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Senior Design Project Report

Windmill Water Pump

Design of Windmill for Pumping Water

**In partial fulfillment of the requirements for the
Degree of Bachelor of Science in Mechanical Engineering**

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Abstract

The demand of alternative sources of energy is increasing significantly due to the increasing cost of the traditional energy sources. Wind energy is one example of alternative sources of energy that will be designed for the purposes of pumping water. There are two types of windmill turbines: Vertical axis windmill turbine and horizontal axis windmill turbine. This project will only consider the horizontal axis wind turbine. The design of windmill is a very wide subject and therefore the design is based on data analysis of various components of wind mill and their actual drawings. This includes the rotor assembly i.e. the blade on the hub, transmission shafts (both vertical and horizontal) which houses the gears, actuating pulley and the piston actuating mechanism, tail and turntable. The design does not cover the design and selection of the pump but the desirable pump that can function with the vertical movement of the actuating rod will be selected. In order to achieve the optimum design characteristics such as torque and power produced by the windmill, various calculations and structural analysis had to be done as well.

Keywords: Wind, Turbine, Energy, Horizontal Axis, Pump.

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Table of Contents

ABSTRACT.....	2
ACKNOWLEDGEMENTS	3
1 Chapter 1: Introduction.....	9
1.1 PROJECT DEFINITION.....	9
1.2 OBJECTIVES	10
1.3 PROJECT SPECIFICATIONS	10
1.4 APPLICATIONS	10
2 CHAPTER 2: LITERATURE REVIEW.....	11
2.1 PROJECT BACKGROUND.....	11
2.2 SITE SELECTION.....	14
2.3 TYPES OF WIND TURBINES	15
2.4 ADVANTAGES AND DISADVANTAGES OF WIND POWER.....	16
2.5 PREVIOUS WORK.....	17
2.7 WIND SPEED IN SAUDI ARABIA	20
3 CHAPTER 3: SYSTEM DESIGN	24
3.1 DESIGN CONSTRAINTS AND METHODOLOGY	24
3.2 CONSTRAINTS.....	26
3.3 THEORY AND THEORETICAL CALCULATION	29
3.4 PRODUCT SUBSYSTEMS AND SELECTION OF COMPONENTS	36
3.4.1 BASE	36
3.4.2 Tower.....	38
3.4.3 Bearing	39
3.4.4 Blade	40
3.4.5 Generator	41
3.4.6 Charge Controller	43
3.4.7 Battery	44
3.4.8 Voltmeter	45
3.4.9 Anemometer	45
3.4.10 Tachometer	47
3.4.11 Water Pump	49
3.4.12 Water Tank	51
4 CHAPTER 4: SYSTEM TESTING AND ANALYSIS.....	52
4.1 THEORETICAL WIND TURBINE POWER CALCULATION	52
4.1.2 EXPERIMENTAL WIND TURBINE POWER CALCULATION	54
4.2. RESULTS, ANALYSIS AND DISCUSSION	55
4.2.1 GOALS.....	56
4.2.2 EXPERIMENTAL METHODOLOGY	56

4.2.3	PROCEDURE.....	57
5	<u>CHAPTER 5: PROJECT MANAGEMENT.....</u>	58
5.1	PROJECT PLAN.....	58
5.2	CONTRIBUTION OF TEAM.....	60
5.3	PROJECT EXECUTION MONITORING.....	63
5.4	CHALLENGING AND DECISION MAKING.....	63
5.4.1	Material and Equipment resourcing.....	64
5.4.2	DESIGN PROBLEMS.....	65
5.4.3	REPORT WRITING AND DOCUMENT.....	66
5.5	PROJECT BILL OF MATERIALS AND BUDGET.....	67
6	<u>CHAPTER 6: PROJECT ANALYSIS.....</u>	69
6.1	LIFE LONG LEARNING.....	69
6.1.1	IMPROVE OUR SKILLS IN SOME SOFTWARE TOOLS.....	69
6.1.2	TIME MANAGEMENT SKILL.....	69
6.1.3	PROBLEM SOLVING.....	70
6.2	IMPACT OF ENGINEERING SOLUTIONS.....	70
6.2.1	Social.....	70
6.2.2	Environment.....	70
6.2.3	Economy.....	70
6.3	Contemporary Issues Addressed.....	71
7	<u>CHAPTER 7: CONCLUSION.....</u>	72
7.1	CONCLUSION.....	72
7.2	FUTURE RECOMMENDATION.....	74
8	<u>REFERENCES.....</u>	75
9	<u>APPENDIX A: CAD DRAWINGS.....</u>	80

List of Acronyms (Symbols) used in the report:

[2] Cp - Coefficient of power
As - Swept Area
AB- Area of one blade
V - Velocity
U_o - Speed of Wind
- Density
D - Diameter
R - Radius
- Tip Speed Ratio
N - Number of Blades
- Angular Velocity
C_t - Torque Coefficient
ḡ - Mass Flux
P_w - Wind Power
P_T - Power Extracted From wind
T - Torque
g - Acceleration due to gravity
Q - Flow rate
H - Head
P_h - Hydraulic Power
P_d - Diametral Pitch
m - Module
- Gear Pressure angle
E - Young's Modulus
- Poisson's Ratio
y - Yield Strength
UTS - Ultimate Tensile Strength
- Shear Stress
J - Polar Moment of Inertia
F - Force
M - Moment

LIST OF FIGURES

FIGURE 1: WIND SPEED IN DAMMAM [2]	20
FIGURE 2: WIND SPEED IN HAIL [2]	21
FIGURE 3: WIND SPEED IN JIZAN [2]	21
FIGURE 4: WIND SPEED IN MECCA [2]	22
FIGURE 5: WIND SPEED IN MADINAH [2]	22
FIGURE 6: WIND SPEED IN RIYADH [2]	23
FIGURE 7: WIND SPEED IN TABUK [2]	23
FIGURE 8: HAWT OVERVIEW LAYOUT [3]	29
FIGURE 9: BASE DESIGN [3]	37
FIGURE 10: TOWER	38
FIGURE 11: BARING DESIGN [3].....	39
FIGURE 12: INDIVIDUAL BLADE [3]	41
FIGURE 13: FIVE BLADE ASSEMBLY [3]	41
FIGURE 14: GENERATOR [3]	42
FIGURE 15: CHARGER CONTROLLER [3]	43
FIGURE 16: BATTERY [3]	44
FIGURE 17: VOLTMETER [3]	45
FIGURE 18: ANEMOMETER [3]	47
FIGURE 19: TACHOMETER [3]	49
FIGURE 20: WATER PUMP [3]	50
FIGURE 21: WATER TANK [3]	51
FIGURE 22: THEROTICAL POWER CALCULATION [4]	53
FIGURE 23: EXPERIMENTAL POWER CALCULATION [4]	54
FIGURE 24: THEORETICAL VS EXPERIMENTAL [4]	56

LIST OF TABLES:

TABLE 1: AVERAGE WIND SPEED IN DIFFERENT AREAS IN THE KINGDOM [1].....	15
TABLE 2: WIND CHARACTERISTICS IN VARIOUS SITES [2]	19
TABLE 3: CONTAINS DETAILS ON THE USED PARTS [3]	24
TABLE 4: TIP SPEED RATION VS NUMBER OF BLADES [3].....	36
TABLE 5: BEARING STANDARDS [3]	40
TABLE 6: WATTS VS WIND SPEED [3]	42
TABLE 7: BATTERY SPECIFICATION [3]	44
TABLE 8: WATER PUMP SPECIFICATIONS [3]	50
TABLE 9 : THEORETICAL GAIN POWER CALCULATION [4].....	53
TABLE 10: EXPERIMENTAL GAIN POWER CALCULATION [4].....	54
TABLE 11: THEORETICAL VS EXPERIMENTAL DATA [4]	55
TABLE 12: DURATION OF THE TASKS [5].....	60
TABLE 13: TASKS DISTRIBUTION [5]	63
TABLE 14: TABLE OF ACTIVITIES [5]	63
TABLE 15: LIST OF MATERIAL AND THEIR COST [5].....	67

1 Chapter 1: Introduction

1.1 Project definition

Power generation is a major requirement nowadays, Saudi Arabia in specific is looking for new methods to find renewable energy sources as part of 2030's vision and wind power was found to be suitable for the country's geographic condition.

Wind is the motion of air that is moving on the surface of the earth, and its speed varies based on the geographical location. The wind energy can be generated from the change of atmosphere unevenly where some parts get warmer than others. The warmer air rises and the colder air patches blow to replace them, therefore, alternating air is resulted and that air is wind [1]. Windmill is a mill that is used to convert kinetic energy of the wind into a mechanical energy by using blades rotor assembly which drives the shaft. The result from the rotating shaft provides a mechanical work that can be used to pump water as an example.

This project is intended to design a windmill based on the various components and their actual drawings. This design will contain the rotor assembly i.e. blades, hub, transmission shaft, the gear box, tower, generator, and yaw system. Windmill has two different designs, the first type is horizontal and the second type is vertical. In this project, it will focus on the horizontal type. The consumption of power in Saudi Arabia is about triple times the world average [2]. There comes the benefit of windmill as it will reflect positively on the country in an economical point of view, as vision 2030 tries to find an alternative power source other than petroleum. Using renewable energy sources will not only benefit Saudi Arabia economically, but also will help the country to reduce its pollution by using free green energy such as wind. The main advantage of windmill compared with solar panel is that the country is located in a desert area where dust is very common, the dust has a big impact on the solar panels. Moreover, solar energy only works during the day while, windmill can operate 24 hours depending on the wind changes [4]

1.2 Objectives

The main objective of this project is to determine the power from a renewable energy source which is the wind. Moreover, to design a windmill with the key characteristics of a windmill. Another objective of this project is to practice and apply the engineering concepts. But there are more objectives, which are:

1. Design and construct a windmill to produce a renewable energy which is going to decrease the pollution.
2. Reduce the cost and energy of pumping water.
3. Study the difference between horizontal axis wind turbine, and the vertical axis turbine.
4. Learn the advantages and disadvantages of windmill.
5. Identify mathematical equations.
6. Compare between theoretical and experimental power.

1.3 Project specifications

There are many necessary components that are the building blocks of a horizontal axis wind turbine, these components starting from the pump, generator, shaft, bearing, rotor and blades will be either designed or selected in accordance with engineering standards. Further discussion of the components will be in section 3.1

1.4 Applications

The windmills that can be used in different applications to ensure they give the best possible results. These applications maybe pumping water in large amounts such as in farms, stand-alone system for homes and businesses, system for community centers, schools and health clinics and also in industrial applications.

2 Chapter 2: Literature Review

This section explains the project's background in terms of historical development, the site selection which is a basic requirement for efficiency, the types of windmills developed and the differences between each to give a better understanding. In addition, the advantages and disadvantages are going to be illustrated to preview the main strengths and weaknesses of the project. Also, an important discussion of previous work done on windmills is included in this part followed by comparative studies as an ending to this part.

2.1 Project Background

For its lower cost production and eco-friendliness, wind energy has been developed over the years as a major alternative source of energy. Though pinpointing the very beginning of wind as a power source is unknown, it has been recorded that its first usage was as an aerodynamic lift for sailboats around 3500 BC in Ancient Egypt. Adapting this advanced invention, the wind wheel, windmill, and wind turbine were gradually brought to life as seen throughout world history. The timeline is going to be skipped in this segment until the invention of horizontal axis type of windmill which followed after the Persians introduced the vertical design in 200 BC to grind grains.

1300 AD – Western Europe adopted the first use of horizontal axis windmill due to its larger efficiency compared to the vertical type. This design of windmill was mainly for irrigation, prioritizing it over its secondary function of grinding grains, as the water in France would come from Netherlands. Moreover, the naming “Windmill” was indicative of respect, power, wealth, and high authority. The villagers' personalization of the windmills was equivalent to village hierarchy. Meanwhile, due to the fact that friction mills are made of wood, they were highly combustible. High winds also made a miller's job dangerous as wind gust can damage the mill arms; hence, to furl the sails the miller must be very skilled and physically strong.

1270 AD – The Post design version of horizontal axis type of windmill was invented, wooden, upright and massive, the entire windmill rotated where the wind blew. Its Vitruvian characteristic was adapted from a horizontal axis water wheel transmitting the rotary motion of the blades to a grindstone which was also horizontally structured and ring gears and wooden cogs were used.

12th Century – The Post mill was used in Arles, France.

13th Century – It was of utmost significance for irrigation with a route via Holland, Germany to France and England, aside from the waterwheel.

1390, 14th-15th Century – The Tower design version of horizontal axis type of windmill was built. Several stories of an elevated tower were mounted with a Post windmill. Bricks were used but the roofing was made of woods. The first floor housed the miller and his family while the revolving top was for blade-positioning, contrary to the Post design. A large wheeled lever at the back and lateral fan were eventually added. Then again, storms made the miller look after the mill at all times. Thus, it was also known as “runaway mill.”

16th Century – The octagonal Dutch Smock mill came into existence highlighting a turn-able top. Lighter woods were used for its body as it was more convenient for the damp quagmire. Besides grinding grains, the smock design was for Dutch polders requiring drainage.

17th Century – In Europe, the slow windmill with eight blades were designed. Unlike a runaway turbine’s destructive tendencies, the wind gust used was moderate with each of the mill’s blade spinning around in its own axis. With the use of a tie rod and a crankshaft, it self-regulated into driving a single-action water pump.

18th – 19th Century – The Dutch Smock mill was standardized in Europe.

1870 – While the eight-bladed design was not popular in Europe, it spread throughout America due to its triumphant, economic and simple design. It became the American windmill, a.k.a. the Western mill, when it went back to Europe and became worldwide later on.

Mid-1870's – The fantail, a wind-driven sail located opposite the main sails, was devised.

