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College of Engineering

Department of Mechanical Engineering

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Senior Project Report

Design of Aeroleaf Wind Turbine

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Abstract

This project (Design of Aeroleaf Wind Turbine) is about designing and manufacturing a Vertical Axis Wind Turbines VAWT to transfer the wind speed to a rotational motion using these turbines. These turbines will be attached to a manufactured tree that will look like a modern design, which can be installed in and around any public area such as parks, roads, public facilities, or business offices. Aeroleaf Wind Turbines are designed to produce power up to 300 watts for each turbine.

This project presents a review on the performance of Savonius wind turbines. This type of turbine is not commonly use and its applications for obtaining useful energy from air stream is still considered as an alternative source. Low wind speed start-up, working with any wind direction, and the less noise are some advantage of VAWT- Savonius model.

This project consists of three phases; designing, fabrication, and evaluating. An actual of gained power is reported to be 31~35% relative to the theoretical gained power due to the instability and inefficient of the wind speed.

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Acknowledgment

This is the time where we reach the end of completing mechanical engineering program at PMU. This senior project is a valuable chance where we implemented most of the skills and knowledge that we gain throughout our studies.

The Aeroleaf Wind Turbine project team would like to thank the group advisor Dr. Nader Nader and the group Co advisor Dr. Ali Chamkah for their supervision and instruction throughout the semester. This thank is also extending to Dr. Nader Sawalhi for the support, guidance, leadership and dedication.

We would like also to thank PMU facility and staff for giving us the education and skills required to be at this level.

Chapter 1

INTRODUCTION

1.1 PROJECT DEFINITION

This project is about designing and manufacturing an Aeroleaf Wind Turbine that can convert wind by using Vertical Axis Wind Turbines (VAWT) to a useful energy.

The current power demanding in Saudi Arabia is very high compared to power consumption world average, as reported by Arab news; Saudis consume three times more electricity than the world average [1]. This high demanding should take the focus of attention in thinking in different sources of energy.

One of the best sources of energy that can apply the concept of sustainability is renewable energy such as sun, wind, and rivers. The positive point of wind energy is that unlike solar energy that only used with sunlight, wind turbine can be useful all the 24 hours all the year.

Another concept of sustainability is the way that we should use in utilizing this renewable energy efficiently, and environmentally friendly. This, in turn will eliminate the environment hazard and improve Saudi Arabia communities' health and life style.

Streets, public parks, schools, and public facilities are consider as main power consumers, these consumers should be vulnerable to wind from time to time. The idea of this project is to convert this wind by using Vertical Axis Wind Turbines (VAWT) to a useful energy by using it as a power source that can serve these consumers.

1.2 PROJECT OBJECTIVES

The main objective of this project is gaining power from wind. Therefore, this project is green source of energy and has no effect on the life of earth. These wind energy turbines are small and can produce up to 300 watts for each turbine.

Another objective of this project is gaining and exercising some engineering concepts such as:

- Learn about wind energy and different ways of convert it to a useful power.

- Learn the different between Vertical Axis Wind Turbines (VAWT) & Horizontal Axis Wind Turbines (HAWT).
- Learn the impact of energy & our rules as engineering students to provide alternatives.

1.3 PROJECT SPECIFICATIONS

This project is 2.8 meter high (tree & turbine), it is expected to produce total of up to 600 watts. The material that the tree is made of is galvanized carbon steel and the turbine blades are made of aluminum alloy. The turbines can start working under low wind speed and can cut-off if the speed is too high.

1.4 PRODUCT ARCHITECTURE AND COMPONENTS

The project main components are tow turbines which include (blades, shaft bearings) for each turbine, electrical generator attached to the end of the shaft for each generator. The generators are connecting through wires to the control banal, which include (converter, controller and battery connected from and to the banal for the popups of changing from and to DC & AC).
Below figure1.1, identifying the initial functional diagram that shows the expected project outlook. And initial real photo of the project is in the below figure 1.2.

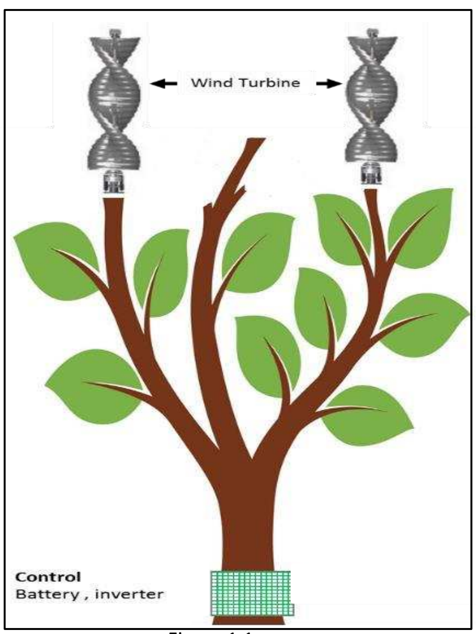


Figure 1.1
Initial functional diagram

Figure 1.2
Project initial real photo

1.5 APPLICATION

This project idea is very simple, where it focuses on utilizing the wind energy by designing and manufacturing two VAWT and attach them to a manufactured tree. This tree can be installed across the public facilities. Facilities such as public parks, in the top of the stadiums where wind is very high and around the stadiums, services' buildings, and over the roads and streets. It can also install in a simulated tree.

Chapter 2

LITERATURE REVIEW

2.1 PROJECT BACKGROUND

Energy is the main economy base of any country. Sources of energy are not easy to have. Having multiple sources of energy is extremely important to secure the basic living requirement of any country. Utilizing the nature could help in converting some of the natural phenomenons such as sun, wind, sea and oil into useful energy. This kind of energy called renewable energy.

Science Daily Research Newspaper has defend renewable energy as “The most common definition is that renewable energy is from an energy resource that is replaced rapidly by a natural process such as power generated from the sun or from the wind.” [2].

Recently, the increasing demand of renewable energy is very well noticed. According to a report by the International Energy Agency, the increase of amount of electricity produced from renewable sources increased from just over 13% in 2012 to 22% the following year. They also predict that that figure should hit 26% by 2020 [3].

The traditional power plants in Saudi Arabia are mainly working on the fuel either gas or oil which are not environmental friendly. EcoSpark environmental charity [4] has considered oil power plants as one of the most contributors of environment pollution. EcoSpark environmental charity has listed the below most significant environmental impacts:

- Oil causes air pollution and greenhouse gas emissions.
- Oil uses large amounts of water, and creates water pollution and thermal discharge.
- Oil creates hazardous sludge and solid waste.
- Extracting and refining oil is environmentally destructive.
- Transporting oil is risky and can harm the environment.
- Oil is a non-renewable electricity source.

Such of the above environment affects lead us to think seriously about the renewable energy sources, which will eliminate the environment hazard and improve health and life style.

Wind energy is one of the most important energy sources. The concept of wind energy is transforming the wind's kinetic energy into mechanical energy. This energy drive blades that turn generators that produce electricity. Our project is fitting with wind energy source. The idea of this project is to convert the wind by using Vertical Axis Wind Turbines (VAWT) into power.

They are two types of wind turbines, Horizontal Axis Wind Turbines (HAWT) as shown in figure 2.1 that is more commonly used across the world and they are used as a power plants.

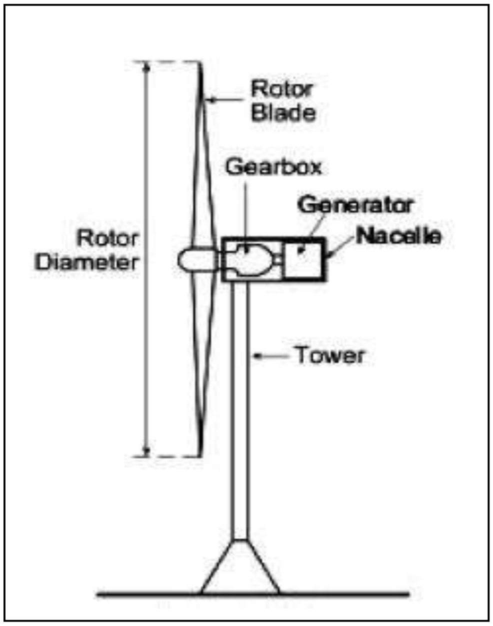


Figure 2.1
HAWT overview layout
http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=15875&context=rtd

These kind of turbines are the most efficient of wind turbine. Cole Gustafson from Dakota State University has mentioned the advantages and disadvantages of horizontal axis vs vertical axis wind turbines, "In research studies evaluating wind turbine performance, horizontal axis machines have been shown to be more efficient than vertical axis machines. However, the blade span of horizontal wind turbines is larger than vertical axis machines which limits placement confined spaces. Some people also find the large blade area of horizontal axis machines objectionable" [5].

The other type of wind turbine is the Vertical Axis Wind Turbines (VAWT) as shown in figure 2.2. VAWT is the most popular of the turbines that people are using to make their home a source of renewable energy.

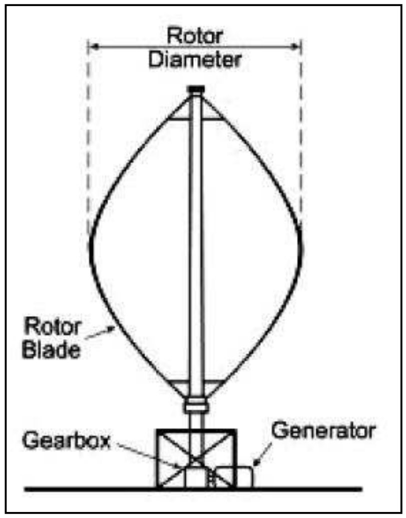


Figure 2.1
VAWT overview layout
http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=15875&context=rtd

VAWT is not as commonly used as the Horizontal Axis Wind Turbine. The reason behind that is that VAWT is less efficient than HAWT when considered as a power plant generator. However, for the small scales like homes, parks, or offices VAWT is more efficient. "Vertical axis turbines are powered by wind coming from all 360 degrees, and even some turbines are powered when the wind blows from top to bottom. Because of this versatility, vertical axis wind turbines are thought to be ideal for installations where wind conditions are not consistent, or due to public ordinances the turbine cannot be placed high enough to benefit from steady wind." [6]. Figure 2.3 shows the configuration of HAWT vs VAWT.

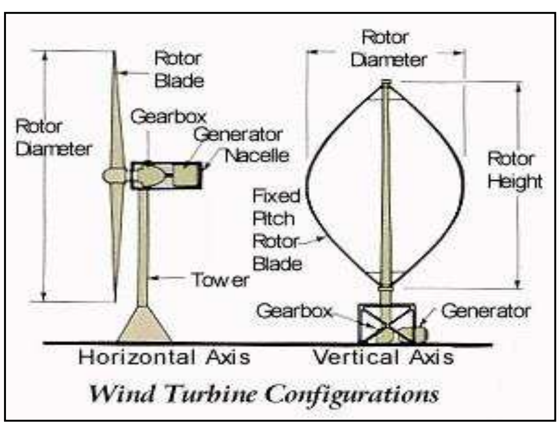


Figure 2.3
Configuration of HAWT Vs VAWT
https://sci10sectionm.wordpress.com/2014/02

2.2 PREVIOUS WORK

There are two different styles of vertical wind turbines. One is the Savonius model, which is our project is based on, and the other type is the Darrieus model. The first model looks like a gallon drum that is been cut in half with the halves placed onto a rotating shaft. The second model is smaller and looks much like an egg beater. Most of the wind turbines being used today are the Savonius models.

Renewable Energy UK website provided some information about these two model. “A Savonius is a type of vertical axis wind turbine (VAWT) generator invented in 1922 by Sigurd Johannes Savonius from Finland though similar wind turbine designs had been attempted in previous centuries."[7].

“A Darrieus is a type of vertical axis wind turbine (VAWT) generator. Unlike the Savonius wind turbine, the Darrieus is a lift-type VAWT. Rather than collecting the wind in cups dragging the turbine around, a Darrieus uses lift forces generated by the wind hitting aerofoils to create rotation.” [8].

In Jun 2.15, International Research Journal of Engineering and Technology (IRJET) has published a research titled “DESIGN, ANALYSIS AND FABRICATION OF SAVONIUS VERTICAL AXIS WIND TURBINE” [9].

This research discussion was to showcase the efficiency of Savonius model in varying wind conditions as compared to the traditional horizontal axis wind turbine. It evaluated some observation that showed that at low angles of attack the lift force also contributes to the overall torque generation. Thus, it can be concluded that the Savonius rotor is not a solely drag-driven machine but a combination of a drag-driven and lift-driven device. Therefore, it can go beyond the limit of Maximum power coefficient Cp established for the purely drag-driven machines.

Some of this researched conclusions are that The vertical axis wind turbine is a small power generating unit with the help of free source of wind energy. It is designed under consideration of household use. Generally, At least 10% power of the consumption can be fulfil by the Savonius model.

The research has also resulted that this turbine is generally suitable for 8 to 10m of height above ground level. Because at ground level velocity of air is very less. And finally the alternate option for turbine blade material is reinforced glass fiber because of its more elastic nature but it is costlier than aluminum alloy.

To have the best efficiency of the power output from our turbine, the team has done some brainstorming in what are the most significant factor that affect the turbine, the blade angle was agreed to be the most significant one.

By doing some researches, we fined an article that focusing in the turbine blade angle.

A research article published by Advances in Mechanical Engineering (AIME) with a title of "EFFECT OF THE BLADE ARC ANGLE ON THE PERFORMANCE OF A SEVONIUS WIND TURBINE" [10].

This article is focusing on how to improve the efficiency of the turbine by selecting the best blade angle.

The effect of the blade arc angle on the performance of a typical two-bladed Savonius wind turbine is investigated with a transient computational fluid dynamics method. Simulations were based on the Reynolds Averaged Navier–Stokes equations, and the renormalization group $k - \varepsilon$ turbulent model was utilized.

The numerical method was validated with existing experimental data.

The results of this article indicate that the turbine with a blade arc angle of 160° generates the maximum power coefficient cp 0.2836, which is the highest that gain from the experiment.

The article provided the below table 2.1, which shows the maximum coefficient of power for different cases. Figure 2.1 shows the blade dynamic torque coefficient for different blade arc angles

Table 2.1
Maximum coefficient of power for different cases [10]

Case	Blade angle	$C_{P\,max}$	C_P gain percentage (relative to *case* 4)
1	150	0.2687	2.67%
2	160	0.2836	8.37%
3	170	0.2835	8.33%
4	180	0.2617	0.00%
5	190	0.2521	−3.67%
6	200	0.2271	−13.22%

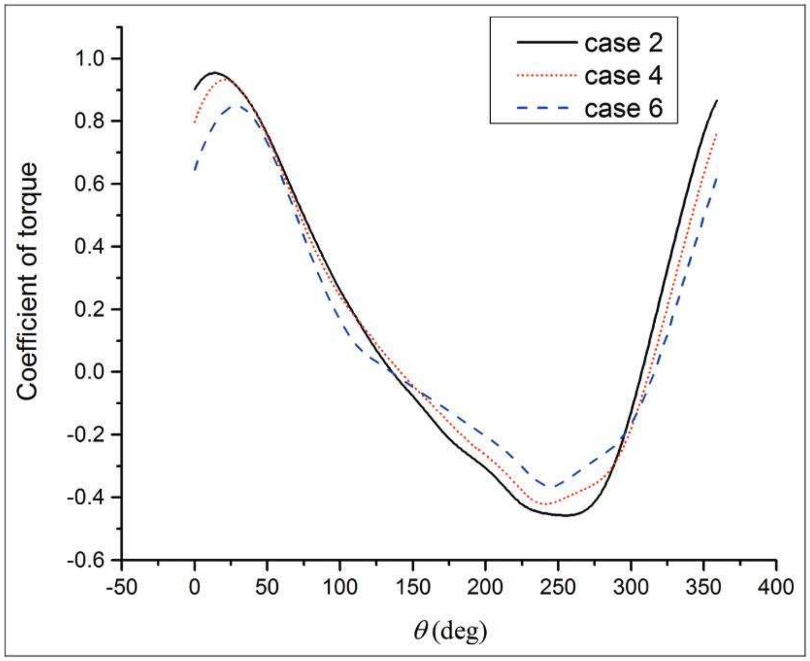


Figure 2.4
Blade dynamic torque coefficient for different blade arc angles [10]

2.3 COMPARATIVE STUDY FOR AEROLEAF PROJECT

There was a student's project which was about designing and evaluating of twisted savonius wind turbine. This project was done under MEMORIAL UNIVERSITY [11]. This work's goal was to testing the self-starting of the turbine, also the work was targeting of the design can be tested under harsh environmental conditions to assess longer-term reliability.

After fabrication and experiments under different wind conditions, this project presented results as shown in the below table 2.2. The project conclusion was that the turbine has proved to be self-starting under low wind speed.

Table 2.2
Wind Speed Calibration Data

Wind Speed	
m/s	Volts
0	-0.0091
1.19	0.0765
3.07	0.2223
5.18	0.3826
7.3	0.5371
8.81	0.6601
9.71	0.7381
10.68	0.8162

Another student project we found was titled "design a Savonius Wind Turbine" from Democritus University of Thrace [12]. The objective of this report is to study and manufacture a wind turbine of vertical axis, Savonius type. In particular, what will be studied is which geometrical design of the wings of the wind turbine is the most efficient, while taking into account the cost, the elegance, the simplicity, the feasibility and the durability.

After fabrication and experiment, this project presented a result which shows the relation between the wind velocity and the actual power of the wind turbine. The conclusion is that for double wind velocity the power becomes 8 times more as shown in the below figure 2.5.

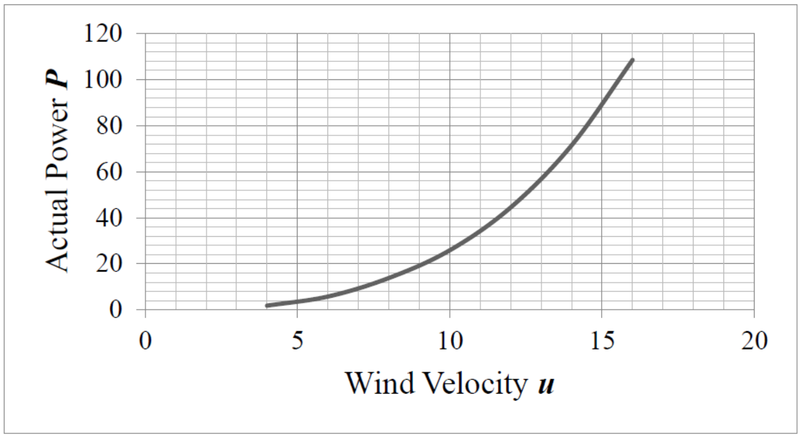


Figure 2.5
Actual Power according to the Wind Velocity

Another very important result is the Rotational Speed of the turbine depending on the wind velocity which is shown to the below table 2.3 and figure 2.6.

Table 2.3
Rotational speed for every Wind velocity

Wind Velocity u	Rotational Speed n
4 m/s	224 rpm
6 m/s	337 rpm
8 m/s	449 rpm
10 m/s	561 rpm
12 m/s	674 rpm
14 m/s	786 rpm
16 m/s	898 rpm

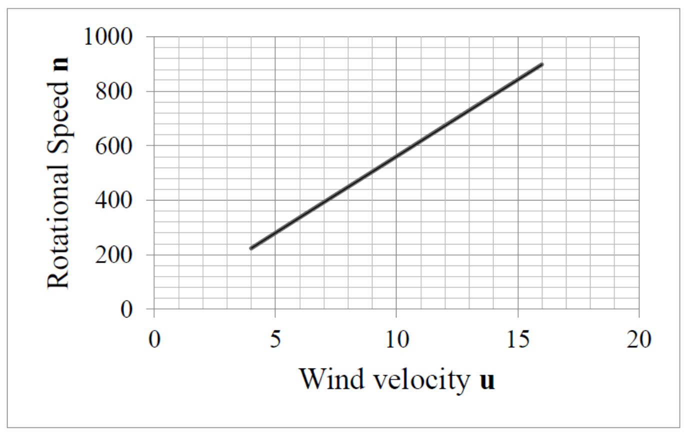


Figure 2.5
Rotational speed according to Wind velocity

This project presented a conclusions that the wind turbine which they constructed has several advantages and uses. First of all, it can take advantage of every wind direction and begin the rotation under very low wind powers. The noise it produces is very low compared to common wind turbines, especially the horizontal axis one.

Chapter 3

SYSTEM DESIGN

3.1 REQUIREMENTS, CONSTRAINTS AND SPECIFICATION

3.1.1 General specifications

Aeroleaf wind turbine is new way of producing energy form Vertical-axis method. This new energy source is useful in the modern cities because of it is nice design and free noise. These wind energy generators are. The Aeroleaf tree is designed hold two wind Savonius turbine, which are small in size and can produce up to 300 watts.

The positive point of wind energy is that unlike solar energy that only can be used with sunlight only. Wind energy can be useful all the 24 hours all the year. This project is green source of energy and has no effect on the life of earth.

There are no effects on the environment at all. Moreover, it is reduce the CO2 and CO gases that effect the environment in the earth. One of the biggest challenges is the social accept of Aeroleaf Wind turbine.

3.1.2 Constraints and requirements

One of the most difficultly problem is the lack of necessary equipment needed for the analysis and selection of materials accurately in the university. Also, in the market, I was really difficult to find some of the needed materials.

These problems make the function of this project relying for some parts in design of previous studies mentioned in chapter 2 by doing the reverse engineering.

Getting a sufficient wind, to analyze and test work. It was also the one of the berries that we have encountered, because of the lack of wind in the area at that time, and the lack of experience in aerodynamic science.

Beside the Lack of important resources, the lack of financial support was a major obstacle in our way even though the budget was estimated

Although the existence of moral support from our professors, Lack of sufficient time was a real challenge to show up the work as long as there was only one semester to complete the senior project.

3.2 DESIGN METHODOLOGY

The methodology applied to this project can be divided into six phases. These phases are information gathering, concept generation, model generation, model analysis and refinement, concept selection, and verification, these phases are shown in figure 3.2.

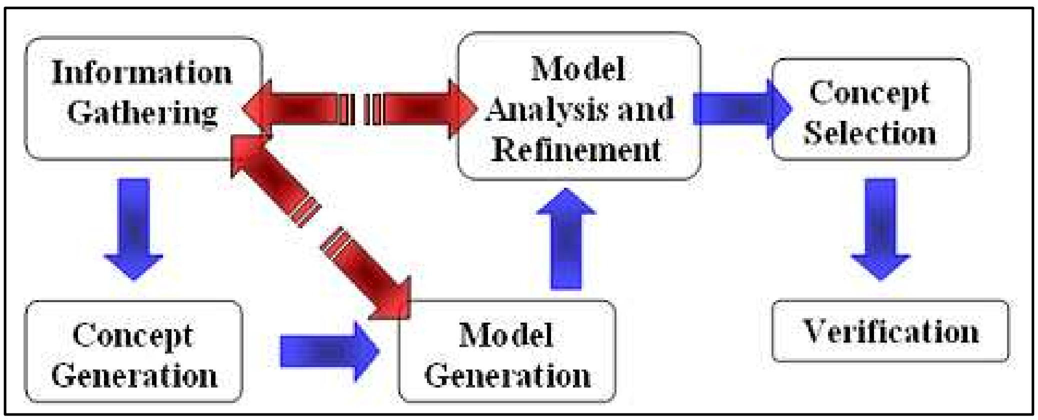


Figure 3.2
Applied Phases of used Methodology

Prior any appropriate solution can be developed, a thorough investigation has to be conducted in order to find out what solutions have already been proposed (information gathering).

Once these solutions have been analyzed and the team has an understanding of why the respective solutions are not currently being implemented, a solution generation phase is taking place. Here various solutions are presented and evaluated against criteria and constraints (concept generation). Solution concepts are then modeling

The results of the models are then analyzed and the model, as well as solution parameters, may be tweaked (model analysis and refinement).

Once the team has satisfactorily modeled all solution concepts of interest, the concept that performs best analytically, in addition to meeting all criteria and constraints, is selected (concept selection). The analytical model may then be verified experimentally, using a small scale modeling scheme or through a full scale experimental model.

The objective of this project is to design a vertical axis wind turbine (VAWT) that could generate power under relatively low wind velocities. To accomplish this goal, the objectives are to:

- Analyze how different geometry of the wind turbines would affect the output power of the wind turbine.
- Vibrations analysis by testing how the vibrations caused from the rotations of the wind turbines affect the structural integrity of various aspects buildings structures.
- Compare the operation of turbines with respect to the numbers of attached plades.

To meet the above objectives, the tasks were to:

- Conduct background research and analysis on wind turbine technology.
- Design initially turbine blade for testing.
- Design tree to hold these turbines.
- Looking for power generator that has good efficiency with low startup speed.
- Create experimental set up.
- Manufacture parts and build model tree.
- Develop future design recommendations.

3.3 Product Subsystems & Components

Vertical axis wind turbine VAWT are one whose axis of rotation is vertical with respect to ground. Generally as shown in figure 3.3, the main components of this turbine are:

- Blades
- Shaft
- Generator

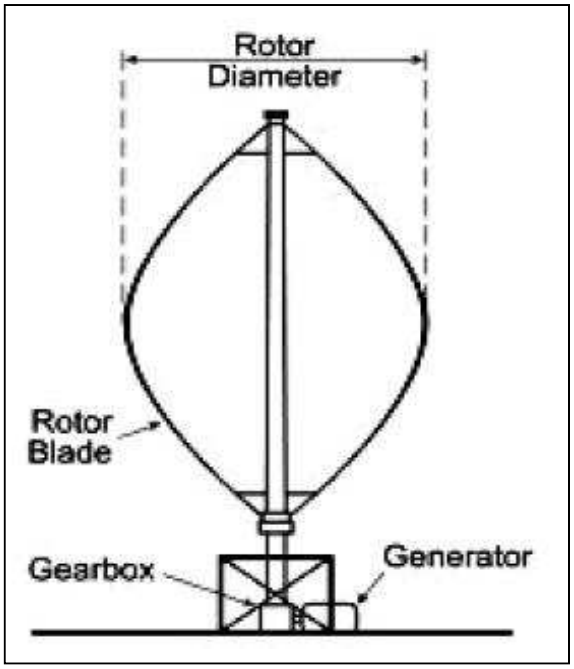


Figure 3.3
Main components of VAWT
http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=15875&context=rtd

.

