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

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A report submitted
in partial fulfillment of the requirements for the degree of
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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.

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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.

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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/

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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.

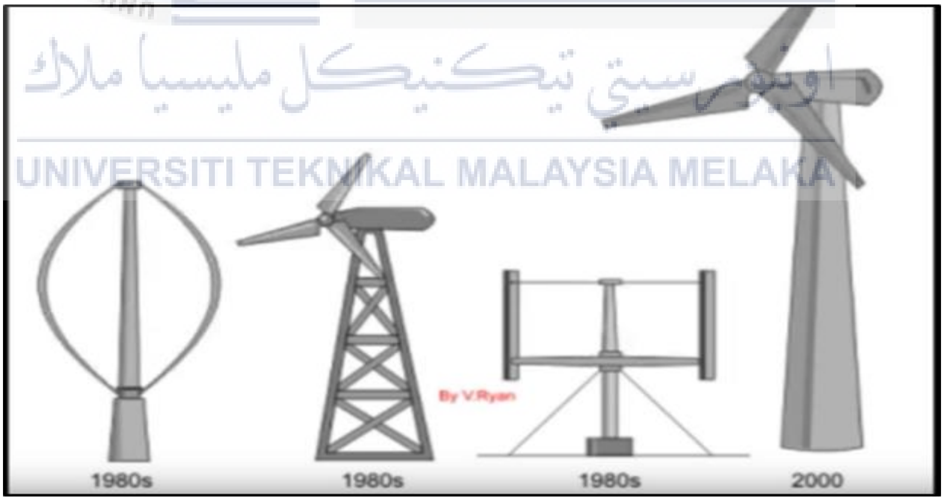

Figure 2.1: Design were built from 1980s to 2000

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].

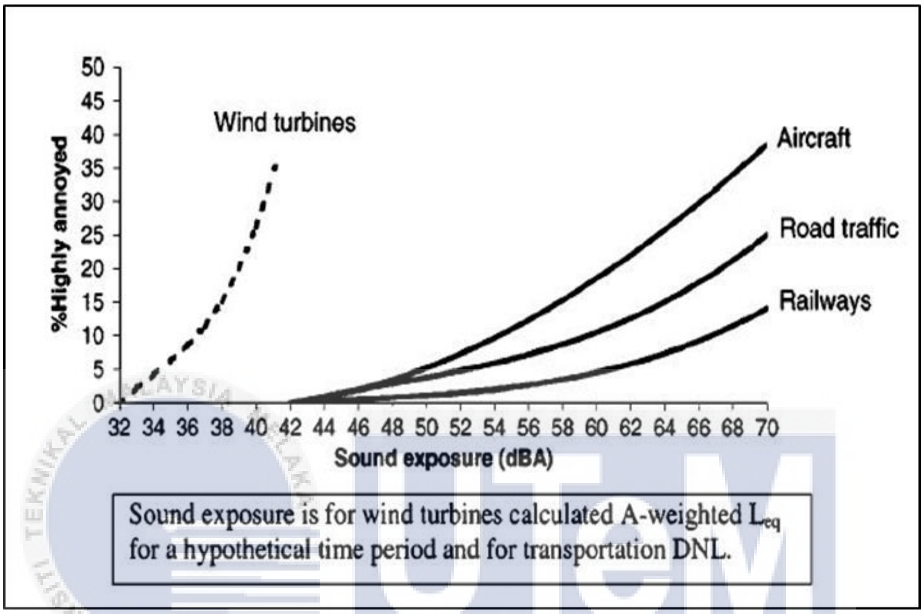

Figure 2.2: A graph of percent highly annoyed against sound exposure [23]

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].

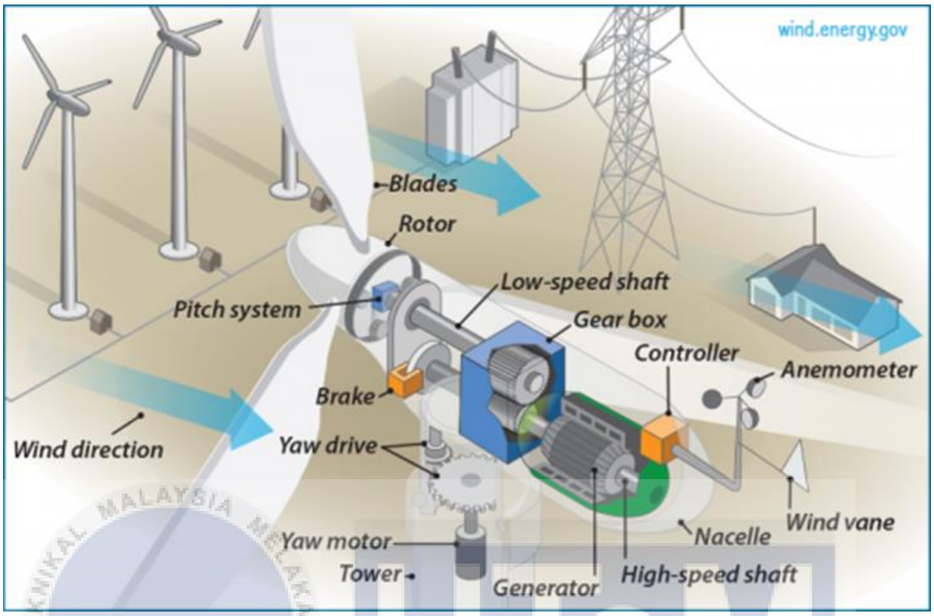

Figure 2.3: The wind turbine components [24]

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.

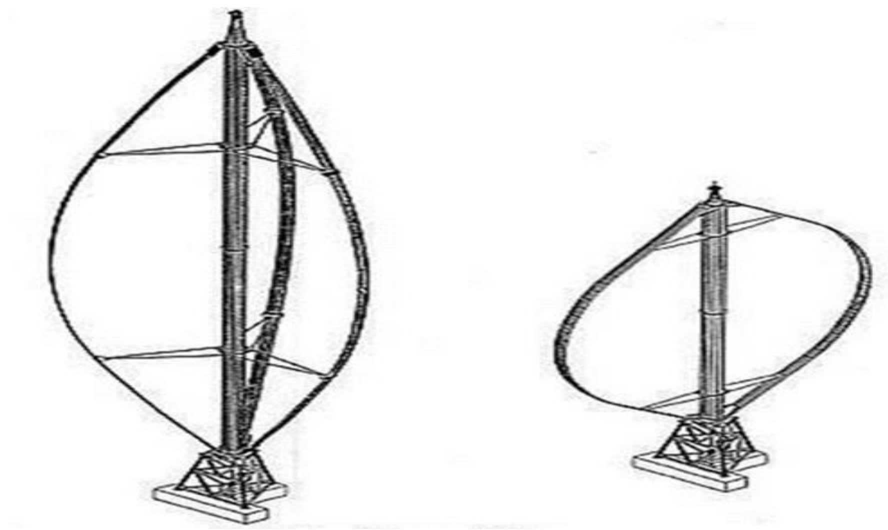

Figure 2.5: Darrieus-type wind turbine model [8]

2.4.1.2 Savonius-Type Wind Turbine

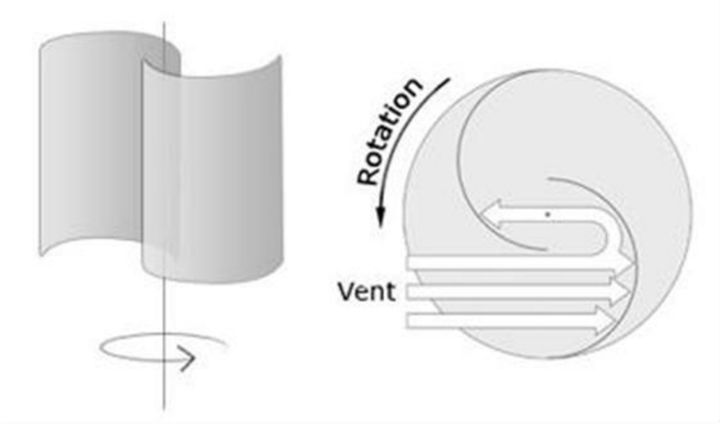

Figure 2.6: Savonius-type working principle [9]

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.

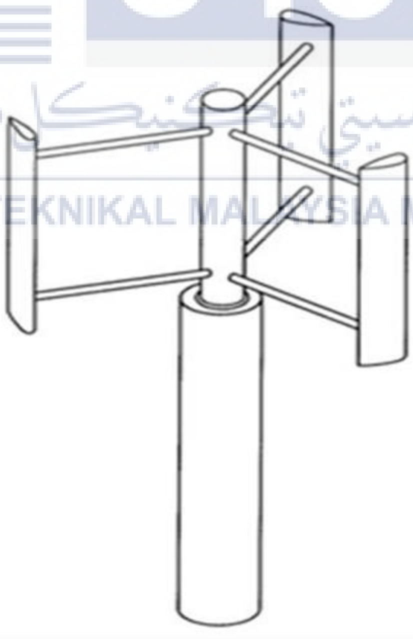

Figure 2.7: Horizontal axis wind turbine model (HAWT) [13]

Table 2.2: Comparison of Vertical Axis Wind Turbine (VAWT) and Horizontal Axis Wind Turbine (HAWT)

VAWT	HAWT
Able to operate starting from 2m/s winds speed.	Able to operate starting from 4 or 5m/s winds speed.
Tip speed ratio around 1.5 to 2 depends to the number of blades.	Tip speed ratio around 5 to 7 depends to the number of blades.
Does not create aerodynamic noise and totally quiet.	Aerodynamic noise will be created by the flow of air.
Low cost to construct because does not require yawing system.	High cost to construct because does not require yawing system.

