# CERTIFICATION OF APPROVAL

## **Investigation on Savonius Wind Turbine in Directed Flow**

by

Mohd Hafiz bin Amran

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

_______________________
(AP Dr Hussain Al-Kayiem)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2008

# CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHD HAFIZ BIN AMRAN

# ABSTRACT

The **Savonius wind turbine** is normally installed in vertical axis configuration and operates in open atmosphere. The wind energy from atmosphere is converted into a mechanical energy rotating of the rotor to produced either electricity or torque. In this study the turbine is to be installed horizontally on top of a chimney. Three different configurations are proposed. The first proposed configuration will exposed the entire rotor to the wind stream. In the second configuration the wind stream will directed to a concave vane by manipulating the angle of flow direction. In the last proposed configuration a guide plate is inserted at one side of the rotor as a casing. An analysis has been conducted on these three different configurations with experimental procedure to verify the result obtained with numerical analysis method in previous work.

# ACKNOWLEDGEMENTS

Bismillahirrahmanirrahim

In the name of God, The most Gracious The Most Merciful

First and foremost I would like to extend my up most gratitude toward Allah the Lord of universe for giving me strength and health to complete this project. In this two semester time, a lot of efforts and time has been put toward achieving the goal of this project.

Next I would like to extent my appreciation to my supportive Supervisor, AP Dr Hussain Al-Kayiem who always gives me support, help and guidance through out my project duration. All his advises and guides give me spirit and strength to give the best for this project.

Not to forget my parents and family who always pray for my success and friends who are willing to lend their hand all the time. And last but not least this acknowledgement goes to those who have contributed toward the completion of this project directly or in directly. The commitment toward accomplishment of this project is highly appreciated.

# TABLE OF CONTENT

**CERTIFICATION OF APPROVAL** .......... i
**CERTIFICATION OF ORIGINALITY** .......... ii
**ABSTRACT** .......... iii
**ACKNOWLEDGEMENTS** .......... iv
**LIST OF TABLES** .......... viii
**ABBREVIATION AND NOMENCLATURE** .......... ix

**CHAPTER 1** .......... 1
INTRODUCTION .......... 1
1.1. BACKGROUND OF STUDY .......... 1
1.2. PROBLEM STATEMENT .......... 1
1.3. SIGNIFICANT OF STUDY .......... 1
1.4. OBJECTIVES .......... 2
1.5. SCOPE OF WORK .......... 2

**CHAPTER 2** .......... 3
LITERATURE REVIEW .......... 3
2.1 INTRODUCTION .......... 3
2.2 WIND TURBINE .......... 4
2.3 SAVONIUS WIND TURBINE .......... 7
2.4 DESIGN CRITERIA .......... 11
2.4.1 Choice of the Material for the Vanes and the End Plates .......... 11
2.4.2 Choice of the Geometry .......... 13

**CHAPTER 3** .......... 17
METHODOLOGY .......... 17
3.1 THE SOLUTION METHODOLOGY: .......... 17
3.2 FLOW OF EXECUTION .......... 18
3.3 GANTT CHART .......... 18
3.4 EXPERIMENTAL PROCEDURE .......... 19
3.4.1 Design and fabrication of the model .......... 19
3.4.2 The Test Rig .......... 23
3.4.3 The Measuring Technique .......... 24

**CHAPTER 4** .......... 26
RESULT AND DISCUSSION .......... 26
4.1 ANALYSIS OF RESULT .......... 26
**CHAPTER 5** .......... 31
CONCLUSION & RECOMMENDATION .......... 31
5.1 CONCLUSION .......... 31
5.2 RECOMMENDATION .......... 31
**REFERRENCES** .......... 33
**APPENDICES** .......... 34

## LIST OF FIGURES


| | |
|---|---|
| Figure 1.0 | Power coefficient of modern type of turbine |
| Figure 1.1 | Savonius rotor |
| Figure 1.2 | Savonius Wind Turbines |
| Figure 1.3 | S shape |
| Figure 1.4 | Curved shape |
| Figure 1.5 | Straight shape |
| Figure 1.6 | Geometries of Traditional Savonius rotor |
| Figure 1.7 | Dimension of the vanes |
| Figure 1.8 | Double steps Savonius rotor |
| Figure 1.9 | Proposed design |
| Figure 2.0 | The three configurations subject to analysis |
| Figure 2.1 | Setting of the machine |
| Figure 2.2 | Setting the initial position |
| Figure 2.3 | Cutting Process |
| Figure 2.4 | Final work piece |
| Figure 2.5 | The shaft of the rotor |
| Figure 2.6 | The Vanes |
| Figure 2.7 | Savonius rotor prototype |
| Figure 2.8 | Schematic diagram of the test rig |
| Figure 2.9 | Rotor installation |
| Figure 3.0 | The Torque Coefficient versus TSR for three different configurations |
| Figure 3.1 | The Power Coefficient versus TSR for three different configurations |

# LIST OF TABLES

Table 1.0: Summary of the velocity and Torque reading for three different configurations

Table 1.1: Value of TSR and Torque coefficient for three different configurations

Table 1.2: Value of TSR and power coefficient for three different configurations

Table 1.3: The comparison of enhancement in torque coefficient at different configuration with respect to configuration 1 for both analytical and experimental analysis

Table 1.4: The comparison of enhancement in power coefficient at different configuration with respect to configuration 1 for both analytical and experimental analysis

## ABBREVIATION AND NOMENCLATURE

| | |
|---|---|
| TSR | Tip Speed Ratio |
| RPM | Revolution per Minute |
| CAD | Computer Aided Design |
| VAWT | Vertical Axis Wind Turbine |

# CHAPTER 1

# INTRODUCTION

## 1.1.BACKGROUND OF STUDY

Normally Savonius wind turbine is installed in vertically and the performance study always been carried out in open atmosphere. An experiment is to be conducted is such a way that the Sovonius wind turbine is installed horizontally in a solar chimney. Previous result from analytical modeling is to be proving with experimental procedure. A different configuration of air flow stream is identified which can improve the performance of the turbine. [1]

## 1.2.PROBLEM STATEMENT

The study on the performance of Savonius wind turbine usually conducted in open atmosphere. The performance of the Savonius wind turbine will change when subjected to the ducted air flow stream. The installation of the Savonius wind turbine in ducted air flow stream is believed will enhance the performance of the turbine.

## 1.3.SIGNIFICANT OF STUDY

The Canadian have conducted experimentation to characterize the Savonius wind turbine performance at different offset settings in open atmosphere.[11] The German have studied another type of vanes also in open atmosphere operation. In this investigation, a focus will be carried to study the Savonius wind turbine performance in 'Directed Flow Operation' at different configurations. This will be additional knowledge for this type of wind turbine.

## 1.4.OBJECTIVES

The objective of this study is

- To design a test rig for experimentation of the Savonius rotor in close conduit and
- To conduct experimental investigation of the Savonius wind turbine in horizontal installation at three different configurations.

## 1.5.SCOPE OF WORK

The scope of the study consists of research on the design of the turbine and manufacturing the Savonius model by using the CNC machine. The suitable directed wind stream arrangement is to be prepared to conduct a series of experiment to investigate the enhancement of the turbine performance. The result then will be compared to the analytical analysis that has been performed.

Characterization of different types of configurations for the Savonius wind turbine subjected to air stream inside a duct with numerical method result obtained. In this study the experiment is to be conducted with three different configurations of wind stream upon Savonius wind turbine. The Savonius wind turbine is to be installed on top of the chimney which will have directed flow toward the vanes. The Savonius is connected to the measuring device where the performance of the turbine with there different configuration can be analyzed.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

Demand for energy is always increased from time to time. The energy can be obtained from various sources. Current world fossil base fuel like petroleum and gas has been used long time ago and this source become less and less which cause the human to find alternative energy. Since that people were started to use alternative energy option. In different country different option of alternative energy has been considered. In the dessert, wind energy has been applied widely by Arab nation. This is due to the strong wind that is available every time. In other equatorial country which has huge source of water, hydro energy is widely used to generate electricity. Currently in this new millennium solar energy is one of the alternative energy options that is being vigorously pursued and studied by a number of countries to reduce their dependent on the fossil base fuel. Bio mass is also another source of alternative energy. In the energy industry, biomass refers to wood, straw, biological waste products such as manure, and other natural materials that contain stored energy. The energy stored in biomass can be released by burning the material directly, or by feeding it to micro-organisms that use it to make biogas, a form of natural gas. Energy from biomass can be used for cooking and heating to generate electricity.

