Design and Development of Hybrid Portable Mini Wind Turbine

By

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17042

Dissertation submitted in partial fulfilment of the requirements for the
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CERTIFICATION OF APPROVAL

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Approved by,

____
(Dr. Hilmi Bin Hussin)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2015

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.

(MOHAMAD SHARUL AFFENDI BIN MOHD JAFRI)

ABSTRACT

Awareness about the important of renewable energy such as solar, wind and geothermal as a primary alternative to non-renewable energy sources has been increase among the world society. Many country like United Kingdom, Spain, United State of America and Japan has started to develop a renewable technology especially wind energy in order to supply electricity to their citizen. In Malaysia the wind energy is not widely used for power generation as the average wind speed which is about 3-6 m/s (East Coast region) make it not very efficient for large scale of power production. However, a small scale of wind turbine can be used to generate an electricity from a low wind speed. This small capacity of electricity that generated by the wind turbine can be useful to many situation. For example, during an emergency or disaster where there is a shortage in electrical supply, the small scale wind turbine can be used to charge up a telecommunication device such as phone to make an emergency call at the disaster area. Other than that, the small scale wind turbine can also be utilize at rural area where there is no electrical supply to power up a small device.

This project is to design and develop a hybrid mini wind turbine that is compatible with small hand-crank generator for small capacity electrical generation purpose. The combination of the wind turbine with the hand crank application is to make the function of the whole product and design become more efficient in term of their function as a power generator. The design research begin with the study about the type of wind turbine, characteristic of wind turbine, review on wind speed in Malaysia and current trend of small scale wind turbine. Next, the methodology of designing was made by construct the morphology chart in to choose the design criteria for the wind turbine. From the morphology chart, the Savonius and Darius wind turbine was choose as the wind blade, NACA 0015 was choose as an airfoil type for Darrius wind turbine and three number of blade for the Darrius wind turbine. Then, the calculation was made to estimate the minimum cross section area for the wind turbine design which is 0.128 m^2. From the design selection and calculation, conceptual sketch was made and general dimension for the wind turbine was define. Next the detailed 3D drawing and animated simulation was made using CATIA software. Fabrication process done by using 3D printer machine Zortrax M200 and conventional lathe machine. At the end of this project, the complete prototype of wind turbine was successfully fabricated and assembled.

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CHAPTER 1: INTRODUCTION

1.1 Background

Renewable energy have becoming an important type of energy that need to be develop at present. Since there are a lot of issue regarding the pollution and world climate, the implementation of renewable energy is becoming crucial especially for future planning. There are a several type of renewable energy sources which are solar, wind and hydro. The wind turbine technology is one of the most popular type of renewable energy source around the world. It harvest the wind through the blade and the rotation of the blade due to the wind blow will produce an electricity power.

The main reason why the wind energy is widely used in many country to generate electricity is because of the cost require to develop a wind turbine is relatively low than cost require to develop a solar station or a hydroelectric station. Other than that, besides being recognize as a green energy, wind energy also practically can operate in any time with the present of wind unlike the solar energy which can only produce an electricity during a day light.

In Malaysia, the implementation of wind turbine as a power grid energy sources is not used widely. This is due to the average wind speed in Malaysia especially at east peninsular is only about 3 to 5 m/s [1]. However, an electricity still can be generate at that speed of wind depend on the design of a wind turbine itself. A studies about a Small-scale wind energy portable turbine (SWEPT) proven that by a correct design and characteristic of small wind turbine, an electricity can be produce at a wind speed below than 5 m/s [2]. Therefore a small scale or mini wind turbine can be practically use to generate electricity in most part of Malaysia especially at east peninsular region.

1.2 Problem statement

The application of wind turbine in Malaysia as the source of electrical generation is not widely use as it is not practical considering the low wind speed. However in the case where small capacity of electrical supply is needed, a small scale wind turbine could be a practical way to generate electricity. For example, a small scale wind turbine can be used to power up communication device for emergency purpose during a natural disaster event where there can be an electricity supply failure. Other than that, compared to solar energy where can only be extracted during day the wind energy can be harvest during day and night. Based on that judgment one of the objective for this project is to design a mini wind turbine that able to produce an electricity at low wind speed.

In order to improve the function of power generation, the wind turbine can be integrated with other source of power generation. Hand crank generator is one of the suitable application that can be combine with a wind turbine to make a hybrid technology for electricity generation. Other than that, the usage of an electrical device is also limited at a place where there is no electrical supply. For example if we go to a remote area, we just can depend on the power supply in form of extra batteries or power bank in order to continue using an electronics devices. Besides, a person who go to recreation place such as beach and mountain areas will also find difficulties to power up their electronics devices. Thus the design of portable mini wind turbine is needed for a better transportation and storage purpose.

1.3 Objectives and Scope of study

The objectives of this project is as the following:

1. To benchmark various type of wind turbine
2. To design a portable mini wind turbine using computer aided design software.
3. To fabricate a prototype of the wind turbine using a Rapid Prototype Technique and other fabrication process.

The scope of study for this project will be focus on the design and development of the blade for mini wind turbine. The study will be test on:

1. Type of design and profile of the blade.
2. Diameter of the blade.
3. Feasibility of the design to the wind rotor function.

CHAPTER 2: THEORY

2.1 Wind Turbine Analysis

2.1.1 Type of wind turbine

Generally, there are two type of wind turbine which are horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). For HAWT type, the direction of wind flow is parallel to the shaft of the rotor. Meanwhile for VAWT type, the direction of wind flow is perpendicular to the shaft of rotor. Each of these two configuration wind turbine design have its own characteristic. Other than that, there are two types of propulsion which are lift and drag.

The method of propulsion generally affect the efficiency if the wind turbine [3]. The lift type using the lift driven mechanism from an aerodynamic airfoil to create a force. As this kind of wind turbine may move faster than the wind flow, it is regularly use for the generation of electricity. For the drag type, it takes less energy from the wind but produce high torque due to the drag force.

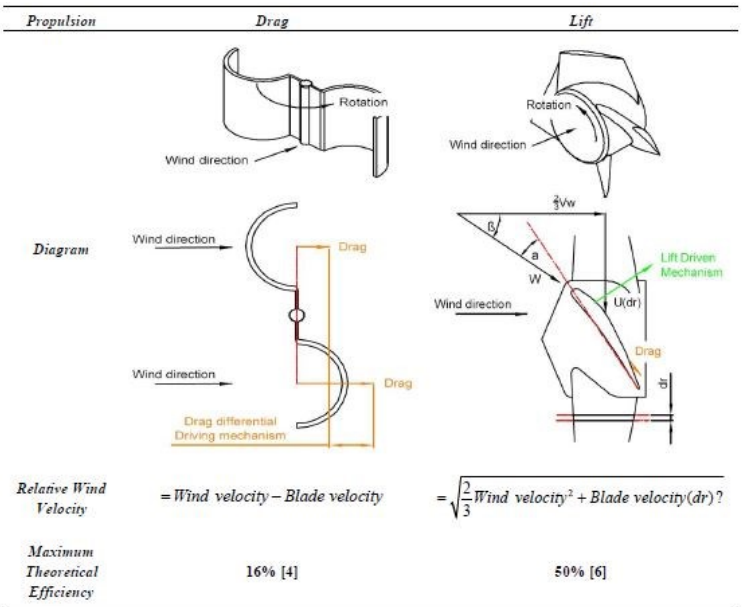


Figure 2-1 Type of propulsion (Schubel & Crossley, 2012)

2.1.2 Efficiency of wind turbine

The efficiency of wind turbine will reduce due to [3]:

- Tip losses
- Wake effect
- Drive train efficiency losses
- Blade shape simplification losses

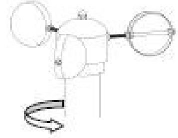
Ref No.	Design	Orientation	Use	Propulsion	* Peak Efficiency	Diagram
1	Savonius rotor	VAWT	Historic Persian windmill to modern day ventilation	Drag	16%	
2	Cup	VAWT	Modern day cup anemometer	Drag	8%	
3	American farm windmill	HAWT	18th century to present day, farm use for Pumping water, grinding wheat, generating electricity	Lift	31%	
4	Dutch Windmill	HAWT	16th Century, used for grinding wheat.	Lift	27%	
5	Darrieus Rotor (egg beater)	VAWT	20th century, electricity generation	Lift	40%	
6	Modern Wind Turbine	HAWT	20th century, electricity generation	Lift	Blade Qty / efficiency: 1 – 43% 2 – 47% 3 – 50%	

Figure 2-2 Type of rotor design (Schubel & Crossley, 2012)

2.1.3 Characteristics analysis of wind turbine

The analysis for the performance of wind turbine is crucial in order to evaluate the result. The parameter for the analysis of a wind turbine include:

- Swept area
- Power extracted
- Tip speed ratio
- Number of blades
- Initial angle of attack

<u>Swept area</u>

The swept area is the cross-sectional part of the wind turbines that face the air movement. Therefore, for HAWT the swept area is the area that cover by the rotation of blade which the formula will be:

$$A = \pi r^2$$

Where A is the swept area, r is the blade radius. Meanwhile, for the VAWT the swept area will be the rectangular cross-section of the turbine and the formula is:

$$A = 2rL$$

Where L is the length of the blade. The swept area cover the volume of air that pass through the turbine. Therefore, the swept area will affect the rotational movement of wind turbine.

