DESIGN AND MEASUREMENT OF LOSSES IN AC INDUCTION MOTOR WITH DIFFERENT ROTOR BAR MATERIAL

GOMESH NAIR A/L SHASIDHARAN

UNIVERSITI MALAYSIA PERLIS
2009

DESIGN AND MEASUREMENT OF LOSSES IN AC INDUCTION MOTOR WITH DIFFERENT ROTOR BAR MATERIAL

by

GOMESH NAIR A/L SHASIDHARAN
(0830910239)

A thesis submitted
In fulfillment of the requirement for the degree of
Master of Science (Electrical Systems Engineering)

School of Electrical Systems Engineering
UNIVERSITI MALAYSIA PERLIS

2009

ACKNOWLEDGMENT

All thanks are to God for the opportunity and the strength He gave me to study towards my masters. The author expresses his gratefulness first and foremost to the superb mentor and would like to state his boundless appreciation and warmest gratitude to supervisor Prof. Dr. Ismail bin Daut, co-supervisors Mr. Anayet Karim and Mr. Rosnazri bin Ali for their valuable supervision, continuous encouragement, inspiring suggestion, and guidance in the research and in the preparation of this thesis. They provided the author with great opportunity and allowed him to go in depth in the areas of induction motors and machine design. Their motivation, advice, encouragement and many discussions have helped the author for the completion of the research and this master's thesis.

The author would like to extend his unlimited appreciation wholly to my friend Mr. Satiyan Marimuthu and Miss Thubaasini Prabhakaran whom is a true friend and inspiration for many friends in need. Throughout the completion of the project they have be an advisor, financier and someone who makes you believe that there really is good in the world. You are forever a good friend. Not forgetting my fellow masters and PhD companion in the Power Electronic and Machine Design Research Cluster. They have opened their hearts and shared important knowledge in completing my research thesis. My stay at the laboratory has indeed provided me wonderful memories as well as adequate information.

My outmost gratitude and apologies I convey to my family for they have sacrificed their life and happiness in enduring many months of separation in my absence. I thank them again for being the pillar of strength and a constant source of encouragement in my quest to pursue my peculiar endeavors. For all those whom I may not mention here I apologies and thank everyone who have been a part of my success.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