Mid-19th Century – The Western mill was mainly used for providing drinking water and water for steam locomotives. It was distinctive of its more than 20 blade sheets with a 3 to 5 m diameter, referred to as rotor rosette.

1890 – The first experiments for generating electricity using the Western mill began.

1891 – An automatic four-bladed electric-producing wind turbine was developed by Paul LaCour in Denmark. To be able to use it in far-flung areas, a DC generator was built along with it. It was produced for more than fifty years and played a major role during World War I.

1920 – The actuator disc theory application became relevant in wind turbines converting 59 percent of the kinetic wind energy to mechanical energy.

1941-1945 – The first grid-connected Megawatt wind turbine was designed and developed by Palmer Putnam together with Smith, a water turbine firm in USA.

1957-1962 – In Denmark, the Gedser wind turbine came into existence. Leading the Sjaelandic electricity supplier's grid expansion division, Johannes Juul built it as robust but simple. Its simple aerodynamic rotor separated the burly winds' flow; thereby, limiting power passively but fully. In times a grid fails, the edges of the blades flapped as breaks.

1958-1968 – The prototype W34 with two blades made of fiberglass was conceptualized. Producing 50Hz AC power, it had a pitch control that is electro-hydraulic.

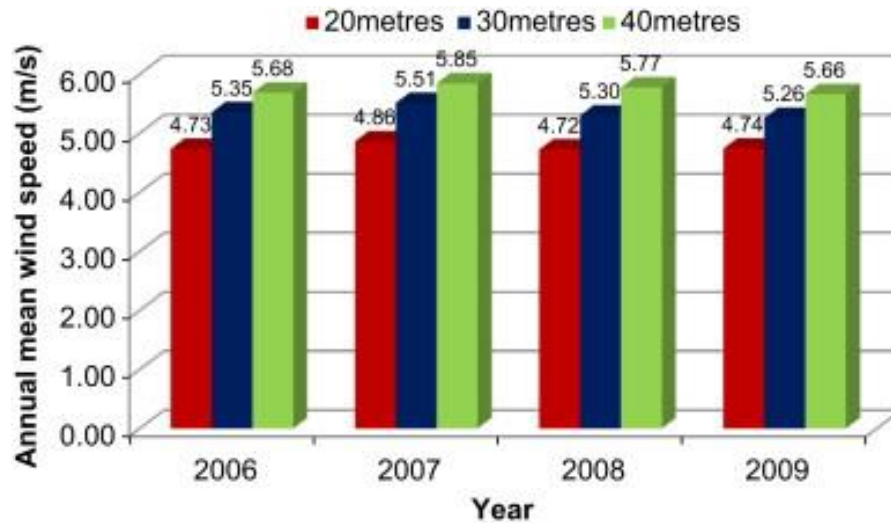
21st Century – Global wind power capacity has been steadily increasing. The world's largest wind power market has been transferred back and forth by US, China, and, Germany.

2.2 Site Selection

One of the most important aspects of how efficient the wind turbine would be is the location of the windmill. The wind speed of any location is not constant; hence, the location of the windmill has to have sufficient wind power as well as away from any obstacles to avoid any turbulence. Also, analysis of the wind energy of a certain location must be recorded for a period of at least one year to determine whether the location is suitable to install the windmill or not. Most windmills are located in hilly areas or making sure that the tower is high enough to insure it is a way from any obstacles [12]

The following charts are obtained from a previous project that includes the average mean wind speed in various areas around the kingdom.

Table 1: average wind speed in different areas in the kingdom



Annual mean wind speed at different heights at Rawdat Ben Habbas.

2.3 Types of Wind Turbines

There are two types of windmills; Vertical and Horizontal axis wind turbine, each has its own upsides and downsides of the variations between the two.

2.3.1 Vertical axis wind turbine (VAWT):

A wind turbine secures the air into a hub which then moves in rotations and the air passes through the blades gets spun into a generator by rotational momentum. The vertical axis wind turbine is designed to be economical and very practical. This type of turbines is always used in residential areas the vertical axis wind turbine is usually shorter in terms of height than the horizontal axis wind turbine. In addition, there are two main different style designs of vertical axis wind turbine. The first design is Darrieus wind turbine, and the second is Savonius wind turbine. The most common used is the Savonius model. Most of the vertical axis wind turbines' features the following qualities.

2.3.2 Horizontal axis wind turbine (HAWT):

Wind industry nowadays is primarily dominated by the Horizontal Axis Wind Turbine. As the name suggests, Horizontal axis wind turbine means that the axis of rotation

of the wind turbine is horizontal. The major advantage of the HAWT is its ability to use as much wind as possible to produce more energy at all times, where the downside of the HAWT is that the efficiency decreases when the winds are turbulent. [7]

2.4 Advantages and Disadvantages of Wind Power

Power generation is the most critical problem of today's constantly developing world. Thus, early planning is very important to secure every requirement and avoid every possible mistake and before doing that, evaluation of the advantages and disadvantages of wind power to decide how much planning is needed.

Wind power is considered the go to solution for future energy shortages. It is now perceived as one of 2030 plans to preserve or create energy. Each idea has its advantages and disadvantages which both shall be evaluated to determine what has more power over the other. So, when it comes to wind power, its advantages are that it is considered a type of renewable energy; meaning that it depends on natural resources to generate power, it is also cost effective; the amounts and efforts spent on fulfilling a wind power project would get a positive pay at the end so there shall be no\ minimum waste. In addition, it is considered environment friendly as it does not produce gases or require any harmful substances to operate and once it is not harming the environment, it saves costs of plans and reaches to preserve the environment. Moreover, it is a sustainable source of energy, whenever there is wind; there would be energy, it does not have to be searched for nor it would require gases. From another aspect, benefits of a wind power are that it can be added to even already built locations so it does not require new locations to implement it and also, form another aspect, having wind power is supposed to secure jobs on the long term. [3]

As from the challenges aspect, there are challenges that wind power projects may come across which are: the fact that the geographic location is going to affect the efficiency of wind power as the locations that are known for a windy climate would generate more power than areas that have mostly dry climate during the year in addition to how exposed to lightning strokes the area is. There is also the challenge of the difficult development of

wind power as throughout many years, not a lot of technical development was reached regarding wind power where is still operates on the basic and same mechanics without managing the few back draws it may have. [4].

On the other hand, there are few disadvantages of wind power such as the blades, as they may damage the bird's life in the surrounding area or such as the noise from the turbines that are used to convert the wind power to an electrical one, they may create a loud noise when many are operated at the same time, so yes it is possible to install it in already built locations but the locations would have to be chosen in locations far from living areas. And there is the disadvantage of land consuming, where the locations as mentioned, has to be set far from living areas. Moreover, manufacturing and maintenance are costly, so a budget must be sat regularly to insure these two. [8]

2.5 Previous Work

The Aeroleaf Wind Turbine was a project that got its name from its design idea where it focused on making it suitable to be used in parks and open areas. The project utilized Savonius turbines to operate even though it is not considered a familiar thing due to its low wind-speed start up, its operation with any wind direction and its minimal noise in comparison to other turbines. It converts wind power through its speed to rotational motions and it is able to generate power that reaches 300 watts. The project focused on the design as a main strength point, then the fabrication and finally the evaluation process. Also, the project helped come with a VAWT framework to increase the power yield. However, the main difference between the project of subject and Aeroleaf is the fact that the project of subject's turbine is designed on a horizontal access while the other is designed on a vertical access [10].

2.6 Comparative Study

Following are comparative studies explained to illustrate the various uses of wind power in locations that are different from Saudi Arabia in many ways.

2.6.1 Study of Wind Water Pumping System in Tunisia

As the Preparatory Institute for Engineering Studies of SFAX has mentioned, the wind through the renewable energy plays an important role for the water supply. This study has shown the perspective of the wind's mechanical pumping in eight different sites distributed at the Tunisian South. This study focuses at the energy evaluation of the wind turbine SEN 5000 P8. From the geographic perspective, Tunisia is an arid country, where regarding characteristics of sites selected, in this study, they were interested in the south side of the country, which represents the good underground water resources. In addition to that, south country diversity of the wind potential distribution. Indeed, the annual mean wind speed (respectively available energy) varies between 2.7 and 3.5 m/s in South-east (respectively 302 and 645 kWh/m² /year) and varies between 4.6 and 5 m/s in Southwest (respectively 1150 and 1997 kWh/m² /year) [5].

2.6.1.1 Table 2: Wind characteristics in various sites

This table shows how the wind characteristic in various sites in Tunisia. As discussed above, the south side of the country has more wind velocity which generates more electricity compared with the other sites based on the wind speed and geographical location. In this study, there will be a comparison between different sites to see where will be the most critical location to use the windmill at, then there will be a comparison between Saudi locations to show different locations with different wind speed.

Table 2: wind characteristics in various sites

TABLE 1: WIND CHARACTERITICS IN VARIOUS SITES.

N°	Sites	V_m (m/s)	V_f (m/s)	V_e (m/s)	E (kWh/m ² /year)
1	Kebili	5,08	2	12	1997.21
2	Tozeur	4,66	3	8	1215.41
3	El Borma	4,73	5	7	1151.97
4	Djerba	4,64	3	7	1149.58
5	Tataouine	3,50	2	6	645.53
6	Ramada	3,43	3	6	564.00
7	Gabes	3,15	3	5	393.85
8	Mednine	2,70	2	5	302.48

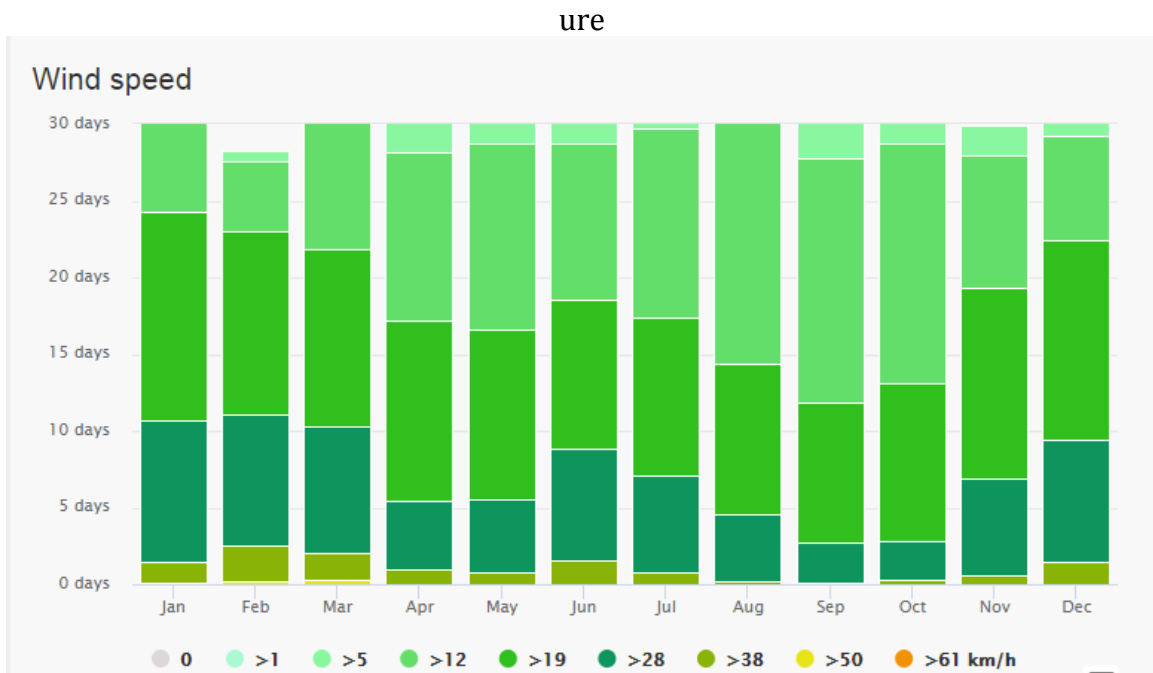
2.6.2 Wind power utilization for water pumping using small wind turbines in Saudi Arabia

In king Fahd University, there was a study which was taken in Arar, Rawdat Ben Habbas and Juaymah localities in Saudi Arabia to utilize power of the wind for pumping water for remotely located inhabitants not connected with national power grid. The study was based on data which was collected for years from different heights which are 10, 20, 30, and 40m. The study used the known data for wind speed, and calculates the amount of pumped water at different heights. The study proved that higher wind speeds were noticed during summer time compared to winter time at all the locations and is showed that annual total water pumping capacity of 30,000 m³ is possible from a depth of total dynamic head of 50 m when using 2.5 kw and also proved that wind turbine with hub heights of 15–40 m at all three sites had cost of water pumping as low as 1.28 USb/m³. [11]

2.7 Wind Speed in Saudi Arabia

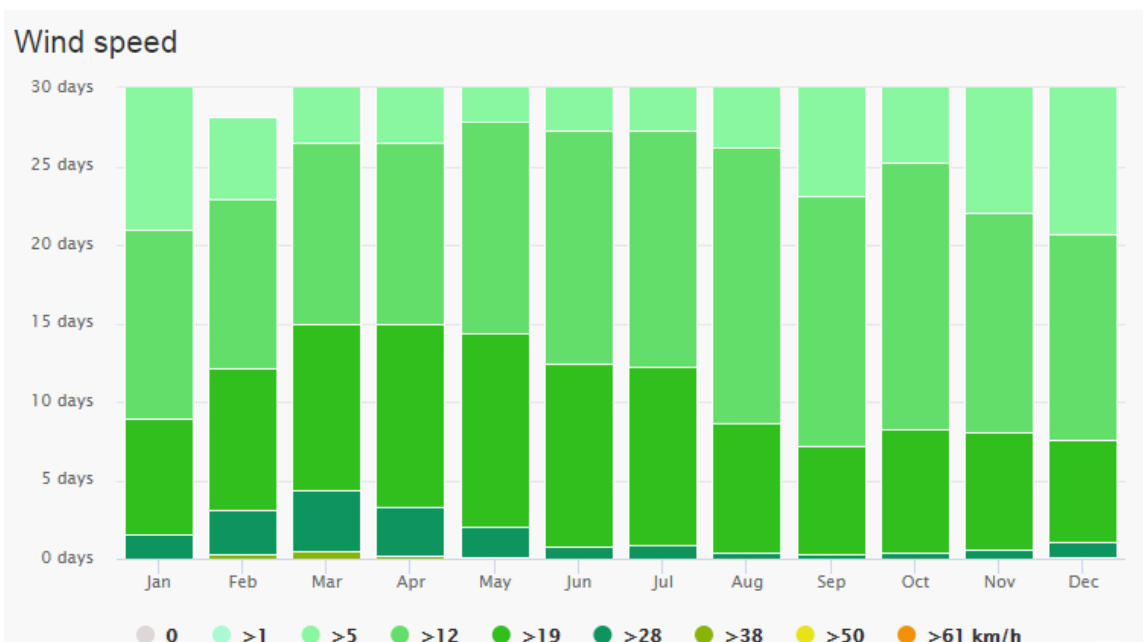
As Saudi Arabia being majorly desert, the winds powers differ from other countries and actually from one area to another as some areas are higher. For a windmill to function efficiently, the location with higher wind speed and power in general is better to be selected. The following figures describe the change of wind power and percentages around the year in multiple areas. (Dammam, Hail, Jizan, Mecca, Madinah, Riyadh and Tabuk).