<u>Power extracted</u>

The power that extracted from wind turbine can be calculated using the following formula:

$$P = \frac{1}{2}\eta\rho A\upsilon^3$$

Where ρ is the density of air, A is swept area, υ is the speed of wind and η is the theoretical limit efficiency of the wind turbine called the Betz's limit where for HAWT, the value is 19/27 and for VAWT the value is 16/25 [4].

Tip speed ratio

The tip speed ratio is defined as a relationship between the tangential speed of rotor and the wind velocity where the equation is as the following:

$$\lambda = \frac{\omega R}{\upsilon}$$

Where λ is tip speed ratio, ω is a rotational velocity in rad/s, R is radius of blade and υ is the speed of wind. Each blade design has an optimal tip speed ratio at which the maximum power extraction is achieve.

Number of blades

Number of blade affect the performance of wind turbine. The increase number of blade will give more adjusting gap to the cut in wind speed without affect the power coefficient too much [5]. However many existing modern wind turbine design have 3 number of blades. This is due to the needed to compromising it with the manufacturing restriction.

Initial angle of attack

Angle of attack is an angle between the incoming wind flows with the trajectory of the blade airfoil. The effect of the angle of attack to the performance of wind turbine may vary according to the design of the wind turbine. However, it is proved that the use of single airfoil along the entire length of blade will cause inefficient design of blade [3].

2.2 Wind Speed in Malaysia

The wind sources of certain region need to be identify in order to develop a wind turbine that able to be operate and generate electricity. The average wind speed analysis at Mersing, Malaysia state that the annual average of wind speed in Malaysia is about 3 to 5 m/s [1].

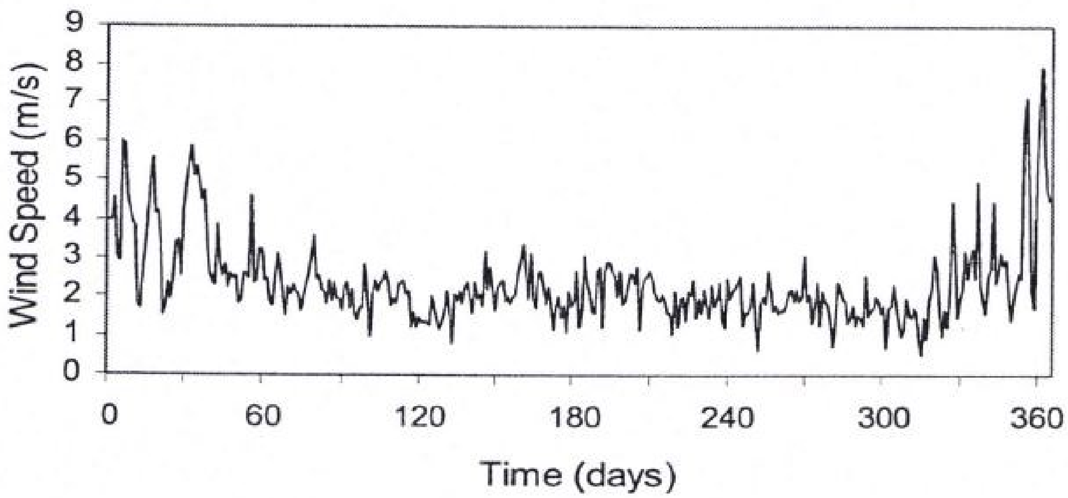


Figure 2-3 Mean daily wind speed in East Coast of Malaysia

Report on the study on SWEPT showed that a wind turbine have a low cut-in wind speed which is 2.7 m/s and able to produced 0.83 W of electrical power at a wind speed of 5 m/s.

2.3 Trend on mini wind turbine development

Currently there are several concept for mini wind turbine development. Most of the mini wind turbine concept use savonius type of wind turbine. The application of VAWT in the development of mini wind turbine give advantage to the wind harvesting process. The blade wind turbine that using VAWT type does not need to be orient to the direction of wind in order to extract the wind efficiently.

Figure 2-4 Ventus Concept mini wind turbine (Xu, 2013)

Other that conceptual design, there are also product that currently exist in market. WinPax is a one of a company that produce portable mini wind turbine for public usage. The design of wind turbine by WinPax use the VAWT savonius type of wind turbine.

Figure 2.0-5 WinPax blade design

CHAPTER 3: METHODOLOGY

3.1 Project Flow

Figure 3.1 show the project flow.

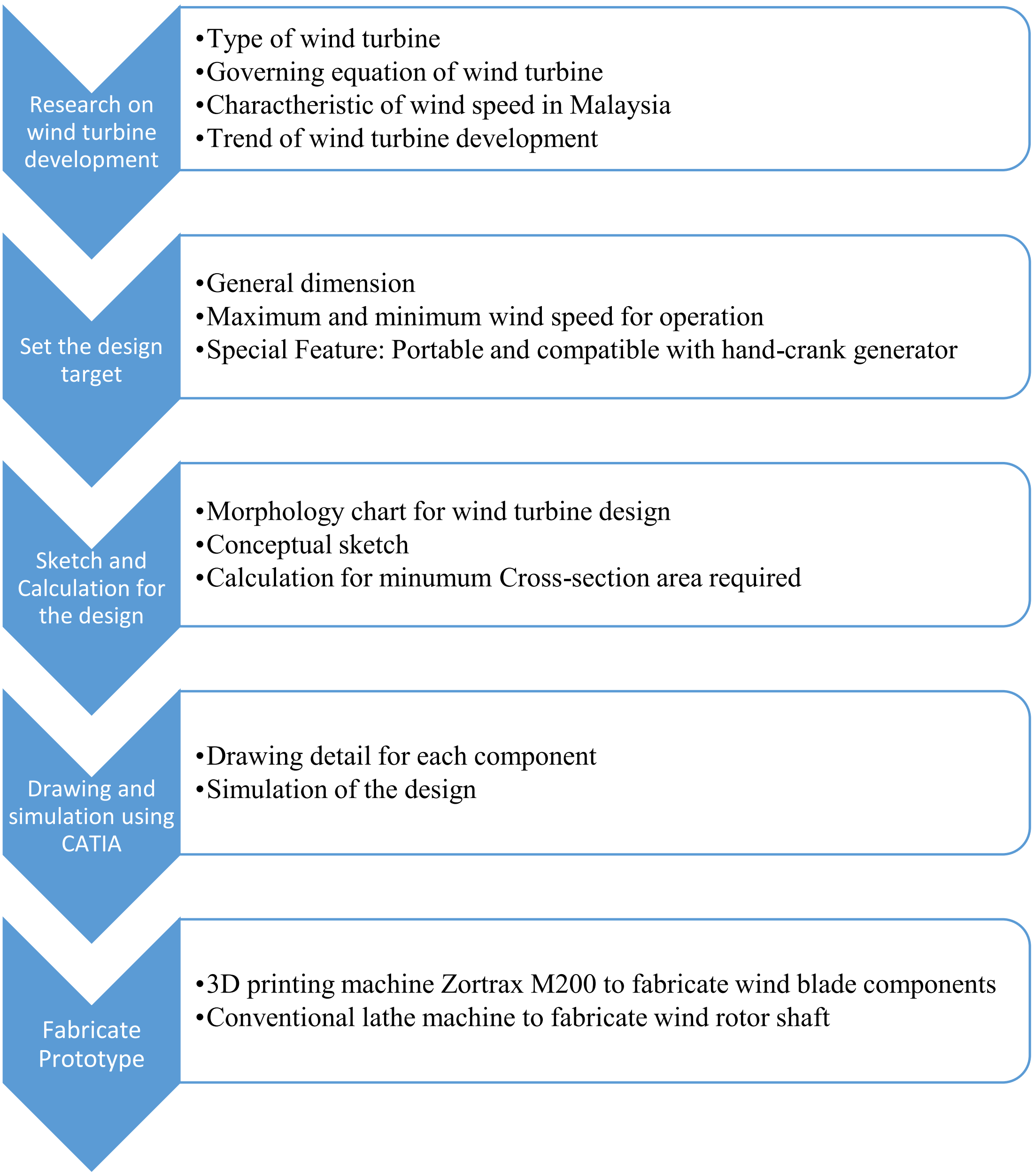


Figure 3.1 Flow Chart of Project

3.2 Project Activities

3.2.1 Morphology Chart for Wind Turbine Design

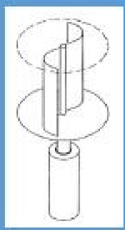
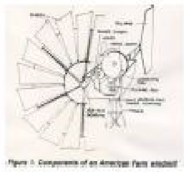
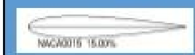
Functional Features	How/Means				
Design Type	Savonius Rotor 	American Farm windmill 	Modern Wind Turbine 	Darrieus Rotor 	Dutch Windmill 
Orientation type	Horizontal Axis Wind Turbine (HAWT)	Vertical Axis Wind Turbine (VAWT)			
Airfoil Type	NACA 0012 	NACA 0015 	NACA 0018 		
Number of blades	2	3	4	5	

Figure 3-2 Design Morphological Chart

For the selection of the type of wind turbine, both Savonius and H-type Darrieus were selected to form a hybrid wind turbine design. Savonius rotor will give a high self-starting rotation value and the H-type Darrieus rotor would contribute to a higher efficiency to the wind turbine. The selection of VAWT was made to adapt the design requirement which need the turbine to be small, portable and easy to be install. The selection of NACA 0015 for the H-type Darrieus turbine was made as the type exhibits more favorable stall characteristics [4]. 3 number of blades was selected as the even number of blade are avoided due to vibration effect and other than that due to the economical reason.

