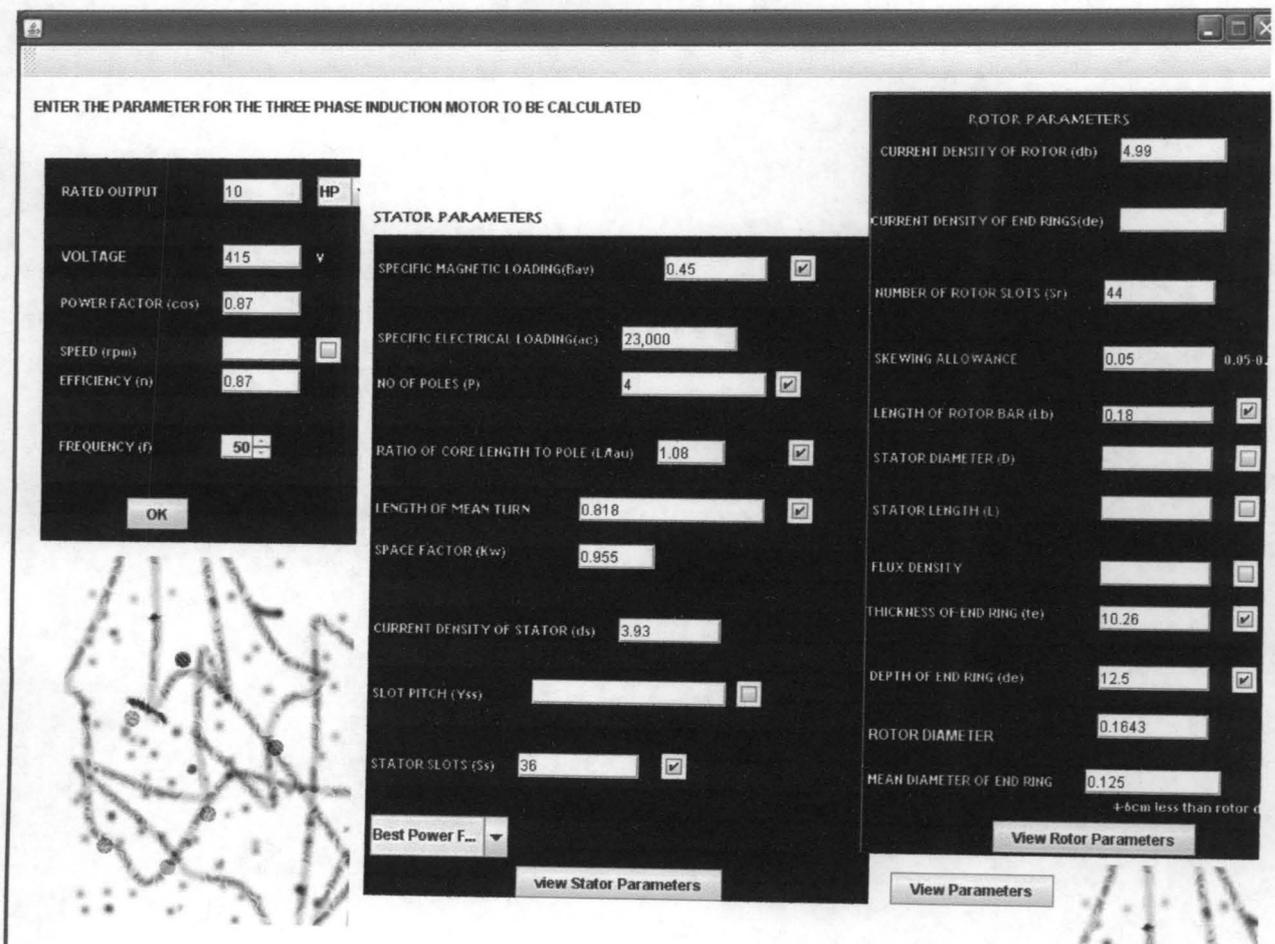
Thickness of end ring t_e = 10.26mm.

Fig. 4.1 Graphical user interface

4.2 FULL LOAD OUTPUT

From

$$KVA = \frac{HP \times 0.746}{\text{Efficiency} \times \text{power factor}}$$

HP = 10

Efficiency $\eta = 0.87$.

