PERFORMANCE ANALYSIS OF SINGLE-PHASE INDUCTION MOTOR USING 14-POLE ROTOR FOR CEILING FAN APPLICATION

MUZZAMMIL BIN AMRAN

UNIVERSITI SAINS MALAYSIA

2016

PERFORMANCE ANALYSIS OF SINGLE-PHASE INDUCTION MOTOR USING 14-POLE ROTOR FOR CEILING FAN APPLICATION

BY

MUZZAMMIL BIN AMRAN

Thesis is submitted in partial fulfillment of the requirements for the degree of

Bachelor of Engineering (Electrical Engineering)

JUNE 2017

ACKNOWLEDGEMENT

Alhamdulillah, this thesis is devoted to all people that have helped me during this project after a hard and long journey in study of performance of single-phase induction motor. Their kindness to make an effort and helped directly or indirectly in completing my final year project task is really helpful and appreciated.

First of all, I would like to offer my sincere appreciation and special thanks to Assoc. Prof. Ir. Dr. Dahaman bin Ishak, my final year project supervisor, who gave me oppurtunity to undertake final year project under his supervision. He is willing to share his opinions, ideas, advices and recommendations on expanding my field of study. He also gives me motivation and encouragement to complete all the task and made it a lot easier.

Futhermore, I cannot express enough thanks to my friend, Khairul Ismadi who tought me a lot on using finite element sofware 2D. All the time he spent on teaching me from the beginning are much appreciated

Finally, I would like to express gratitude to my beloved family and to all my friends who have always give me the moral supports in completions of my project till the end. All the continuuous moral support that they give help me to improving myself and keep moving forward.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A	Ampere
AC	Alternating current
Cos θ	Power Factor
DC	Direct Current
H	Henry
Hz	Hertz
I_o	Input current
I_m	Main winding current
I_a	Auxiliary winding current
N	Motor speed
Ns	Synchronous speed
R	Resistance
R_m	Main winding resistaance
R_a	Auxiliary winding resistance
S	Slips
SPIM	Single-phase induction motor
V	Voltage
W	Watt

θ_m	Phase difference between input voltage and main current
θa	Phase difference between input voltage and auxiliary current
F	Farad
mm	Millimeter
rpm	revolutions per minute
rms	Root mean square
α	Phase difference between main and auxiliary current

ANALISIS PRESTASI MOTOR ARUHAN SATU FASA MENGGUNAKAN 14-KUTUB PEMUTAR UNTUK APLIKASI KIPAS SILING

ABSTRAK

Motor aruhan fasa tunggal telah lama digunakan untuk kerja-kerja yang remeh dan berulang-ulang kerana kesederhanaan dalam pembinaan dan mudah tersedia dari bekalan kuasa fasa tunggal di dalam hampir setiap isi rumah. Oleh itu, ia sering digunakan dalam aplikasi industri kecil di mana bekalan tiga fasa tidak tersedia. Kipas siling adalah salah satu aplikasi yang popular yang sering digunakan di Malaysia bagi penyejukan dan tujuan pengudaraan. Tujuan projek ini adalah untuk membuat peningkatan dengan menganalisis prestasi motor kipas siling. Reka bentuk dan model adalah perkara yang penting perlu direka dengan menggunakan kaedah unsur (FEM). Terdapat dua jenis analisis dilakukan untuk mengkaji prestasi motor kipas siling contohnya analisis arus selang-seli keadaan stabil dan analisis pergerakan putaran pada motor. Kedua-dua analisis boleh dilaksanakan dalam perisian FEM. Semua simulasi yang dilakukan adalah untuk mengukur dan merekod arus masukan, kuasa masukan, faktor kuasa dan tork keluaran. Perbezaan fasa antara voltan masukan,arus utama dan arus bantuan motor dan keberkesanan boleh diramal dengan tepat. Pelbagai reka bentuk berbeza kelajuan dan berbeza nilai kapasitor dari 1.8μF, 2.0μF dan 2.5μF dalam analisis pergerakan putaran pada motor. Kesemua data yang diperoleh disusun dan dianalisis. Semakin tinggi nilai kapasitor, semakin tinggi kuasa masukan dan tork keluaran. Reka bentuk motor dengan kapasitor 2.0μF menunjukkan prestasi yang terbaik.

PERFORMANCE ANALYSIS OF SINGLE-PHASE INDUCTION MOTOR USING 14-POLE ROTOR FOR CEILING FAN APPLICATION

ABSTRACT

Single-phase induction motor has been used for a long time for trivial and repetitive chores due to its simplicity in construction and easy availability of single-phase power supply in almost every household. They are robust, relatively cheap, high efficiency and almost free maintenance. Therefore, it is often used in light-duty industrial applications where three-phase supply is not readily available. Ceiling fans are one of the popular applications often used in Malaysia for cooling and ventilation purpose. The purpose of this project is to make an improvement by analyzing the performance of ceiling fan motor. The design and model are the important thing to create by using finite element method (FEM). There are two types of analysis conducted to study the performance i.e. steady-state AC analysis and rotational motion analysis. Both analyses can be implemented in FEM software. All FEM models are built and simulated to calculate and record the input current, input power, power factor and output torque. The phase difference between the input voltage, main and auxiliary currents of the motor and also the efficiency of the motor can be accurately predicted. Different motor designs that have different angular velocity and values of the capacitor varied from 1.8μF, 2.0μF and 2.5μF in rotational motion analysis. All information obtained are compiled and analyzed. The greater the value of the capacitor, the greater the input power required and output torque. Designed motor with capacitor value of 2.0μF shows the best performances.