2.5 Tip Speed Ratio (TSR)

The ratio of the velocity of the revolve blade tip to the velocity of free wind flow is known as TSR or Tip Speed Ratio. In order to develop a blade set and to perfectly match to a specific generator, TSR is used by wind turbine engineers [14]. In theoretical equation, TSR is known as [TSR= (ω*R)/V]. For a specific generator, the wind that flow through rotor cannot being captured if the blade rotates to slow. However, it is different when comparing to the blade that rotate fast because it enables to perform in well in turbulent wind. The ideal TSR depends on the number of blades. The less the quantity of blades, the quicker the wind turbine rotor needs to divert to extricate most extreme power from the wind. [4]

Table 2.3 : Approximate ideal TSR's for a certain number of blades

TSR	Number of Blades
2-3	5
5-6	3
6-7	2

TSR is commonly calculated by:

- An anemometer.
- A digital tachometer.

The tip speed ratio of VAWT is best presented from the graph in figure 2.8 until Figure 2.11 respectively:

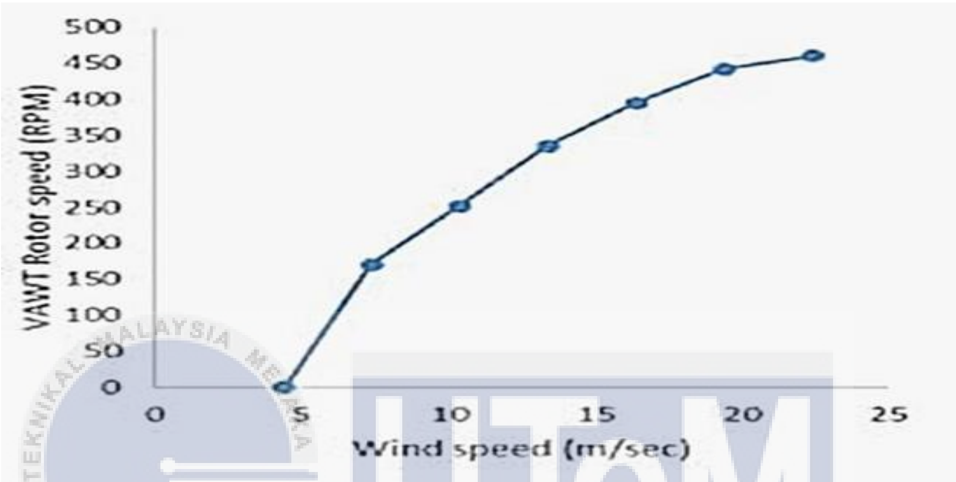

Figure 2.8: A graph of RPM versus wind speed [15]

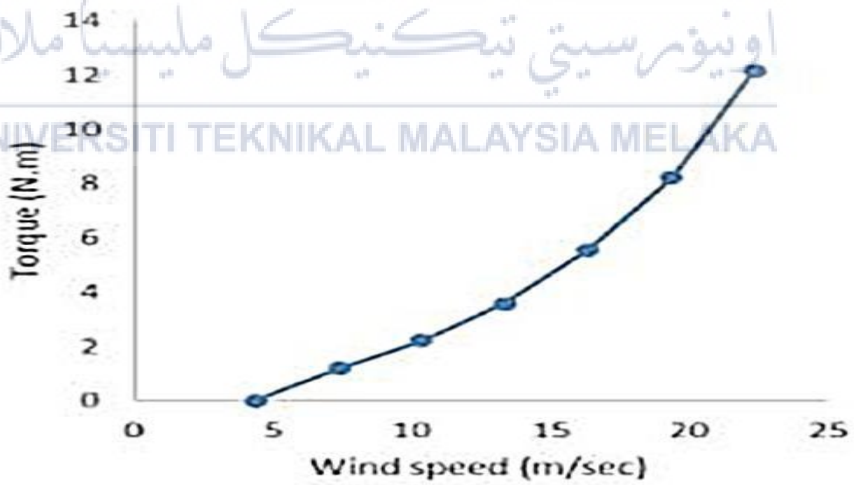

Figure 2.9: A graph of torque versus wind speed [15]

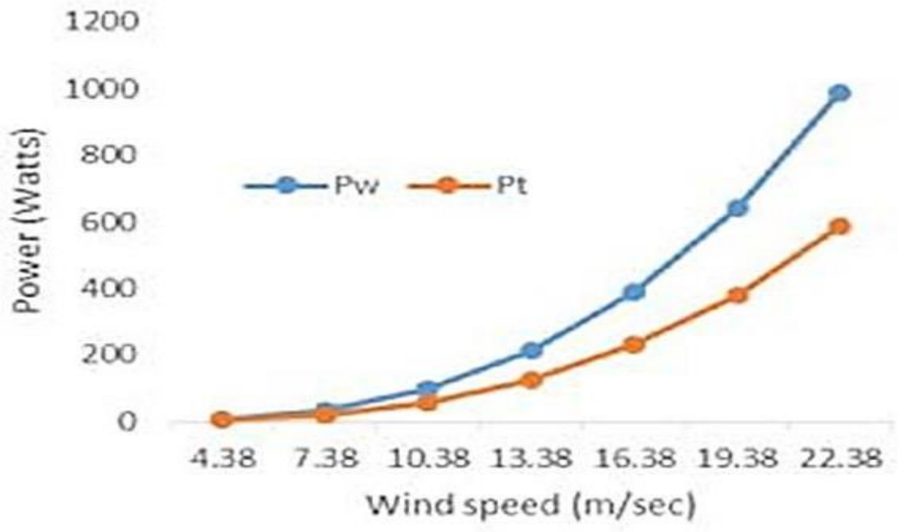

Figure 2.10: A graph of power versus wind speed [15]

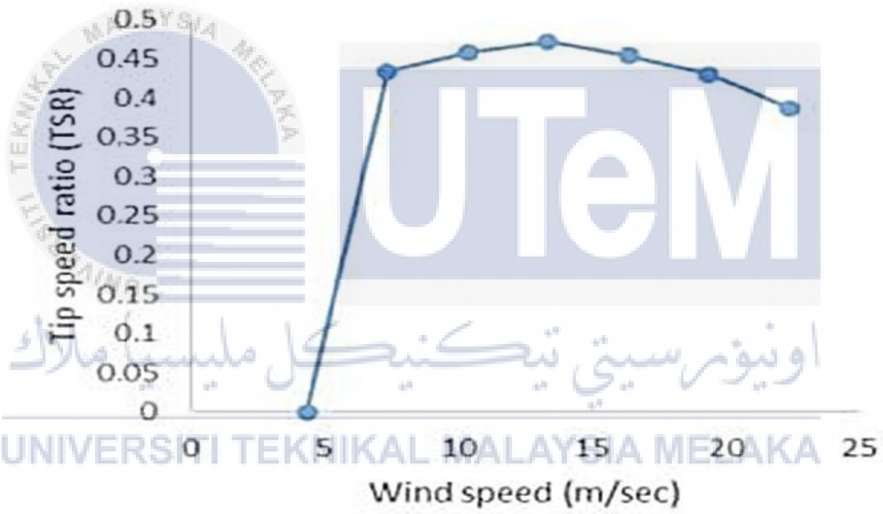

Figure 2.11: A graph of TSR versus wind speed [15]

From the graphs in the Figure 2.8, Figure 2.9, Figure 2.10 and Figure 2.11 shown above, [4] has conclude that TSR is directly proportional to the wind speed, but when it comes to the specific wind speed level, the TSR will maintained nearly a closure value. This parameter research shows the most effective of the wind turbine prototype.

2.6 Summary of review

No	Authors (years) & Title	Field of study	Project description
1.	**Lim, Chong, & Hsiao (2013)** [16] Performance Investigation and Optimization of a Vertical Axis Wind Turbine with the Omni-Direction-Guide-Vane.	This paper present a methodology on upgrading the structure of the omni-bearing-guide-vane (ODGV) which is used to boost the performance of VAWT.	An ODGC is created for a better performance VAWT and a two-level full factorial is utilized to recognize the VAWT performance critical factors.
2.	**Cheng et al. (2016)** [3] Aerodynamic modelling of floating vertical axis wind turbines using the actuator cylinder flow method	This paper offer to develop an aerodynamic code by using the AC technique for model floating VAWTs.	By using the dynamic stall model of Beddoes-Lieshman, the aerodynamic loads were determined by the helps of aerodynamic code which acting on the VAWT blades. From the study, it is proved that modified linear solution is better than experimental data in term of good aerodynamic power.
3.	**Giorgetti, Pellegrini, & Zanforlin (2015)** [17] CFD Investigation on the Aerodynamic Interferences between	This paper adds to comprehend physical systems associated with an attainable power improvement	The little size of these turbines and the generally low tipspeed proportion are in charge of low Reynolds numbers.

