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LAPORAN PROJEK SARJANA MUDA

TO CONSTRUCT AND ANALYSIS OF FIVE-PHASE INDUCTION MOTOR

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Bachelor of Electrical Engineering (Power Electronic and Drive)

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TO CONSTRUCT AND ANALYSIS OF FIVE-PHASE INDUCTION MOTOR

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A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering (Power Electronic and Drive)

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2014

“ I hereby declare that I have read through this report entitle “ To Construct and Analysis of Five-Phase Induction Motor” and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Power Electronic and Drive with Honors.”

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Date : 18 JUNE 2014

I declare that this report entitle “To Construct and Analysis of Five-Phase Induction Motor” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……………………………………………..

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Date : 18 JUNE 2014

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ABSTRACT

One of the most common electrical motor used in most applications is known as Induction Motor. Three-phase and single phase induction motor is common widely used in industry because only three-phase supply is available. But in five-phase induction motor, it is still not be used in general because the information about this motor is not matured yet and the development of five-phase induction motor still not widely available in industry today. Advantage of 5-phase induction motor compare with the previous type which is three-phase and single-phase induction motor is, this motor capable to start and run even on one or two its many stator phase open or short circuited, lower current per phase without an increase voltage per phase, higher reliability and increased power in the same frame. In this project, the focus is to design and develop a motor by using stator frame available in FKE laboratory. There are 24 slot of stator core used to develop five-phase motor, difference with the previous five-phase motor that has been design, the number of stator slot used multiples of five example 20-slot, 30-slot, 45-slot and so on. But in this project will implement in multiple of four (24-slot). The SWG copper wire used to develop motor winding. Besides that, this project focuses on analysis performance of three-phase and five-phase induction motor in term of current, voltage and speed. However the phase shifts between phase-to-phase at the motor also observe. Thus, with this proposed of five-phase induction motor, which can be used in application because nowadays the five-phase motor drive is widely used and easy available in the market.

ABSTRAK

Satu daripada motor elektrik yang biasa digunakan didalam aplikasi hari ini ialah motor aruhan. Motor aruhan tiga-fasa dan satu-fasa biasanya digunakan secara meluas didalam industri kerana bekalan tiga-fasa mudah didapati. Tetapi didalam motor lima-fasa masih tidak digunakan secara umum sebab maklumat berkenaan motor ini masih belum matang dan pembinaan motor aruhan lima-fasa masih belum boleh didapti secara meluas di pasaran sekarang. Kelebihan motor aruhan lima-fasa berbanding dengan motor yang jenis sebelum ini iaitu motor tiga-fasa dan satu-fasa, motor lima-fasa ini berupaya mula dan bergerak walaupun satu atau dua fasa stator terbuka atau litar pintas, rendah arus elektrik setiap fasa tanpa menaikkan voltan setiap fasa, tinggi kebolehpercayaan, menaikkan kuasa didalam frame yang sama. Didalam projek ini, hanya tumpu kepada rekabentuk dan pembinaan motor menggunakan frame stator yang sedia ada di dalam makmal FKE. Terdapat 24 slot teras stator yang dugunakan untuk membina motor lima-fasa, berbeza yang pernah di reka bentuk, bilangan slot yang digunakan ialah gandaan lima contohnya 20-slot, 30-slot, 45-slot dan sebagainya. Tetapi didalam projek ini akan dilaksanakan mengunkan gandaan empat (24-slot). Dawai kuprum SWG digunakan untuk membuat gegelung motor. Selain itu, didalam projek ini fokus kepada prestasi analisis tiga-fasa dan lima-fasa motor aruhan dari segi arus elektrik, voltan dan kelajuan. Walaubagaimanapun perbezaan fasa diantara fasa-kepada-fasa pada motor juga diperhatikan. Oleh itu, dengan ini mencadangkan motor aruhan lima-fasa, yang mana boleh diaplikasikan didalam penggunaan sebab pada masa kini pemacu motor lima-fasa sudah digunakan secara meluas dan mudah didapati dipasaran.

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CHAPTER 1

INTRODUCTION

1.1 Background

An induction or asynchronous motor is an AC electric motor in which the electric current in the rotor is needed to produce torque is induced by electromagnetic induction from the magnetic field of the stator winding. An induction motor therefore does not require mechanical commutation, separate-excitation or self-excitation for all or part of the energy transferred from stator to rotor, as in universal motor, DC machine and large synchronous motors. The rotor for induction motor can be either wound type or squirrel-cage type.

Induction motor with squirrel-cage rotor is the workhorses of industry because of their low cost and rugged construction. When operate directly from line voltages (50 – 60 – Hz utility input at essentially a constant voltage), the induction motor will operate at a nearly constant speed. Induction motor employs a simple but clever scheme of electromechanical energy conversion.

Three phase induction motor are the motors most frequently using in industry. They are simple, rugged, low price, and easy to maintain. They run at essentially constant speed from zero to full load. The speed is frequency-dependent and consequently, these motor are not easily adapted to speed control. In three phase system, there are three single phase line with 120° phase difference. So the rotating magnetic field is having the same phase difference which will make the rotor to move. Beside that the single phase motor also dominant for domestic and low power level, this is because it is used in home appliances and portable machine tool. In general, they are employed when three-phase power is not available. The construction of single phase induction motor is almost similar to the squirrel cage three-phase induction motor except that in case of single phase induction motor, the stator has two windings instead of one-phase as compare to the single stator winding per-phase in three-phase induction motor.

Now this project, the five-phase induction motor is introduced, The construction of five-phase induction motor is almost similar to the squirrel cage three-phase and single-phase induction motor except, they need a five-phase incoming ac voltage and the stator consist of five-phase winding. In five-phase system, there are five phase line with 72° phase difference. Advantages of the five-phase machine over three-phase machine are superior torque density, better efficiency, low torque pulsations, better fault tolerance, and reduced rating per inverter leg. Furthermore, the noise levels of the drive improve as well. The limitation of five-phase machine is that it needs a five-phase power supply or power electronic drive for phase conversion because only three-phase supply is easily available.

1.2 Motivation

In a balance 5-phase induction motor, the five stator phase groups are distribute with a spacing of 72°. Advantage of 5-phase induction motor is, that motor capable to start and run even on one or two its many stator phase open or short circuited, lower current per phase without an increase voltage per phase, higher reliability and increased power in the same frame. The limitation of 5-phase machine is that it needs a power electronic circuitry or special transformer for phase conversion because three-phase supply is only easily available.

1.3 Problem Statement

The purpose of designing and constructing of five-phase induction motor is to observe the characteristic of five-phase induction motor, because nowadays knowledge on five-phase induction motor are not matured yet. The three-phase and single-phase motors, there are widely used and many people have knowledge about it and can be found in almost every production machine today. Besides that, five phase induction motor also are not widely available in the market, because majority of the application is design for three phase and single phase motor only.

1.4 Objective

i. To design and develop three-phase and five-phase induction motor using available single phase motor frame

ii. To analyse the performance of three-phase and five-phase induction motor in term of current, voltage and speed.

1.5 Scope

The scope of this project is to design and analyse of five-phase induction motor by using stator and rotor same as single-phase induction motor that available in the lab. The equipment for the hardware is cooper wire, stator frame, and squirrel cage rotor. The enamelled copper size for winding is 0.7mm and this size ability to carry current capacity as much as 1.2A, while for the stator frame included stator core which is contents 24 number of slot. Maximum supply voltage is 300V. Five-phase voltage supply is not develop in this project but experiment is perform by using available five-phase transformer in the laboratory.

1.6 Report Outline

This report consists of five chapters. The first chapter covers about introduction including background, problem statement and objective of this project. The scope of research and report outline is also included in this chapter.

Then for the second chapter emphasize on theory and principle operation of induction motor. Study about both type of induction motor which are three phase induction motor and five phase induction motor will be carried out. It also mention about the characteristic of the component used in this project.

The following chapter is the methodology which explains in detail the procedures and steps that have been done to complete this project to get result. Design and development of the three phases and five phase motor also explained briefly in this chapter. Besides that, this chapter also discusses the experiment set-up that has been made in order to test the performance of the induction motor.

In chapter four, the result of this project will be shown. The experiment result is used for comparison between three-phase and five-phase induction motor. Several test were implement to observe the performance of induction motor during no-load and with load test. The experiment result analysed to measure the performance of induction motor are voltage, current and speed.

Lastly, chapter five concludes the outcome this project. It also present about how to improve the design of five-phase induction motor and other recommendation in order to provide benefit for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

An electric motor is a device that converts an electrical energy to mechanical energy. One of the most common electrical motor used in most applications which is known as Induction Motor. This motor is also called as asynchronous motor because it runs at a speed less than synchronous speed. In this project, we need to define what actually synchronous speed. Synchronous speed is the speed of rotation of the magnetic field in a rotary machine and it depends upon the frequency and number poles of the machine. An induction motor always runs at a speed less than synchronous speed because the rotating magnetic field which is produced in the stator will generate flux in the rotor which will make the rotor to rotate, but due to the lagging of flux current in the rotor with flux current in the stator, the rotor will never reach to its rotating magnetic field speed i.e. the synchronous speed.

2.1.1 Faraday's Law of Electromagnetic Induction

In 1831, while pursuing his experiment, Michael Faraday made one of most important discoveries in electromagnetism. Now known as Faraday's Law of electromagnetic induction, it reveals a fundamental relationship between the voltage and flux in a circuit [1]. Faraday's low state:

a) If the flux linking a loop (or turn) varies as a function of time, a voltage is induce between it terminals [1].
b) The value of the induce voltage is proportional to the rate of change of flux [1].

By definition and according to the SI system of units, when the flux inside a loop varies at the rate of 1 Weber per-second, a voltage of 1V is induce between its terminals [1]. Consequently, if the flux varies inside a coil of N turns, the voltage induced is given by

$$E = N\frac{\Delta\phi}{\Delta t} \tag{2.1}$$

Where :

E = induce voltage [V]

N = number of turns in the coil

$\Delta\phi$ = change of flux inside the coil [Wb]

Δt = time interval during which the flux changes [s]

Faraday's law of electromagnetic induction opened the door to a host of practical applications and established the basis of operation of transformers, generator and alternating current motor.

2.1.2 Voltage Induced in a Conductor

In many motor and generator, the coil move with respect to a flux that is fixed in space. The relative motion produces a change in the flux linking the coil and consequently, a voltage is induced according to faraday law. However, in this special (although common) case, it is easier to calculate the induced voltage with reference to the conductors, rather than with reference to the coil itself [1]. In effect, whenever a conductor cuts a magnetic field, a voltage is induced across its terminals. The value of the induced voltage is given by

$$E = Blv \tag{2.2}$$

Where

E = induced voltage [V]

B = flux density [T]

l = active length of the conductor in the magnetic field [m]

v = relative speed of the conductor [m/s]

2.1.3 Lorentz Force on a Conductor

When a current-carrying conductor is placed in a magnetic field, it is subjected to force which we call *electromagnetic* force, or Lorentz force [1]. This force is of fundamental importance because it constitutes the basis of operation of motors, of generators, and of many electrical instruments. The magnitude of the force depends upon the orientation of the conductor with respect to the direction of the field. The force is greatest when the conductor is perpendicular to the field and zero when it is parallel to it. Between these two extremes, the force has intermediate values[1].

The maximum force acting on a straight conductor is given by

$$F = BlI \tag{2.3}$$

Where

F = force acting on the conductor [N]

B = flux density of the field [T]

l = active length of the conductor [m]

I = current in the conductor [A]

2.1.4 Slip, S

Slip of an induction motor is the difference between the synchronous speed and the rotor speed, expressed as a percent (or per-unit) of synchronous speed [1]. The per-unit slip is given by the equation

$$s = \frac{ns - nr}{ns} \tag{2.4}$$

Where

s = slip

n_s = synchronous speed [r/min]

n_r = rotor speed [r/min]

The slip is practically zero at no-load and is equal to 1(or 100%) when the rotor is locked.

2.1.5 Torque

Torque is the starting twist or forces that rotor to produces rotation in a motor. This rotation is necessary to get motors started. In AC and DC machines two type two type of torque are taken (i) starting torque (ii) running torque. Starting torque is that torque which is required to start the motor at the load or no load. Running torque is the torque which is required to run the motor at normal speed and normal load [2].