Figure 1: wind Speed in Dammam



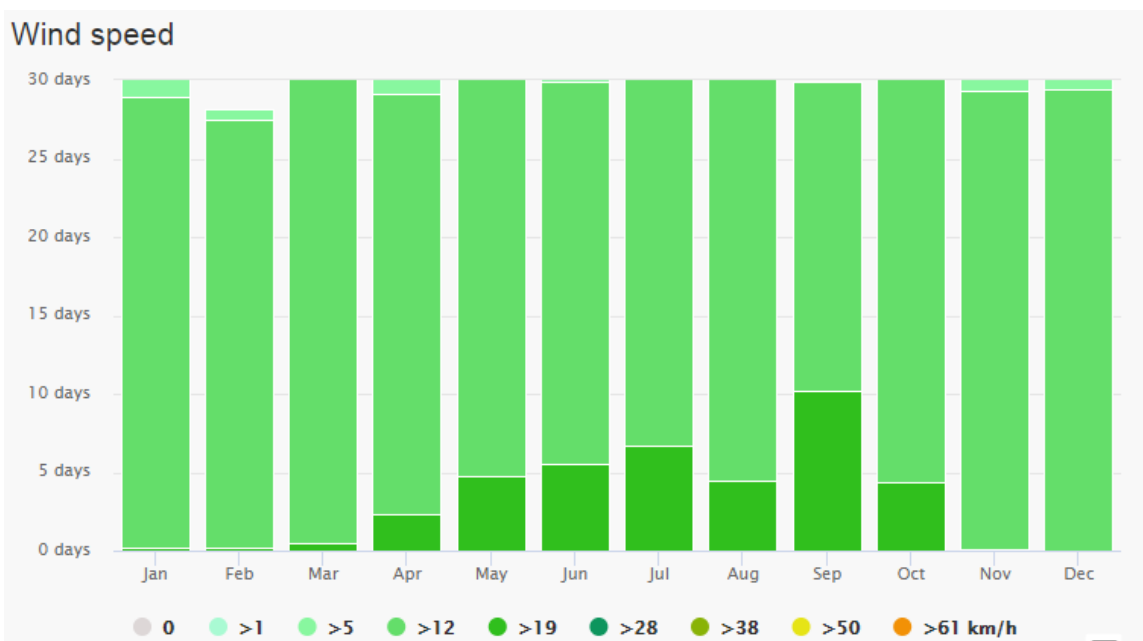
[22]

Figure 2: wind Speed in Hail



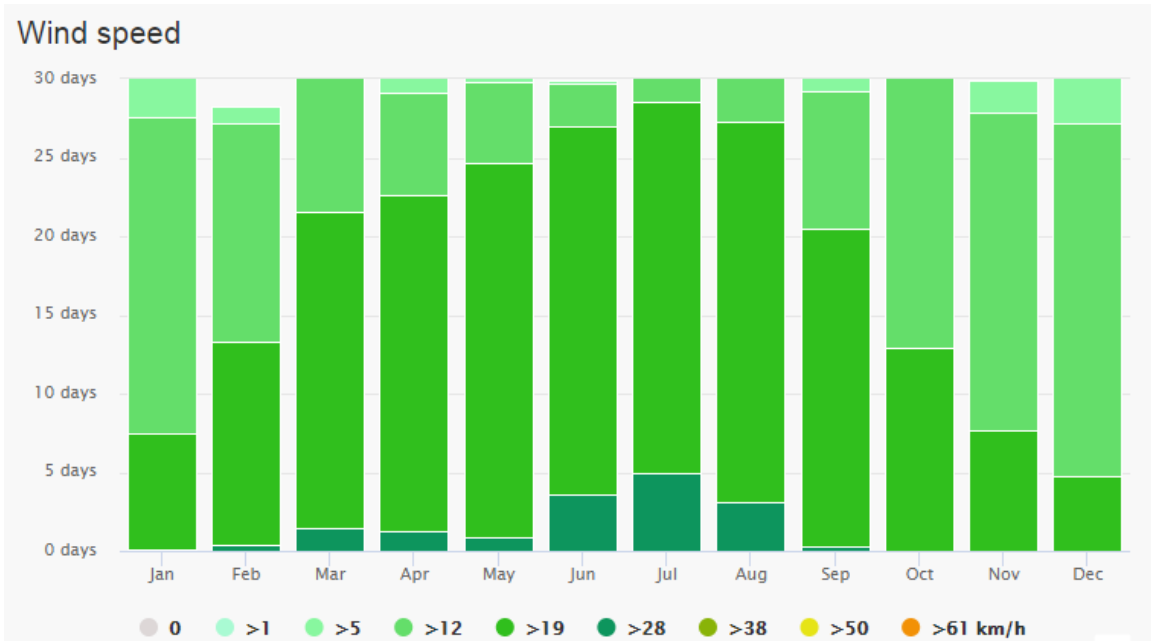
[23]

Figure 3: Wind Speed in Jizan



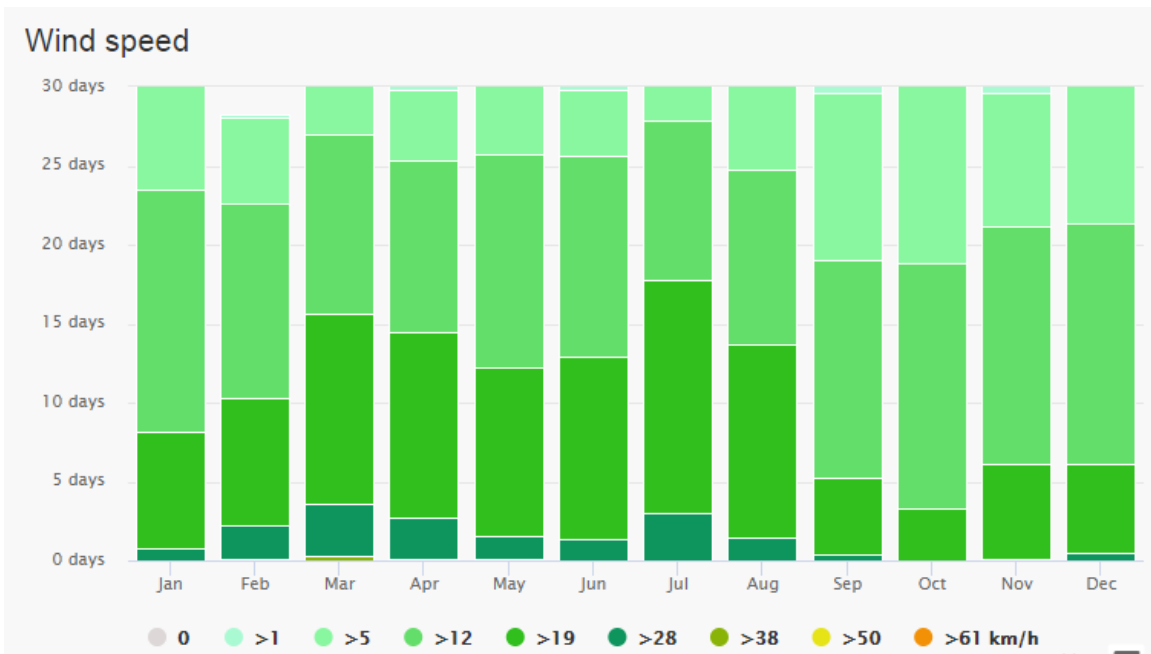
[24]

Figure 4: Wind speed in Mecca



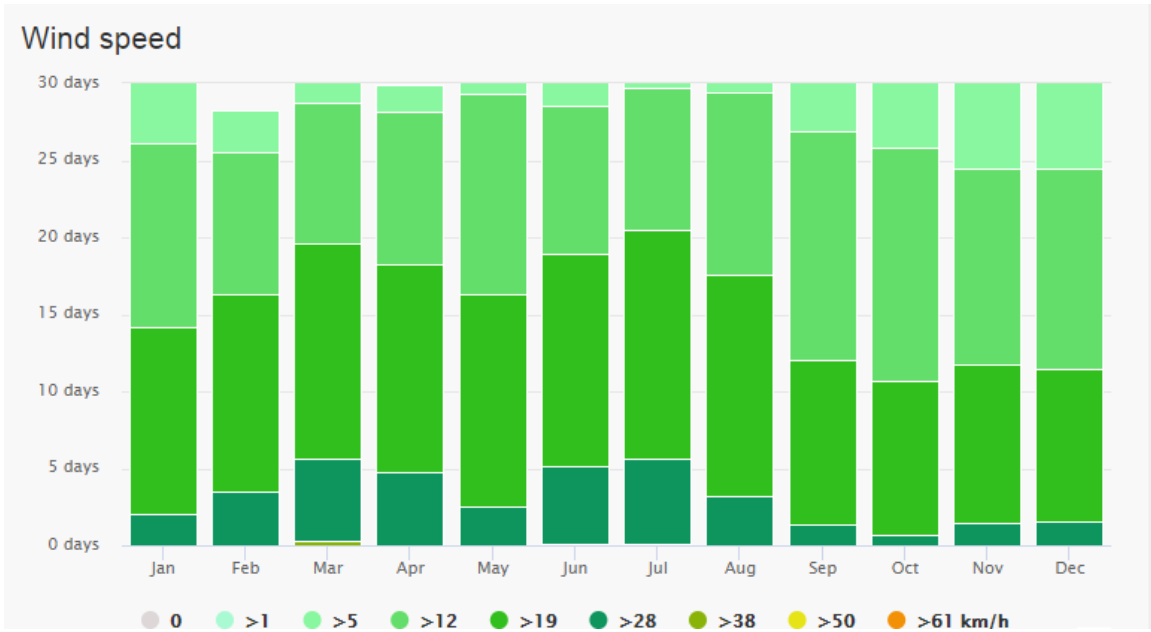
[25]

Figure 5: Wind Speed in Madinah



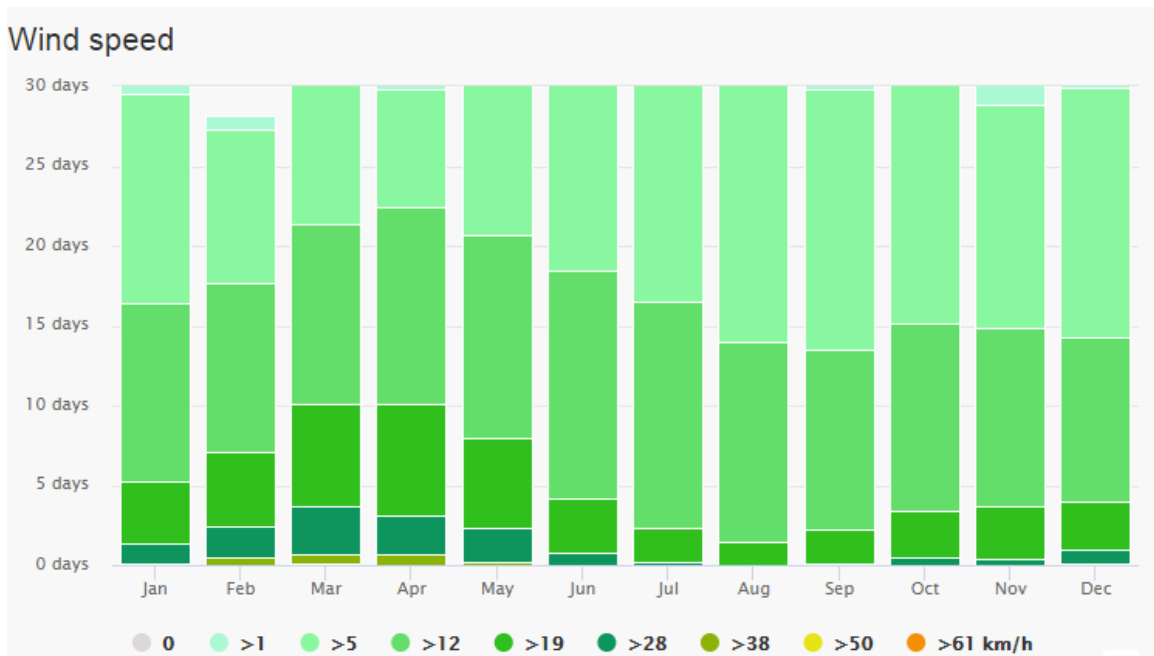
[26]

Figure 6: wind Speed in Riyadh



[27]

Figure 7: wind Speed in Tabuk



[28]

3 Chapter 3: System Design

3.1 Design Constraints and Methodology

The constraints of the used parts are listed in table 3 the table will contain details on the item, its size, the environment constraints effecting the part, the weight of the part and its cost.

