DESIGN OF OUTER ROTOR BLDC MOTOR FOR HIGH VOLUME LOW SPEED FAN

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This Report is submitted in Partial Fulfillment of Requirements for the Degree of Bachelor in Electrical Engineering
(Power Electronic & Drives)

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2018

DECLARATION

I hereby declare that this report entitle work 'Design Of Outer Rotor BLDC Motor For High Volume Low Speed Fan' is my own work. This report is a presentation of my original research work. All contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions.

Written and submitted for the purpose of fulfillment of the requirements for the degree of Bachelor of Electrical Engineering (Power Electronic & Drives). The work was done under the supervision and guide from Prof. Madya Dr. Kasrul bin Abdul Karim of the Universiti Teknikal Malaysia Melaka.

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APPROVAL

" I hereby declare that I have read through this report entitle 'Design Of Outer Rotor BLDC Motor For High Volume Low Speed Fan' and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Power Electronic & Drives)"

Signature : ……

Supervisor Name : Prof Madya Dr. Kasrul bin Abdul Karim

Date :

DEDICATION

To my beloved father and mother, and all the lectures and my friends that had help me all the time…

ABSTRACT

Nowadays, due to the rapid advance of power electronic controller technology, the used of Brushless Permanent Magnet (BLPM) motor for electric fan application had become a trend due to its advantages in term of power efficiency than induction motor. This is because the rotor speed of BLPM motor is equal to the synchronous speed of the motor, compared to the rotor speed of induction motor that has a slight different of slip speed from the synchronous speed. BLPM motor has two types of motor, which is Brushless DC (BLDC) motor and Brushless AC (BLAC) motor. BLDC motor has trapezoidal back EMF criteria, while the BLAC motor has sinusoidal back EMF criteria. So, in term of speed control, BLDC motor is much simpler to control its speed compared to BLAC. This project will cover about designing an outer rotor BLDC motor for high volume and low speed motor fan that has rated power of 200W, torque of 13N.m and 150 rpm rated speed using Asys Maxwell Rmxprt software. The design steps are started by validating the feasibility of the combination of poles and slot numbers that are used for the motor design. Then, other parameters such as tooth width, tooth height and the tooth pitch of the stator part are designed with appropriate calculation, to be a suitable design based on the fixed desired design parameter of the motor such as the rotor outer diameter, the airgap of the motor and the size of the magnet used. The analysis of the motor performance has been simulated using Ansys Maxwell 2D software. As the result, the design of the motor that has closed value as the desired performance with desired motor dimension is achieved.

ABSTRAK

Pada masa kini, teknologi kawalan dengan penggunaan kuasa elektronik semakin berkembang. Justeru, selari dengan perkembangan ini, penggunaan Brushless Permanent Magnet Motor (BLPM) sebagai aplikasi untuk kipas elektrik turut menjadi pilihan dalam industri kerana motor BLPM mempunyai kecekapan kuasa yang lebih tinggi berbanding dengan induction motor, kerana berbanding induction motor, motor BLPM mempunyai kelajuan rotor yang selari dengan kelajuan sinkronisasi berbanding kelajuan rotor induction motor yang mempunyai sedikit perbezaan kelajuan dengan kelajuan sinkronisasi dengan nilai gelinciran. Motor BLPM terbahagi kepada dua jenis, iaitu motor Brushless DC (BLDC) dan motor Brushless AC (BLAC). Perbazaan antara keduanya ialah, motor BLDC mempunyai kriteria Back EMF berbentuk trapezoidal, manakala motor BLAC pula mempunyai kriteria back EMF berbentuk sinusoidal. Jadi,dari segi kawalan motor, motor BLDC lebih mudah dikawal berbanding dengan motor BLAC. Projek ini merangkumi dalam mereka bentuk motor BLDC yang mempunyai rotor luaran sebagai motor kipas gergasi yang mempunyai tork yang tinggi. Spesifikasi reka bentuk motor menggunakan kuasa sebanyak 200W, dan mempunyai nilai tork sebanyak 13N.m dan kelajuan 150 rpm menggunakan perisian komputer Ansys Maxwell Rmxprt. Proses mereka bentuk motor dimulakan dengan mengesahkan kesesuaian kombinasi bilangan pole dan slot yang akan digunakan dalam rekabentuk motor. Kemudian, nilai parameter seperti kelebaran gigi, ketinggian gigi dan saiz mulut gigi bagi bahagian statik motor direka dengan pengiraan yang sesuai, untuk menjadi reka bentuk yang sesuai berdasarkan parameter reka bentuk yang telah ditetapkan pada motor seperti diameter luar rotor, jarak udara pada motor dan saiz magnet yang digunakan. Simulasi untuk menganalisa prestasi motor telah dibuat menggunakan perisian komputer Ansys Maxwell 2D Analysis. Hasilnya, reka bentuk motor yang mempunyai nilai yang hampir sama dengan prestasi motor dengan dimensi motor yang dikehendaki telah dicapai.