## 2.2 WIND TURBINE

Several technologies had existed many years ago to utilize the wind energy for other purposes like generate electricity and water pumping. Different types of wind turbine were invented many years ago for specific purposes. Wind turbine is defined by performance curve which give Cp as a function of λ. Such the curves are determined experimentally. Betz Theory says that in horizontal axis wind turbine the power coefficient always inferior to the theoretical value of 0.593.In fact the modern type of wind turbine in present day hardly to get the maximum value of the power coefficient.[5]

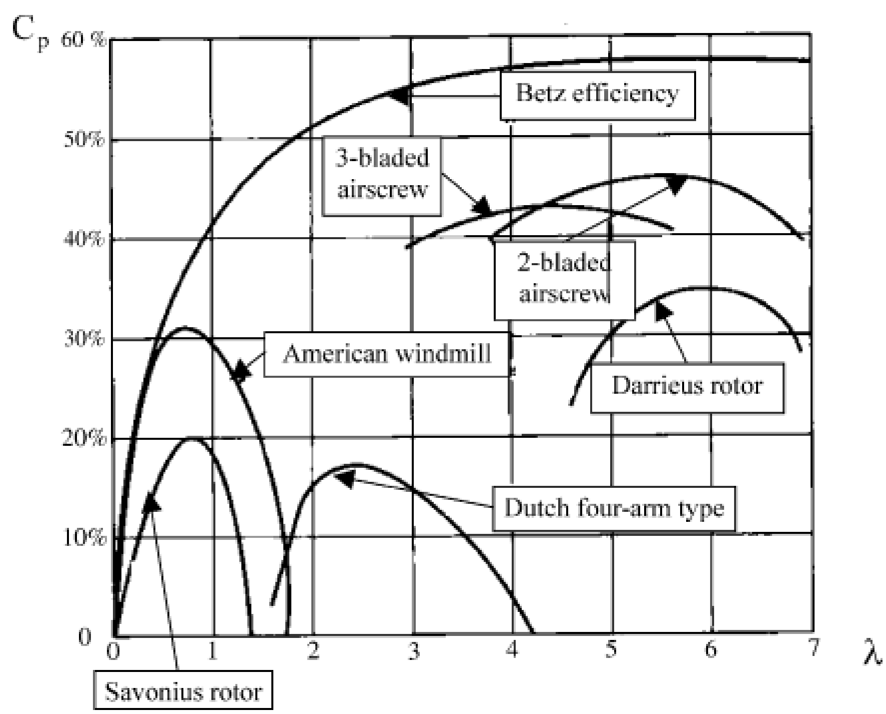



FIGURE 1.0: Power coefficient of modern type of turbine [10]

Wind turbine can be divided into two main categories of mechanisms:

1) Axial Wind Axis Turbine

2) Cross Wind Axis Turbine

**Axial Wind Axis Turbine**

This category includes all mechanisms where the axis of rotation must be oriented to face directly into the wind. An extremely early version of this mechanism was the Dutch-style windmill, which was used primarily for milling grain. An early style of this mechanism was the American windmill that was on most all farms in the early part of the Twentieth Century. It was a rather simple (and somewhat inefficient) design, but it was only intended to pump water up a well. Its extremes of performance were of little importance, as were its low efficiency in converting the energy in the wind to useful work. The efficiency of farm windmills is never above 15%, and that is only at a fairly narrow wind velocity range, with efficiency dropping off rapidly for both faster and slower windspeeds. This variety is technically called a slow-tip-speed wind-axis turbine. Most actual windmills have flat blades and not airfoils. An improved version is called the multi-blade wind-axis turbine. This version uses airfoils instead of flat surfaces, which improves its maximum efficiency to around 40%. Otherwise, the operation is relatively similar to farm windmills. The third common version of wind-axis turbine is the Propeller-style. These tend to be too expensive for small residential installations, and they are almost universally used on giant towers on wind farms. The Propeller style is what is called a high-tip-speed wind-axis turbine. Because of the high tip speed, the theoretical efficiency can be higher, around 45%. This higher efficiency probably explains the usage of Propeller-style turbines on those wind farms. On these large, expensive systems, often the individual blades are rotatable, like on a helicopter rotor. These variable pitch blades can be tilted to capture more or less wind energy, in order to try to maintain fairly constant rotational speed. [2]

**Cross Wind Axis Turbine**

This category includes wind turbines where the axis direction is at a right angle to the wind direction. In more practical terms, this virtually always involves a vertical axis. There is a wonderful advantage from this situation. It works identically well, no matter what direction the wind comes from. So no provision for aiming the mechanism is necessary. An early style is called a Savonius Rotor. The spinning part of a weatherman's windspeed device (anemometer) is a Savonius Rotor. Sideways mounted cups catch the wind and cause the vertical shaft to spin. A Savonius Rotor has an advantage over the farm windmill in that it does not have to be pointed into the wind. It works equally well with wind from any direction. Savonius Rotor has a maximum efficiency, around 30%. That efficiency does not drop off as rapidly as most other designs (only the propeller style has a wider range of windspeeds for high efficiency).In addition, the Savonius Rotor has tremendous starting torque where most other designs have very little torque at low rotational velocity. This design is technically called a low-tip-speed (or slow speed) cross-wind-axis turbine. No airfoil shape is involved, which is part of the explanation for the very low efficiency. However, the Savonius design is by far the simplest of these various mechanisms. Nearly all of the others involve advanced airfoil shapes and complicated structures. The economy and simplicity of a Savonius Rotor cannot be matched. A very sophisticated cross-wind-axis turbine is the Darrieus Rotor. This design looks something like an egg-beater, with usually either two or three curved airfoils. This design is technically called a high-tip-speed cross-wind-axis turbine. The airfoils and the high airfoil velocities allow this style to have efficiencies as high as about 35%, over a fairly wide range of wind speeds.

## 2.3 SAVONIUS WIND TURBINE

Savonius Wind Turbine is a Vertical Axis Wind Turbine (VAWT) type of generator. This type of turbine was invented originally by the Finnish engineer Sigurd J Savonius in 1922. The concept of Savonius wind turbine is base on the principle established by Flettner which is formed by cutting a cylinder into two halves along the central plane and then moving to two semi-cylindrical surfaces sideways along the cutting plane, that the crosssection resembled the letter ‘S’.(Figure 1.1) [8]

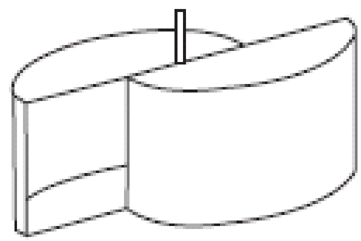


FIGURE 1.1: Savonius Rotor

They are drag type turbine consisting of two or three vanes. The energy from the wind is converted into torque when rotor is turned into rotational mechanical energy. Because of the curvature, the vanes experience less drag when moving against the wind rather than when moving with the wind. The differential drag causes the Savonius turbine to spin. The miscellaneous advantages of using Savonius are because this type of wind turbine is easy to fabricate and constructed. Their high starting torque enables them not only to run, but to start what ever the wind velocity. They are supposed to run in the case of high velocity wind when most of the high running wind turbine must be stopped due to over spinning. The component that converts the mechanical energy into electricity cab simply be located at the surface level of the turbine. Savonius wind turbine also considerably low cost maintenance. However Savonius wind turbines typically only have an efficiency of 20%.This efficiency is much less compared to other types of wind turbine. Their slow running behavior which the vanes move slower compared to the wind velocity make them difficult to be used as electric generator especially when the current produced transferred directly to network distribution.[8]

Because the speed of the rotor cannot rotate as fast as the wind, therefore Savonius wind turbine will experience a tip speed ratio (TSR) of 1 or below.[1] Since the efficiency is much less than other types of wind turbine it is not suitable to be used as electricity generator because turbine generator need to be turned at much higher RPM to generate current and voltages .However this type of turbine is suitable to be used in application like water pumping system and grinding grain for which slow rotation with high torque is essential.