Table 3: Contains details on the used parts

Item	Size	Environment	Weight	Cost
Blades	Five blades each blade is 0.7 m in length and 0.15 m width.	Blades are made of carbon fiber that will resist the ultraviolet light	Each blades weighs about 0.450 kg	Cost of each blade is 71.25 SR
Rotor – Alternator	28 magnet dual rotor with 2 rectifiers and provides up to 2800 watts output	To keep the windmill running in case of no or little wind	3 kg	Cost is 446 SR
Shaft	17 mm shaft	Coefficient of friction has to be low and high tensile strength must be present to prevent dynamic load	1.5 kg	150 SR
Battery	Standard 12 V battery	Outdoor 12 volt.	25 kg	300 SR

Tower – Base	0.7 m in height	Steel manufactured and coated for minimizing corrosion	7 kg	100 SR
Hub	Hub thickness is 0.47 cm. Hub OD is 16.5 cm.	Zinc plated for corrosion resistance	Weighs about 0.7 kg	Cost is 67 SR
Hub Spacer and stabilizer	17 mm center with dimensions of (17.46 * 50.8 mm)	Gold zinc plated so it can resist corrosion and won't rust	0.5 kg	Cost of material is 41 SR
Mounting Bracket	22 mm in height and 100 mm in length.	Steel manufactured with hot galvanic dipping for corrosion resistance	0.7 kg	Cost is 190 SR

Collar	The inside diameters is 49 mm and the outer diameter is 76 mm	Made from high quality steel with high tensile strength. Zinc plated for corrosion resistance.	1 kg	Cost is 36 SR
Pump	12 Volts	Internal mounted in tank 12 volt dc, 1.6 gallon/ min	0.9 kg	Cost is 250 SR

3.2 Constraints

A horizontal axis wind turbine can be used all over the world as long as sufficient wind energy is present. However, there are many constraints that can affect the design of the wind turbine such as:

1. Environment.
2. Economical
3. Manufacturability.
4. Safety.
5. Sustainability.
6. Engineering standards.

3.2.1 Environmental Constraints

One of the most important factors or constraints to consider when approaching any research is the environmental factors, as the environment can play a major role in determining the efficiency of the project.

Wind turbines are a clean source of energy that can produce a considerable amount of energy whenever a sufficient wind is present, thus, location of the wind turbine is crucial as if no wind exists the turbine will not work. Also, because the prototype of this device is relatively small compared to an actual wind turbine that usually produce loud sound when operated, the sound produced can be very loud and it is advised that the wind turbine should be installed at an area away from the general public to avoid this noise pollution.

3.2.2 Economical Constraints

There have been few obstacles faced in terms of economics. One of them was to collect an amount to set the basic budget for buying the required materials, which for students with no income, took a long time to reach the needed budget, also in the supplying places where there were no student's discount policies for the materials which were required in addition to the cost of online transactions and shipping fees for the materials ordered online. Other than that, financing the workshops where the manufacturing process was held was an issue, as the charge was calculated based on the time to finish, the personal effort of the labor and the machines used.

3.2.3 Safety Constraints

Safety is an essential factor that must not be ignored or understated at any cost. Wind turbines are safe to operate and use as they don't produce emission, hence, there is less or no chance of releasing toxic or hazardous material. A safe distance should be kept from the device to avoid any hazard that the blade can cause when running on high speeds. Noise is another factor to be considered, as an actual wind turbine produces loud noises

that can be harmful to individuals but on a small device scale a noise will be produced but not as loud as the actual wind turbine.

3.2.4 Manufacturability Constraints

In the manufacturing process, there are some constraints that became an obstacle. First of all was the selection of the materials based on the calculations and design. The real struggle begins on the second obstacle, which was the materials' properties and their standards which had to be accepted in the engineering standards. The third obstacle was the lack of the materials in the kingdom. Finally, the last obstacle was finding proper workshops to start the manufacturing process.

3.2.5 Sustainability Constraints

Wind energy is not only a clean source of energy but also a renewable sustainable source. The only downside of wind energy is that having a constant wind speed is not possible year around. Casual maintenance may be needed, but in the long term as blades may need to be replaced, while other parts are not expensive to replace or fix.

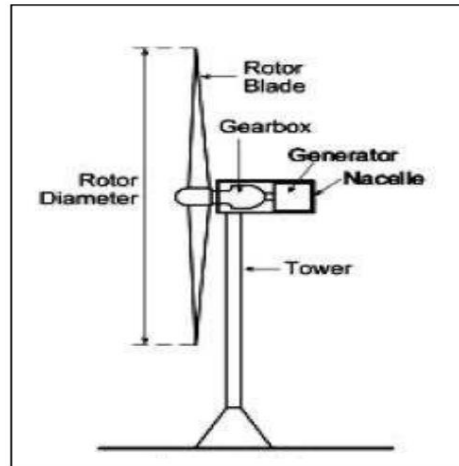
3.2.6 Engineering Design Standards Constraints

Horizontal axis wind turbine means that the axis of rotation of the wind turbine is horizontal.

3.2.6.1 HWAT consists of these main parts:

- Blades
- Shaft
- Generator

Figure 8: HAWT overview layout



Engineers should always follow the standards which are definition and guide for how to instruct designers, users, and manufacturers. Standards were invented to guarantee safety, reliability, productivity, and efficiency in all terms of products that are involved in engineering components or equipment. It is not mandatory to follow standards, however, many businesses and companies rely on it because it serves as a regulation. Following the standards is important for the end user whenever there is maintenance required; because the user can go to manufacturers that follow the same standard and get replacement parts, it also makes engineering life easy because everything is calculated in terms of corrosion, material property, or life of a component. In this design, it is going to follow the standard to reduce cost, to make the system more user friendly and to avoid manufacturing new parts that are complicated to manufacture such as generator [11].

3.3 Theory and Theoretical Calculation

To fulfill the project, there has to be some calculations that are done prior to the manufacturing process to insure the required outcome and some afterwards. These calculations are the Power Coefficient, Swept Area, A_s , Tip Speed Ratio, λ , Specific Speed of the Windmill, Cut in Speed, Cut out Speed, Rated Wind Speed, Torque Coefficient, C_t ,

Rotor Solidity, Thrust Coefficients, C_T , Wind Power, Efficiency in Wind Power Extraction, Torque Extracted,

Definitions:

1. Power Coefficient:

The power coefficient is the ratio of the actual power output to the theoretical power in the wind.

$$\text{Power} = \text{Force} \times \text{Velocity}$$

$$\text{Force} = \text{Rate of change of Momentum}$$

But: $\text{Momentum} = \text{Mass} \times \text{Velocity}$

For a fluid of density (ρ). Flows through a cross-sectional area of A, the mass flow rate \dot{m} is given by:

$$\dot{m} = \rho AV$$

$$\text{Average Force} = \frac{1}{2} \rho AV^2$$

$$H_T = \frac{1}{2} \rho AV^3$$

$$C_P = \frac{H_W}{H_T} = \frac{H_W}{0.125 \rho \pi D^2 V^3} \dots\dots\dots (3.1)$$

2. Swept Area, A_S

This is the section of air that encloses the wind turbine or windmill in movement and interacts with the rotors to produce the rotation motion. For a Horizontal Axis Wind Turbine (HAWT), the swept area is circular in shape. On the other hand, for a Vertical Axis Wind Turbine (VAWT) with straight blade, the swept area us rectangular in shape.

The swept area for the HAWT is calculated by:

$$A_s = \frac{1}{4}\pi D^2 \dots\dots\dots (3.2)$$

Where A_s - Swept area (m^2)

D - Rotor Diameter (m)

NOTE: the rotor radius is the distance from the tip of the one blade to the center and the diameter is twice its length.

3. Tip Speed Ratio, λ

Tip Speed Ratio is ratio of the speed of the windmill rotor tip at radius R when rotating at

Radians per second to the speed of the wind V m/s. It is numerically represented as:

$$\lambda = \frac{\omega R}{U_0} \dots\dots\dots (3.3)$$

When the windmill is stationery, the tip speed ratio is zero; this implies that rotor has stalled. This is experienced when the torque produced by the wind is below the level needed to overcome the resistance of the load. While with a tip speed ratio of 1, it implies that the blade tips are moving at the same speed as the wind (the wind's angle that is 'seen' by the blades will be). Whereas at a tip speed ratio of 2, the tips are moving at twice the speed of the wind and so on.

From empirical results, the optimal tip speed ratio to ensure maximum power extraction is achieved for a windmill with N blades is:

$$\lambda = \frac{1}{4} \frac{\omega R}{U_0} \dots\dots\dots (3.4)$$

4. Specific Speed of the Windmill

This is the angular velocity in revolution per minute at which a turbine will operate if scaled down in geometrical proportion to such a size that will develop unit power under unit head.

5. Cut in Speed

This is the speed at which the turbine starts to produce any useful power. It is the lowest speed at which power developed by the wind turbine H_W is greater than zero.

6. Cut out Speed

This is the speed at which the turbine stops to produce any useful power. This is the highest speed at which power developed by the wind turbine is just zero.

7. Rated wind speed

Wind speed at which the rated power is produced, this value defines the shape of the power curve.

8. Torque Coefficient, C_t

The Torque coefficient is the non-dimensional measure of the torque produced by a given size of rotor in a given wind speed. This is given as the ratio of the actual Torque produced to the torque due to the force of the wind on the rotors.

It is represented mathematically by:

$$C_t = \frac{T}{\frac{1}{2} \rho A_s U_0^2} \dots \dots \dots (3.5)$$

Where: T- the actual torque produced (Nm)

U_0 - Wind Speed (m/s)

A_S - Swept Area (σ)

R: Radius (m)

9. Rotor Solidity

Solidity of a windmill loosely refers to the proportion of a windmill rotors' swept area that is filled with solid blades. This is the ratio of the sum of the width or 'Chords' of all the blades to the circumference of the rotor.

This is represented mathematically by:

$$\text{Solidity} = \frac{NA_B}{A_S} \dots\dots\dots (3.6)$$

Where: σ :-Rotor Solidity

N: Number of Blades

A_B - Area of one blade (m^2)

A_S : Swept Area (m^2)

10. Thrust Coefficients, C_T

This is non-dimensional measure of the force that falls on the windmill, it is given as the ratio of the actual thrust force on the windmill to the average force from the wind.

It is represented mathematically as:

$$\text{Force of the wind} = \frac{1}{2} \rho A_S U_0^2$$

Thrust Force on the windmill. F_T ;

$$F_T = \frac{1}{2} C_T \rho A_S U_0^2$$

$$\therefore C_T = \frac{F_T}{\frac{1}{2} \rho A_S U_0^2} \dots\dots\dots (3.7)$$

11. Wind Power

Wind power (P_W) = Kinetic Energy Per Unit Time

$$= \frac{1}{2} \dot{m} v^2 \dots\dots\dots (3.8)$$

Where (Mass Flux) $\dot{m} = \frac{dm}{dt} = \rho AV$

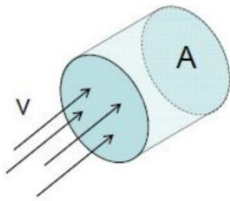
$\rho = \text{Density of air (kg/m}^3\text{)}$

Thus Power (P_W) = $\frac{1}{2} \rho AV^3$ Watts $\dots\dots\dots (3.9)$

Where $A = \text{Swept area of blades (m}^2\text{)}$

$$A = \pi R^2$$

Where $R = \text{Radius of the blade (m)}$



12. Actual Output Power

$$P = IV$$

I: Current in Ampere

V: Voltage

13. Efficiency in Wind Power Extraction

The efficiency in wind power extraction is a function of power Coefficient C_p , where C_p , is the ratio of power extracted by the windmill to the total contained in wind sources.

$$C_p = \frac{P_T}{P_W} \dots\dots\dots (3.10)$$

/

Where windmill Power Extracted = $P_T = P_W \times C_P$

$$= \frac{1}{2} \rho A V^3 \times C_P \text{ (Watts)}$$

The Betz Limit is the maximum possible value for C_P which is equal to $\frac{16}{27}$ but the optimum possible for a multi-blade windmill is 30%.

14. Torque Extracted

In the windmill used for pumping water, Torque output is key.

Torque is given by the ratio power extracted to rotor speed.

$$T = \frac{P_T}{\omega} \dots\dots\dots (3.11)$$

$$\text{Rotor Speed } \omega = \frac{\lambda v}{R}$$

Where v = wind Speed (m/s)

λ = Tip speed Ratio

R = length of blade (m)

$$\text{Thus: } T = \frac{P_T}{\lambda v / R} \dots\dots\dots (3.12)$$

$$\text{But } P_T = \frac{1}{2} \rho \pi R^2 V^3 \times C_P \text{ (Watts)}$$

$$\text{Therefore: } T = \frac{\frac{1}{2} \rho \pi R^2 V^3 \times C_P}{\lambda v / R}$$

$$T = \frac{1}{2} \frac{\rho \pi R^2 V^3}{\lambda} V^2 C_P \text{ (Nm)} \dots\dots\dots (3.13)$$

The two main components in mechanical power are force and speed. Torque is twisting or turning force and pumping requires a lot of torque particularly when starting off from an idle state. Generators used for power production on the other hand require a lot of speed. The power might be the same but the pump and generator will utilize this power differently. The power from the rotator is a function of both torque and rotation per minute (angular velocity of the rotators). The following table shows the typical choices

for the tip speed ratio and blade number for the case pump (windmill) and generators (wind turbine).