CHAPTER 1

INTRODUCTION

1.1 Overview

Malaysia is a tropical areas of the world including Thailand and Indonesia which are located on the equator. Ceiling fan are frequently and widely used in tropical areas which is hot climate countries. Because of factor like easy maintenance and availability, low cost and less power consumption, ceiling fans are most used as common electrical appliances for cooling compared to air conditioning units [1]. Normally, there are three stages of speed of ceiling fan from low, medium to high. For low speed, the power consumption is in range of 15 to 30 watt, power for medium speed is in range of 30 to 50 watt and for high speed is in range 50 to 100 watt [2].

1.1.1 Principle of Ceiling Fan

Ceiling fan is a mechanical fan, usually electrically powered, suspended from the ceiling, that uses suspension rod mounted to the small motor and rotate it blade paddles to circulate air. They are having an electric motor with separate stationary and rotating part. Actually, ceiling fan has two funtion in different season which is clockwise in winter and counterclockwise in summer [3]. In Malaysia, normally ceiling fan was invented to improve quality of air movement instead of changing ambient temperature to cooling system like air-conditioner. Ceiling fan consists internal part and external part. The common part of ceiling fan is made up of seven components which are elctric motor, blades, blade flanges, canopy/switch cup, ball bearing, suspension rod and speed regulator [4]. Table 1.1 shows a common part of ceiling fans with all the descriptions referring to the Figure 1.1 which is available in [4].

Table 1.1 : Common parts of ceiling fan

Common Ceiling Fan Parts	**Description**
Electric motor	Single phase capacitor run and start induction motor, rated at 230V ± 10% at frequency of 50Hz.
Blades	The blades are made up of alminium sheets or sheet steel. Lighter blades enhance the efficiency of the fan like aluminium blades. Generally there are 3 or 4 angular blades ceiling fan which weight and sizes were considered during manufacture.
Blades flanges	Alternatively termed as blade irons, blades arm or blade holders. Connected the blades to the motor through these metal arms.
Canopy/ Switch Cup	There are two canopy, top and bottom, located along the suspension. The function of top canopy is to cover the hook, nut and bolt. The function of bottom canopy is to cover the motor wires and capacitor. These canopy is employed for user safety and protection.
Ball bearing	Ball bearing is a high quality steel and working as gear that uses balls to hold the separation between bearing races. It is to make sure the separation between rotating

	and statianary parts are free friction and noise free movement.
Suspension rod	This part is used to attach fan to ceiling fan from fan motor to the top ceiling wall. There are three important aspect involve on suspension rod endurance measurement for safety issue. • Fan weigh • Fan vibration • Fan start-up motion
Speed regulator	Speed regulator is employed to control the speed of fan by 3 stages (low,medium,high) varied by the apply voltage. There two general technique to control the fan speed • Tapped series inductor • Tapped field resistor

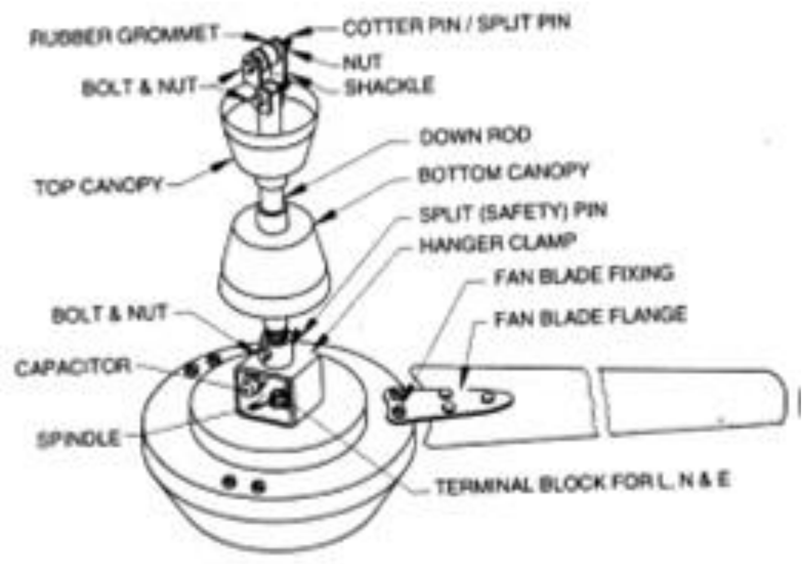


Figure 1.1 : Parts of ceiling fan

Based on [5], there are suggested sizes of ceiling fan for a good airflow according to area of room. Table 1.2 below show the specific size of fans according to the square feet of the area.

Table 1.2: Suggested sizes of ceiling fan

Suggested Ceiling Fan Sizes	
Fan Size, inch	**Room Square Feet, ft^2**
42	144
44-48	225
52-54	400
56	500

1.1.2 Principle Concept of Induction Motor

Induction motor also called as asynchronous motor because it runs at a speed less than its synchronous speed. Squirrel cage induction and slip ring induction motor are the two type of induction motor. Frequency and number of poles of the machine define the synchronous speed of rotation of the magnetic field in a rotary machine. Like any other electrical motor, asynchronous motors also have two main parts namely stationary stator and rotor [7]. Table 1.3 below shows two basic parts of an induction motor with it description.