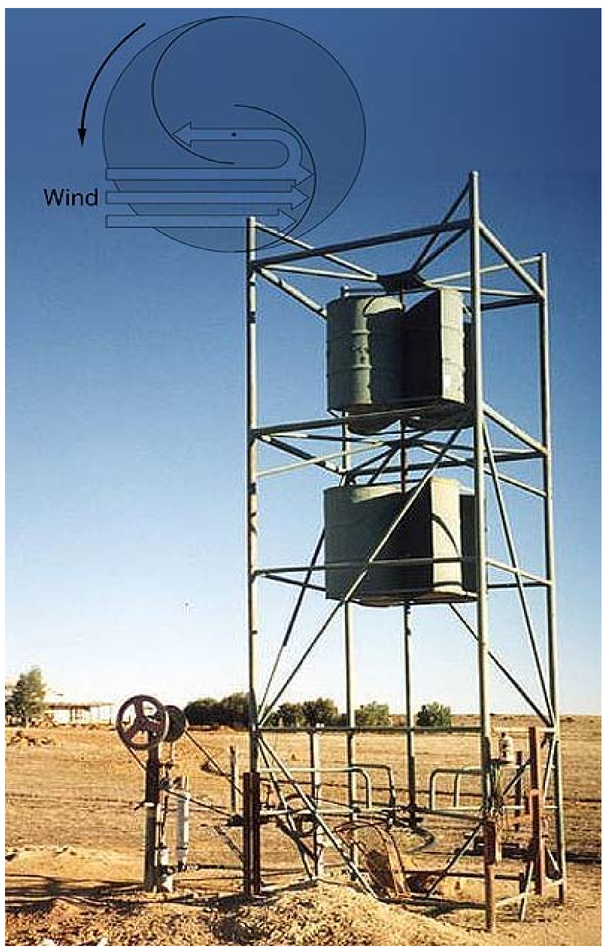



FIGURE 1.2: Savonius Wind Turbine [8]

Savonius wind turbine may come into different rotor shape. These different rotor shapes may result into different efficiency and performance. Three types of normal rotor shapes are S shape, curved shape and straight shape. The traditional rotor shape which is the S type is the main concern in this study. The figure of the different rotor shapes are as follow.

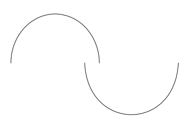


FIGURE 1.3: S shape

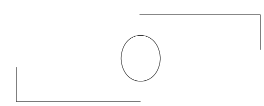


FIGURE 1.4: Straight shape

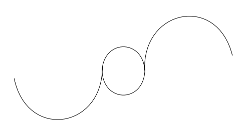


FIGURE 1.5: Curved shape

The traditional Savonius wind turbine is shown with the corresponding dimension in figure 1.6. The dimension S is called offset and d is the vanes diameter. With h is the turbine axial length and D is the rotor diameter, the wind capturing area becomes: [1]

$$\mathbf{A\ rotor = h(2d\text{-}S) = hD}$$

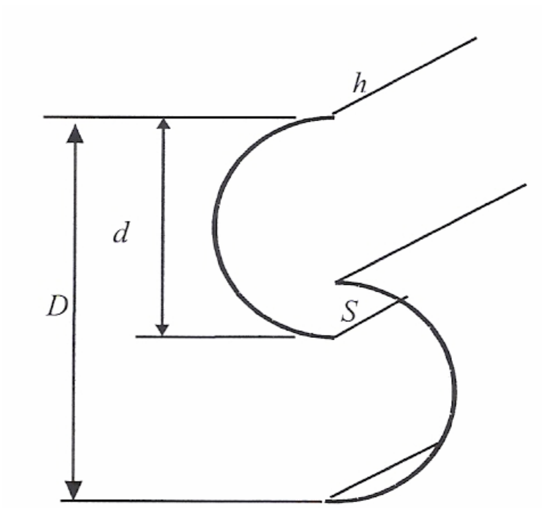



FIGURE 1.6: Geometries of Traditional Savonius rotor

The value of A is important to determine the power conversion of the wind energy where;

$$P_{wind} = \tfrac{1}{2}mv^2$$
$$P_{wind} = \tfrac{1}{2}\rho v^3 A$$

$$\tfrac{1}{2}\rho v^3 A \times C_p = P_{turbine} \text{ where } C_p \text{ is power coefficient}$$

$$\text{Thus } C_p = P_{turbine}/P_{wind}$$

## 2.4 DESIGN CRITERIA

To fabricate the Savonius wind turbine several consideration base on previous study must be taken into consideration.

### 2.4.1 Choice of the Material for the Vanes and the End Plates

The choice of the material is the most crucial part before fabrication. Several design criteria are to be considered for the choice. Low price, light weight, easiness for fabrication and resistance to the outside environment like corrosion are the important aspect. For the vanes the material to be used is PVC pipe. The cylindrical shape of pipe will be cut identically into two (2). Reason leading to the choice of PVC pipe material due to its light weight, cost as well as durability and assembly easiness. The end plates material will be Perspex which is light and easy to be machined. The properties of the Perspex are as follow: [9]

| | |
|---|---|
| **1.Weathering resistance** | The resistance of' ‘Perspex' to outdoor exposure is outstanding and in this respect it is superior to other thermoplastics. After many years under tropical conditions the degree of colour change of both clear and coloured materials is very small. The best stability is developed if the 'Perspex' is shaped. |

| | |
|---|---|
| **2.Thermoplastic behavior** | Perspex' softens gradually as the temperature is increased above about 100C. At a temperature of 150-160C it is sufficiently rubber-like to be shaped easily. Because it is a true thermoplastic, it retains the property of softening on re-heating even after shaping. When the temperature of a shaping is raised above a particular level the material demoulds and will revert in time to its original form.<br>Provided that the temperature does not rise above 80C the shaping will remain stable indefinitely. When 'Perspex' is first heated to its shaping temperature it will shrink approximately 2% in both length and breadth, this shrinkage being accompanied by an increase in thickness sufficient to maintain the total volume constant. |
| **3.Water absorption** | Perspex' has a low water absorption but although the equilibrium water content is small, its effect on dimensions may not be negligible and absorbed water may have a slight effect on mechanical properties, acting to some extent as a plasticiser. The water content of' ‘Perspex' as supplied is in the range 0.5-0.8% by weight. |
| **4. Abrasion resistance** | The abrasion resistance of' ‘Perspex' is roughly comparable with that of aluminium but because the material is indented rather than removed, the resultant visual effect is rarely noticed in service. |
| **5. Relative density** | The low relative density of' ‘Perspex', 1.19, enables large components to be made which are sufficiently strong to be self-supporting and yet light in weight. |
| **6. Impact** | Various arbitrary impact tests have been devised from time to time, but the strength amount of information they give is limited. The impact strength of a carefully prepared specimen determined by an arbitrary test does not necessarily give an accurate indication of the |

| | |
|---|---|
| | resistance to breakage of a fabricated component in service. In the design of' 'Perspex' components, particularly those liable to be subjected to impact, sudden changes in cross-section should be avoided because they may lower the effective impact resistance of the component Hardness is another complicated property to express in a single figure. Numerous test methods have been devised and a simple guide for plastics is the pencil scratch method using a set of graphite pencils covering the hardness range from 6B to 9H. 'Perspex', which is one of the hardest of the thermoplastics, is scratched by a 9H pencil only. |

### 2.4.2 Choice of the Geometry

Although Savonius wind turbine has low efficiency there are number of geometrical parameter which will affect the efficiency. Among those, aspect ratio is one of the significant parameter. This is a very important criterion that affects the aerodynamic performance of the Savonius rotor.

$$x = H/D$$

Generally the highest value of x should greatly improve the efficiency. Values of x around 4.0 seem to lead to the best power coefficient of conventional Savonius wind turbine.[6]

It is also known that the end plate lead to better aerodynamic performance. Experimental procedure shown that the diameter Df of the end plate relative to the diameter D of the rotor has some influence of the aerodynamic performance.[7] The higher value of power coefficient obtained when the value of Df 10% larger than the value of D.