Table 4: tip speed ration vs number of blades

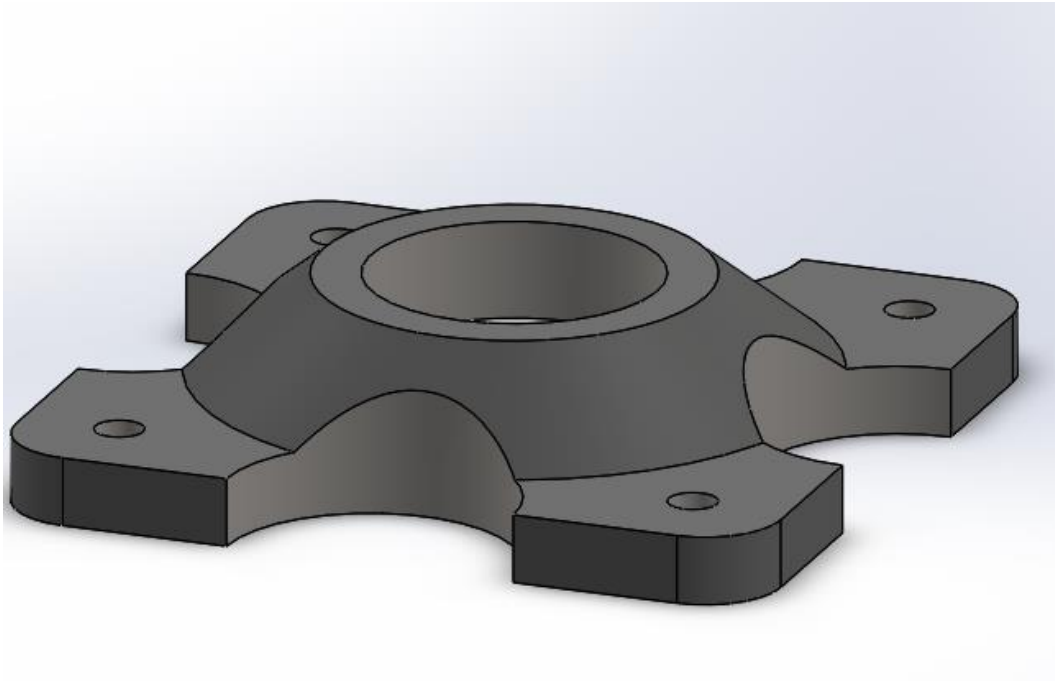
1	6-20	Slow pumps
2	4-12	Faster pumps
3	3-6	Dutch 4-bladed
4	2-4	Slow generators
5-8	2-3	Generator
8-15	1-2	Fastest possible

3.4 Product Subsystems and selection of Components

3.4.1 Base

The base was also manufactured form using same material as the tower “Stainless Steel ase 304” with a hole in the center to install the tower. The bridge must be able to sustain all of the weight starting from the tower and ending with the five blade

Figure 9: base design

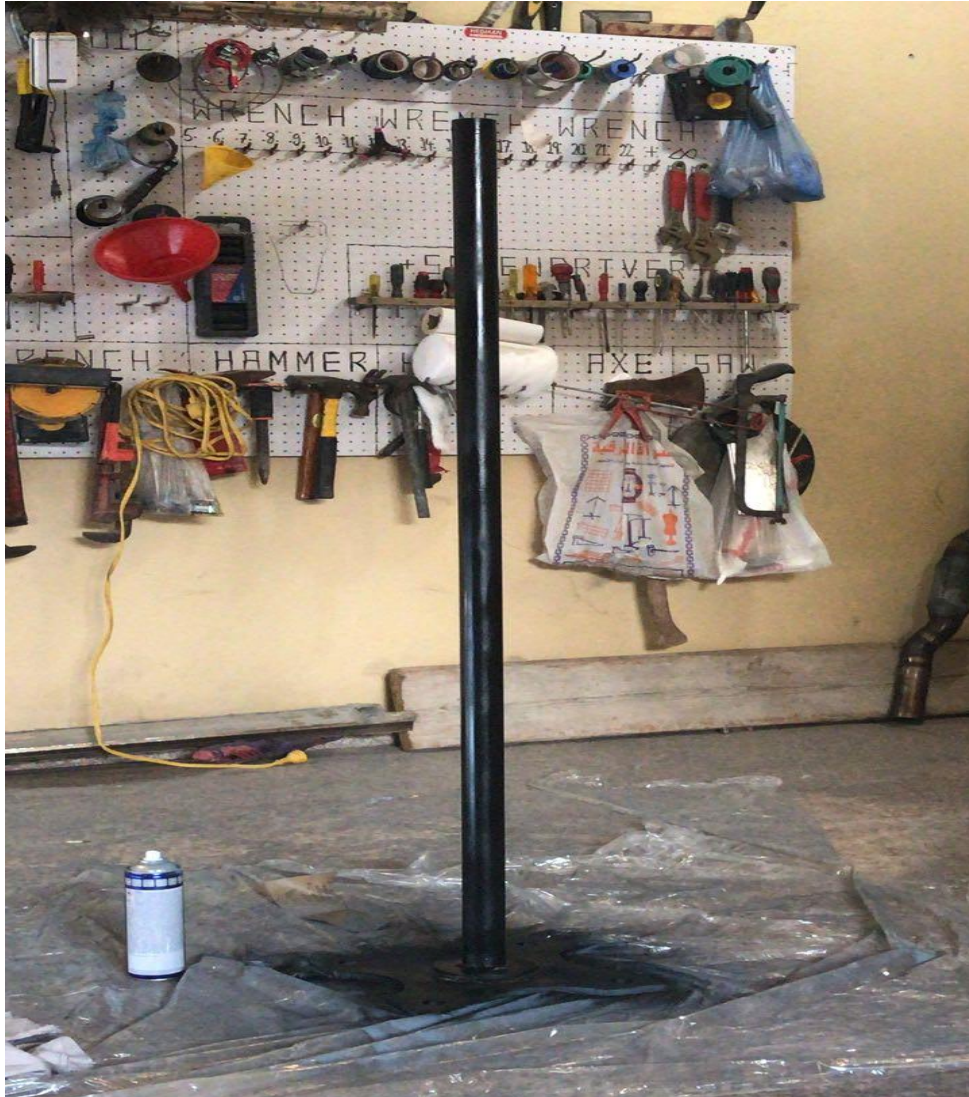


3.4.2: Tower

Base and tower manufacturing or selection plays an essential role of the wind turbine design as the bridge and tower must be able to withstand the external force and vertical load. The external force being the wind energy and the vertical load is what will be installed on the tower starting from the shaft, bearings, rotor and blades. The tower is 1.5 m in height with thickness of 3 mm. Material used in manufacturing this tower is with accordance to

engineering standards where “Stainless Steel ase 304” was used. The water tank is a regular tank with capacity of one gallon bought from local grocery stores.

Figure 10: Tower



3.4.3 Bearing

There is different type of bearing like needle bearings, ball bearings and roller bearings. Base on the selected shaft which has inner diameter of 17mm and outer diameter of 40mm ball bearing was selected according to sanders in figure 11.

Figure 11: bearing design

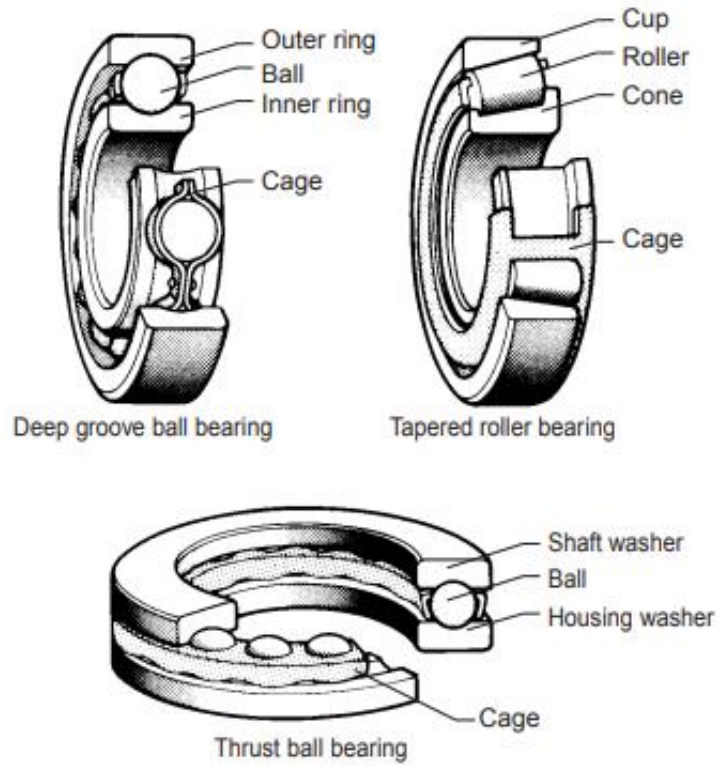


Table 5: Bearing Standards

Dimensions and Load Ratings for Single-Row 02-Series Deep-Groove and Angular-Contact Ball Bearings

Bore, mm	OD, mm	Width, mm	Fillet Radius, mm	Shoulder		Load Ratings, kN			
				Diameter, mm d_S	d_H	Deep Groove		Angular Contact	
						C_{10}	C_0	C_{10}	C_0
10	30	9	0.6	12.5	27	5.07	2.24	4.94	2.12
12	32	10	0.6	14.5	28	6.89	3.10	7.02	3.05
15	35	11	0.6	17.5	31	7.80	3.55	8.06	3.65
17	40	12	0.6	19.5	34	9.56	4.50	9.95	4.75
20	47	14	1.0	25	41	12.7	6.20	13.3	6.55
25	52	15	1.0	30	47	14.0	6.95	14.8	7.65
30	62	16	1.0	35	55	19.5	10.0	20.3	11.0
35	72	17	1.0	41	65	25.5	13.7	27.0	15.0
40	80	18	1.0	46	72	30.7	16.6	31.9	18.6
45	85	19	1.0	52	77	33.2	18.6	35.8	21.2
50	90	20	1.0	56	82	35.1	19.6	37.7	22.8
55	100	21	1.5	63	90	43.6	25.0	46.2	28.5
60	110	22	1.5	70	99	47.5	28.0	55.9	35.5
65	120	23	1.5	74	109	55.9	34.0	63.7	41.5
70	125	24	1.5	79	114	61.8	37.5	68.9	45.5
75	130	25	1.5	86	119	66.3	40.5	71.5	49.0
80	140	26	2.0	93	127	70.2	45.0	80.6	55.0
85	150	28	2.0	99	136	83.2	53.0	90.4	63.0
90	160	30	2.0	104	146	95.6	62.0	106	73.5
95	170	32	2.0	110	156	108	69.5	121	85.0

[29]

3.4.4 Blade

Horizontal blades are a crucial and basic part of a wind turbine figure 3.1 & figure 3.2. They are mainly made of fiber glass, carbon fiber or aluminum alloy. We selected Carbon Fiber because it is light weight and carbon fiber has high strengths.

Overall design of the rotor affects by the design of blades. Rotor blades take the energy out of the wind and convert its kinetic energy into the rotation of the hub. For this project the group decided to go with five blades because the wind speed in the region is low so five blade will rotate easier than the 3 blades, but the issue is with having more blades the vibration will increased and the torque will be less.

Figure 12: individual blade



Figure 13: five blades assembly



3.4.5 Generator

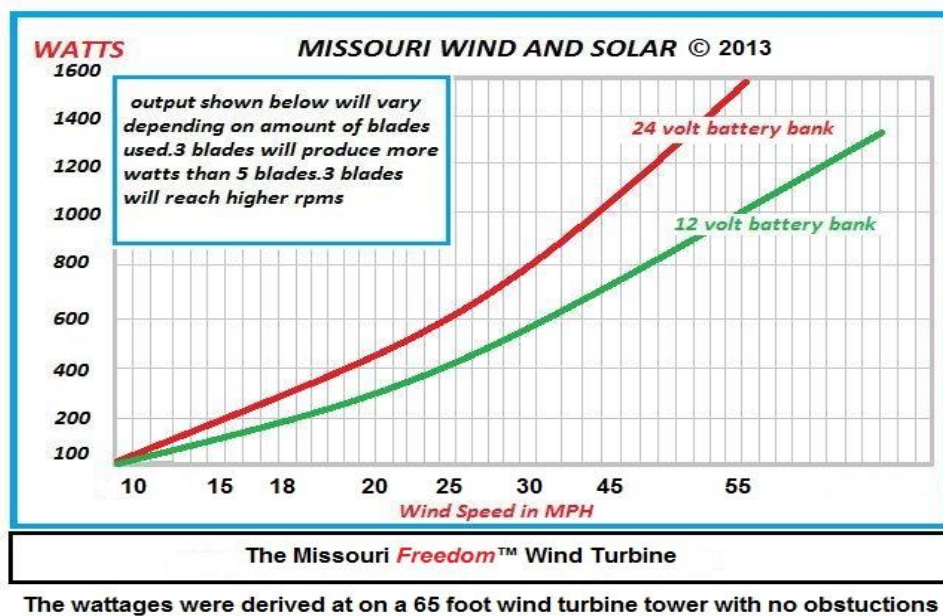
A wind turbine generator is one that is used to help convert the wind power into an electrical one to operate the windmill and it represents an automatic module for the pitch angle of the windmill's blades making a regular output in result. [30]. For this project, the chosen wind turbine generator was The Missouri Wind and Solar power generator, which is one that is considered a new innovation in the generator's line. It can produce up to 2800 watts and has a dual rotor and stator and it is aimed to provide the windmill a

hydroelectric power. It was used because it is found to be suitable for the design and standards due to how smooth it rotates. [31]

Figure 14: generator



Table 6: Watts VS Wind speed



3.4.6 Charge Controller

A charge controller act as a regulator that limits the rate at which electric current is added to or drawn from the batteries. Its job is to prevent overcharging and may protect against overcharge which can lower the battery life or performance [35].