Table 1.3: Basic Parts of an Induction Motor

Basic Parts	**Descriptions**

Stator	• Stationary part
	• Laminated stamping to reduce eddy current losses
	• Has two stator windings namely the main winding and the auxiliarry winding
	  ○ Main winding – create a set of North
	  ○ Auxiliary – operates for the motor start up
	• These two windings are placed in space quadrature with respect to each other

Rotor	• Rotating part
	• Connected to the mechanical load such as blades
	• Cylindrical in shape and has slots all over its perihery
	• Consist two type of rotor
	  ○ Squirrel-cage rotor made up of aluminium, brass or copper bars. Also known as rotor conductors and permenantly shorted by the copper with a welded at the end of both copper bar.
	  ○ Wound rotor have a set of three-phase winding and slip rings.

1.2 Problem Statement

Ceiling fan has been ideal choice and widely used in Malaysia due to comfort and energy savings for cooling purpose. Easy to do maintenance, low cost and low power consumption compared to air-conditioner make it affordable to almost everyone in Malaysia. Since most users choose ceiling fan as their cooling purpose in Malaysia, an improvement on ceiling fan performance is very important to the users.

Ceiling fan energy consumption varies by model. Power consumption draw ranges from 15 to 100 Watts depend on the speed which are low,medium and high. For current condition, output torque of single-phase induction motor is not yet optimized [8]. Futhermore, motor will occur power loss and heating if long period of operation of ceiling fan without being turned off. Efficiency of the ceiling fan will reduce because of these problem and waste more elctrical power. Thus, this may led to increase in electricity bill.

The current method used in estimating single-phase induction motor for ceiling fan application is not very precise. Thus, single-phase induction motor applied to the ceiling fan lead to inaccurate torque-speed characteristic. Therefore, ceiling fan speed and energy consumption need an improvement.

1.3 Research Objective

The objectives of the project are:

- To build a 2D model of 14-pole single-phase induction motor with AutoCAD and finite element sofware.
- To simulate the design of 14-pole single-phase induction motor
- To estimate the main current, auxiliary current, phase angle, losses and efficiency of single-phase induction motor with 14-pole stator construction

1.4 Scope of The Project

The aim of the project is to study the performance analysis of single-phase induction motor for improvement of ceiling fan application. 14-poles single-phase induction motor is being used in this project. Basicly, common ceiling fan single-phase induction has 18-poles rotor construction. This project involves an experiment on prototype ceiling fan motor design and run analysis on 14-poles single-phase induction motor.

The simulation is in finite element software to measure the value of main and auxiliary current. There are several types of single-phase induction motor which use the concept of main and auxiliary windings to start the motors such as capacitor-start, split-phase, capacitor-run and capacitor-start capacitor-run.

AutoCAD software is used to draw the full 2D model of stator parts of the single-phase induction motor. While in finite element sofware the full 2D motor model with its parameter completely build. finite element software is used to conduct two type of analysis of single-phase induction motor. To analyze and compare the performance of the

14-pole induction, steady-state ac analysis and rotatioanal motion analysis are conducted by using finite element sofware.

Lastly, this project was conducted to improve the performance of single-phase induction motor used in ceiling fan by designing different number of speed and value of capacitor.

1.5 Outline of the Thesis

This thesis for the performance analysis of single-phase induction motor using 14-poles rotor construction for ceiling fan application consists of five chapters. The content of each chapter is described as follows:

Chapter 1: Introduction – briefly review and discuss the principle operation of the induction motor and ceiling fan. State the problem statement of motor that can be improved. Introduction also includes the research objective, scope of the projects and the outline of the report.

Chapter 2: Literature Review – discuss most operation involved in single-phase induction motor. Research background of the principle operation of single-phase induction motor is included to review the two performance operation theory which are double-revolving theory and cross-field theory. Futhermore, it also discusses the induction motor equivalent circuit, types of the single-phase induction motor and the starting techniques. Moreover, single-phase induction motor test which are blocked-rotor test, no-load test and DC test were discussed. This chapter discuss all the contents based on research, analysis and theories from the written thesis, article, journal books and other qualified materials.

Chapter 3: Methodology – states all process taken to complete the project. Flow chart of the process taken are elaborated in the chapter. Moreover, this chapter elaborate the process taken to build a finite element model for single-phase induction motor using 14-poles rotor construction. It’s starting with constructed the half-pole model by using AutoCAD and completing the 14-pole motor construction model by using finite element sofware. Futhermore, simulation set-up for steady-state ac analysis and rotating machine analysis are covered in this chapter.

Chapter : Experimental Results and Discussion – prototype ceiling fan motor are tabulated and compiled in this chapter. Besides that, sinusoidal graph are plotted from all the results from simulation analysis. All the result obtained from the simulation and experiment are discussed in this chapter.

Chapter 5 : Conclusions – the achievements of the project objectives are given and explained. Then, future works on improving this project is discussed in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Single-phase motor are small motors having an output less than one horsepower and generally operated on single-phase AC supply. These motors perform varieties of service in the home, office, business, farm and factories. Single-phase motors have been used for a long time for trivial and repetitive chores due to its simplicity in construction and easy availability of single-phase power supply.