B-Magnetic Flux Density

H-Magnetic Field Intensity

DC-Direct Current

AC-Alternating Current

HP-Horse Power

2D-Two Dimension

IEEE-Institute Electric and Electronic Engineering

IEC-International Electrotechnical Commission

EMTP-Electromagnetic Transient Program

LIM-Linear Induction Motor

POT-Plot Magnetic Line Potential

PWM-Pulse Width Modulation

IPM-Interior Permanent Magnet

EMF-Electromagnetic Force

IG-Induction Motor Generator

FEM-Finite Element Method

LF-Load Factor

ASD-Adjustable Speed Drive

NEMA-National Electrical Manufacturers Association

TNB-Tenaga Nasional Berhad

SESB-Sabah Electricity Supply Sendirian Berhad

SEU-Energy Consumed per unit physical product

AES-Annual Energy Saving

TCS-Total Cost Saving

REKABENTUK DAN PENGUKURAN KEHILANGAN KUASA DALAM MOTOR ARUHAN ULANG ALIK DENGAN BAHAN ROTOR BAR BERLAINAN

ABSTRAK

Dalam tesis ini, Motor aruhan arus ulang alik tiga fasa telah di kaji dengan teliti dan dianalisa pada aspek parameter, kecekapan, faktor kuasa dan kehilangan kuasa yang berlaku pada motor aruhan. Sepanjang projek ini, satu rotor kuprum bar difabrikasi dan dibandingkan dengan rotor aluminium bar yang sedia ada. Fasa pertama projek adalah perbandingan dilakukan dengan menggunakan simulasi perisian Opera 2D diantara rotor aluminium bar dan rotor kuprum bar untuk motor aruhan kuasa kuda 0.5 yang mempunyai konfigurasi belitan pemegun yang sama. Perbandingan Opera 2D yang dilakukan merangkumi aspek kehilangan kuasa, ketumpatan fluks magnet, keamatan medan magnet, ketumpatan arus pusar, tork terhadap kelajuan, tork terhadap gelincir, kehilangan kuasa terhadap kelajuan dan kehilangan kuasa terhadap gelincir. Fasa kedua projek adalah perbandingan yang dilakukan di makmal iaitu perbandingan diantara rotor kuprum bar yang dibikin dengan rotor aluminium bar sedia ada. Dalam bahagian ini, rotor kuprum bar dan rotor aluminium bar dikaji dengan melakukan ujian tanpa beban, ujian rotor tertahan dan ujian rintangan arus terus untuk mengkaji perbezaan kecekapan, kehilangan dan pembaikan faktor kuasa diantara kedua-dua rotor berkenaan. Ujian beban juga telah dilakukan untuk mengkaji kecekapan motor aruhan pada masa faktor beban yang rendah dan keputusan menunjukan pada faktor beban yang rendah, motor aruhan kehilangan kecekapan dan faktor kuasa. Kesimpulan penyelidikan, baik perisian mahipun ujian makmal menunjukkan bahawa rotor kuprum bar mampu menaikkan kecekapan motor dan faktor kuasa sebanyak 1% dan mengurangkan kehilangan kuasa sebanyak 5 Watt berbanding dengan pengunaan rotor aluminium bar. Satu perhitungan ekonomi telah disediakan untuk menunjukkan bilangan tenaga dan wang yang boleh dijimat dengan mengantikan rotor aluminium bar dengan rotor kuprum bar. Untuk aspek penjimatan tenaga tahunan (AES) dan penjimatan jumlah kos (TCS), rotor kuprum mampu menjimatkan 40.32kWh untuk setahun dan kadar utiliti sebanyak RM13.54 untuk satu motor setahun. Akhir sekali, satu anggaran kasar dibuat untuk penjimatan 100, 000 biji motor aruhan yang telah digantikan dengan rotor kuprum bar dan menunjukkan sebanyak RM1.3 juta boleh dijimatkan.

DESIGN AND MEASUREMENT OF LOSSES IN AC INDUCTION MOTOR WITH DIFFERENT ROTOR BAR MATERIAL

ABSTRACT

In this thesis, the three phase AC induction motor have been thoroughly investigated and analyzed in terms of the induction motor parameter, efficiency, power factor and loss segregation. Through out this project, a copper rotor bar is fabricated and compared with the existing aluminium rotor bar. The first part of comparison is done with software simulation using Opera 2D between aluminium rotor bar and copper rotor bar for the same 0.5HP stator slot design and winding configuration. The Opera 2D is compared in terms of power loss, magnetic flux density, magnetic field intensity, eddy current density, torque vs. speed, torque vs. slip, power loss vs. speed and power loss vs. slip. The second part is the hardware comparison between the fabricated copper rotor bars with the existing aluminium rotor bar. In this part, the copper rotor bar and aluminium rotor bar are tested using no load, blocked rotor, and DC resistance test to obtain the difference of efficiency, losses and power factor improvement. The load test is also performed to investigate the efficiency of the induction motor at low load factor and result shows that at lower load, the induction motors lose its efficiency and power factor. From the overall experiment of software and hardware, results shows that copper rotor bar does increase the efficiency and power factor to 1% and reduce losses to 5 watts compare to aluminium rotor bar. An economical aspect is presented to show the amount of energy and money that can be saved from replacing the aluminium rotor bar with a copper rotor bar. As for the annual energy saving (AES) and total cost saving (TCS), the copper rotor manage to save 40.32kWh per year and utility billing by RM13.54 per year per motor. Finally a rough estimation of 100,000 pieces induction motor that have been replaced with the copper rotor bars is assumed and shows that it will save approximately RM1.3 million.