3.2.2 Specification Target

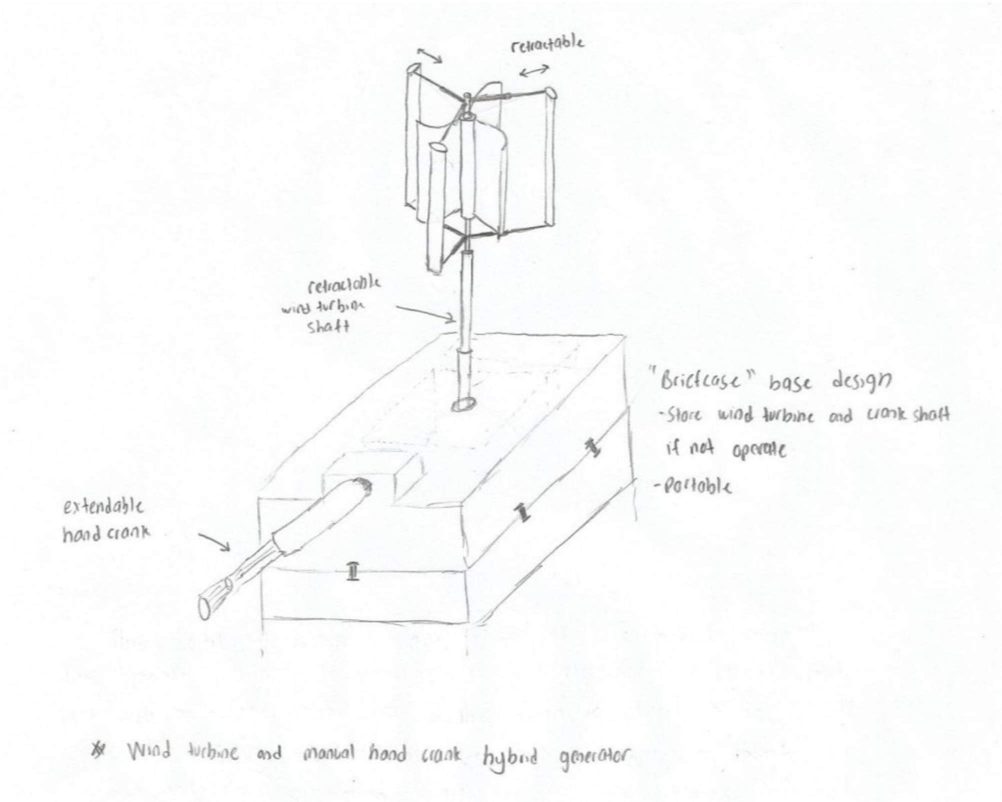


Figure 3-3 First Conceptual Sketch

In order to meet the needed of a power resource for small electronic gadget such as a cell phone, voltage of the wind turbine output is set in the design requirement. Other than that, the maximum dimension of the wind turbine need to be specified as the initial requirement which is portable and easy to use can be adapted. Therefore the design requirement and specification is set as below:

- Minimum Operating wind speed: 3 m/s
- Maximum Operating wind speed: 10 m/s
- Maximum Dimension : 0.5 m x 0.5 m x 0.5 m
- Minimum Speed of Rotation: 350 RPM
- Portable

3.2.3 Calculation and Assumption

Assumption:

- For Darrius type of rotor take $C_P = 0.32$ thus the TSR = 6±0.2

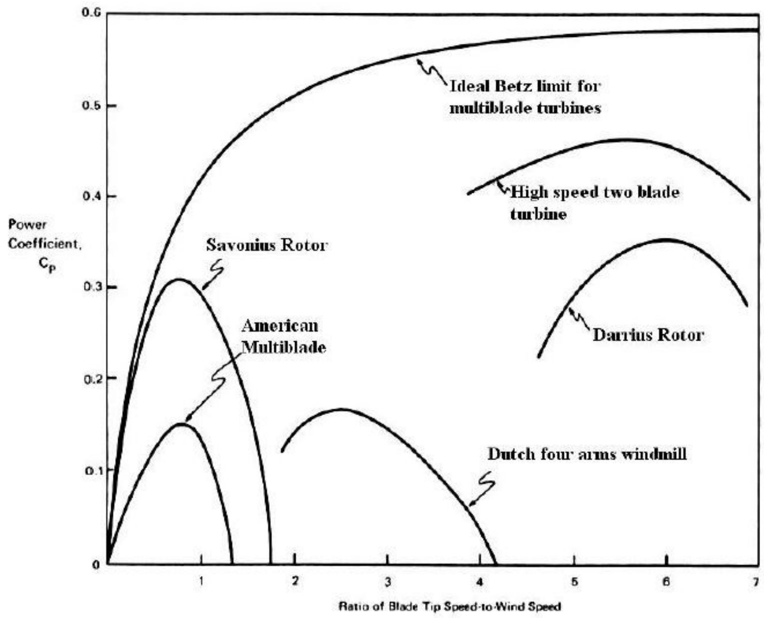


Figure 3-4 Power coefficient Cp as a function of the tip speed ratio for different wind machine

- Take efficiency of gear box and generator, $\eta_{gb} = 0.95$ and $\eta_g = 0.96$
- Total efficiency $\eta_{total} = 0.32 \times 0.95 \times 0.96 = 0.29$

From: $\eta_{total} = \frac{P_{electric}}{P_{wind}}$

$P_{wind} = \frac{3}{0.29} = 10.34$ watt

From: $P_{wind} = \frac{1}{2}\rho A V^3$ take density of air = 1.2kg/m^3

$A = \frac{(2)(10.34)}{(1.29)(5^3)} = 0.128\ m^2$

- Minimum swept area for wind turbine design is 0.128 m^2

Expected RPM of wind rotor at minimum operating wind speed is 3 m/s.

Take TSR = 5, as the value of 5 is between the most and lowest of the optimal value of C_p

Therefore from $\lambda = \frac{\omega R}{v}$ where R = 0.4 m

ω = 37 rad/s = 353 RPM

Finalize the conceptual design by sketching

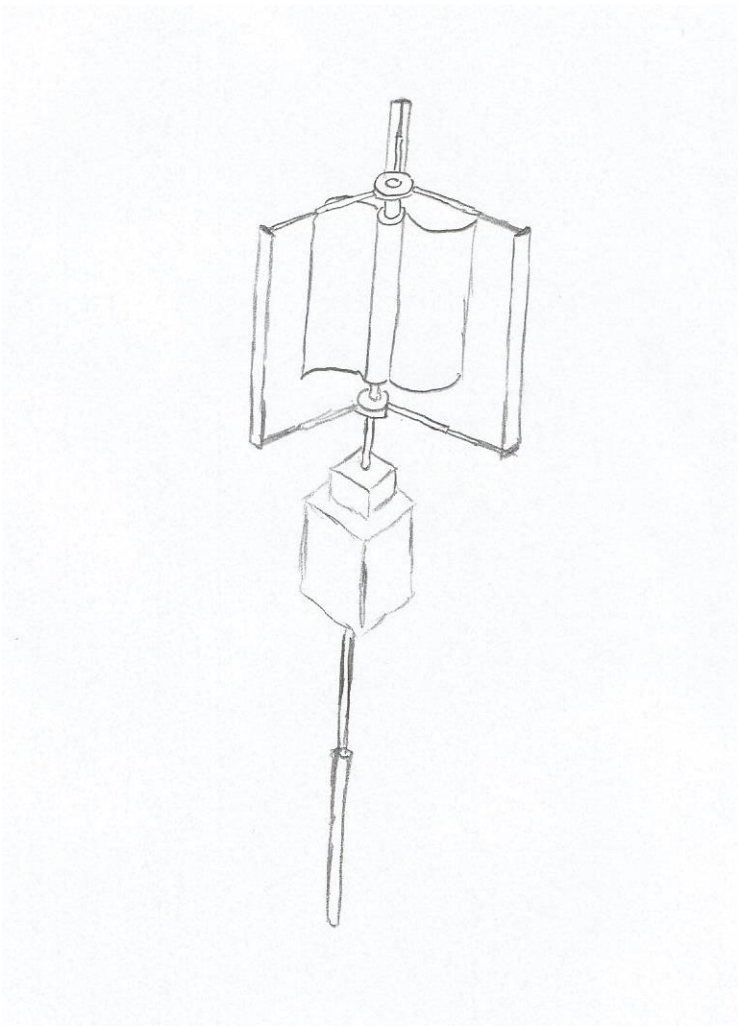


Figure 3-5 Final conceptual sketch

The final selection concept of the wind turbine design is consist of the Darrieus and Savonius blade. The savonius rotor will connect to the drive shaft by one way bearing and the darrieus rotor is directly connect to the drive shaft.