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LIST OF ABBREVIATION

BLDC	-Brushless Direct Current
HVAC	-High Voltage Alternate Current
CNC	-Computer Numerical Control
HVLS	-High Volume Low Speed
DC	-Direct Current
BLPM	-Brushless Permanent Magnet
BLAC	-Brushless Alternate Current
2D	-2 Dimension
3D	-3 Dimension
RMF	-Rotating Magnetic Field
EMF	-Electromotive Force
FEA	-Finite Element Method
NdFeB	-Neodium Iron Boron

CHAPTER 1

INTRODUCTION

1.1) Overview

Nowadays, as the technology of power electronic controller had growing more advanced, the use of brushless DC (BLDC) motor had been widely used in the industry instead of the used of brushed DC motors and induction motor, as it has many advantages over the other motor types because of its efficiency, easy to control, smooth torque delivery, and high-speed operation. In the past time, the application of BLDC motor has been limited in factor of the additional cost of the complex motor controller needed to operate these motors. Consequently, right now, the controller costs have cut off in recent years as it keep evolving, so the application of brushless dc motors had become a trend in the industry. From the limited application of BLDC motor at past as it is applied limitedly in the automotive, HVAC, electronic, computer, semiconductor and medical industries sector, now BLDC motors have long been used in industrial applications such as actuators, feed drives for CNC machines, industrial robots and HVLS fan.

Brushless DC motors are controlled by a motor controller with DC source using inverter. The motor controller is used to control inverter and phase voltage that supply to the electric motor. The switching sequence of the power switches is referred from the output of the Hall Effect sensor, which is placed at the stator and near the rotor. Hall Effect sensors are needed to sense the location of the South and North poles of the Permanent Magnet and send the feedback to the motor controller. The controller will determine the current flow of the three phases from the Hall Effect sensor output and provide the power switching sequence.

1.2) Project Motivation

Nowadays, the economy of Malaysian had become much more challenging as all the cost of living had been increased. One of the way to reduce life economic cost is to save the electricity power consumption in one usage per time. So, in order to solve this problem as an engineer view, instead of the usage of high power consumption of air conditioner in a certain place, people can use low power consumption fan. Also, it is much more better to use one big fan that can cover all the area instead of using many small fans. By doing this, not only we can reduce electrical power consumption and cost of electrical bill, but it is also eco-friendly as fan will not let out greenhouse gases that trap heat and lead to depletion of the ozone layer and contribute to global warming.

1.3) Problem Statement

The technology of large fan in industry had been introduced a long time ago. Mainly, the construction of large fan are using induction motor as main motor for the fan. Nowadays, as the technology of power electronic controller are becoming more advance, the usage of Brushless Permanent Magnet (BLPM) motor as main motor for large fan had become a trend because it has simpler speed control criteria and is more efficient in term of power consumption.

BLPM motor has two types of motor, which is Brushless DC (BLDC) motor and Brushless AC (BLAC) motor. BLDC motor has trapezoidal back EMF criteria, while the BLAC motor has sinusoidal back EMF criteria. So, in term of speed control, BLDC motor is much simpler to control its speed compared to BLAC. Based on this criteria, BLDC motor is chosen to be further analyzed for the fan motor application.

BLDC motor has two types of construction, that is outer rotor and inner rotor. In this project, BLDC outer rotor is chosen to be analyzed because it will produce higher torque compared to BLDC inner rotor while its design is suitable for fan motor application.