Ceiling fan is a small motor that commonly used an 18-pole single-phase induction motor. Single-phase induction motor are robust, relatively cheap, almost free maintenance and have reasonable efficiency and operating torque [9]. However, single-phase induction motor unlike three-phase induction. Single-phase motor is not self-starting. Hence, it is provided with an extra winding known as auxiliary or starting winding in addition to main or running winding.

Single-phase induction motor is not self-starting but there are a few starting techniques to apply in single-phase induction motor. The self-starting techniques catagorize into three types which are split-phase, capacitor start capacitor run and shaded pole induction motor. All the induction motor types have their own advantages and disadvantages.

2.2 Research Background

The single-phase induction motor are simple in construction, cheap in cost, realible and easy to repair and maintain. Single-phase induction motor is similar to three-phase induction motor. Both of them have same basic parts which are stator and rotor. Its need double excitation to make a machine to rotate. Althought, single-phase induction motor is simpler in construction compared to three-phase induction motor and both are made from same basic parts, however single-phase induction motor has more complex principle operation [8].

Since the single-phase AC is being supplied to the motor, the motor would not able to rotate itself. AC supply is sinusoidal wave and it produces pulsating magnetic field in uniformly distributed stator winding. The pulsating magnetic field can be assumed as two oppositely rotating magnetic field, there will be no resultant torque produced at the starting and due to this the motor does not run. The motor will start to run and rotate in any direction after giving the supply if there are external force in any direction.

This problem has been solved by making the stator winding into two windings. One is main winding and another is auxiliary winding and a capacitor is fixed in series with auxiliarry winding. This will make a phase difference when current flows through both coils. When there is a phase difference between main current and auxiliary current the rotor will generate a starting torque and the rotor will start to rotate. The complex performance operation of single-phase induction motor can be explained by double-revolving theory and cross-field theory.

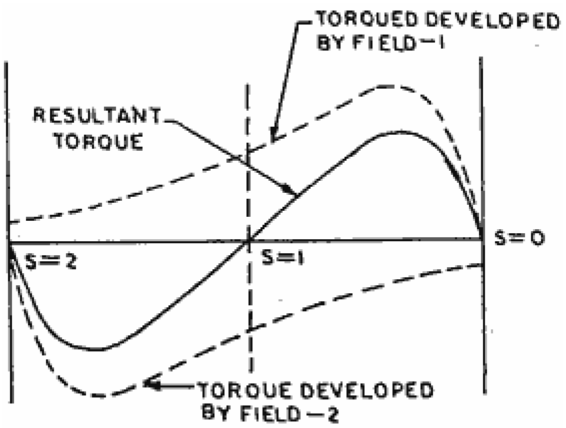


Figure 2.1 : Torque-speed characterictic magnetic field

2.2.1 Double-revolving theory

Double revolving field theory states that stator magnetic field can be decomposed into two rotating magnetic fields, each of equal magnitude but rotating opposite direction. Backward field rotates in the opposite direction while forward field rotates in the direction of mechanical movement [10, 11].

The slip with respect to forward field can be represented as:

$$Slip, s_f = \frac{Ns-Nm}{Ns} \tag{2.1}$$

The slip with respect to backward field can be represented as:

$$Slip, s_b = \frac{Ns+Nm}{Ns} \tag{2.2}$$

Upon rearrange the backward direction equation:

$$s_b = \frac{N_s-(-N_m)}{N_s} \tag{2.3}$$

$$s_b = \frac{N_s+N_m}{N_s} \tag{2.4}$$

$$s_b = \frac{2n_s - n_s + n_m}{n_s} \tag{2.5}$$

$$s_b = 2 - s \tag{2.6}$$

As stated in [12], the only way to develop a torque is by making sure that motor in running condition which can be done by spinning the motor manually or using auxiliary circuit.

2.2.2 Cross-Field Theory

By the help of figure 2.2 and according to the cross-field theory, the main flux generated by the rotor and stator current are considered seperately quadrature angle in 90 degree to each other [13]. When the rotor at standstill and single-phase power source is supply to the motor, rotor current will create a flux on the same axis as the stator flux. Net torque produce on the rotor will be zero, hence there’s no torque exist on the rotor and the rotor cannot start rotating.

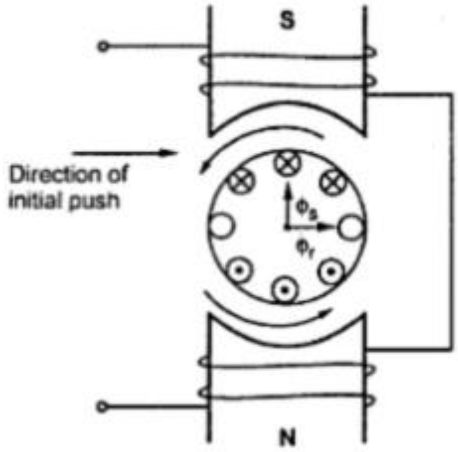


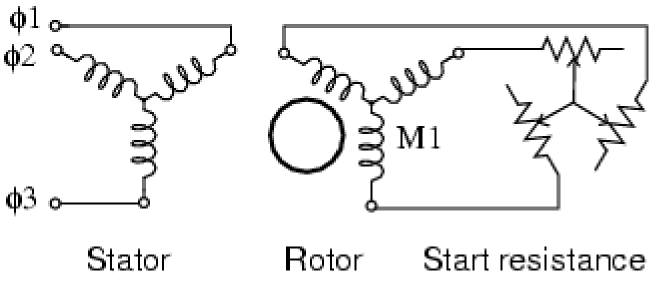
Figure 2.2: Direction of force experience by rotor