Figure 15: Charge Controller



3.4.7 Battery

The battery that is used for the project is The Long WPL150-12N rechargeable power guard, which is, sealed lead acidic battery as shown in figure 16 and table 7

Figure 16: Battery



Table 7: Battery Specification

Brand	Long
Weight	4.5 kg
Capacity	150Ah
Dimension	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

3.4.8 Voltmeter

A Voltmeter is a device or instrument that is aimed to measure electrical voltages' variations between two points or measures electrical potential in electrical circuits. [32]. It works by having a scale that shows readings once a variation happens. There are different types of voltmeters with different usages. The one used for this project is the Digital Voltmeter and it was used to measure the electrical voltages in the generator used as a major component of the windmill. [33]

Figure 17: voltmeter



3.4.9 Anemometer:

The device we selected is Proster TL017 Handheld Anemometer Wind Speed Meter Scale Gauge. This device basically used for some parameters such as wind speed and air temperature. It has a large LCD display with backlight which makes it readable. This device is ideal for the outdoor activities such as windsurfing. With the help of the device,

we will calculate the wind speed to get the actual power and compare it with the theoretical power [34].

Specification:

Powered by a 3V CR2032 battery

Thermometer: NTC Thermometer

Operating Humidity: less than or equal to 90%RH

Storage Temperature: -40~60 centigrade, -40~140F

Current Consumption: About 3mA

Item Size: 105 * 40 * 18mm

Item weight: 50g

Air Velocity:

Range: 0 – 30m/s, 0 – 90km/h, 0 – 5860ft/min, 0 – 65mph, 0 – 55Knots

Resolution: 0.1m/s, 0.3km/h, 19ft/min, 0.2mph, 0.2Knots

Threshold: 0.1m/s, 0.3km/h, 39ft/min, 0.2mph, 0.1Knots

Accuracy: $\pm 5\%$

Air Temperature:

Range: -10 – 45 centigrade, 14 – 113F

Resolution: 0.2 centigrade, 0.36F

Accuracy: ± 2 centigrade, ± 3.6 F

Figure18: Anemometer



3.4.10 Tachometer

This Digital tachometer is a high-quality instrument to measure the Rotational Speed (RPM) with wide measuring range and high resolution. It's featured with high accuracy measurement, quick measuring time and long detecting distance up to 500 mm (20" inches) with Laser.

Features:

- Large LCD displaying Screen
- Wide measuring range & high resolution. The use of durable.
- The last value/min. value will be automatically stored in memory and can be displayed by turn anytime.
- The RPM of motors and machine parts.
- The housing has been carefully shaped to fit comfortably in either hand.
- Digital display gives exact RPM with on guessing or errors. It is a great tool to measure

- In wood and metal working it can be used to accurately measure the speed of a lathe.

Specification:

- Display: 5 digits, 18 mm (0.7" inch) LCD with Function Annunciation
- Testing Range: 2.5 ~ 99,999 RPM (rate / min)
-

Resolution:

- 0.1 RPM (2.5 ~ 999.9 RPM)
- 1 RPM (over 1,000 RPM)
- Accuracy: $\pm(0.05\% + 1 \text{ digit})$
- Sampling Time: 0.8 seconds (over 60 RPM)
- Test Range Selection: Automatic
- Memory: Maximum value, Minimum value and Last Measured value
- Detecting Distance: 50 ~ 500 mm (2 ~ 20 inch) (Laser)
- Time base: Quartz Crystal
- Circuit: Exclusive one-chip of microcomputer LSI circuit
- Power: 9V PP3 Battery (not included)
- Operating Temperature: 0 ~ 50 °C (32 ~ 122 °F)
- Dimension: approx. 131 (L) x 70 (W) x 29 (D) mm (5.16' x 2.76' x 1.14' inch)
- Weight: approx. 160g

Figure19: Tachometer



3.4.11 Water Pump

Is mechanical device that moves fluid or gas by pressure or suction. The pump used in this project is a small 12 V pump with 1100 GPH, it's made of stainless steel shaft. The pump also ignition protected and submersible. For this project the pump starts after the generator provide it with power while the pump placed in the bottom of the tank and its carry the water through plastic pipe to move the water into the second tank.

Figure 20 : Water Pump



Table 8: Water Pump Specifications

SPECIFICATIONS		
Height	4 1/4"	(108mm)
Width	2 3/8"	(61mm)
Depth	2 3/8"	(61mm)
Footprint	2 3/8"	(61mm) Round
Volts DC	12	
Amp Draw	3.3 @ 12v / 5.0 @ 13.6v	
Hose Size	1 1/8"	(28mm) I.D.
Fuse Size	6 amps	

3.4.12 Water Tank

The water tank is a regular tank with capacity of one gallon bought from local grocery stores. There will be two water tank one full of water and an empty one. One will be used for pumping water and the other for storing it.

Figure 21: Water Tank



3.5 Manufacturing and assembly (Implementation)

The base and tower of the wind turbine will be manufactured according to the figures above in section 3.4. Bearing will be chosen in accordance with engineering standards of SKF. Shaft will also meet ASME engineering standards. Generator, blades and pump will be selected according to the engineering standards and purchased.

4 Chapter 4: System Testing and Analysis

4.1 THEORETICAL WIND TURBINE POWER CALCULATION

The most important factors of the calculation are:

- speed of air (velocity)
- mass of air (density)
- area of the blade (swept area)

The power calculated by equation (3.9) in page 35

$$(P_w) = \frac{1}{2} \rho A V^3$$

Where:

P: power in watts

ρ : air density approximately $1.2 \frac{kg}{m^3}$

A: swept area which can be calculated by equation (3.2) in page 32

$$A_s = \frac{1}{4} \pi D^2$$

v^3 : wind speed in $\frac{m}{s}$

C_p : Power coefficient, usually varies according to wind turbine design, ranging between 0.05 and 0.45.

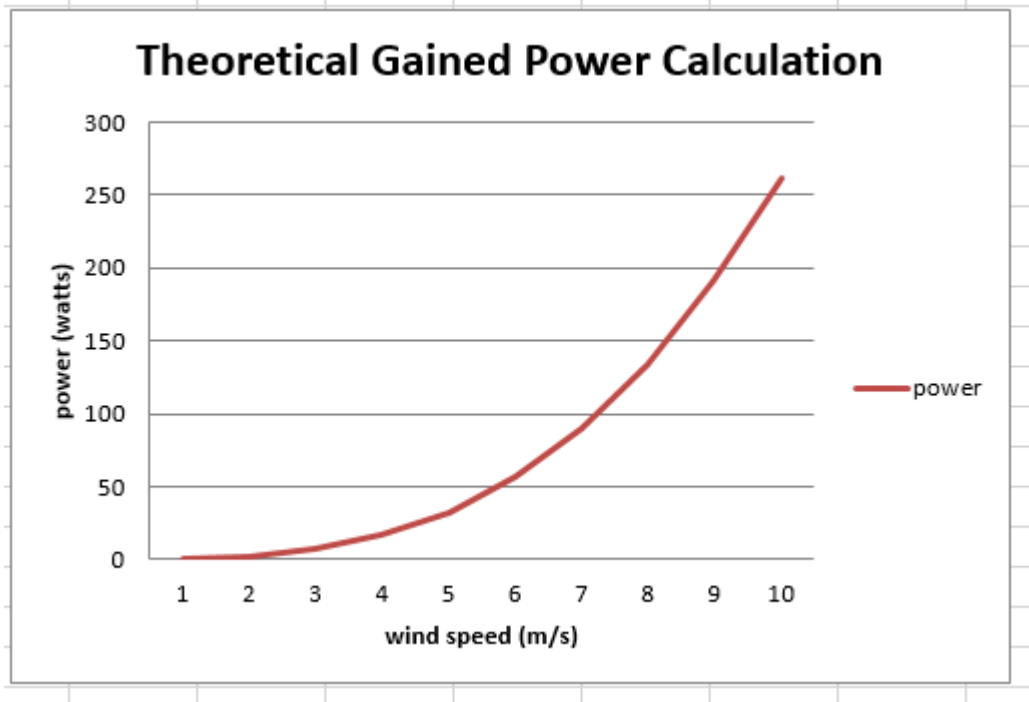
Wind velocity is the only variable in this equation. Table 9 and figure 22 represent the theoretical power in the windmill at different air velocities:

Table9: theoretical gain power calculation

Theoretical Gained Power Calculation				
Density ρ	Area A	Wind speed v	power coefficient c_p	power
1.2	1.5393	1	0.2836	0.261927
1.2	1.5393	2	0.2836	2.095418
1.2	1.5393	3	0.2836	7.072037
1.2	1.5393	4	0.2836	16.76335
1.2	1.5393	5	0.2836	32.74091
1.2	1.5393	6	0.2836	56.57629
1.2	1.5393	7	0.2836	89.84106
1.2	1.5393	8	0.2836	134.1068
1.2	1.5393	9	0.2836	190.945
1.2	1.5393	10	0.2836	261.9273

Figure 22: power calculation

Theoretical Turbine Gained Power



4.1.2 EXPERIMENTAL WIND TURBINE POWER CALCULATION

After designing the windmill system and selected material for the all parts. In order to test the power output of the windmill and compare it with the theoretical result which provided in chapter 3. Result for the windmill was taken in special set up.

Testing was taking in Al Dammam, which was basically in an open area. A lot of devices were used in our project such as, anemometer, tachometer and voltmeter. The purpose of using these devices is to find the power output of the windmill by using equation [3.12]

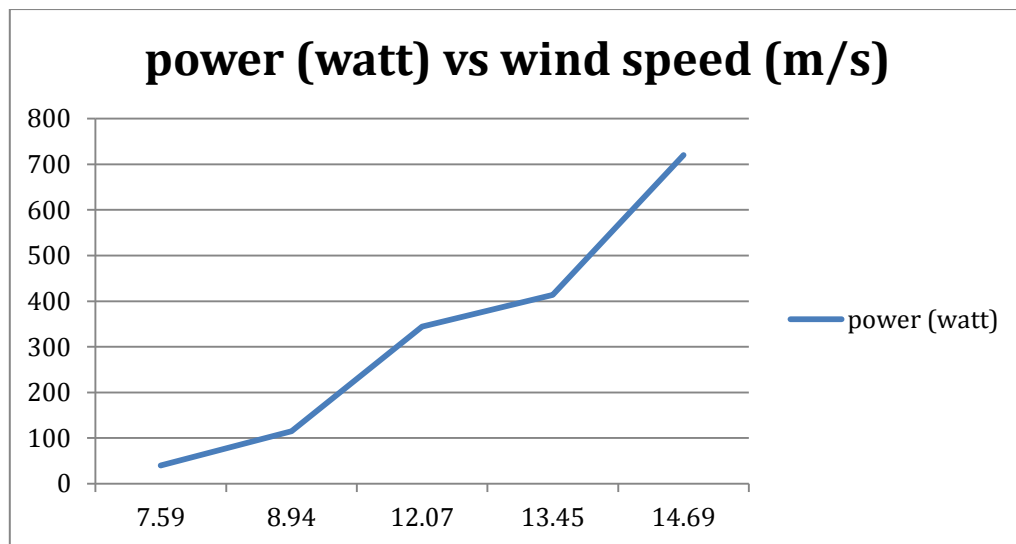
$$P = IV$$

The Result below represents the data taken from the experiment.

Table 10: Experimental data

Experimental Reading				
wind speed (m/s)	voltage(v)	current (A)	revolution(RPM)	power (watt)
7.59	10	4	150	40
8.94	23	5	300	115
12.07	43	8	500	344
20.56	46	9	750	414
24.58	60	12	1000	720

Figure 23: Calculated power



4.2 Results, analysis and discussion

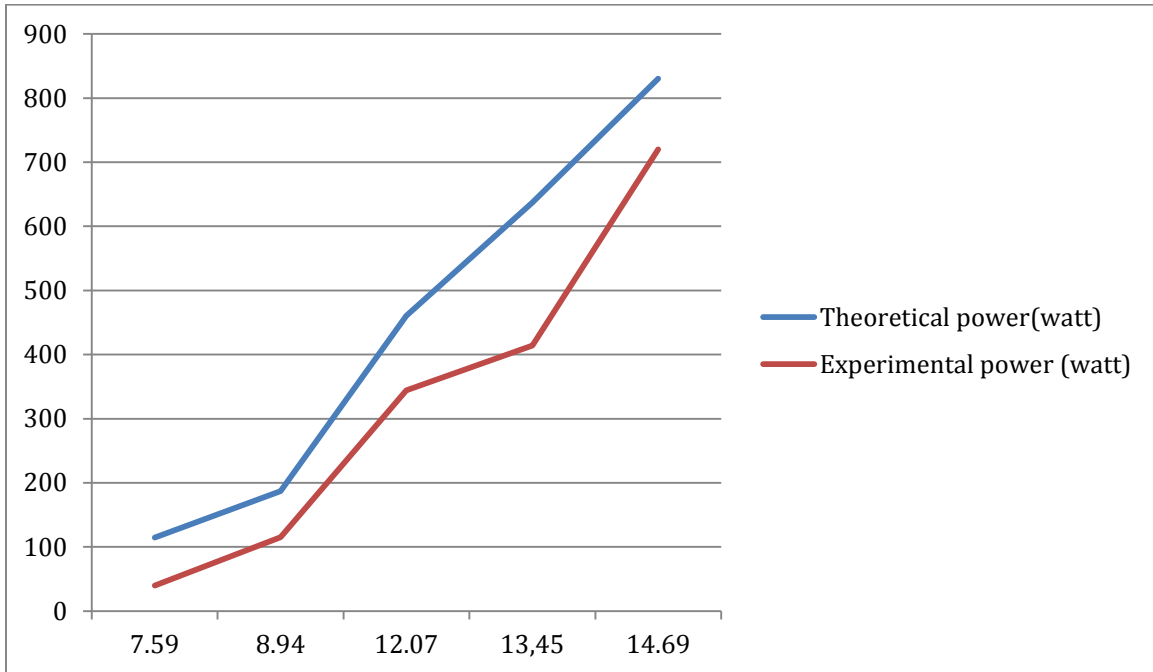
As a result, the experiment shows the difference between power output in theoretical and experimental which are represented as graph and table above. Noticed that, there is a gap between theoretical and actual power output as expected due to several factors. These factor are human error, manufacturing error, device reading error and drag error. The percentage of error between 10% to 60%. Another reason for this gap is the friction develops in the surface of the blades. The tower elevation plays an important role as well. In addition, unexpected vibration happened led to disturb Conservative of the wind energy. These are the most important factors that may justify the difference between two readings. The number of blades used is 5 with a total surface area of 0.24628 m² and this gives a solidity of 0.8, the minimum (optimum) value of solidity for a windmill and therefore ensures conformity with the standard specifications. Bearings are subject to very high heat losses due to friction and this will be greatly minimized by application of oil and grease and therefore greatly improving the efficiency.