3.3.1 ROTOR BLADES

Savonius blades are a crucial and basic part of a wind turbine figure 3.4. They are mainly made of aluminum, fiber glass or carbon fiber. We selected the aluminum alloy as recommended in the study mentioned in chapter 2.2 because they provide batter strength to weight ratio.

The design of the individual blades also affects the overall design of the rotor. Rotor blades take the energy out of the wind; they capture the wind and convert its kinetic energy into the rotation of the hub. The arc angle was selected based on the pervious study mentioned in chapter 2.2, which recommended an angle of 160°

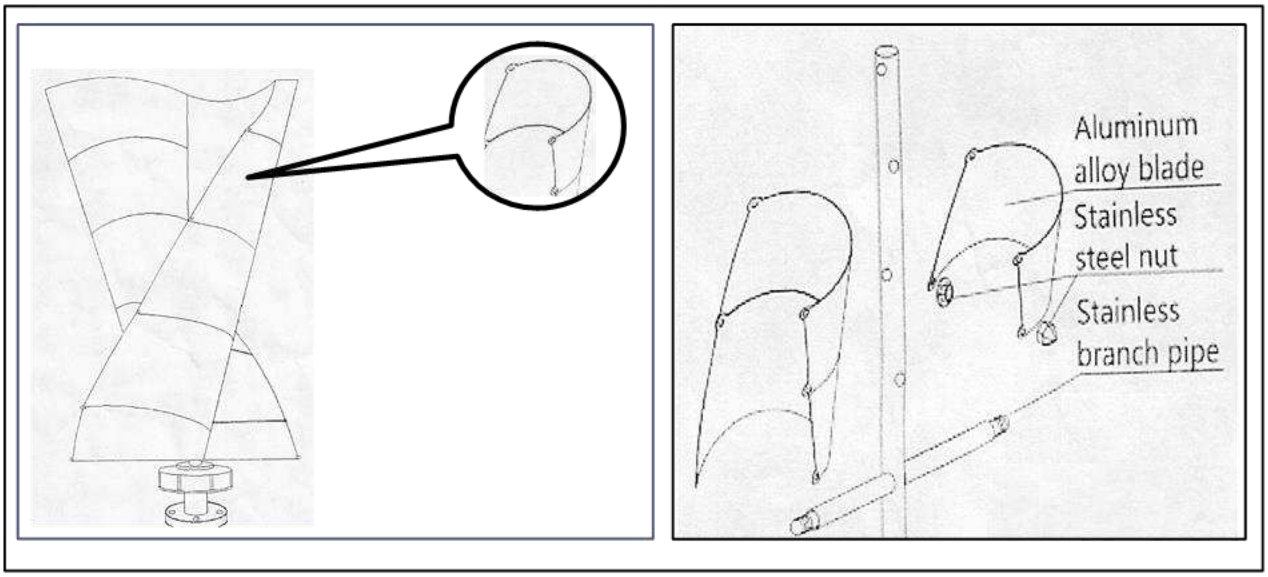


Figure 3.4
Turbine Blade Design

3.3.2 SHAFT

The shaft is the part that gets turned by the turbine blades. It in turn is connected to the generator within the main housing.

A solidworks tools have been used in designing the blades and the shaft as shown in the below figure 3.5

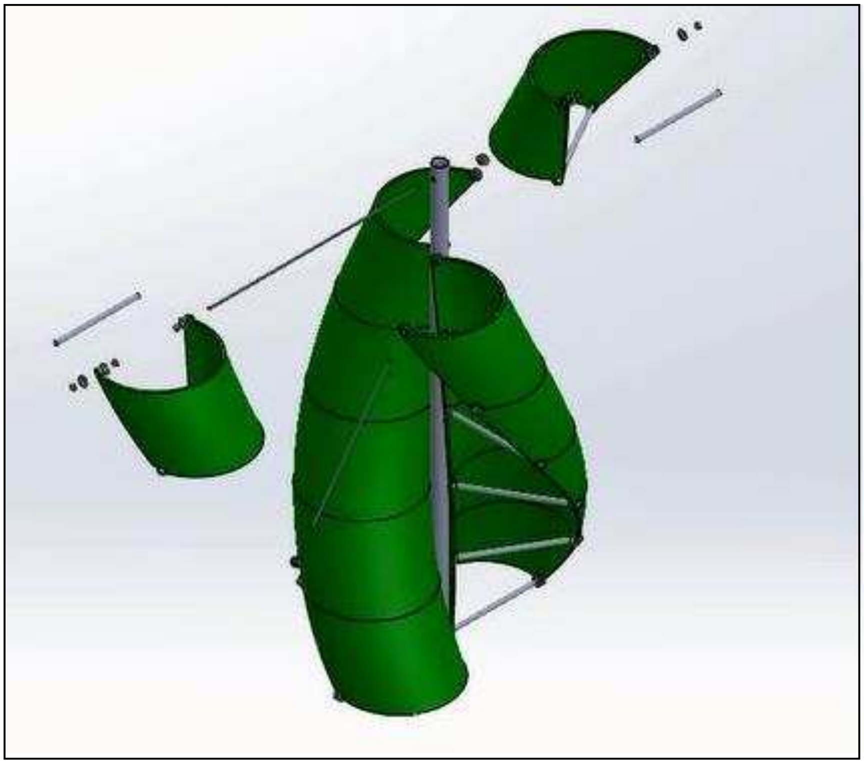


Figure 3.5
Solidworks sketch for Turbine Blade and Shaft Design

3.3.3 Radial & Thrust Bearings

The bearing is integral part of the overall system. The lubricant and sealing elements also play a crucial role. To enhance bearing effectiveness in the system, the right type should be selected. However the procedure of the selection is a science but we restricted on three simple steps:

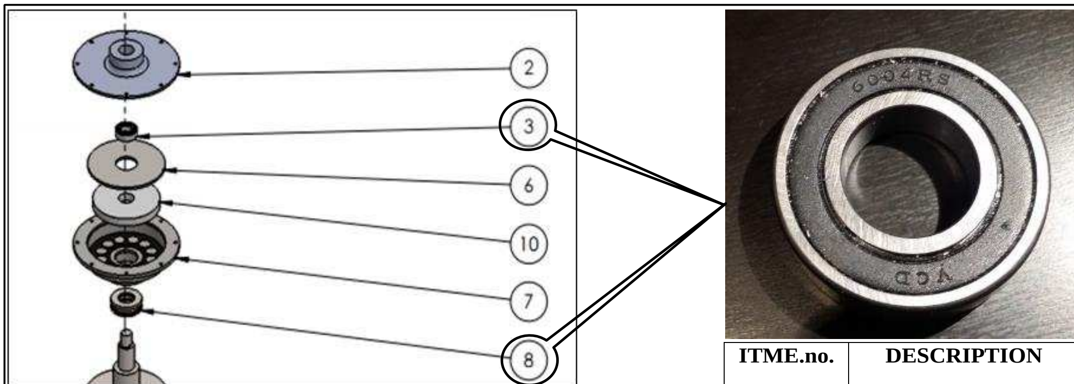
1- Confirm operating conditions and operating environment.
2- Select bearing type and configuration.
3- Select bearing dimensions.

The correct amount of an appropriate lubricant must be present to reduce friction in the bearing was consider. As long as the sealing elements are important because of the environment surrounding our project and keep the lubricant in, and away from the dust and contaminants. On another side, the low speed of the system was consider too in the selection with axis and radial forces which is the weights of upper system.

$$F\,axial = project\ wight\ \times Gravitional$$ **Equation 3.1**

$$F\,radial = m \times \omega \times 2r$$ **Equation 3.2**

As result we came up with two ball bearing 6004RS as shown in figure 3.6 where can function as thrust and radial bearing (sealed and self-lubricant) and can carry the Static Load Rating and Dynamic Load Rating 5 KN and 9 KN respectively and the distance between the two bearings was based on as simulation Xpress done by Central University Campus [13].



ITME.no.	DESCRIPTION
3 and 8	ball bearing_6004 RS

Figure 3.6
Selected Bearing Details

3.3.4 Electrical Parts

The turbines are connected to electrical parts in order to get the required power. These parts are as shown in the below table 3.1.

Table 3.1
Electrical Parts

Part	Function
Electrical Generator	Converting the rotating speed to an electrical
Turbine Controller	
Combiner	Combining the earned power from each turbine to one output power
Battery	Charged electrically to provide a static potential for power or released electrical charge when needed.
Fuse	an electrical device that can interrupt the flow of electrical current when it is overloaded
Converter	Converting DC current to AC current
Turbine Sensors	Braking overload
Consumption reading	Reading battery percentage

3.3.5 GENERATOR

The conversion of rotational mechanical energy to electrical energy is performed by generator. Different types of generator have been used in wind energy system over the years. For large, commercial size horizontal-axis wind turbines, the generator is mounted in a nacelle at the top of a tower, behind the hub of the turbine rotor. Typically wind turbines generate electricity through asynchronous machines that are directly connected with the electricity grid. Usually the rotational speed of the wind turbine is slower than the equivalent rotation speed of the electrical network - typical rotation speeds for wind generators are 5-20 rpm while a directly connected machine will have an electrical speed between 750-3600 rpm. Therefore, a gearbox is inserted between the rotor hub and the generator. This also reduces the generator cost and weight.

The generator used for the prototype is the Low RPM permanent magnet DC generator created by Wind Stream Power and is a 12-volt step generator. The generator has an internal resistance of 21Ω.

The current generator can only operate continuously with a current of 1.5 amperes and at a max of 1.5 minutes with a current of 3 amperes the below figures 3.6 and 3.7 are explaining the generator parts.

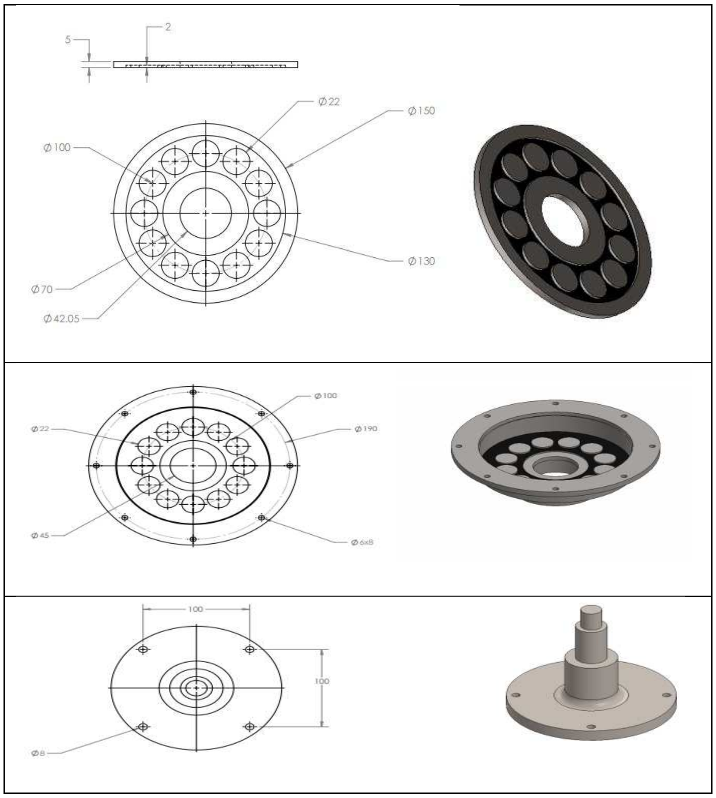
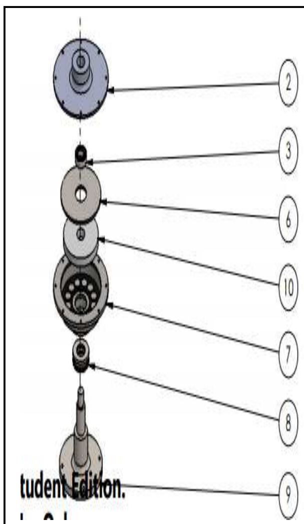


Figure 3.6
Generator parts



ITME.no.	DESCRIPTION
2	End Cap
3	radial ball bearing_68_am
6	Magnetic Steel
7	Shell
8	thrust ball bearing3_68_am
9	Shaft
10	Coil

Figure 3.7
Generator parts with description

3.3.6 Battery

The battery that we used in our project is The Long WPL150-12N rechargeable power guard sealed lead acid battery as shown in the below figure 3.8, and table 3.2

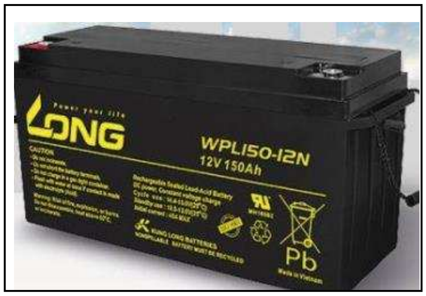


Figure 3.8
Long WPL150-12N Battery

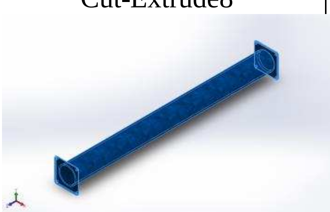
Table 3.2
Long WPL150-12N Battery Details

Brand Name	Long
Item Weight	45.5kg
Capacity	150Ah
Dimensions	19.02 x 6.7 x 9.5
Maximum Discharge Current For (5 Seconds)	1500A
Maximum Charging Current For (5 Seconds)	45A
Design Life	12 Years

3.3.7 Bottom Pipe

Considering the total weight of the so far construction and the desirable design of the wind turbine three support bases will be used. These three levels are connected and supported, the material we used for the bases was metal as shown in simulation figure 3.9.

Model name: Bottom Pipe
Current Configuration: Default

Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Cut-Extrude8 	Solid Body	**Mass:12.342 kg** **Volume:0.00156823 m^3** **Density:7870 kg/m^3** **Weight:120.951 N**	

Model Reference	**Properties**		**Components**
	**Name:**	Galvanized Steel	SolidBody 1(Cut-Extrude8)(Bottom Pipe)
	Model type:	Linear Elastic Isotropic	
	Default failure criterion:	Unknown	
	Yield strength:	2.03943e+008 N/m^2	
	Tensile strength:	3.56901e+008 N/m^2	
	Elastic modulus:	2e+011 N/m^2	
	Poisson's ratio:	0.29	
	Mass density:	7870 kg/m^3	

Figure 3.9
Simulation of Bottom Pipe

3.4 Implementation

3.4.1 Turbine design & sketch

After compiling background research, we started the planning for the project. We reached a point where we started the initial drawings of the design. Basically, we drew the overall project outlook, which is a tree, turbine(s), electrical generator, and light as shown in figures 3.10, 3.11.

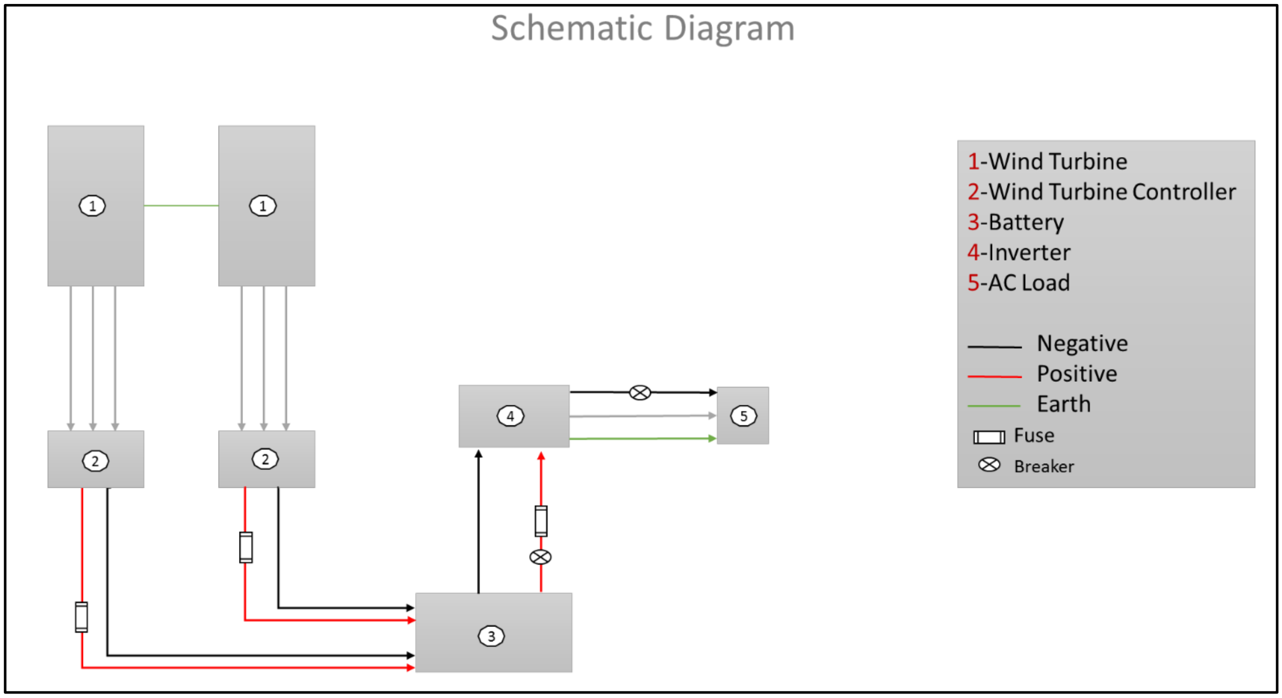


Figure 3.10
Schematic Diagram

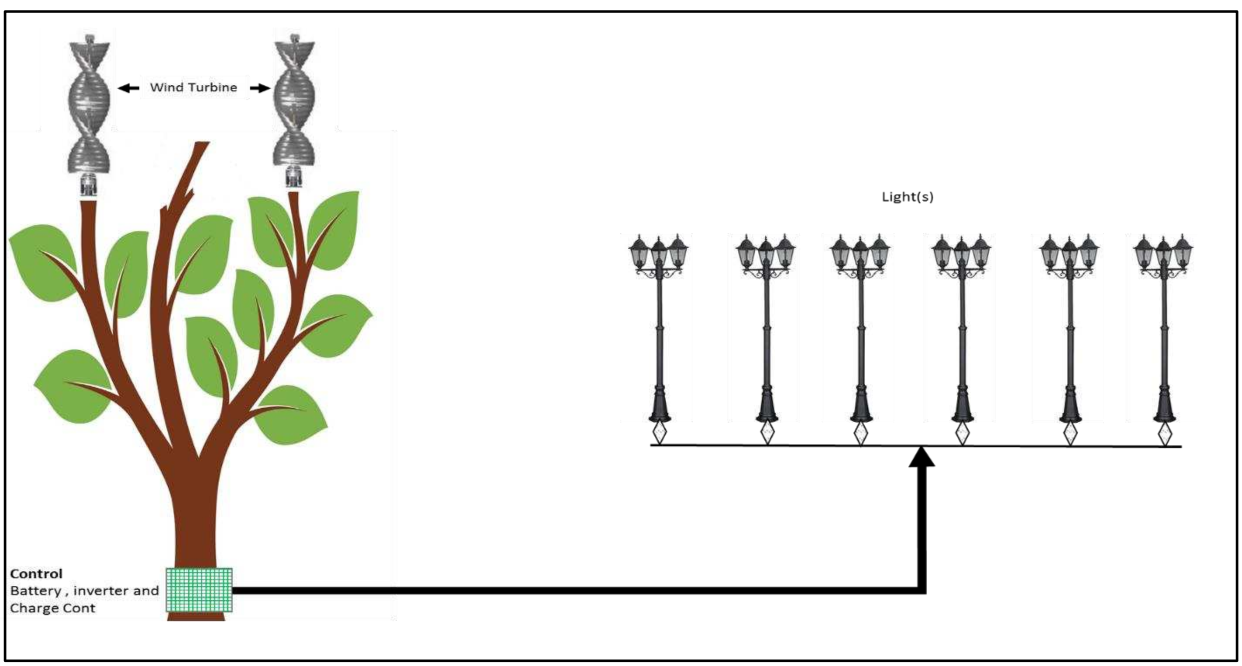


Figure 3.11
Visual Schematic Diagram

As shown in figure 3.11, the turbine design was made using the SolidWorks tools which we used at the beginning to identify the design initial parameters for better understanding.

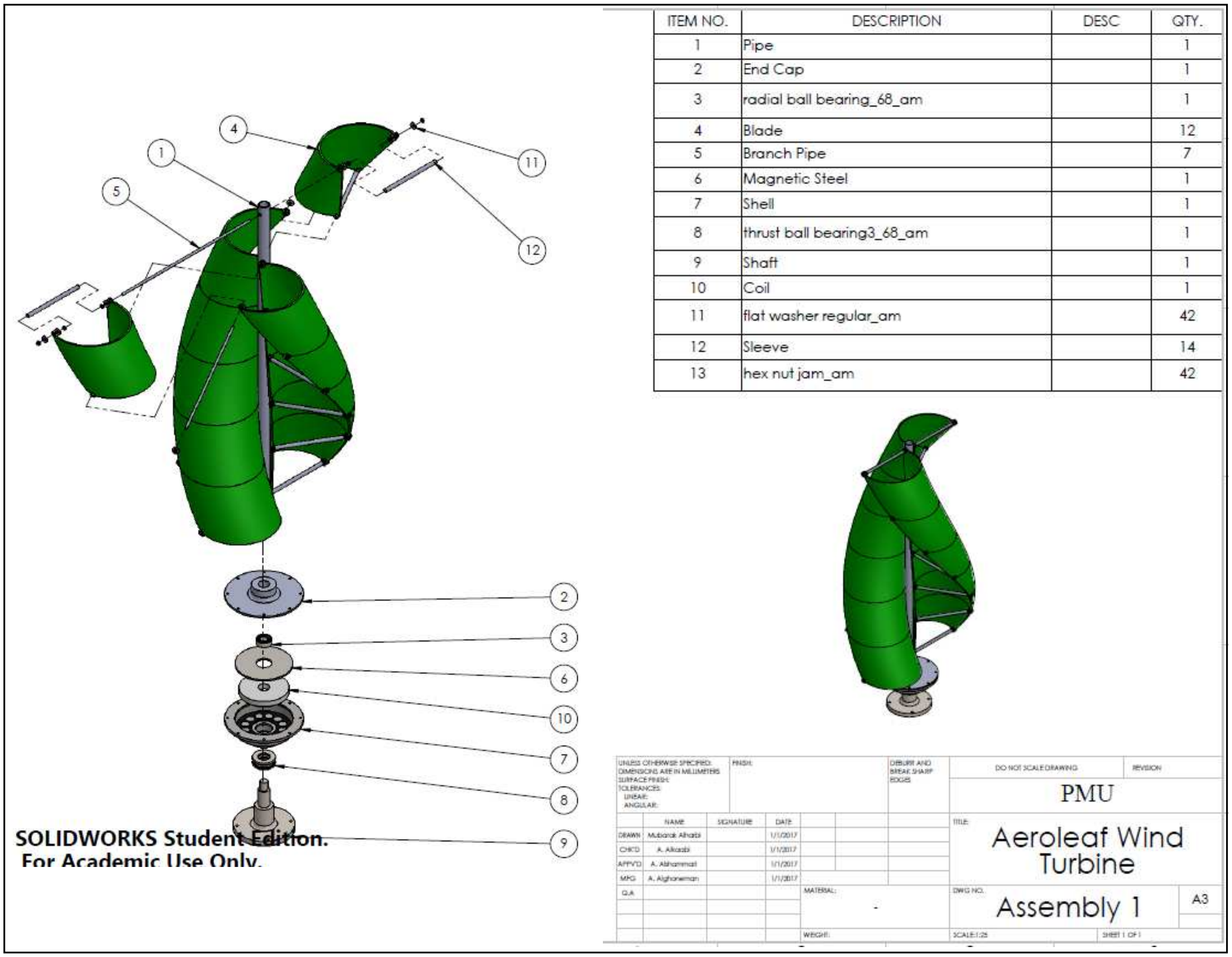


Figure 3.11
Turbine SolidWork sketch

3.4.2 Designing tree Model

At this stage, we reached to a point where we need to start planning for designing the tree. This planning starting from defining the high and width of the tree, which we agreed leader to be 2.8 meter high to achieve as much wind as possible and 2 width.

A goal for defining a tree branches was to have the most popular design and material that would be able to provide realistic results. Initially, we tried to use aluminum material for the tree branches. But, this marital will not hold the turbines easily, and if it did it will not hold them for long time.

We finally came to the conclusion that a carbon steel galvanizing materials (Pipe, flanges & blade) for the tree would satisfy our requirements. Figure 12.13 shows initial tree design. And figure 3.13 shows the solidworks drawing.