2.1.6 Working Principle of Induction Motor

In induction motor works is very simple, from the name itself we can understand that there is induction process occurred. Actually when the supply is giving to the stator winding, flux will generate in the coil due to flow of current in the coil [1]. Now the rotor winding is arranged in such a way that it becomes short circuited in the rotor itself. The flux from the stator will cut the coil in the rotor and since the rotor coils are short circuited, according to Faraday's law of electromagnetic induction, electric current will start flowing in the coil of the rotor [3].

When the current will flow, another flux will get generated in the rotor. Now there will be two fluxes, one is stator flux and another is rotor flux and the rotor flux will be lagging to the stator flux. Due to this, the rotor will feel a torque which will make the rotor to rotate in the direction of rotating magnetic flux. So the speed of the rotor will be depending upon the ac supply and the speed can be controlled by varying the input supply [6].

2.1.7 Principle of Component

A five phase induction motor has two main parts, first is stationary stator and second is revolving rotor. The rotor is separated from the stator by a small air gap that range from 0.4mm to 4mm.depending on the power of the motor. The stator consists of a steel frame that support a hollow, cylindrical core made up of stacked lamination. A number of evenly space slots, punch out of the internal circumference of the lamination, provide the space for stator winding.

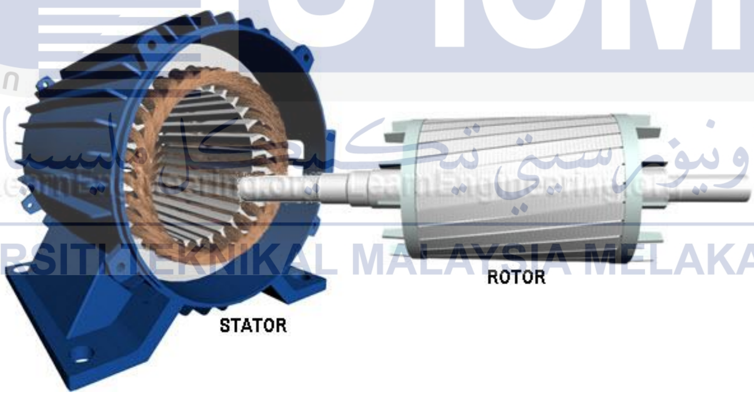


Figure 2.1: Mains component in induction motor [2]

The Rotor consists of a core made of the same thin laminations of silicon steel that the stator uses, but instead of copper windings has several bars which run along its length which are connected to end rings. If the steel laminations were to be removed, these bars look like a squirrel cage, hence the name, Squirrel Cage Induction Motor (SCIM).

2.1.8 Squirrel Cage Rotor

A squirrel-cage rotor is the rotating part (rotor) used in the most common form of AC induction motor. It consists of a cylinder of steel with aluminium or copper conductors embedded in its surface. An electric motor with a squirrel-cage rotor is termed a squirrel-cage motor [4].

Figure 2.2: Thin layers of iron lamina which are packed in rotor [2]

This kind of rotor consists of a cylindrical laminated core with parallel slots for carrying the rotor conductors, which are not wires, as we think, but thick, heavy bars of copper or aluminium or its alloys. 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 or even bolted at both ends of the rotor, thus maintaining electrical continuity. These end rings are short-circuited, after which they give a beautiful look similar to a squirrel thus the name [7].

Figure 2.3 : Squirrel cage rotor [3]

One important point to be noted is that the end rings and the rotor conducting bars are permanently short-circuited, thus it is not possible to add any external resistance in series with the rotor circuit for starting purpose. The rotor conducting bars are usually not parallel to the shaft, but are purposely given slight skew. In small motors, the rotor is fabricated in a different way. The entire rotor core is placed in a mould and the rotor bars & end-rings are cast into one piece. The metal commonly used is aluminium alloy. Some very small rotors which operate on the basis of eddy current, have their rotor as solid steel without any conductors.

2.1.9 Stator

As its name indicates stator is a stationary part of induction motor. A stator winding is placed in the stator of induction motor and the five phase supply is given to it. The stator of the five phase induction motor consists of three main parts [3]:

a. Stator frame
b. Stator core
c. Stator winding or field winding

Figure 2.4: Construction detail of stator [2]

2.1.9.1 Stator Frame

It is the outer most part of the five phase induction motor. Its main function is to support the stator core and the field winding. It acts as a covering and it provide protection and mechanical strength to all the inner parts of the induction motor. The frame is either made up of die cast or fabricated steel. The frame of five phase induction motor basically same as three phase induction motor, should be very strong and rigid as the air gap length of induction motor is very small, otherwise rotor will not remain concentric with stator, which will give rise to unbalanced magnetic pull [3].

2.1.9.2 Stator Core

The main function of the stator core is to carry the alternating flux. In order to reduce the eddy current loss, the stator core is laminated. These laminated types of structure are made up of stamping which is about 0.4 to 0.5 mm thick [7]. All the stamping are stamped together to form stator core, which is then housed in stator frame. The stamping is generally made up of silicon steel, which helps to reduce the hysteresis loss occurring in the motor [3].

2.1.9.3 Stator Winding or Field Winding

The slots on the periphery of stator core of the three-phase induction motor carries five phase windings. This five-phase winding is supplied by five-phase ac supply using multilevel inverter (5-phase). The five-phases of the winding are connected in star because the squirrel cage induction motor is mostly started by star. The winding wound on the stator of five phase induction motor is also called field winding and when this winding is excited by three phase ac supply it produces a rotating magnetic field [7].

2.1.10 Effect of 3-Phase Current Passing through Stator Winding

When a 3 phase AC current passes through the winding, something very interesting happens. It produces a rotating magnetic field. As shown in figure below a magnetic field is produced which is rotating in nature.

Figure 2.5: Rotating magnetic field produce in an induction motor [2]

2.1.11 Concept of Rotating Magnetic Filed

To understand this phenomenon much better consider a simplified 3 phase winding with just 3 coils [2]. A wire carrying current produces magnetic field around it. Now for this special arrangement magnetic field produced by 3 phase A.C current will be as shown at a particular instant.

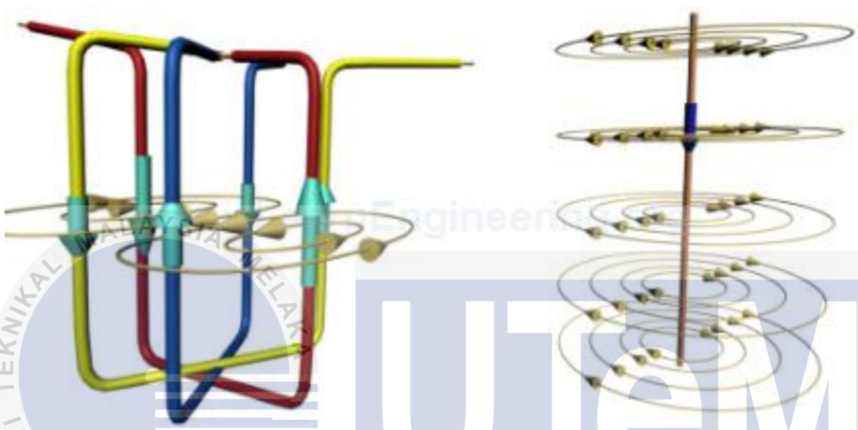


Figure 2.6: Magnetic field produced around the simplified winding and a single wire [2]

With variation in A.C current, magnetic field takes a different orientation as shown. From these 3 positions it's clear that, it is like a magnetic field of uniform strength rotating. Speed of rotation of magnetic field is known as synchronous speed [2].

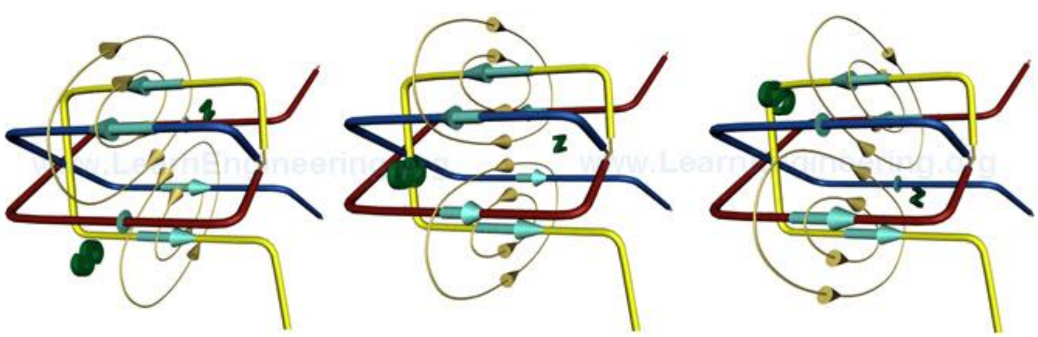


Figure 2.7: Rotating magnetic field produced over simplified winding [2]

2.1.12 Effect of RMF on a Closed Conductor

Assume you are putting a closed conductor inside it. Since the magnetic field is fluctuating an e.m.f will be induced in the loop according to Faraday's law. The e.m.f will produce a current through the loop. So the situation has become like a current carrying loop is situated in a magnetic field. This will produce magnetic force in loop according to Lorentz law. So loop will start rotating [2].

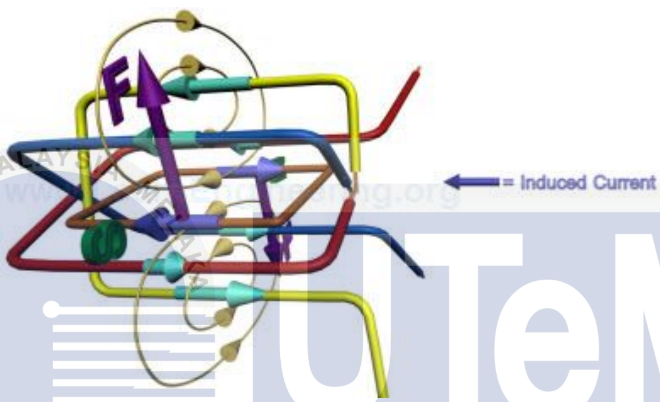


Figure 2.8: Effect of RMF on a closed conductor [2]

2.1.13 End Cover

These are made of cast iron and keep the rotor exact in the centre of this stator so that the rotor may move easily. These are fitted with bolt with the stator frame. The frame also is made of cast iron [3].

2.1.14 Bearings

Mostly in 3 phase motor ball bearing are used and small single phase motor bush bearing are used. In 5 phase motor, it also use ball bearing. Their working is to give the rotor free rotation in the stator[3].

2.1.15 Fan

In motor, its working is so cool the motor. Mostly these are made of cast iron and fitted on the rotor shaft. When the motor runs on load, the heat is produced in the motor due to loses [7]. If this heat is not transferred out the winding will be burnt. The fan serves the purpose of transferring heat from inside to outside of the motor. It sucks the cold air from the atmosphere. This air comes inside the motor through holes and goes out after cooling the winding of the motor.

Figure 2.9: A cooling fan is used to remove heat at induction motor [2]

2.2 Related Previous Work (Five-Phase Induction Motor)

For the previous work, there are about four articles and journals IEEE papers that relate with five-phase induction motor. First journal is discusses about "Five-phase Induction Motor Behaviour under Fault Condition". In this thesis, it done using MATLAB-SIMULINK to study about motor behaviour under fault condition not used the real hardware to implement this experiment. The analysis included is focus on speed (rpm), torque (Nm), and stator phase current. Besides that, this paper also present about the five-phase induction motor operation under rated load and open circuit fault in one-phase at steady state. [5]

Second title is about “Studied on Inverter-Fed Five-phase Induction Motor Drive” source from paper conference [4]. This paper focused on motor drive for five-phase motor performance under difference condition. This paper also discusses about the advantage of high phase order (HPO) drive over three-phase drive. However, till now there is not much progress that had been made in the development of this drive because of difficulty in obtaining suitable power supply [4]. This paper more focuses on power electronic drive system, and nor really cover about the hardware development of five-phase motor.

Next article are from University of Strathclyde, Glasgow, UK and the title is about “Design of Five-Phase Induction Motor using Flux Distribution Optimisation”. From this paper [9] they discuss about how to design motor by using finite element and they also cover about saturation characteristic of the five-phase motor. Other than that, this paper also share detail about the requirement characteristic how to design motor using finite element software.

The next source is come from School of Electrical Engineering, Zhejang Universiti. This paper addresses the bearing less motor with a single set of multiphase windings. Based on this principle, bearing less machine has dual windings, levitation windings and torque windings, which produce the two magnetic fields. In the proposed bearing less motor, the two needed magnetic fields are produced by feeding two groups of currents to a single set of multiphase windings. This paper also shows the construction of induction motor using 30 slot number. But the technique how to construct the motor not mention yet, only done using simulink MAT-LAB. [10]

By compare with this project, the implementation of five-phase induction motor done by using stator frame of single-phase motor. Difference with the previous five-phase motor that has been design, the number of stator slot used multiples of five example 20-slot, 30-slot, 45-slot and so on. But in this project, it will implement in multiple of four (24-slot) because that slot are only available in the lab.

