PERFORMANCE EVALUATION OF COUNTER ROTATING VERTICAL AXIS WIND TURBINE IN LOW WIND SPEED CONDITION

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2019

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A report submitted
in partial fulfillment of the requirements for the degree of
Bachelor of Electrical Engineering with Honours

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I declare that this thesis entitled "PERFORMANCE EVALUATION OF COUNTER ROTATING VERTICAL AXIS WIND TURBINE IN LOW WIND SPEED CONDITION" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Supervisor Name : ....

Date : ....

APPROVAL

I hereby declare that I have checked this report entitled "PERFORMANCE EVALUATION OF COUNTER ROTATING VERTICAL AXIS WIND TURBINE IN LOW WIND SPEED CONDITION" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature	:	....
Supervisor Name	:	....
Date	:	....

DEDICATIONS

To my beloved mother and father

ACKNOWLEDGEMENTS

In the name of ALLAH, the Most Gracious, the Most Merciful. Praise be to ALLAH with by His permission and blessings, I am able to accomplish this thesis with patience and strength.

Firstly, I would like to express my sincere appreciation to my supervisor Ir. Mohd Khairi bin Mohd Zambri, who has shown the method and guidance or support me for doing this project. His supervision helped me a lot in solving the problems and adding some spirit during this project. I highly appreciate his valuable time in giving me useful ideas to complete this project.

My deepest appreciation also goes to my beloved parents, my father Mohd Radzi Bin Osman and my mother Sofinat Binti Abu Yazid. They give their support in term of moral and continuously give an encouragement and full support on me to finish the project.

Besides, I would like to thank to my friends who have provided insights into both the topic and technical guidance in this compilation. Cooperation between friends helps me so much. The information that we have exchanged with each other ease the way of my project completion. A friend in need is a friend indeed. Thank you so much.

Lastly, I am truly grateful for all the hands and hearts who involved direct and indirectly to made this project possible. Thank you from the bottom of my heart.

ABSTRACT

In the present study, designing and development of counter rotating wind turbine (CRWT) has been studied experimentally. CRWT is a system where dual rotors of wind turbine are spinning or rotating in an opposite direction to one another. The type of CRWT system used in this study is Vertical Axis Wind Turbine (VAWT). Most of the existing VAWT has a poor self-starting and not be able to operate well in low wind speed condition. A Darrieus type (H-type) wind turbine has been chosen as the auxiliary rotor because of its longer blades that can generate highest power output. Meanwhile, a Savonius type (S-type) wind turbine is chosen because of its good selfstarting. Thus, a prototype model of Darrieus rotor and Savonius rotor has been established in this study to enhance the performace of the wind turbine at low wind speed and get more power. The main purpose of this study is to design a Hybrid CRWT that combine Savonius type and H-type system that can operate in low wind speed condition. The performance of proposed VAWT system in low wind speed condition in term of aerodynamics parameters such as RPM, torque input, torque coefficient and power coefficient has been investigated in this research through an experimental approach. The results from this study shows that S-type rotor can produce a maximum RPM at lower wind speed compare to H-type rotor. The mechanical torque input of this CRWT system is decreasing as the wind speeds increase since S-type rotor required less torque input to produce greater RPM compare to the H-type rotor. The development of this CRWT prototype model is expected to be used as alternative ways to generate electric power in rural or urban area that has wind speed range as low as from 2 m/s.