	Medium-solidity Darrieus Vertical Axis Wind Turbines	by setting VAWT in nearness	
4.	**Djamal Hissein Didane, Nurhayati Rosly, Mohd Fadhli Zulkafli, Syariful Syafiq Shamsudin (2016)** [18] Development and performance evaluation of a novel vertical axis wind turbine concept	The motivation behind this paper is to examine the benefits of utilizing the contrarotating idea to a VAWT framework while improving its change proficiency.	The examination uncovered this new framework's topology could improve the execution of the wind turbine by relatively fivefold and triple regarding power yield and aerodynamic torque individually at some random wind speed.
5.	**Sunny & Kumar (2016)** [4] Vertical axis wind turbine: Aerodynamic modelling and its testing in wind tunnel	This paper presents aerodynamic demonstrating, manufacture and the performance assessment of (VAWT).	Wind burrow test results demonstrated the adequate execution. Anyway future work ought to be done on choosing a high caliber and lighter weight material for structuring.
6.	**Galinos et al. (2016)** [7] Vertical axis wind turbine design load cases investigation and comparison with horizontal axis wind turbine	The investigation depends on aeroelastic calculations utilizing the HAWC2 air-servo-versatile code A 2-bladed 5 MW. VAWT rotor is utilized dependent on a changed rendition of the DeepWind rotor For the HAWT	From the load correlation between the VAWT and HAWT was discovered that the most extreme and the identical 1 Hz exhaustion basic curving of VAWTare a lot higher contrasted and the HAWT proportionate under ordinary power creation.

		reproductions the NREL 3-bladed 5MW	
7.	**Verelst et al. (2015)** [19] Integrated simulation challenges with the DeepWind floating vertical axis wind turbine concept	This paper introduces the encounters and difficulties with simultaneously doing numerical model advancement, incorporated simulations and structure of a novel coasting VAWT, the DeepWind idea.	This paper exhibited the difficulties experienced amid the DeepWind design in completing incorporated numerical simulations of the gliding VAWT idea
8.	**(Chaichana & Chaitep, 2015)** [2] Performance Evaluation of Co-Axis CounterRotation Wind Turbine	The present paper was examined the impact of TSR to the beginning revolution, rev up turn, power and torque coefficients of CRWT.	In this investigation, the CRWT is utilized which comprises of 2 center points 2 axis and 4 arms. The internal axis is clockwise turn and external axis is anticlockwise turn. The internal and external are in the similar axis. The two axis are driven the pulley by utilizing the counter turning rigging.
9.	**(Chowdhury, Mustary, Loganathan, & Alam, 2015)** [20] Adjacent wake effect of a vertical axis wind turbine	The principle target of this examination is to understand the impact of turbine situation and encompassing design.	From the wake investigation over a scope of expected wind and rotor speeds it was demonstrated that specifically downstream of a turbine enough flow

			of conservation was seen multiple times the distance across of the turbine downstream.
10.	**Wang, Hansen, & Moan (2014)**[21] Dynamic analysis of a floating vertical axis wind turbine under emergency shutdown using hydrodynamic brake	A 5-MW VAWT with a Darrieus rotor mounted on a semi-submersible help structure was analyzed in this examination.	In view of the coordinated model, a progression of load cases were chosen to examine the impact of the hydrodynamic brake and wind turbine shutdown process under ordinary working situation. The outcomes got from the correlation of the distinctive blame setups for each amount case are adequate for assessing the impact of the hydrodynamic brake on the FAVWT amid the shutdown procedure.
11.	**Feng et al. (2013)** [10] Torque Characteristics Simulation On Small Scale Combined type Vertical Axis Wind Turbine	In this examination the Savonius rotor was joined on the SBVAWT to improve its beginning torque on the grounds that Savonius rotor has great beginning torque coefficient.	In this paper, the torque execution of the straight bladed VAWT at low rotational speed is enhanced by making the Savonius rotor joined into the SB-VAWT.
12.	**Paulsena, Madsen, Hattel, Baran, & Nielsen (2013)** [22]	This paper diagrams consequences of a proposed format of a	The present paper shows the outcome of an increment directed on the

	Design Optimization of a 5 MW Floating Offshore Vertical-Axis Wind Turbine	light 2-bladed rotor, with a driving torque imperative coordinating the generator plan, and shows points of interest of the moulded blade and rotor calculation.	DeepWind idea, considering rotor structure. The present capacity of the wind production for the plan and development of the solid connection joints in composite blades makes the formed composite blades an interesting structure alternative. In any case, the related assembling cost is high when analyze with the pultrusion procedure
13.	**Bianchini et al. (2016)** [12] Critical Analysis Of Dynamic Stall Models In Low-Order Simulation Models For Vertical-Axis Wind Turbines	In the present investigation, the VARDAR examine code, depend on of the BEM hypothesis, is utilized to fundamentally analyze about the guessing of some dynamic stall prototype for Darrieus wind turbines.	In this examination, a basic investigation of three dynamic stall prototype for use in low-arrange simulations of Darrieus VAWTs was completed. Inside this specific situation, the utilization of a dynamic stall prototype in BEM codes is crucial.
14.	**Yen & Ahmed (2013)** [6] Improving safety and performance of smallscale vertical axis wind turbines	This investigation, thusly, proposes that diminished oscillatory burdens and more vigorous yield power can be accomplished with zero-net mass	A trial examination was completed to decide the effectiveness of utilizing ZNMF motivation to enhance the execution however further work must be done to explore

		transition activation on VAWT working at below blade speed proportions.	the reliance of vortex elimination with ZNMF energy coefficient on a VAWT prototype.
15.	**El-Samanoudy, Ghorab, & Youssef (2010)** [15] Effect of some design parameters on the performance of a Giromill vertical axis wind turbine	This paper illustrates the impact of some plan parameters on the execution of a Giromill VAWT.	The impact of some structure parameters, for example, pitch point and airfoil type has been recently presented with some test information for correlation and investigation. Yet, no examinations were completed to decide the impact of various parameters variety, for example, number of blades, arc length, turbine space, pitch edge and airfoil category.

CHAPTER 3

METHODOLOGY

This part reviews the methodology of this project. First the model is described. At that point, the prototype is being tested experimentally. Thus, the experiments are explained in term of experimental setup, fabrication of prototype and also the procedures.

3.1 Designing the Counter-rotating Wind Turbine Prototype

The procedure in building up this model included the designing, fabrication, installation and observe the prototype and also collecting data from the lab experiment. Figure 3.1 reveal the flowchart that clarified about the procedure of modelling the CRWT prototype. In the beginning, the vertical axis wind turbine is created by modelling Savonius-type wind turbine. The modelling process is redo until the Savonius-type shape is establish. Then the S-type will combine with the H-type blade. The experiment will be manage starting from 2 m/s which is low-wind speed condition. The data is taken from the test. If the data taken is not valid, the test will be organized again. The procedure is repeated until the CRWT model can be work at low-wind speed condition. Generally, wind turbine cannot generate power in direct current (DC), so a bridge rectifier is utilizing to convert the alternating current (AC) to direct current (DC). To supply the collected energy, an inverter which borrowed from faculty is used. Next, to protect the batteries from overcharging, a charge controller also is used.

This model counter rotating wind turbine is planned by joining the Savonius and Darrius wind turbine where S-type rotor shape is being put on top while H-type rotor shape is being set at the base of the model. The upper rotor that is associated with thepole is considered as the primary rotor and the lower rotor that is connected to the generator is allocated as the auxiliary rotor.