2.3 Summary of Review

The references on a five-phase induction motor construction are very limited because almost paper or journal has only focus on drive of five-phase motor but not for their construction. While reference in three-phase motor is easy to find because it is conventional motor compared to five-phase motor. Most of reference that relate in this project are used core multiples of 5 such as 30 number of slot, 35 number of slot and so on their construction of stator, but in this project the implementation is used only 24 number of slot stator core. [8]

CHAPTER 3

METHODOLOGY

3.1 Introduction

The project methodology has focus on hardware design. This chapter will explain and elaborate the methods and tools that used to design and develop of three-phase and five-phase inductions motor. For this semester, the focus is on the project planning and the gathering all necessary information for the induction motor especially three-phase and five-phase induction motor as well as implementation design five-phase induction motor.

3.2 Project Flowchart

Flowchart are very important because it is indicates the step or flow from start to the end of this project. If any problem occur during the project progress, by referring to flowchart the problem may be solve. The description of the flowchart will explains on next subtopic.

The full stage of the project are represented by the process flowchart in figure 3.1

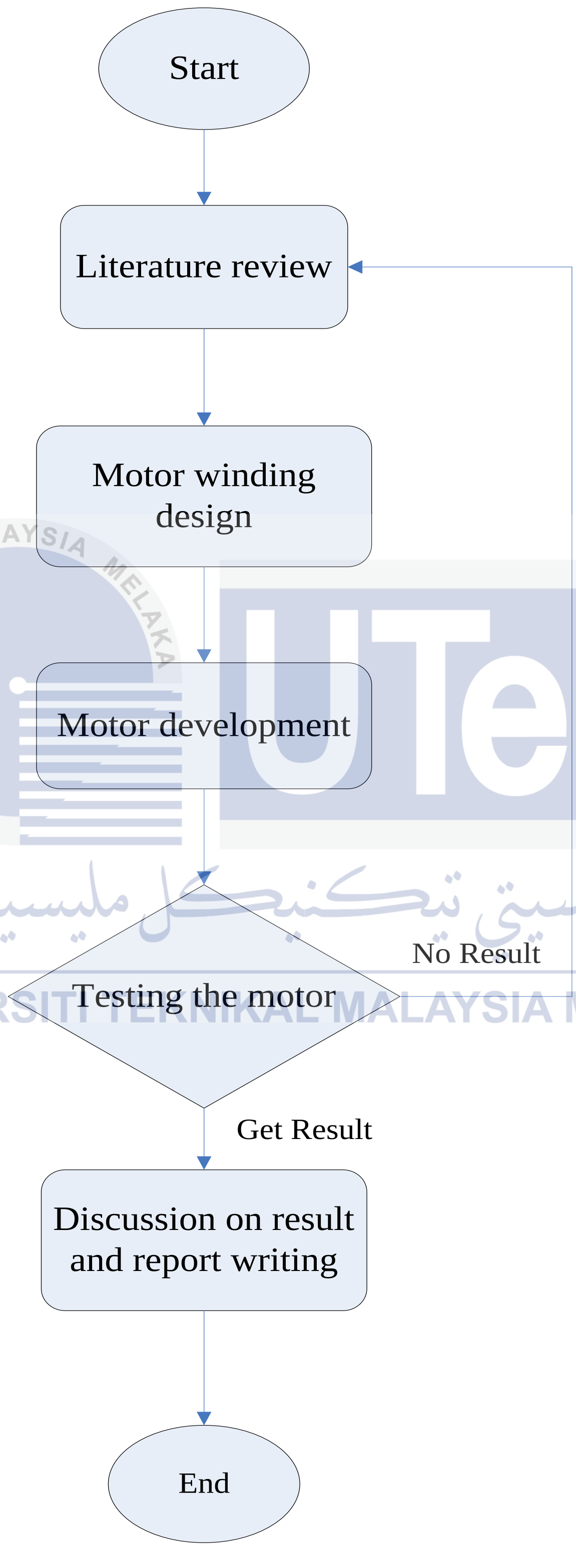


Figure 3.1: Methodology Flowchart

3.3 Start

At the beginning of this project, the task that has been carry out is about planning the execution of the project, discussion with supervisor about the project scope, objective of the project, problem statement and also expectation on the project. Then start writing the progress report for the project.

3.4 Literature Review

The literature review is about finding and collecting as much as possible information and notes to guide the project. This is very important task as for the information is to understand the principle and characteristic of induction machine.

For the method and tool used to design induction motor, it is important to know the parameter needed to be implementing in design the induction motor. It is for development of five phase induction motor to ensure the motor ability to running properly and get the correct of result. Theory about induction motor has been focus in previous chapter.

3.5 Motor Winding Design

For the implementation motor winding design, it must be carry out step by step for motor to work properly; knowledge on the right technique should be implementing in order to do winding process. Winding process must be done by using the proper equipments. It is important to know how many winding is needed to each group of phase winding. Winding process can be start after the calculation on winding required is done. First and foremost, it is done by using 0.7mm copper wire. For the five-phase induction motor, the stator core contains 24 slots and each group winding contains 50 numbers of turns. The same numbers of slot are used for three-phase induction motor while the number of turn is 50.

3.5.1 Terminologies Used in Winding Diagrams

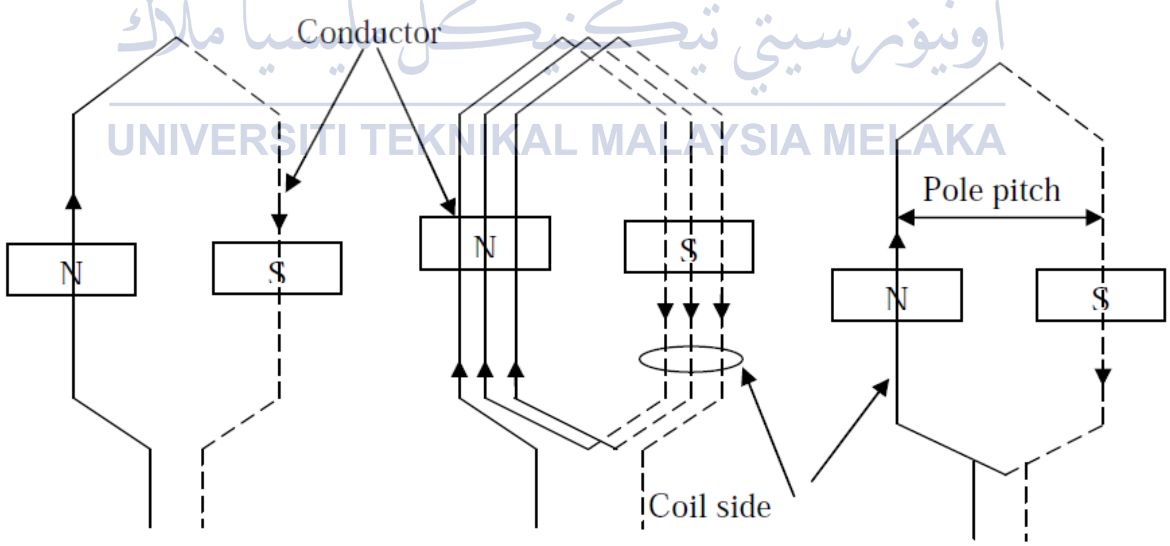
Conductor : An individual piece of wire placed in the slots in the machine in the magnetic field.

Turn : Two conductors connected in series and separated from each other by a pole pitch so that the e.m.f induced will be additive.

Coil : When one or more turns are connected in series and placed in almost similar magnetic positions. Coils may be single turn or multi turn coils.

Single layer winding : Only one coil side placed in one slot.

Double layer winding : Two coil sides are placed in a single slot.



(a) Single turn Coil (b) 3 – turn coil (c) Multi turn coil

Figure 3.2: Different Types of Winding Coils Representations

3.5.2 Determination of RMS value of the induce e.m.f per-phase (three-phase)

Radius of the motor, r = 0.039m,

Long of stator core, L = 0.13m

A = DL = 0.13 x 0.2 = 0.6

Ǿ = BA = 1.2 x 0.6 = 0.0312

No of turn, T = 50N

N0. Of slot per pole, Q = slot / pole = 24 / 2 = 12

Angular displacement between adjacent slots, $\gamma = \frac{180}{Q} = \frac{180}{12} = 15$

No. of slot per pole per phase, $q = \frac{\text{Q}}{\text{m}} = \frac{12}{3} = 4$

Distribution factor, $K_d = \frac{\sin qr/2}{q \sin \gamma/2} = \frac{\sin 4(15)/2}{4 \sin 15/2} = 0.958$

Coil span factor , $K_p = cos\frac{\Theta}{2} = cos\frac{180-180}{2} = 1$

Induced e.m.f per phase (fundamental component)

$E_{ph1} = 4.44\ K_d\, K_p\, Ǿ\, f\, T$

= 4.44 x 0.958 x 1 x 0.0312 x 50 x 50

= 331.775 V

3.5.3 Determination of RMS value of the induce e.m.f per-phase (five-phase)

Radius of the motor, r = 0.039m,

Long of stator core, L = 0.13m

A = DL = 0.13 x 0.2 = 0.6

Ǿ = BA = 1.2 x 0.6 = 0.0312

No of turn, T = 50N

N0. Of slot per pole, Q = slot / pole = 24 / 2 = 12

Angular displacement between adjacent slots, $\gamma = \frac{180}{Q} = \frac{180}{12} = 15$

No. of slot per pole per phase, $q = \frac{\mathrm{Q}}{\mathrm{m}} = \frac{12}{5} = 2.4$

Distribution factor, $K_d = \frac{\sin qr/2}{q \sin \gamma/2} = \frac{\sin 2.4(15)/2}{2.4 \sin 15/2} = 0.987$

Coil span factor , $K_p = cos\frac{\Theta}{2} = cos\frac{180-180}{2} = 1$

Induced e.m.f per phase (fundamental component)

$E_{ph1} = 4.44\, K_d\, K_p\, Ǿ\, f\, T$

= 4.44 x 0.987 x 1 x 0.0312 x 50 x 50

= 341.8 V

3.5.4 Winding Arrangement for Three-Phase Induction Motor

Mostly in three-phase motors there are number of coil equal to the slots that is the whole coil winding is done. The coil is connected in such a way that three separate windings are formed which is called phase windings. Coils group and coil per group these may be arranged so that the number of coil in each phase should be equal. Figure 3.4 and 3.5 below show about winding arrangement of three phase motor by using available motor in the laboratory. Thus the three phase windings are connected in star (Figure 3.3).