All materials used are either locally available or easy to order from The United States and at a low cost making the model economically viable.

Table 11: Theoretical Vs Experimental data

Theoretical vs Actual Reading					
Density ρ	Area A	Wind speed v	power coefficient c_p	theoretical power	power (watt)
1.2	1.5393	7.59	0.2836	114.5265225	40
1.2	1.5393	8.94	0.2836	187.1514958	115
1.2	1.5393	12.07	0.2836	460.5773287	344
1.2	1.5393	13.45	0.2836	637.3054014	414
1.2	1.5393	14.69	0.2836	830.3212135	720

Figure 24: Theoretical Vs Experimental



4.2.1 Goals

The main factor to be considered in this experiment is wind speed. In order for water to be pumped the turbine needs a minimum wind speed of 8 mph or 12.8 kmh. If no sufficient wind is existed an air blower is used to provide a sufficient wind speed for the purpose of testing the device.

4.2.2 Experimental methodology

Numerous tools and devices were used in order to test the system and they are as follows

1. Anemometer: a device used for measuring wind speed
2. Tachometer: A device used to measure the rpm of the moving rotor.
3. Air blower: used in case no sufficient wind is available.

4. Water tanks: two water tanks one full and one empty with a hose to be connected through a whole between the two tanks for fluid transfer.
5. Water pump: to pump water for a tank to another using the wind energy.
6. Generator: providing power output that will operate the water pump
7. Charge control: is a device used to provide a constant voltage to the pump as a safety procedure so the generator will not overcharge the pump and damage it.

4.2.3 Procedure

The device is located at an open area away from walls or any objects that might block the wind. Anemometer device is installed or set near the turbine blades to measure wind speed. If no sufficient wind available, the air blower will be used for testing purpose. Tachometer laser will be pointed at the rotor for 1 minute to measure the rotor's revolution per minute. After the blade's rotation the rotor will rotate causing the shaft to rotate and power will be generated. Power is transferred through wires to the charge control and then to the pump. Finally, water will be pumped from one tank to another. Data will be recorded from tachometer, anemometer and voltmeter.

5 Chapter 5: Project Management

5.1 Project Plan

As group started to work on this project from the beginning of the semester until the end of it, with limited period of the semester giving a limited time to work on each task which had to be divided between each one of the five members so that the work can be completed before the deadlines. The following table describes the tasks and the time period each team member was given to complete.

Table 12: Duration of the tasks

No.	tasks	start date	finish data	days to complete
1	introduction	2/8/2018	2/10/2018	2
2	Literature Review	Project background	2/10/2018	2/13/2018
		Previous Work		
		Comparative study		
				3

		Advantages and disadvantages of windmill			
3	System Design Solid works	design of base	3/13/2018	3/15/2018	2
		design of rotor			
		design of tower			
		design of bearing			
4	Design Methodology	calculation of power	3/15/2018	3/17/2018	2
		calculation of torque			
		calculation of mass flow rate			
		calculation of swept Area			
5	Material Selection		3/18/2018	3/21/2018	3

6	System Testing and Analysis	4/10/2018	4/15/2018	5
7	Conclusions and Future Recommendations	4/20/2018	4/24/2018	4

5.2 Contribution of Team

To finish the project on time, each member worked on a certain task and some times more than one worked on the same task and other time the whole group worked on one certain task. The following table clarifies which tasks were given for whom.

Table 13: Tasks distribution

No.	tasks	Assigned to	Contribution
1	introduction	Abdulhadi	20%
		Hussain	20%
		Mohammed	20%
		Yousef	20%

			Yassin	20%
2	Literature Review	Project background	Yassin Abdulhadi	100%
		Previous Work	Yousef Mohammed	100%
		Comparative study	Hussain Abdulhadi	100%
		Advantages and disadvantages of windmill	Yousef Yassin	100%
3	System Design solid works	design of base	Yassin	100%
		design of rotor	Yousef Hussain	100%
		design of tower	Yousef Yassin	100%

		design of bearing	Yousef Abdullahadi	100%
4	Design Methodology	calculation of power	Mohammed	100%
		calculation of torque		
		calculation of mass flow rate		
		calculation of swept Area		
5	Material Selection	Yousef Hussain Yassin Abdullahadi	100%	
6	System Testing and Analysis	Yousef Hussain Yassin Abdullahadi	100%	
7	Conclusions	Hussain Mohammad Abdullahadi	100%	

8	Future Recommendations	Yassain Yousef	100%
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5.3 Project Execution Monitoring

As students who had other projects and Assignments to work on, having a timetable and an agenda to follow was a must.

Table 14: Table of activities

Time	Assignments
Twice a month	Assessment class
Weekly	Group Meeting
Twice a month	Advisor Meeting
Tue, March 4	Midterm presentation
	Test the system
May,3rd	Final presentation

5.4 Challenging and Decision Making

During the senior project development, few difficulties and issues were seen, such as the following:

- 6 Material standard and equipment resourcing.
- 7 Manufacturing to the design specification.
- 8 Report writing and documenting.

5.4.1 Material and equipment resourcing

Based on the needs of this project, buying some materials from local stores was required, and some from international stores. Problems with both local and international stores were faced due to shipping.

- Wind turbine generator.

One of the most important parts of the project was the generator. Initially, it was planned to buy a generator from local stores, but there was no luck finding a generator that will give the power output needed for low revolution per minute. Moreover, the best chance was to order a generator that was specifically made for wind turbines, which meant that it is a must to find a way to ship it. It was such a challenge to find a store that shipped internationally, thus, an address account in the United States of America was opened to ship the generator directly from there to Saudi Arabia, and this was the solution in hand. However, another problem with the shipping company was faced where they had not updated the tracking number and the shipment was nowhere to be found, so, it was necessary to deal with the shipping company for one month to get the package.

- Blades.

Another challenge was to manufacture the blades that were designed using the solid works. The big composite material shops were so busy making big projects such as water tanks which meant that this project was not a priority or aim for them, on the other hand the small composite shops are usually controlled by none Saudis whom don't speak English nor Arabic very well, so it was hard to explain to them the specification and angle or the blades without having an actual sample and the solution found was to buy a similar blade to the specification and use it for testing. Doing so led to insure that manufacturing errors got avoided and saved money.

- Water pump.

After searching for a 12-volt pump in local stores, there was no luck finding one, and so online shopping was the alternative and a pump that is compatible with the system design and calculations was purchased. It was better to order the pump online rather than having to buy a 24-volt pump that had to have an additional a converter in order to make it work and operate.

- **Material Standard.**

One of the challenges was to buy the material from big companies as no company was willing to sell a small quantity of what they have. For example, to buy a stainless-steel pipe, companies were not willing to cut a section for the length that was required. They claimed that ten meters had to be bought then cut it to the length needed. Another example, when to buying some aluminum sheets for the tail section of the wind turbine, they only offer a big sheet of aluminum. These problems caused a huge waste of materials, and the solution found was to go to one of the blacksmithing shops that buy their material from the same big company that supply the materials and use their left over materials to design the project based on the chosen standards.

5.4.2 Design problems

One of the main issues that have been seen during manufacturing the design was that the solid works design was a bit complicated in shape, for example, while manufacturing the base of the tower and the case, the shop worker mentioned that design required machinery process using the latest machine and welding, so, the given advice was to simplify the system more in order to reduce the cost and labor cost. The direction was followed because it was better cost-wise, time-wise and had no effect on the performance or durability of the overall design.

5.4.3 Report writing and document

Due to the fact that the report was written by all members, it was obvious that some were stronger than others in making sentences and grammar. Therefore, the solution in order to make the report appear more professional was as follows:

- 1- Each graph written by a member is checked by the other members.
- 2- Check with the advisor, and co-advisor before submission.
- 3- Show the instructor a draft before submission.

By doing so, the problem of the report being written by different people was solved, which meant mistakes chances are decreased.

Material and equipment resourcing (purchasing)

The project needs many things to purchase either from local stores or international stores. A variety of difficulties were faced during the start purchasing of the parts needed. Some difficulties were:

- International stores.

The most important part of this project is silica gel, so the group looked for the local stores that distribute silica gel, but did not find a local store that has this specific kind of silica gel. The problem that was faced was that most of the international stores could not deliver the silica gel to Saudi Arabia, because of that time was consumed to find a solution for this problem. The solution which was decided was to deliver the material to Bahrain and then send it from Bahrain to Saudi Arabia. By this solution, the silica gel made it to Saudi Arabia.

- Motor has specific speed.

A challenge that was faced also was when the group decided to buy a motor and started looking for a motor that has a specific speed based on the made calculations. But a motor that meets the requirements was not found. The solution was a speed control that can be

used to control the speed. So the group decided to buy this speed control to solve this problem.

- Heat source.

At the beginning, the members of the group planned to use a solar panel to produce the heat that required to dry the silica gel. But unfortunately, the short of time prevented building the solar panel system. So it was decided to use an electric heater instead of solar panel system.

5.5 Project Bill of Materials and Budget

Table 10 provides the costs of all the materials and equipment that were purchased and manufactured.

Table 15: List of material and their cost

Material	Cost (SR)
Generator	1400
Blades	1200
Pipe	400
Stainless-steel	300
Water pump	450
Wires	89
Battery	380
Charge controller	600
On off switch	56
Bearing	350
Aluminum	250
Water house	15

Water tank	24
Hardware	90
Tachometer Rpm Speed Kit	300
Anemometer Digital LCD	340
Voltmeter	115

6 Chapter 6: Project Analysis

6.1 Life Long Learning

The senior design project did not only examine the team's engineering skills, but also played a major role in developing other technical and non-technical skills. One of the main aspects that developed the team member's time management skills is the tight schedule of this semester, where the team had to do many challenging tasks in a very short period of time. This also enhanced the ability of each team member to work efficiently as a team and encourage every individual to do a quality and a professional work.

6.1.1 Improve our Skills in Some Software Tools

The project required using many software's, some of the team members were familiar with and other not quite. The senior design project developed the team's skills in designing as it was not easy to design the wind turbine. Other software's such as Microsoft Word, Excel and Microsoft PowerPoint were essential in the team's development. Some software's were already known and familiar to the team but the skills and knowledge required for them did substantially increase and develop.

6.1.2 Time Management Skill

Time management skill is the most important skill that is learnt through university life. Team can achieve great outcome just by managing time of every individual member of the team. When there is a need to achieve a certain goal in a specific time, the jobs get divided to every member of the team to do it on his time within the range of time put in GANTTS chart. Off course, a lot of difficulty to do the job in specific time were faced, because of them, skills to manage the time on daily basis was developed. GANTTS chart was used to organize the time and tasks that must be done in the project life. GANTTS chart is one useful tool that has been used in this project to organize time of starting and ending task.

6.1.3 Problem Solving

While working on the project, many problems were faced but got solved eventually. These problems provided some skills, knowledge and experience of how to handle problems to find the appropriate solutions within a minimum time. Many issues required the use of critical thinking skills to solve, such as to select the right materials, tools, design, find good machinist and the purchase of some tools from abroad. In fact, these problems made the team gain experience to face any future obstacles in the project.

6.2 Impact of Engineering Solutions

The project achieved great impact on the social, environment, and economy. Each impact is explained in details next.

6.2.1 Social

Here comes one of the important sources that had to be taken into consideration, which is the impact of the society. The main goal basically is to provide good and healthy Impact on the society. There are several applications for the project to be used, for example; telecom towers, offshore platforms and other purposes that require energy where there is no electric grid.

6.2.2 Environment

Wind turbine is increasingly being used worldwide as an important contribution to renewable energy. The development of this project might lead to environment impacts, such as noise pollution, bird and bat fatalities, greenhouse gas emissions and land surface impacts. This project is going to provide a good impact to prevent all these problems.

6.2.3 Economy

Regarding the project's impact on the economical point of view, it costs a huge amount of money, but in the project selected a small scale and it simplified the components and made it a little bit affordable for the students.

6.3 Contemporary Issues Addressed

Electricity and pumping water are really hard to find in some places such as Saudi Arabia, especially in the remote area. According to this problem, the group designed the project to fix this issue by pumping water through an electrical pump via the power that comes from the wind.