However, the stator flux can be resolved. Voltage is induced on the rotor side and the voltage created in the rotor winding will pass directly to the stator winding if the rotor is rotating. Current in rotor which created by the rotor induced voltage will be lag approximately 90 degree to the rotor voltage due to resistance exist in rotor. Thus, rotor rotate at approximately 90 degree to the rotor voltage and current angular phase where it is approximately at synchronous speed.

2.2.3 Single-Phase Induction Motor Rotating Part

There are two types induction motor rotors which are wound or slip ring rotor and squirrel-cage rotor [14]. Table 2.1 describe the two types of rotor.

Table 2.1: Description of type of rotor

Rotor	Description
Wound rotor	A wound rotor induction motor has a stator like squirrel-cage inductin motor, but a rotor with insulated windings brought out via slip rings and brushes. However, no power is applied to the slip rings. Their sole purpose is to allow resistance to be placed in series with rotor windings while starting. Plus, wound rotor is the rotating part of motor that has a set of three-phase windings which usually in wye connection.  Figure 2.3: Wound Rotor circuit diagram
Squirrel-cage rotor	This kind of rotor consist of a cylindrical laminated core with parallel slots for carrying the rotor conductors. The conductor bars are inserted from one end of the rotor and as one bar in

	each slot. There are end rings which are welded or electrically braced at both ends of the rotor, thus maintaning electrical continuity.

2.3 Single-Phase Induction Motor Self-Starting Techniques

Single-phase induction motor is not self-starting machine since its torque due to single-phase winding alone would only cause the motor to vibrate instead of rotating. Phase-shifted magnetic field has to be created in order to create a starting torque. This generally accomplished by having main and auxiliary windings in quadrature to ensure that the auxiliary winding current from the main supply is phase shifted [15]. However, single-phase induction motor have few a techniques of self-starting. The common techniques is split-phase, capacitor start, capacitor run and shaded pole.

2.3.1 Split-Phase Motor

The single-phase induction motor main winding has low resistance but high reactance and starting winding has high resistance but low reactance. Current in the auxiliary called starting winding lags the supply voltage by lesser angle. The current in the main winding being highly inductive lags the supply voltage with greater angle. As a result, current lags behind applied voltage. With the help from figure 2.4 based on example in conference [16]. As shown in the figure below, the current in the starting winding lagging the voltage by angle φ_s. the angle between the two currents is θ as shown in the figure. The torque produced is such that it gives circular movement to the rotor. However, rotation of the motor depend on the leading or lagging of auxiliary winding current. The direction of rotation of motor can be reversed by reversing the connection of auxiliary winding [14].

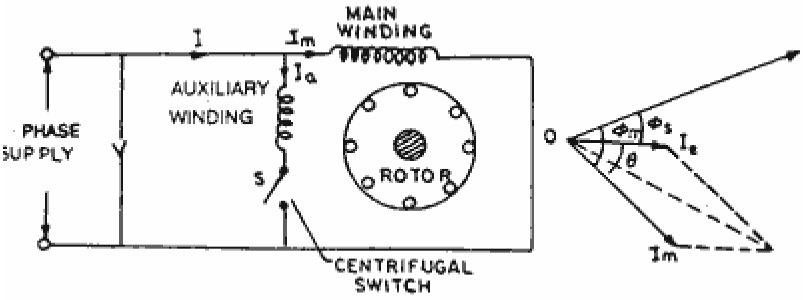


Figure 2.4: Diagram of split-phase motor

2.3.2 Capacitor start motor

Capacitor-start motor also using two winding, the main winding and auxiliary winding. With the auxiliary winding and centrifugal switch has a capacitor in series with it. Capacitor is chosen as main current leads the auxiliary current by 90 degree. The motor gives high starting torque due to large value of capacitor. Based on study [17], few requirement need to be satisfied in order to design a capacitor-start motor which are capacitor current and voltage at locked rotor must be equal to or less than specified value, and slot for insulated value must be filled more than the specified amount.

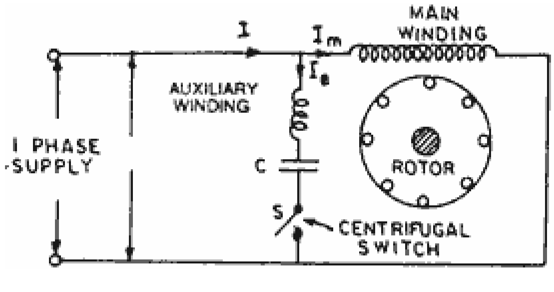


Figure 2.5: Diagram of capacitor-start motor

2.3.3 Capacitor-Run Motor

Capacitor-run motor has the same connection as capacitor-start motor. Refer to the diagram below, there is no switch in starting winding and capacitor is permanently connected. The starting torque is lower about 50% to 100% of fullload torque. Actually, the capacitor-run motor is essentially a 2-phase motor that receive single-phase source. If the main flux is equal to auxiliary flux and out of phase by 90^o, the motor will vibration-free. Based on case study [18], to have auxiliary winding voltage displaced 90^o before the main winding, while the amplitude of auxiliary voltage is higher than the amplitude of main voltage with equal to turns ratio is such a common practice.

