REPORT 1

FINAL YEAR PROJECT (FYP)

SKEE 4812

Title:

SAVONIUS WIND TURBINE PERFORMANCES ON WIND CONCENTRATOR

[redacted]

Prepared By:

Name	**:**	**DYGKU. ASMANISSA BINTI AWG. OSMAN**
Matric No.	**:**	**A11KE0168**
IC No.	**:**	**920426-13-6266**
Course	**:**	**4 SKEE**

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Energy has always been the most important asset for the economy and social growth development of a country. It is no longer viewed as affluence as it used to be but it has become a compulsion in our everyday life. As in Malaysia, the dominant source of energy is still very much sustained by fossil fuels for the past 100 years. It is also caused by the absentees of suitable replacement for the fossil fuels as the main source of energy which can fulfil the consumer's energy requirement for the usage of electricity. According to the current rising trends of fuel prices, especially the crude oil price in the world market, somehow it affected the price of consumer's total electricity bills where it becomes one of the burdens they needed to bear in term of living cost nowadays.

The Malaysian Government comprehended the potentials of some renewable energy resources such as hydro, wind, solar, geothermal and tidal wave where most of these renewable energies are not fully utilized as an option to ensure the sustainability of energy resources [1]. Between all those available renewable energy, the chosen green energy that has the potential to be developed in coming years in Malaysia is wind energy. However, one big issue arises in this case which causes the delay in the development of it. The problem is to find the most suitable location to place the wind turbines as the speed of the winds in Malaysia are not constantly high and sometimes varies between months and its specific locations.

Nowadays, the wind energy is one of the most important sources of clean energy available. The generation of electricity by converting this type of energy has become increasingly important in recent years. The term wind energy itself describes its process by which the wind is used to generate mechanical power which then able to generate electricity. Wind turbines convert the kinetic energy from the wind into mechanical power. The energy conversion principle of the wind turbine is caused by the effect of the kinetic energy from the air flow. The energy from the wind is then converted into rotational energy by the wind turbine rotor. The conversion can be made either by aerodynamic forces or the air pressures which are acting on the rotor blades. Afterwards, the rotational energies produced are converted into electrical energy via a generator to be utilized for mechanical work. [2]

There are so many types of wind turbines that are currently being used to generate electricity, such as horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT) where both types of turbines depend on the orientation of their axis of revolution. HAWT has the main rotor shaft and electrical generator at the summit of a tugboat, and may be placed inward or out of the current air movement. Small turbines are pictured by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most of them have a gearbox which runs around the slow rotations of the blades into quicker rotations that is more suitable to drive an electric generator. VAWT is also known as cross–wind axis machine. In this machine, the axis of rotation is perpendicular to the direction of the wind. VAWT is generally not self-starting and has a low power coefficient [3]. The advantages of using HAWT and VAWT are shown in Table 1.1.

Table 1.1: Advantages of HAWT and VAWT

HAWT	VAWT
Able to pitch the rotor blade during a storm to minimize the damages experienced	The cost is lower because a yaw device is unnecessary as the rotor blades are vertical
Tall tower allows access to a stronger wind speed that result of the higher output power	Easier to maintain because most of the moving parts are located near the ground
Applied in big wind application	Applied in small wind application
Ideal for installation in big wind farm	Ideal for installation in residential area

Since the potential of wind energy in Malaysia is low, the most suitable wind turbine is using the vertical axis wind turbines (VAWT). Despite its ability to produce only low power efficiency, there are various ways to amend the power coefficient in VAWT. One of them is by showing the ideal condition of the rotor blades or by selecting the optimal number of stages of the rotor. Furthermore, installing a wind concentrator to the VAWT will cancel the negative moments that affect the rotational movements of the rotor and increase the speed of the air at the entrance of the rotor. Therefore, it can be resulted in improving the VAWT's power coefficient [4].

1.2 The Application of the Wind Concentrator to the Savonius Wind Turbine

Wind concentrator is one of the design that can compress lower wind velocity, and then increase the wind velocity when it through the concentrator. As the speed of wind in Malaysia is quite low, the idea of designing wind concentrator may improve the speed of wind and increase the performance of the wind turbine as the wind flow across the rotor blade. This project will use Vertical Axis Wind Turbines (VAWT) as it suitable for low wind speed and the sensitivity to the changes of the direction of the wind or velocity is high [5].

Hence, the use of wind concentrator in this project to increase the performance of VAWT is important. Besides, designing small scale wind concentrator is convenient for personal usage to reduce the electricity cost as it helps on generating power supply to the small application in the household. The idea of designing a wind concentrator was based on the contraction section of the wind tunnel and the shroud concentrator in Nicholas P.'s book [6]. The effect of shrouds concentrator has the potential to increase the wind machine performance, which is increasing the air stream's velocity and the turbulence of the nature of the wind can be reduced. The advantages of using shrouds are:

i. The axial velocity of the turbine portion tends to increase for a steady upstream wind speed. This makes it possible to build smaller rotors which can operate at higher rpms.
ii. It is actually an enclosure around the blades and hence can greatly reduce tip losses.
iii. The turbine exit would not have to be rotated in a direction to the wind for small changes in wind stream direction.

1.3 Problem Statement

In Malaysia, wind speed is low and sometimes varies either in month or location. The monthly mean wind speed is generally below 5.00 m/s where the speed is in the range between 1.20 to 4.10 m/s and it is also among the lowest wind classes of level 1 which shown in tower data from the Kennedy Space Center (Florida) [1, 2]. Since the potential of wind energy in Malaysia is low, the most suitable wind turbine is by using VAWT. However, it is generally not a self-starting wind turbine and have low power coefficient. In static condition, the system required additional mechanism to allow the rotor of VAWT to rotate and then, start the turbine. [3, 7] Besides, it is important to investigate the suitable type of rotor design in order to maximize the performance of wind turbine.

Nowadays, the air-conditioner system already been built in many buildings either workplace or residential. The air streams that flow out from the air compressor which is one of part of air-conditioner system will be useful to operate the wind turbine. However, the air velocity from the air compressor is low. Thus, this project has to find a way to increase the air velocity so that the wind turbine will shows a better performance.

1.4 Objective

The aims of this project are as follows:

i. To design and develop two different Savonius wind turbine rotors and a wind concentrator.
ii. To study the performances of two different Savonius wind turbine rotors with and without a wind concentrator in term of rotations per minute (RPM), power coefficient (C_P), torque coefficient (C_T) and tip speed ratio (TSR).

1.5 Scope of project

The scopes of this project are as follows:

i. Literature review on the conventional and the helical Savonius wind turbine and the wind concentrator.
ii. Design and fabricate a conventional and helical Savonius wind turbine rotor and the wind concentrator model.
iii. Conduct the testing of conventional and helical Savonius wind turbine with and without the wind concentrator.
iv. Analyze and conclude the findings.