So, it is concluded that it is better to choose BLDC outer rotor to be designed for high volume low speed fan motor.

1.4) Objectives

1.4.1) To design an outer rotor BLDC motor and simulate its performance in RMxprt

1.4.2) To analyze the BLDC motor using Finite Element Method(FEM) in Ansys Maxwell 2D in term of its electromagnetic performance.

1.5. Scope of Research

This project is focused on designing and analyzing the outer rotor BLDC motor for high volume and low speed motor. The outer diameter of the rotor, air gap of the motor, motor speed, motor rated power and the magnet thickness is being fixed and specified based on commercial and availability of HVLS fan, while the other parameters such as no. of poles, no. of slots and tooth width are varied and being analyzed.

1.6. Report Outline

A brief description of this report is described in this section. Generally, this report contains five chapters in total, and all these chapters will deliver the overall information about this report, consequently.

The first chapter of this report will contain the introduction of this project. The overall idea of the project is briefly explained in this chapter.

The second chapter in this report will deliver the information on literature review of this project. The previous work related to the project will be analyzed in detail as guideline to improve the current project so that it will be much better.

The third chapter in this report will explain about the methodology that is being implemented to execute this project. All the formulas and theory used will be explained in this chapter.

The fourth chapter in this report will show the early results of the progress from the methodology used for this project. The data obtained from the results will be analyzed further to verify either the desired outcome of this project is achieved or not, and the results gain will be used for the next phase of the project.

Lastly, the fifth chapter in this report will summarize the overall conclusion obtained by from this project. The further work will be planned for the next step of this project, and all the references source will be cited in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1) Theory