Base on previous study the vanes will be fabricate offset. The best gap between the two vanes is 1/12 of the total length from the tip of the first vane and the second one.

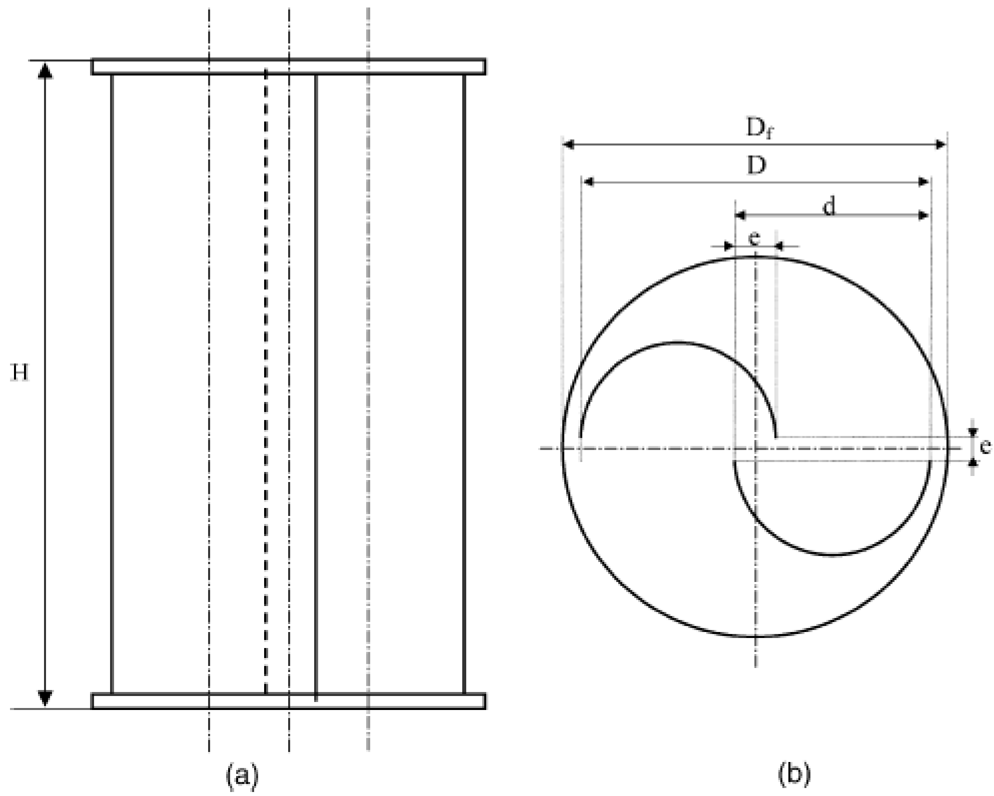



FIGURE 1.7: Dimension of the vanes

This design will consist of two sections of the vanes which one set of the vanes are 90˚ to another set. (Figure 1 .8)

This type of design is called double steps Savonius rotor. Beside of those criteria that should give the best performance of Savonius wind turbine, the rotor could not start alone as it has low starting torque. Therefore a few direction of wind velocity can be manipulated to allow the rotor to start moving. That's why double steps Savonius rotor being used in this study.[6] In any case the double steps rotor is said to be lightly superior than single step rotor in both torque and power coefficient.

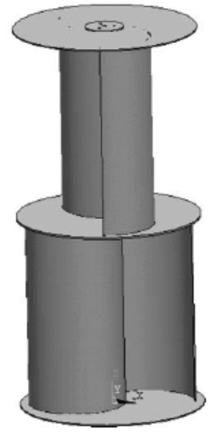


FIGURE 1.8: Double steps Savonius rotor

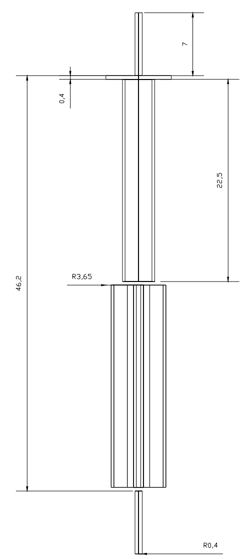



FIGURE 1.9: Proposed design

As mentioned earlier, three configurations that the rotor can be installed will be tested to determine the change in Sovonius performance as in the figure 2.0. In the first configuration the rotor subject to the full wind stream. In the second configuration the wind is directed toward one side of the rotor and the last configuration the wind is directed to one side of the rotor with 90˚ guiding case. [1]