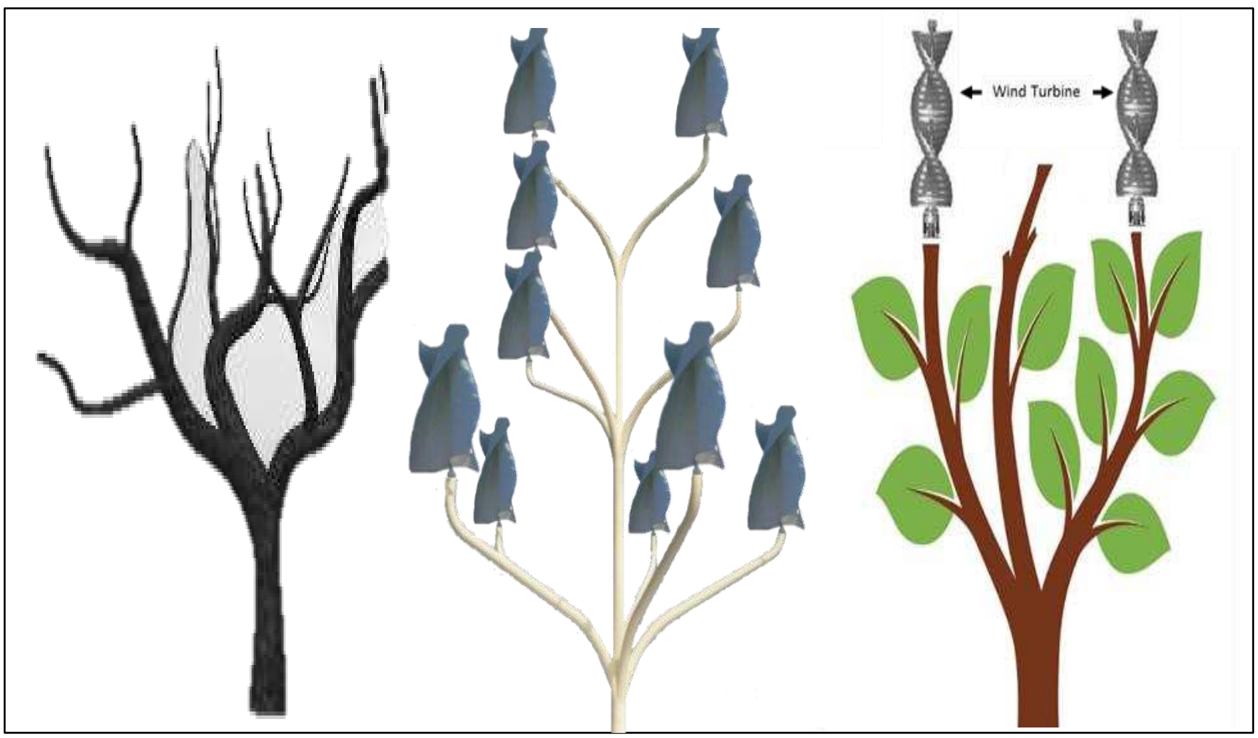


Figure 3.12
Initial Tree Design

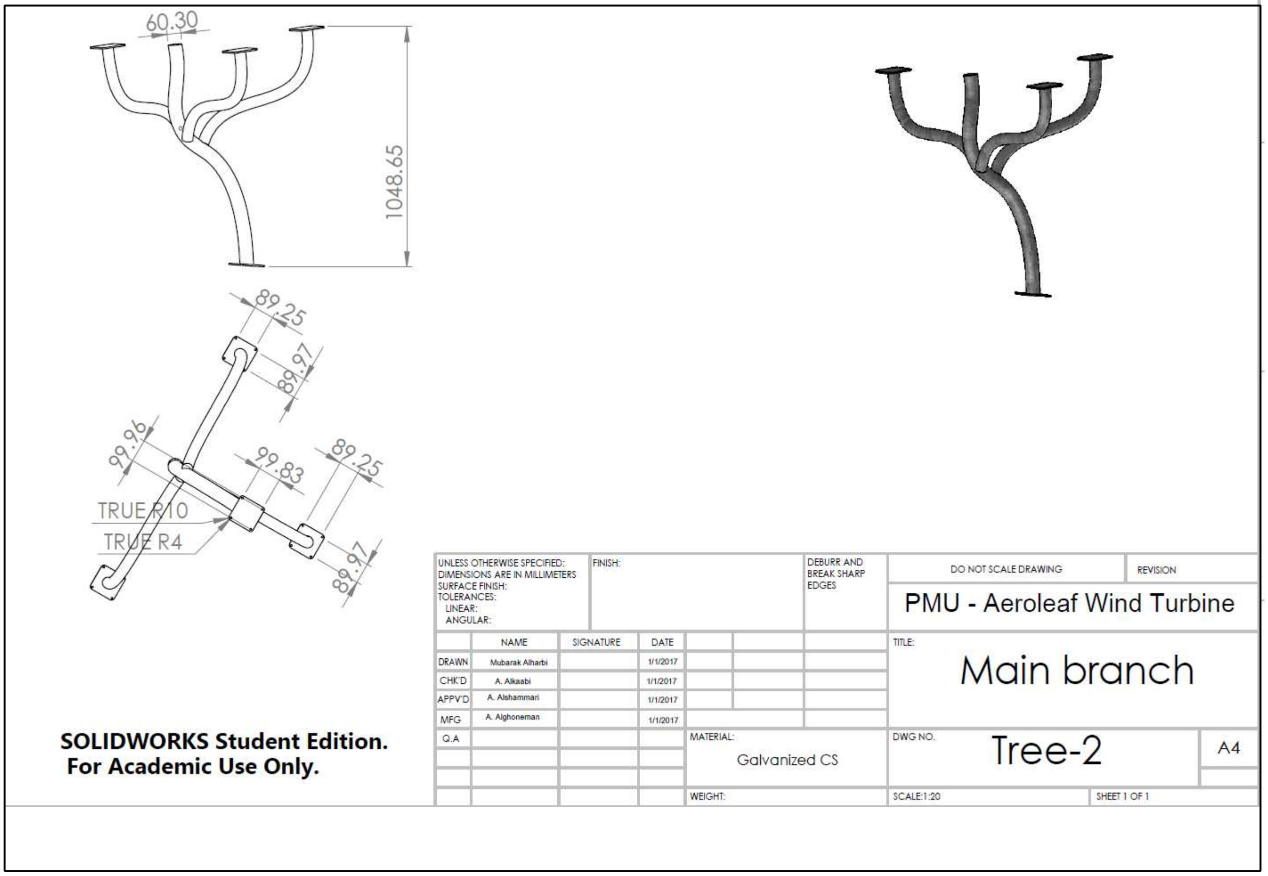


Figure 3.13
solidworks drawing

A carbon steel galvanizing pipes that we used to build the tree are shown in Figure 3.10.

Figure 3.13
Carbon Steel Galvanizing Pipes

3.4.3 Manufacturing of turbine blades and rod.

The vertical shaft that held the turbine was manufactured out of quarter inch stainless steel with press fits designed to attach to the generator. It also had two set screws which kept the shaft connected to both instruments as well as a set screw in the middle to lock turbine in place.

The blade manufacturing was assigned to a workshop plant in Jubal using the solid work drawings and the given requirements and specifications.

The top and bottom pieces were cut out of 3/8th inch acrylic and then glued together.

The metal rods used to lock the adjustable blade to the top and bottom pieces were glued together with epoxy.

In the below figures 3.14 & 3.15 pictures of the tree and blades manufacturing respectively.

Figure 3.14
Tree Branches Manufacturing

Figure 3.15
Tree Holding Turbines

Chapter 4

SYSTEM TESTING AND ANALYSIS

4.1 THEORETICAL WIND TURBINE POWER CALCULATION

Wind Power depends on:

- amount of air (volume)
- speed of air (velocity)
- mass of air (density)

Kinetic Energy definition:

$$\boldsymbol{KE = \frac{1}{2} \times m \times v^2}$$ **Equation 4.1**

Where:

$\boldsymbol{m}$: **Mass** $\boldsymbol{v}$: **velocity**

Since Power is Energy per time, we can formulate equation 4.1 to be

$$P = \frac{1}{2} \times \dot{m} \times v^2 \qquad \dot{m} = \frac{dm}{dt}$$

Fluid mechanics gives mass flow rate (density × volume flux): $\frac{dm}{dt} = \rho \times A \times v$

Thus, power of the wind is $P = \frac{1}{2} \times \rho \times A \times v^3$

Taking in consideration the turbine Power coefficient, power in the wind is calculated using this formula:

$$\boxed{\boldsymbol{P = \frac{1}{2} \times \rho \times A \times v^3 \times Cp}}$$ **Equation 4.2**

Where:

P: Power in watts

ρ: Air density "At sea level 'air density' is approximately 1.2 $\frac{kg}{m^3}$

A: Turbine Area in m^2, which can be calculated from the length of turbine blades. $A = Turbine\ hight\ \times turbine\ width$ See figure 4.1. in our project the turbine high is 0.9m and width is 1.25m. Therefore, area is $A = h \times w, A = 0.9 \times 1.25 = 1.125m$

v^3: wind speed, which is the velocity of the wind in $\frac{m}{s}$.

Cp: Power coefficient, usually varies according to wind turbine design, ranging between 0.05 and 0.45. In this case, referring to the previously mentioned study in chapter 2, we are taking 0.2836 based on the selected angle 160°.

The only variable in this equation is the wind speed. Table 4.1 and graph 4.1 are reported the Theoretical gained power at different wind speeds.

Table 4.1
Theoretical Gained Power Calculation

Theoretical Gained Power Calculation						
Density ρ	A =h*w= 1.125m		Wind Wpeed V	Power coefficient Cp	Power P	Power (2) Turbines P
	h=0.9m	w=1.25m				
1.2	1.125		1	0.2836	0	0
			2		2	3
			3		5	10
			4		12	25
			5		24	48
			6		41	83
			7		66	131

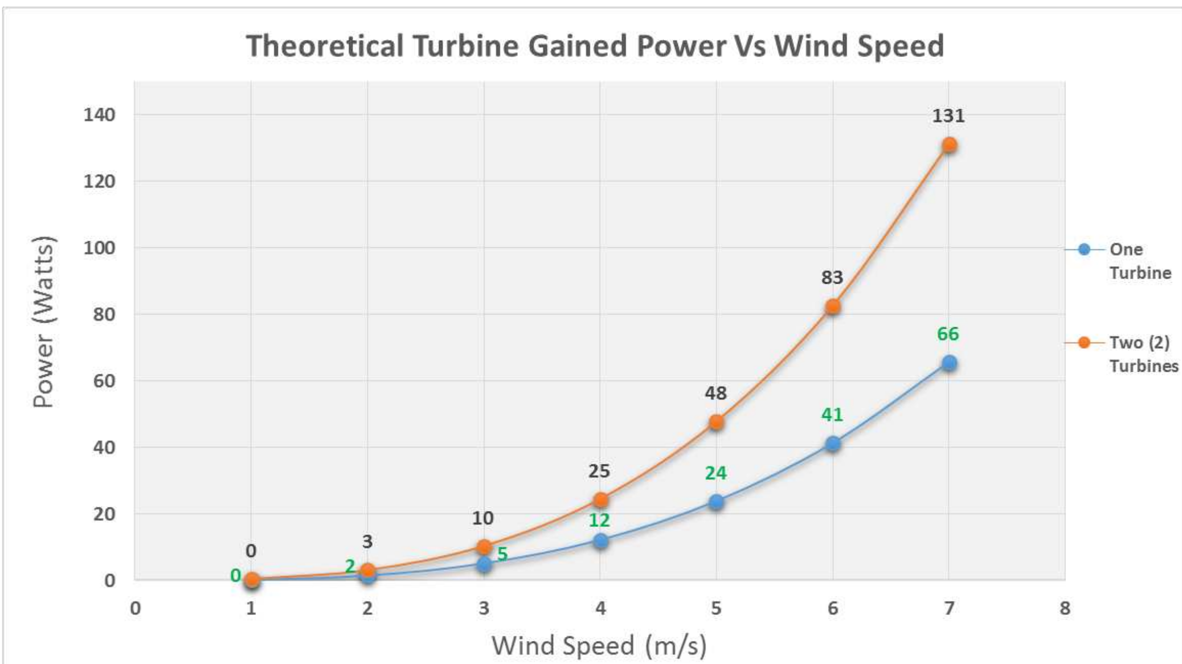


Figure 4.1
Theoretical Turbine Gained Power vs. Wind Speed

4.2 EXPERIMENTAL READINGS

After designing the components and structures desired for testing power output for wind turbine designs and the structures desired to be tested, we created the experimental set-ups required to test the prototypes and structures.

In order to determine the effectiveness of the products that were manufactured, we performed tests to evaluate them. The test set up was in Half Moon (open area). We also tested the power output of the turbine blades and evaluated how the vibrations from the turbine affect the stress and strain on a tree structure.

Two experiments have been conducted; the procedure of calculating the power is counting the voltage & current that feeding the battery. The power gained can be calculated using the below equation.

$$\boxed{P = IV}$$ **Equation 4.3**

Where:

I: Current in Ampere V: voltage

Below are the results that we got from the experiments. Table 4.2 and figure 4.2 are for experiment# 1, table 4.3 and figure 4.3 are for experiment# 2

4.2.1 Experiment# 1

Table 4.2
Experiment# 1 Reading

Experimental Readings					
Experiment# 1 Normal weather					
Time	Wind Speed m/S	Voltage (V)	Current (I)	Power (Watt)	Power (2) Trubines (Watt)
21:00	0.7	8.6	0.05	0	1
18:00	1.6	10.6	0.15	2	3
15:00	3.4	12.3	0.24	3	6
12:00	4.3	13.7	0.43	6	12
9:00	5.2	14.2	0.52	7	15

* Sorted by increasing in wind speed

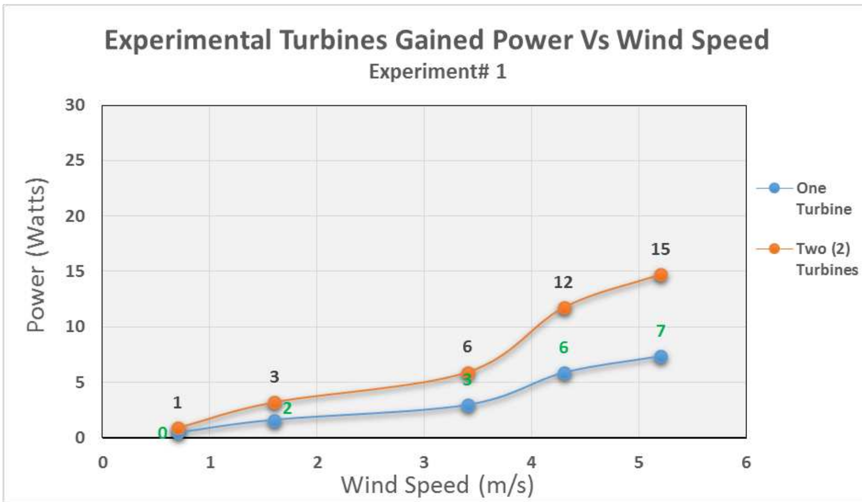


Figure 4.2
Experiment# 1 Readings

4.2.2 Experiment# 2

Table 4.3
Experiment# 2 Reading

Experimental Readings					
Experiment# 2 Windy Day					
Time	Wind Speed m/S	Voltage (V)	Current (I)	Power (Watt)	Power (2) Turbines (Watt)
21:00	6.2	15.8	0.51	8	16
18:00	6.6	16.5	0.57	9	19
15:00	7.1	17.2	0.84	14	29
12:00	7.5	17.7	1.2	21	42
9:00	8.4	18.4	1.9	35	70

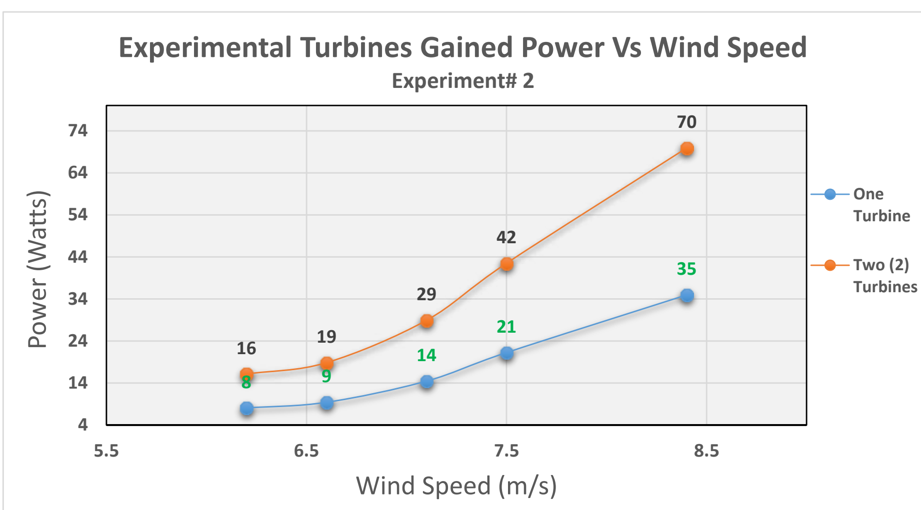


Figure 4.3
Experiment# 2 Readings

4.2.3 Theoretical comparing to Experimental Gained Power Calculation.

Table 4.4
Theoretical Vs Experimental Reading

Theoretical Vs Experimental Gained Power Calculation*					
Density kg/m^3	Area m^2	Wind Wpeed m/s	Power coefficient Cp	Theoretical Power Watt	Experimental Power Watt
1.2	1.125	6.2	0.2836	46	8
		6.6		55	9
		7.1		69	14
		7.5		81	21
		8.4		113	35

* Data for wind speed taken from experiment# 2 to compare the theoretical power using the same wind speed

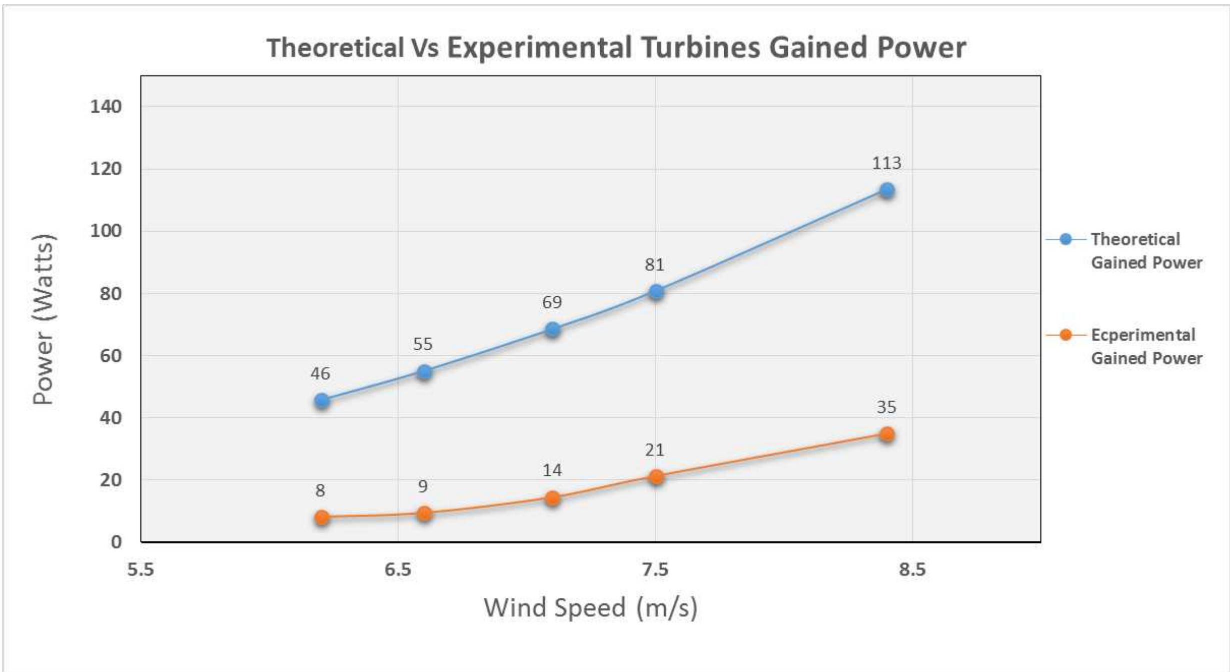


Figure 4.4
Theoretical Vs Experimental Reading

4.3 DISCUSSION

As a result, This studies (experimentally and theoretically) present a review on the performance of Savonius wind turbines and show the gap between the actual and ideal output power, where a several factors have affected clearly on the actual performance, these factors are due to external factors, lack of resources, process, geometrically, or due to human error. These factor resulted in drop of 31~ 35% between the theoretical and experiment results.

If we apply equation 4.2 at wind speed 11.6 m/s, we will reach 300 watts that our turbine can produce theoretically. Savonius rotor performance are affected by operational conditions such as Instability and insufficient of wind speed as shown if figure 4.5, while considered as maximum speed in theoretical, on another side air flow direction were effected on torque and power coefficient, while assumed as average in theoretical.

01st Jan, 2017	Weather Information							
Time	0:00	3:00	6:00	9:00	12:00	15:00	18:00	21:00
Weather								
Temp	21 °c	20 °c	21 °c	26 °c	27 °c	27 °c	24 °c	20 °c
Wind	1 m/s	2 m/s	2 m/s	4 m/s	5 m/s	6 m/s	7 m/s	6 m/s
	WNW	NW	NNW	NNW	NNW	NNW	NNW	NNW
Humidity	49%	48%	47%	49%	52%	56%	68%	70%

02nd Jan, 2017	Weather Information							
Time	0:00	3:00	6:00	9:00	12:00	15:00	18:00	21:00
Weather								
Temp	19 °c	19 °c	17 °c	19 °c	24 °c	25 °c	21 °c	19 °c
Wind	6 m/s	6 m/s	6 m/s	6 m/s	6 m/s	5 m/s	5 m/s	5 m/s
	NW	NW	NW	NW	NW	NNW	NNW	NNW
Humidity	68%	63%	60%	52%	48%	47%	65%	73%

03rd Jan, 2017	Weather Information							
Time	0:00	3:00	6:00	9:00	12:00	15:00	18:00	21:00
Weather								
Temp	19 °c	19 °c	18 °c	21 °c	23 °c	23 °c	22 °c	20 °c
Wind	5 m/s	5 m/s	4 m/s	5 m/s	7 m/s	7 m/s	7 m/s	7 m/s
	NNW	NW	NW	NNW	NNW	NNW	NNW	NNW
Humidity	74%	77%	70%	70%	59%	63%	69%	67%

Figure 4.5
Wind speed in khobar for 3 days
www.worldweatheronline.com

Moreover, Negligence of blades surface friction and dust contamination gained the ideal efficiency a level up comparing with the actual.

The assumption of the frictionless in the rotating parts bearings, rods generator shaft beside the resistless assumption in generator wires controller panel wires, where they have the capability to effect easily on comparison with actual condition.

Over that as geometrically side, Uniformed arc angle in each blade, where could be due the lack of skills in manufacturing or due to the sun rays effectiveness. In addition, unexpected vibration happed led to disturb Conservative of the wind energy.

These are the major factors have been played a real role of dropping the Savonius rotor performance, perhaps some factor been hidden due to the limitation in time and suffering of financial support to provided advance equipment in analyzing.

Chapter 5

PROJECT MANAGEMENT

Our belief in the professionalism and workmanship at work put us in a position where we work in the concept of project management. Project management is the process and activity of planning, organizing, motivating, and controlling resources, procedures and protocols to achieve our goals.

A project is a temporary endeavor designed to produce a unique product, service or result with a defined beginning and end (usually time-constrained, and often constrained by funding or deliverables), undertaken to meet unique goals and objectives, typically to bring about beneficial change or added value.

Like any other project, the senior student project described in this report needed attention in terms of project management. Achieving minimum goals set by the university (client in project management terminology) regarding the senior projects was a challenge in presence of certain constraints such as time, scope and budget. Furthermore, achieving the best quality was simply not possible in the absence of a proper equipment and the required laboratories and tolls that needed for such projects.

On the contrary, to the above-mentioned importance of applying project management strategy in the discussed project, it is also evident that the project had a limited scope and resources to be managed. Therefore, a simple and traditional strategy, as outlined in the following block diagram, was adopted to make sure the project is successfully completed within the specified time and budget frames.

5.1 PROJECT PLAN

The project planning has started when the projects were assigned to the groups. Team leader also nominated and assigned by the group members. We start planning for work distribution to meet the millstones that been given by the instructor.

The below figure shows a timeline that the team developed to plan carefully for the required tasks and meet the deadlines.

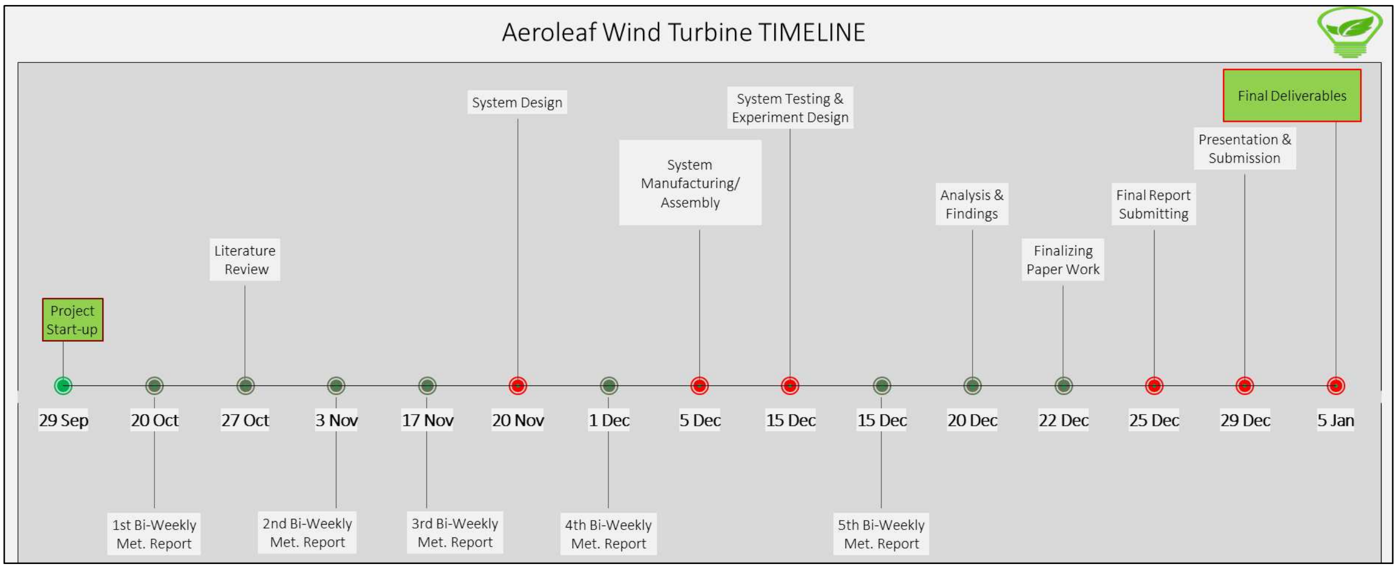


Figure 5.2
Project Timeline

5.1.1 Contribution of Team Members

Contribution of the team members of this project was proactive, the team work was going smoothly over the semester achieving the milestone one by one. All the group members were participating in all of this project steps,

This project steps are:

- Planning
- Designing and Manufacturing
- Weekly meetings
- Mid and Final presentation
- Research and Analysis
- Bi-weekly reports
- Final report writing
- Final demonstration

Designing and manufacturing was totally a full group work. However, writing the report was assigned as the below table:

Final Report Writing Work Distribution			
Task		Assigned member	Assigned proofreading member
Introduction	Project Definition	AHK	MZH
	Project Objectives	MZH	AHK
	Applications	AAS	AZG
Literature Review	Project background	AZG	AAS
	Previous Work	AHK	MZH
	Comparative Study	MZH	AHK
System Design	Design Constraints	AAS	AZG
	Design Methodology	AZG	AAS
	Product Subsystems & Components	AHK	MZH
	Implementation	MZH	AHK
System Testing & Analysis	Testing	AAS	AZG
	Analysis	AZG	AAS
Project Management	Project Plan	AHK	MZH
	Contribution of Team Members	MZH	AHK
	Challenges & Decision Making	AAS	AZG
	Project Bill of Materials & Budget	AZG	AAS
Project Analysis	Life-long Learning	AHK	MZH
	Impact of Engineering Solutions	MZH	AHK
	Contemporary Issues Addressed	AAS	AZG
Conclusions & Future Recommendations	Conclusions	AZG	AAS
	Future Recommendations	AHK	MZH

MZH Mubarak Alharbi **AHK** Abdulrahman Alkabi **AAS** Abdulkarim Alshamari **AZG** Abdullah Alghoniman

Table 5.1
Final Report Writing Work Distribution

5.2 CHALLENGES & DECISION MAKING

In our project we planned to use plastic material with shaft, tree and turbine blades and due the difficult to find plastic manufacturers and also, due to the high coast for plastic to fabricate this design we decided to change it to metal. However, we believe if could be made from plastic it will be more flexible to move it to different places. Also, the design of branches would be easier to carry plastic turbine.