CHAPTER 1

INTRODUCTION

1.1 Introduction

An induction motor is sometimes called a rotating transformer because the stator is essentially the primary side of the transformer and the rotor is the secondary side (Chapman, 2005). Induction motors are widely used, especially poly-phase induction motors, which are frequently used in industrial arena (B.L. Theraja & A.K. Theraja, 1998). The induction motor machine is an important class of electric machines which finds wide applications. More than 85% of industrial motors in use today are in fact induction motors. Induction motors are complex electromechanical devices utilized in most industrial applications for the conversion of power from electrical to mechanical form. Three phase induction motor are used because it is simple, rugged, low price, and easy to maintain. They run at essentially constant speed from zero to full-load (W. Theodore, 2006).

Based on the analysis of industrial energy use in Malaysian companies, it has been found that electrical motors used the highest amount of energy (47%) followed by pumps (14%), air compressors (9%), air-conditioning systems (7%), workshop machines (6%,), lighting (6%), overhead cranes (3%), ventilation (2%), furnace (1%), conveyor system (1%), boiler (1%), refrigeration system (1%) and other equipments (4%) (Saidur et al., 2009). The majority of motors in the industry are induction motors. There may be various reasons for the desire of testing an existing induction motor in the field, such as consideration of exchanging out of date or worn motors with new, or checking the efficiency after rewinding. Particularly the output power of motor is hard to detect. One of established procedures is therefore to calculate the efficiency by measuring the losses and subtract them from the input to find the output (Chapman, 2005).

Induction motors are used worldwide as the workhorse in industrial applications. Such motors are robust machines used not only for general purposes, but also in hazardous locations and severe environments. General purpose applications of induction motors include pumps, conveyors, machine tools, centrifugal machines, presses, elevators, and packaging equipment. On the other hand, applications in hazardous locations include petrochemical and natural gas plants, while severe environment applications for induction motors include grain elevators, shredders, and equipment for coal plants. Additionally, induction motors are highly reliable, require low maintenance, and have relatively high efficiency. Moreover, the wide range of power of induction motors, which is from hundreds of watts to megawatts, satisfies the production needs of most industrial processes.

The stator of an induction motor is similar to that of a synchronous machine and is wound for three places, modern practice being to use the two-layer winding. Two type of construction are employed for the rotor; wound rotor and squirrel cage rotor. The rotor core is of laminated construction with slots suitably punched in for accommodating the rotor winding/rotor bars. The punched laminations are stacked and fitted directly onto a shaft in the case of small machines; while in the case of large machines a stack of annular punching of a suitable cross-sectional area are fitted onto a spider web arrangement on the shaft. An induction motor is a type of asynchronous AC motor where power is supplied to the rotating device by means of electromagnetic induction. An electric motor converts electrical power to mechanical power in its rotor (rotating part). There are several ways to supply power to the rotor (Nagrath & Kothari, 2002).

In general, the losses of a machine can be estimated either by calculation or determined by measurement, but the nature of electrical machines is such that it is almost impossible to predict the losses with high precision. The losses of the AC induction motor can be divided into five categories. The first five loss components are stator copper loss, rotor copper loss, core loss, stray load loss and friction and windage losses are obtain from no-load test and block rotor test. The copper loss is determined based on stator resistance, slip and input power measurements. The fifth loss component is known as stray loss. Indeed the term 'stray losses' came about because of the discrepancies between predicted and measured losses. The accurate measurement of loss, which itself presents many difficulties, can be approached in a number of ways first by the difference between the measured input and output powers, second by the segregation and separate measurement of the loss components, and finally by the measurement by the effects of the losses (Turner et al., 1991). Stator and rotor copper loss I^2R make up the largest share. Both are influenced by the presence of harmonics. Whereas what occurs within the stator winding is directly measurable, what occurs in the rotor is not. Iron or core loss is frequency-dependent. It's determined in standard test procedures (refer to IEEE Standard 112 B) from measurements made during a no-load running test. These losses can affect the efficiency and can be reduced by using quality materials, as well as by optimizing the design.