1.6 Outline of Proposal

There are four chapters in this proposal. The aims and the scopes of the task and also the summary of deeds through this semester and the complete work plan for the second semester are discussed in Chapter 1. In Chapter 2, the literature review will be hashed out. Meanwhile, in Chapter 3 will cover up the research methodology for this project. Lastly, in Chapter 4 will be the result and discussion of the preliminary result of the current progress and the expected outcomes for this project.

1.7 Summary of Work and Complete Work Plan for Second Semester

During this semester, the works for this project has been carried out in Gantt Chart of Table 1.2 while the works that will be implemented in the next semester is shown Table 1.3.

Table 1.2: Gantt chart for first semester

ACTIVITIES/WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Task																
Decide Topic																
Analyze Topic																
Literature Review																
Project Proposal																
Designing																
Forming The Design																
Seminar Presentation																
FYP 1 Project Report																

Table 1.3: Gantt chart for second semester

ACTIVITIES/WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Development of The Hardware																			
Testing and Verification																			
Troubleshooting and Collecting Data																			
Final Seminar Presentation																			
Final Thesis Draft																			
Thesis Submission																			

CHAPTER 2

LITERATURE REVIEW

2.1 Vertical Axis Wind Turbines (VAWT)

The current air energy systems are counted among the most cost effective of all the available exploited renewable sources. Therefore, the demands and investments in expanding the wind energy systems have increased significantly. In especial, the interests in vertical axis wind turbine (VAWT) particularly in the urban areas have increased as much as the dispersal of wind power generation. In urban areas, the wind is very turbulent and unstable with fast changes in direction and speed. In these kind of environments, the usage of VAWT has several advantages over using HAWT [8].

VAWT is a type of wind turbine where the axis of its blade rotation is vertical to the ground. It is also perpendicular to the wind direction and can receive winds from any directions [7]. Besides, the first VAWT rotor was developed by S.J. Savonius in 1929 and later being modified by Bach. Although the concept never became popular because of its low efficiency, there are some advantages over HAWT such as simple construction and can accept wind from any directions without new orientation [9].

Rus L.F stated that VAWT may be divided into two categories which depends on their own operating principles. Firstly, a wind turbine which operates under the effect of aerodynamic lift (L); such as Darrieus wind turbines. It is almost similar to the case of HAWT because in order to operate at full capacity, it needs a source of high speed wind energy. However, this category may be less attractive because it produces low power coefficient. The second category is where the wind turbine operates under the principal of aerodynamic drag (D), which is Savonius wind turbine [4]. This type of VAWT can be a very suitable solution for the generation of electricity in Malaysia where it is one of the countries with low potential of wind energy.

2.1.1 Type of Performances on Wind Turbine

Mathew [7] stated that the energy available in wind basically the kinetic energy of heavy masses of air going over the earth's surface. The blades of the wind turbine receive this kinetic energy, which is then being translated into mechanical or electrical form of energies, depending on the end purposes. The kinetic energy of a stream of air mass (m) and moving with velocity (v) is given by

$$K_e = \frac{1}{2} m v^2 \qquad \textbf{(2.1)}$$

When considering the kinetic energy of air stream available in the wind turbine, the expression of energy per unit time which representing the theoretical Power (P_T) and the actual power (P) can be expressed as

$$P_T = \frac{1}{2} \rho_a A_R v^3 \qquad \textbf{(2.2)}$$

$$P = VI \qquad \textbf{(2.3)}$$

Where ρ_a is the density of air and A_R is the cross-sectional area of the rotor. Meanwhile, V and I are voltage and current generated by the motor. Based on Equation 2.2, the factors which influenced the power available in total wind flow are the air density, cross-sectional area of wind turbine's rotor and air velocity.

However, when the wind stream passes through the wind turbine, the turbine cannot fully extract the wind power completely as some parts of its kinetic energy is being transferred to the rotor and the air that leaves the turbine carries all the remainder aside. The actual power produced by a rotor can be decided by the efficiency or usually known as the power coefficient(C_P). It can be defined as the ratio of actual power developed by the rotor to the theoretical power available in the wind. Thus,

$$C_P = \frac{2P}{\rho_a A v^3} \qquad \mathbf{(2.4)}$$

The thrust force experienced by the rotor (F) is given by

$$F = \frac{1}{2}\rho_a A v^2 \qquad \mathbf{(2.5)}$$

Therefore, the expression of the theoretical rotor torque (T_T) is

$$T_T = \frac{1}{2}\rho_a A v^2 R_R \qquad \mathbf{(2.6)}$$

Where R_R is the radius of the rotor. For actual torque (T) can be expressed as

$$T = \frac{P}{\omega} \qquad \mathbf{(2.7)}$$

Where ω is the angular velocity which can be determined by converting the value of RPM to rad/s. The ratio between the actual torque developed by the rotor and the theoretical torque is known as torque coefficient(C_T). Thus,

$$C_T = \frac{2T}{\rho_a A v^2 R_R} \qquad (2.8)$$

Furthermore, the tip speed ratio (TSR) is the ratio of the velocity of the rotor tip to the wind velocity. It can be expressed as

$$TSR = \frac{\omega R_R}{v} \qquad (2.9)$$

As the wind energy force the wind turbine rotor to rotate, the shaft of the wind turbine that connected to the shaft of the motor will rotate. The revolutions per minute (RPM) is a measure of the frequency of a rotation. It annotates the number of turns completed in one minute around a specified axis. It is applied as a measure of rotational speed of a mechanical part.

2.1.2 Savonius Wind Turbine

The Savonius wind turbine is one of simplest turbines. It can provide high starting torque and the manufacturing cost of the rotor blades can be very low. The standard Savonius rotor design or known as the conventional Savonius rotor was built of semi-cylindrical blade. Savonius wind turbine also can be categorized as 'small' type VAWT where its specialty is an omnidirectional for accepting the drag force of wind and can produces the power from a few watts to 20kW [10].

Figure 2.1 below shows the schematic drawing of drag forces exert on the blades of the conventional Savonius rotor. From the wind direction, the concave part caught the wind current and forces the blade to rotate about its central vertical shaft. It will experience more drag forces. However, the convex part will experience less drag forces as when the wind hits the blade and causes the air wind to be deflected away around it. Hence, the differential drag causes the rotor to rotate and leads the Savonius turbine to spin [11].

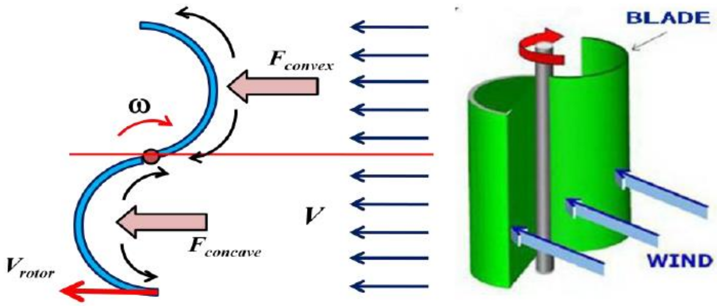


Figure 2.1: The schematic drawing of drag forces exerts on blades of conventional Savonius rotor

The design of the Savonius rotor gives the highest power coefficient compared to the Darrius rotor. Norhazwani [12] claimed that the power coefficient depends on the power generated and the swept area which is known as the cross-sectional area of the rotor. A smaller swept area of the turbine tends to generate a higher power coefficient. The power coefficient can be converted by the turbine into mechanical work where higher power coefficients will effects to a higher potential for the turbine to generate more power.