Power factor = 0.87.

Therefore,

$$KVA = \frac{10 \times 0.746}{0.87 \times 0.87}$$

$$KVA = \frac{7.46}{0.7569}$$

$$KVA = 9.86$$

SYNCHRONOUS SPEED IN RPS

From

$$f = \frac{PN_s}{120} = \frac{Pn_s}{2} \quad ,$$

$$n_s = \frac{2f}{P}$$

Where, f = 50Hz,

P = 4 Poles

Therefore,

$$n_s = \frac{2 \times 50}{4} = \frac{100}{4} = 25 rps$$

OUTPUT COEFFICIENT C_0

$$C_o = 1.11 \times \pi^2 \times K_{ws} \times B_{av} \times ac \times 10^{-3}$$

Where, $K_{ws} = 0.955$,

$B_{av} = 0.45$ wb/m^2

$ac = 23,000$ A/ m

Therefore,

$$C_o = 1.11 \times 3.142^2 \times 0.955 \times 0.45 \times 23,000 \times 10^{-3}$$

$$C_o = 108.31$$

MAIN DIMENSIONS

D and L are the main dimensions.

From

$$KVA = C_o D^2 L n_s,$$

$$D^2 L = \frac{KVA}{C_O n_s}$$

Where

$KVA = 9.86$,

$C_o = 108.31$,

$n_s = 25\text{rps}.$

Therefore,

$$D^2L = \frac{9.86}{108.31 \times 25} = \frac{9.86}{2,707.75}$$

$$D^2L = 3.6414 \times 10^{-3}m^3$$

To calculate for the values of D and L, the ratio of the gross core length to pole pitch must be known or given. The ratio of gross core length to pole pitch is:

$$\frac{L}{\tau_p} = \frac{140mm}{129.59mm} = 1.08$$

But,

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

Therefore,

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

But

$$\frac{L}{\tau_p} = 1.08$$

Therefore,

33

$$\frac{LP}{\pi D} = 1.08$$

Where, P = 4

Then,

$$\frac{4L}{3.142D} = 1.08$$

Cross multiplying, we get:

$$L = \frac{1.08 \times 3.142D}{4} = 0.84834D$$

From

$$D^2L = 3.6414 \times 10^{-3} m^3$$

Substituting L = 0.84834D into D^2L above gives;

$$D^2 \times 0.84834D = 3.6414 \times 10^{-3} m^3$$

$$0.84834D^3 = 3.6414 \times 10^{-3} m^3$$

$$D^3 = \frac{3.6414 \times 10^{-3}}{0.84834}$$

$$D^3 = 4.2924 \times 10^{-3}$$

$$D = \sqrt[3]{4.2924 \times 10^{-3}}$$

$$D = 0.1625m$$

Also, from

$$L = 0.84834D$$

$$L = 0.84834 \times 0.1625$$

$$L = 0.1379m$$

4.30 STATOR CALCULATIONS.

4.31 FLUX PER POLE φ_m

$$\varphi_m = \frac{B_{av} \times \pi DL}{P}$$

Where:

$B_{av} = 0.45$wb/m

$D = 0.1625$m

$L = 0.1379$m

$P = 4$

Therefore,

$$\varphi_m = \frac{0.45 \times 3.142 \times 0.1625 \times 0.1379}{4}$$

$$\varphi_m = 7.9209 \times 10^{-3} wb$$

TURNS PER PHASE T$_s$

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

Where:

E$_s$ = 415V

K$_{ws}$ = 0.955

f = 50Hz

φ_m = 7.9209 × 10^{-3}wb.