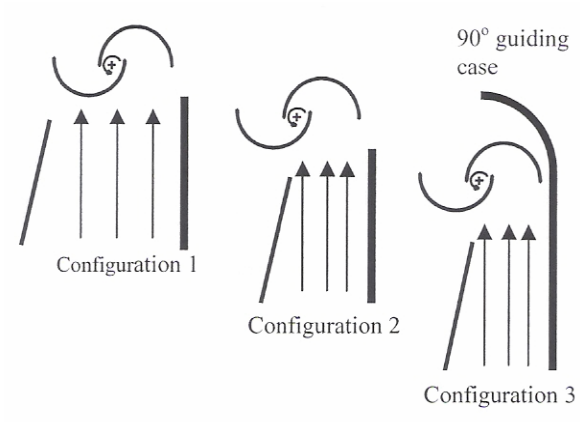



FIGURE 2.0: The three configurations subject to analysis

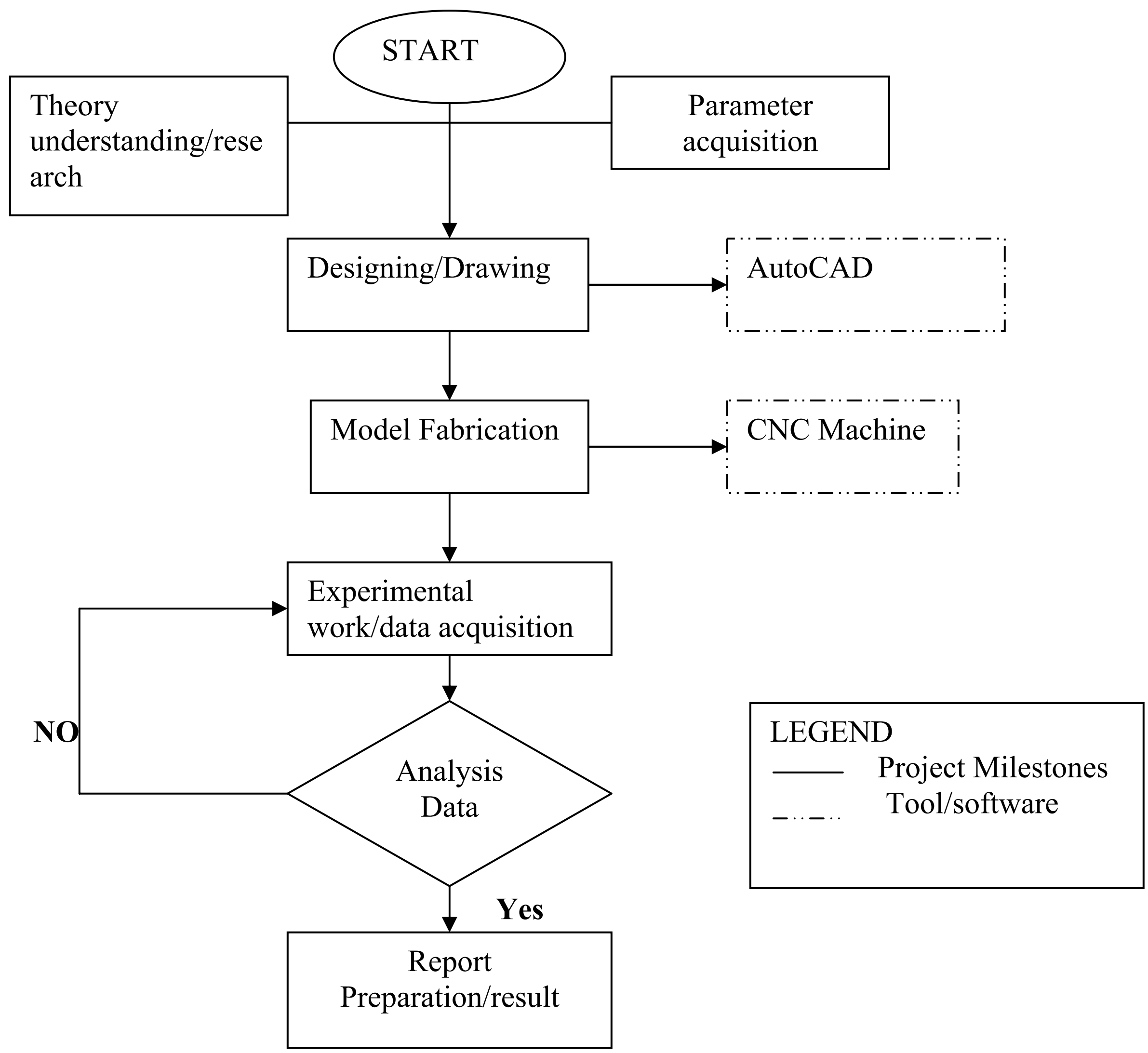
# CHAPTER 3

# METHODOLOGY

## 3.1 THE SOLUTION METHODOLOGY:

The analysis of the resent study has been conducted experimentally by design and fabrication of three (3) different models of the proposed wind turbine. The experiment has been conducted in close conduit .The measurement of performance of three different configuration of installation will be recorded by using specific equipment. The result obtained will be compared to the result by previous work. The detail of the procedure will be discussed in section 3.4.

### 3.2 FLOW OF EXECUTION




### 3.3 GANTT CHART

Refer to the Appendices one (1) and two (2)

## 3.4 EXPERIMENTAL PROCEDURE

### 3.4.1 Design and fabrication of the model

The design of Savonius wind turbine is base on traditional type of double steps Savonius rotor. Several geometric parameters that have been discussed in chapter 2 literature review were taken into consideration. The drawing of the Savonius rotor and end plate were done by using AutoCAD software. The drawing is important during fabrication process. he most important part of model fabrication is machining the vane's slot by using CNC machine. In this case milling process is conducted by using CNC Trainer machine. The first step of machining is to convert the drawing of the machining part into Mastercam Software. From this software the cutting simulation can be performed thus converting it into machining codes. These represent the cutting process including cutting path, tool selection and etc. The codes then transferred into CNC Trainer's main processing units to begin the cutting process. As mention before milling process will be used to perform the cutting slot. The smallest bit size has been used which is 3mm in diameter. Before the cutting process can be performed the centre of the plate is to be determined. This is because the entire cutting path referring to the initial position that being set up. In this case the initial position is the center of the plate since the plate is circular in shape. The spindle speed is set to be 2000 rev/s with the feed rate of 48. After everything was set up the machining started and the machine performs cutting automatically. Although the cutting process is automatic the need for monitoring is still essential for precaution purposes.

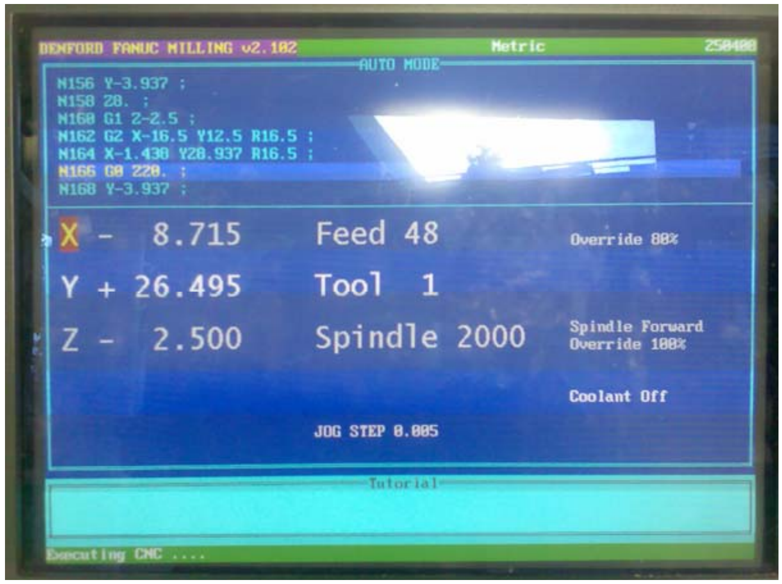



FIGURE 2.1: Setting of the machine

FIGURE 2.2: Setting the initial position

FIGURE 2.3: Cutting process starts

FIGURE 2.4: Final work piece

The shaft of the turbine is made of aluminum. In order to fit the shaft into the ball bearing the shaft is machined to reduce the size by using lathe machine. From the original size of 1.5cm the shaft is machined to reduce the size to 0.8 cm. All the cutting process is done manually. The final shape of the shaft can be seen in figure 2.5

FIGURE 2.5: The shaft of the rotor

The vanes are made of PVC pipe that is cut into two. The cutting process of the vanes must be precise so that it can be fixed into the respective slot. Automatic saw with directional guide was used to cut the pipe into half. The result of the cutting can be seen as shown in figure 2.6.

FIGURE 2.6: The Vanes

The next step of the model fabrication is part assembling. The vanes are fixed into the slot that has been machined by using CNC Trainer. In order to make sure that the vanes stick nicely in the slot, super glue is applied. The assembling process must be done carefully to ensure that there is no misalignment between the vanes and the plate. As far as the alignment is concern the shaft must be installed properly to make it rotation become as smooth as possible.

FIGURE 2.7: Savonius rotor prototype

### 3.4.2 The Test Rig

The test rig is another important element of the experimentation. In this study the Savonius rotor is installed on the chimney. The chimney is taken from the previous work done by other person. The use of chimney will allow the wind flow to pas through the Savonius rotor in directed way. Portable fan is used as a source of wind for this analysis. Figure 2.8 shows the schematic diagram of the test rig where the experiment ha been conducted.

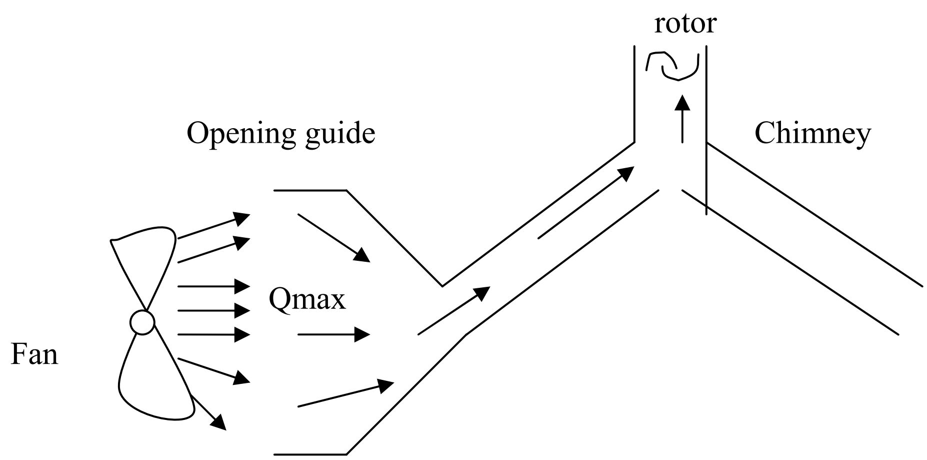



FIGURE 2.8: Schematic diagram of the test rig

### 3.4.3 The Measuring Technique

Since the objective of this study is to determine the performance of Savonius wind turbine in three different installation configuration the prototype must be set up and ready for experimentation. Figure 2.9 shows how the rotor being installed on top of a chimney where directed flow of wind will pass through.