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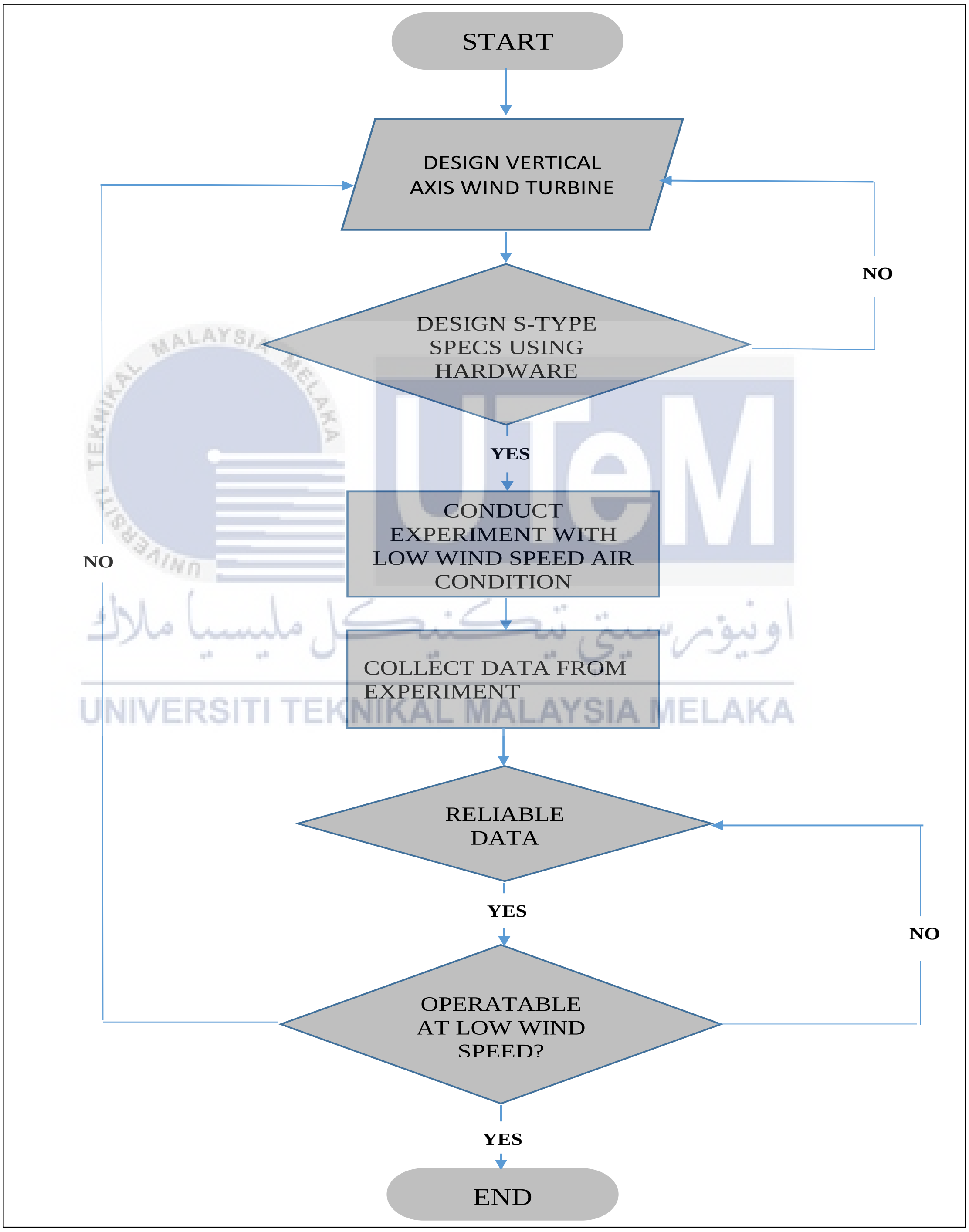

Figure 3.1 : Process of designing the S-type blade design

3.2 Gantt Chart and Key Milestone

3.2.1 Gantt Chart

Table 3.1: Project Gantt chart

Tasks	October			November				December				March				April				May				June			
	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Literature Review	■	■	■	■	■	■	■																				
Significant finding of Title	■	■	■	■	■	■	■																				
Developed Methodology and Design using Solidworks				■	■	■	■																				
Collecting and Analyze Data					■	■	■	■	■																		
Writing Report			■	■	■	■	■	■	■	■	■																
Presentation PSM 1						■	■																				
Fabrication and Collecting more data												■	■	■	■	■	■	■	■	■	■	■	■				
Do an analysis												■	■	■	■	■	■	■	■	■	■	■	■				
Writing Report			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
Presentation PSM 2																						■	■				
Send final report																									■	■	

3.2.2 Key Milestone

Table 3.2 shows the key milestone of this project.

Table 3.2 : Key Milestone

Project Progress	Duration
Collect all of Journal and Literature Review	21 SEPTEMBER 2018
Design prototype using solid works	1 NOVEMBER 2018
Write progress report draft	3 NOVEMBER 2018
Prepare presentation slide for first seminar	13 NOVEMBER 2018
First seminar PSM 2018/2019	22 NOVEMBER 2018
Submit Report	7 DECEMBER 2018
Fabrication process	2 MARCH 2018
Collect the data	14 APRIL 2018
Do a final analysis	30 APRIL 2018
Write progress report draft	17 MAY 2018
Second seminar PSM 2018/2019	29 MAY 2019
Submit Report	19 JUNE 2018

3.3 Experimental Setup Equipment and Fabrication Process

The basic wind turbine parts such as generator, two sets of rotors, shaft and PVCs were used as an experimental device in order to set up and installing the CRWT prototype.

3.3.1 Blades profile selection

There are a few factors that were viewed as while choosing the proper material for the blade creation, for example, weight, weakness quality, cost, local manufacturing ability and accessibility. It is crucial to pick the materials that are lighter, affordable, simple to create and fit to withstand high wind condition [30]. The blade material ought to be lightweight with the goal that it can begin at low wind speed conditions with the end goal to accomplish more effective and productive behavior of the system [31]. The blades of the hybrid-counter rotating model are produced using a symmetrical NACA 4-digit arrangement with H-type Darrius rotor. Thus, the NACA0012 profile with 21 mm thickness was embraced in this analysis. This NACA0012 is applied because its blade shape is one of the most measured and ordinarily used as a rotor blade aero foil segment [4]. A pinewood material is applied for H-type Darrius rotor shape since of its light, moderately solid, affordable and adaptable. Hence, a sum of three wooden blades was made where the height and the length of each blade is 50cm and 10cm individually as appeared in Figure 3.2. Next, Figure 3.3 and Figure 3.4 showed the certain aspect of the blade which are the top and the front view.

Due to its good resistance to disturbance, a galvanized steel is utilized for the S-type rotor because it can withstand in high vibration and disturbance. The main reasons it was selected because of its effectiveness where it can withstand high pressure due to its high tensile strength. The height and the length of each Savonius blade are 10m and 38cm which were installed in the prototype respectively as shown in Figure 3.5. The model of the Savonius blade consists of the-top and side-view is shown in the Figure 3.5 to Figure 3.7.