3.2.4 Finalize the major dimension of the design

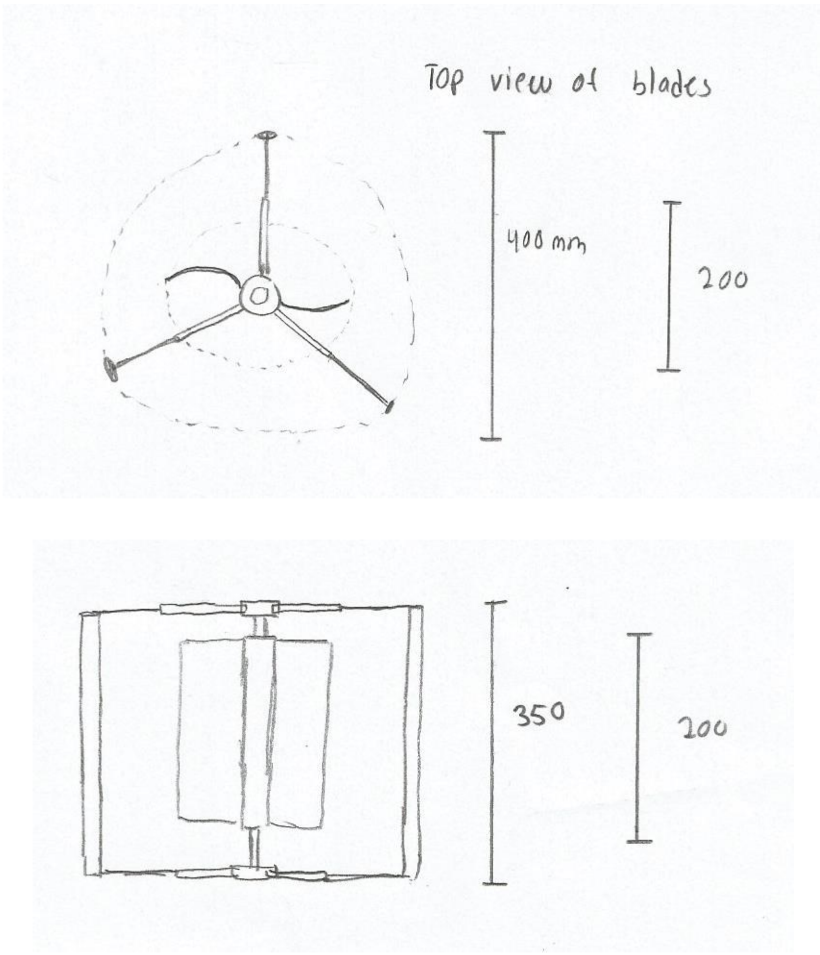


Figure 3-6 Finalize on major dimension

The figure show the major dimension of the wind turbine. The dimension was made based on the calculation from the earlier part.

3.3 Project Schedule

3.3.1 Key milestone

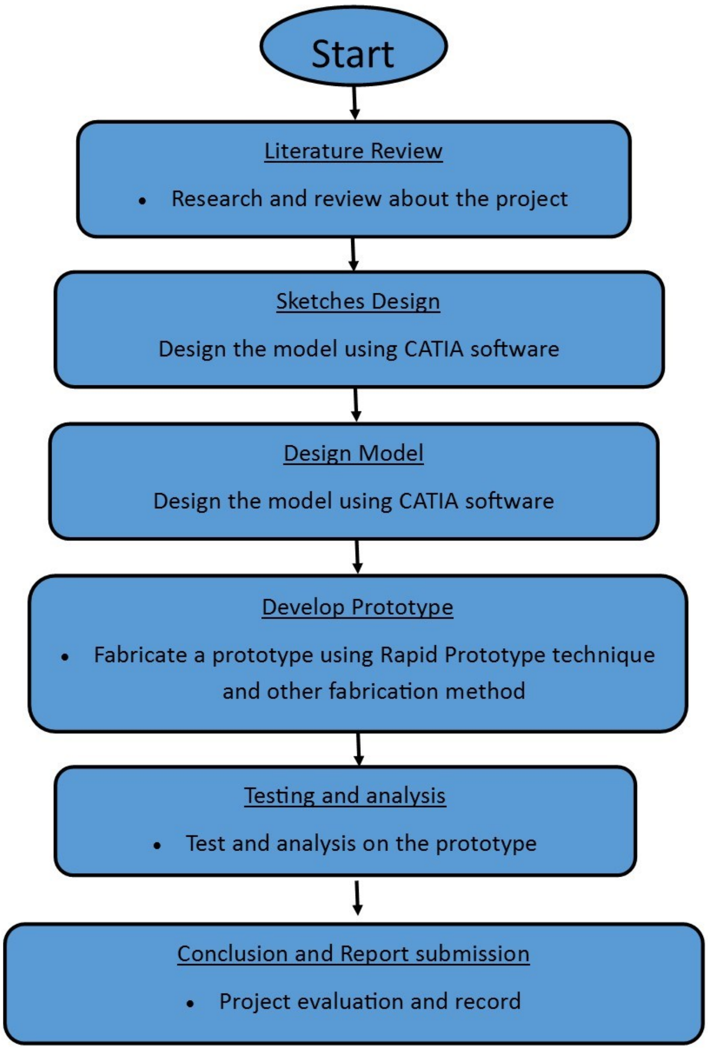


Figure 3-7 Key Milestone

3.3.2 Gantt Chart

No		Details	Week																											
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	*FYP 1 Timeline*	Project Title Selection	■	■																										
2		First Meeting with Supervisor			■																									
3		Research Work & Data Gathering			■	■	■																							
4		Literature Review Research				■	■																							
5		Submission of Extended Proposal					■	■																						
6		Software Design of Wind Turbine						■	■	■	■	■	■																	
7		Design Evaluation & Finalization							■	■	■	■	■																	
8		Proposal Defense								■	■																			
9		Interim Report Draft Preparation												■	■															
10		Interim Report Final Submission													■	■														
11	*FYP 2 Timeline*	Continuation of Project Work															■	■	■	■	■	■	■							
12		Rapid Prototyping of the Model																■	■	■	■	■	■							
13		Model Testing, Evaluation and Improvisation																■	■	■	■	■	■							
14		Submission of Progress Report																					■	■						
15		Pre-SEDEX																								■				
16		Draft Final Report Submission																								■	■			
17		Dissertation Submission (Soft Copy)																									■	■		
18		Technical Paper Submission																									■	■		
19		VIVA																											■	
20		Project Dissertation Submission (Hard Bound)																											■	■

Figure 3-8 Gantt Chart

CHAPTER 4: RESULT AND DISCUSSION

4.1 Design Analysis

4.1.1 Overall view on conceptual design

From the sketch and dimension, the first version of the wind turbine model is created using the SolidWork software.

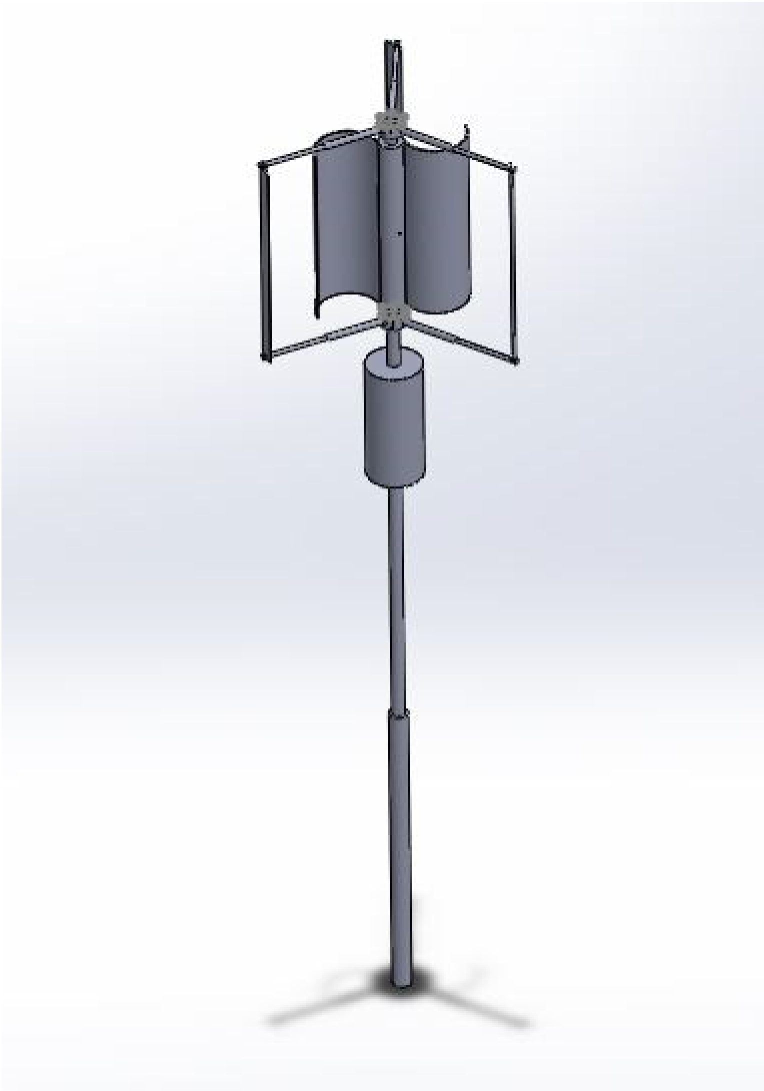


Figure 4-1 First Conceptual Drawing Model

The design consist of two blade which are savonius blade and darrieus blade. The combination of these two type of blade would increase the performance of the wind turbine as they neglecting each weakness and provide support to each other by their strength. In term of manufacturing, the blades and the darrieus branch and holder design are able to be manufactured by using plastic as a material. However for the prototyping purpose, 3D rapid prototype is an approach for the manufacture part. Aluminium is selected as a material for the drive shaft. Special standard part which is one way bearing used in the connection between the savonius rotor and the drive shaft. Other standard part includes bolt and locking screw without head.