2.1.1) General Structure of Motor Classification

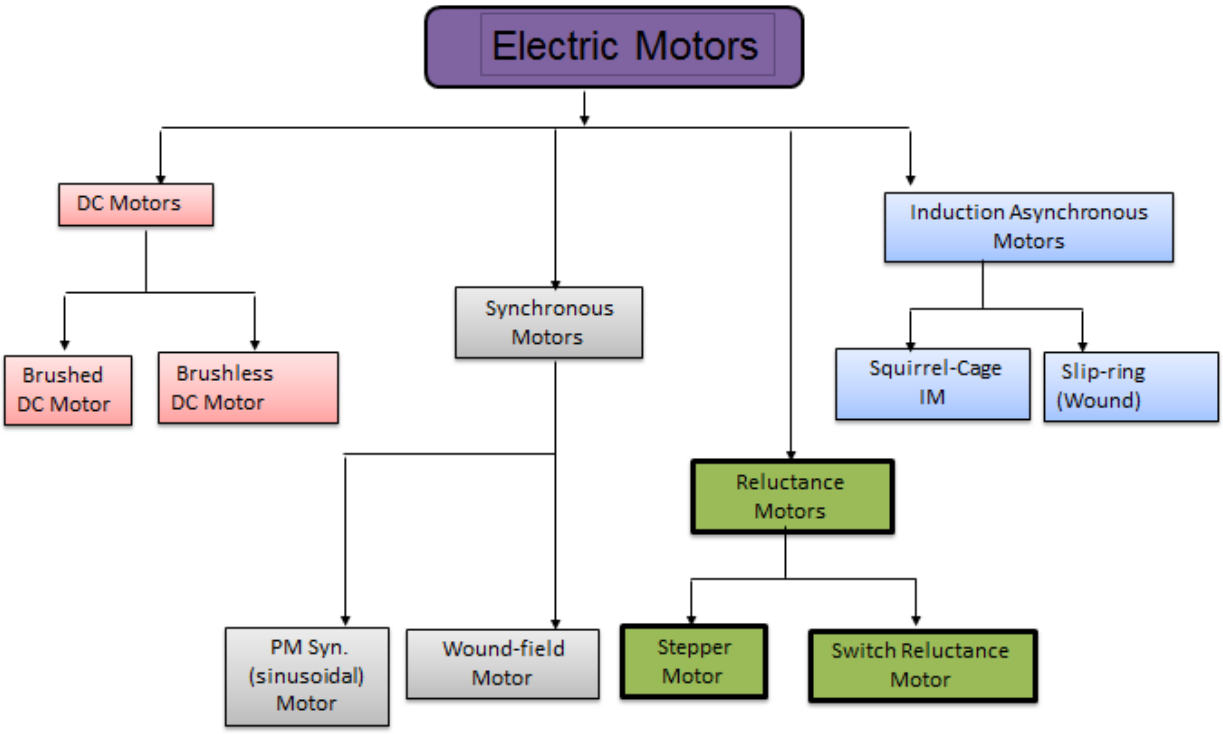

Figure 2.1: General classification of electrical motors type

Figure 2.1 shows the general classification of electrical motor type that is being used in current industry. All these motors have their own pros and cons, that make each of them are being used in the industry, according to the justification of the industrial player and the purpose of the usage of the motor.

For the large fan of motor application, the type of motor used in industry are induction motor. As the technology of the power electronic control are becoming more advance, the usage of brushless permanent magnet (BLPM) motor are becoming a new trend, since the efficiency of the BLPM motor is higher than induction motor.

As the BLPM motor is a motor that use permanent magnet as rotor, it has a numerous advantages rather than the induction motor that does just use a non-magnetic material as rotor such as squirrel cage and wound rotor, mainly about its performance. Table 2.1 below is a shortlist of the advantages and disadvantages between both induction and permanent magnet motor.

Table 2.1: Advantages and disadvantages of induction and permanent magnet motor

	Induction motor	Permanent magnet motor
Efficiency	-high I^2R losses -lower efficiency compared to synchronous motors	-Higher than induction motor -no conductor losses(I^2R) on rotor, thus more efficient than induction motor
Power	3-phase induction motors need 3 power supply lines	higher power density because it has higher magnetic flux compared to induction motor due to the permanent magnet rotor.
Speed	rotor speed is always less than the synchronous speed by slip	Speed constant regarding any load

2.1.2) BLPM motor

There are two types of BLPM motor, that is BLAC and BLDC. BLAC motor has a back emf shape of a sine wave, due to its stator winding is distributed winding, so it has sinusoidal phase currents in order to get in ripple-free torque operation. The BLDC motor has a back emf of a trapezoidal wave due to its concentrated stator winding, so its phase current at the stator is injected with quasi- square currents in order to get ripple-free torque operation.

The sinusoidal back emf characteristic of BLAC motor require high resolution position sensor because the rotor position need to be detected at particular instant time for optimal operation. This requires more complex controller circuit. This makes the BLDC motor is easier to be controlled compared to the BLAC motor because of its trapezoidal shape waveform.

2.1.3) BLDC motor

BLDC motor is same like brushed DC motor, that has internal shaft position feedback that has roles of determining which windings need to be energized (switch on) at the particular moment. This characteristic makes the BLDC motor has linear speed-torque curves, and make it easy to control the speed and has high torque.

BLDC motor is a part of permanent magnet AC motor that has same torque-speed characteristic like DC motor. The BLDC is using electronic commutation, instead of using brush as commutator in brush DC motor. The flux position of the rotor is detected by Hall Effect position sensors, usually by 3 Hall sensors that are placed 120° apart from each other. Those three hall sensors will determine the position of the rotor field. So, it is like the using of permanent magnet synchronous motor, but it much lower in cost and savvy because it only requires simple and cheap converter to control it.

Brushless DC motor, or known as an electronically commutated motor, is a synchronous motor feed by a DC source connected with an inverter as switching power supply, which converts DC to AC signal to control the motor. Here, AC signal from inverter does not represented as sinusoidal shape of the wave, but as a bi-directional current with no restriction on its waveform.[3]

Same like other types of motors, a BLDC motor consists of a stator and a rotor. Permanent magnets are mounted on the rotor, while the stator is made of the stacking slotted steel laminations. The stator can also be either slotted or slotless. A slotless core has lower inductance, and results in the motor operate in high speed.[4]

The inverter is responsible for commutation, which will triggered the motor phase currents at the appropriate time and switching to create a rotating magnetic field (rmf) at the stator, which will producing rotational torque. The rmf is maintained by using the appropriate phase switching sequence to supply the stator phases. While one pair slot of the stator is energized, stator electromagnet will attracts one of the rotor poles, while the second pair of the slots is energized, stator phase repels the corresponding pole of the rotor. This action of the rotor chasing the electromagnet poles on the stator makes the rotor speed has same speed as the synchronized speed.