The conventional wind turbine is often used by researchers to complete their studies. However, some researchers had introduced a helical-shape blade Savonius wind rotor and study its performances. Zhenzhou Zhao [13] research stated that the performance in terms of power coefficient (C_p) using helical-bladed Savonius was improved from C_p =0.15 to C_p=0.20. There are four types of helical rotor with different twisted angles shown in Figure 2.2. The twist angles are 90°, 180°, 270° and 360° respectively.

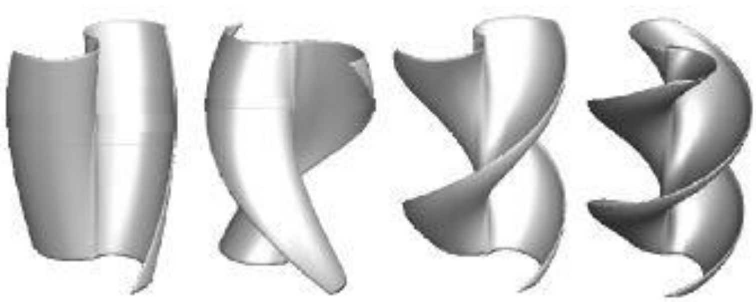


Figure 2.2: The four types of helical rotor with different twisted angle

Overall, the highest performance is achieved by the helical rotor with the angle of 180° and it can be observed in the graph shown in Figure 2.3. Because of its 180° helical configuration, the rotor has downwind surface part that exposed to the wind at any rotational angles. It also produces a continuous positive torque which gives better performance than the helical rotor with other twist angles.

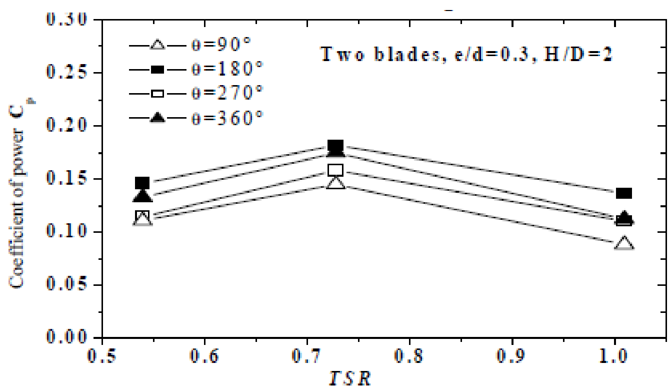
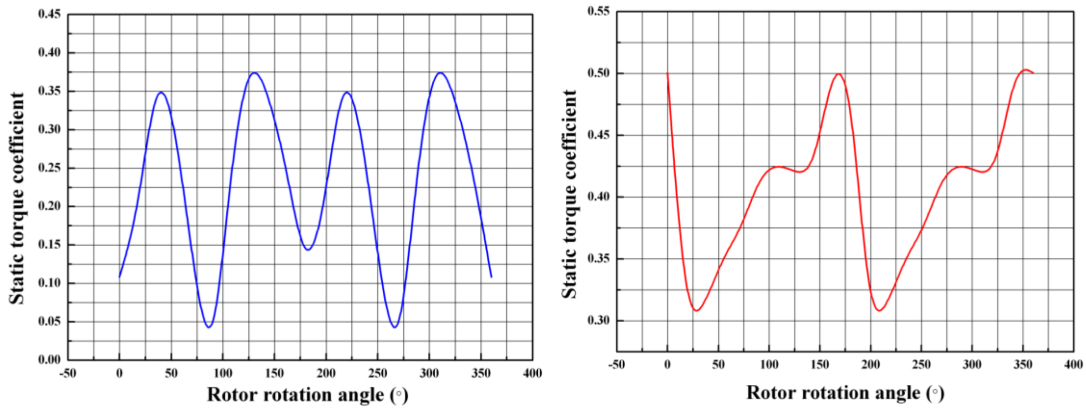


Figure 2.3: The power coefficient performance curve of four types of helical rotor

The research conducted by Kang Can, Zhang Feng and Mao Xuejun [14] had found that the torque performance of spiral rotor is better than the conventional rotor. Figure 2.4 below shows the variation of torque result with blade rotation angle. For conventional rotor, the maximum torque coefficient is 0.37 while the minimum is below than 0.05. It is also experiencing wavy variation. Whereas the spiral rotor had undergone large fluctuations of torque coefficients where the maximum and the minimum torque coefficient is around 0.50 and 0.31.



(a) Conventional savonius rotor (b) Spiral rotor

Figure 2.4: Variation of torque with blade rotation angle

2.1.3 Number of Rotor Blades

The number of blades of the rotor should be minimized to two blades only. Mohammed Hadi Ali [11] found that the two-bladed savonius wind turbine is more efficient and has a higher power coefficient compared to a three-bladed savonius wind turbine under the same test condition. It is because as the number of blades increases, it will also increase the drag on the surfaces when the wind flows around them. This will cause the reverse torque to increase and causing the net torque working on the blades of savonius wind turbine to decrease. A. A. Kadam and S. S. Patil [10] also stated that, in order to increase the efficiency of the operation parameters, using two blades wind turbine is better compared to using either three blades or four blades rotors.

The evidence of using two blades was supported by Zhenzhou Zhao, Yuan Zheng, Xiaoyun Xu, Wenming Liu and Guoxiang Hu [13] where if the number of blades was increased from two to three, the power coefficient of the wind turbine rotor will decreases. Figure 2.5 shows the performance curve of both two blades and three blades rotor which explained that when TSR = 0.8, the power coefficient for two-bladed rotor is 0.165 while three-bladed rotor is 0.12. Meanwhile, Figure 2.6 shows the fluid field of two-bladed and three-bladed rotor. The two-bladed rotor has a bigger downwind pressure surface compared to the three-bladed rotor which has a bigger upwind pressure surface. To obtain a better rotor performance, the pressure on downwind surface should be bigger and upwind surface is smaller.