5.3 BROJECT BILL OF MATERIALS & BUDGET

5.3.1 Bill of materials (BOM)

A bill of materials (BOM) is a hierarchical list of components used in an assembly. The bill of materials is used chiefly for cost estimates, but is also used for inventory control and tracking where parts are used.

#	Parts	Spec.	Quantity	Unit Price SR	Total Price/part SR
1	Flange bolts	M12*45	4	8	32
2	Plain washer	D12.2	8	24	192
3	Spring washer	D12.2	4	30	120
4	Nuts	M8	48	6	288
5	Connecting rod	M8	6	18	108
6	Screw	M8	12	24	288
7	Nuts	M12	4	8	32
8	Blades	Aluminum	36	100	3600
9	Electrical Gen.	Wind Stream RBM	3	600	1800
10	Battery	Lead-acid	1	1600	1600
11	Elect. Combiner	-	1	120	120
12	Turbine Controller	-	2	80	160
13	Turbine Sensor	-	2	150	300
14	Consuming reader	-	1	110	110
15	Converter	-	1	80	80
16	Pipe	Carbon Steel	8	150	1200
Total Prices					**10,030**

Table 5.2
Bill of Materials (BOM)

5.3.2 Budget

This section contain the full budget that were spend in this project from the beginning all the way to the demonstration day.

Below Table 5.3 is the budget breakdown.

#	Item	Cost SR
1	Marital	10030
2	Manufacturing	4000
3	Final Report (3) Spiral Copies	360
4	Final Report (3) Leather Copies	540
5	Poster	280
6	Brochures	150
Total Cost		**15,360**

Table 5.3
Project budget breakdown

Chapter 6

PROJECT ANALYSIS

6.1 LIFE-LONG LEARNING

This experience that the team have went through is very valuable in term of engineering sense, skills, and knowledge. Guidance from PMU instructor and advisors were very valuable and help achieving the main goal of this course. Teamwork and leadership were applied through this experience which add good management skills to the team members.

Fabrication and manufacturing was not easy where we had to change the manufacturing workshop several time and that is due to the inefficient tools that they are using, choosing better workshop with high stander will cost more money .We were facing a lot of difficulties getting the required equipment and materials with the right dimensions. Testing, analysis, and evaluating our result was difficult specially when come to calculation the experimental results. The assigned time to finish such senior project was not enough, which add more pressure to the team members taking in consideration the others courses the team members are taking in the same semester.

6.2 IMPACT OF ENGINEERING SOLUTIONS

6.2.1 Renewable Energy

Energy resources are getting more difficult to get. With the increasing of the population, and high demand of the power, and taking in consideration the current situation of the oil prices and it reliability. Saudi Arabia has to start as soon as possible implementing the use of renewable energy. Wind energy can be very useful for this purpose. This project and research as any other similar studies are convincing that wind energy can help a lot the country supplying power with these renewable energy which can be costly at the beginning, but it will be the most reliability solution that can apply the concept of sustainability.

6.2.2 Economy

As the largest economy by far in the Middle East, Saudi Arabia is also the largest potential RE market in the region. The country developed a massive renewable energy program that aimed to install 54 GW by 2032; this program, however, has been delayed and likely will not be implemented as originally announced.

Nevertheless, Saudi Aramco and Saudi Electricity Company are both going ahead with their own initiatives and joint plans to develop renewable energy in Saudi Arabia in the short and medium term. Expect significant growth in the coming years for both solar and wind, as the Kingdom strives for a sustainable energy mix to preserve a large share of extracted oil for future export.

Within GCC, Saudi Arabia is the most promising market for wind. With a surface area of 2.25 million km^2 and a GDP of USD 730B, Saudi Arabia is the largest country and economy in the GCC.

Saudi Arabia accounts for half of GCC's power demand (273 TWh in 2012) and will be the region's primary wind market in the short term (100 out of the region's 200 MW installedcapacity by 2015). As a result of the immense power demand, an additional 47 GW and approximately 29 GW of replacement capacity are needed by 2020.

Saudi Arabia provides various suitable sites for large-scale onshore wind generation. The first criterion for site suitability is a minimum wind speed of around 3.7 m/s at a height of 10 m in order for wind generation to be competitive with the LCOE of oil-fired electricity generation. Secondly, suitable wind power sites must also have adequate access to the electricity network.

The majority of sites fulfilling these requirements are situated along the two coastlines, for example, Yanbu in the West and Juaymah and Dammam/Al Khobar/Dhahran in the East (Figure 6.1). With existing wind measurements limited to location of meteorological stations only, additional attractive sites can be expected in unchartered regions.

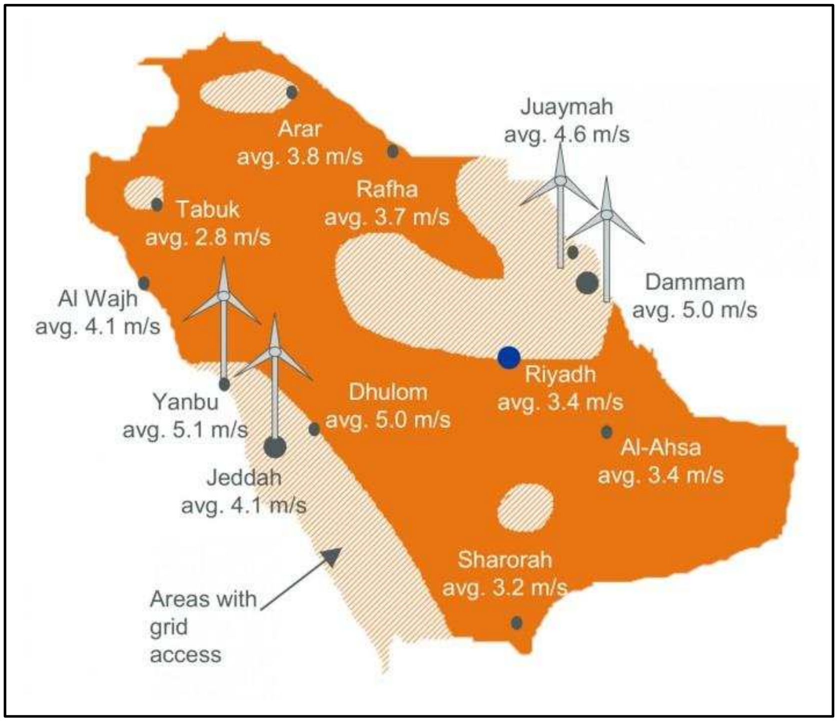


Figure 6.1
Average Wind Speed Reading in Saudi Arabia

6.3 CONTEMPORARY ISSUE ADDRESSED

In May 2012, the Saudi government announced one of the world's most ambitious renewable energy programs. Government body K.A.CARE plans for the installation of 9 GW of wind power capacity by 2032 and aims to release the first round of tenders in large renewable power generation projects in the next couple of months. By 2017, a cumulated capacity of up to 1.8 GW is expected to be installed.

The country's ambition to strongly develop wind alongside solar power is serious. Countrywide assessments for suitable wind sites are currently being conducted on behalf of K.A.CARE and national oil and gas company Saudi Aramco.

Chapter 7

CONCLUSIONS AND FUTURE RECOMMENDATIONS

7.1 CONCLUSION

From our research we were able to come up with many important conclusions and suggestions which will profit the future advancement of individual vertical pivot wind turbines. We could outline a VAWT framework that enhanced power yield when contrasted with the past projects. From our results we were able to recommend new design aspects to improve the system and efficiency.

Inefficient wind speed was the huge impact getting the required power output, minimum speed of 12 m/s is required to have acceptable output power taking in consideration 31~35% of efficiency between theoretical and experimental results.

Even though we were able to make this design of Vertical Axis Wind Turbine but there is a never ending process to always improve upon inventions and new designs. Wind turbines are a start for society to lessen the damage done to the earth by not using energy sources that produces pollution. Hopefully the project could propel research and testing on VAWT frameworks and give knowledge for different gatherings to finish additionally testing and enhance productivity and execution of vertical pivot wind turbines.

7.2 FUTURE RECOMMENDATIONS

Using the data received we made recommendations for future studies regarding the potential of commercial tree wind turbines. These recommendations will hopefully aid in the development of a technology that would allow green energy to reduce energy costs in the average household and better the environment. Future tests could help determine the feasibility of houses, neighborhoods, or cities powered by wind turbines and being able to run off of renewable energy.

The turbine performance testing and results from the research in this venture demonstrated that the split Savonius is the best plan that has been tried to this point at WPI. The reason is because of the expansive surface range of the split Savonius which empowers it to catch most maximum amounts of wind. We trust that further research ought to be finished with different Savonius plans in view of this reality. The Savonius turbine outlines are basic and modest to make, and are additionally not incredibly influenced by turbulence in the wind.

Another suggestion to improve the Savonius design in our opinion would be to create a more aerodynamic backing to the Savonius cusp. This design would reduce the energy it requires to spin with the wind. this will allow the Savonius to rotate into the wind more efficiently, thus increasing the rate of revolution. While we do not expect this to make a significant difference, our testing demonstrates that even small differences in wind speeds lead to significantly improved power output.

To gain the best power gain in the concept of green energy, we strongly recommend having some solar panels attached to the tree. These panels will add more power and they are easy to install and connected to the electrical components that are already added to the system. Below figures 7.1, 7.2 & 7.3 are some recommended design sketches having the solar panels.

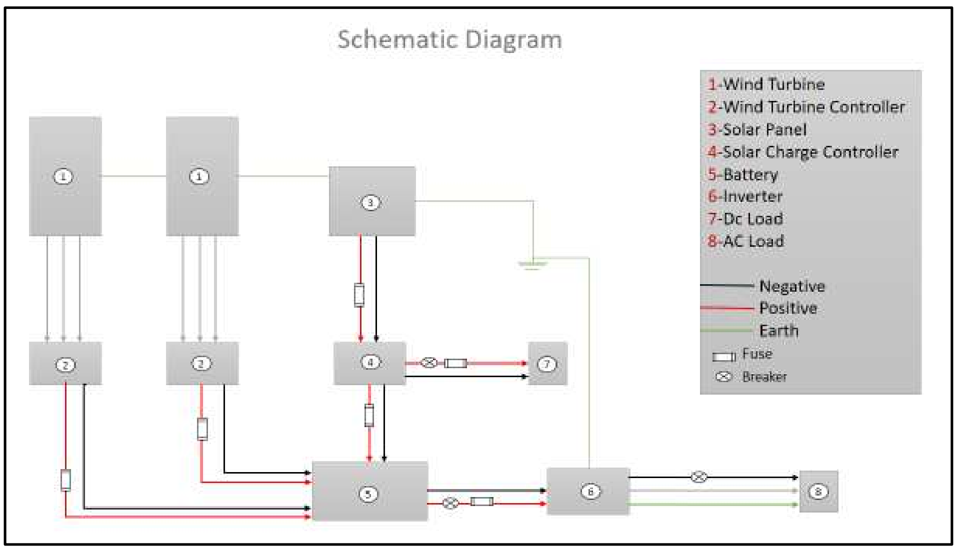


Figure 7.1
Recommended Design Sketch

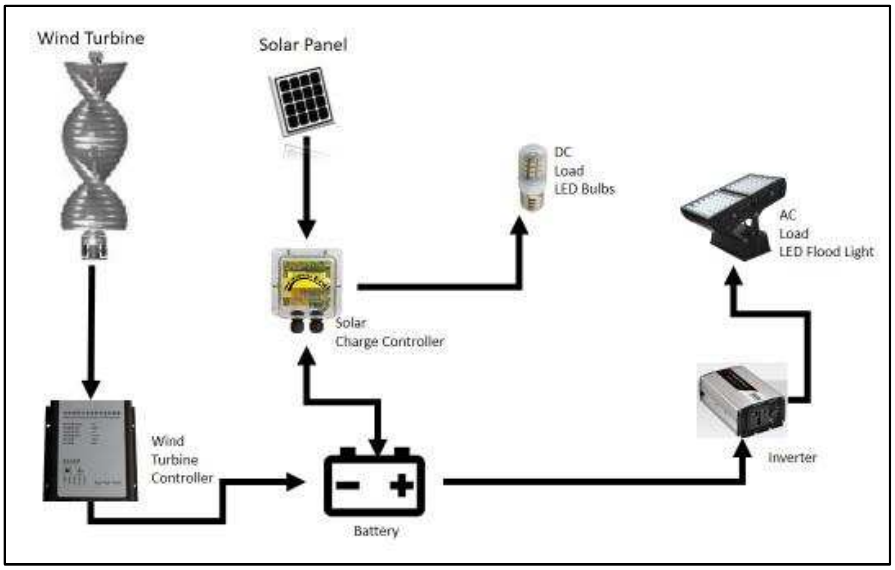


Figure 7.2
Recommended Design Sketch

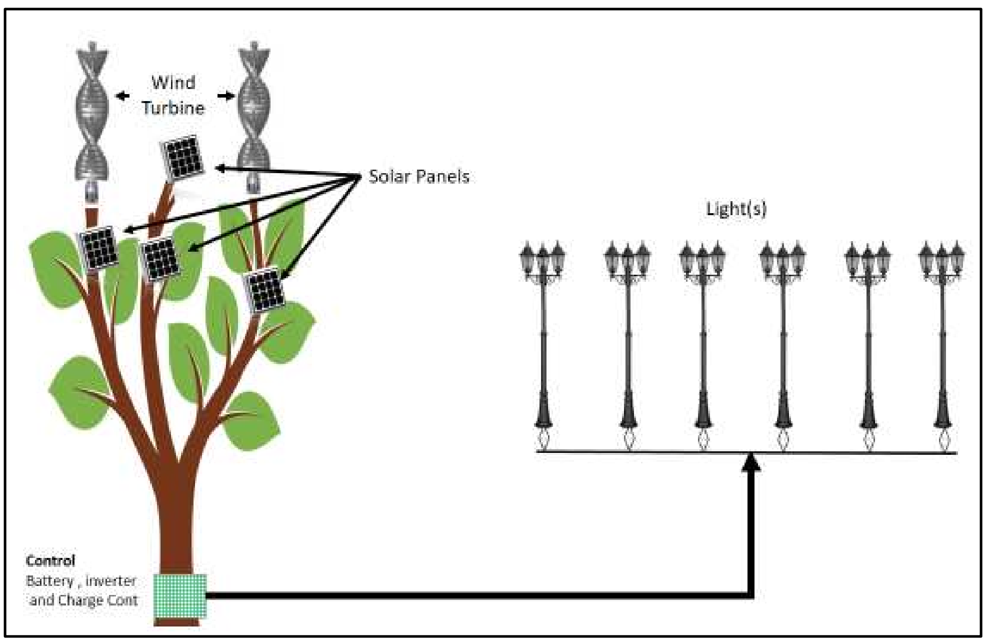


Figure 7.3
Recommended Design Sketch

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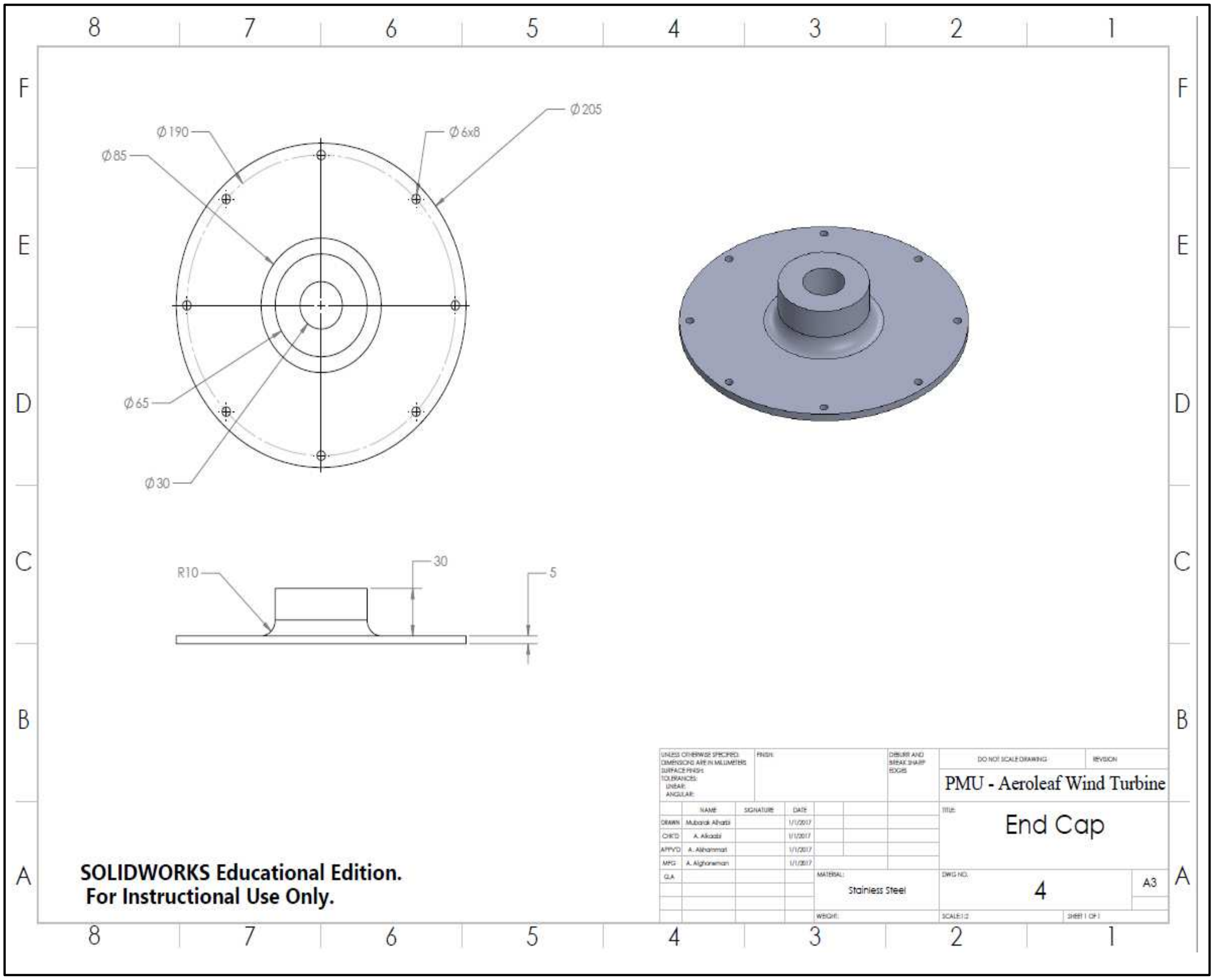
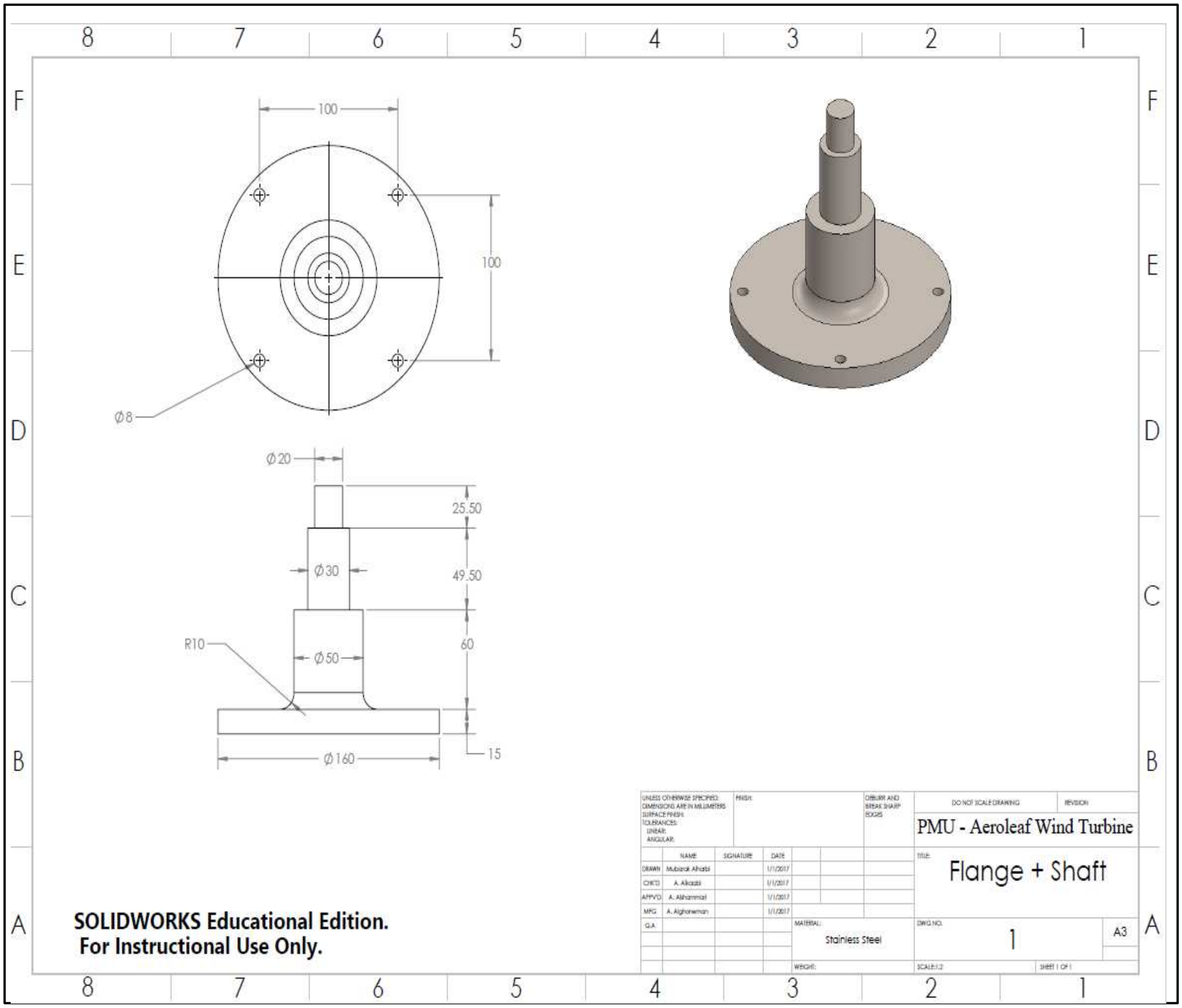
Appendix A

Solidworks Drawings

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Ø8
Ø20
25.50
Ø30
49.50
R10
Ø50
60
Ø160
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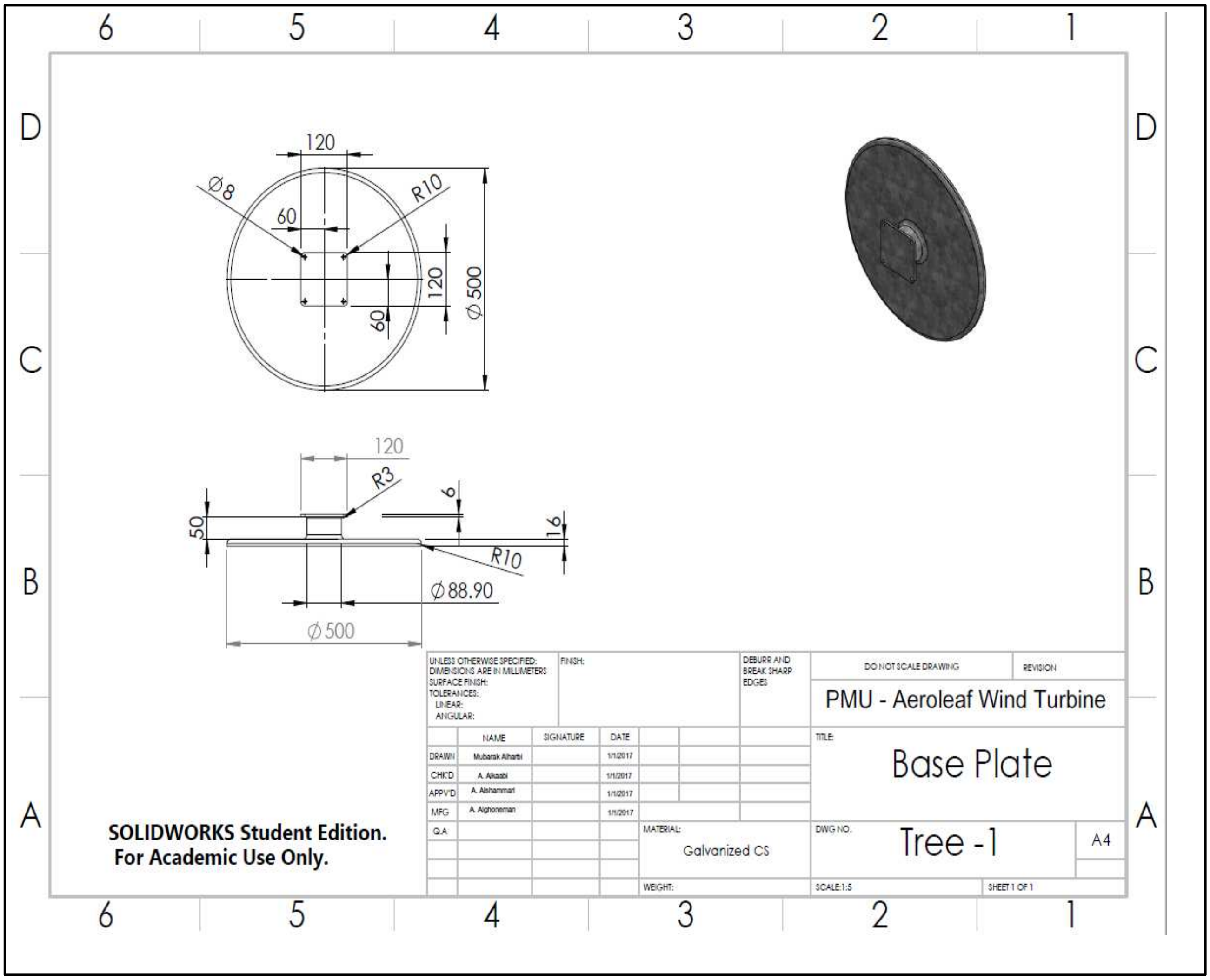
SOLIDWORKS Educational Edition.
For Instructional Use Only.
PMU - Aeroleaf Wind Turbine
Flange + Shaft
Stainless Steel
A3
1