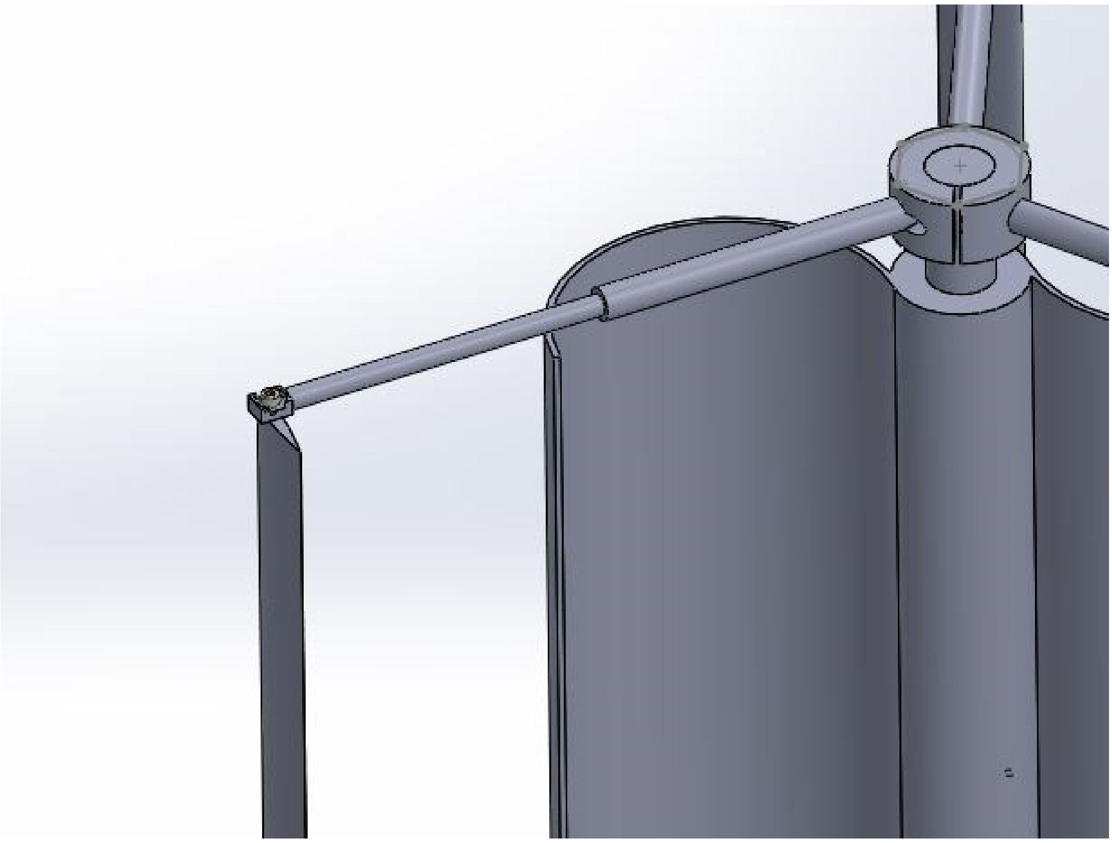


Figure 4-2 Zoom-in drawing of the Blades

4.1.2 Wind Turbine Design Advantage

I. Combination of two types of wind turbine

The unique value for the wind generator design is on the design of the blade itself. The design uses two types of Vertical Axis Wind Turbine (VAWT) namely Darrieus and Savonius Blades. This combination aims to improve the performance of wind energy extraction. Darrieus wind turbine has higher efficiency of power extraction from wind energy than that of Savonius. However, it needs high torque to start rotating. Savonius wind turbine, which requires low torque for rotation, is attached together to the overall wind turbine design to provide sufficient torque to start Darrieus rotation.

II. One way bearing

The starting step for the wind generator requires the Savonius blade to drive the wing turbine and generator. As the rotation of wind turbine rotor reaches higher speed, the Darrieus wind turbine will start to move faster than the Savonius wind turbine due to its higher efficiency. At this point, the rotation of Darrieus wind turbine will be cut off from the rotation of Savonius wind turbine and left only the Darrieus wind turbine to drive the generator. This mechanism requires one way bearing in the design as the function of one way bearing is to allow only one way of rotation and hold back the opposite direction of rotation. The advantages of using one way bearing are that it is easy to do maintenance and does not produce noisy sound during its working operation.

III. Portable-retractable wind turbine branch

The maximum dimension of the overall wind turbine set is 400 mm x 400 mm x 500 mm and it can be minimized to 200 mm x 200 mm x 500 mm. The minimizing of the size is enabled by the design of retractable Darrieus wind turbine branch. The retractable branch allow the overall diameter of Darrieus wind turbine to be the same as the diameter of Savonius wind turbine for smaller area of storage. Furthermore, during the operation of wind generator the retractable branch allows the diameter of Darrieus wind turbine to be expanded twice than its storage diameter (Figure 4.3).

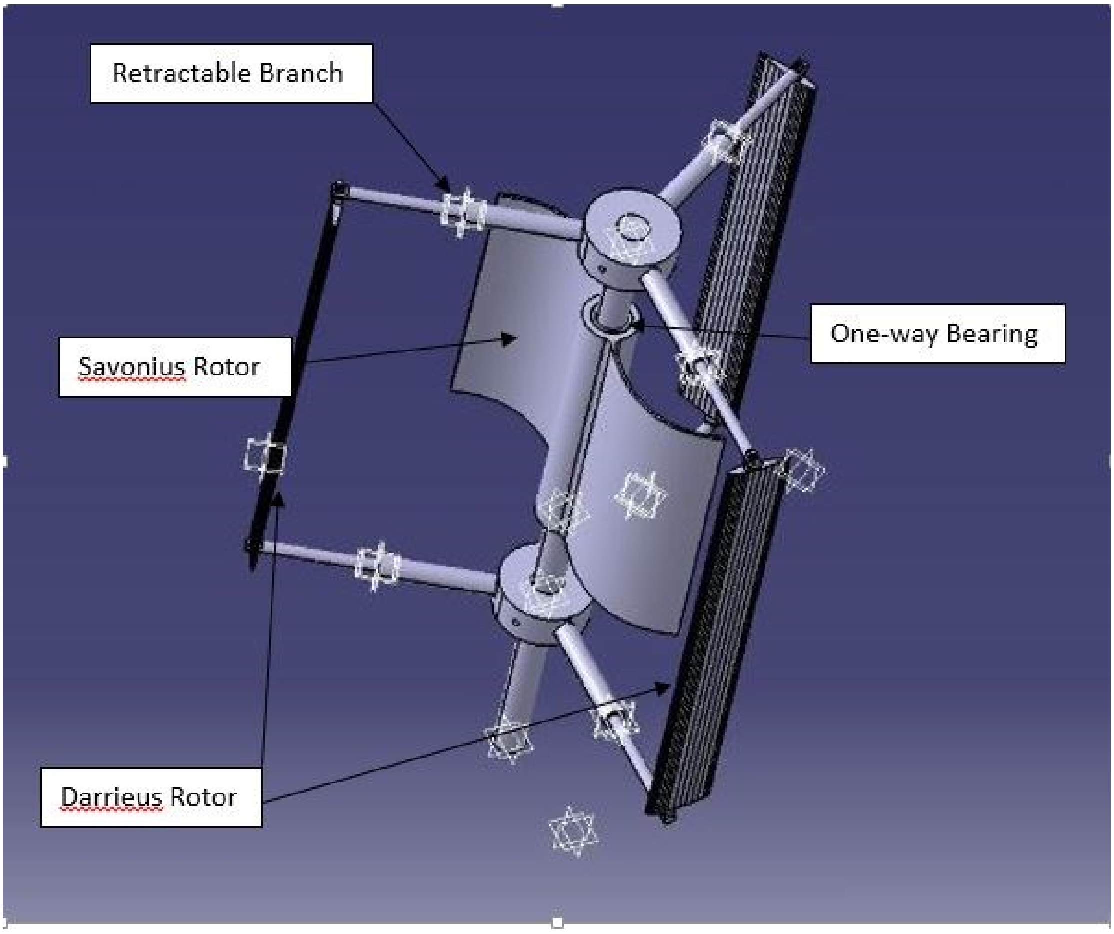


Figure 4-3 Components of Blades Tree of wind turbine

4.1.3 Design Advantage as a portable hybrid mini wind turbine

- *Portability*

The design for Portable Mini Smart Generator make it easy to be installed for operation and to be stored in a casing when not being used. The maximum size of the casing is about 50 m x 50 m x 70 m of dimension. All the components of this product can be easily stored when not in use and suitable to be carried to any places. This feature make it very suitable to be used in emergency situation (Figure 4.4).