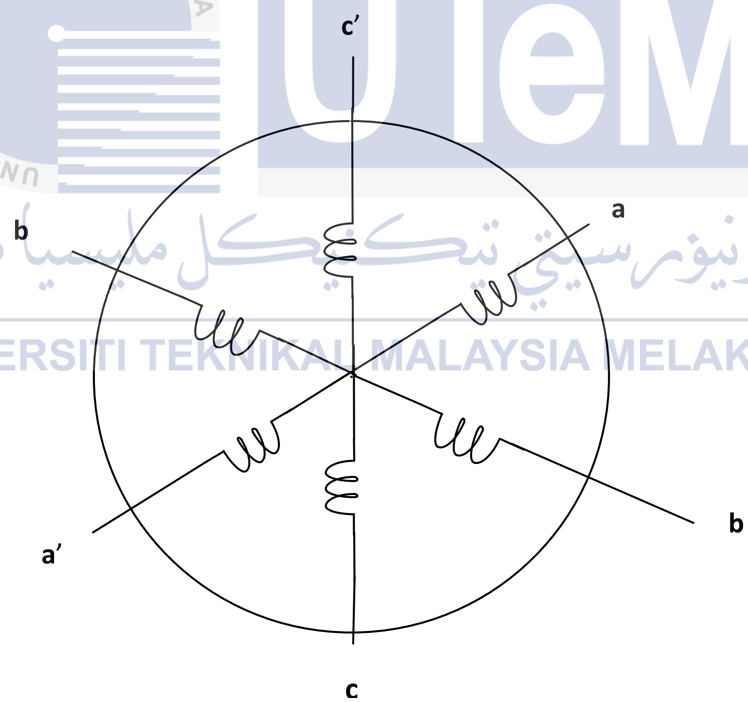


Figure 3.3: Idealized Three-Phase Induction Motor Diagram

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
A+	A+	A+	A+	C-	C-	C-	C-	B+	B+	B+	B+	A-	A-	A-	A-	C+	C+	C+	C+	B-	B-	B-	B-
A+	A+	A+	A+	C-	C-	C-	C-	B+	B+	B+	B+	A-	A-	A-	A-	C+	C+	C+	C+	B-	B-	B-	B-

Figure 3.4: Make a diagram of connections of a motor having 3Ǿ, 24 slots, 2 poles, double layer winding

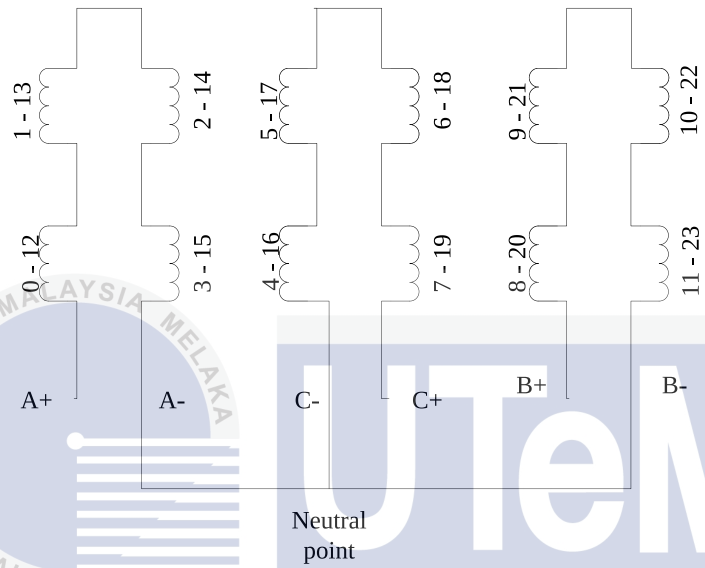


Figure 3.5: Three Phase Winding Diagram on 24 Slot Stator

3.5.5 Winding Arrangement for Five-Phase Induction Motor

In the five phase motor, basically the stator frame and stator core are same with single-phase motor available in the laboratory. The different is in five-phase induction motor is there are using five phase incoming, coils group and coil per group these may be arranged so that the number of coil in each phase should be equal. Figure 3.7 and 3.8 below shows about winding arrangement of five phase motor. Five-phase motor also connected in star (Figure 3.6).

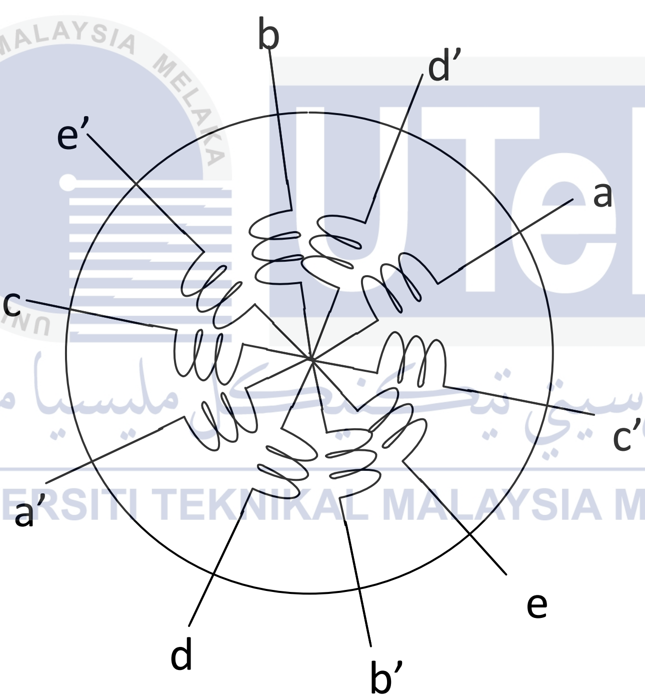


Figure 3.6: Idealized Five-Phase Induction Motor Diagram

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
A+	A+	D-	D-	B+	B+		E-	E-	C+	C+		A-	A-	D+	D+	B-	B-		E+	E+	C-	C-	
A+	A+	D-	D-	B+	B+		E-	E-	C+	C+		A-	A-	D+	D+	B-	B-		E+	E+	C-	C-	

Figure 3.7: Make a diagram of connections of a motor having 5Ǿ, 24 slots, 2 poles, double layer winding.

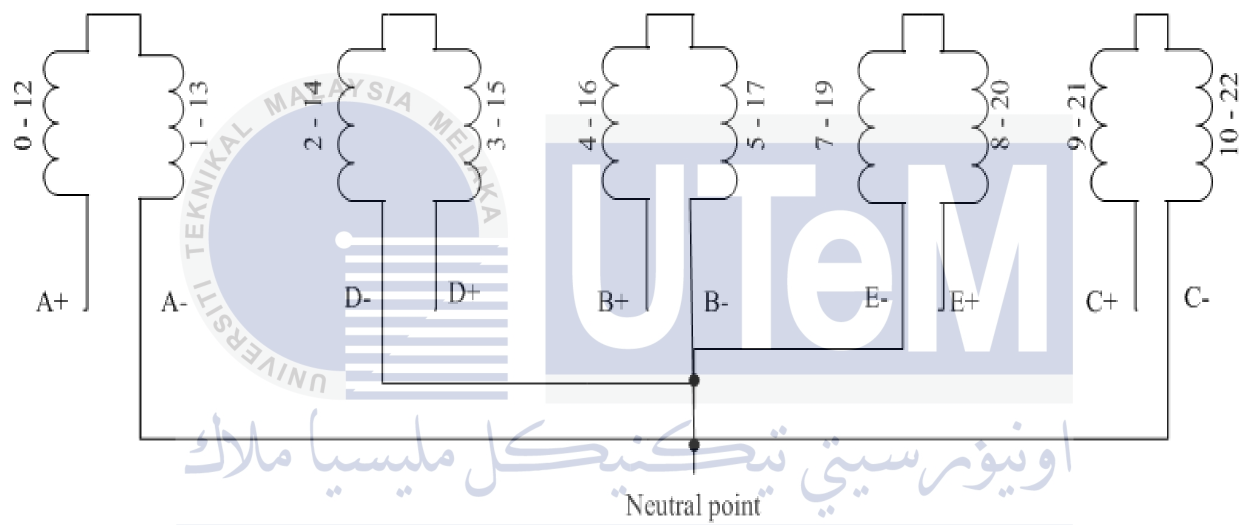


Figure 3.8: Five Phase Winding Diagram on 24 Slot Stator.

3.6 Motor Development

In this winding coil are first made on wooden former. Each wingding group contains 50 turns for three-phase and there are four groups of winding per-phase. After finish does the winding coil for three-phase that mean there are 12 group phase winding for this motor, each group of winding per-phase should be to insert into the 24 slot of the stator core, this stator are available in the laboratory. After insert all coil into the motor stator, ensure that no connection between phase to phase for each winding and also no connection between winding and stator body.

In the five-phase motor winding coil are first made on wooden same as like in three-phase motor. Each winding group contains 50 turn for five-phase and there are two group of winding per-phase. After finish does the winding coil for 5-phase that mean there are 10 group phase winding for this motor, each group of winding per-phase should be to insert into the 24 slot of the stator core, this stator also are available in the laboratory. After insert all coil into the motor stator, ensure that no connection between phase to phase for each winding and also no connection between winding and stator body.

3.6.1 Implementation of the Project

Before start design of five phase induction motor winding, firstly needed to understand basic operation and configuration of three-phase induction motor. There are several methods and components used to develop induction motor.

3.6.1.1 Copper Wire

Copper wire also known as magnet wire is chosen for this project because it is an insulated copper electrical conductor. It is normally used in motor, transformer and other electromagnetic equipment. Magnet wire creates an electromagnetic field when it wound into a coil and energize.

Figure 3.9: 0.70mm SWG copper wire

3.6.1.2 Slot Insulation

Before starting the winding of the motor in a slot, some form of insulation must be placed so that wire does not touch any part of iron core. Mostly leatheriod paper and empire cloth are used for motor slots insulation. Then other type of insulator slot is mica-nitre, usually used for high temperature motors. Figure 3.10 shows type of slot insulation.

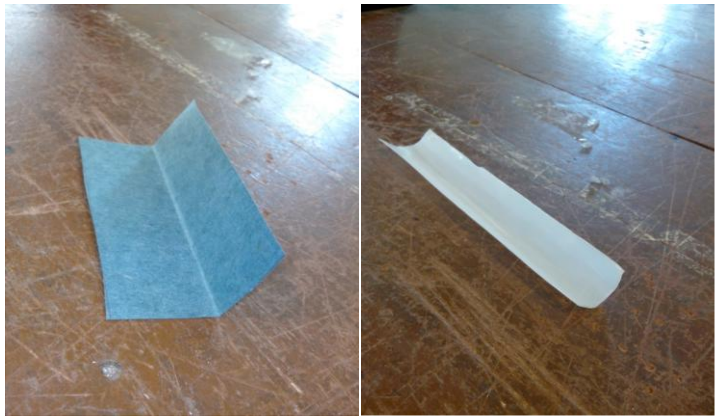


Figure 3.10: Slot insulation

3.6.1.3 Pole

It is important that the number of coil in opposite N and S poles should be equal so that they may produce the same strength. This project design used 2 poles only.

3.6.1.4 Procedure of Build Hardware for three-phase motor

The step to construct the motor is;

1. Firstly decide to used stator frame there had 24 slot stator cores.
2. Design the play wood (figure 3.11) that can be used as moulding to made coil winding of the motor.

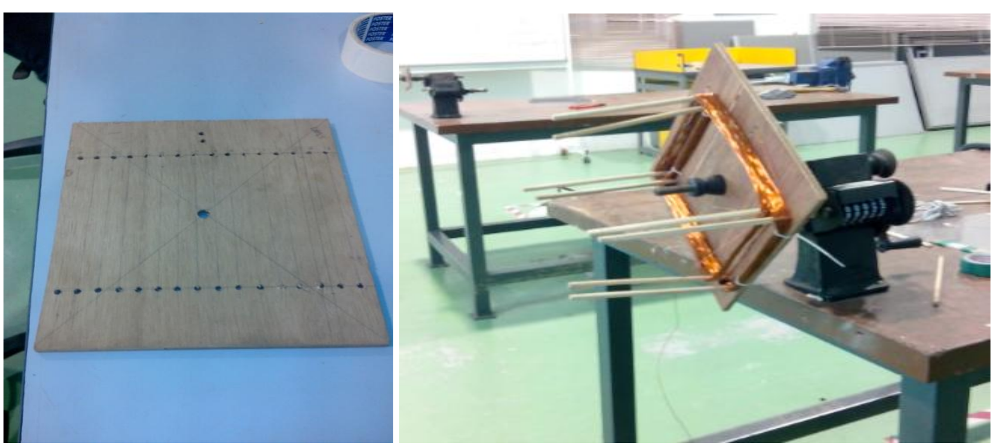


Figure 3.11: Play wood moulding for copper winding.

3. 0.7mm copper wire was used to make phase winding or group winding using play wood moulding. The winding machine was being rotated manually.
4. The copper wires was arranged neatly and fitted to each other. For three-phase, this step was repeated until 50 turn to make complete winding for 1 group turn.
5. This process was repeated until 4 times to make 1 group of phase winding, example 1 x 4 = 4 for one phase per-group, this phase used 8 number slot of stator for phase A only.

Figure 3.12: Phase group of winding

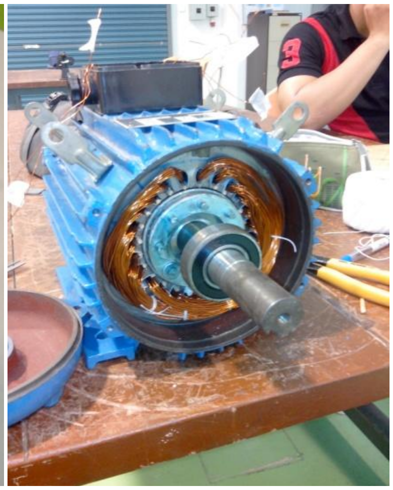
6. Step 4 and 5 was repeated for phase B and C group. The slot used is 3 x 8 = 24 number of slot.
7. After winding process completed, copper winding was installed or inserted that into stator core. Insulator paper or slot insulation was used before start inserts the copper winding into the each slot.