1.2 Aims and Objectives

The aim of the thesis is to investigate the losses in AC induction motor using different rotor bar material which is copper and aluminium and to obtain the efficiency and performance of the induction motor in both rotor materials.

The objective of this research can be summarized as follows:

1. Mathematical modeling of 5 HP three phase AC induction motor.
2. Design and simulation of three phase AC induction motor using Opera 2D software version 12.0 for aluminium and copper rotor bars.
3. To construct a rotor with copper rotor bar and compare it with the existing aluminium rotor bars of the 0.5 HP induction motor.
4. To investigate the performance of the copper rotor bar in terms of efficiency, power factor, losses reduction potential and economical aspect analysis in terms of money and energy saving.
5. To investigate the efficiency of the 0.5 HP AC induction motor based on loss parameters such as stator copper loss, rotor loss, core loss, friction & windage losses and stray load loss in both rotors.

1.3 Scope of Project

The scope of the project involves many areas of studies; each scope has its importance towards completing this project. First, the mathematical modeling of AC induction motor to calculate all the loss parameters for 5 HP three phase AC induction motor. This is to show the efficiency and the amount of energy that is consumed in an induction motor. Second, the research involves designing and simulating the 0.5 HP three phase AC induction motor using Opera 2D version 12.0. From the simulation, analysis such as magnetic line potential, power loss, magnetic flux density, magnetic field strength, eddy current density, torque vs. speed, torque vs. slip, power loss vs. speed, and power loss vs. slip is investigated. A comparative study is also done between the usage of aluminum and copper material in the rotor bars of induction motor. Third, an induction motor rotor with copper rotor bar is fabricated and investigated in terms of efficiency increment, power factor improvement and loss reduction capabilities. Fourthly, experimental procedures is performed to the 0.5 HP three-phase induction motor such as no load, DC resistance and block rotor test to investigate the losses differences and to obtain the efficiency of three-phase induction motor with aluminium rotor bars and copper rotor bars. The load test is performed to investigate the efficiency and power factor when interfaced with lower load factor. Finally, based on the overall experiment, the amount of energy and money that can be save from using copper rotor bars in an AC induction motor is presented and discussed thoroughly.

1.4 Problem Statement

The efficiency of induction motor depends on percentage of losses. In electrical machines, core losses amount to 20-25 % and copper loss amount to 15-30 % of the total losses (Hubert, 2002). A substantial portion of the losses in electrical machines is loss in the iron core. Calculations of iron losses in the electrical machines are normally based on experimental characteristics of core material used in the machines. Efficiency of induction motor is very much debated these days. Different standards are used in the world making actual manufacturer numbers hard to compare. Energy efficient electric motors generally represent one of the biggest opportunities for cost effective electricity saving around the world. Induction motor efficiency is dependent on the amount of motor losses such as stator copper loss, rotor loss, core loss, friction and windage loss and stray load loss. If these losses can be decreased, the motor efficiency can be increased and energy consumption can be reduced. The increase in the efficiency of electric machines is the main problem in the production of induction motors, especially in the range of small motors.

1.5 Project Overview

Figure 1.0 shows the overview of project that is implemented step by step to investigate the motor's efficiency, losses, power factor using two different rotor bar material.