ABSTRAK

Dalam kajian ini, reka bentuk dan pembangunan counter rotating wind turbine (CRWT) telah dikaji secara eksperimen. CRWT adalah sistem di mana rotor ganda turbin angin berputar atau berputar dalam arah yang bertentangan dengan satu sama lain. Jenis sistem CRWT yang digunakan dalam kajian ini adalah vertical axis wind turbine (VAWT). Kebanyakan VAWT yang sedia ada mempunyai permulaan yang tidak baik dan tidak dapat beroperasi dengan baik dalam keadaan kelajuan angin yang rendah. Turbin angin jenis Darrieus (jenis H) telah dipilih sebagai pemutar bantu kerana bilahnya yang lebih panjang yang boleh menghasilkan output kuasa tertinggi. Sementara itu, turbin angin jenis Savonius (jenis S) dipilih kerana permulaannya yang baik. Oleh itu, model prototaip rotor Darrieus dan rotor Savonius telah ditubuhkan dalam kajian ini untuk meningkatkan prestasi turbin angin dengan kelajuan angin yang rendah dan mendapatkan lebih banyak kuasa. Tujuan utama kajian ini adalah untuk merekabentuk CRWT Hibrid yang menggabungkan rotor jenis Savonius dan rotor jenis H yang boleh beroperasi dalam keadaan kelajuan angin yang rendah. Prestasi sistem VAWT yang dicadangkan dalam keadaan kelajuan angin rendah dari segi parameter aerodinamik seperti RPM, torque input, torque coefficient dan power coeffcient telah dikaji dalam kajian ini melalui pendekatan eksperimen. Hasil daripada kajian ini menunjukkan bahawa pemutar jenis S boleh menghasilkan RPM maksimum pada kelajuan angin rendah berbanding dengan pemutar jenis H. Input tork mekanikal sistem CRWT ini berkurang seiring dengan peningkatan kecepatan angin sejak pemutar jenis S diperlukan input tork kurang untuk menghasilkan RPM yang lebih besar berbanding dengan pemutar jenis H. Pengembangan model prototaip CRWT ini dijangka digunakan sebagai cara alternatif untuk menjana kuasa elektrik di kawasan luar bandar atau bandar yang mempunyai kelajuan kelajuan angin serendah 2 m/

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LIST OF SYMBOLS AND ABBREVIATIONS

ρ	-	Air density
ω	-	Angular velocity
λ	-	Tip speed ratio
A	-	Swept area of the wind turbine
Cp	-	Power coefficient
Ct	-	Torque coefficient
F	-	Thrust force
g	-	Gravity
N	-	Number of rotational per minute
Pw	-	Theoretical power
PT	-	Actual mechanical power
Pex	-	Maximum power extractable
R	-	Radius of rotor
V	-	Free stream velocity
T	-	Theoretical torque
Tm	-	Mechanical torque
W	-	Weight of load
CFD	-	Computational Fluid Dynamic
CRWT	-	Counter-rotating Wind Turbine
HAWT	-	Horizontal Axis Wind Turbine
RPM	-	Rotational Per Minute
TSR	-	Tip Speed Ratio
VAWT	-	Vertical Axis Wind Turbine

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Electricity power is conventionally generated by the combustion of fossil fuel. Yet the fossil fuel is a non-renewable and unsustainable resources as their formation takes up to billions of years. Besides, contaminating emission will be produced as the result of the combustion of fossil fuel. Therefore, in order to generate electricity from renewable and clean source of energy, wind turbine is created. Horizontal Axis Wind Turbine (HAWT) which is the most common wind turbine has been built up and used over the years as its ability has been proven in producing more electricity from a given amount of wind. Sadly, HAWT is heavy and it does not able to operate well in turbulent wind. In contrast, Vertical Axis Wind Turbine (VAWT) is the most excellent model claimed by the productions whereas it is more quiet, economical, efficient, and suitable for local energy production, especially in urban area.

There are two kinds of vertical axis wind turbines which are Savonius and Darrieus model. The Savonius model is a drag-type wind turbine which the way it operates is more likely the same to anemometer. This model of wind turbine is ideal and fits for areas with turbulent wind as the rotor will continually keep spinning no matter what direction the wind is blowing as long as there is force exerted on it. Unfortunately, this type of wind turbine is very raw, low-tech and inefficient because it does not able to rotate faster thathe wind speed. It also have a tip speed ratio (TSR) of 1 or below. The Savonius model is not suitable for power generation as it spins slowly. However, it is still a good self-start type of wind turbine.