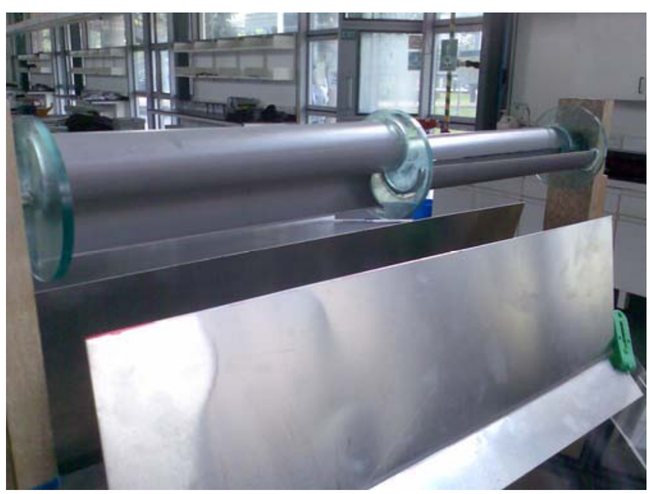


FIGURE 2.9: Rotor Installation

In this study the source of wind coming from 3 speed portable fan. The variable for this study is the wind velocity which is taken between range of 1 m/s to 6 m/s. Since the source of the wind is the portable fan the range of the velocity is taken by manipulating the distance of the fan to the opening and its speed. At one time three different readings are measured and recorded which are wind velocity,V the RPM of the rotor,N and the torque produced,T. Five reading of wind velocity are measured at different spot at the outlet of the chimney to get an average value. The RPM of the rotor is measured 30 second after the rotor start to spin to ensure it reach consistent speed. The last data that is measured is the torque produced. The torque is measured by using torque meter. The shaft is clipped to the cramp. Once the shaft starts to rotate, it will measure the torque. The measurement is repeated after ten readings are measured. For each wind velocity applied all the three configuration installation is tested one after another. This is to ensure the consistency in term of the wind velocity applied.

# CHAPTER 4

# RESULT AND DISCUSSION

## 4.1 ANALYSIS OF RESULT

The experiment has been conducted under normal condition with room temperature. All the results are based on study of three different configurations of installation. A range of wind velocity from 1 m/s- 5 m/s were studied on the three different configurations and the findings of the Savonius rotor performance are presented. The result, test variables, and test calculations are shown below.

- Wind speed V, was measured using digital anemometer.
- RPM, N was measured using digital tachometer.
- Torque, N.m was measured by using digital torque meter.
- Torque coefficient, CT is evaluated as $C_T = T / \frac{1}{2}\rho V^2 A_{rotor} (D/2)$.
- TSR, $\lambda$ is evaluated as $\lambda = \omega D / 2V$
- $\omega$ is calculated from $\omega = 2\pi N/60$
- Power coefficient Cp is evaluated as $C_p = \lambda C_T$.
- Area, $A = 0.028 m^2$
- $D = 0.061$ m
- $h = 0.46$ m

| Set | Velocity(m/s) | Torque (N.m) | | |
|---|---|---|---|---|
| | | Configuration 1 | Configuration 2 | Configuration 3 |
| 1 | 1,282 | 0,00014 | 0,00019 | 0,00012 |
| 2 | 1,498 | 0,00023 | 0,00024 | 0,00031 |
| 3 | 2,16 | 0,00076 | 0,00087 | 0,0010 |
| 4 | 2,63 | 0,0011 | 0,0012 | 0,0019 |
| 5 | 2,952 | 0,0012 | 0,0016 | 0,0019 |
| 6 | 3,332 | 0,0013 | 0,0015 | 0,0018 |
| 7 | 3,698 | 0,0011 | 0,0013 | 0,0013 |
| 8 | 3,976 | 0,00049 | 0,00048 | 0,00032 |
| 9 | 4,496 | 0,00034 | 0,00041 | 0,00027 |
| 10 | 5,268 | 0,00025 | 0,00034 | 0,00026 |

TABLE 1.0: Summary of the velocity and Torque reading for three different configurations

| Set | Torque Coefficient, $C_T$ | | |
|---|---|---|---|
| | Configuration 1 | Configuration 2 | Configuration 3 |
| 1 | 0,17 | 0,23 | 0,14 |
| 2 | 0,20 | 0,25 | 0,27 |
| 3 | 0,32 | 0,34 | 0,42 |
| 4 | 0,31 | 0,35 | 0,53 |
| 5 | 0,27 | 0,35 | 0,42 |
| 6 | 0,23 | 0,27 | 0,32 |
| 7 | 0,15 | 0,18 | 0,18 |
| 8 | 0,06 | 0,06 | 0,04 |
| 9 | 0,03 | 0,04 | 0,03 |
| 10 | 0,02 | 0,02 | 0,02 |

TABLE 1.1: Value of TSR and Torque coefficient for three different configurations

| Set | Power Coefficient, $C_P$ | | |
|---|---|---|---|
| | Configuration 1 | Configuration 2 | Configuration 3 |
| 0 | 0 | 0 | 0 |
| 1 | 0,05 | 0,07 | 0,04 |
| 2 | 0,07 | 0,08 | 0,09 |
| 3 | 0,15 | 0,16 | 0,2 |
| 4 | 0,19 | 0,18 | 0,25 |
| 5 | 0,19 | 0,21 | 0,25 |
| 6 | 0,17 | 0,21 | 0,24 |
| 7 | 0,15 | 0,18 | 0,18 |
| 8 | 0,08 | 0,07 | 0,05 |
| 9 | 0,05 | 0,06 | 0,04 |
| 10 | 0,03 | 0,04 | 0,03 |