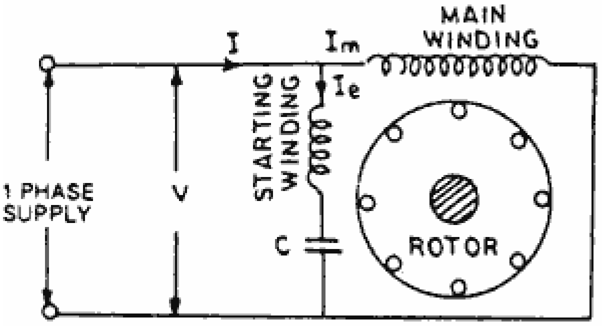


Figure 2.6: Diagram of capacitor-run motor

2.3.4 Shaded-Pole Motor

The stator of the shaded pole single-phase induction motor has salient or projected poles. These poles are shaded by copper band band or ring which is inductive in nature. There are two unequal halves divided each pole. Each shaded pole has its own exciting coil. The small portion carries the copper band and is called as shaded portion of the pole.

In deriving the equation V=R∗I+1/ωb ∗ dψ/dt used in shaded-pole motor, few assumption are made such as considering effect of slotting [19].

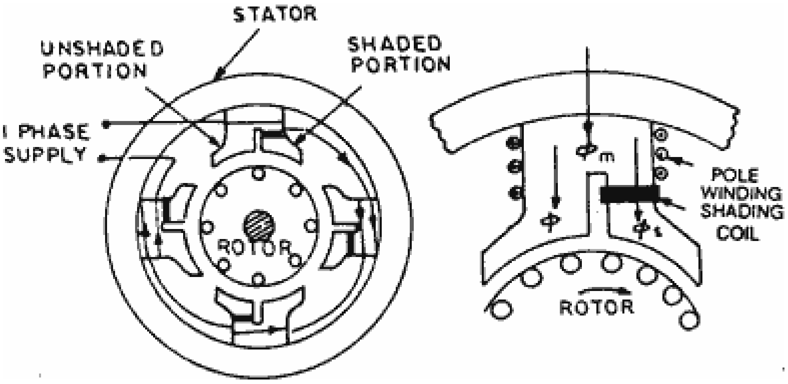


Diagram 2.7: Construction of Shaded-pole motor

2.4 Test of Single-Phase induction Motor

Single-phase induction motor equivalent parameters can be calculated from DC test, no-load test and blocked rotor test. IEEE Standard [20] and [9] are used as reference for single-phase induction motor test. Figure 2.8 shows a preferred instrument connection to run a test for single-phase induction motor [21].

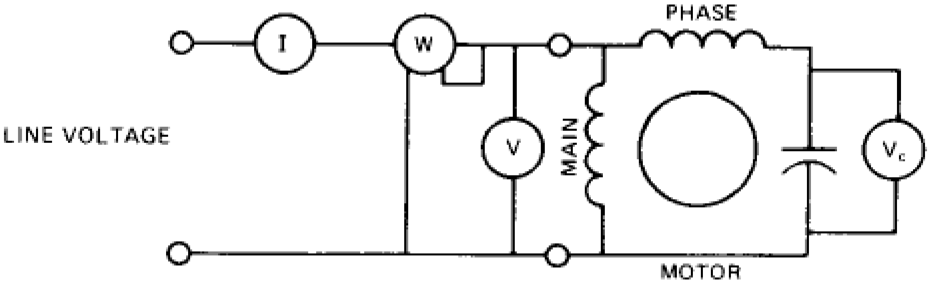


Figure 2.8: Preferred connection of instruments for tests

2.4.1 DC Test

DC test for stator resistance, R_2 plays a great critical role in the operation of an induction motor. However, to find R_2 accurately, it is necessary to know R_1 by this dc test [22]. Refer to the figure 2.9, the source is DC then there is no induced voltage in rotor circuit, no resulting rotor current flow and the reactance of the motor is zero. To perform the test, the current in the stator windings is adjusted to the rated value, and the voltage between the terminals is measured. The current in the stator windings is adjusted to the rated value. The current in flows through two of the windings, so the total resistance in the current path is $2R_1$.