Meanwhile, Darrieus model is a lift-type wind turbine. It is unlike the Savonius model which operated similarly like an egg beater. In order to create rotation, the Darrieus model uses lift forces. Lift forces is where a force created when air is passing through the two sides of the airfoils (wind turbine blades). Darrieus model wind turbine will continuously keep rotating as long as there exists forward motion over the airfoil to generate the required lift. The airfoils are secured to a hub, which then attached to a generator shaft. The air passing through the wind turbine blades will then be converted into rotational momentum which end up in spinning the generator. A Darrieus wind turbine is able to spin swiftly compared to the speed of the wind hitting through it. Thus, it shows that the turbine has the tip speed ratio (TSR) which greater than 1. Apart from that, the Darrieus generates less torque than a Savonius type. Yet, Darrieus is able to rotate speedily which make it much suitable for electricity generation. In addition, the Darrieus type cannot start by itself. Hence, it requires a small power motor to start up the rotation. There are different kinds of Darrieus wind turbine which are Helical shape and H-type Darrieus.

A counter-rotating concept was used in prototypes where it does not need to use two shafts or a contra-rotating generator in order to achieve the opposite rotation. Yet, one of the shafts is attached to the generator itself so that both generator and the rotor are able to spin together in a clockwise direction. Despite that, the other rotor which is the main rotor is attached to the shaft so that it can rotate in a counter-clockwise direction. As the primary rotor turns the shaft, the auxiliary rotor turns the generator with the goal that the magnetic coil inside the generator gain extra rotational speed since the shaft is turning in one way even at facing directions of both rotors. The counter-rotating helicopter is somewhat similar if compared to the concept that has been used in this study. However, only with the existence of air flow, wind turbine is able to generate the torque. This means that it is not exactly the same if compared to the helicopter where it generates the torque by using generator or motor.

1.2 Problem Statement

Wind turbines which are now in the market usually manufactured from European countries. Most of the wind turbines are not able to operate in our country, Malaysia. This is due to Malaysia has a low wind speed condition. The average of the speed of air flow is as low as 1 m/s to 4 m/s [1]. Next, the issue that emerges is that it requires a wide area and open space. The base of the wind turbine or the site cannot be utilized if the wind turbine created is too extensive, so there is wastage there. In addition, the wind turbine able to capture a lot of wind in other words, it contributes to higher energy production without compromising its efficiency. In order to study the performance in low wind speed condition, the prototype of the vertical axis is designed.

1.3 Objective

The objective of this project is:

i. To study the vertical axis wind turbine which able to operate well in low wind speed.
ii. To design the vertical axis wind turbine in low wind speed condition.
iii. To test and measure the performance of wind turbine.

1.4 Project Scope

Based on the study of this project, the project is done at block F Faculty Electrical Engineering (FKE) using tachometer, vane anemometer and multimeter which provided by the faculty themselves. This study highlighted on how wind speed will affect the performance of wind turbine. The prototype will be designed on vertical axis wind turbine in low speed condition. The design of the prototype focus on Savonius type and Darrieus type wind turbine. The experiment will be handled to test the performance of the prototype beginning from 2m/s to 9m/s wind speed.

CHAPTER 2

LITERATURE REVIEW

Chapter 2 discusses the literature review which includes the counter rotating concept as well as explanation in detail of vertical axis wind turbine. Previous studies which related to this research are also included in this chapter.

2.1 History of Wind Turbine

Due to the rapid rise in oil prices in the late 1970s and 1980s, the development of wind generators accelerated. Also, there is a greater understanding that using fossil fuels to produce electricity, causes pollution that damages the environment and causes global warming. Some modern design based on Figure 2.1. All the designs are built from composite materials that are light and very strong.