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Ø8
R10
60
120
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Ø 500
120
R3
6
50
16
R10
Ø 88.90
Ø 500
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DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
PMU - Aeroleaf Wind Turbine
NAME
SIGNATURE
DATE
DRAWN Mubarak Alharbi 1/1/2017
CHK'D A. Alkaabi 1/1/2017
APPV'D A. Alshammari 1/1/2017
MFG A. Alghoneman 1/1/2017
Q.A
TITLE:
Base Plate
MATERIAL:
Galvanized CS
DWG NO.
Tree -1
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1
SOLIDWORKS Student Edition.
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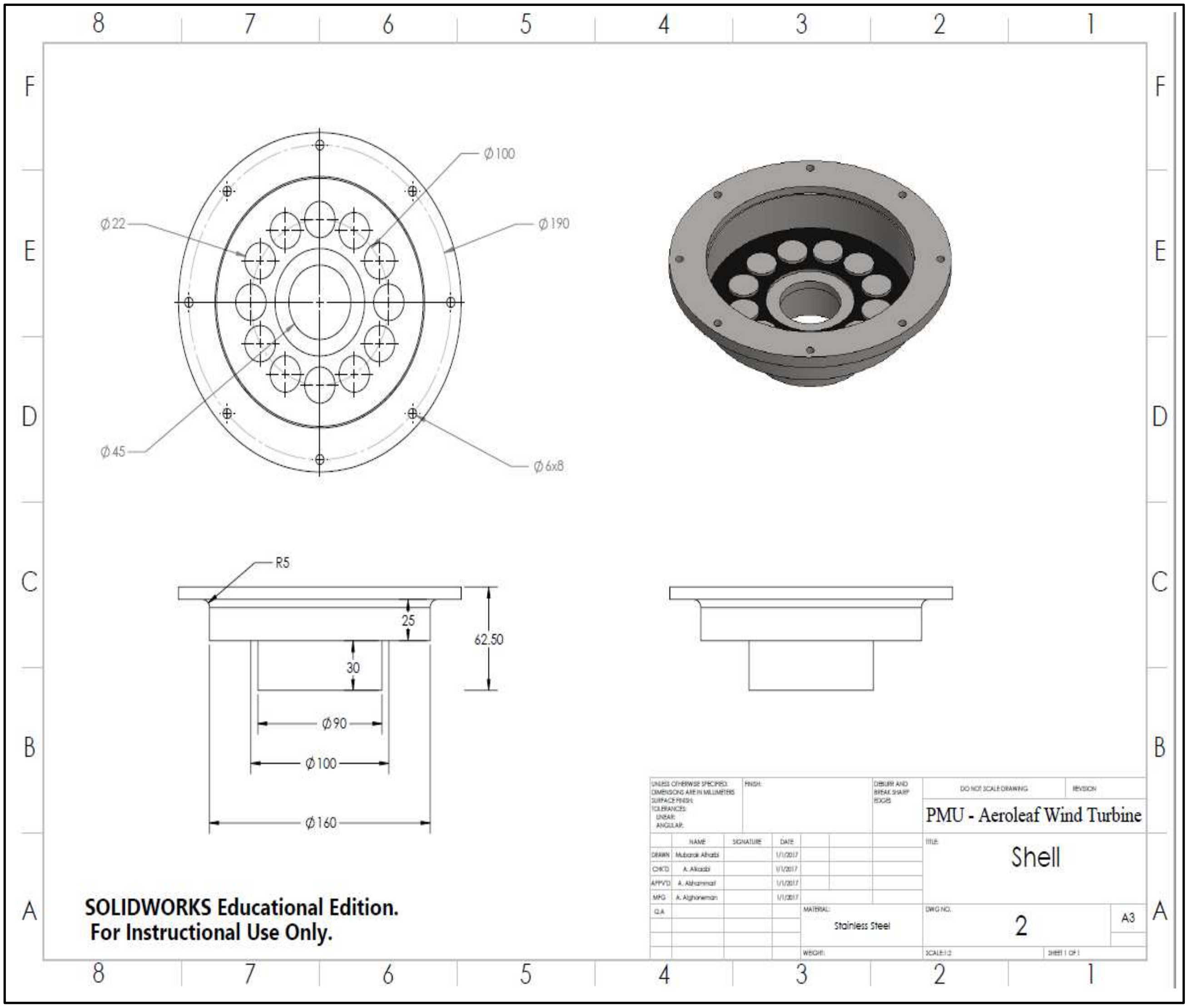
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Ø45
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R5
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Ø90
Ø100
Ø160
SOLIDWORKS Educational Edition.
For Instructional Use Only.
UNLESS OTHERWISE SPECIFIED:
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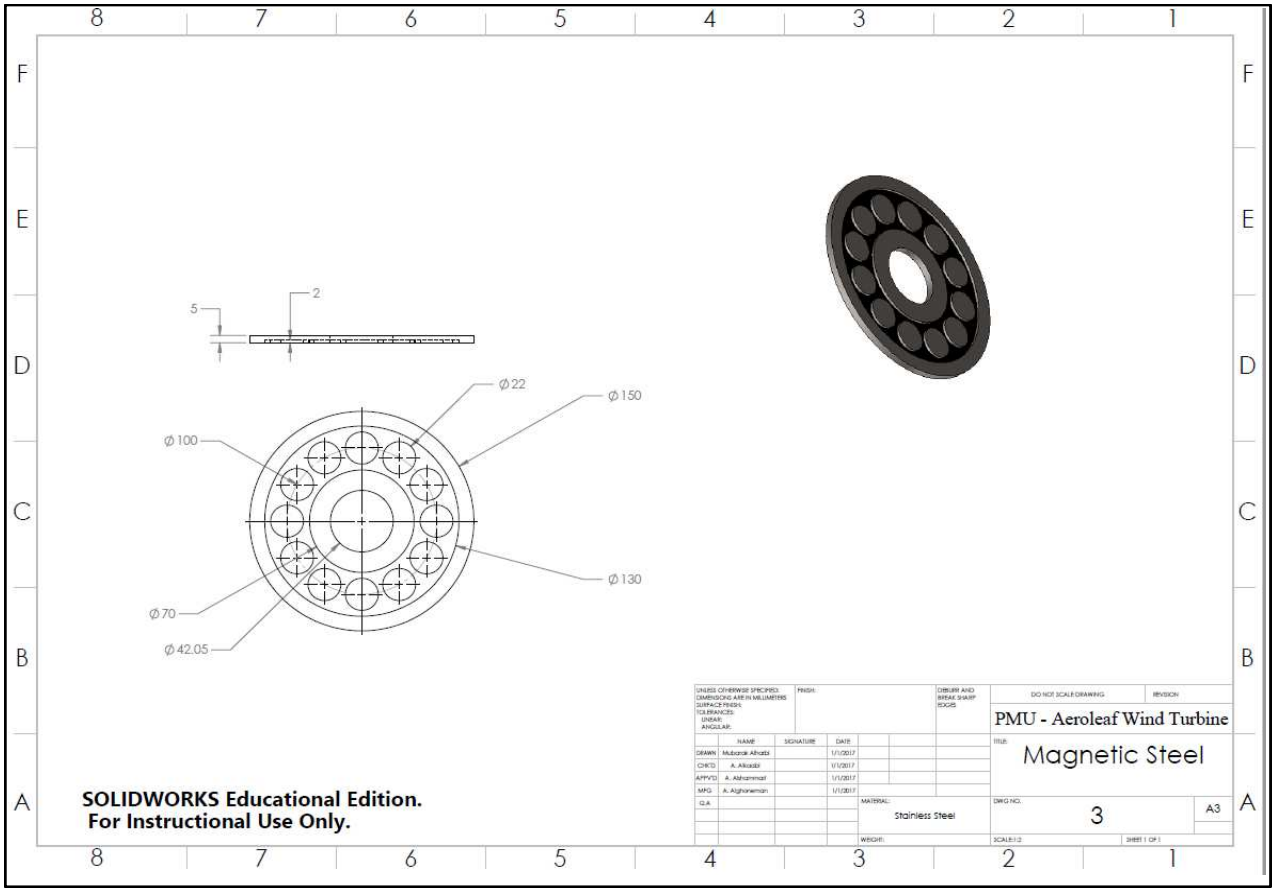
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND
BREAK SHARP
EDGES
DO NOT SCALE DRAWING
REVISION
PMU - Aeroleaf Wind Turbine
NAME
SIGNATURE
DATE
DRAWN Mubarak Alhabi 1/1/2017
CHK'D A. Alkaabi 1/1/2017
APPV'D A. Alshammari 1/1/2017
MFG A. Alghoneman 1/1/2017
Q.A
TITLE:
Shell
MATERIAL:
Stainless Steel
DWG NO.
2
A3
WEIGHT:
SCALE:1:2
SHEET 1 OF 1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Ø150
Ø100
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For Instructional Use Only.
UNLESS OTHERWISE SPECIFIED:
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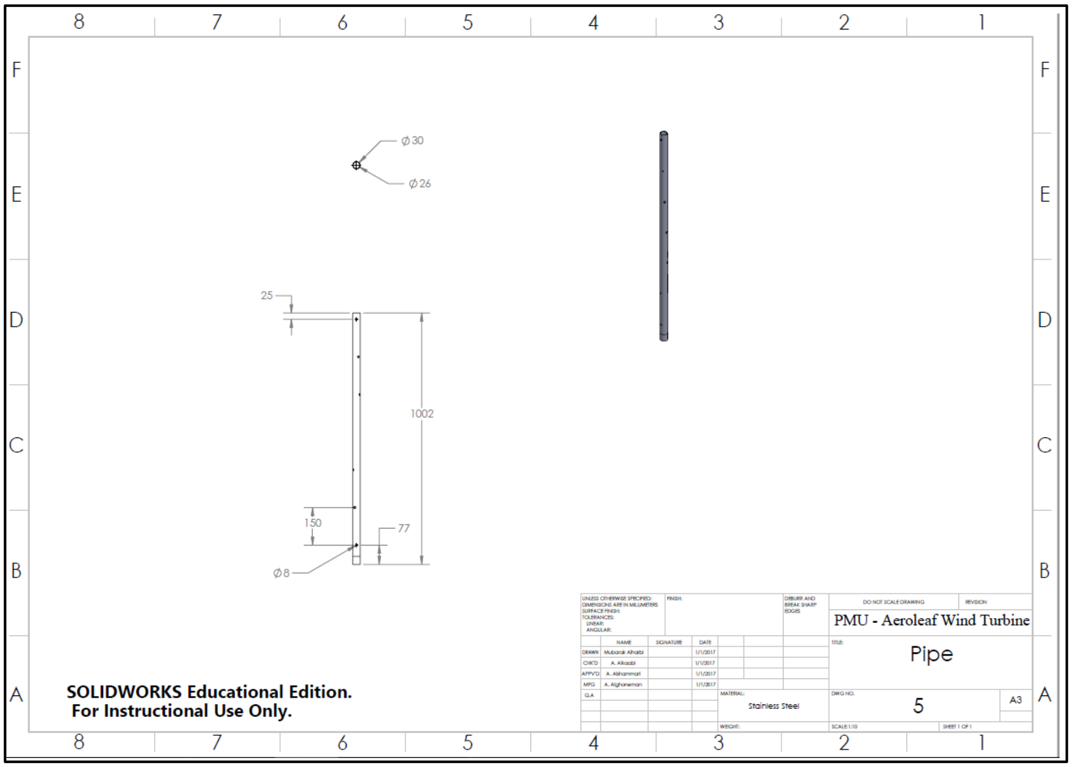
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
PMU - Aeroleaf Wind Turbine
NAME
SIGNATURE
DATE
DRAWN Mubarak Alhatbi 1/1/2017
CHK'D A. Alkadbi 1/1/2017
APPV'D A. Alshammari 1/1/2017
MFG A. Alghaneman 1/1/2017
Q.A
TITLE:
Magnetic Steel
MATERIAL:
Stainless Steel
DWG NO.
3
A3
WEIGHT:
SCALE:1:2
SHEET 1 OF 1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Ø26
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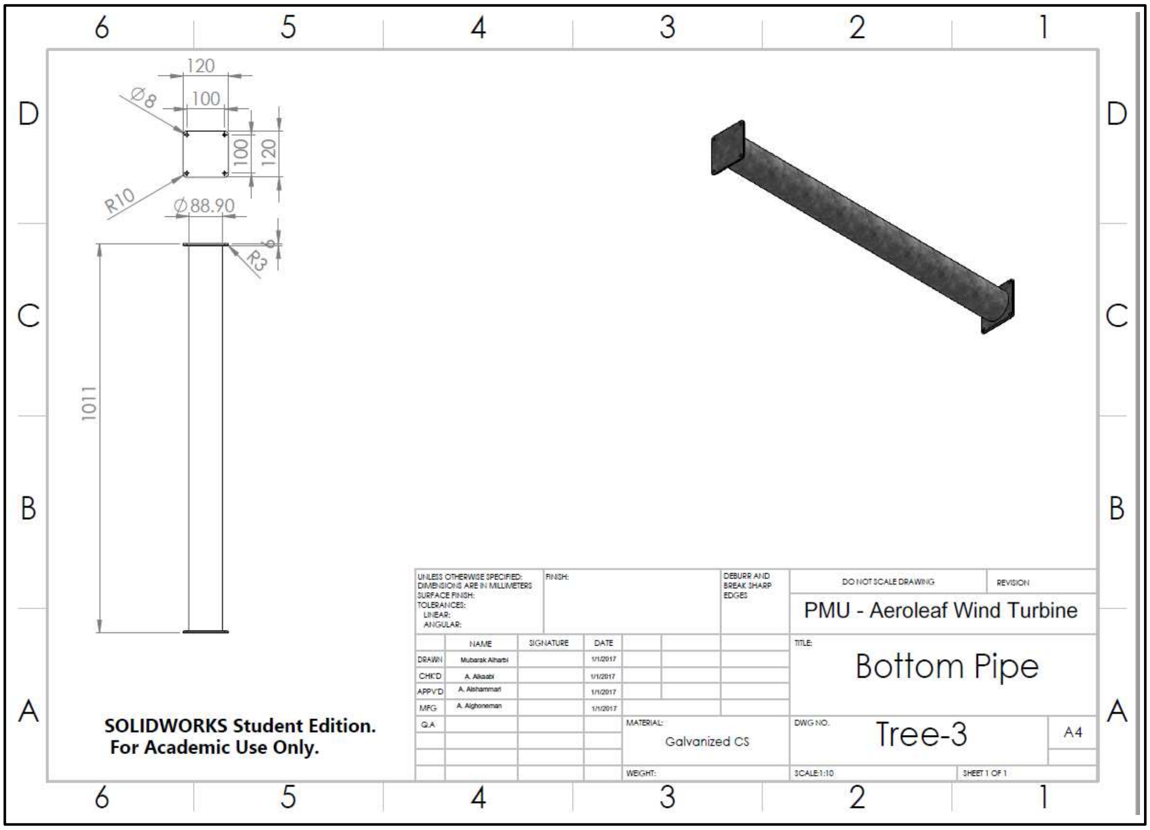
Ø8
SOLIDWORKS Educational Edition.
For Instructional Use Only.
PMU - Aeroleaf Wind Turbine
Pipe
Stainless Steel
5
A3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Ø8
100
120
R10
Ø88.90
6
R3
1011
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
PMU - Aeroleaf Wind Turbine
NAME
SIGNATURE
DATE
DRAWN Mubarak Alharbi 1/1/2017
CHK'D A. Alkaabi 1/1/2017
APPV'D A. Alshammari 1/1/2017
MFG A. Alghoneman 1/1/2017
Q.A
TITLE:
Bottom Pipe
MATERIAL:
Galvanized CS
DWG NO.
Tree-3
A4
WEIGHT:
SCALE:1:10
SHEET 1 OF 1
SOLIDWORKS Student Edition.
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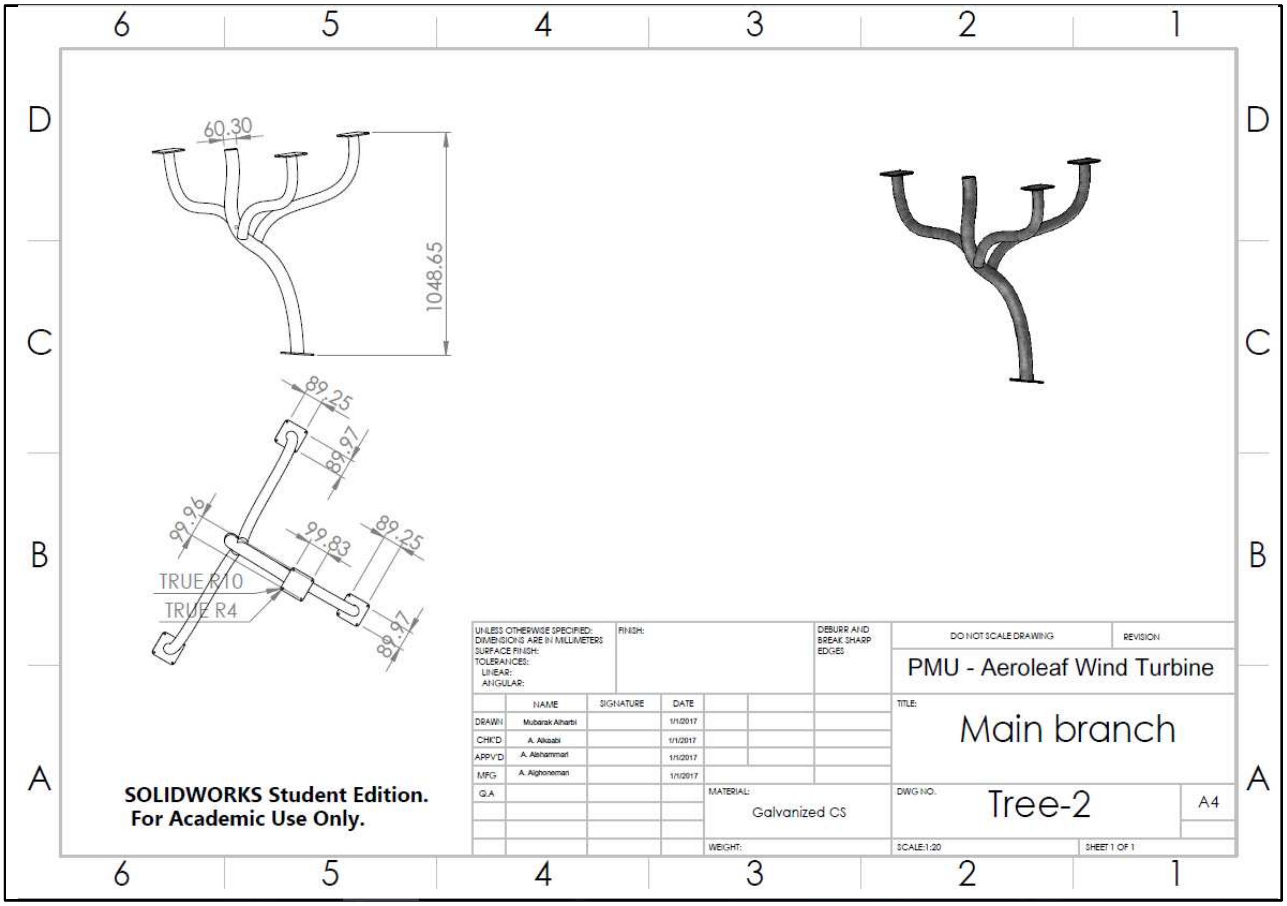
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D
C
B
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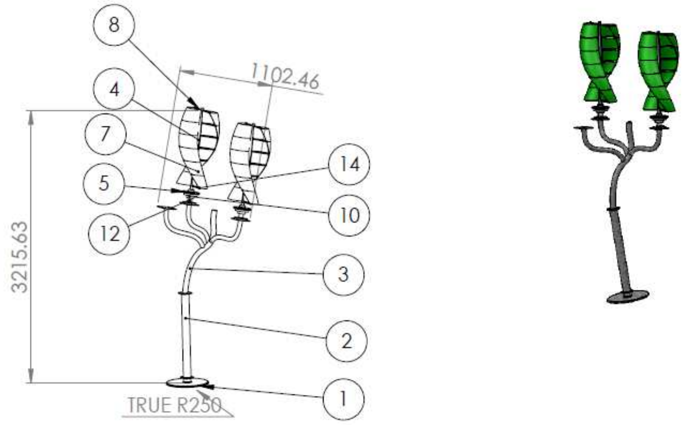
99.83
89.25
89.97
TRUE R10
TRUE R4
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
PMU - Aeroleaf Wind Turbine
NAME
SIGNATURE
DATE
DRAWN
Mubarak Alharbi
1/1/2017
CHK'D
A. Alkaabi
1/1/2017
APPV'D
A. Alshammari
1/1/2017
MFG
A. Alghoneman
1/1/2017
Q.A
TITLE:
Main branch
MATERIAL:
Galvanized CS
DWG NO.
Tree-2
A4
WEIGHT:
SCALE:1:20
SHEET 1 OF 1
SOLIDWORKS Student Edition.
For Academic Use Only.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Base Plate		1
2	Bottom Pipe		1
3	Main Branch1		1
4	Pipe		2
5	End Cap		2
6	radial ball bearing_68_am		2
7	Blade		24
8	Branch Pipe		14
9	Magnetic Steel		2
10	Shell		2
11	thrust ball bearing3_68_am		2
12	Shaft		2
13	Coil		2
14	flat washer [illegible]		84
15	[illegible]		28
16	hex nut jam_am		84

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING / REVISION

PMU - Aeroleaf Wind Turbine

	NAME	SIGNATURE	DATE
DRAWN	Mubarak Alharbi		1/1/2017
CHK'D	A. Alkaabi		1/1/2017
APPV'D	A. Alshammari		1/1/2017
MFG	A. Alghoneman		1/1/2017
Q.A			

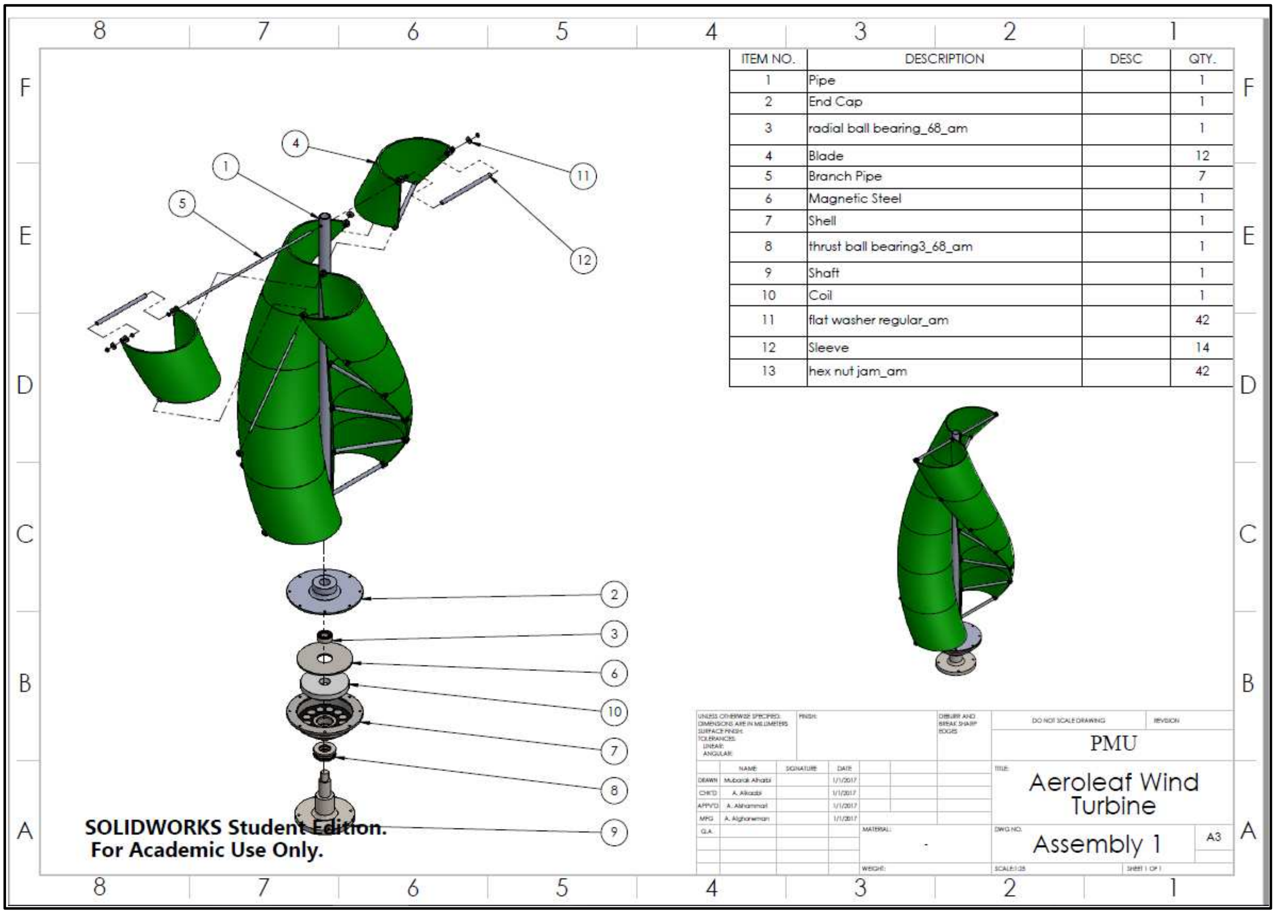
TITLE: Tree + Turbine Assembly

MATERIAL: Galvanized CS

DWG NO. 1 | A4

WEIGHT:

SCALE:1:50 | SHEET 1 OF 1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2 | End Cap | | 1
3 | radial ball bearing_68_am | | 1
4 | Blade | | 12
5 | Branch Pipe | | 7
6 | Magnetic Steel | | 1
7 | Shell | | 1
8 | thrust ball bearing3_68_am | | 1
9 | Shaft | | 1
10 | Coil | | 1
11 | flat washer regular_am | | 42
12 | Sleeve | | 14
13 | hex nut jam_am | | 42
PMU
Aeroleaf Wind Turbine
Assembly 1
A3
SOLIDWORKS Student Edition.
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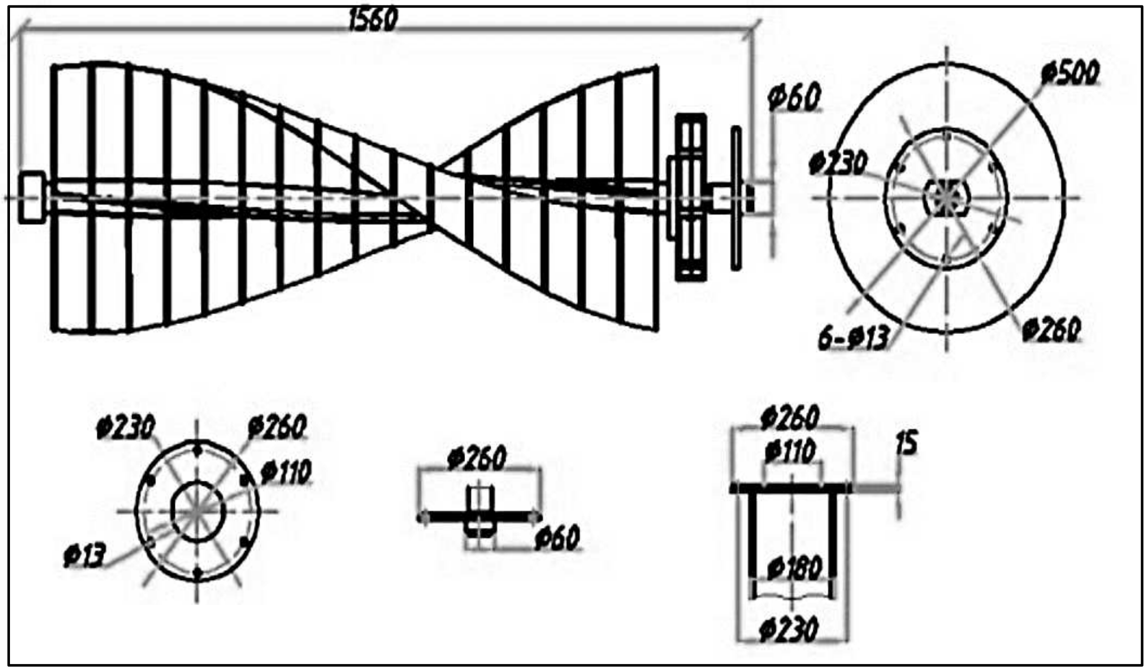
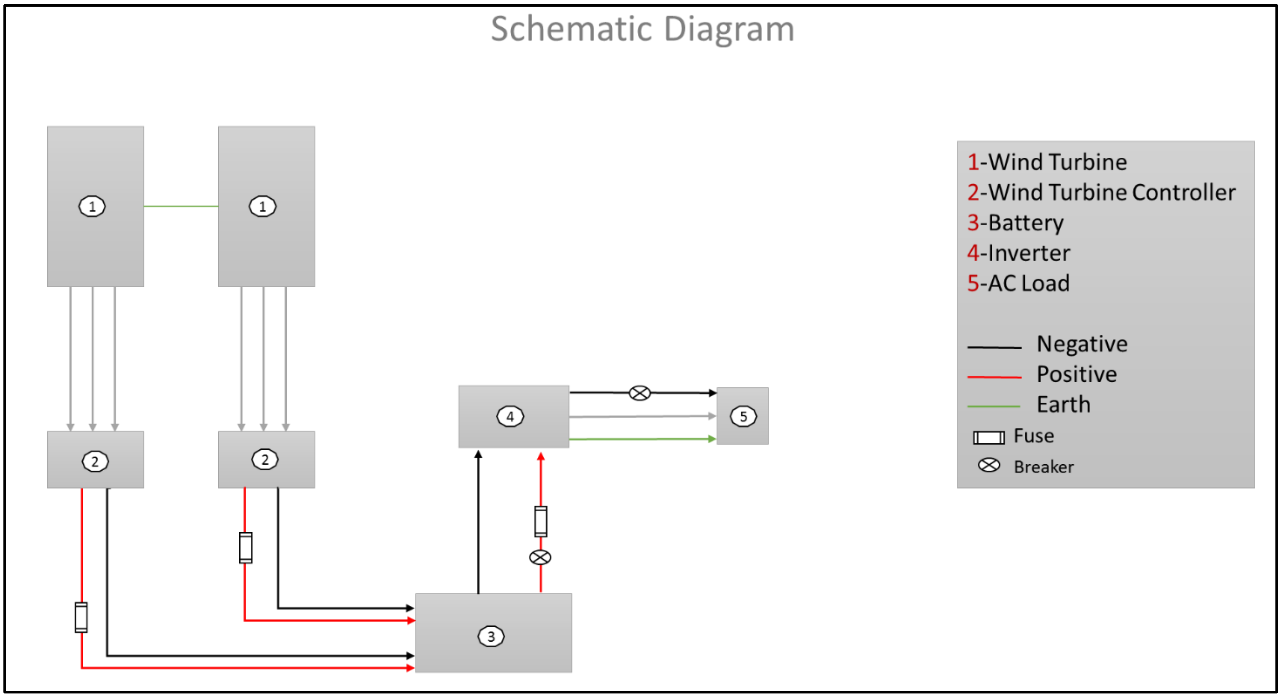
Appendix B

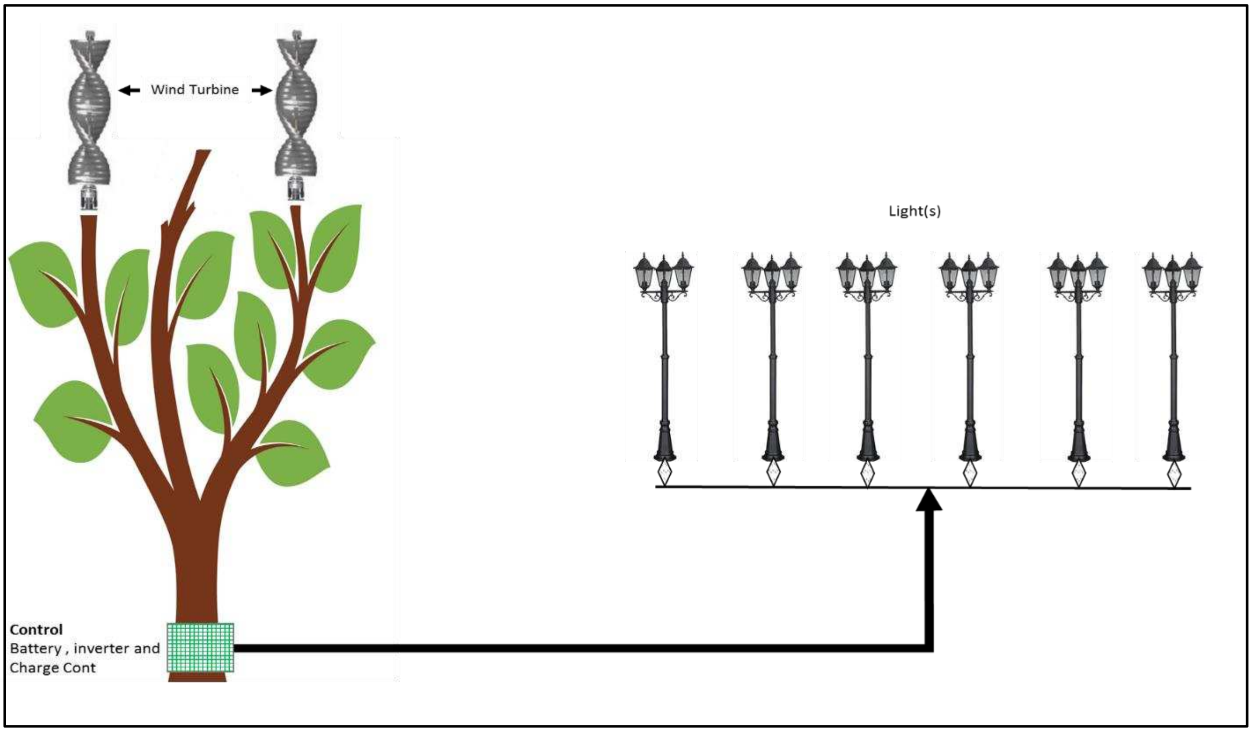
Drawing & Designing Pictures



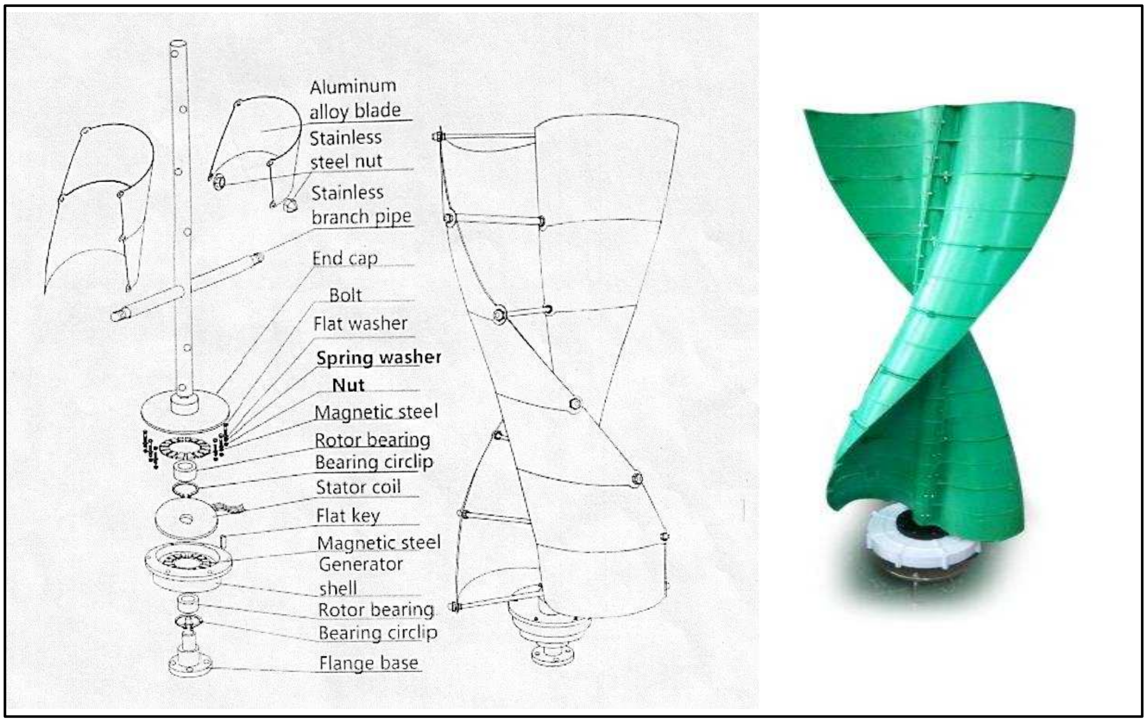
Turbine sketch



Schematic Diagram



Visual Schematic Diagram

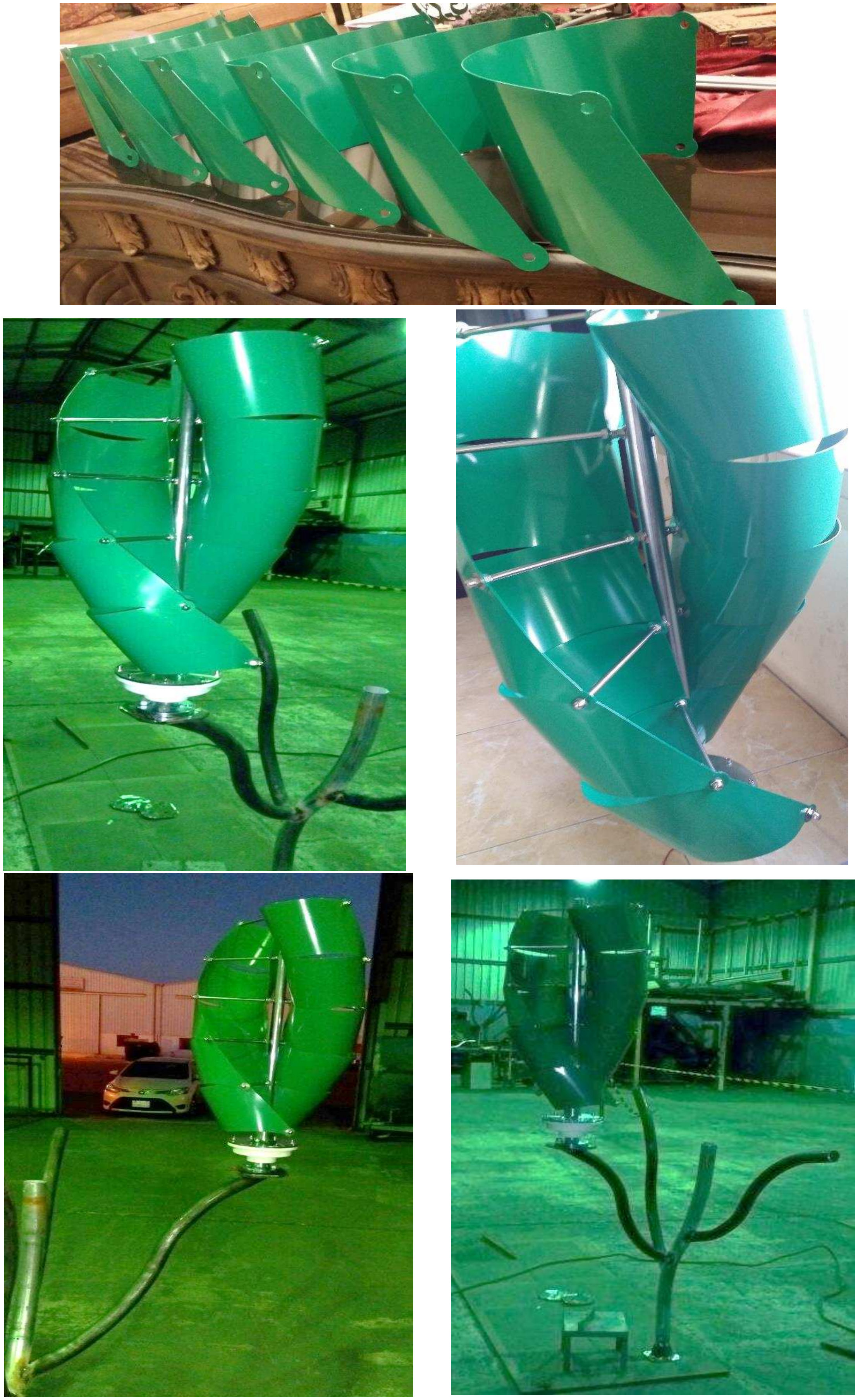


Full Turbine Design

Appendix C

Manufacturing Pictures

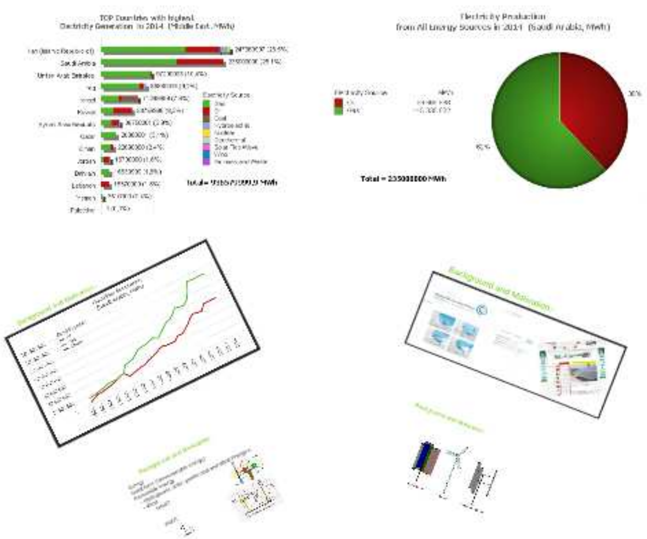
Tree Branches Manufacturing



Tree Holding Turbines

Generator

Background and Motivation:-



Aeroleaf Wind Turbine

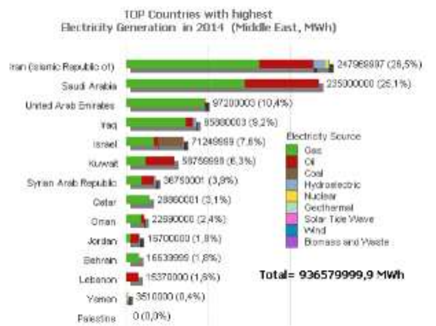
New aera of wind energy

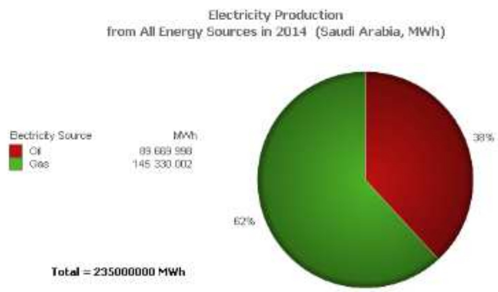
Group# 3

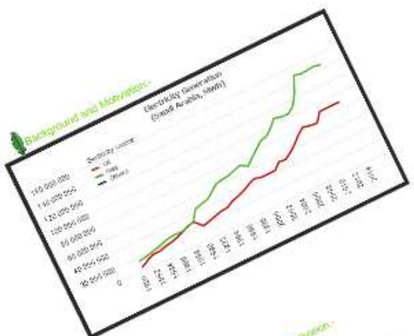
outlines

- Background and Motivation
- Design and Specification
- Implementations and testing
- Conclusions and Future Recommendations

Background and Motivation:-







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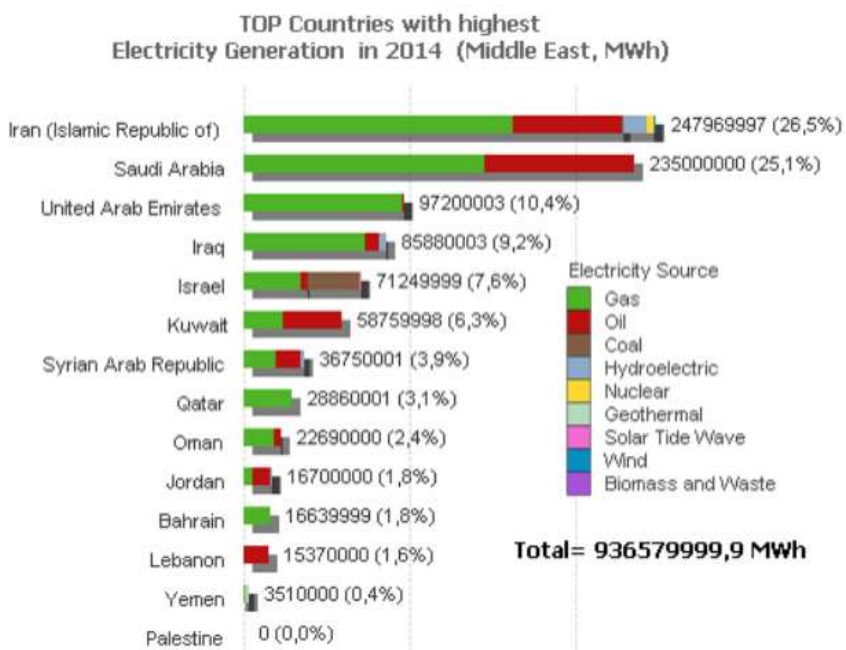
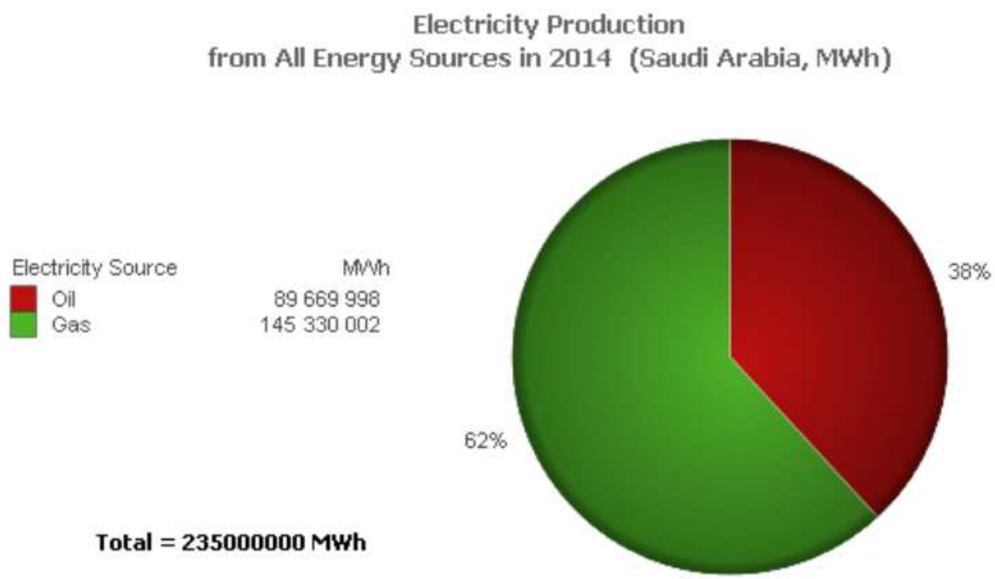
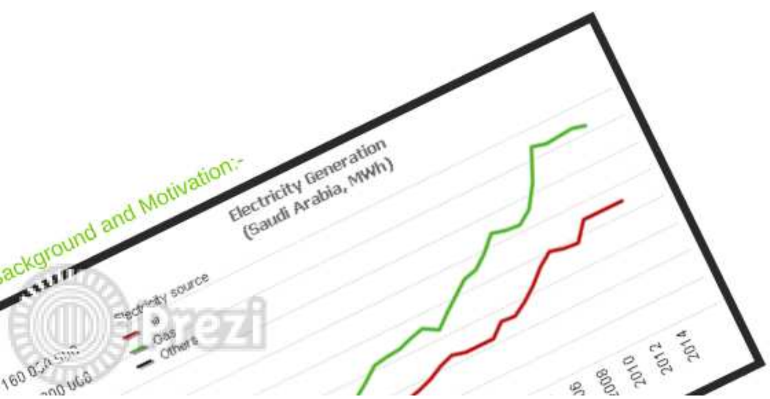
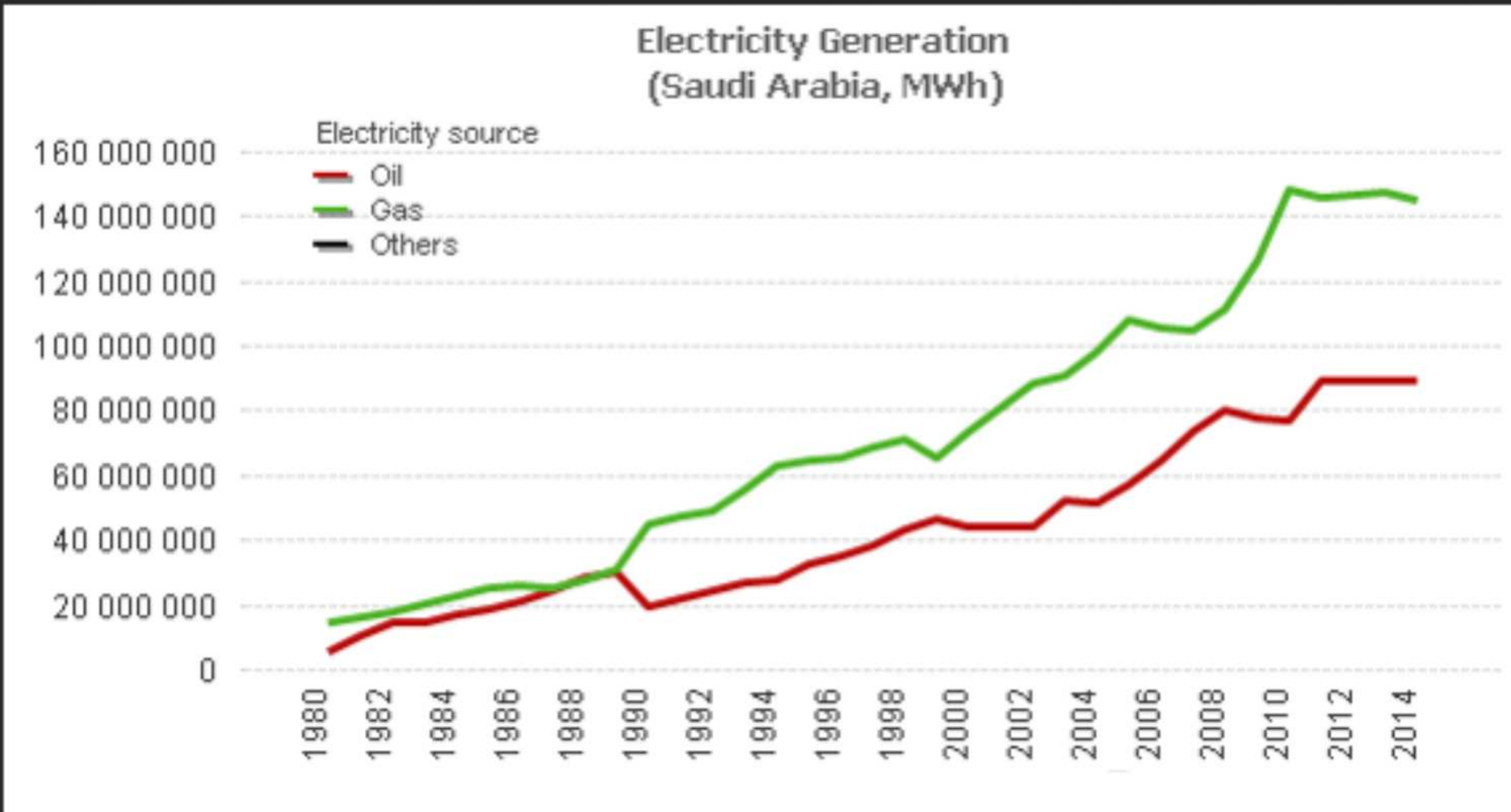