(a) (b)

Figure 3.13: (a) Inserted copper winding into the stator. (b) Stator frame

Figure 3.14: Position of copper wire in the stator

8. After complete inserted all phase winding into stator, the rotor was installed into the stator.

(a) (b)

Figure 3.15: (a) Squirrel cage rotor. (b) Completely winding in the stator with rotor inside that

9. The complete of induction motor was screwed after whole coil and rotor inserted into the stator. This motor ready to test and running.

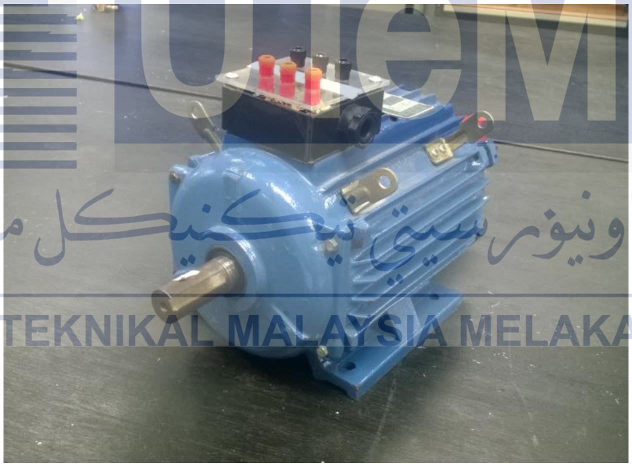


Figure 3.16: Complete three-phase induction motor was screwed.

3.6.1.5 Procedure of Build Hardware for five-phase motor

The step to construct the motor is;

1. Firstly stator frame that had 24 slot stator cores was decided to use same as the three-phase motor as above.
2. Play wood (figure 3.11) were used to make motor winding, this step also same as three-phase motor.
3. 0.7mm copper wire was used to make phase winding or group winding using play wood moulding. The winding machine was being rotated manually.
4. The copper wires was arranged neatly and fitted to each other. For five-phase, this step was repeated until 50 turn to made complete winding for 1 group turn.
5. This process will repeated 2 times to make 1 group of phase winding, this is because in five-phase motor, there is 5 phase of group winding. example 1 x 2 = 2 for one phase per-group, this phase used 4 number slot of stator. This step for phase A only.

Figure 3.17: Phase group of winding for five-phase motor

6. Step 4 and 5 was repeated to proceed for next phase group until complete five-phase group of winding. That means the next phase is phase B, C, D and phase E are included. The slot used is 5 x 4 = 20 number of slot.
7. After winding process completed, the next step was installed or inserted that copper winding into stator core. Use insulator paper or slot insulation before start inserts the copper winding into the each slot.

(a). (b)

Figure 3.18: (a) Inserted copper winding into the stator. (b) Stator frame

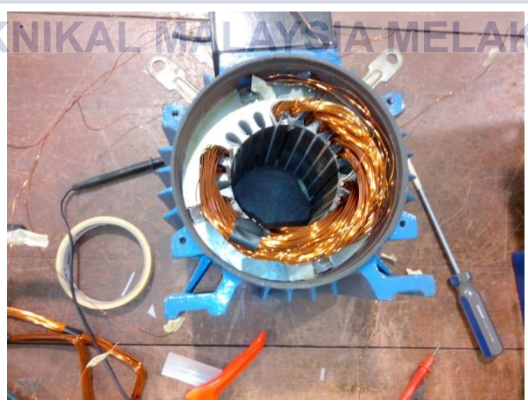
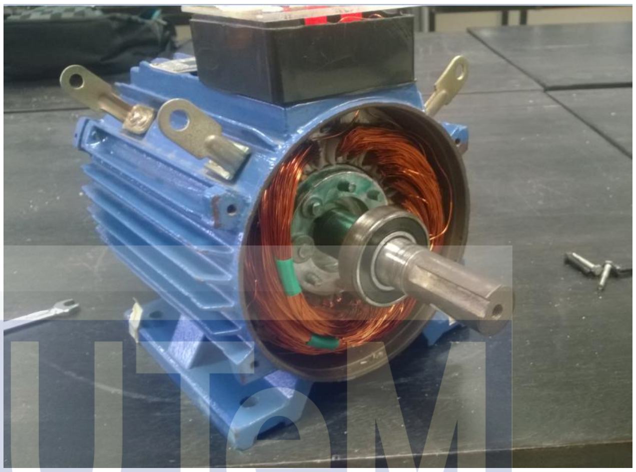


Figure 3.19: Position of copper wire in the stator

8. The winding in the stator slot was inserted carefully, this is because to prevent the insulator of winding broken or wound. This process was repeated for phase A, B, C, D and E. After complete inserted all phase winding into stator, the next is inserting the rotor into the motor stator.

(b)



(b)

Figure 3.20: (a) Squirrel cage rotor. (b) Completely winding in the stator with rotor inside that

9. The complete of induction motor was screwed after whole coil and rotor inserted into the stator. This motor ready to test and running.

Figure 3.21: Complete five-phase induction motor was screwed.

❖ **Testing and Measurement.**

After motor completed screwed and finish build, then this motor ready to test and check. Before this motor operating by using three-phase power supply, each phase need to check between phase-to-phase and phase to body by using multimeter. The purpose of this checking is because to prevent the current leak occur and to ensure that no connections between phase-to-phase and phase to body of the motor. If all condition is good, end of each winding for three-phase motor, the winding of phase A, phase B and phase C, need to short circuit to make star connection. These steps also repeat to implement for five-phase motor and at the end of each winding for five-phase motor also to short between phase A, B, C, D and E.

3.7 Motor Testing

After finish develops the motor, then the motor will be test to ensure that motor is able to run or not. The set-up of measurement has mention in figure 3.22 and figure 3.23. When the motor can operate and running, we can start the analysis and get the result of the three-phase and five phase of induction motor. If the motor fail to operate, we need to do some inspection on it and review back to literature review and need to do rewinding on the stator. The testing that will be implementing in this analysis is:

a. Induction motor no-load test

b. Induction motor test on DC generator

c. Induction motor test on DC motor

3.7.1 Induction motor no-load test

The no-load test on an induction motor is to measure the speed of the motor, voltage and current without load. In this test, three-phase balance AC voltages with rated 50Hz are applied to the stator and rotor runs without any load. It is noted that the slip is close to zero when an induction motor runs on no-load. The input power, the line voltage, speed and phase the motor are measure. With this data, the desired parameter may be able to compare between three phase motor and five-phase motor.

3.7.1.1 The no-load test setup

The no-load tests were performed on the two type of induction motor, the first is three-phase motor and the second is five-phase motor. To test the motor with no-load test, the circuit is shown in figure 3.22 for three-phase and figure 3.23 for five-phase. For three-phase motor, it was connected directly from three-phase variable transformer while for five-phase motor, it needs to connect between the three-phase transformer and five-phase transformer and then the output from five-phase transformer connect to the five-phase motor.

In this testing, there is several equipment and measurement device that will be used :

Table 3.1: Equipment and measurement device that will be used in no-load testing

Equipment	**Measurement Device**
• 1 unit three-phase motor • 1 unit three-phase variable transformer • 1 unit DC power supply • 1 unit DC shunt generator • 1 unit Resistive load • 1 unit 5-phase transformer	• 3 digital AC voltmeter • 2 digital AC ammeter • 1 digital RPM meter

❖ **Procedure of no-load test on three-phase motor**

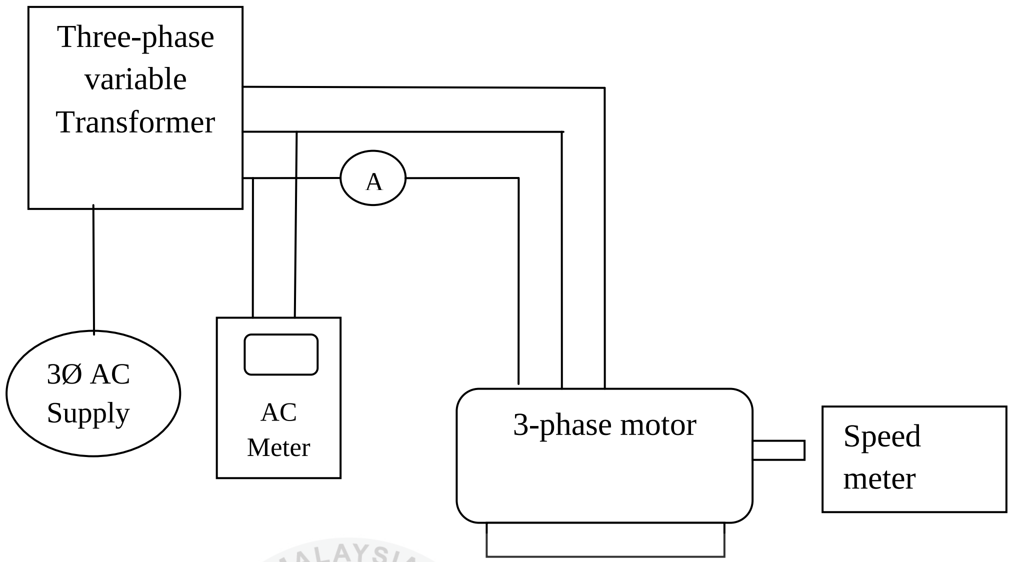


Figure 3.22: Three-phase motor no load test

Start:

Step 1: Test circuit as shown in Figure 3.22 was constructed. Make sure the tested motor is disconnected from loads and the three-phase switch is open. The output of the variable transformer is adjusted to 0%. The range of ammeters is selected as 0-10 A. The ranges of the voltmeters are selected as 0-200 V.

Step 2: The three-phase switch was closed and the AC power was ON. The output voltage of the transformer was increased. All meters were checked their work correctly. Input voltage was increased slowly since the starting current of the motor could be very high.

Step 3: The output of the transformer was adjusted until the input voltage of the motor reaches its rated value. Check whether the motor runs at the rated speed.

Step 4: The three-phase motor's line voltages, phase currents and speed was measured.

Step 5: All data was recorded.

Step 6: The output of the transformer was adjusted to 0%. The power and open the three-phase switch was turned off. All meters were switch off.

End

❖ **Procedure of no load test on Five-phase induction**

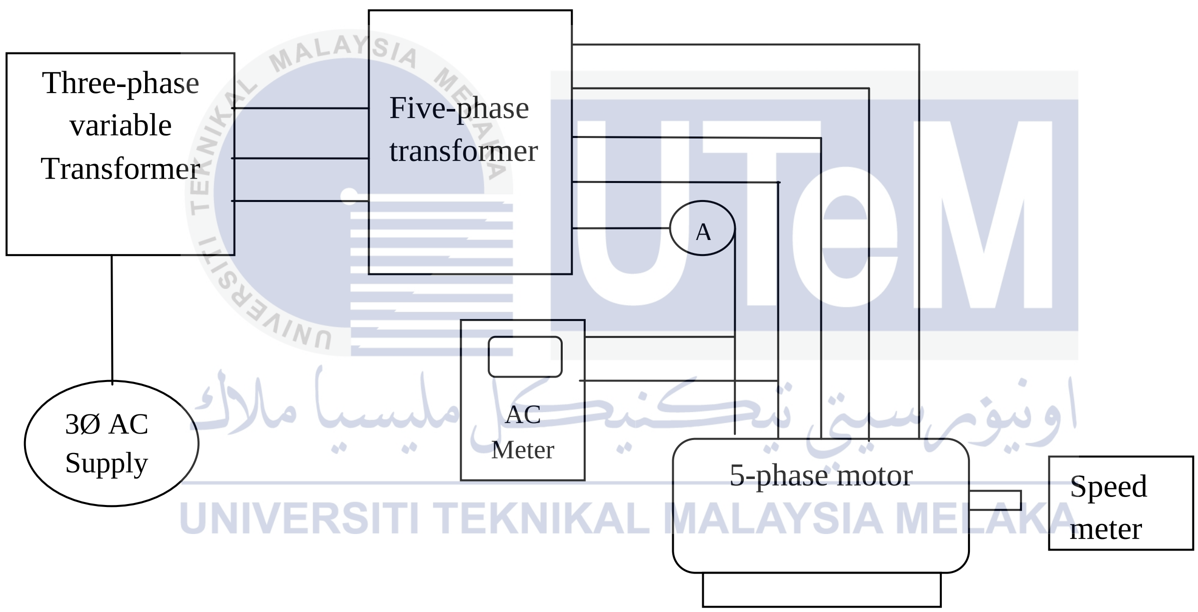


Figure 3.23: Five-phase motor test with no-load

Start:

Step 1: Set-up the circuit as shown in Figure 3.23. Check the connection of each terminal between the motor and transformer. Make sure the tested motor is disconnected from loads and the three-phase switch from incoming supply is open. For five-phase motor, it needs to take supply from five-phase transformer using power conversion from three-phase supply because the five-phase supply is not available. The range of ammeters is selected as 0-10 A. The ranges of the voltmeters are selected as 0-200 V.