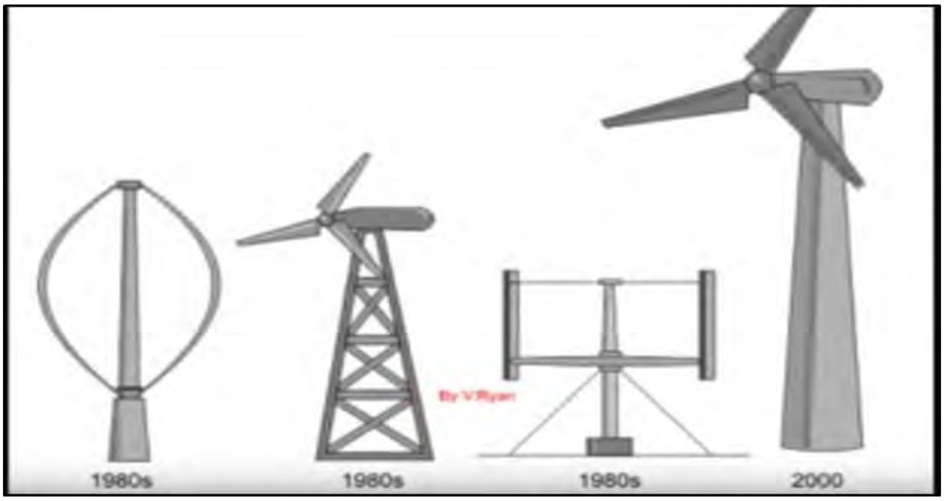

Figure 2.1: Design were built from 1980s to 2000

Wind power generators are rarely seen in isolation as they are normally put together in groups forming wind farms. This is the most efficient way of producing electricity from the wind and feeding it into the national grid. Single generators are normally much smaller and used on farms or in remote areas where it is not possible to cable electricity from the national grid. Wind farms tend to be located in the countryside, were installed away from towns and people. Many people believe that these large structures spoil the look and peace of the countryside. Wind generators create a lot of noise. It is said that each one is as loud as a car engine running at 70 MPH. Figure 2.2 shows the noise of wind turbine that presented from the graph [23].

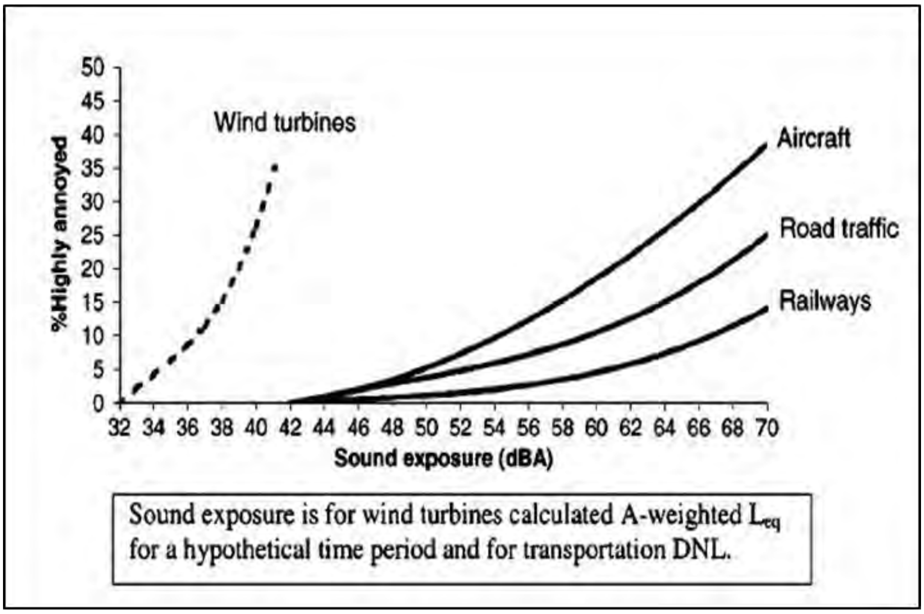

Figure 2.2: A graph of percent highly annoyed against sound exposure [23]