Hence,

$$T_s = \frac{415V}{4.44 \times 0.955 \times 50 \times 7.9209 \times 10^{-3}}$$

$$T_s = 247.125$$

4.32   STATOR CURRENT PER PHASE I$_s$

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

Where:

E$_s$ = 415V

KVA = 9.86

Therefore,

$$I_s = \frac{9.86 \times 1000}{3 \times 415}$$

$$I_s = 7.92A$$

4.33 CROSS SECTIONAL AREA OF STATOR CONDUCTOR a_s

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

Where:

$I_s = 7.92A$

$\delta_s = 3.93 \, A/mm^2$

Therefore,

$$a_s = \frac{7.92A}{3.93 \, A/mm^2}$$

$$a_s = 2.01mm^2$$

4.34 STATOR SLOTS S_s

For a single lap winding,

$$S_s = MgP$$

Where:

M = Number of phases = 3

g = Number of slot per pole per phase = 3

P = Number of poles = 4.

Therefore,

$$S_s = 3 \times 3 \times 4$$

$$S_s = 36 slots$$

4.35 CONDUCTORS PER SLOT Z_{ss}

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

$T_s = 247.125$

$S_s = 36$

Hence,

$$Z_{ss} = \frac{3 \times 2 \times 247.125}{36} = \frac{1482.75}{36}$$

$$Z_{ss} = 41.19 conductors$$

4.36 AIR GAP LENGTH L_g

$$L_g = 0.2 + \sqrt{DL}$$

$D = 0.1625m$

$L = 0.1379m$

$$L_g = 0.2 + \sqrt{0.1625 \times 0.1379}$$

$L_g = 0.3497m$

4.37 SLOT PITCH Yss

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

$D = 0.1625$

$S_s = 36.$

$$Y_{ss} = \frac{3.142 \times 0.1625}{36} = \frac{0.5106}{36}$$

$$Y_{ss} = 0.01418m = 14.18mm$$

4.38 STATOR WINDING RESISTANCE r_s

$$r_s = \rho \times \frac{L_{mts} T_s}{a_s}$$

$\rho = 0.021$

$L_{mts} = 0.818m$

$T_s = 247.125$

$a_s = 2.01mm^2$

$$r_s = 0.021 \times \frac{0.818 \times 247.125}{2.01}$$

$$r_s = 2.11 ohms$$

4.39   STATOR COPPER LOSSES AT FULL LOAD L_s

$$L_s = 3 \times I_s^2 \times r_s$$

$I_s = 7.92A$

$r_s = 2.11$

$$L_s = 3 \times 7.92^2 \times 2.11$$

$$L_s = 397.06w$$

4.40   ROTOR CALCULATIONS

ROTOR SLOT PITCH Y_{rs}

$$Y_{rs} = \frac{\pi D_r}{S_r}$$

$D_r = 0.1643m$

$S_r = 44$

$$Y_{rs} = \frac{3.142 \times 0.1643}{44} = \frac{0.5162}{44}$$

$$Y_{rs} = 0.01173m = 11.73mm$$

4.41 ROTORS BAR CURRENT I_b

Number of rotor bars N_b = Number of rotor slots S_r = 44

$$I_b = \frac{0.85 \times 6I_s T_s}{S_r}$$

$I_s = 7.92A$

$T_s = 247.125$

$S_r = 44$

$$I_b = \frac{0.85 \times 6 \times 7.92 \times 247.125}{44} = \frac{9,981.873}{44}$$