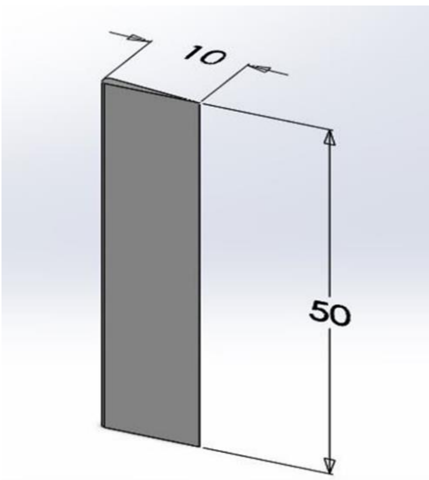

Figure 3.2 : Dimension of H-type blade design

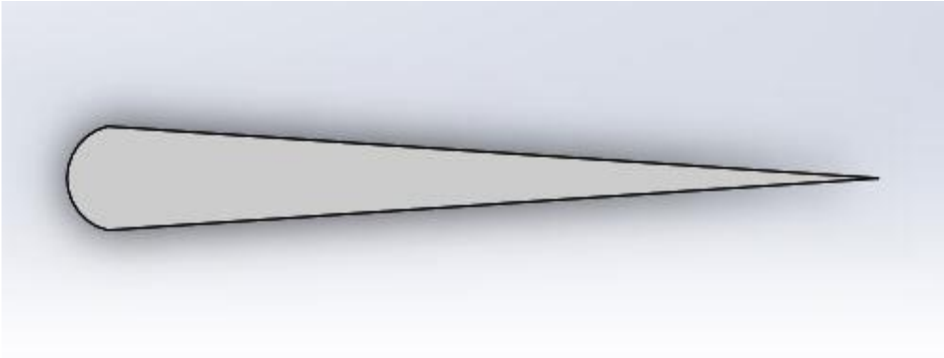

Figure 3.3 : H-type blade profile using NACA 0021airfoil

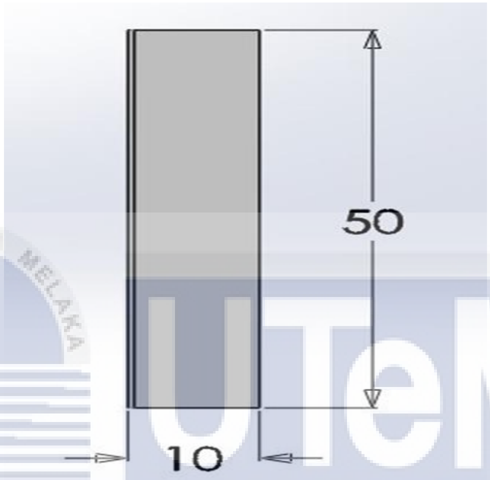

Figure 3.4 : Front view of H-type blade design

Figure 3.5 : Dimension of S-type blade design

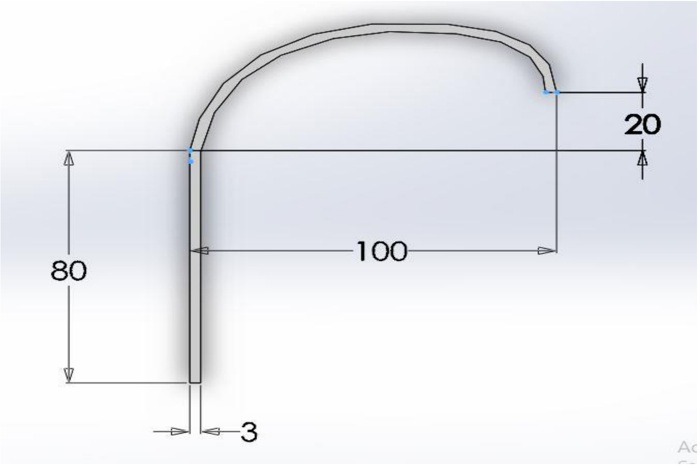

Figure 3.6 : Top view of S-type blade design

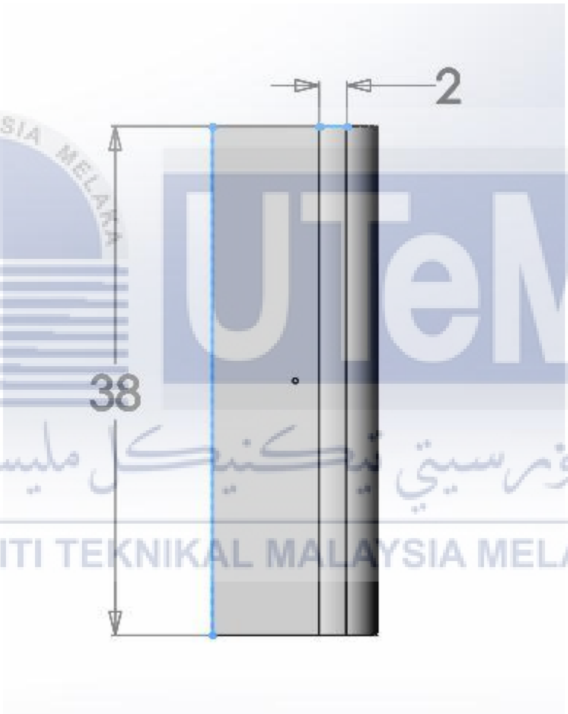

Figure 3.7 : Side view of S-type blade design

3.3.2 Generator

One of the crucial parts of the wind turbine is a generator which is responsible in changing over the kinetic energy into usable power. This generator revolves alongside the shaft and to ensure that rotor moves with efficiently, a bearing is being installed at the base of the system. The generator that expected to be used in this project is a NE-100 model where the diameter, height and shaft length are 145mm, 65mm and

28mm individually. The generator for this prototype has not been decided yet due to only focusing on study about wind turbine in final year project 1. The aspect for the generator descriptions is shown in the Table 3.3.

Table 3.3 : Generator Specifications

Feature	Specifications
Model	NE-100
Rated Power (W)	100 W
Maximum Power (W)	130 W
Rated Voltage (V)	12/24 V
Rated Rotation Speed (RPM)	750 rpm
Size (Height x Diameter x Shaft length)	(65 x 145 x 28) mm
Net weight	3.5 kg
Generator configuration	3 phase permanent magnet synchronous alternator

3.3.3 Bearing

In this prototype, a bearing is used for the generator and the function of this bearing is to ensure the smooth and easy rotation of the rotor. This bearing gives smoother spinning of the rotor and attain high rotational speeds (RPM). A higher RPM means a higher volume of electricity will be generated by the wind turbine.

3.4 Testing the prototype

Figure 3.8 described the evaluating process where the prototype is set up and tested at the Faculty of Mechanical Engineering Laboratory at Universiti Teknikal Malaysia Melaka (UTeM). A wind tunnel is used to test the prototype with 7.5 kW capacity, 10 HP capacity and 2880 rated RPM. The prototype is left in the open air at the vent of the wind tunnel. The capability and the performance of the prototype is analyzed at low wind speed condition. A digital temperature and vane anemometer were used to investigate and measured the wind speed from 0.4 to 20 m/s range. The wind speed is tried beginning from 2 to 9 m/s.

By measuring its power output and also the mechanical torque, the performance of the prototype is determined at the different wind speed level. In order to measure the RPM of the rotor, a digital tachometer was used and finally the power output will increase. By using the specific formula, the value of the RPM achieved from the experiment will later be used to calculate the value of power and torque output produce by the wind turbine system.

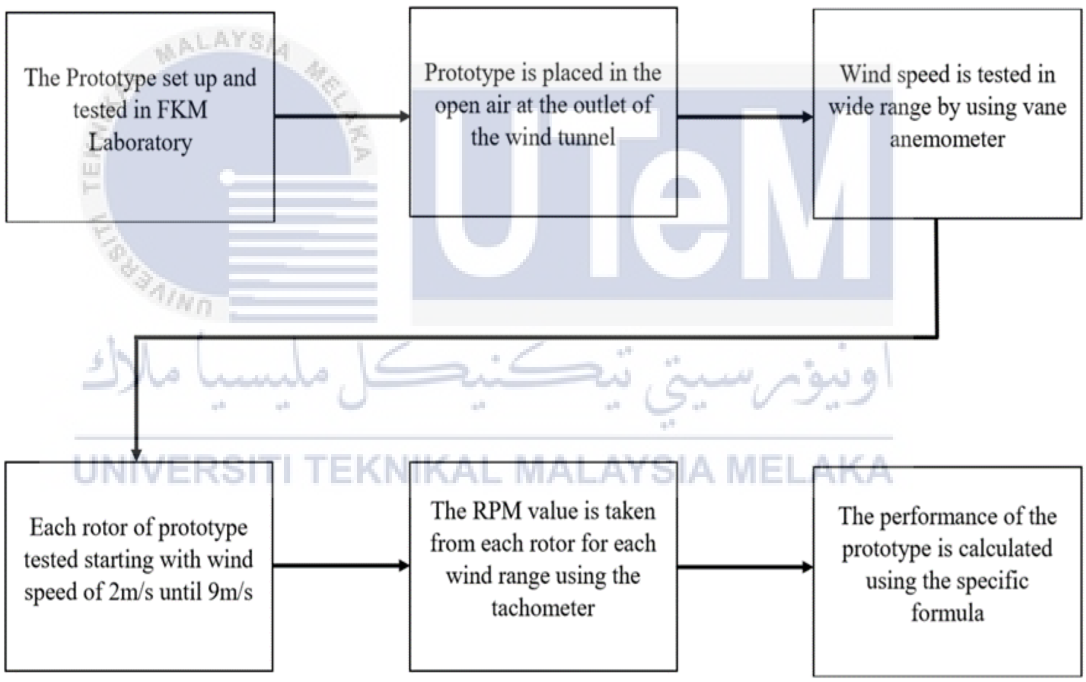

Figure 3.8: Schematic diagram of testing process

3.5 Experimental Device

Multimeter, vane anemometer and tachometer were used in this test to calculate the torque and power output. The function of the vane anemometer is to evaluate the wind speed while the tachometer is to determine the RPM value of each rotor. Figure 3.9 shows the list of devices that is used for this experiment.

(a)Voltmeter reading

(b)Vane Anemometer

(c)Tachometer

Figure 3.9: List of experimental equipment

3.6 Experimental Set-up

First the prototype is being set in Mechatronics Laboratory as presented in figure below. After that, the testing and experimenting the prototype will then begin using wind tunnel which located at Instrumentation Laboratory, FKM.

Figure 3.10 : S-type wind turbine

Figure 3.11 : H-type wind turbine

Figure 3.12 : Wind Tunnel in lab

3.7 Theoretical Formulation

In order to obtain the objective of this project, the theoretical equation that was used to calculate the desired output quantities was explained in this section. Wind turbine torque, power, torque coefficient and power coefficient are the several theoretical value that have been used in this research.

3.7.1 CRWT Power and Power Coefficient

The CRWT power must achieve first so that the performance of the prototype and the best possible power rating are decided. The power also will allow this research to produce the suitable power-curve-of-current and utilized it to observe the general state of the model. Equation below shows three equations are used in this part which the first equation is theoretical power, the second equation is actual mechanical power and the third is the maximum power extractable from the prototype

$$P_w = \frac{1}{2}\rho A V^3 \tag{3.1}$$

$$P_T = T_m \times \omega \tag{3.2}$$

$$P_{ex} = (0.593) T_m \times \omega \tag{3.3}$$

While power coefficient is referring to the performance and productivity of a wind turbine and also characterize as the proportion of actual power to theoretical-power in the prototype. Betz's theory stated that only 59.3% of the maximum power can be separated from the wind turbine since it encounters air friction and air drag on the rotor blades. The equation of power coefficient generated from wind turbine performance can be referred on the Equation 3.4,

$$C_P = \frac{P_{ex}}{P_w} = \frac{2Tm \times \omega}{\rho A V^3} \tag{3.4}$$

3.7.2 Tip Speed Ratio (TSR)

TSR is the proportion of the upstream tip speeds of blades to the approaching free stream speed. In order to get an accurate TSR, it is important to appropriately design the wind turbine blades and select a suitable generator. TSR is determined in Equation 3.5 below for a blade of radius, R.

$$TSR = \frac{R\omega}{V} = \lambda \qquad (3.5)$$

Equation 3.6 shows that the blade rotational velocity (N) in rpm is related to the angular velocity, (ω) in radius per second.

$$\omega = \frac{2\pi N}{60} \qquad (3.6)$$

3.7.3 CRWT Torque and Torque Coefficient

In order to choose the proper shaft, the torque of the rotor shaft must be calculated so that it can be determined whether the rotor shaft can withstand to the subjected load or not. To verify the exactness of the results and the reliability towards assumptions that were produced from the earlier study are by obtaining the value of torque. Equation 3.7 shows the equation for the rotor thrust force while equation 3.8 are the equation for the rotor theoretical torque.

$$F = \frac{1}{2}\rho_a AV^2 \qquad (3.7)$$

$$T = \frac{1}{2}\rho_a AV^2 \qquad (3.8)$$

The ratio of real torque and the theoretical torque are known as the torque coefficient, CT. The solidity of the prototype can be determined from the torque coefficient where the optimum range of solidity factor has been set from 0.2 to 0.6. Equation 3.9 below shows the equation of the torque coefficient, CT,

$$C_T = \frac{2Tm}{\rho_a Av^2 R} \qquad (3.9)$$

CHAPTER 4

RESULTS AND DISCUSSIONS

This segment talked about the results which includes the design of each blade that will be tested in terms of performance in low air flow situation. The results are given regarding of quantitative aerodynamic specifications which are power, torque, power coefficient and torque coefficient.