Background and Motivation:-



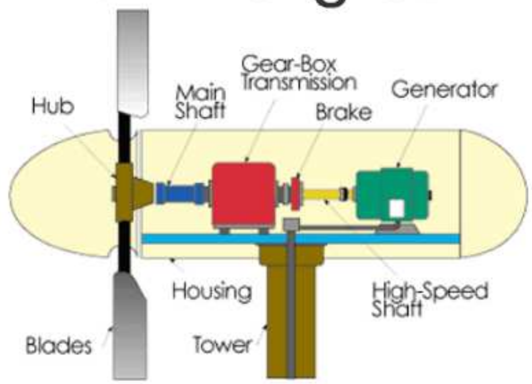
Background and Motivation:-

Background and Motivation:-

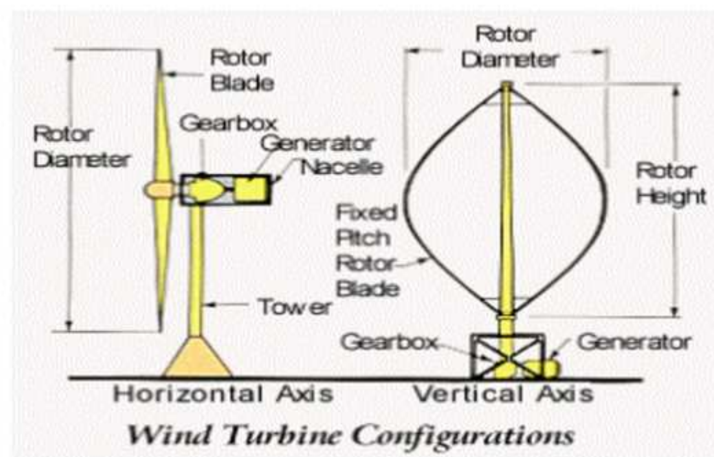
Energy
fossil fuels (Nonrenewable energy)
Renewable energy

- Hydropower, solar, geothermal and Wind Energies.
- Wind

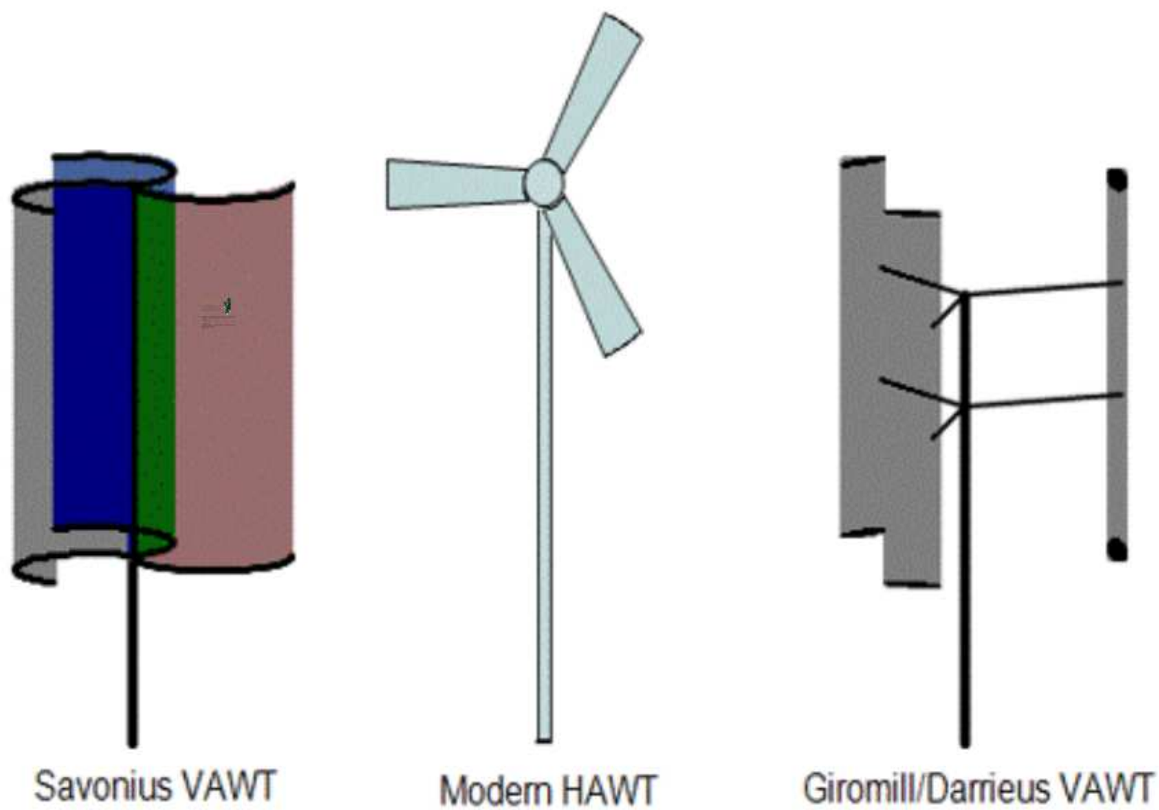
  HAWT.



  VAWT.



Background and Motivation:-



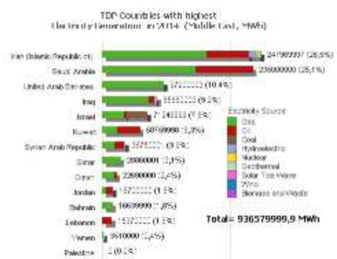
Savonius turbines

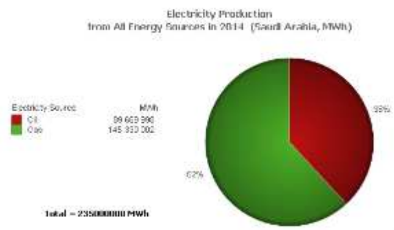
are used whenever cost or reliability is much more important than efficiency.

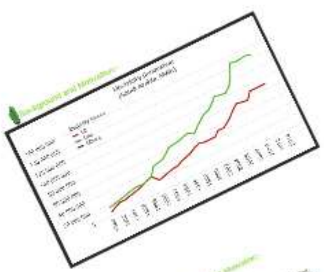
Objectives

– Less wind, more power: to easily generate power and have off-grid emergency power for any neighborhood.
– Helps homeowners enjoy secure power and cost savings.
– Easy to install. Flexible tower top interface adapts to a variety of towers.
Easy to wire.

Background and Motivation:-

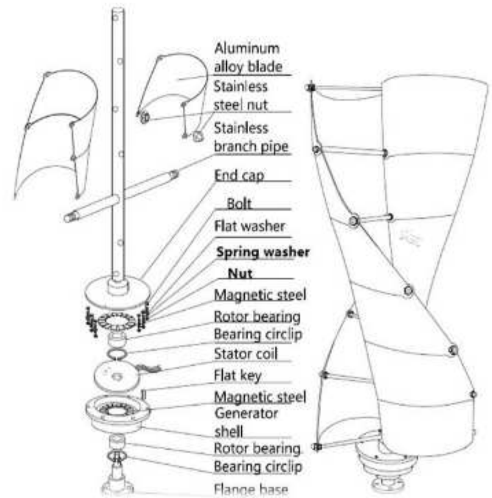


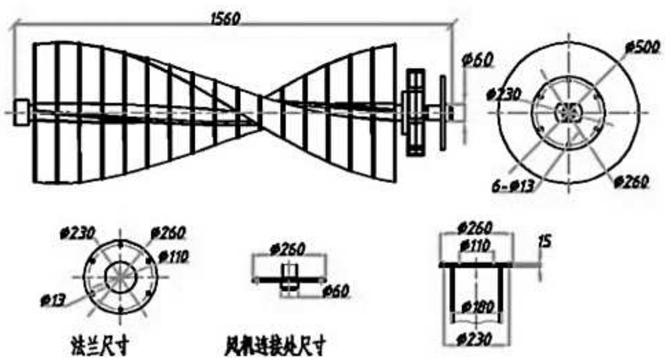




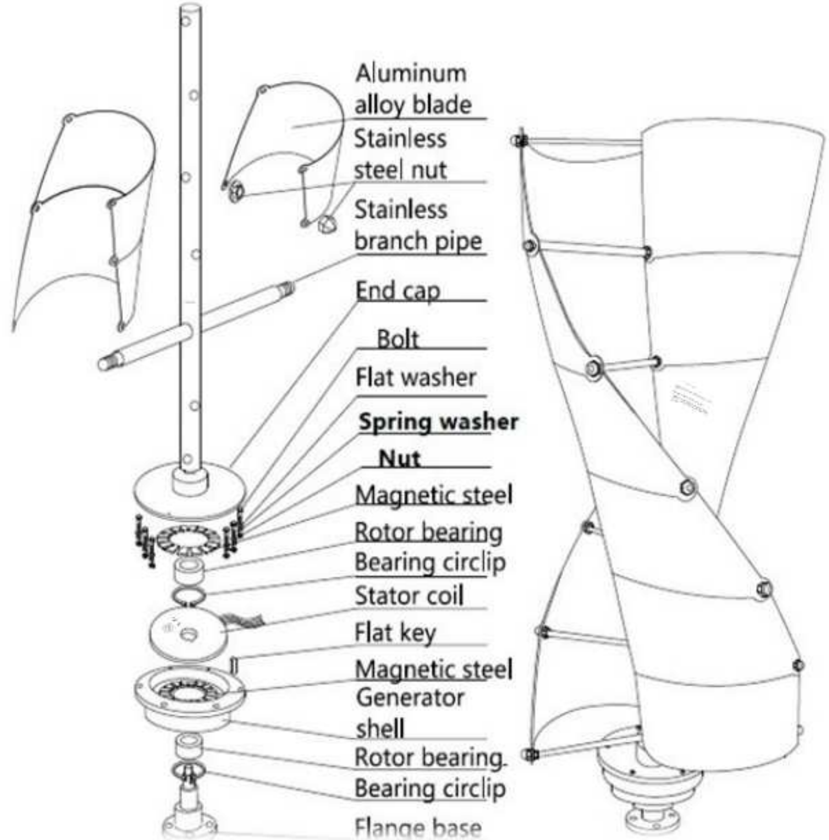
Design and Specification:-

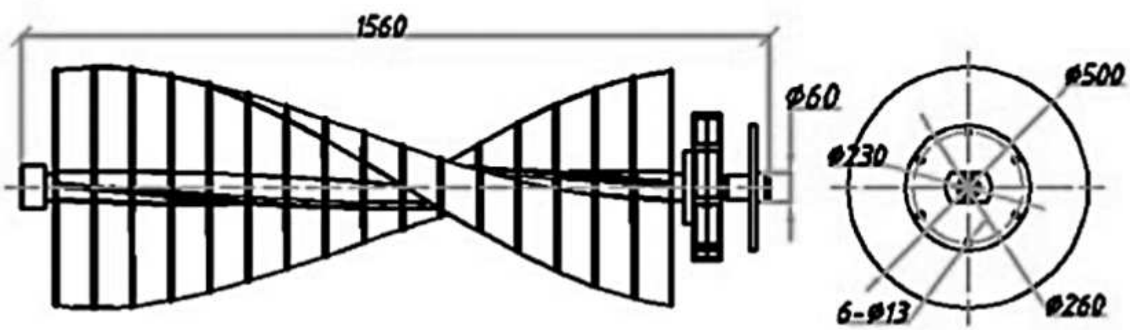
Generator power	200w
Wheel diameter	0.5m
turbine height	0.92m
Blades material	aluminum
Number of blades	12
Rated wind speed	12m/s
Start-up wind turbine	1.5m/s
Survival wind turbine	45m/s
Output voltage	12v/24V
Net Weight	10kg
Generator type	Core less generator
Control system	Electromagnet



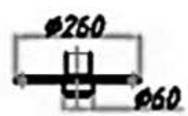


Generator power	200w
Wheel diameter	0.5m
turbine height	0.92m
Blades material	aluminum
Number of blades	12
Rated wind speed	12m/s
Start-up wind turbine	1.5m/s
Survival wind turbine	45m/s
Output voltage	12v/24V
Net Weight	10kg
Generator type	Core less generator
Control system	Electromagnet

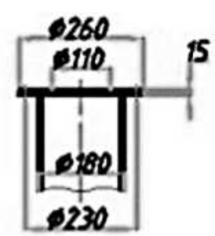




法兰尺寸

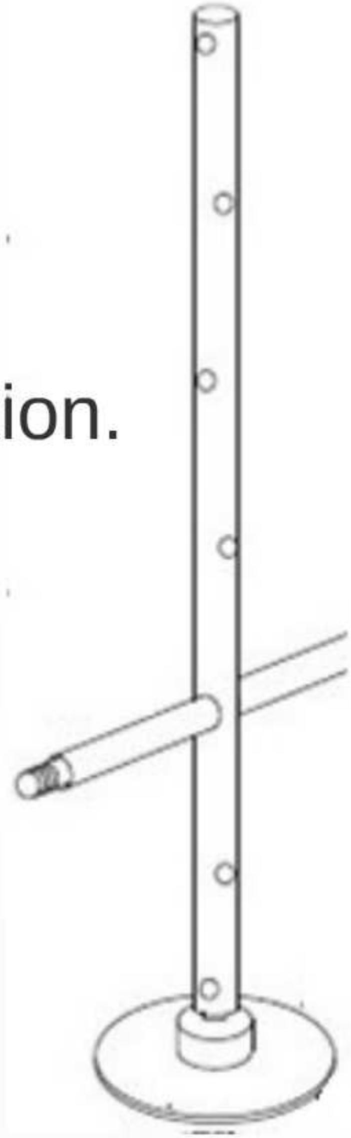


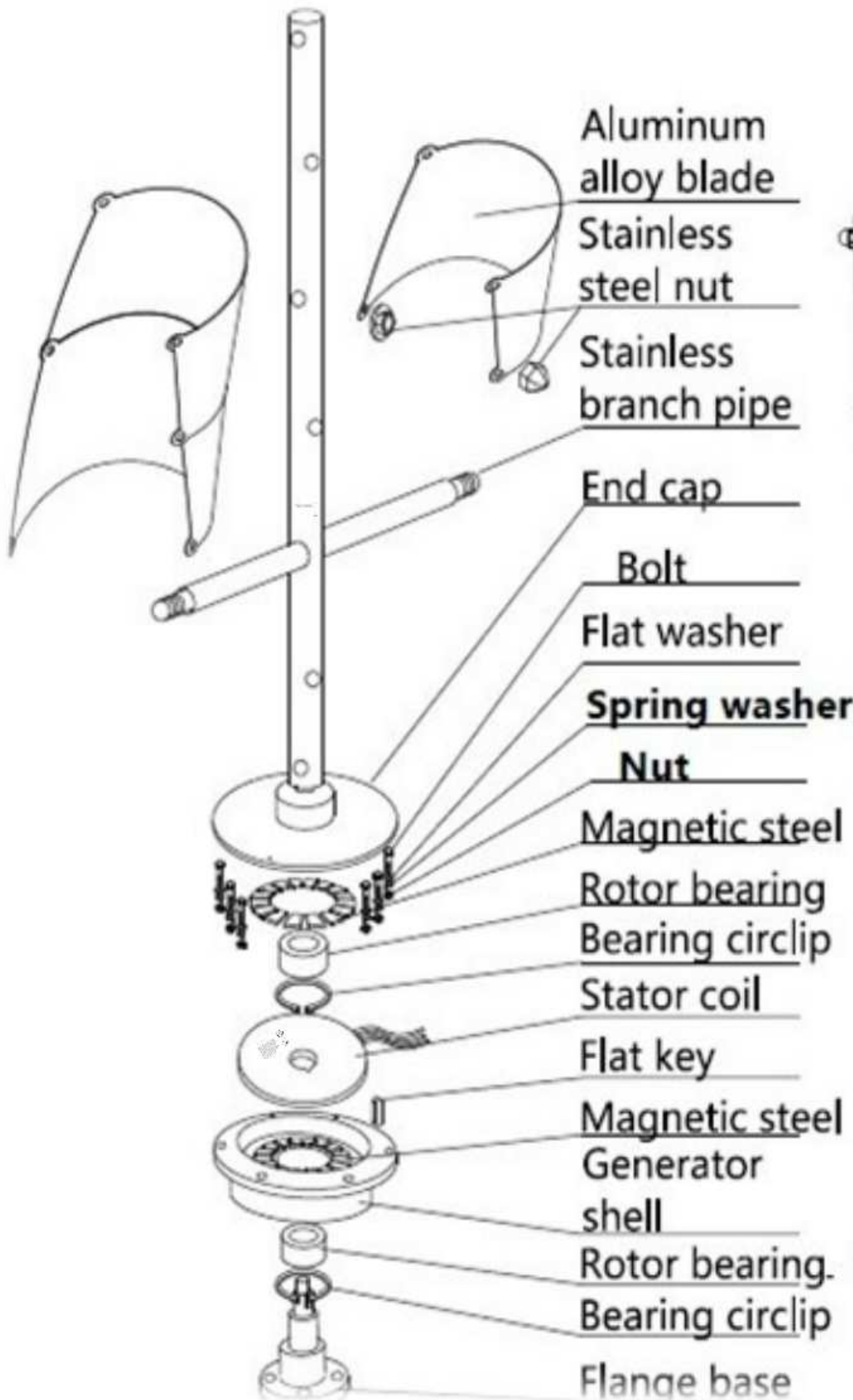
风机连接处尺寸



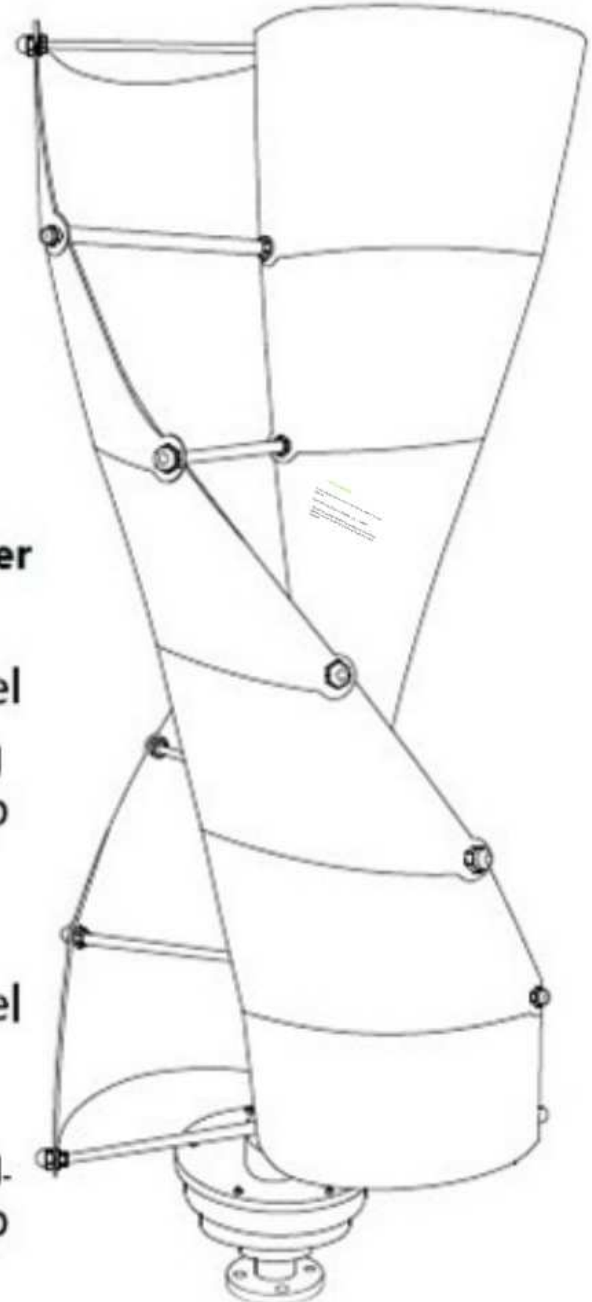
ROTOR:-

It is the turbine component responsible for collecting the energy present in the wind and transforming this energy into mechanical motion.

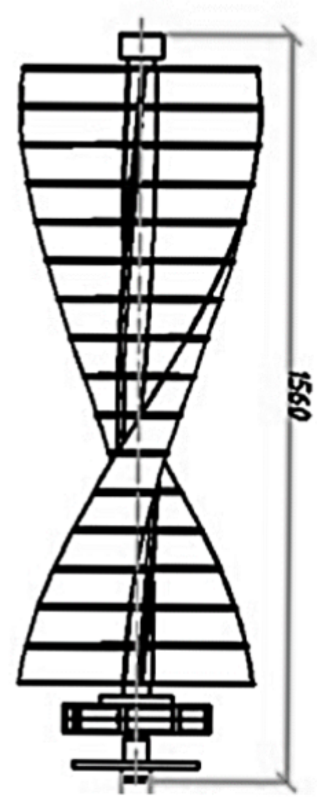




Aluminum alloy blade
Stainless steel nut
Stainless branch pipe
End cap
Bolt
Flat washer
Spring washer
Nut
Magnetic steel
Rotor bearing
Bearing circlip
Stator coil
Flat key
Magnetic steel
Generator shell
Rotor bearing
Bearing circlip
Flange base



ROTOR BLADES:-



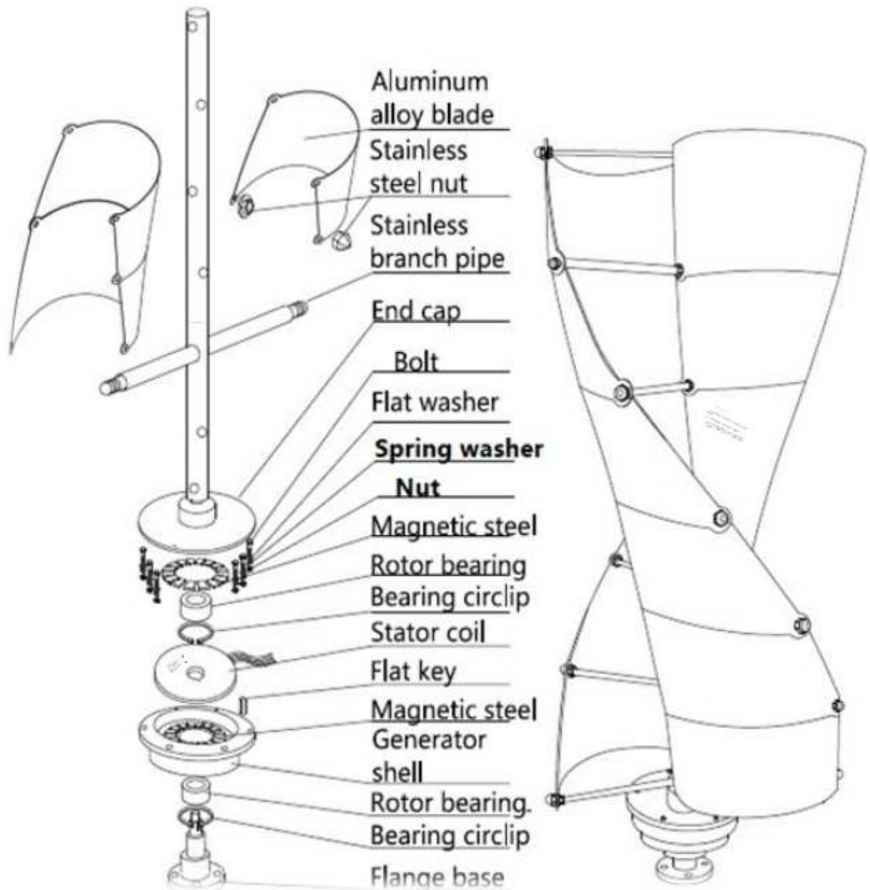
Rotor blades are a crucial and basic part of a wind turbine.