2.2 Operation of Wind Turbine

Wind energy is becoming very popular with growth of clean energy; this is reliable source of power for significant percentage of the population that is limited or no access to grid electricity. For planet already suffering in the effect of climate change and environmental pollution, wind energy can be green and clean solutions. Wind is moving air that contains kinetic energy and the wind turbine converts this kinetic energy into electricity. A wind turbine most prominent components are its blade; most turbine usually have either two or three blades. The hub and the blades together form the rotor while the main body of the turbine sitting on top of the tower and behind the rotor is called the nacelle. Inside the nacelle, the heart of the turbine consists of the low speed drive shaft, the gearbox, high speed drive shaft, the generator and the wind charge controller. Behind the nacelle is the anemometer, a device that measure of the wind speed and the wind vane is measure the wind direction and orients the turbine accordingly, so that the blade is face directly into the oncoming wind and captures the maximum amount of energy [24].

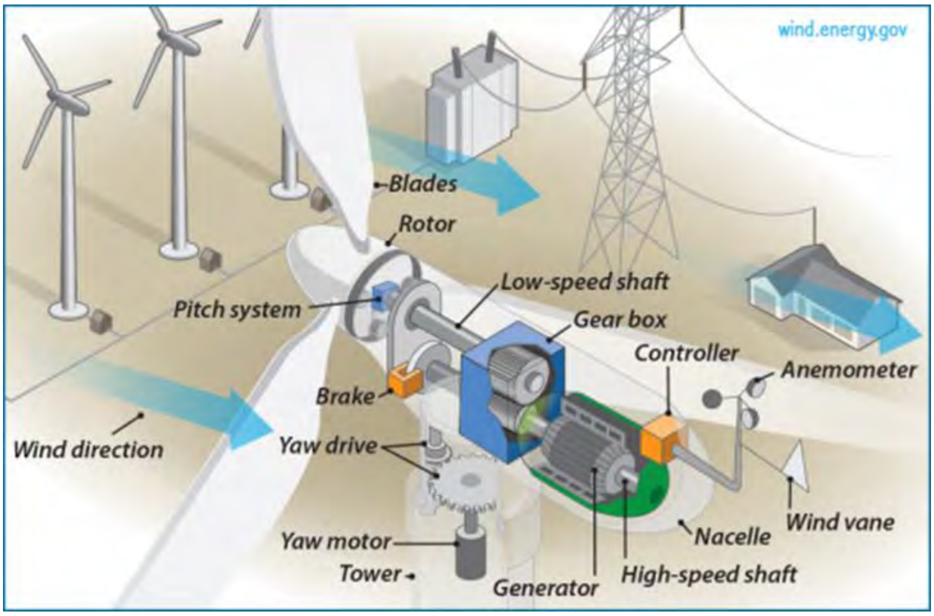

Figure 2.3: The wind turbine components [24]

2.3 Counter-rotating Wind Turbine (CRWT) Concept

Figure 2.4 : The concept of counter-rotating wind turbine system [2]

Counter-rotating system is where two rotors spins in opposite direction on the same axis [2]. Figure 2.4 shows the concept of counter-rotating wind turbine (CRWT) where two rotors are placed separated from one another. One of the rotors rotates in anti-clockwise direction while the other one rotates in clockwise direction. This concept of wind turbine's application has been used for decades particularly on helicopters and horizontal axis wind turbines (HAWT). Additionally, recent studies have discovered that this particular technique is also has been used on vehicles such as boats, airplanes, and submarines in order to rise up the efficiency of the system as well as to get rid the unbalanced torque faced by the two rotors [3]. The upwind and downwind rotors are also being known as primary and secondary (auxiliary) rotors.

Several studies had been carried out in determining or predicting the performance of CRWT systems. An experiment on a scale model in a wind tunnel had been performed by using the quasi-steady strip theory in order to predict the CRWT system aerodynamic performance [4]. Another research was conducted to analyze the performance of CRWT system of different parameters such as pitch angles, blades radius, and also rotating speed. At the end of the study, it was found that, for a maximum extracted power of the system, the total extracted power was shared by the two rotors, the back rotor must be lower than the one of the front rotor and the turning rate of the back rotor is lower than the one of the front rotor. Meanwhile, at low wind speed, rotational speed was suggested to be reduce in order to capture more energy. Additionally, the performance of CRWT can be enhanced when it operates at low wind speeds at the tip-speed-ratio where a maximum Cp is captured.