Step 2: Close the three-phase switch and turn on the AC power. Increase the output voltage of the transformer. Check whether all of meters work correctly. Since the starting current of the motor could be very high, make sure its input voltage is increased slowly.

Step 3: Continue to adjust the output of the transformer until the input voltage of the motor reached certain value to make the motor start to rotate. Since the motor start to rotate, increase the supply time by 10 until the line voltage reached 110V. This is because the maximum value of line voltage for five-phase transformer supply to five-phase motor is 110V. Also check whether the motor runs at the rated speed.

Step 4: Read and record the five-phase motor's line voltages, phase currents, speed and

Step 5: Decrease the voltage on the motor and record all the data.

Step 6: Adjust the output of the transformer to 0%. Turn off the power and open all connections between motor and transformer. Switch off all of the meters.

End.

3.7.2 Induction motor test on DC generator

3.7.2.1 The load test setup

In the load test, the induction motor will coupled to a DC generator to evaluate the efficiency of induction motor under the load. To test the induction motor with load, the connection of the motor done as shown in figure 3 and figure 4. This test still used same parameter in the no load test, the difference is this motor will couple with DC shunt generator where is the 100V DC power was apply to field winding of generator. Since the field winding is an electromagnet, current must flow through it to produce magnetic field. Then, the armature of generator will connect to 273Ω resistive load. The generated emf Vg is the voltage across the armature terminals when no load is connected to those terminals. If there is some electrical load connected to the armature, the resulting load voltage will be different from no load voltage. This test will implement to investigate the ability of induction motor to operate during load condition in term of speed, phase current and line voltage.

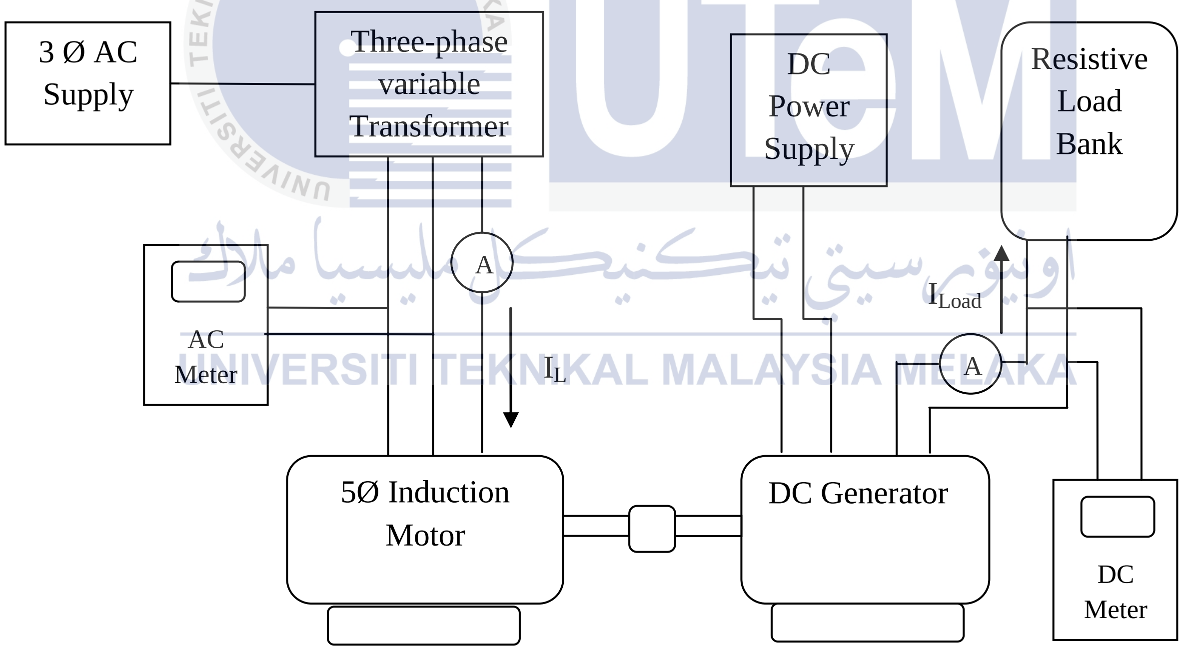


Figure 3.24: Three-phase motor test on DC generator

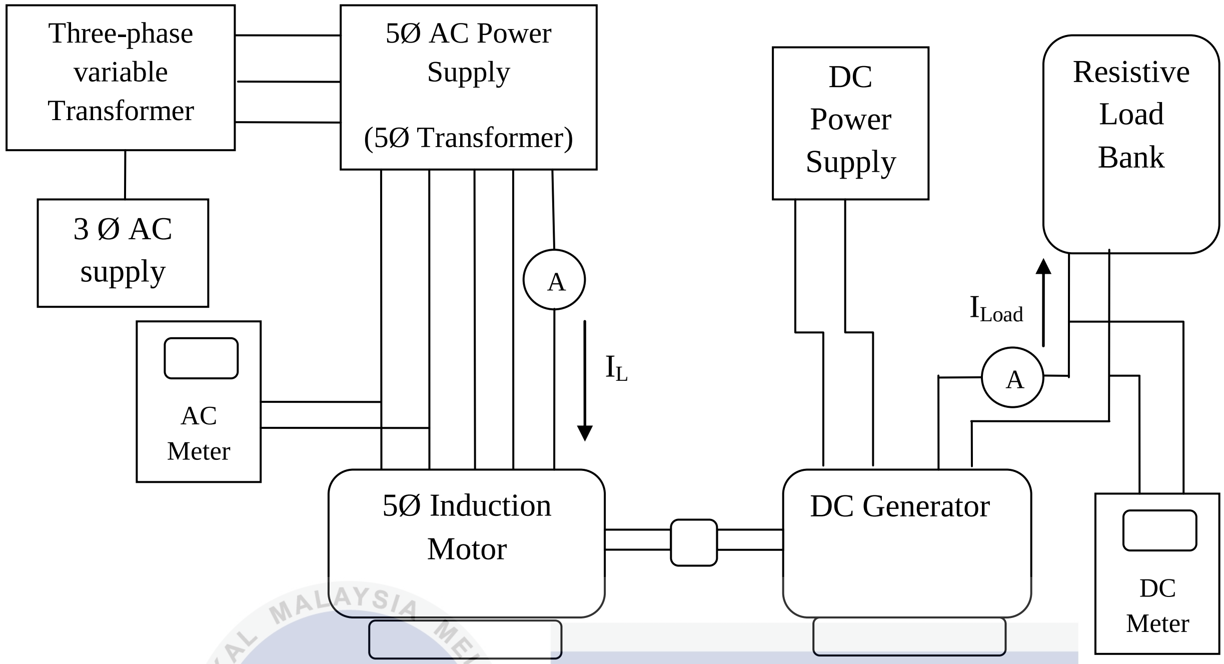


Figure 3.25: Five-phase motor test on DC generator

In the testing induction motor on DC generator, there is several equipment and measurement device that will be used:

Table 3.2: Equipment and measurement device that be used in motor test on DC generator.

Equipment	Measurement Device
• 1 unit three-phase motor • 1 unit 5-phase motor • 1 unit 5-phase transformer • 1 unit three-phase variable transformer • 1 unit DC power supply • 1 unit DC shunt generator • 1 unit Resistive load	• 3 digital AC voltmeter • 2 digital AC ammeter • 1 digital RPM meter

❖ Procedure of the load test on DC generator

Start

Step 1: Build the test circuit as shown in figure 3.24. Couple the three-phase induction motor with DC generator and tight it using nut to ensure coupling is secure during test.

Step 2: Check the connection and make sure the phase sequence is correct and the load is turn off. The variable transformer is set to 0% and the three-phase switch is open. The range of the measurement device are selected as same as those in the no-load test.

Step 3: Close the switch and turn on the AC power. Increase the output of the transformer until the line voltages of the induction motor are equal to 100V. Set the resistive load value to 273Ω. Increase the DC supply slowly to produce magnetic field in the DC generator and then make load to the induction motor.

Step 4: Read and record data, including the line current, line voltage, armature current and the armature voltage. Also record the speed of the motor during DC supply increasing from 0V to 90V.

Step 5: After the data were record, the next is increase DC supply until reach 100V. Reduce the value of resistive load to make a load to induction motor. Record corresponding data like line current, line voltage, armature current, armature voltage and speed. Turn off the supply.

Step 6: Change the three-phase motor to five-phase motor and couple it to DC generator as mention above. Set up the five motor as shown in figure 3.25.

Step 7: repeat step 2 to step 5 and data were record. Turn off the resistive load banks

Step 8: Reduce the output of the transformer to 0%. Turn off the power supply and open all connections between motor and transformer. Switch off all of the meters.

3.7.3 Induction motor test on DC Motor

In order to evaluate the load test on DC motor, the induction motor will coupled to a DC motor. This test also same as load test on generator but there is no resistive load will apply to DC motor. The connection of the motor done as shown in figure 3.26 for three-phase motor and figure 3.27 for five-phase motor. This test still used same parameter in the no load test, DC power was apply to DC motor. This test will implement to investigate the performance of induction motor to operate under load condition in term of speed, phase current, load current and line voltage.

There is several equipment and measurement device that will be used:

Table 3.3: Equipment and measurement device that be used in motor test on DC motor

Equipment	Measurement Device
• 1 unit three-phase motor • 1 unit 5-phase motor • 1 unit 5-phase transformer • 1 unit three-phase variable transformer • 1 unit DC power supply • 1 unit DC shunt generator • 1 unit Resistive load	• 2 digital AC voltmeter • 2 digital AC ammeter • 1 digital RPM meter