4.1 Performance Analysis for Prototype

4.1.1 Evaluation of Rotational Speed (RPM)

The RPM value that obtain from the performance of the prototype is calculated and explained in this section. From the experiment, it has been shown that the rotational speed for both rotors kept increasing as the wind speed increase. The prototype has been tested with the range of wind speed starting from 2 m/s until 9 m/s. As expected, the main rotor (S-type rotor) can start to rotate from 2 m/s because of its good self-starting performance.

However, the auxiliary rotor (H-type) only can start to rotate from 5 m/s. From the Table 4.1, the RPM value for main motor is greater than the rpm value of auxiliary rotor. The main reason is because the main motor is only rotated the shaft while the auxiliary rotor is attached to the generator which effect its rotational speed as it rotated slower.

Table 4.1: Experimental rotational speed of prototype

Wind speed (m/s)	Revolution per minute (RPM)		
	H-type rotor	S-type rotor	CRWT
2	0	60	60
3	0	80	80
4	0	97	97
5	23	110	133
6	35	130	165
7	50	146	196
8	58	158	216
9	76	171	247

The data collected from the Table 4.1 has been explained into graph as shown in the Figure 4.1. From the graph, it shown that the performance of CRWT has been improved significantly in term of rotational speed due to the combination of the two rotors. The advantage achieved by using the of S-type rotor, CRWT system can generate power output as low as 2 m/s of wind speed because of the behavior of the S-type itself which is a good start.

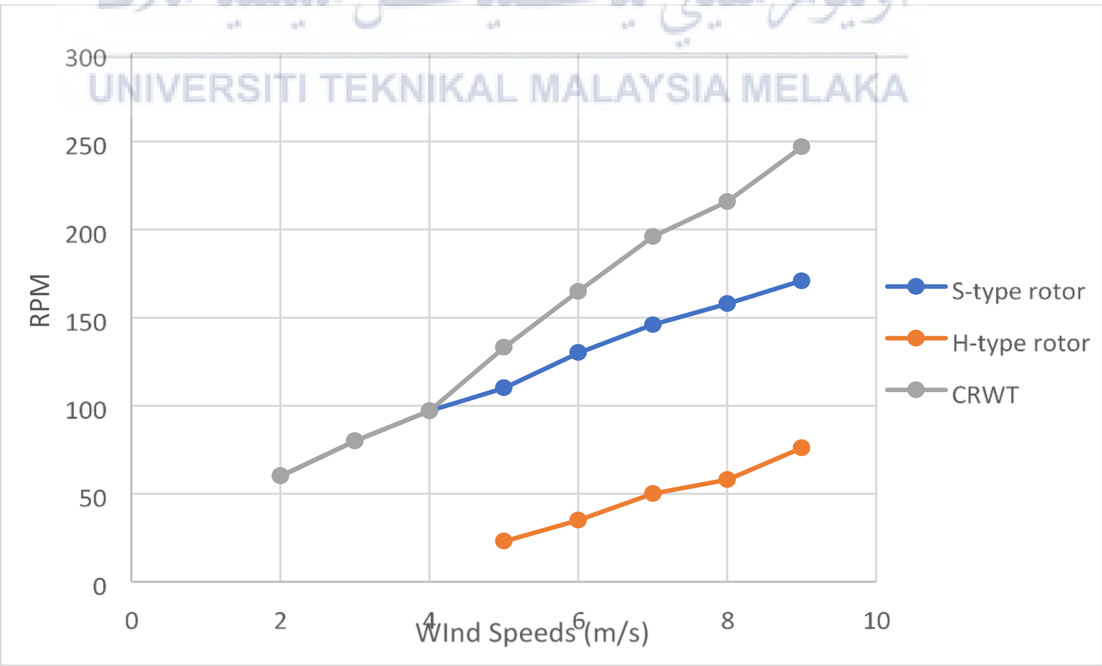

Figure 4.1: A variation graph of RPM for each rotor and CRWT system

4.1.2 Evaluation of Mechanical Torque Input

Another significant aerodynamic performance of the model which is the mechanical torque input from the test. The model was tested and set up with the exact procedure as before. From the Table 4.2, it displays that, the torque input for S-type rotor de-escalate as the speed of the wind rise. This can be defined by the neediness of the S-type rotor to be lesser in the input of torque so that higher rpm is gained. In another point of view, the input of the torque of the rotor of the H-type surging up meaning that the H-type rotor acquire bigger torque input to gain a larger rpm.

Table 4.2: Experimental mechanical torque input results of prototype

Wind speed (m/s)	Revolution per minute (RPM)			Torque Input (Nm)		
	H-type rotor	S-type rotor	CRWT	H-type rotor	S-type rotor	CRWT
2	0	60	60	0	0.05	0.05
3	0	80	80	0	0.08	0.08
4	0	97	97	0	0.12	0.12
5	23	110	133	0.09	0.16	0.25
6	35	130	165	0.21	0.22	0.43
7	50	146	196	0.43	0.29	0.72
8	58	158	216	0.58	0.33	0.91
9	76	171	247	0.99	0.38	1.37

From the Figure 4.2, it can be demonstrated that the input of torque of the H-type rotor increase drastically relatively at large circular speed while torque input of S-type is slightly small. It shows that the design of S-type is pretty good compared to H-type as it only requires a small torque input to attain bigger rpm.

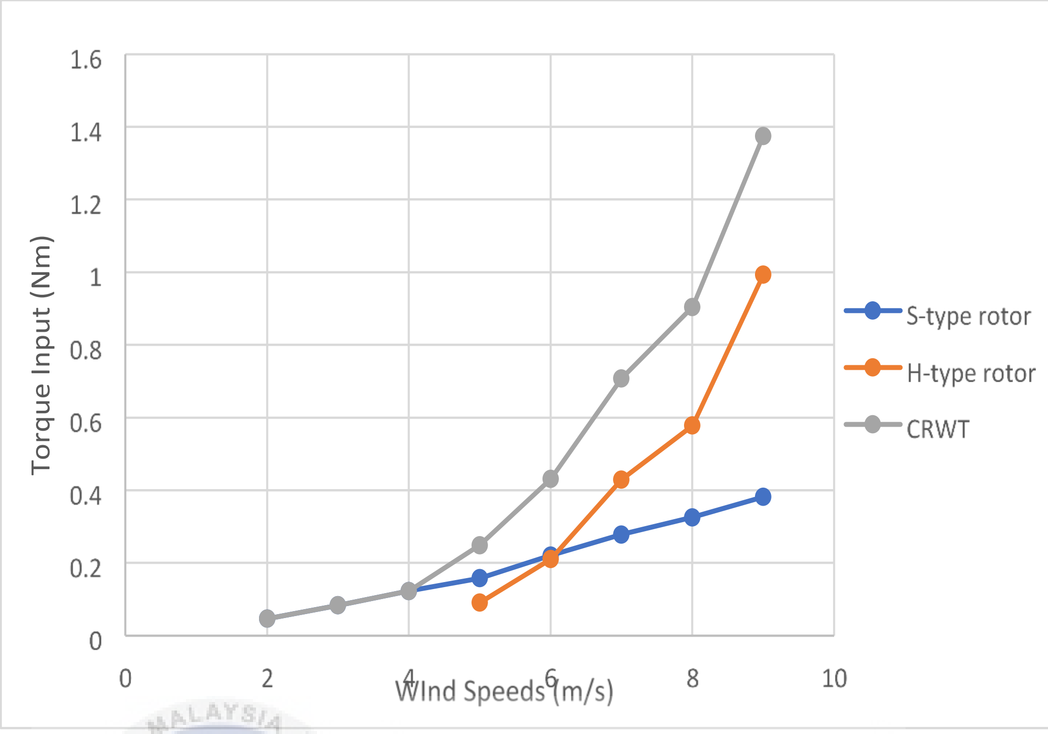

Figure 4.2: A variation graph of torque input for each rotor and CRWT system

4.1.3 Evaluation of aerodynamic coefficients

From the experiment, the data achieved can be calculated to find the aerodynamic coefficients such as power and torque coefficient. To determine the behavior of the CRWT system and to analyze the parameters, it is crucial to find the aerodynamic quantity first such as the optimum or rated wind speed and optimum tip speed ratio (TSR).