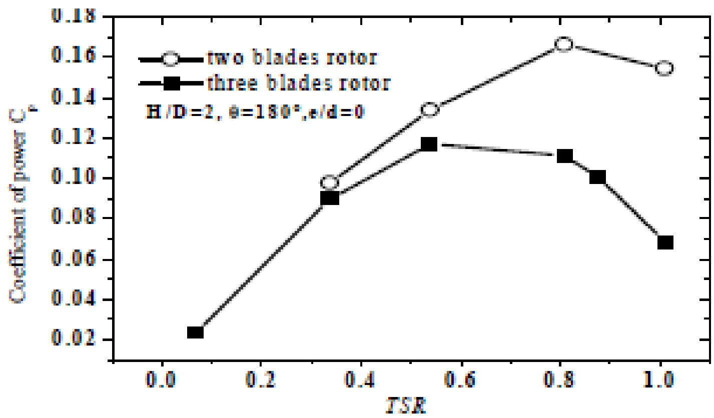


Figure 2.5: The performance curve of two and three blades rotor

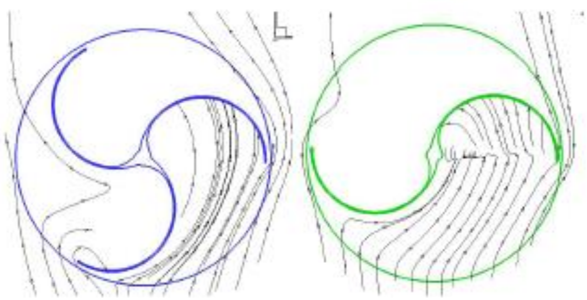


Figure 2.6: The fluid field of two and three blades rotor

2.2 Background of Wind Concentrator

In the new era of technology, the application of wind tunnel is still being used to concentrate or diffuse the air stream's velocity that flows through it. There are two types of wind tunnel which are closed circuit wind tunnel and open circuit wind tunnel. Consequently, most of the high performance wind tunnels were designed as closed circuit types to ensure a controlled return flow. However, to reduce cost of building a wind tunnel and save some spaces, the open circuit wind tunnel design is chosen. It is also much simpler compared to closed circuit wind tunnel [15].

The design for concentrator of the wind tunnel is important in the low wind potential so that it can compress the air stream's velocity and subsequently increase the wind velocity when it flows through the concentrator. M. N. Mikhail [16] had presented a method of designing a low-speed wind tunnel contraction. He stated that the optimum ratio for the area of the concentrator is the most important parameter which will satisfy the flow quality requirements in the test section while the contraction exit will be considering the flow uniformity. Furthermore, in some particular case of a contraction cone, Hsue-Shen Tsien claimed that some modifications of contraction design which partly circular and partly octagonal can also increase the local velocity at some points on the contraction cone's wall [17].

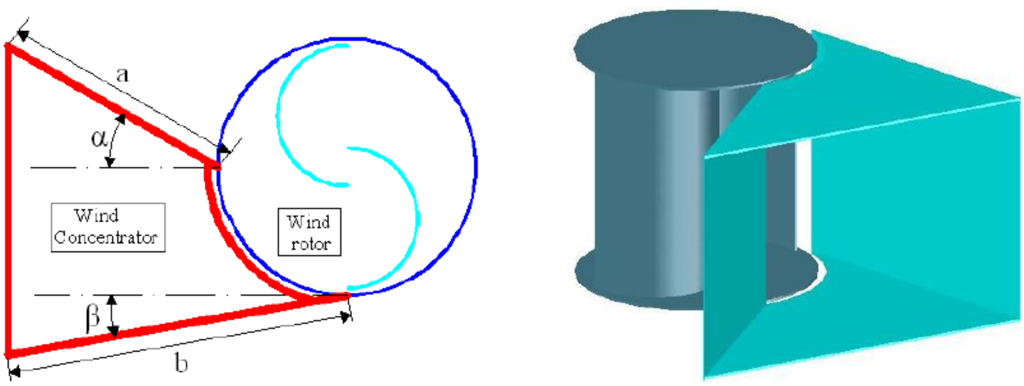
2.2.1 Wind Concentrator

This study is focused on finding ways to improve the potential of wind energy to increase the speed of blade rotations and the performances of the Savonius rotor. Chapter 1 earlier had stated that the monthly mean wind speed in Malaysia is generally below 5.00 m/s. The wind concentrator can be designed for operations at a very low wind speed. Hence, it is very useful for solving the aerodynamic problems in this study.

Rus L. F. [4] had designed a concentrator nozzle to the Savonius rotor in order to increase the inlet of air stream's velocity to the rotor which is shown in Figure 2.7. In his research's findings, he also claimed that installing a wind concentrator to the wind turbine may increase the efficiency of the turbine about 10% to 20% when using a single-stage rotor with the dimension of $\alpha = 45^{o}$ and $\beta = 15^{o}$. As the concentrator nozzle is focused on the direct airflow only over the concave blade, the advantages of using this design are as follows:

i. The negative moment produced by the action of the wind on the convex part will be cancelled out.

ii. It offers the possibility of increasing the movement and efficiency of the rotor.



(a) Top view (b) Side view

Figure 2.7: The design of wind concentrator

Furthermore, the study by J. A. Orasa, E. J. Garcia-Bustelo and J. A. Perez [18] had designed a subsonic nozzle in order to produce a constant pressure drop and considering moist air as principal fluid. This convergent nozzle has almost similar functions with Rus L.F. [4] study. The functions are listed as follows:

i. It will amplify the wind's velocity.
ii. It will prevent negative torque where it can act as a barrier for wind striking on the concave part of the blade of the rotor.

The study also claimed that when using a convergent nozzle rotor, the speed can be significantly increased, and so does the power coefficient. The study also stated that the conservation of energy in a nozzle can be termed as Bernoulli's equation as shown in Equation 2.10 where it can be defined as the sum of all forms of wind flow are same at the same point; however, this requires the sum of kinetic energy and potential energy to be kept constant. Based on this equation, v_1 can be considered as the inlet velocity of the wind concentrator while v_2 is the outlet velocity of the wind concentrator.

$$\rho_{a1} A_1 v_1 = \rho_{a2} A_2 v_2 \quad \textbf{(2.10)}$$

The idea of designing the wind concentrator for the wind turbine can be obtained from the study of the contraction section of the wind tunnel. Based on Ivan Torrano, Manex Martinez-Aggire and Mustafa Tutar [19], determining the size and shape of the test section is the first step when designing a wind tunnel. This dimension is given by the blockage ratio which defined as the relation between the area of the item which causes drag and the test section area. After the dimensions of the test section were chosen, the other sections of the wind tunnel can be determined. Figure 2.8 shows the general design model of a wind tunnel.

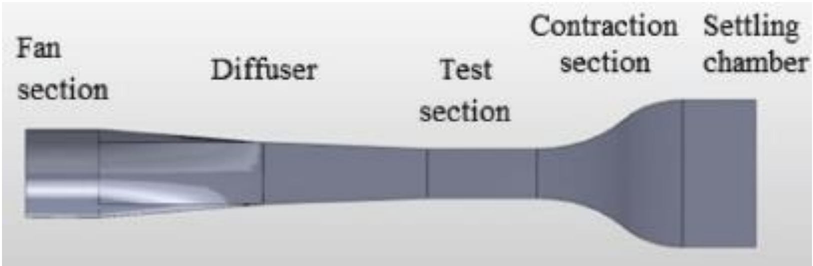


Figure 2.8: The general assembly of a wind tunnel model

The settling chamber is a section for conditioning the airflow or stabilize them as the effects of irregular flows due to swirl, low-frequency pulsation and turbulence which can be suppressed [20]. In order to stabilize the airflow, the length settling chamber needs to be sufficient where it must be half of the inlet diameter.