2.4 Wind Turbine

2.4.1 Vertical Axis Wind Turbine

Based on the axis in which the turbine rotates, there are two types of wind turbines which are horizontal axis wind turbine (HAWT) and Vertical-axis wind turbines (VAWT). VAWT's main rotor shaft is vertically arranged. This kind of arrangement is effective as the turbine can still be functioning even it is not pointed into the wind. The VAWT only requires a low wind speed beginning from 2 m/s to work in all directions [5]. This wind turbine is typically used as the cost is low, simple in its design, and also it has good maintenance. Unfortunately, VAWT has a bad starting performance. Several previous studies have been conducted in improving the self-starting performance of VAWT. In beating the problem, a Savonius rotor was combined with VAWT as the rotor has a good starting torque coefficients where it was able to function at low wind speeds. Benefits of using VAWT is that, its application within the urban environment provided a good safety and operation [6]. Additionally, due to their inherent axisymmetric design, VAWT is also well suited to such environments.

2.4.1.1 Darrieus-type Wind Turbine

VAWTs are ending up more essential in creating wind power because of their conservativeness and flexibility for residential establishments. As the reason to its compactness and adaptability for domestic installations, the use of VAWTs are now increasingly becoming much more important in producing wind power. However, in terms of efficiency HAWT is more precisely compared to VAWT. In order to enhance the performance of VAWT, many researchers as well as producers are involve in developing different types of rotors. Hence, models are important since they can be use in predicting performance before fabrication, optimization of parameter, monitoring condition, as well as faulty detection and prediction [7]. Even though there is a lot of design that can be found for VAWT, Darrieus-type is the most popular one due to easy understanding for the electrical engineering network specifically. Furthermore, as wind energy is multidisciplinary domain with increasing resources, it has now become a huge importance in the practical of electrical engineering. There are two different kinds of Darrieus-type wind turbine in term of size shown in Figure 2.5 which is commonly used in non-rural area.

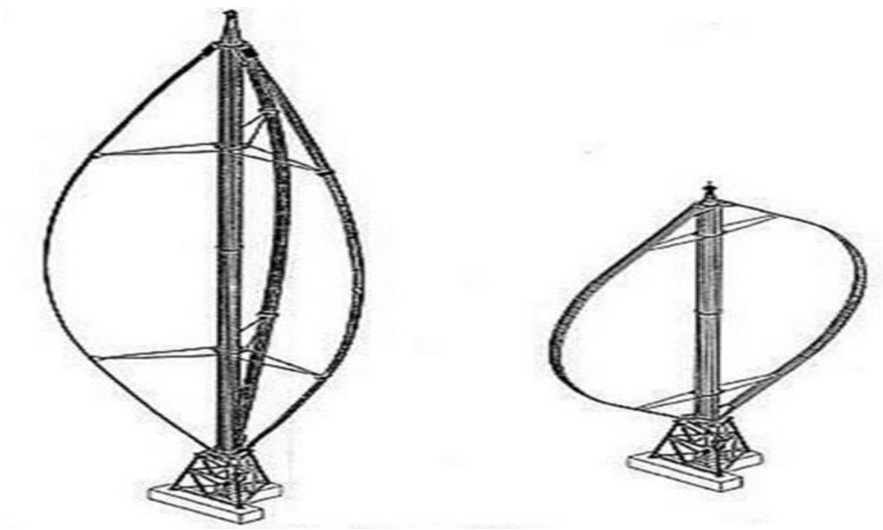

Figure 2.5: Darrieus-type wind turbine model [8]