4.1.3.1 Evaluation of Power Coefficient

As tabulated in Table 4.3, it tells that obvious differences were discovered between the conversion efficiency of S-type rotor and H-type rotor. The increment of the power coefficient for S-type rotor obtained at lower wind speeds was larger than at high wind speed but for the H-type rotor is vice versa as shown in Figure 4.3. This is because S-type rotor has a bigger drag force based on its surface area of blades which are facing the upcoming wind. Meanwhile, the H-type rotor has a minimize surface area thus its drag force is pretty small that's why it has a larger power coefficient compared to Rotor 1.

Table 4.3: Experimental power coefficients results of prototype

Wind speed (m/s)	Power coefficient C_p		
	S-type rotor	H-type rotor	CRWT
2	0.942	0	0.942
3	0.588	0	0.588
4	0.442	0	0.442
5	0.330	0.040	0.370
6	0.315	0.081	0.396
7	0.281	0.149	0.430
8	0.239	0.156	0.394
9	0.213	0.246	0.459

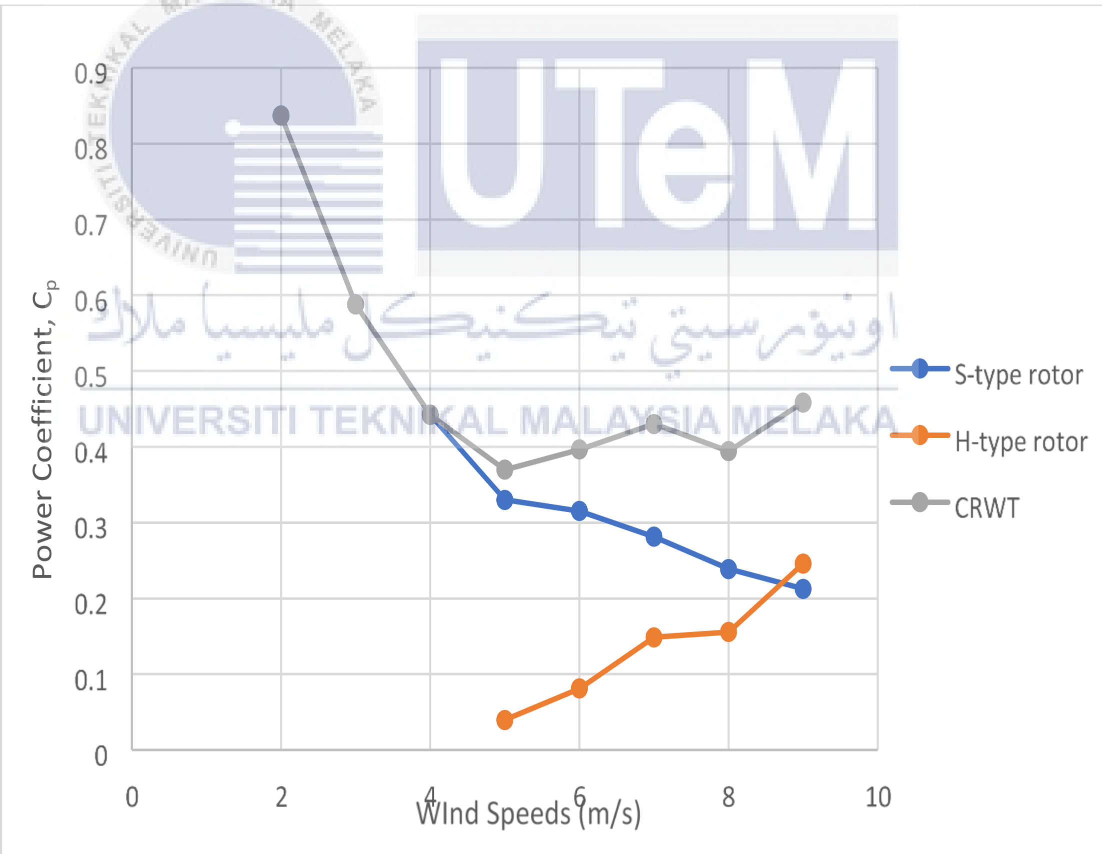

Figure 4.3: A graph of power coefficient each rotor against wind speed

4.1.3.2 Evaluation of Torque Coefficient

A significant trend was discovered for aerodynamic performance analysis in terms of torque coefficient as displayed in Table 4.4 and illustrated in Figure 4.4. It looks that the H-type rotor has better torque coefficients in term of high speed of the wind than S-type rotor but the sum of torque coefficient gained from the summation of the two rotors have been led to the enhancement of the system efficiency. The high value of the sum of torque coefficients of both rotor is due to the self-starting ability from the S-type rotor which can circulate as low as 2 m/s wind speed and H-type rotor which require more input of the torque to attain a better or much higher RPM.

Table 4.4: Experimental torque coefficients results of prototype

Wind speed (m/s)	Torque coefficient, C_t		
	S-type rotor	H-type rotor	CRWT
2	1.000	0	1.000
3	0.702	0	0.702
4	0.580	0	0.580
5	0.477	0.275	0.752
6	0.463	0.442	0.905
7	0.429	0.663	1.092
8	0.385	0.683	1.068
9	0.356	0.927	1.283

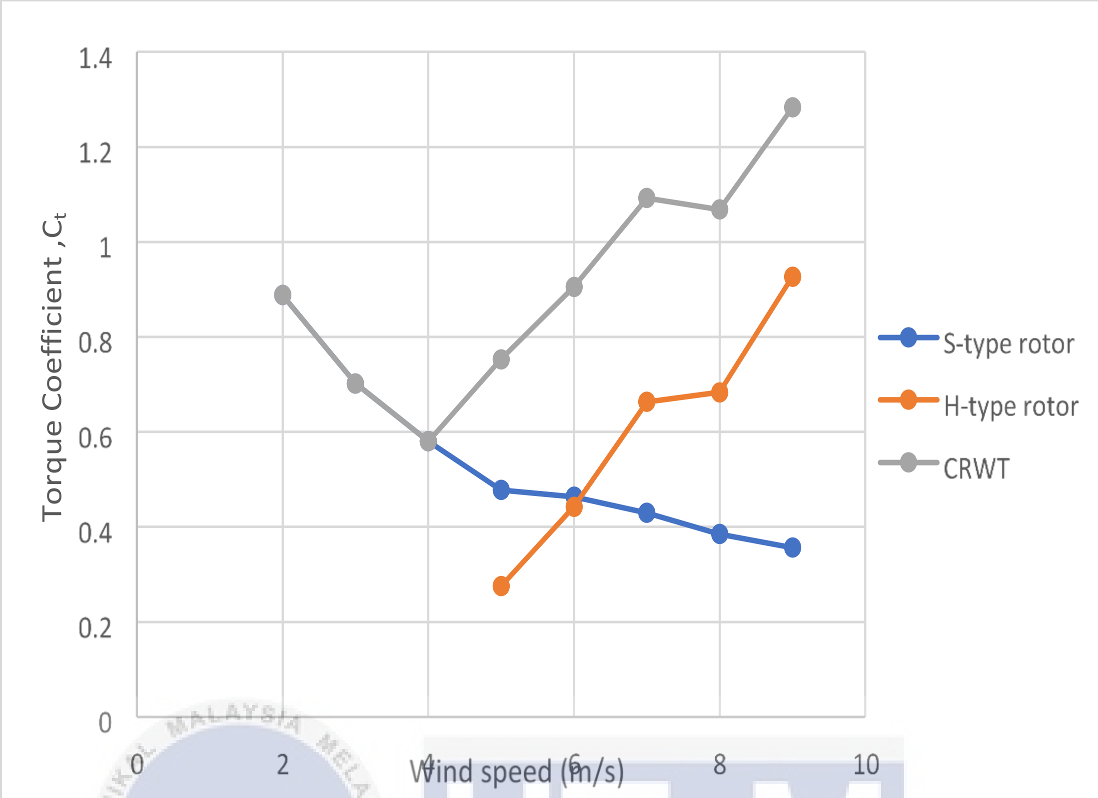

Figure 4.4: A graph of torque coefficient each against wind speed

4.2 Comparison between CRWT of S-type and H-type rotor and CRWT of both H-type rotors system

The study before has been done by using both H-type rotors as its primary and auxiliary rotor in CRWT system [1]. The comparison of the performance between two distinctive CRWT system is analysed by the aerodynamic parts or components of rpm and input of mechanical torque in each system. As illustrated in Figure 4.5, the CRWT of S-type and H-type rotor begin to rotate at wind speeds of 2 m/s meanwhile the Counter Rotating Wind Turbine (CRWT) of both H-type rotors can only get going to rotate at 5 m/s.