The contraction section shown in Figure 2.9 is known as contraction cone or nozzle zone. The function of this zone is to accelerate the flow of air stream's velocity from settling chamber to test section. The expected out-going flow from this section should be steady, uniform and free from separation. The typical value of the contraction ratio (CR) which is the ratio of the area between inlets an outlet of contraction is between 7 to 12.

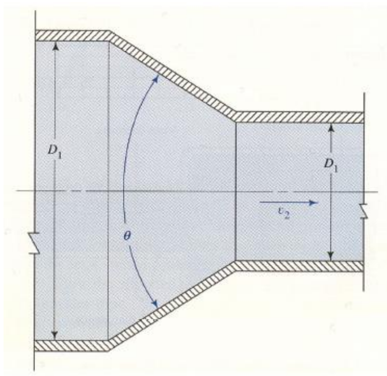


Figure 2.9: Main geometry parameters of contraction section

The test section is the zone where the drag item is located. It is defined by the blockage ratio (BR) which is the ratio between the drag frontal area and the cross-sectional area of the test section. The length of test section should be sufficient to let the flow after the drag item is fully developed when BR less than 6% and the length-to-hydraulic-diameter ratio greater than 2.

By observing the velocity contours in Figure 2.10, Ivan Torrano [19] claimed that a greater radius at the inlet of the contraction section (Model 2) will reduce the low velocity zone, so it is more difficult to have reverse flow in this zone. This effect can be better observed in Figure 2.11 which shows the velocity vector fields at the entrance section. Therefore, it can be concluded that the higher curvature radius of the contraction section of the wind tunnel reproduces less pressure drop values due to a better control of change in a velocity vector field in the contraction zone.

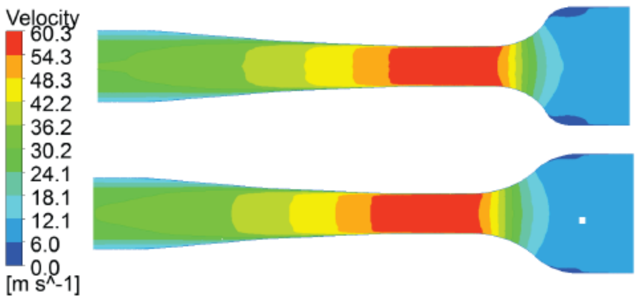


Figure 2.10: Velocity contour fields for Model 1 (upper) and Model 2 (lower)

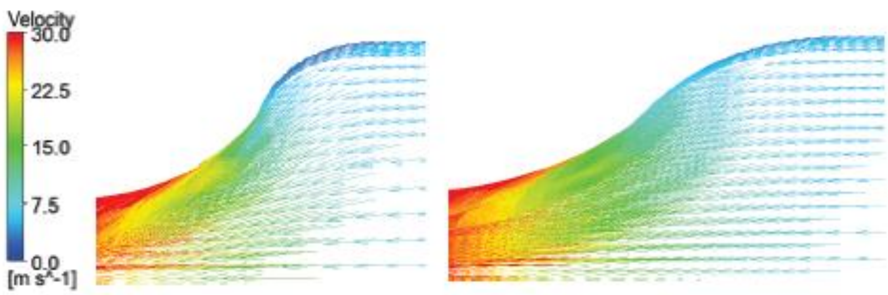


Figure 2.11: Velocity vector fields in the curvature of the contraction section for Model 1 (left) and Model 2 (right)

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

In this project, there will be two vertical axis wind turbines that will be designed in order to determine the most efficient design of the blade rotor. Some experiments regarding the most efficient design of vertical axis wind turbine had been conducted by some other researchers and students earlier before. The researches consisted of comparing the types of VAWT that have been built, the factor for a better performances such as rotations per minute (rpm), power coefficient (C_P), torque coefficient (C_T) and tip speed ratio (TSR). The design for both shapes of the blade rotors was chosen based on the literature reviews done and also their theoretical measurements.

To fulfil the objectives of this project, there are some alternative ways to get a better performance for VAWT. The position of the wind concentrator had been proposed where it will allow a better wind energy flow to the blade in order to get a better performance of VAWT. This model will be focusing on the direct airflow only over the concave blade of the rotor wind turbine. Instead of using wind as the only source of air stream, the additional source of air from the air compressor of an air-conditioner system can also be used for good. The flow rate of the air compressor can be measured by determining the characteristics of the air compressor model. The design of the wind concentrator was chosen based on the literature reviews and theoretical measurements. Therefore, the performances of Savonius wind turbine with and without wind concentrator can be investigate.

The real hardware will be fostered by referring to the proposed design and analysis of conventional and helical Savonius rotor including the design of wind concentrator. The final output will be recorded and analyzed to obtain the final result of the experiment. The summary of the methods are constructed on the project flow plan as follow:

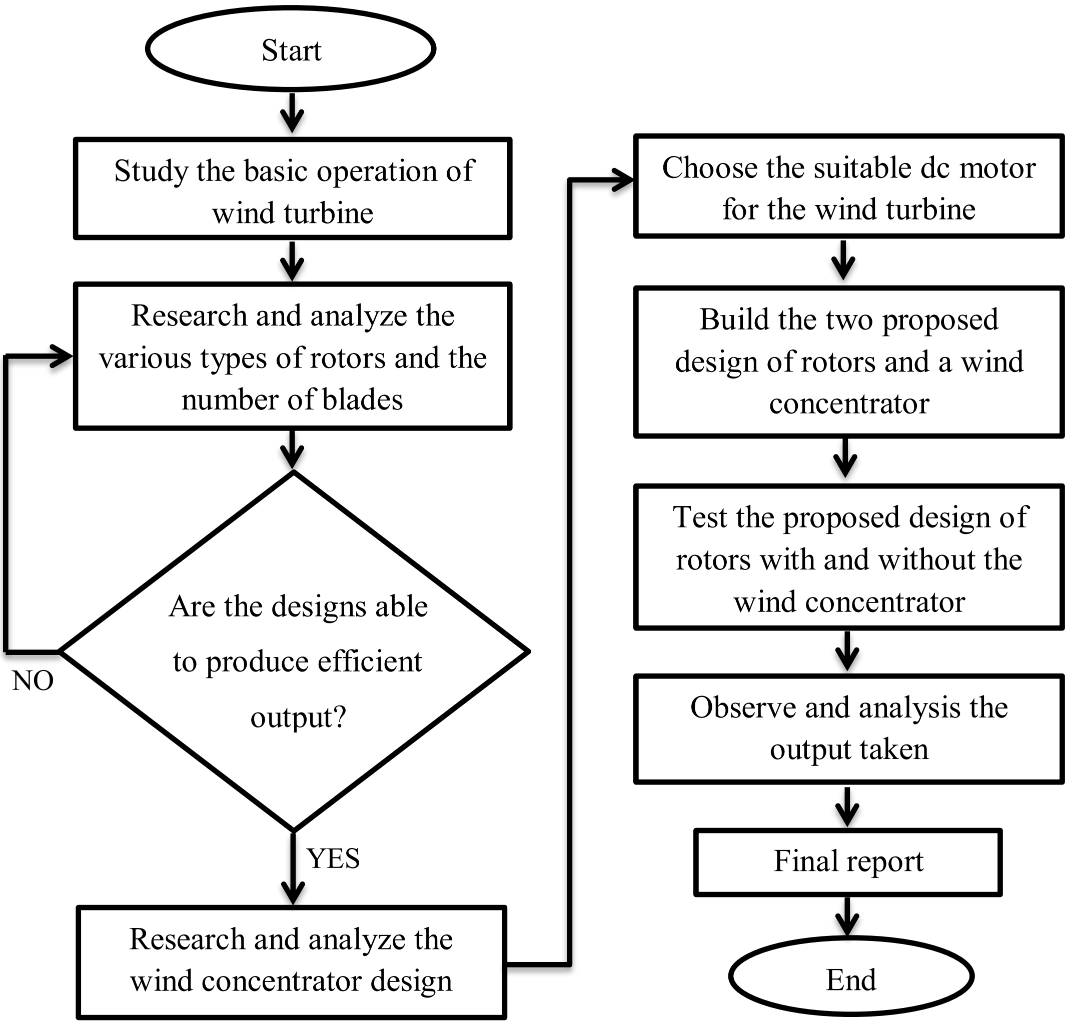


Figure 3.1: Project flow plan

3.2 Wind Turbine Blade Rotor Design

The designs of the two proposed rotors of Savonius wind turbine varies in their shape. However, the dimensions of the rotors are both the same where both of the rotors depend on the outlet dimension of the wind concentrator. The parameters that are being considered in this design are listed as follow:

i. Power coefficient : $\boldsymbol{C_P = \frac{2P}{\rho_a A_R v^3}}$

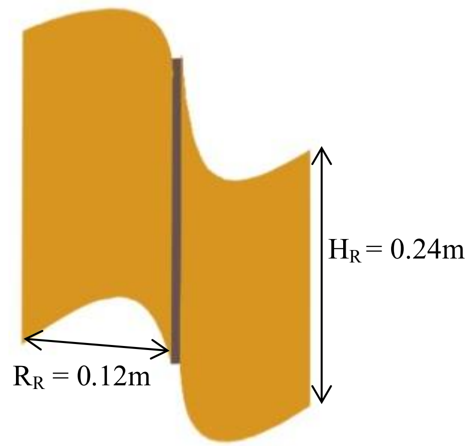
ii. Torque coefficient : $\boldsymbol{C_T = \frac{2T}{\rho_a A_R v^2 R_R}}$

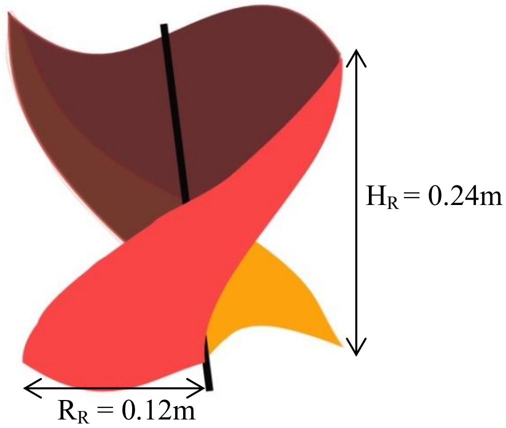
iii. Tip speed ratio : $\boldsymbol{TSR = \frac{\omega R_R}{v}}$

iv. Revolution per minute (**RPM**)

Table 3.1 below visualizes the two different designs of wind turbine blade rotors. The chosen material for both of the designs is aluminium because of its suitable material properties. Aluminium is light in weight, corrosion resistance, good rigidity, a recyclable material, easy to construct and low in cost [11].

Table 3.1: Designs of wind turbine blade rotors

No.	Design	Orientation	Diagram
1	Conventional Savonius Rotor	VAWT	

2	Helical Savonius Rotor	VAWT	

3.3 Wind Concentrator Design

The wind concentrator design specification was chosen based on literature reviews conducted. The design of wind concentrator in Figure 2.7 had been improvised for the purpose of this project by also considering the Bernoulli's Equation (2.10) where the velocity of air can be increased when flowing through a large area to small area with a constant air density.

Figure 3.2 below shows the design and the dimensions of the wind concentrator. The inlet of the wind concentrator design is where the air from the air compressor of an air-conditioner system flows in. The low air stream from the outlet of the air compressor is useful to become the source of inlet wind for the wind concentrator and the speed of air stream can be measured by using the anemometer. The chosen material for this design is also aluminium.

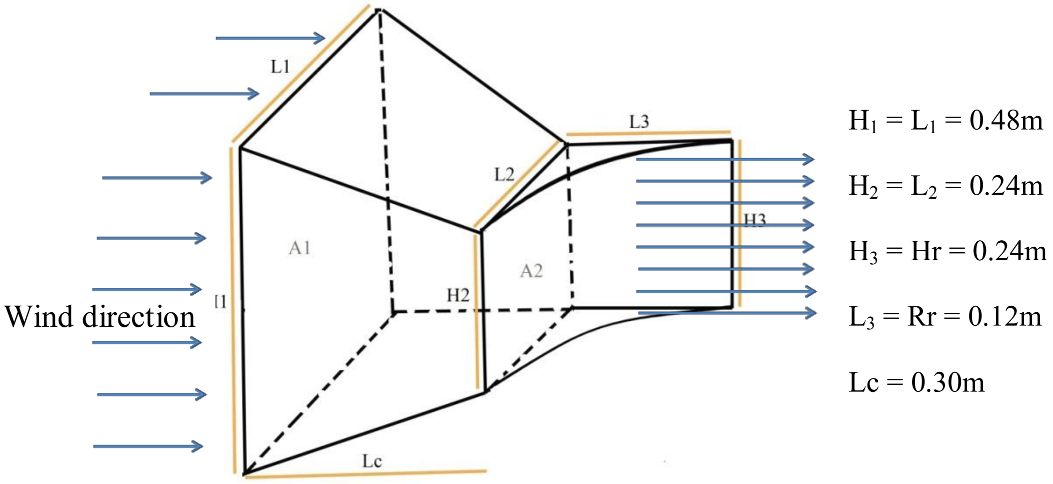


Figure 3.2: Wind concentrator design

3.4 DC Motor

DC motor is a device that can convert mechanical energy to electrical energy. Mechanical energy comes from the rotation of the rotor which is connected to the shaft of the DC motor and the electricity produced will be connected to the load from the output terminal as shown in Figure 3.3. Furthermore, in order to produce high reliability and high efficiency of small wind turbine, the preferred choice of motor is the brushless DC motor as shown in Figure 3.4.

Figure 3.3: DC Motor

Figure 3.4: Brushless DC Motor

3.5 Shaft

To design the shaft of the rotor wind turbine, the chosen design is the hollow shaft. The hollow shaft was chosen for this project because of its ability to facilitate the switching of the two designs for wind turbine blade rotor during the testing. In addition, the material used to design this shaft is also aluminium. In order to design the hollow shaft, it depends on the diameter of the DC motor’s shaft.