- *Dual Modes of Operation*

The Portable Mini Smart Generator can be powered by two sources of power generation namely human energy and wind energy. The human energy is gained when the generator of this product is driven by hand crank rotation and the wind energy is harvested by the wind turbine.

- *Low cost power source solution during emergency*

This product provides a cheap alternative solution for supplying power source to electronics devices in the situation where normal power source is inaccessible or down. During a disaster time, such as the big flood that occurred in East coast of Malaysia in December 2014, the reinforcement team and affected people faced a great deal of difficulty to power up their phones and make an important call to update situations in disaster areas and relief center. The solution back then was by asking for fully charged power bank to be distributed to the disaster relief center. This can involve high amount of money as one unit of power bank can cost about RM 60 to RM 80. Furthermore, the power bank needs to be recharged when the capacity is fully discharge. It is also time consumption to send power bank back and forth for charging and distribution. With this product which is cost below than RM 300, the problem of power demand for electronic devices can be solved effectively and efficiently.

- *Power source during travelling to remote area*

Other than its usage as the power supply for electronics devices during disaster time, this product can also be used by travelers who travel to remote areas where there is a limited or no access to electricity supply. The crank generator would provide an easy solution to obtain emergency power supply. In areas with good wind speed, such as mountain and beaches, the wind generator would be useful to provide needed spare power. It can also be used by fisherman during emergency case.

Figure 4-4 The rendering image of Portable Hybrid Mini Generator (Wind)

4.1.4 Fabrication of Components

Most part of the wind turbine for this project which is the blades and its auxiliary's part was fabricated by rapid prototype method using three dimensional (3D) printing machine. Other part which is the shaft was fabricated using cutting and lathe machine. The material for part that fabricated by 3D printing machine is Acrylonitrile Butadiene Styrene (ABS) and the shaft was made by an aluminum.

- *Rapid Prototyping Method*

The 3D printing machine used for this project is Zortrax M200. The maximum dimension that the printer can fabricate is 180 mm x 180 mm x 180 mm. In order to do the printing process the drawing file must be converted in to Stereo Lithography (STL) format before the file can be transfer to the 3D printer software. After the drawing file was downloaded to the printer software, the program will start to generate the path of printing bit and estimate the printing time.

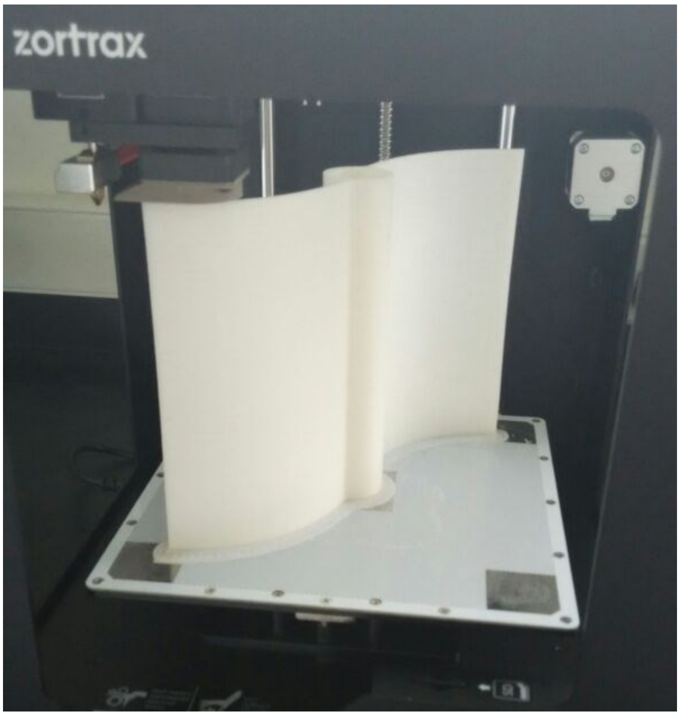


Figure 4-5 Zortrax 3D printing machine

The part that have been completely fabricated then removed manually from the printer table for next printing process. The parts that have been fabricated using 3D printer is shown in table 4.1

Table 4.1: Parts Fabricated Using 3D Printer

No	Part Name	Quantity
1	Savonius Blades	1
2	Darrius Blade	3
3	Darrius Holder	2
4	Darrius Branch	6

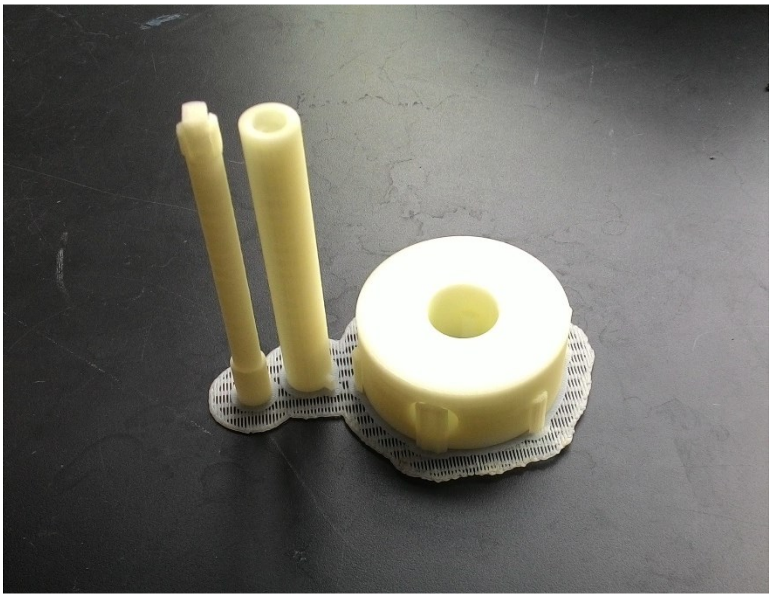


Figure 4-6 Part Fabricated by 3D printer

- *Lathe Process*

The lathe process using a conventional lathe machine was used to fabricate the drive shaft of the wind turbine. The material use is aluminum rod. Design of the drive shaft is shown in figure 4.8

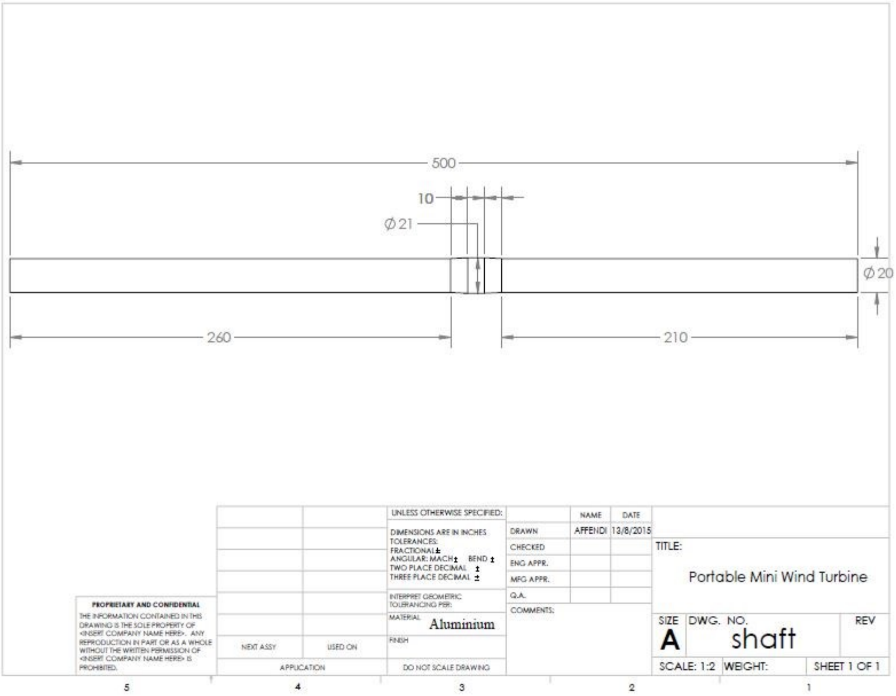


Figure 4-7 Technical Drawing for shaft

- *Assemble Process*

Assemble process considered the last step in fabrication process. This process can be completed after all part of component of the wind turbine were fabricated. During this step, many process such as abrasion, tapping and fitting include during the assemble process. Abrasion process need to be done as the parts that has been fabricated by the 3D printing machine has not have a good surface finish. For the part that have a screw that need to be fitted in it, tapping process was done to make the groove at that part. Figure 4.8 show the full assemble part of the wind turbine.