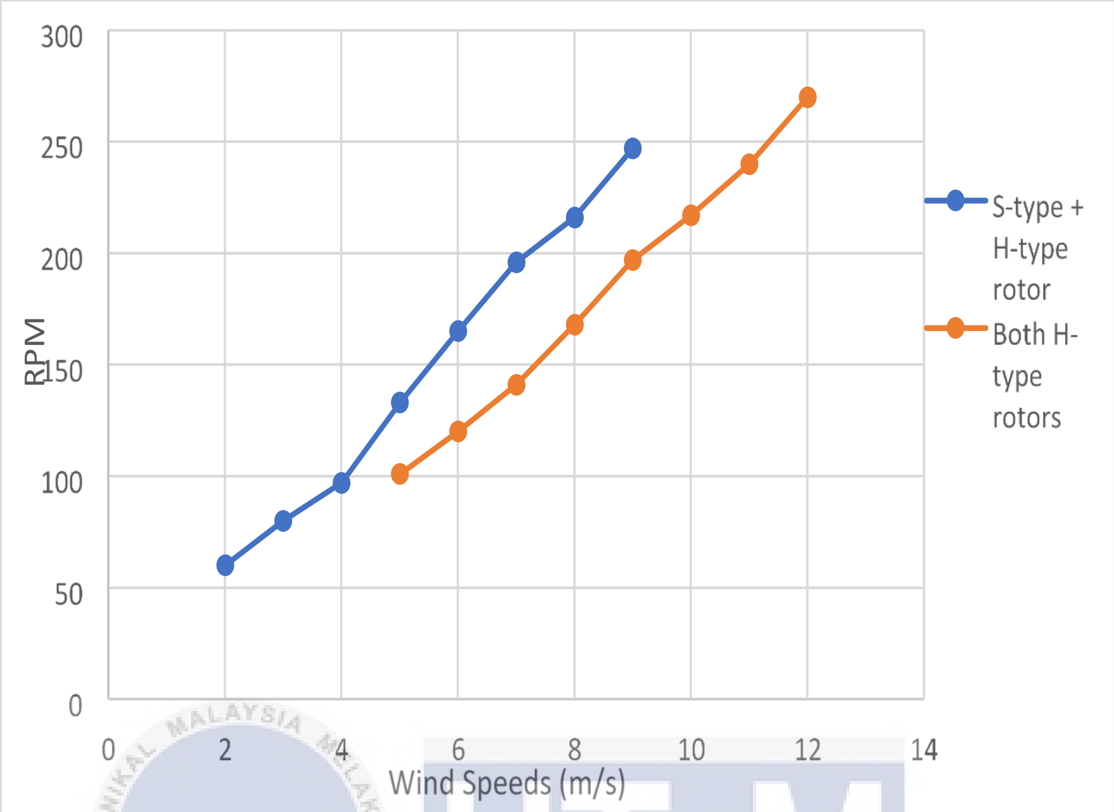

Figure 4.5: Comparison of rpm between CRWT of S-type and H-type rotor and CRWT of both H-type rotors

As CRWT of both H-type rotors does not have a good self-starting like S-type rotor, it can only start to rotate at 5m/s. The RPM of this CRWT increases as the speed of wind increases. Yet the maximum RPM which can be achieved was 270 at the wind speed of 12 m/s as shown in Figure 4.5. Meanwhile, for the CRWT of S-type and H-type rotors, it generated a maximum RPM of 250 at low wind speed at 9 m/s as shown in Figure 4.1. From this analysis, it was proven that the CRWT with the combination of S-type and H-type rotors came out with a better result as this model is able to produce a maximum RPM at a very low wind speed condition compared to CRWT system which consists of both H-type rotors.

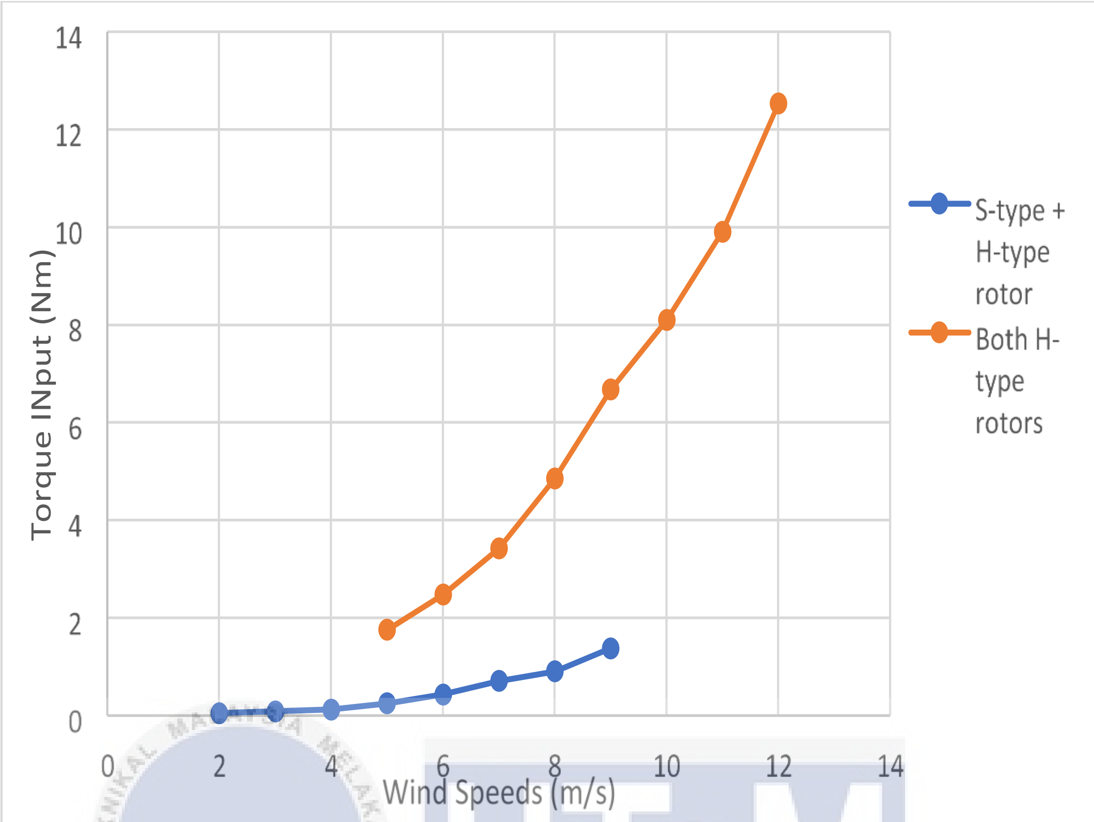

Figure 4.6: Comparison of torque input between CRWT of S-type and H-type rotor and CRWT of both H-type rotors

Meanwhile, another comparison of performance in term of torque input between two CRWT systems also have been made. Torque input for CRWT of both H-type rotors has increase as the wind speeds increase. The maximum torque input for this CRWT system is 6.449 Nm at 12 m/s. While for the CRWT of S-type and H-type rotor the maximum torque input is only 1.375 Nm at wind speeds of 9 m/s as illustrated in Figure 4.6. From this analysis, it can be concluded that this CRWT of both H-type rotors need more torque input to produce a maximum rpm compare to CRWT of S-type and H-type rotor.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

Chapter 5 discusses the main objectives and aims that have been achieved for this study. Findings from the experimental approach of the development and evaluation of CRWT which involve the Savonius and also Hype rotors will also be included in this chapter.

5.1 Conclusion

The execution of the VAWT prototype will assessed from trial approach by testing the model utilizing wind burrow with scope of wind speed beginning from 2 m/s until 9 m/s. Torque, power, torque coefficient and power coefficient are the parameters that be calculated. In order to identify the performance of each prototype, taking the RPM is necessary by using the tachometer. This research has built up dependent on three objectives. The first objective has been obtained by gaining a lot of information and knowledge from previous research in order to identify which type of wind turbine that applicable in low wind speed condition. Previous research has shown that vertical axis wind turbine or known as VAWT was the most suitable which used especially in low wind speed area compare to HAWT which not able to operate well in such condition. It proved that only VAWT can operate well in low air flow beginning from 2m/s wind flow [5]. Savonius and H-type Darrieus are the type of VAWT which have been studied due to the low cost, not difficult to build the prototype and also the effectiveness in low air speed condition. Second objective of this study also has been accomplished by modelling the Savonius and H-type Darrieus in order to evaluate the capability of each wind turbine in low wind speed condition. Pipe and cardboard is materials that be used to create the S-type blade due to economical and easy to construct. Besides that, H-type is construct by choosing pinewood material because of inexpensive and easy to build too.

Last objective for this project also has been obtained by testing and measuring the performance of each wind turbine. In this experiment, S-type and H-type wind turbine is used to compare which one is applicable in low wind speed condition by calculating the torque, power, torque coefficient and power coefficient beginning form 2m/s. In addition, assumption of CRWT concept (S-type combining with H-type) performance has been made by adding each parameters that been calculated from S-Type and H-Type in order to prove that CRWT concept is applicable in low wind speed condition. This is because S-type is self-starting type while H-type is not self-starting start but it's can generate a lot of power even in the increasingly strong wind. Finally, It demonstrates that by utilizing S-type rotor can give a superior performance for CRWT concept in view of it shape and light-weighted material. In this manner, the majority of the objectives in this project have been accomplished.

5.2 Future Recommendation

This CRWT concept demonstrated that it worked well in low wind speed condition even it have not yet accomplished a high torque and power yield to produce greater power particularly for the provincial and urban environment. From this project, it demonstrates that how crucial of the base area of the blade in order to obtained the most extreme torque and power coefficient of the CRWT concept. There are a couple of future recommendations for those that are plan to continue especially for the project that linked to the topic:

i) Directly calculate the electrical power from CRWT.
ii) Apply 'slip ring' into the prototype to increase the performance.
iii) Observe the optimal number of blades of each wind turbine.
iv) Utilize another NACA aerofoil profile for Darrieus wind turbine

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