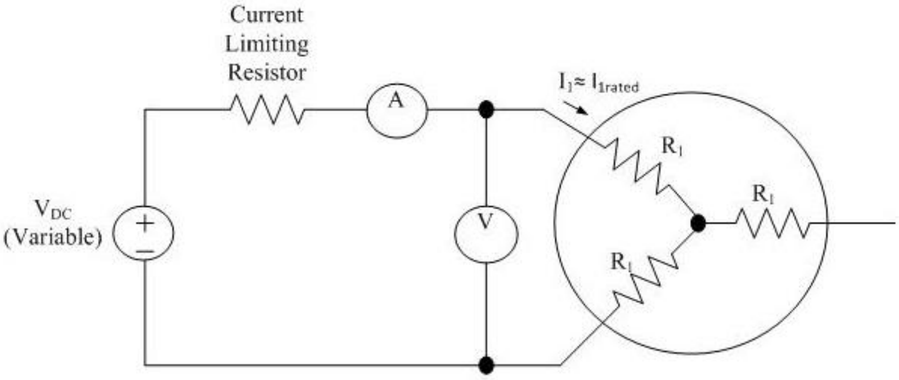


Figure 2.9: Diagram of DC test

$$2R_1 = \frac{V_{dc}}{I_{dc}} \tag{2.7}$$

$$R_1 = \frac{V_{dc}}{2I_{dc}} \tag{2.8}$$

2.4.2 No-Load Test

No-load test is performed when when rotor rotates with synchronous speed and there is no load torque. Figure 2.10 show the rotor resistance in forward rotating field is infinity [6]. Actually, it’s impossible to achieve synchronous speed. However, the synchronous speed can be achieved by taking slip=0 which creates infinite impedence in rotor branch. This test is used to evaluate the resistance and impedence of the magnetizing path of induction motor.

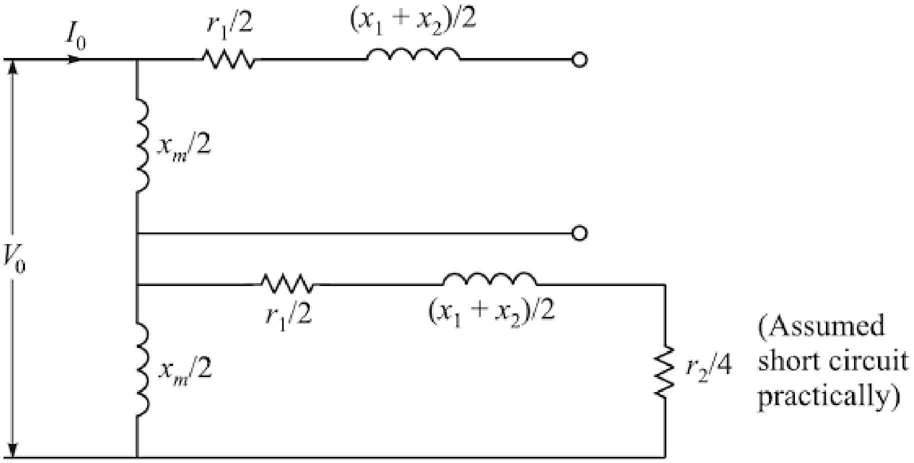


Figure 2.10: No-load test circuit

2.4.3 Blocked-Rotor Test

In blocked-rotor test, supply voltage is gradually increased until rated full-load current flow through it while the rotor is at standstill, s=1. Based on [6], figure 2.13 shows the blocked-rotor circuit used in blocked-rotor test.

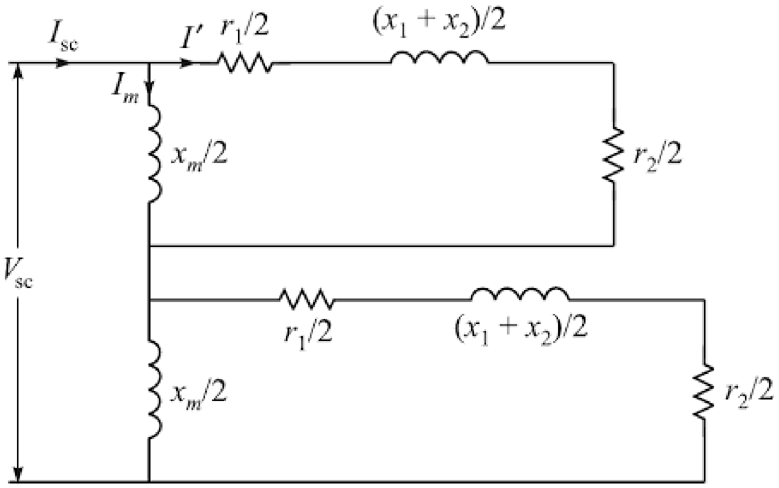


Figure 2.11: Blocked-rotor test circuit

Based on figure 2.13, (r1+r2’) and (x1+x2’) can be found out by using equation (2.9) and (2.10) and by conduction dc voltage test on stator winding.

$$I_a = I_o - I_m \tag{2.9}$$

$$I_m = {}^{V}\!/_{jx_m} \tag{2.10}$$

$$ {}^{V}\!/_{I_a} = (r_1 + r_2') + j(x_1 + x_2') \tag{2.11}$$

By measuring Io and W by using ammeter and wattmeter. Motor power factor can be calculated.

$$W = VI \cos\theta \tag{2.12}$$

$$\cos\theta = W \;/\; VI_o \tag{2.13}$$

CHAPTER 3

METHODOLOGY

3.1 Introduction

This project is conducted to create an improvement on ceiling fan application by analyze the performance of single-phase induction motor. Basically, there are three case study to be performed; to undergo the research on different type self-starting technique of single-phase induction motor, to build a finite element model for 14-poles induction motor and to simulate the proposed model using finite element analysis to analyze the performance and the torque characteristics of ceiling.