TABLE 1.2: Value of TSR and power coefficient for three different configurations

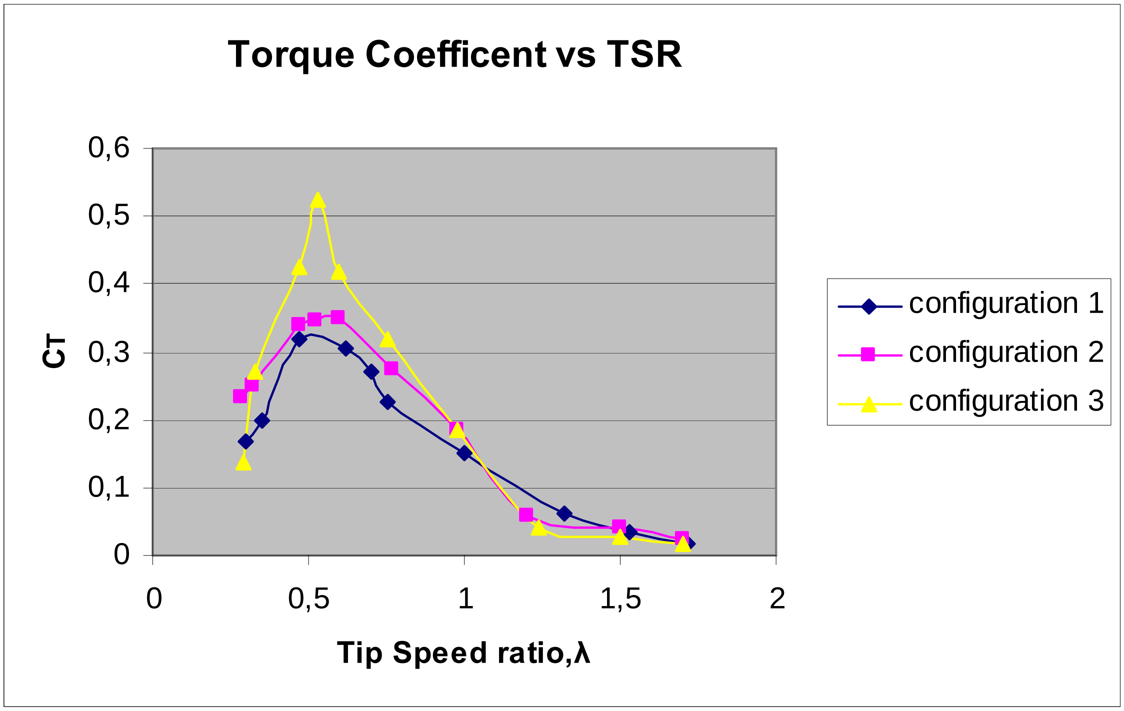



FIGURE 3.0: The Torque Coefficient versus TSR for three different configurations

Figure 3.0 shows the result of torque coefficient versus TSR for three different configurations. For configuration 1 the maximum torque coefficient occurs at TSR of 0.47. For configuration 2 the maximum $C_T$ is recorded at TSR of 0.52 and 0.6 .Meanwhile the maximum $C_T$ for configuration 3 occur at TSR of 0.53. From the graph of $C_T$ versus TSR we can see that the maximum torque coefficient is not highly affected under configuration 2 with respect to configuration 1.However large increment of torque coefficient can be seen in configuration 3 compared with configuration 1. The result also shows that for both configurations 2 and 3 torque coefficient is lower compared to configuration 1 between TSR of 1.1 and 1.5. The comparison of percent of enhancements in the torque coefficient by analytical analysis and experimental analysis are shown in the table 1.3.

| Configuration | Analytical Analysis | | Experimental Analysis | |
|---|---|---|---|---|
| | $C_{T\ max}$ value | % of increase in $C_{T\ max}$ | $C_{T\ max}$ value | % of increase in $C_{T\ max}$ |
| 2 | 0.2 | 10 | 0.34 | 6.3 |
| 3 | 0.59 | 70 | 0.53 | 65.6 |

TABLE 1.3: The comparison of enhancement in torque coefficient at different configuration with respect to configuration 1 for both analytical and experimental analysis.

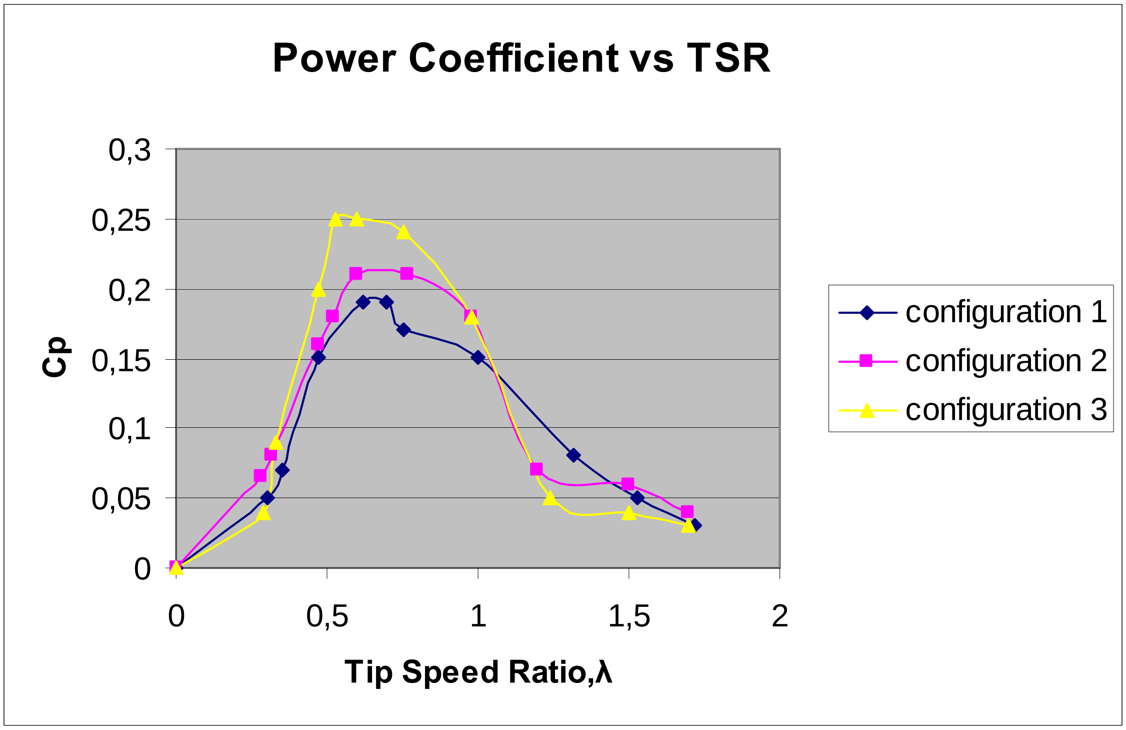



FIGURE 3.1: The Power Coefficient versus TSR for three different configurations

Figure 3.1 shows the graph of power coefficient versus TSR. The trend of the power coefficient obtained from the experimentation show the significant increase in power coefficient for configuration 3 with respect to configuration 2 and configuration 1. For configuration 1 the maximum value of Cp is 0.19 at TSR of 0.62 and 0.7. Under configuration 2 the maximum value of Cp increases to 0.21 at TSR of 0.6 and 0.77. Compared to configuration 1 the Cp is increased by 10.5%.

As expected the maximum value of Cp under configuration 3 has increase to maximum value of 0.25 at TSR of 0.53 and 0.6. The maximum power coefficient is increased by 31.5%. The maximum value 0.19 for configuration 1 is considered high with respect to the normal open atmosphere installation. Since in all configurations other geometrical parameter that may influence the value like offset S are the same, therefore it is the installation configuration become the criteria that affect the value obtained. In configuration 1 the wind flow will exerted on the down concave and upward concave.(refer to figure 2.0) Therefore net force acting on the turbine blade will be lower resulting to a lower performance. In configuration 2 the flow is directed toward the upward concave. The force exerted on the down concave is eliminated and only upward concave contribute to the net force. That is why the performance of configuration 2 is slightly increased with respect to configuration 1.The best configuration is configuration 3.The 90º guiding case along the rotation path will guide the flow toward the down concave thus reduce the escaping flow rate. This has enhanced the rotor performance considerably. However from the analytical analysis the value of maximum Cp is 0.32 for configuration 3 and for configuration 2 is 0.24. This result is slightly greater from the experimental result. Many factors may effects the result. Most of the reason is because of the fabrication procedure. One of the factors may be caused by the friction at the bearing. Since the bearing are made of steel it may exposed to corrosion. This will reduce the performance of the turbine. Comparison between analytical and experimental analysis for the enhancement of power coefficient between configuration 2 and 3 with respect to configuration 1 is presented in table 1.4.

| Configuration | Analytical Analysis | | Experimental Analysis | |
|---|---|---|---|---|
| | $C_{P\,max}$ value | % of increase in $C_{P\,max}$ | $C_{P\,max}$ value | % of increase in $C_{P\,max}$ |
| 2 | 0.24 | 12 | 0.21 | 10.5 |
| 3 | 0.32 | 34 | 0.25 | 31.5 |

TABLE 1.4: The comparison of enhancement in power coefficient at different configuration with respect to configuration 1 for both analytical and experimental analysis.