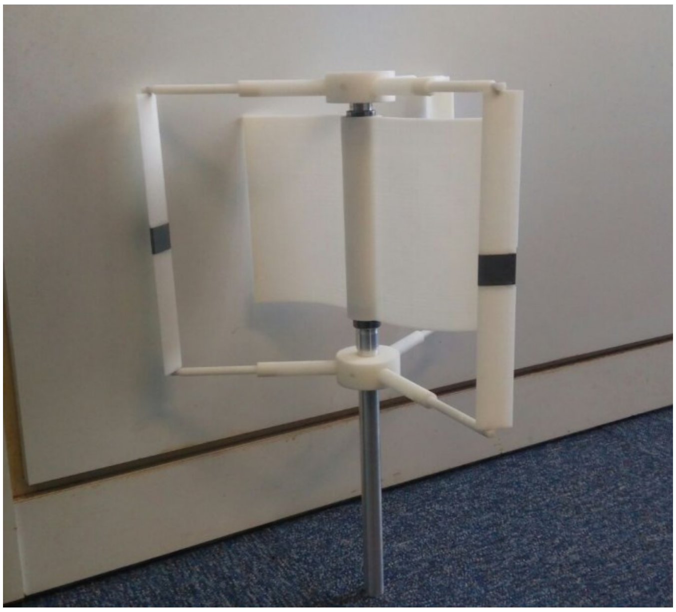


Figure 4-8 Completed Assemble of the Wind Turbine

4.1.5 Prototype Production Cost

The cost of the production of prototype for wind rotor is shown in table 4.2

Table 4.2: Production Cost of Prototype for Wind Rotor

No	Item	Quantity	Total Cost
1	ABS Filament (3D Printer)	700 grams	RM 200 (estimated)
2	Aluminium Rod	1.02 Kg	RM 18.40
3	FCB 20 One way Bearing	2	RM 120
4	Others (Screw, Sand Paper)	-	RM 20
		TOTAL	RM 358.40

4.2 Economical View

4.2.1 Marketing/Business Plan

As the product mainly aims for the location which regularly being hit by natural disasters, the product can be promoted globally, not only restricted to Malaysia region. The global map for natural disaster-prone places is shown in the figure below.

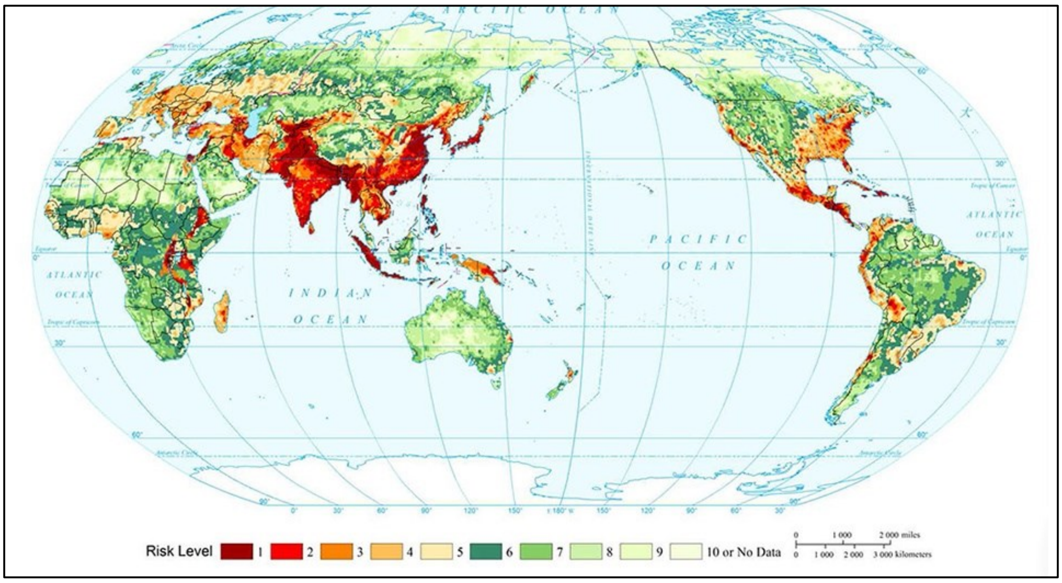


Figure 4-9 Global mapping of annually multi-hazard risk level

From this map at Figure 4.9, it can be seen that the most highly risked level areas are in Asian, Europe and Central America regions. Types of natural disasters include earthquakes, floods, wildfire, landslides and volcanoes. Taking into account that the targeted user for this product is roughly 1% from the total affected population with high risk level, it is estimated that the potential users for this product is about 10 million.

4.2.2 Production

For the prototype cost, the product can be produced below RM500 as a single device. It will be much cheaper when it goes into the mass production later. To estimated costs of product which components consist of molded plastics, motor, gearbox, simple electronic circuit board, bearings, coupler, rechargeable battery and rubber feet, is roughly around RM300, including the wind blade and crank.

The product is mainly in the polymer based material (plastic), thus injection molding technology is required in order to produced small parts in which require precise measurements with tiny features. As the technology is widely available and much cheaper in mass production scale, thus it is possible to produce it in a large scale.

In a small scale, to reduce the production cost of the product, 3D printer is required to replace the injection molding technology. Even though it is still contributes to higher cost in total, but it is feasible in a small scale. The production time for small quantity also can be shortened as the parts can be printed instantly.

Table 4.3 below shows the rough estimation on the production cost of the product:

Table 4.3: Rough cost estimation for single production of portable mini smart generator

Components	**Cost (MYR)**
Generator Box (Circuit Board, DC Generator, Rechargeable Battery, Wires, Gearbox, Crank, Rubber Feet, Rubber Holder)	160
Wind Turbine (Shafts, Blades, Foils, Mounting Base, Bearings, Coupler)	300
TOTAL	**460**

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion and Recommendation

In conclusion, the design and development of hybrid mini wind turbine that compatible with hand crank generator is success. The design was made from the scratch idea until it is fabricated and assembled as a one unit of wind turbine. The design process begin with the construction of morphology chart until the drawing and animated simulation using CATIA software. The design was also proven by the fabrication using 3D printing machine Zortrax M200 and conventional lathe machine. Finally the wind turbine was assemble to according to the design target.

As a recommendation, further analysis on the performance of the wind turbine can be performed. Result from the analysis can be used to improve the efficiency of the wind turbine for power generation. The improvement could be changed in term of material, dimension, and technique of fabrication. For the change in material, plastic are recommend to replace current material of wind blade which is ABS for production purpose. Other than that, the change in dimension can be revised based on an analysis of current dimension. Finally, the technique of fabrication can be improve. For example the surface of the aluminum shaft can be smoothed using a sand paper.

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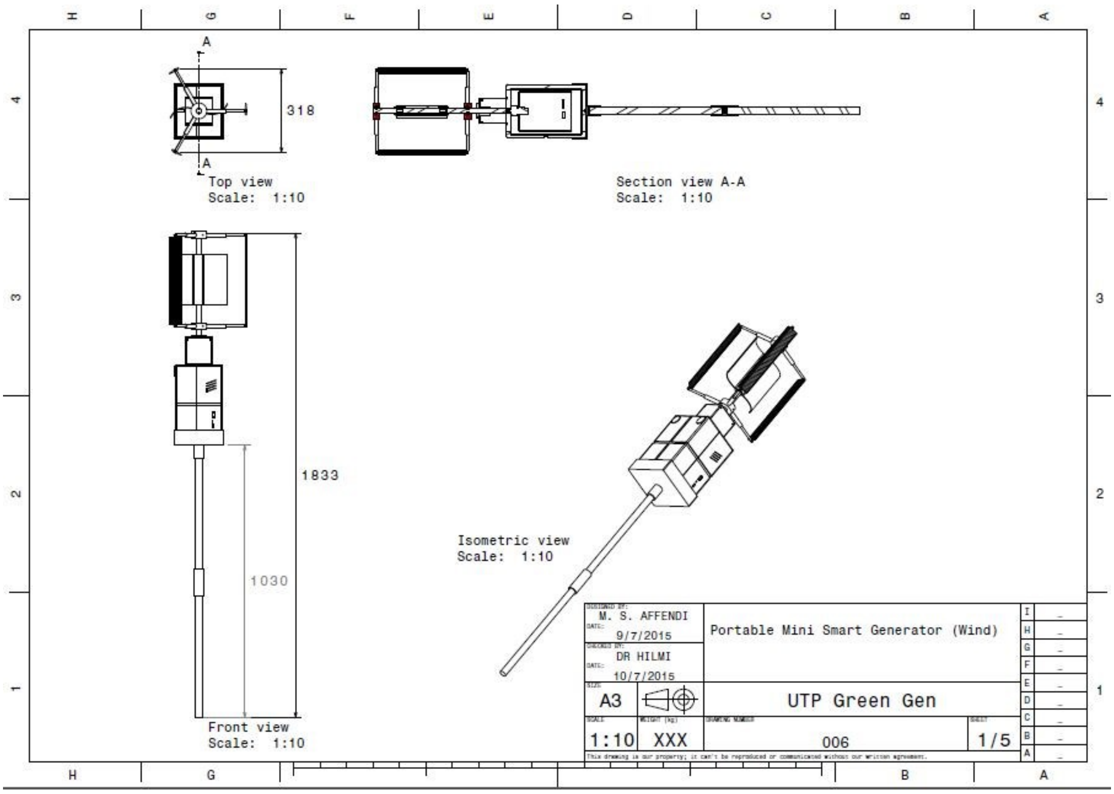
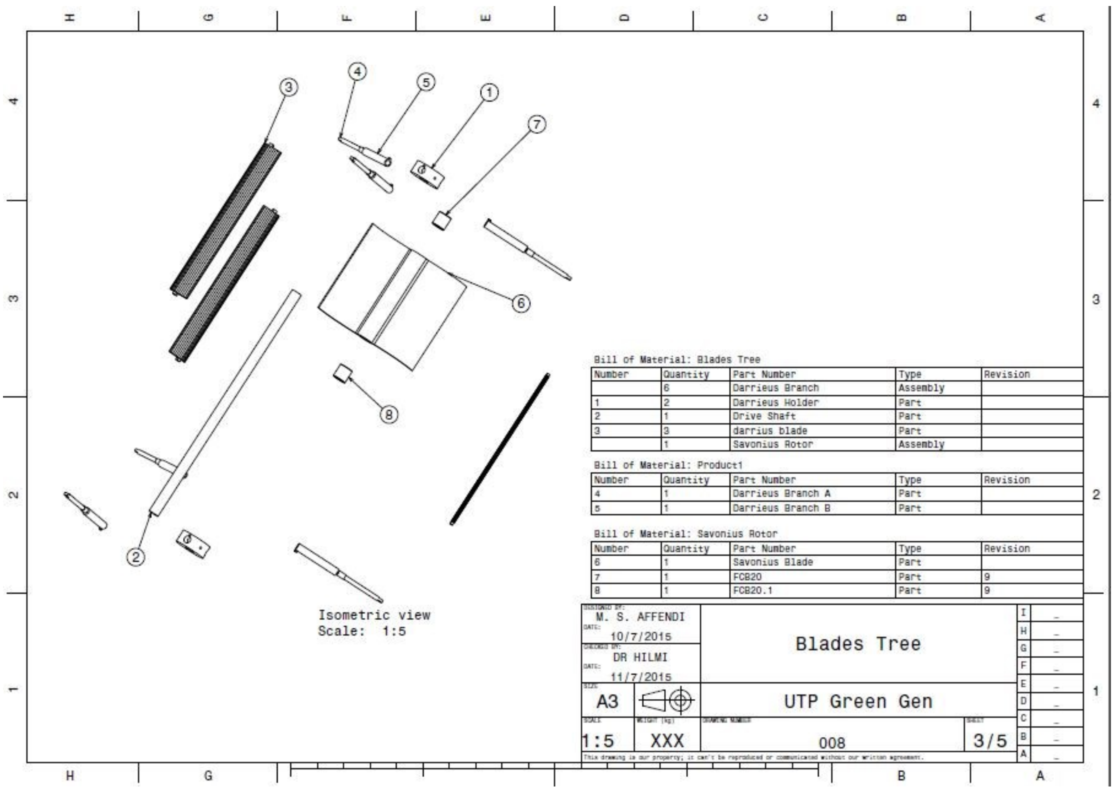
APPENDICES