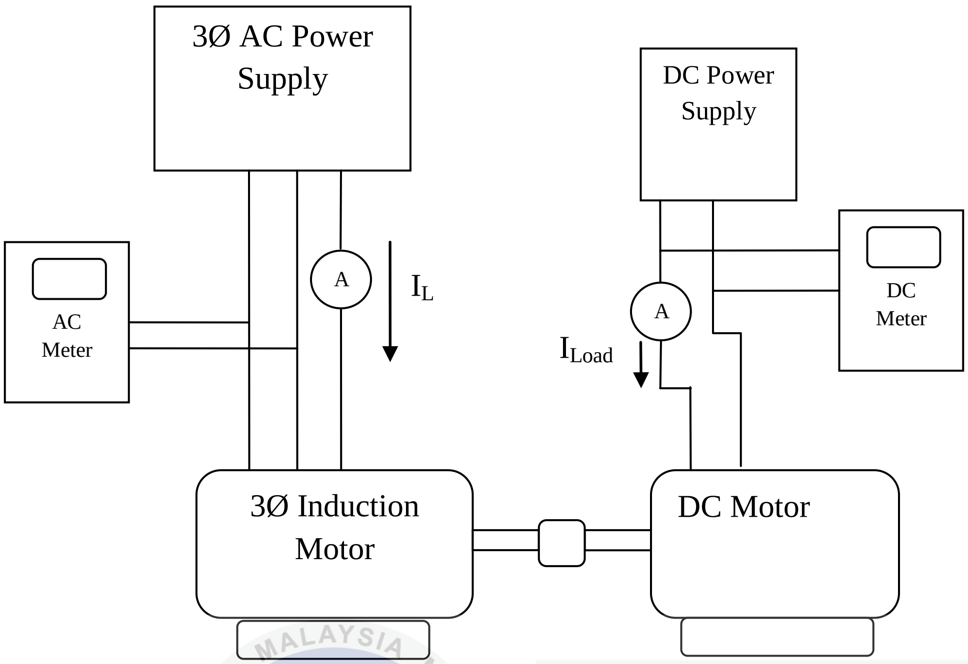


Figure 3.26: Three-phase induction motor test on DC motor

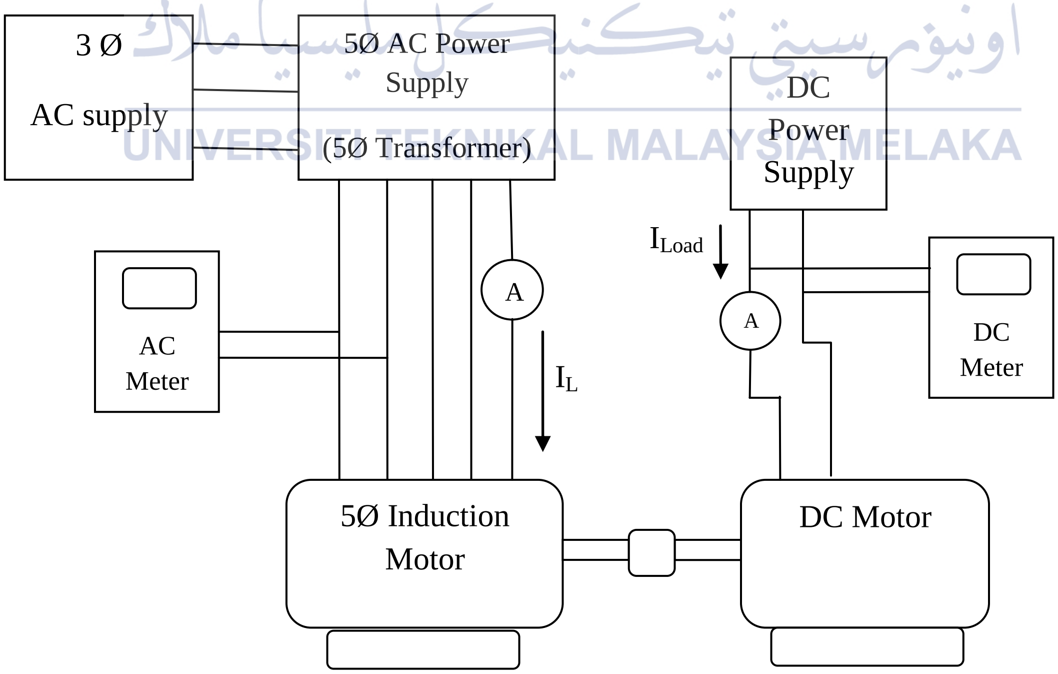


Figure 3.27: Five-phase induction motor test on DC motor

❖ **Procedure of the load test on DC motor**

Start

Step 1: Build the test circuit as shown in figure 3.27. Couple the three-phase induction motor with DC generator and tight it using nut to ensure coupling is secure during test.

Step 2: Check the connection and make sure the phase sequence is correct and the load is turn off. The variable transformer is set to 0% and the three-phase switch is open. The range of the measurement device are selected as same as those in the no-load test.

Step 3: Close the switch and turn on the AC power. Increase the output of the transformer until the line voltages of the induction motor are equal to 100V. When the motor operate at the rated speed, start to increase the DC supply slowly until the induction motor stop running.

Step 4: Read and record data, including the line current, load current, line voltage, and also record the speed of the motor during DC supply increasing from 0V to 90V.

Step 5: After the data were record, the next is change the three-phase motor to five-phase motor and couple it to DC motor as mention above. Set up the five motor as shown in figure 3.28.

Step 6: repeat step 2 to step 4 and record the data in term of line current, load current, line voltage and speed the induction motor..

Step 7: Reduce the output of the transformer to 0%. Turn off the power supply and open all connections between motor and transformer. Switch off all of the meters.

Summary

In this section, the experimental plan was state to evaluate induction motor parameter. The basic principles of the test were introduced. The physical setups of the experiments were displayed and explained. The test procedure was given in detail. The necessary equipment and measurement device were also present in detail during the experiment had conduct. All of the testing and measurement result were record and it provided in chapter 4.

3.8 Discussion on Result and Report Writing

The discussion is base on the result obtain from testing on the motor. We will study and discuss about the result of current, voltage and speed characteristic of induction motor. The earlier part such as introduction and literature review of the report writing is in parallel with the project progress. The later part such as result, discussion and conclusion on the project depends on the finished project.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter discuss about the result of the hardware that had conduct in PSM 2 and analysis of these project especially on five-phase motor and three-phase motor. The purpose to build the three-phase motor in this project is to compare the characteristic of motor with five-phase motor in term of performance like phase current, line voltage speed and load test on the motor. In the induction motor test, there is three type of test which are no-load test, test on DC generator and test on DC motor. All data were recorded.

4.2 Experimental Result

This chapter will discuss about the result of no-load test experiment, test on DC generator and test on DC motor. The result is presented for five-phase and three-phase of induction motor.

4.2.1 No Load Test

Five-phase motor No load test

Table 4.1 below shows the result of voltage, current and speed of the five-phase motor. Based on this table, it shows that when line-voltage increased until reach 28.9V, the induction motor has to start rotate. The motor was already achieved their rated speed when the line voltage increase to 50V. Logically, in five-phase induction motor, there is more power and high stating torque to achieve their rated speed compared to three phase induction motor. The maximum value of line voltage is 110V, it is because when the value of the voltage increasing upper than that, the transformer starts to harm and vibrate. That is the limitation of this project.

Table 4.1: Experimental output of five-phase induction motor no load test

Line Voltage, V_L (V)	Current phase A, I_A (A)	Current phase B, I_B (A)	Current phase C, I_C (A)	Current phase D, I_D (A)	Current phase E, I_E (A)	Speed, (Rpm)
28.9	1.07	1.24	1.26	1.03	1.33	171
30	1.11	1.28	1.32	1.06	1.40	270
40	0.44	0.6	0.47	0.43	0.69	2805
50	0.31	0.51	0.34	0.31	0.55	2907
60	0.28	0.51	0.31	0.27	0.54	2937
70	0.28	0.52	0.30	0.25	0.54	2955
80	0.29	0.56	0.31	0.25	0.56	2963
90	0.31	0.60	0.31	0.25	0.60	2970
100	0.36	0.64	0.35	0.26	0.62	2975
110	0.39	0.68	0.37	0.26	0.65	2980

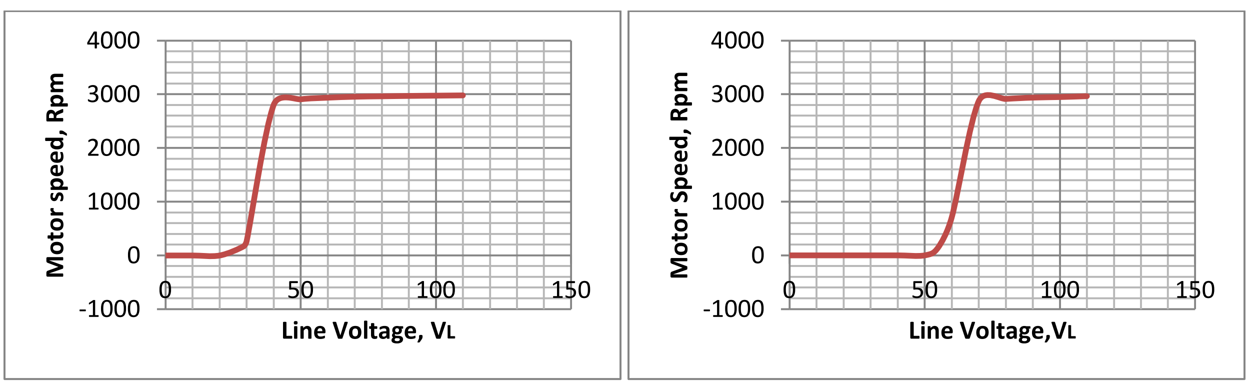
Three-phase motor No load test

Table 4.2 below shows the result of voltage, current and speed of the three-phase motor. In this testing that has conduct, the induction motor start to rotate when the line voltage increase to 55V. Line voltage was increased up to 80V to make motor speed up to rated speed and the maximum value of line voltage was set to 110V. The reason is to compare the performance of induction motor between three-phase motor and five-phase motor.

Table 4.2: Experimental output of three-phase induction motor no load test

Line Voltage, V_L (V)	Current phase A, I_A (A)	Current phase B, I_B (A)	Current phase C, I_C (A)	Speed, (Rpm)
55	1.13	1.15	1.03	149
60	1.25	1.26	1.10	710
70	0.36	0.36	0.33	2873
80	0.30	0.34	0.27	2912
90	0.29	0.29	0.25	2937
100	0.28	0.28	0.24	2947
110	0.27	0.27	0.24	2963

Both graphs below are represent the three-phase motor and five-phase motor in term of starting torque of motor and the rated speed of motor. In figure 4.1, it shows the relationship of line voltage versus speed of induction motor. Figure 4.1(a), shows the motor start achieved their rated speed when the line voltage increase up to 50V and it means that, there is more power and high starting torque for five-phase motors. In figure 4.1 (b), the motor start achieved their rated speeds, when compare to five-phase motor when the line voltage increase up to 80V, during 28.9V the motor has already start to rotate. Based on that presentation in Figure 4.1, it shows that the three-phase motor lag than five-phase motor



(a). (b).

Figure 4.1: Line voltage vs. motor speed in five-phase motor (a) and three-phase motor (b)

4.2.2 Motor test on DC shunt generator.

DC generator, supply voltage of line voltage and DC voltage are set to 100V in induction motor test. The value of resistive load is change according in Table 4.3. When the value of resistive load is decrease, the data were recorded. Based on six of differences value of resistive load has been implemented in this experiment, the observation has shown that the speed of motor is decrease when the resistant value is reduced. The value of line voltage, phase current, load current and speed on induction were recorded. Table 4.3 shows the result for five-phase motor performance during testing on DC generator while in Table 4.4 data were recorded for three-phase motor. When the value of resistive is reduced, we can conclude that the five-phase has good performance of speed and torque during operation on load.

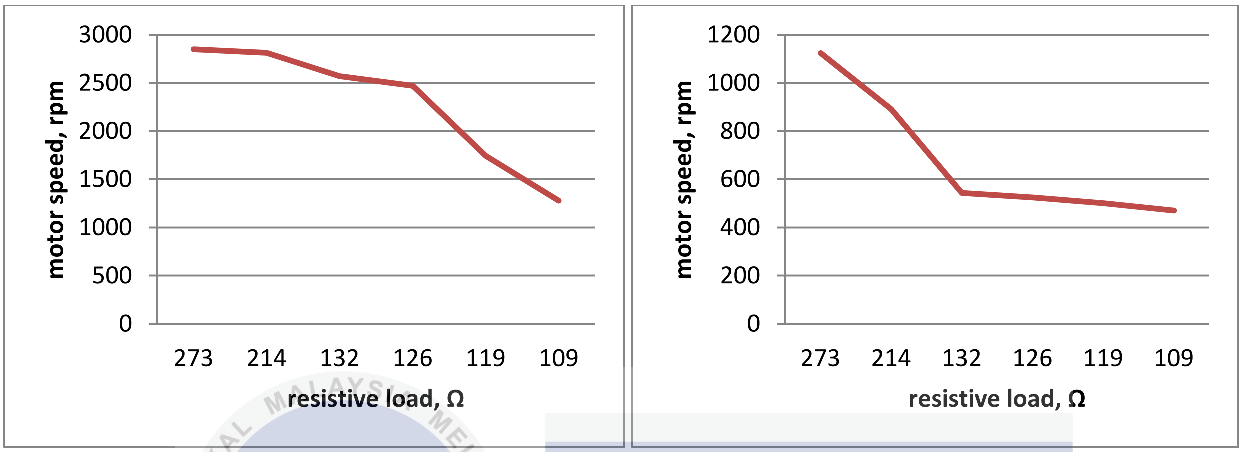
Table 4.3: five-phase motor test on DC generator

Line voltage, V_{L-L}	Generator voltage, Vg (V)	Line current, I_L (A)	Load current, I_{Load} (A)	Resistor, (Ω).	Speed, (rpm)
100	183	1.38	0.68	273	2849
	180	1.56	0.85	214	2814
	163	2.43	1.25	132	2570
	155	2.69	1.20	126	2471
	114	3.52	1.00	119	1744
	83	3.79	0.78	109	1277

Table 4.4: three-phase motor test on DC generator

Line voltage, V_{L-L}	Generator voltage, Vg (V)	Line current, I_L (A)	Load current, I_{Load} (A)	Resistor, (Ω).	Speed, (rpm)
100	71.7	2.20	0.26	273	1124
	60.8	2.23	0.27	214	890.6
	33.5	2.30	0.26	132	543.6
	32.6	2.30	0.26	126	525.0
	30.7	2.30	0.26	119	500.0
	28.8	2.31	0.27	109	470.3

In figure 4.2, it shows the relationship between resistive loads versus motor speed of induction motor. Both graphs represent the different of speed condition in five-phase and three-phase motor during load test using DC generator and resistive load.