3.6 Source of Wind

Based on the introduction in Chapter 1, the wind speed in Malaysia is below 5.00m/s. This project may use the wind energy as the source of wind for the wind concentrator. However, to benefit the air produce by the air compressor, this project will also consider the air from the air compressor as an additional input as well. Hence, the air can be useful on generating electricity. Anemometer will be used to measure the speed of air.

3.7 Procedure of the Experiment

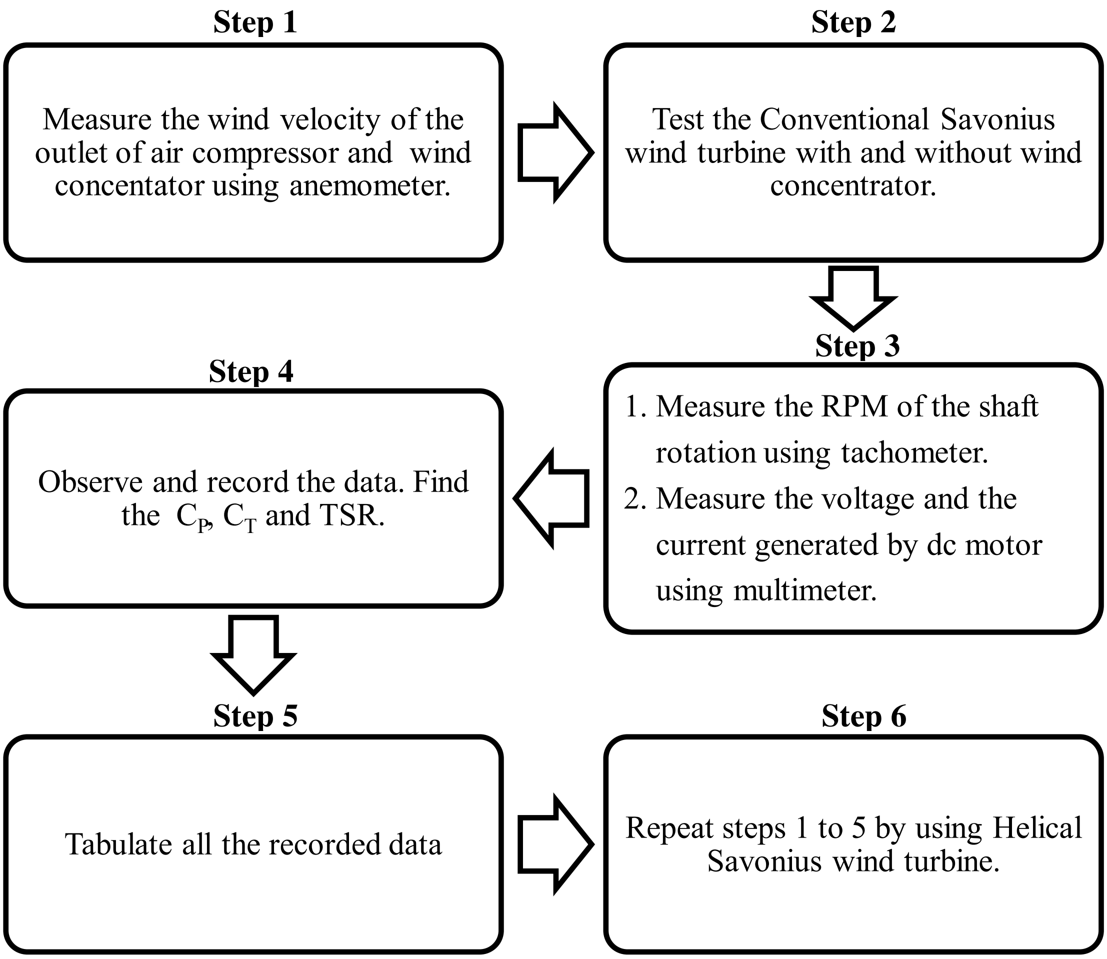


Figure 3.5: The flow of procedure of the project's experiment

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this section will be the result and discussion of the preliminary result of the current progress and the expected outcomes for this project.

4.2 Preliminary Result

The air velocity from one of the air compressors installed at P16, Faculty of Electrical Engineering (FKE) had been measured by using an anemometer. The temperature of the air can also be measured by using the anemometer where the result was 35°. The measurements of the air velocity had being conducted for six times and the results were tabulated in Table 4.1.

Table 4.1: The result of the air velocity from the air compressor

No.	1	2	3	4	5	6	7	8
Air Velocity (m/s)	0.64	1.16	1.24	1.04	0.32	0.60	1.51	0.87

From Table 4.1, the range of air velocity is between 0.32m/s to 1.51m/s. The calculation of the average air velocity is shown below:

$$v_{Average} = \frac{Sum\ of\ air\ velocity}{Sum\ of\ number} \tag{4.1}$$

$$v_{Average} = \frac{0.64 + 1.16 + 1.24 + 1.04 + 0.32 + 0.60 + 1.51 + 0.87}{8}$$

$$= 0.93 m/s$$

Based on the recorded data, the theoretical value of power and torque can be calculated and the equation for both of the theoretical values was based on Equation 2.2 and Equation 2.6. The results of the theoretical values with and without using the wind concentrator are shown in Table 4.2 and Table 4.3. The calculation of the air velocity of the outlet of wind concentrator is based on Equation 2.10. The air density was assumed to be constant at 1.1455kg/m^3 as the temperature was also kept constant at 35^o. Thus, $\rho_{a1}=\rho_{a2}$. The value of the cross-sectional area of the rotor (A_R), the inlet area of the wind concentrator (A_1) and the outlet area of the wind concentrator are 0.0576m^2, 0.3600m^2 and 0.0288m^2 respectively; where all the values were based on the proposed dimension in the research methodology of Chapter 3. The derivation formula for outlet velocity (v_2) is shown as follow:

$$v_2 = \frac{A_2}{A_1} v_1 \tag{4.2}$$

Table 4.2: The theoretical value results of power and torque without using the wind concentrator

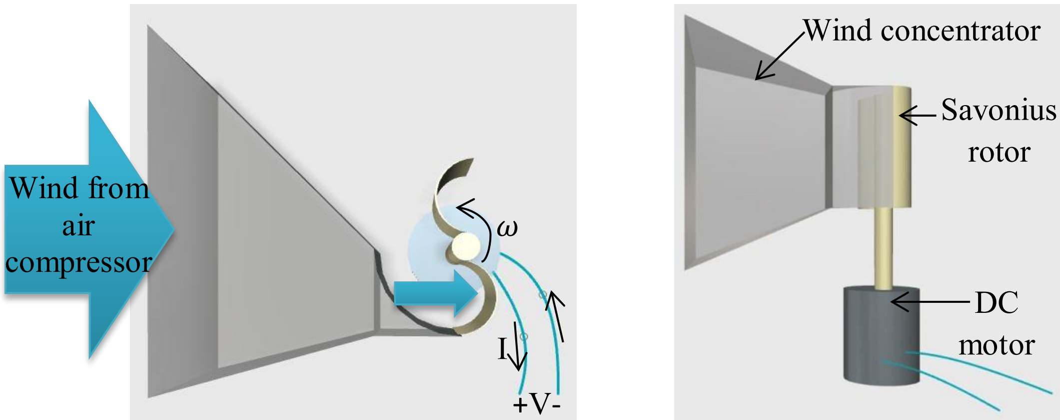
Condition of Air Velocity	**Minimum** 0.60m/s	**Maximum** 1.51m/s	**Average** 0.93m/s
P_T (W)	2.111	221.844	51.828
T_T (Nm)	0.063	1.41	0.535