For the design part AutoCAD and finite element sofware are used. Full-pole 2D model of stator is draw in AutoCAD into a complete 14-poles while the rotor parts is draw through the template in the finite element sofware.

There are two main analysis are conducted on the simulation designed induction motor. The analysis carried out are Steady-State AC Analysis and Rotating Machine Analysis. Two different simulation model will undergo all the analysis to be analyze and compare for suitable and best motor design for ceiling fan.

3.2 Design Flow-Chart

Figure 3.1 shows the design flow chart of the final year project. Performance analysis of single-phase induction motor using 14-pole rotor construction is conducted to create an improvement on ceiling fan application. The project begun by research of the single-phase induction motor by studying the books, journals and related articles from trusted source such as IEEE Xplore and ScienceDirect.

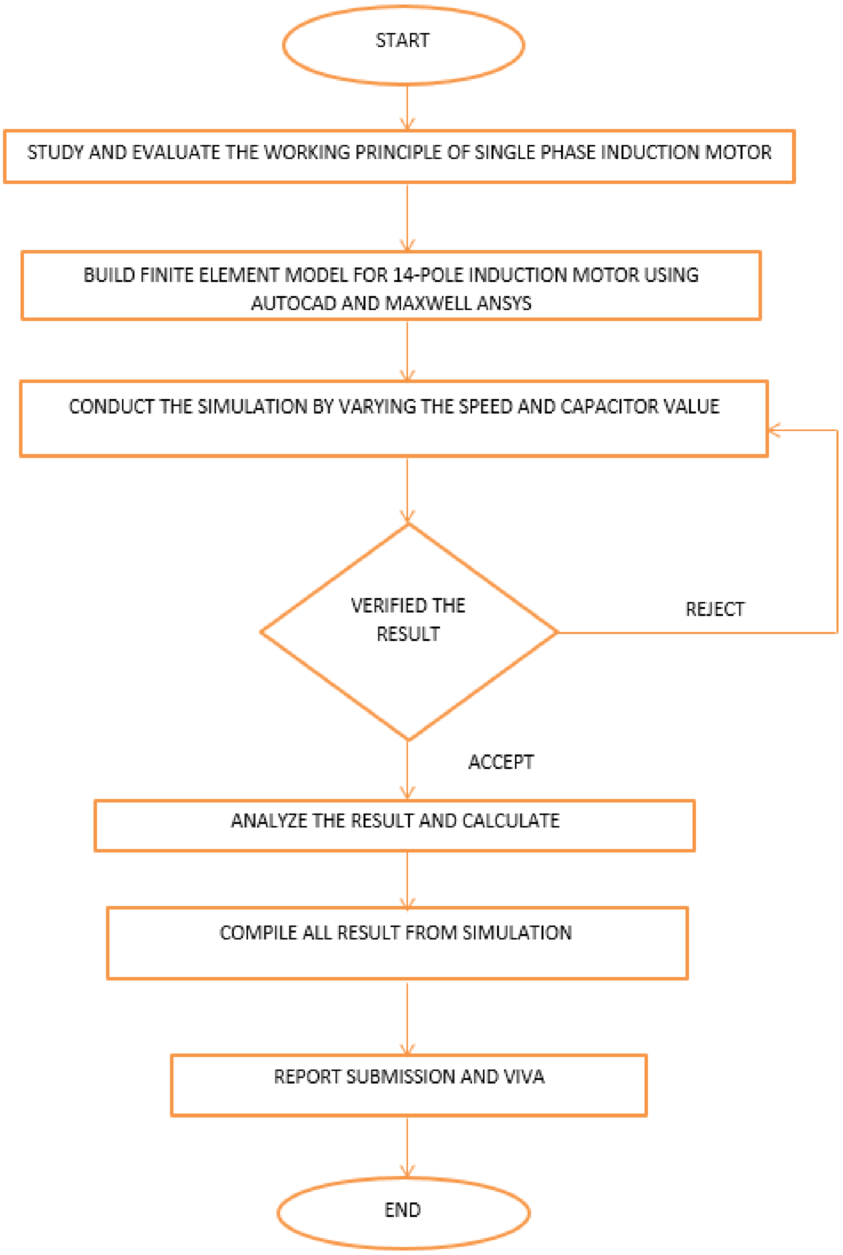


Figure 3.1: Design Flow Chart

Firstly, design 14-pole single-phase induction motor by using AutoCAD and finite element software. Then, evaluate and analysis the performance. Through the available parameters of ceiling fan motor, steady-state analysis and rotating machine analysis are simulated. Permanent split-capacitor in the rotating machine analysis and different set of capacitor are use in the simulation.

In the end, all the result were calculated and estimated to see if there is any similarities in the performances and as expected in theoretical. The results obtained from finite element software simulation are analyzed and compiled.

3.3 14-poles Induction Motor Model

Before designing the single-phase induction motor, dimension of 14-pole single-phase induction motor need to be taken. The dimension of existing 14-pole single-phase induction motor are preferred from past work. There are 3 important main part of dimension and specification which is rotor, stator and system air gap.

Table 3.1: Dimension and specification of 14-pole indction motor

Stator	
Outer diameter (mm)	161.00
Width of slot opening (mm)	2.00
Length of stator slot (mm)	14.00
Rotor	
Number of rotor slot	65
Outer diameter (mm)	189.00
Inner diameter (mm)	161.40