(a). (b)

Figure 4.2: induction motor test on DC generator, (a) five-phase motor, (b) three-phase motor.

In table 4.5 and table 4.6, it is show about the result when the values of resistive load are fixed while the DC voltage for generator is increase slowly and the speed of the motor are observed. In the table 4.5, it shows about five-phase motor characteristic during DC voltage is increased and the Vg or voltage generator also increased even the rated speed of the motor slightly decreased. While in Table 4.6, it shows the result about three-phase motor testing same as five-phase motor, but in three-phase motor, the result shown is significant decreased of motor speed when DC voltage is increased. The speed of motor decrease caused by the load and the voltage generator also low at the end of testing even voltage generator initially shown increment during DC supply increased slowly.

Table 4.5: 5phase-phase motor test on DC generator by increasing DC voltage

Line voltage, V_{L-L}	Generator voltage, Vg (V)	Line current, I_L (A)	Load current, I_{Load} (A)	DC Voltage, (Vdc).	Speed, (rpm)
100	0.00	0.44	0.00	0	2951
	25.00	0.44	0.09	10	2950
	44.00	0.45	0.16	20	2948
	67.00	0.49	0.25	30	2945
	90.00	0.53	0.33	40	2939
	110.00	0.58	0.40	50	2936
	129.00	0.64	0.47	60	2931
	146.00	0.72	0.54	70	2907
	160.00	0.80	0.59	80	2891
	174.00	1.66	0.64	90	2741

Table 4.6: Three-phase motor test on DC generator by increasing DC voltage

Line voltage, V_L (V)	Generator voltage, Vg (V)	Line current, I_L (A),	Load current, I_{Load} (A)	DC Voltage, (Vdc).	Speed, (rpm)
100	0.00	0.55	0.00	0	2867
	25.80	0.65	0.10	10	2848
	43.40	0.66	0.16	20	2836
	64.10	0.74	0.24	30	2810
	85.10	0.87	0.31	40	2762
	100.50	1.01	0.37	50	2696
	113.40	1.21	0.42	60	2600
	119.80	1.55	0.44	70	2370
	90.00	2.05	0.36	80	1570
	69.30	2.30	0.26	90	1143

In the figure 4.3 show about the difference speed characteristic during induction motor test on DC generator while increasing the DC voltage. The green line represents three-phase motor while the red line represents five-phase motor. From the graph we can conclude that the five-phase is better than three-phase in term of torque and speed during load test condition.

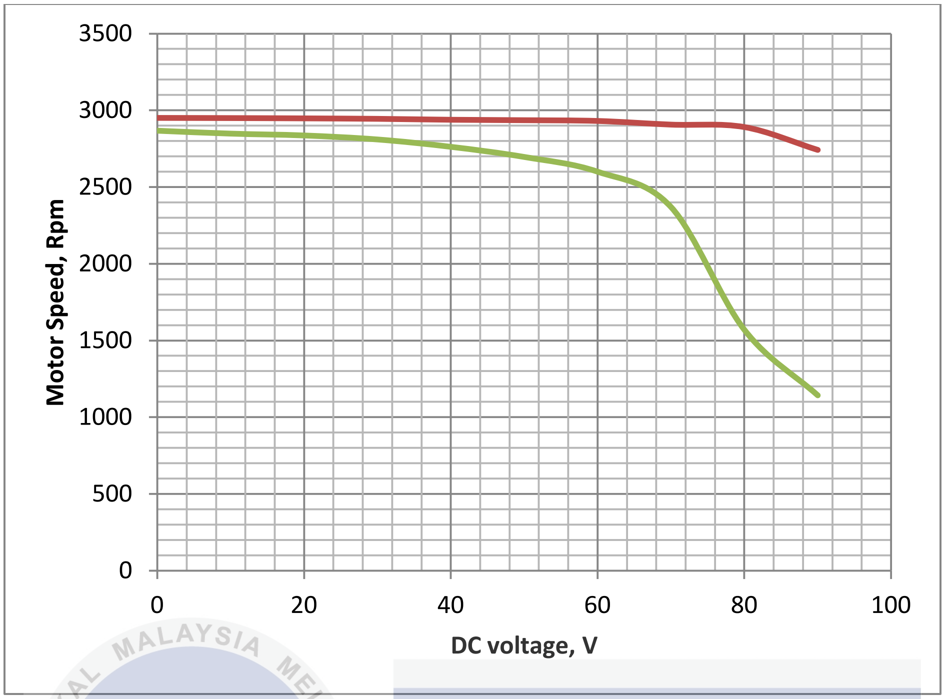


Figure 4.3: Differential speed characteristic during load test.

4.2.3 Induction Motor test with DC motor

For eddy current test, induction motor was couple with DC motor to evaluate the efficiency of induction motor under the load. This test also same as load test on generator but there is no resistive load applied to DC motor. Table 4.7 and Table 4.8 shows about the result of speed of motor, phase current, line voltage and load current when the value of DC voltage is increased slowly by keeping the motor speed. In Table 4.7, it show about three-phase motor characteristic when DC voltage was increased, the motor speed decreased until the dc voltage up to 70V and motor speed stop to rotate. While in Table 4.8, it records the result for five-phase motor and the result is difference from three-phase test. In five-phase motor, dc supply was increased until 70V, the motor still rotate and it only stop to rotate when the dc voltage up to 110V. That means in five-phase motor, they have high torque during eddy current test compared to three-phase motor.

Table 4.7: Eddy current test with three-phase motor

Line voltage, V_L (V)	DC voltage, V_{DC} (V)	Line current, I_L (A),	Load current, I_{Load} (A)	Speed, (rpm)
100	0	0.36	0	2922
	10	0.37	0.01	2915
	20	0.42	0.03	2895
	30	0.51	0.04	2860
	40	0.71	0.05	2790
	50	0.99	0.06	2647
	60	2.37	0.08	353.5
	70	2.39	0.09	0

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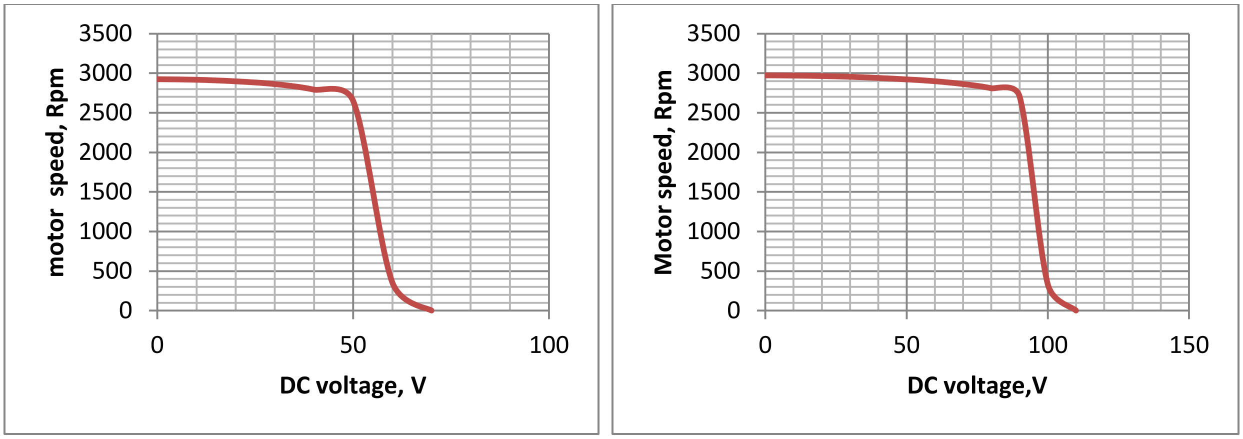
Table 4.8: Eddy current test with five-phase motor

Line voltage, V_L (V)	DC voltage, V_{DC} (V)	Line current, I_L (A),	Load current, I_{Load} (A)	Speed, (rpm)
100	0	0.38	0	2972
	10	0.38	0.01	2969
	20	0.40	0.03	2963
	30	0.43	0.04	2954
	40	0.49	0.05	2939
	50	0.58	0.06	2921
	60	0.70	0.07	2898
	70	0.88	0.09	2862
	80	1.11	0.10	2809
	90	1.51	0.11	2708
	100	3.55	0.12	332.6
	110	3.56	0.14	0

Figure 4.4 shows about the difference speed characteristic during induction motor test on DC motor. When the DC voltage was increased, the motor speed decreased caused by the increasing of eddy current in DC motor. Figure 4.4(a) represent three-phase motor and Figure 4.4(b) represent five-phase motor. Both graph below shows that the five-phase is better than three-phase in term of torque and speed during eddy current test.



(a).

(b)

Figure 4.4: induction motor test on DC motor (eddy current test)

In final year project 2, the hardware of three-phase and five-phase motor was successfully build. The analysis for no load test, test on DC generator and test on DC motor in term of speed, phase current, load current, line voltage also has done and all data has successful recorded. From the graph in Figure 4.1 until Figure 4.4, it shows that the performance of five-phase motor is better than three-phase motor during load test. The better performances in five-phase motor compared with three-phase motor are high starting torque and high speed.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The motor that had developed are five-phase induction motor by using the stator that has same as with three phase induction motor by maintaining the constant frequency. The design of these induction motor is able to function by using five-phase transformer but the limitation of their line voltage, this motor cannot test on full load generator and DC motor. In Chapter 4, by comparing the result from the experiment that had conduct, it shows that the performance of five-phase motor is better than three-phase motor during load test. In five-phase motor, there is high starting torque and high speed compared to three-phase. This is because in five phase motor, they have five magnetic fields, that's why this motor very power in term of starting torque and speed regulation.

5.2 Recommendation

Even five-phase motor has fully constructed and functioned by using single-phase motor, the motor still has losses in unbalance of flux current. This is because by using stator core from single phase motor, there is only 24 number of slot, for the five-phase motor they need 25 number of stator slot or number of stator slot need multiple by 5 to make motor is balance during operation. The recommendation for this project is for the further study, this motor need to build and fabricate using stator core multiple by 5, example 25, 30, 35 and so on. Second is, FKE UTEM should provide the five-phase motor drive in the laboratory to facilitate some improvement study in the five-phase induction motor.

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APPENDIXS

APPENDIXS A : SWG Standard of Current Rating.

AWG	Dia mm	SWG	Dia mm	Max Amps	Ohms / 100 m
11	2.30	13	2.34	12	0.53
12	2.05	14	2.03	9.3	0.67
13	1.83	15	1.83	7.4	0.85
14	1.63	16	1.63	5.9	1.07
15	1.45	17	1.42	4.7	1.35
16	1.29	18	1.219	3.7	1.70
18	1.024	19	1.016	2.3	2.7
19	0.912	20	0.914	1.8	3.4
20	0.812	21	0.813	1.5	4.3
21	0.723	22	0.711	1.2	5.4
22	0.644	23	0.610	0.92	6.9
23	0.573	24	0.559	0.729	8.6
24	0.511	25	0.508	0.577	10.9
25	0.455	26	0.457	0.457	13.7
26	0.405	27	0.417	0.361	17.4
27	0.361	28	0.376	0.288	21.8
28	0.321	30	0.315	0.226	27.6
29	0.286	32	0.274	0.182	34.4
30	0.255	33	0.254	0.142	43.9
31	0.226	34	0.234	0.113	55.4
32	0.203	36	0.193	0.091	68.5
33	0.180	37	0.173	0.072	87.0
34	0.160	38	0.152	0.056	110.5
35	0.142	39	0.132	0.044	139.8

APPENDIXS B : Gant Chart of the PSM 1 and PSM 2

Gant Chart of the PSM 1

Activities 2013														
PSM 1	Sep-13			Oct-13					Nov-13			Dec-13		
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Find Project Title and Supervisor														
Register Project Title and Supervisor														
Collection of Literature														
Study of Literature														
Design and Develop the Project														
Preparation of Proposal														
Submission of Proposal														
Seminar														
Modifying of Returned Proposal														
Submission of Proposal														

Table A: Gant Chart of PSM 1

Gant Chart of the PSM 2

Activities 2014														
PSM 2	Feb-14			Mar-14					Apr-14			May-14		
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Find Project Title and Supervisor														
Register Project Title and Supervisor														
Study of Literature														
Design and Develop the Project														
Test the motor and collect the data														
Preparation for report writing														
Submit the report to panel														

Table B: Gant Chart of PSM 2