Table 4.3: The theoretical value results of power and torque by using the wind concentrator

Condition of Air Velocity	**Minimum** 0.60m/s	**Maximum** 1.51m/s	**Average** 0.93m/s
v^2 (m/s)	4.000	18.875	11.625
P_T (W)	2.111	221.844	51.828
T_T (Nm)	0.063	1.410	0.535

4.3 Expected Outcomes

At the end of this project, the work concept of this project must be clearly understood. This project expected that the performances of the helical Savonius rotor should be better than the conventional Savonius rotor and the performances of both rotors should be better when the wind turbine being installed with the wind concentrator. The expected design of Savonius wind turbine with wind concentrator is shown in Figure 4.1. Since the design of wind concentrator was considering the Bernoulli's law, the outlet velocity of wind concentrator assume to be increased when flow through it. This will allow the RPM to increase and tends the DC motor to produce more electricity. Hence, the increases in power and torque will increase the power coefficient and torque coefficient of the wind turbine.



(a) Top view (b) Side view

Figure 4.1: The expected design of wind turbine with wind concentrator

4.4 Discussion

Based on the literature review in Chapter 2, the proposed design of Savonius rotors for this project are conventional and helical with 180º. Furthermore, based on the results in Table 4.2 and Table 4.3 earlier, it showed that the air velocity increases for about 11.50% and the performances of wind turbine in terms of power and torque are higher when using wind concentrator. Thus, it can be concluded that the performances of both rotors can be improved by installing the wind concentrator to the Savonius wind turbine.

REFERENCES

[1] A. Y. Azman, A. A. Rahman, N. A. Bakar, F. Hanaffi and A. Khamis, "Study of Renewable Energy Potential in Malaysia," *IEEE First Conference on Clean Energy and Technology (CET),* pp. 170-176, 2011.

[2] M. B. Farriz, A. N. Azmi, N. A. M. Said, A. Ahmad and K. A. Baharin, "A Study on the Wind as a Potential of Renewable Energy Sources in Malaysia," *Electrical Engineering/Electonics Computer Telecommunication and Information Technology Conference (ECT-CON),* pp. 651-655, 2010.

[3] Mohamad Sabhi Hissam. *Maximum Power Point Tracking of a Small Wind Turbine with Permanent Magnet Synchronous Generator*. Thesis of Bachelor of Engineering. Universiti Teknologi Malaysia; 2012.

[4] R. L.F., "Experimental Study on the Increase of the Efficiency of Vertical Axis Wind Turbines by Equipping them with Wind Concentrators," *Journal of Sustainable Energy,* vol. 3, no. 1, pp. 30-35, 2012.

[5] J. A. Orosa, E. J. Garcia - Bustelo and J. A. Perez, "Climate Effects in Low Wind Turbine's Concentrators," *Power Engineering, Energy and Electrical Drives (POWERENG),* pp. 174-179, 2009.

[6] C. Nicholas P., Fundamentals of Wind Energy, Michigan: Ann Arbor Science, 1978, pp. 61-62.

[7] S. Mathew, Wind Energy Fundamentals, Resource Analysis and Economics, New York: Springer, 2006.

[8] Nicola Bianchi, Silverio Bolognani, Emanuele Fornasiero, Mattia Morandin and Giorgio Pavesi, "Optimal Drive and Machine Sizing for a Self Starting, Vertical Axis, Low Power Wind Generator," in *Energy Conference and Exhibition (ENERGYCON)*, Florence, pp.178-183, 2012.

[9] P. Clague and T. Z. Qi, "A Novel Design of a Savonius Wind Turbine Water Heating in Residential Settings," in *International Conference on Mechatronics and Machine Vision in Practice (M2VIP08)*, Auckland, pp. 259-262, 2008.

[10] A. A. Kadam and S. S. Patil, "A Review on Savonius Wind Rotors for Accesing the Power Performance," *Journal of Mechanical and Civil Engineering,* vol. 5, pp. 18-24, 2013.

[11] M. H. Ali, "Experimental Comparison Study for Savonius Wind Turbine of Two and Three Blades at Low Wind Speed," *International Journal of Modern Engineering Research (IJMER),* vol. 3, no. 5, pp. 2978-2986, 2013.

[12] Norhazwani. *Comparison Performance Among Micro-Size of Vertical Axis Wind Turbines*. Thesis of Bachelor of Engineering. Universiti Teknologi Malaysia; 2014.

[13] Zhenzhou Zhao, Yuan Zheng, Xiaoyun Xu, Wenming Liu and Guoxiang Hu, "Research on the Improvement of the Performance of Savonius Rotor Based on Numerical Study," in *Sustainable Power Generation and Supply (SUPERGEN)*, pp. 1-6, 2009.

[14] Kang Can, Zhang Feng and Mao Xuejun, "Comparison Study of a Vertical-Axis Spiral Rotor and a Conventional Savonius Rotor," in *Power and Energy Engineering Conference (APPEEC)*, Chengdu, pp. 1-4, 2010.

[15] R.D. Mehta and P. Bradshaw, "Design rules for small low speed wind tunnels," *The Aeronautical Journal of the Royal Aeronautical Society,* pp. 443-449, 1979.

[16] M. N. Mikhail, "Optimum Design of Wind Tunnel Contractions," *AIAA,* vol. 17, no. 5, pp. 471-477, 1979.

[17] Hsue-Shen Tsien, "On the Design of the Contraction Cone for a Wind Tunnel," *Journal of the Aeronautical Sciences,* vol. 10, pp. 68-70, 1943.

[18] J. A. Orasa, E. J. Garcia-Bustelo and J. A. Perez, "Wind Turbine Concentrator Design Based on Moist Air Phase Change," in *Power Engineering, Energy and Electrical Drives (POWERENG)*, Lisbon, pp. 490-494, 2009.

[19] Ivan Torrano, Manex Martinez-Aggire and Mustafa Tutar, "Numerical Characterization of Pressure Drop through a Low Speed Wind Tunnel: Some Design Aspects," in *Renewable and Sustainable Energy Conference (IRSEC)*, pp. 240-245, 2013.

[20] Normayati Nordin, Zainal Ambri Abdul Karim, Safiah Othman and Vijay R. Raghavan, "Design and Devepoment of Low Subsonic Wind Tunnel for Turning Diffuser Application," *Advanced Materials Research,* Vols. 614-615, pp. 586-591, 2013.