The BLDC motor can be classified as,

a) Inner Rotor operation- The rotor that is embedded with permanent magnets is located in the center of the machine, while the windings of the stator surround the rotor.

b) Outer Rotor operation- The stator coils is form at the center (core) of the motor while the rotor embedded with permanent magnets spin around the stator. [5]

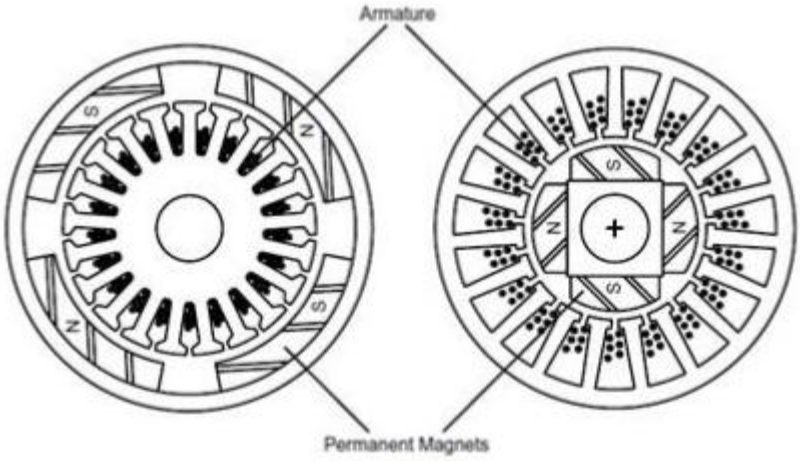

Figure 2.2: Outer Rotor Motor (Left), Inner Rotor Motor (Right) [6]

The BLDC motor's control is based on the information of position of its rotor. The detection of rotor position in brushless DC motors can be done by using sensor or sensorless.

For the sensor based control, a Hall-effect position sensor detects the position of the rotating magnet in the rotor and gives the corresponding windings through appropriate switching. The rotating permanent magnet moving across the front of the sensor causes it to change state. The sensor operates when each South Pole approaches the sensor. [7]

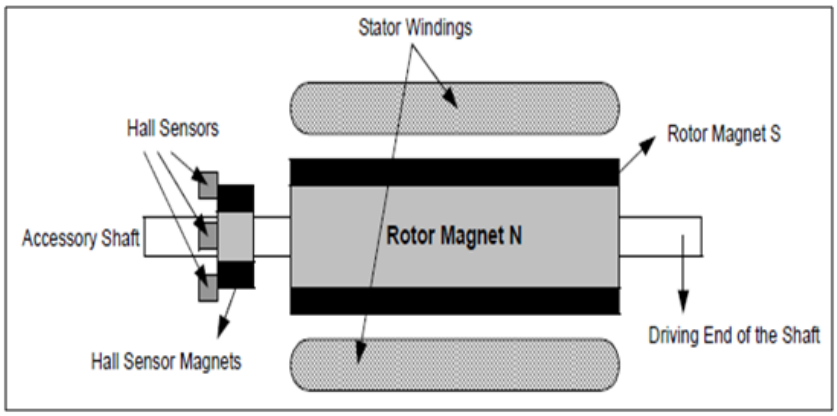

Figure 2.3: Hall Effect sensor at BLDC motor

For sensorless control, the concept used for rotor position estimation and control is the analysis of the Back Electromotive Force (back EMF) from the motor. Back EMF is the voltage value induced in the stator winding of the motor because of a rotating magnetized of the rotor. The magnitude of back EMF is accordance to the speed of the motor. [8] A BLDC motor has trapezoidal back EMF waveform shape, while the sinusoidal back EMF waveform shape found in permanent magnet synchronous motor.[9]

BLDC motor also can be design as axial flux or radial flux.

a) Axial Flux – Has a flux that runs parallel to the output shaft characteristic, (along the axis of the shaft)

b) Radial Flux – Has its flux running in and out from the center of the shaft, on the peripheral radius.