# CHAPTER 5

# CONCLUSION & RECOMMENDATION

## 5.1 CONCLUSION

The initial stage of this project had given the exposure of understanding theory and current design of Savonius wind turbine. The approach taken along this project will ensure that the design is efficient and fully functional for the experimentation procedure. The first model that completed will be tested to study the result. The Savonius wind turbine has been studied by analytical method. The rotor is proposed to be installed horizontally on top of the solar chimney. The air flow stream will be directed toward the vane with three different configurations. The result obtained from experimental analysis has shown that the performance of Savonius wind turbine increase by configuration 2 and 3 with the best performance obtained by configuration 3. Although the data obtained by experimental procedure is slightly different with analytical analysis, the enhancement in turbine performance had proved the analytical analysis result obtained previously.

## 5.2 RECOMMENDATION

A few recommendations to improve the result obtained can be divided into two parts.

1. Prototype fabrication
2. Experimental procedure.

The fabrication of prototype is very essential to get the best and accurate result. The use of better type of bearing with less friction may increase the Savonius performance. The installation of turbine shaft must be accurate and precise to get a better alignment.

Because of the time constraint the experimental only conducted once. Therefore it is recommended to repeat the experiment a few times to ensure the consistency of the result obtained.

As mention earlier this study is conducted with traditional type of Savonius rotor.

For the future work it is recommended that the test of Savonius wind turbine performance to be conducted by using different shape of Savonius rotor‘s blade. A few recommended shapes of Savonius rotor blade as in figure 1.4 and 1.5 which are curved shape and straight shape are recommended to be tested.

# REFERRENCES


[1] **H.H. Al-Kayiem and A.E. Sa'ad Al-deen**.2007, "*Performance Analysis of Savonius Wind Rotor for Directed Flow Operation*", 1st Engineering Conference on Energy & Environment.

[2] **A.S Grinspan,P Suresh Kumar ,U K Saha, P Mahanta, D.V Ratna Rao and G Vedha Vanu**.2001, "*Design,Testing and Development of Savonius Rotor with Twisted Blade"* Indian Institute of Technology.

[3]**A.J Alexander and B.P Holownia**, "*Wind Tunnel Test on Savonius Rotor*".Department of Mechanical Engineering, Loughborough University of Technology, Loughborough, Leicestershire.

[4] **Carl Johnson**, "*Practical Wind Generated Electricity*"

[5] **J-L Menet**.2002, "*A Double Steps Savonius Rotor for Local Production of Electricity: A Design Study"* Universite' de Valenciennes, France.

[6] **Ushiyama I, Nagai H**. "*Optimum design configurations and performances of Savonius rotors*". Wind Eng 1988;12(1):59–75.

[7] **Fujisawa N**. "*Torque mechanism of Savonius rotors"*. J Wind Eng Ind Aerod 1992;40:277–92.

[8] Savonius Wind Turbines, Wind, http://www.reuk.co/wind.htm

[9] Properties of Perspex, http://www.paradisespa.co.za/docs/PersProp.html

[10] **Wilson RE, Lissaman PBS**. *Applied Aerodynamics of wind power machines*, *Research Applied to National Needs,* GI-41840, Oregon State University, 1974.

[11] **Newman BG.** *Measurements on a Savonius rotor with variable gap*. In Proceedings of Univ. Sherbrooke, Conf. On Wind Energy, Sherbrooke, Canada, 1974.

# APPENDICES

**Gantt chart for Final Year Project Part I (Appendices 1)**

| No | Detail/ Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Selection of Project Topic | ■ | ■ | | | | | | Mid-semester break | | | | | | | |
| 2 | Preliminary Research Work | | ■ | ■ | ■ | | | | | | | | | | | |
| 3 | Submission of Preliminary Report | | | | ● | | | | | | | | | | | |
| 4 | Design Identification(Part I) | | | | | ■ | ■ | ■ | | | | | | | | |
| 5 | Submission of Progress Report | | | | | | | | | ● | | | | | | |
| 6 | Seminar 2 (compulsory) | | | | | | | | | ■ | | | | | | |
| 7 | First Model Fabrication (Part I) | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 8 | Submission of Interim Report | | | | | | | | | | | | | | | ● |
| 9 | Oral Presentation | | | | | | | | | | | | | | | ● |

● Project submission

■ Project progress

**Gantt chart for Final Year Project Part II (Appendices 2)**

| No | Detail/ Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Project work continue | ■ | ■ | ■ | | | | | Mid-semester break | | | | | | | |
| 2 | Submission of progress report I | | | | ● | | | | | | | | | | | |
| 3 | Experimental work | | | | ■ | ■ | ■ | ■ | | | | | | | | |
| 4 | Submission of progress report II | | | | | | | | | ● | | | | | | |
| 5 | Seminar (compulsory) | | | | | | | | | ■ | | | | | | |
| 6 | Project work continue | | | | | | | | | ■ | ■ | ■ | ■ | | | |
| 7 | Submission of Dissertation (soft Bound) | | | | | | | | | | | | | | ● | |
| 8 | Oral presentation | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | ● | |
| 9 | Submission of Project Dissertation | | | | | | | | | | | | | | | ● |

● Project submission

■ Project progress

Appendix 3

Configuration 1

| | RPM | Torque(Nm) | Average Voutlet(m/s) |
|---|---|---|---|
| 1 | 120 | 0,00014 | 1,282 |
| 2 | 164 | 0,00023 | 1,498 |
| 3 | 317 | 0,00076 | 2,16 |
| 4 | 510 | 0,0011 | 2,63 |
| 5 | 646 | 0,0012 | 2,952 |
| 6 | 782 | 0,0013 | 3,332 |
| 7 | 1157 | 0,0011 | 3,698 |
| 8 | 1642 | 0,00049 | 3,976 |
| 9 | 2153 | 0,00034 | 4,496 |
| 10 | 2836 | 0,00025 | 5,268 |

Configuration 2

| Set | RPM | Torque(Nm) | Average Voutlet(m/s) |
|---|---|---|---|
| 1 | 112 | 0,00019 | 1,282 |
| 2 | 151 | 0,00024 | 1,498 |
| 3 | 318 | 0,00087 | 2,16 |
| 4 | 428 | 0,0012 | 2,63 |
| 5 | 554 | 0,0016 | 2,952 |
| 6 | 803 | 0,0015 | 3,332 |
| 7 | 1135 | 0,0013 | 3,698 |
| 8 | 1494 | 0,00048 | 3,976 |
| 9 | 2111 | 0,00041 | 4,496 |
| 10 | 2804 | 0,00034 | 5,268 |

Configuration 3

| Set | RPM | Torque(Nm) | Average Voutlet(m/s) |
|---|---|---|---|
| 1 | 116 | 0,00012 | 1,282 |
| 2 | 155 | 0,00031 | 1,498 |
| 3 | 318 | 0,0010 | 2,16 |
| 4 | 436 | 0,0019 | 2,63 |
| 5 | 555 | 0,0019 | 2,952 |
| 6 | 782 | 0,0018 | 3,332 |
| 7 | 1135 | 0,0013 | 3,698 |
| 8 | 1544 | 0,00032 | 3,976 |
| 9 | 2112 | 0,00027 | 4,496 |
| 10 | 2804 | 0,00026 | 5,268 |

Outlet Velocity (m/s)

| Set | 1st reading | 2nd reading | 3rd reading | 4th reading | 5th reading |
|---|---|---|---|---|---|
| 1 | 1,26 | 1,29 | 1,26 | 1,29 | 1,31 |
| 2 | 1,45 | 1,51 | 1,48 | 1,62 | 1,43 |
| 3 | 2,23 | 2,15 | 2,12 | 2,18 | 2,12 |
| 4 | 2,68 | 2,6 | 2,57 | 2,76 | 2,54 |
| 5 | 2,73 | 2,96 | 2,93 | 2,99 | 3,15 |
| 6 | 3,43 | 3,35 | 3,21 | 3,31 | 3,36 |
| 7 | 3,72 | 3,65 | 3,74 | 3,7 | 3,68 |
| 8 | 4,01 | 4.00 | 3,97 | 3,98 | 3,92 |
| 9 | 4,52 | 4,48 | 4,41 | 4,5 | 4,57 |
| 10 | 5,2 | 5,12 | 5,24 | 5,28 | 5,5 |