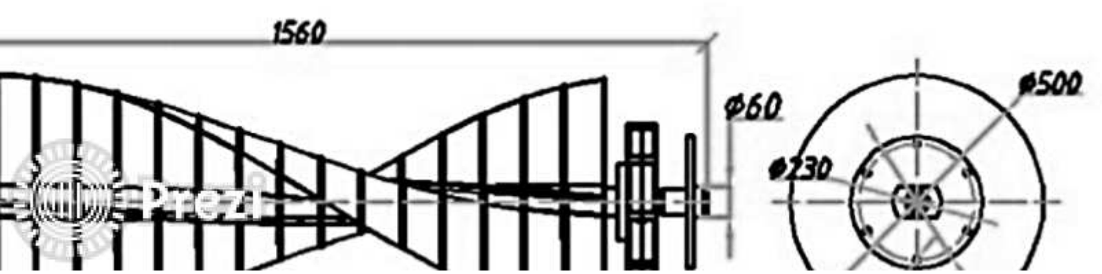
there are two types of blades use in VAWT

- Drage force type blades (savonius wind turbine)
- Lift force type blades (Darrieus and giromill wind turbine)

n and Specification:-

	200w
	0.5m
	0.92m
	aluminum
	12
l	12m/s
ne	1.5m/s
ne	45m/s
	12v/24V
	10kg
	Core less generator
	Electromagnet



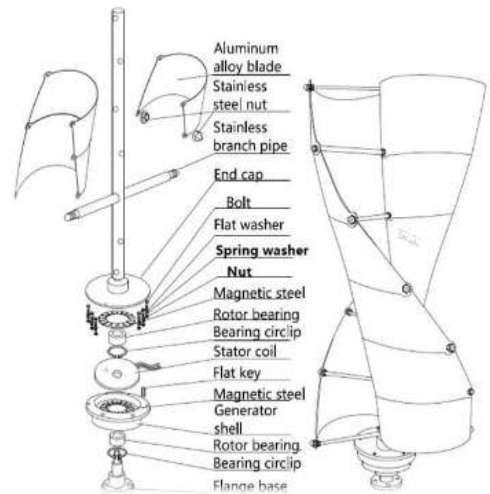


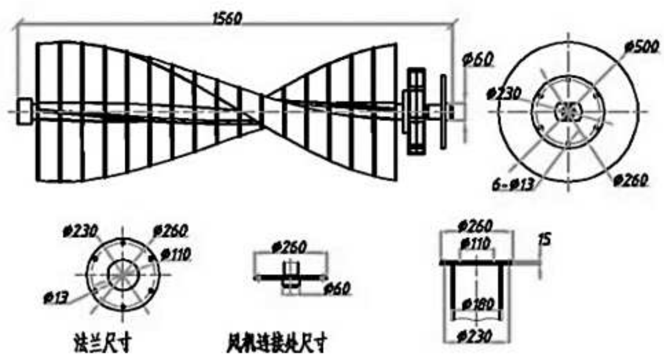
GENERATOR

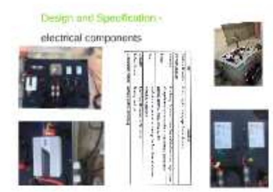
Usually the rotational speed of the wind turbine is slower than the equivalent rotation speed of the electrical network - typical rotation speeds for wind generators are 5-20 rpm while a directly connected machine will have an electrical speed between 750-3600 rpm.

Design and Specification:-

Generator power	200w
Wheel diameter	0.5m
turbine height	0.92m
Blades material	aluminum
Number of blades	12
Rated wind speed	12m/s
Start-up wind turbine	1.5m/s
Survival wind turbine	45m/s
Output voltage	12v/24V
Net Weight	10kg
Generator type	Core less generator
Control system	Electromagnet

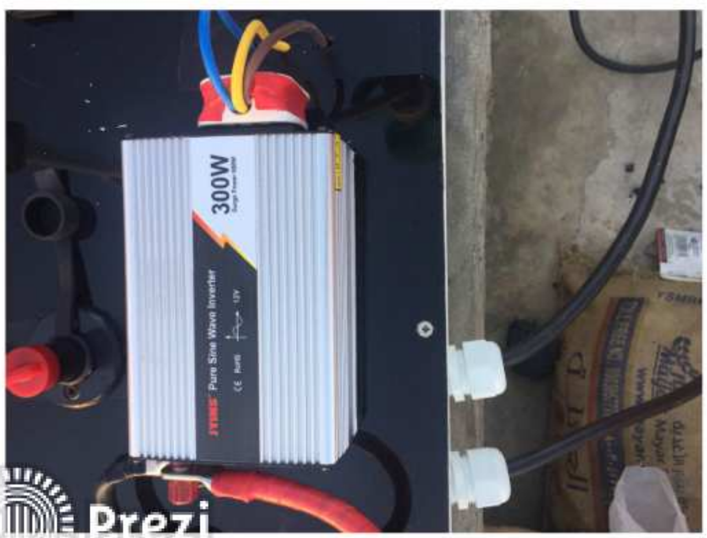






Design and Specification:-

electrical components



Part	Function
Electrical Generator	Converting the rotating speed to an electrical
Turbine Controller	
Combiner	Combining the earned power from each turbine to one output power
Battery	Charged electrically to provide a static potential for power or released electrical charge when needed.
Fuse	an electrical device that can interrupt the flow of electrical current when it is overloaded
Converter	Converting DC current to AC current
Turbine Sensors	Braking overload
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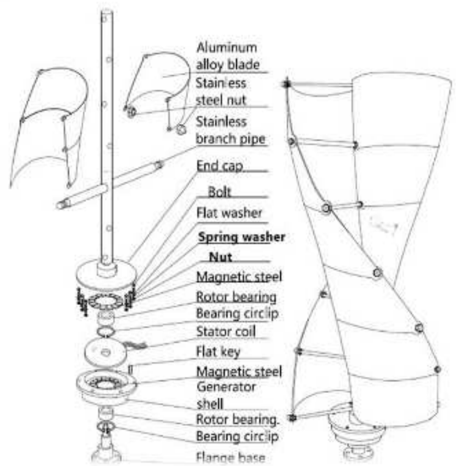
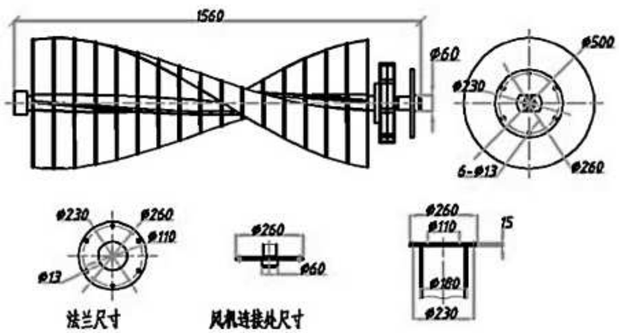
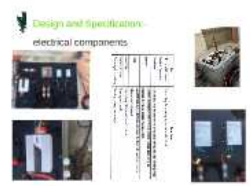
Consumption reading	Reading battery percentage

Design and Specification:-

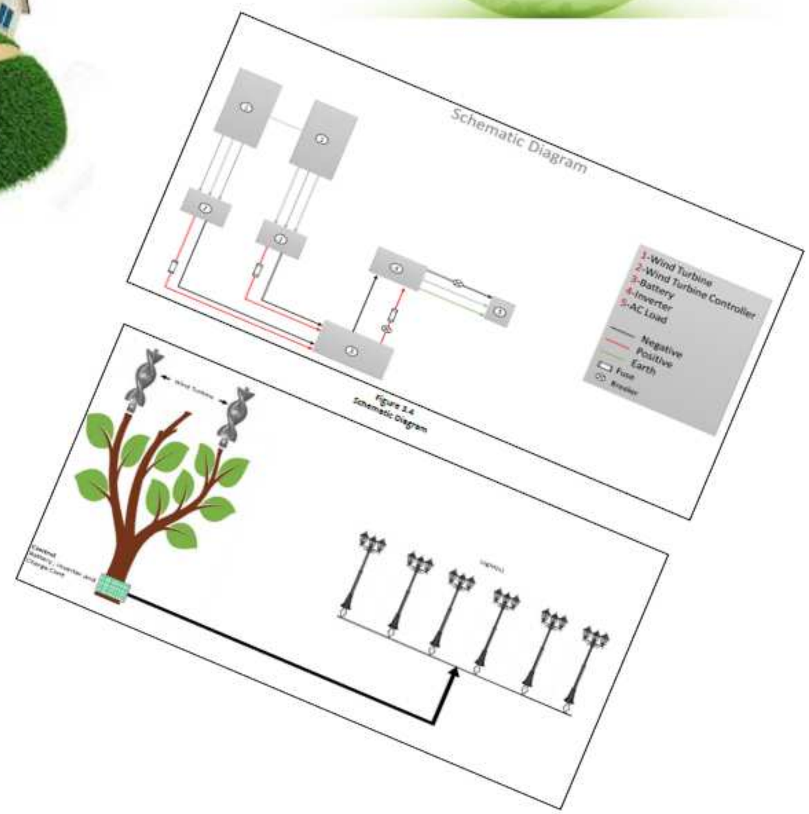
Generator power	200w
Wheel diameter	0.5m
turbine height	0.92m
Blades material	aluminum
Number of blades	12
Rated wind speed	12m/s
Start-up wind turbine	1.5m/s
Survival wind turbine	45m/s
Output voltage	12v/24V
Net Weight	10kg
Generator type	Core less generator
Control system	Electromagnet







Implementations and testing



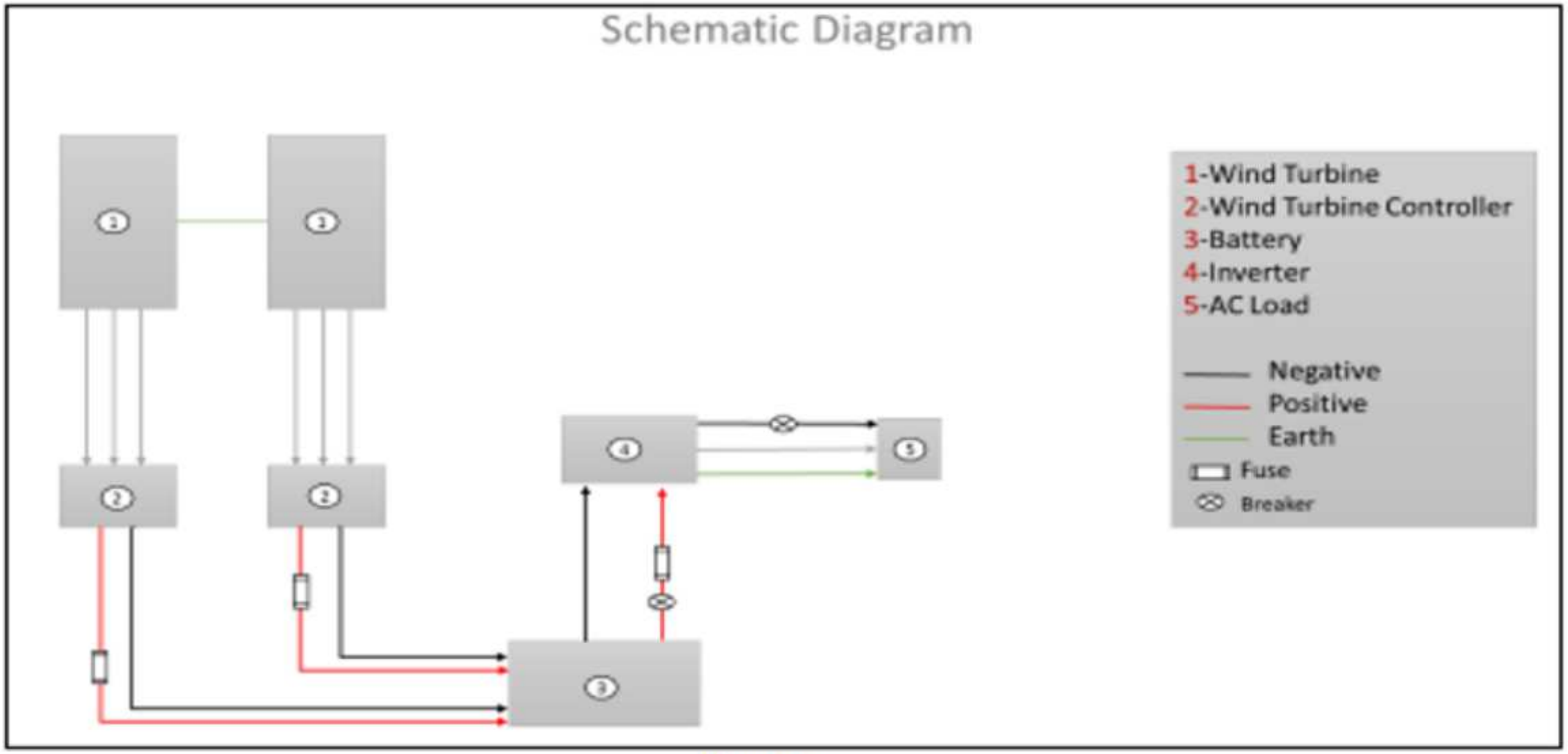
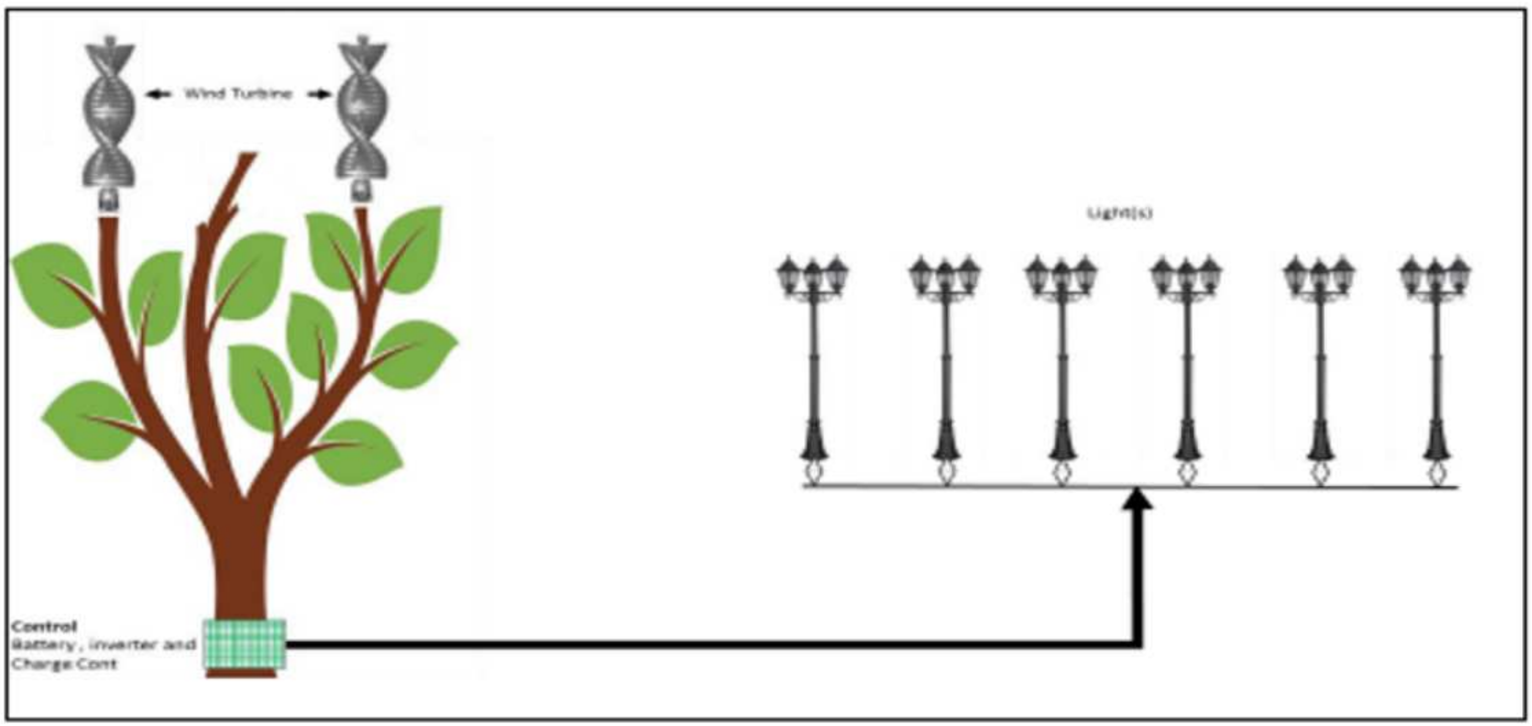
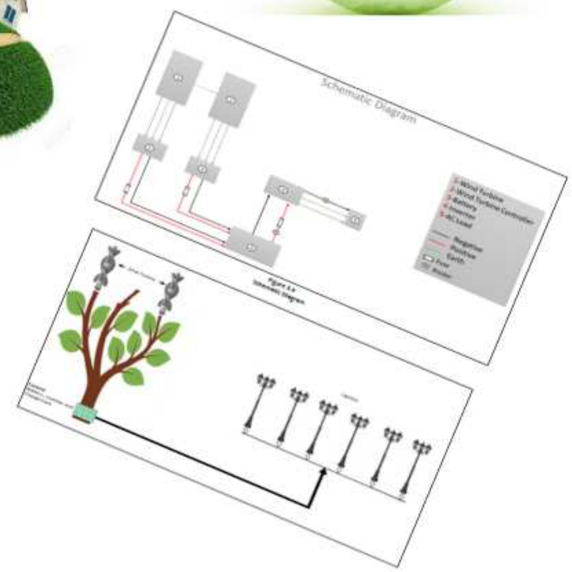


Figure 3.4
Schematic Diagram



Implementations and testing



TESTING THE SYSTEM:-

Electrodacus

Only input data on cells with this color.

V/kRPM	Ri [ohm]
93	8.1

Savonius Wind Turbine Calculator

Use [%] 96.8995

10.8km/h	14.4km/h	18km/h	21.6km/h	25.2km/h	28.8km/h	32.4km/h	36km/h	39.6km/h	43.2km/h	46.8km/h	50.4km/h	54km/h	57.6km/h
3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
127.389	169.851	212.314	254.777	297.24	339.703	382.166	424.628	467.091	509.554	552.017	594.48	636.943	679.406
44586	59448	74310	89172	104034	118896	133758	148620	163482	178344	193206	208068	222930	237792
44586	59448	74310	89172	104034	118896	133758	148620	163482	178344	193206	208068	222930	237792
17.496	41.472	81	139.968	222.264	331.776	472.392	648	862.488	1119.74	1423.66	1778.11	2187	2654.21
11.34	13.88	13.92	14.64	10.21	9.27	6.19	3.34	3.08	2.75	1.17	1.09	0.37	0.55
19.8357	57.5606	112.769	204.86	226.889	307.395	292.362	216.739	265.316	307.888	166.835	194.264	80.7578	146.61
3.4992	8.2944	16.2	27.9936	44.4528	66.3552	94.4784	129.6	172.498	223.949	284.731	355.622	437.4	530.842
123425	219455	342930	493849	672212	878020	1111271	1371968	1660108	1975693	2318722	2689196	3087113	3512475
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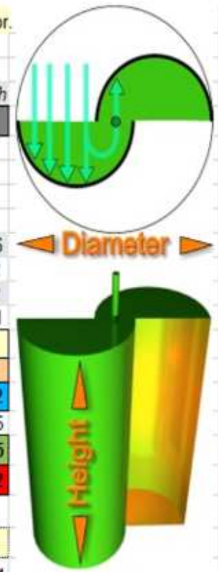
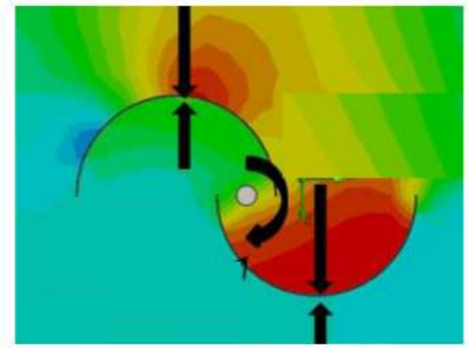
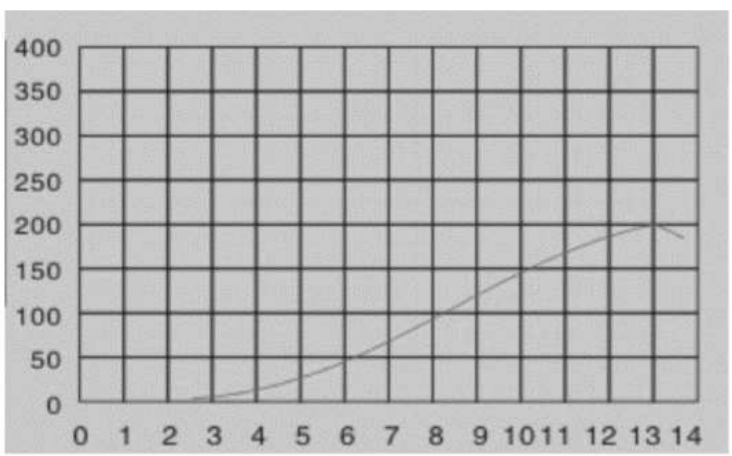
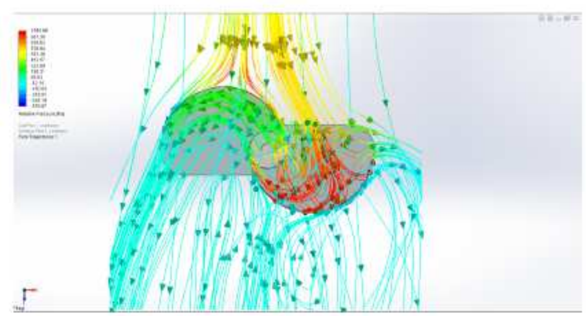
3.4992	8.2944	16.2	27.9936	44.4528	66.3552	94.4784	129.6	172.498	223.949	284.731	355.622	437.4	530.842
0.39671	1.15121	2.25538	4.0972	4.53779	6.1479	5.84723	4.33477	5.30632	6.15776	3.33671	3.88528	1.61516	2.9322
0	0	1	1	1	1	1	1	1	1	1	1	1	1
0	0	112.769	204.86	226.889	307.395	292.362	216.739	265.316	307.888	166.835	194.264	80.7578	146.61



52.0680484	KWh / month
50.4536961	36.32666







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3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
127.389	169.851	212.314	254.777	297.24	339.703	382.166	424.628	467.091	509.554	552.017	594.48	636.943	679.406
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17.496	41.472	81	139.968	222.264	331.776	472.392	648	862.488	1119.74	1423.66	1778.11	2187	2654.21
11.34	13.88	13.92	14.64	10.21	9.27	6.19	3.34	3.08	2.75	1.17	1.09	0.37	0.55
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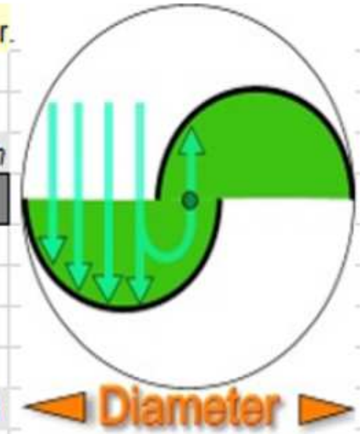
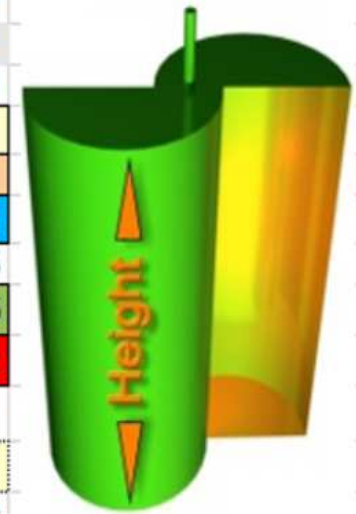
0	0	1	1	1	1	1	1	1	1	1	1	1	1
0	0	112.769	204.86	226.889	307.395	292.362	216.739	265.316	307.888	166.835	194.264	80.7578	146.61





52.0680484	KWh / month
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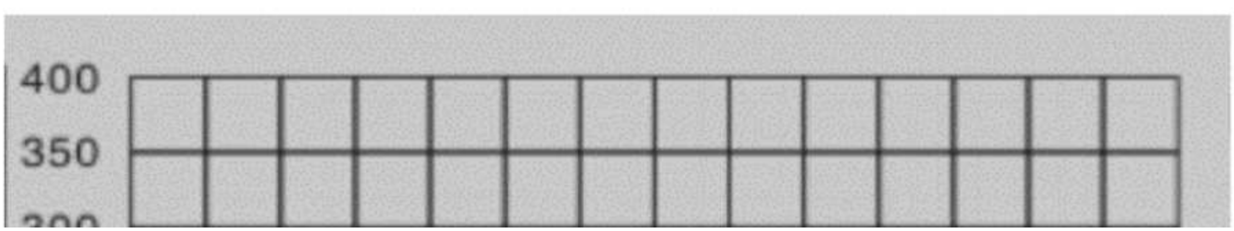
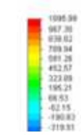
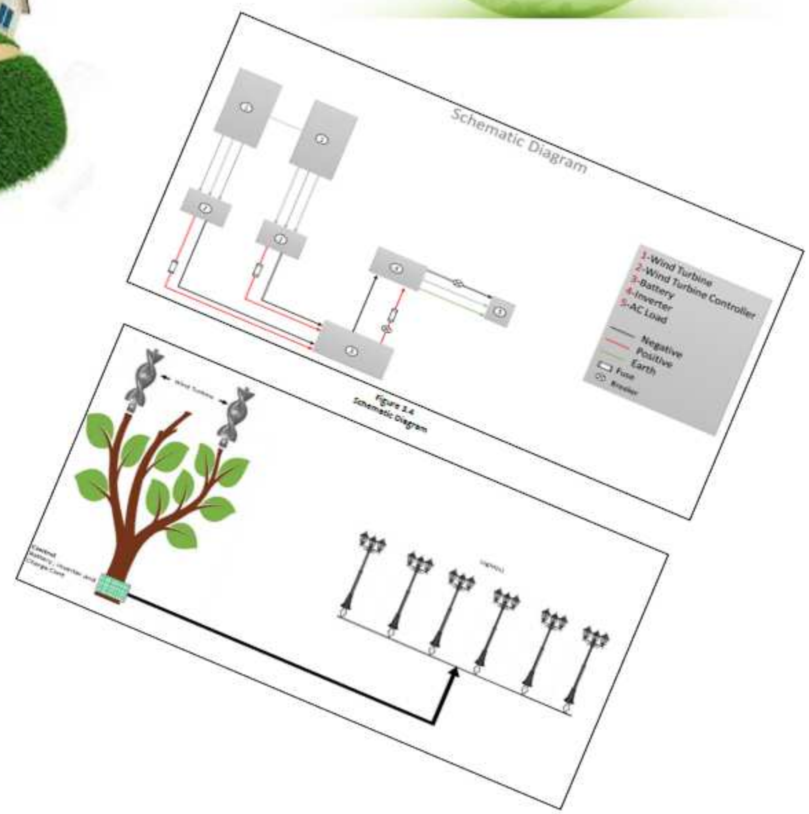




Implementations and testing



Aeroleaf Wind Turbine

New aera of wind energy

Group# 3