2.4.1.2 Savonius-Type Wind Turbine

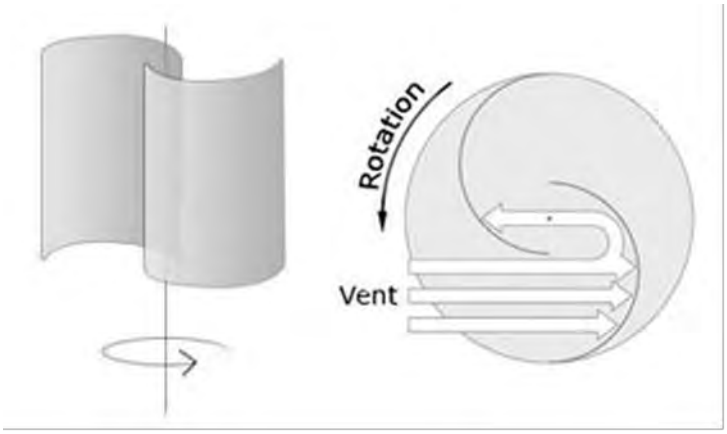

Figure 2.6: Savonius-type working principle [9]

S-type or known as Savonius-type is the most preferable vertical axis wind turbine because it is applicable in low wind speed condition. The rotors of VWAT moves in the same axis as the wind direction. ‘Drag force’ is one of the mechanisms that pushing the Savonius rotor as shown in Figure 2.6. The design of S-type blade is basically modification of ‘S’ rotor which is consist of concave and convex rotor [10]. Half part of the surface of the rotor move accordingly with the wind while the other is vice versa. The differences between these two semi-circular rotor blades are in term of creating the pressure and induces rotation. Advantages of using vertical axis Savonius-type wind turbine:

- Easy manufacture.
- Enable to capture any direction of wind speed and does not require yawing system like HAWT.
- Low-cost in term of manufacturing (small scale).

Table 2.1: Differentiation between Darrieus and Savonius type wind turbine

Darrieus-type	Savonius-type
Vertical rotor shaft	Direction of wind flows is the same axis as its rotation (horizontal direction).
Complex and difficult to manufacture.	Simple manufacture and low-cost.

2.4.2 Horizontal Axis wind Turbine (HAWT)

Generally, Horizontal-axis wind turbines or to be known as HAWT have the primary rotor shaft and electrical generator at the upper part of a tower. As an example, from the Figure 2.7 below explained the horizontal-axis which involve the 3 blades wind turbine model. Smaller size turbines are pointed by a basic wind vane, while larger size turbines basically utilize a wind sensor attached together with a servo motor. Commonly gearbox is included in HAWT [11]. It helps in increasing the speed of blades rotation where this is more preferable towards an electrical generator operation [11]. There are two styles for horizontal axis wind turbine blades known as 'Drag' and 'Lifting'. The Lifting style is the best for capturing the wind especially in high wind speed condition while for the drag style, it is created to capture the energy of increasing winds and commonly used for the water mill. In overall, the lifetime of a HAWT is set at around 20-25 years or 120,000 hours [12]. It needs a higher cost to conduct the maintenance and do a restoration on few parts because it is consisting of moving components like gearbox during their operation time.

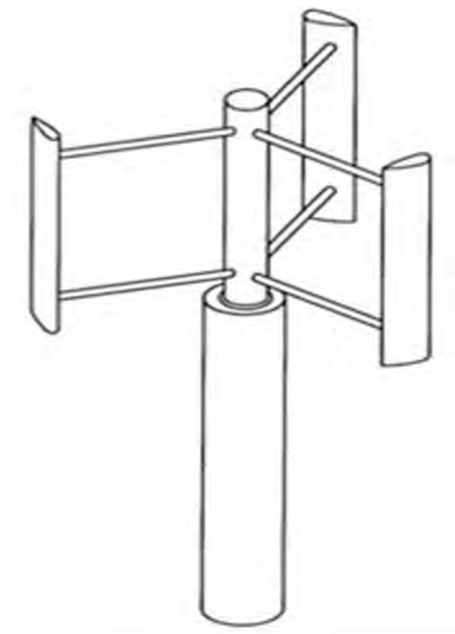

Figure 2.7: Horizontal axis wind turbine model (HAWT) [13]