Bill of Material: Blades Tree

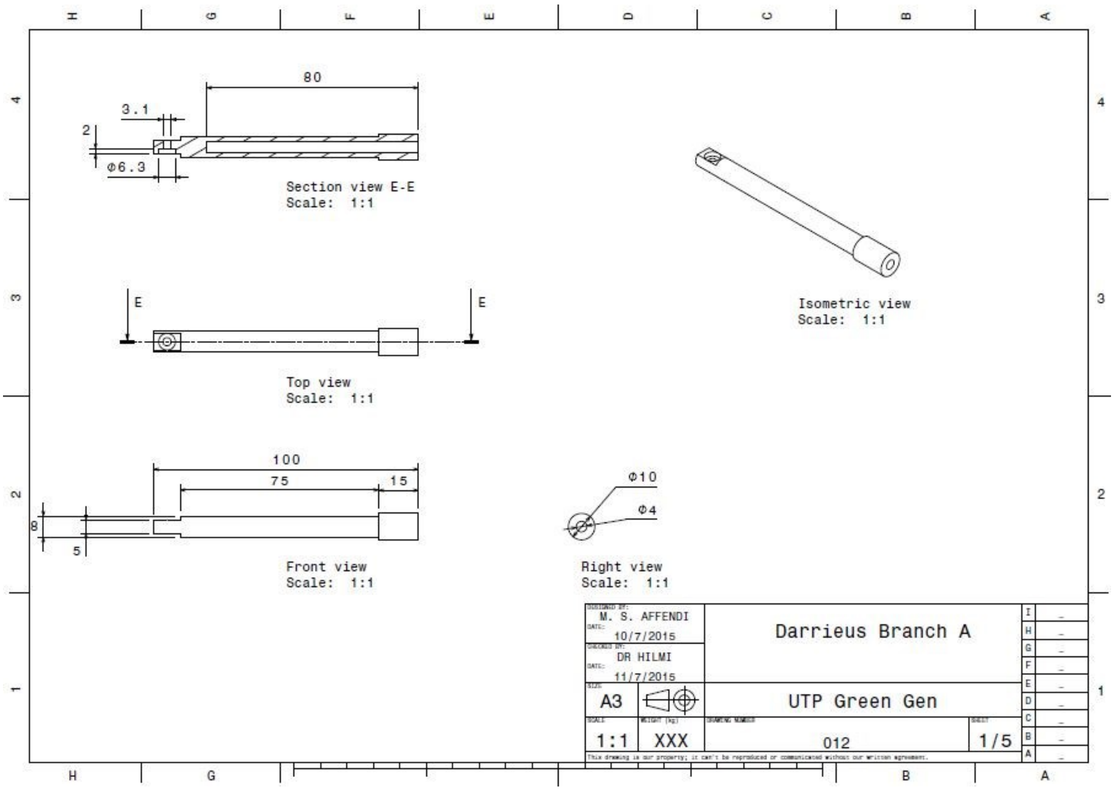
Number	Quantity	Part Number	Type	Revision
	6	Darrieus Branch	Assembly	
1	2	Darrieus Holder	Part	
2	1	Drive Shaft	Part	
3	3	darrius blade	Part	
	1	Savonius Rotor	Assembly	

Bill of Material: Product1

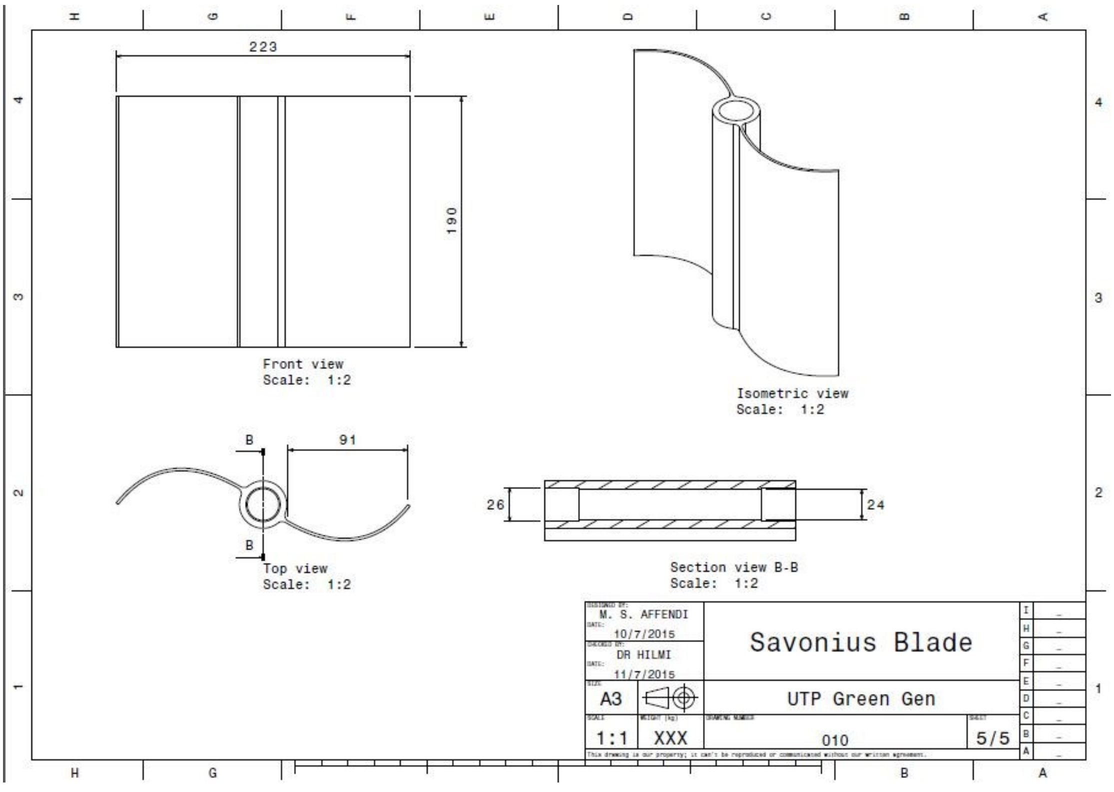
Number	Quantity	Part Number	Type	Revision
4	1	Darrieus Branch A	Part	
5	1	Darrieus Branch B	Part	

Bill of Material: Savonius Rotor

Number	Quantity	Part Number	Type	Revision
6	1	Savonius Blade	Part	
7	1	FCB20	Part	9
8	1	FCB20.1	Part	9



Section view E-E
Scale: 1:1
Top view
Scale: 1:1
Front view
Scale: 1:1
Isometric view
Scale: 1:1
Right view
Scale: 1:1
M. S. AFFENDI
10/7/2015
DR HILMI
11/7/2015
Darrieus Branch A
A3
UTP Green Gen
1:1
XXX
012
1/5



Front view
Scale: 1:2
Isometric view
Scale: 1:2
Top view
Scale: 1:2
Section view B-B
Scale: 1:2
M. S. AFFENDI
10/7/2015
DR HILMI
11/7/2015
Savonius Blade
A3
UTP Green Gen
1:1
XXX
010
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