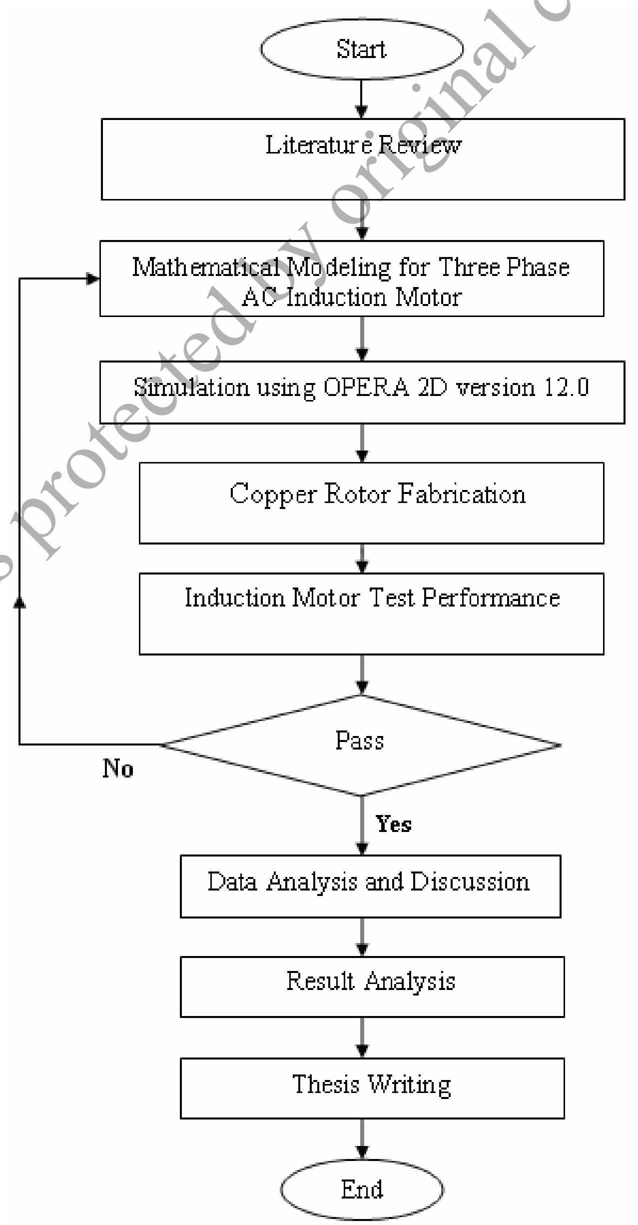

Figure 1.0: Flow Chart of Project Overview

1.6 Thesis Synopsis

The thesis is divided into five chapters. Chapter one introduces the introduction, aims and objectives, scope of project, problem statement, project overview and the synopsis of the thesis.

Chapter two discusses about the literature review based on induction motor performance, types of experiment carried out by other researcher and the contribution from the researchers in Malaysia, the aspect of research involved in induction motor such as losses of the 0.5 HP induction motor, the induction motor test phenomena literature such as no load, DC resistance, block rotor and load test, the literature on load factor evaluation is stated as well, and finally the performance of three phase AC induction motor in terms of the energy policy and energy saving prospect.

Chapter three explains the details of methodologies implemented in the project based on software and hardware phases. This chapter explains the mathematical modeling concept, design and simulation phase of Opera 2D electromagnetic analysis software and laboratory procedures carried out such as the no load, block rotor, DC resistance and load test, this to investigate the losses, power factor and efficiency of the 0.5 HP AC induction motor. Finally the fabrication of rotor with copper bars is stated.

Chapter four contains results and discussion from the simulation of Opera 2D design as well as comparison between the aluminium and copper rotor bars in terms of power loss, magnetic flux density, magnetic field strength etc.., As for the laboratory experimental, the analysis of aluminium and copper rotor bar in terms of loss segregation and loss reduction capabilities, efficiency and power factor improvement is stated and finally the overall result is analyzed in terms of the economical aspect and energy saving prospect towards the benefits of Malaysian industries.

The conclusion is listed in chapter five. In this chapter, the project is summarized and a conclusion is made based on the results obtained from chapter 4, towards the fulfillment of the proposed objectives stated in chapter 1, a product of copper rotor bar is proposed and future recommendation is stated.