$I_b = 226.86A$

4.42 ROTORS BAR AREA A_b

$$A_b = \frac{I_b}{\delta_b}$$

$I_b = 226.87A$

$\delta_b = 4.99A/mm^2$

$$A_b = \frac{226.87}{4.99}$$

$A_b = 45.46mm^2$

4.43   ROTOR BAR RESISTANCE r_b

$$r_b = \frac{0.021 \times L_b}{A_b}$$

L_b = length of bars = 0.180m

A_b = Rotor bar area = 45.46mm^2

$$r_b = \frac{0.021 \times 0.180}{45.46} = \frac{3.78 \times 10^{-3}}{45.46}$$

$$r_b = 83.15 \times 10^{-6} ohms$$

4.44 ROTORS BAR LOSSES L_b

$$L_b = I_b^2 \times r_b \times N_b$$

I_b = 226.87A

r_b = 83.15×10^{-6}

N_b = Number of rotor bar = 44

$$L_b = 226.87^2 \times 83.15 \times 10^{-6} \times 44$$

$$L_b = 188.31w$$

4.45   END RING CURRENT I_e

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

$S_r = 44$

$I_b = 226.87A$

$P = 4$

$$I_e = \frac{44 \times 226.87}{3.142 \times 4} = \frac{9982.28}{12.566}$$

$$I_e = 794.36A$$

4.46   END RING AREA A_e

$$A_e = t_e \times d_e$$

$t_e = 10.26mm$

$d_e = 12.5mm$

$$A_e = 10.26 \times 12.5$$

$$A_e = 128.25mm^2$$

4.47   END RING RESISTANCE r_e

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

But,

$l_{me} = \pi D_e$

$D_e = 0.125cm$

$A_e = 128.245 \text{mm}^2$

$$r_e = \frac{0.021 \times 3.142 \times 0.125}{128.245} = \frac{8.24775 \times 10^{-3}}{128.245}$$

$$r_e = 64.31 \times 10^{-6} ohms$$

4.48   TOTAL COPPER LOSSES IN THE END RINGS L_e

$$L_e = 2 \times I_e^2 \times r_e$$

$I_e = 794.36A$

$$r_e = 64.31 \times 10^{-6} ohms$$

Therefore,

$$L_e = 2 \times 794.36^2 \times 64.31 \times 10^{-6}$$

$$L_e = 81.160w$$

4.49   TOTAL ROTOR COPPER LOSSES L_{rt}

$$L_{rt} = Total\ copper\ losses\ in\ end\ rings + Copper\ losses\ in\ rotor\ bars$$

$$L_{rt} = L_e + L_b$$

$$L_{rt} = 81.16 + 188.31$$

$L_{rt} = 269.47w$

TABLE 4.1: SHOWING BOTH ANALYTICAL AND COMPUTER AIDED DESIGN RESULTS OF THREE PHASE INDUCTION MOTOR

INDUCTION MOTOR PARAMETER	ANALYTICAL RESULT	COMPUTER AIDED DESIGN RESULT
Stator	Output	Output
The revolution per minute	1500.00	1500.00
The revolution per seconds	25.00	25.00
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	41.20
Air gap length	0.3497m	0.3497m
Slot pitch	0.01418m	0.014182m
Stator Resistance	2.11ohms	2.108ohms
Stator copper loss	397.06w	396.375w

Rotor		
Rotor Slot pitch	11.73mm	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	0.000083ohms
Resistance in the end ring	0.00006431ohms	0.000064ohms
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

4.50   DISCUSSION OF RESULTS.

The computer aided design of three phase induction motor is greatly affected by some of the assumed parameters when compared to the analytical calculation. Some of the assumed parameters include winding factors of rotor and stator, specific magnetic loading, current density etc. This is because these parameters are either assumed or chosen from a table of approximate values or calculated. A little alteration or a wrong choice or usage of the assumed parameter will lead to a variation of the result from what is expected.

It can also be seen from the analytical calculations made and the computer aided program used, that is, from the results shown in the table above, that there are slight differences in the calculated results of both methods. This is due to the fact that the analytical calculations are full

46

of approximations, laborious and hence very prone to errors when compared to the computer aided design method.

This slight difference is however negligible and most time does not have significant effect on the design.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

With the recent trend in Technology, most lengthy calculations and simulation of circuits are done with the use of computer aided design program designed to serve the purpose. Mat lab and others are examples of such software programs.

Three phase induction motor finds its application in almost all facets of life and thus its demand will be 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 reduce the error associated with the analytical method.

It is seen from the analytical calculations carried out and the computer aided design method used that there is a slight difference in the results so gotten when both methods are compared.

It can thus be said that both methods gives almost the same result but the analytical method presents too lengthy process of arriving at the final design and design calculations are error prone in the analytical calculations due to approximations and thus resulting in slight differences in the results. This slight difference in the output result is negligible.

In conclusion, the product final performance is slightly better in the computer aided design than the analytical method and the computer aided design is less time consuming and should be highly recommended.

5.2 RECOMMENDATION

As the designer of this work, I recommend this work as follows:

1. That the design be provided with regular maintenance to avoid failure.

2. That further work and modification be done on this project by other students to meet up with the changes and advancement in technology.

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