7 Chapter 7: Conclusion

7.1 Conclusion

Throughout human's life, change and development was always an aspiration, a goal to be reached. Thus, many efforts and support has been given to enrich research and development, which is why researchers and innovators have always been valued, where the changes they help making or make themselves affect lives all over the world. They affect economy, science, politics and more. They save lives and they change a way of living for good, one example is the generation that once lived without a cooling system but cannot spend a day in the nature's temperature today. To be more specific, power generation was developed through research and innovations until it became a major concern due to its effect on counties, societies, individuals and the whole earth in general. For that reason, power generation is valuable, especially nowadays where changes on the nature is noticed and its result on economy and politics are the most critical.

Taking the demand for power generation and its effect on the quality of life in consideration, the group decided to go for a project that is concerned with power generation and how mechanics can be utilized to develop sustainable energy as it is also the aim of the countries to have, where governments are searching for new ways to reserve energy. Saudi Arabia in particular stated it as one of its aims of 2030's vision; to have sustainable energy. So, the project's idea should be a problem solver for governments and counties in addition to a savior for environments and a profit for developers.

For the facts surrounding the need for sustainable power generation systems, the group has thought of this project as a key for future paths. Also due to the fact that previous research has been made on the same idea of Windmills, having references was an addition to the reason of choosing the project.

Where references existed, the group have decided to build their system based on studying the previous researches and experiences to better understand the mechanics but

the group based some of the calculations based on the chosen materials and methods after a full research was made. In addition, the built Windmill system had to be tested in local environment, thus, the choices of materials and methods had to be suitable for the environment where the Windmill is to be used at, which is in Saudi Arabia, so it was based on the climate of Saudi, its Government regulations and the suitable areas after full research was done on climates of critical locations in Saudi where every climate factor was taken into consideration, such as humidity as it differs from one area to the other. Moreover, choice of materials that followed the Engineering standards was also a major concern.

Moreover, the group chose the Horizontal Axis Wind Turbine because it is more likely to utilize as much wind as possible to guarantee energy supply at all times.

On the other hand, other than the group's evaluation of the advantages and disadvantages of the Windmill and analyzing the constraints, the group made sure to follow correct Calculations and theories to guarantee best results and most benefit. So, Power Coefficient, Swept Area, A_s , Tip Speed Ratio, λ , Specific Speed of the Windmill, Cut in Speed, Cut out Speed, Rated Wind Speed, Torque Coefficient, C_t , Rotor Solidity, Thrust Coefficients, C_T , Wind Power, Efficiency in Wind Power Extraction, Torque Extracted were separately explained, measured and calculated to ensure all desirable results.

Once the system was built, it was tested, results were noted down and correction were made where needed and every aspect was analyzed and stated for evidence and future reference.

7.2 Future Recommendation

After doing the testing, analyzing the result, and along with the average wind speed in Saudi Arabia. The recommendation for those who want to do future studies on horizontal wind turbine system is that the more number of blades added the more torque and revolution at slower wind speeds. Another recommendation would be adding a solar system along with wind turbine so the solar system charge the batteries in case there is no wind, and the wind turbine charge the battery in case there is no sun. the average speed for Saudi Arabia is 5.5 in the eastern provenance. another recommendation is to place the wind turbine in higher or longer tower so that more power output is gained according to the comparative study mentioned in chapter tow. Another recommendation would be to improve the design by making it more aerodynamic to get the most out of the winds by improving the design of the tip and the design of the tail.

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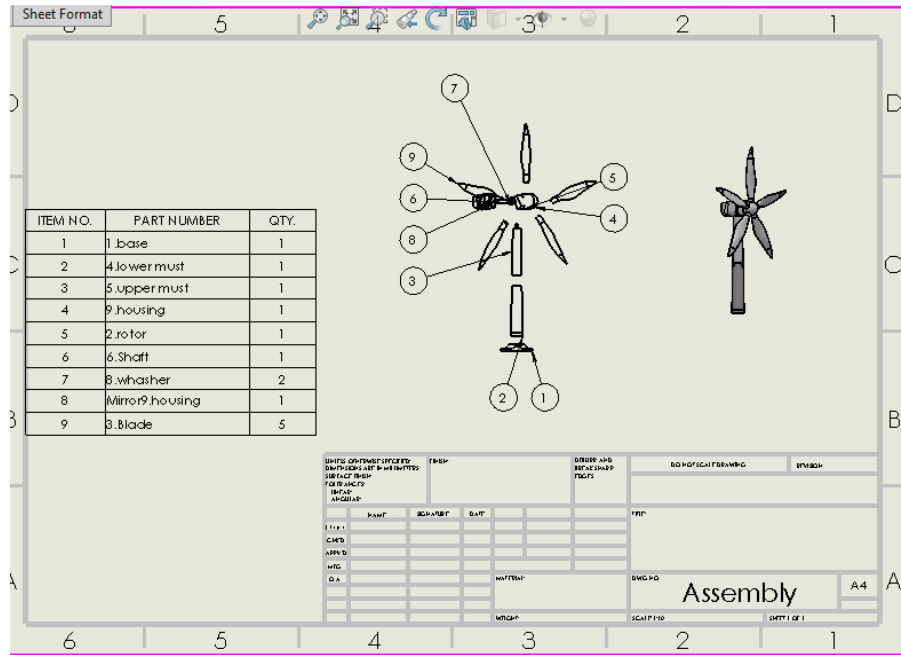
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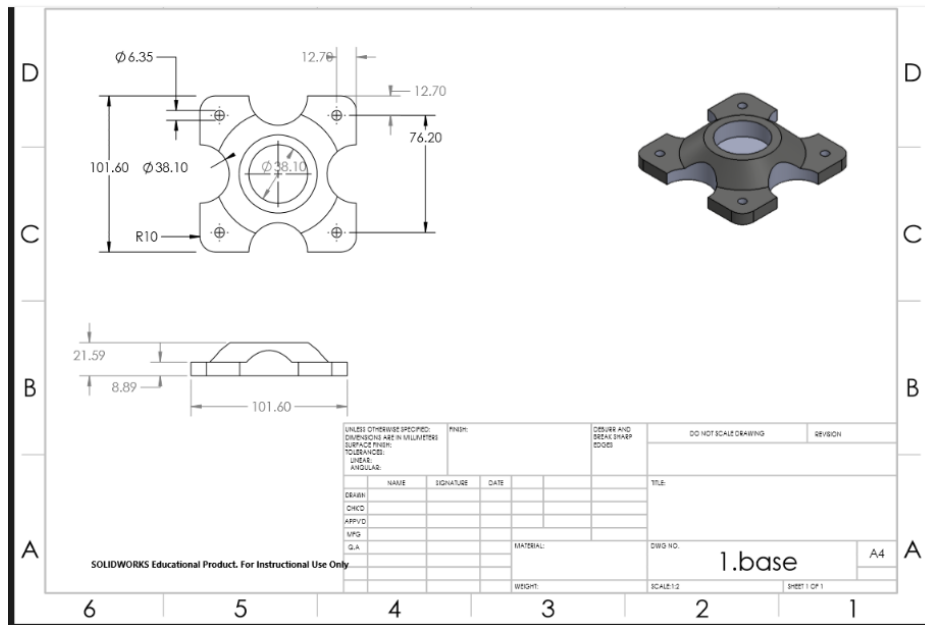
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9 Appendix A: CAD drawings

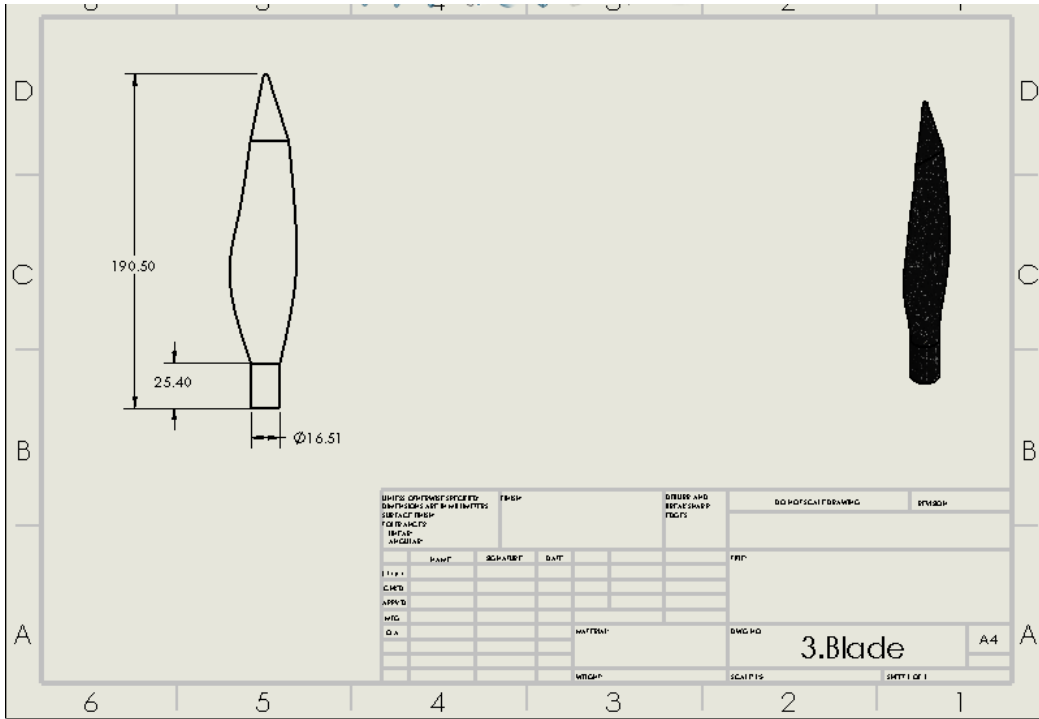
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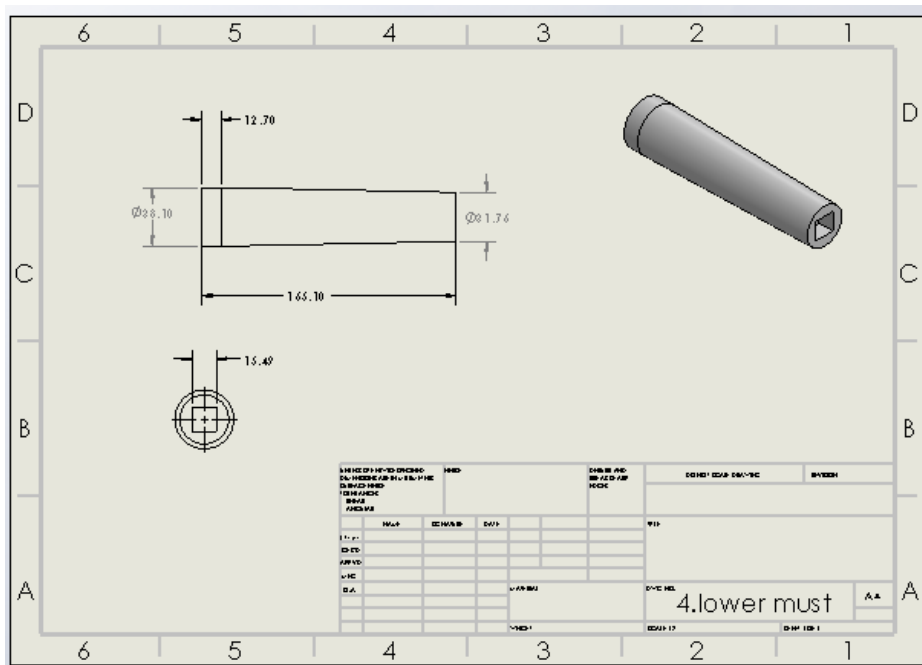
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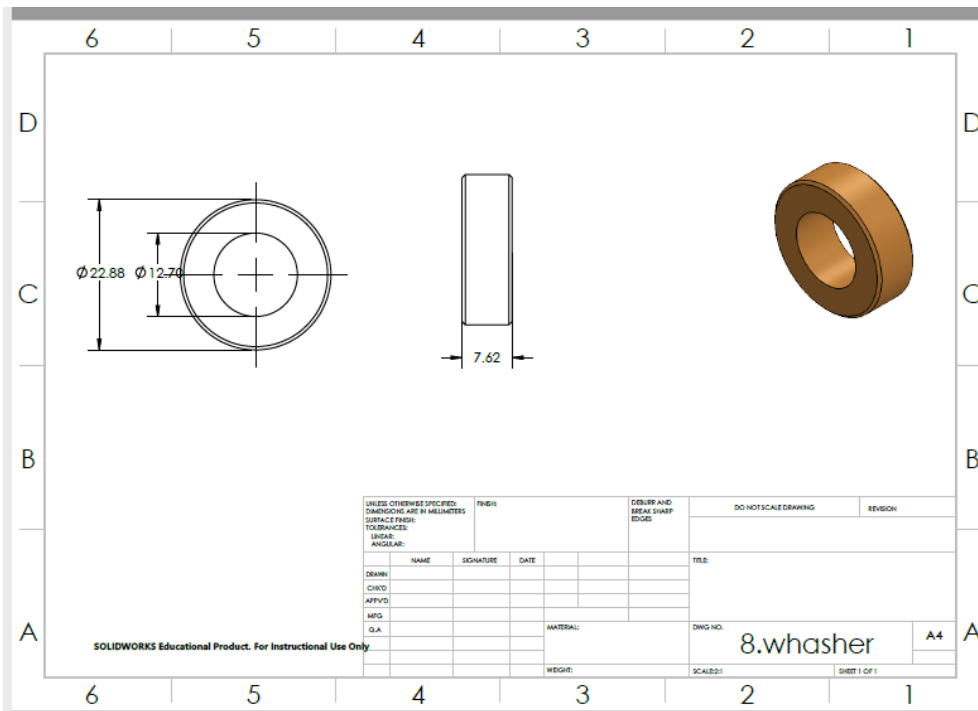
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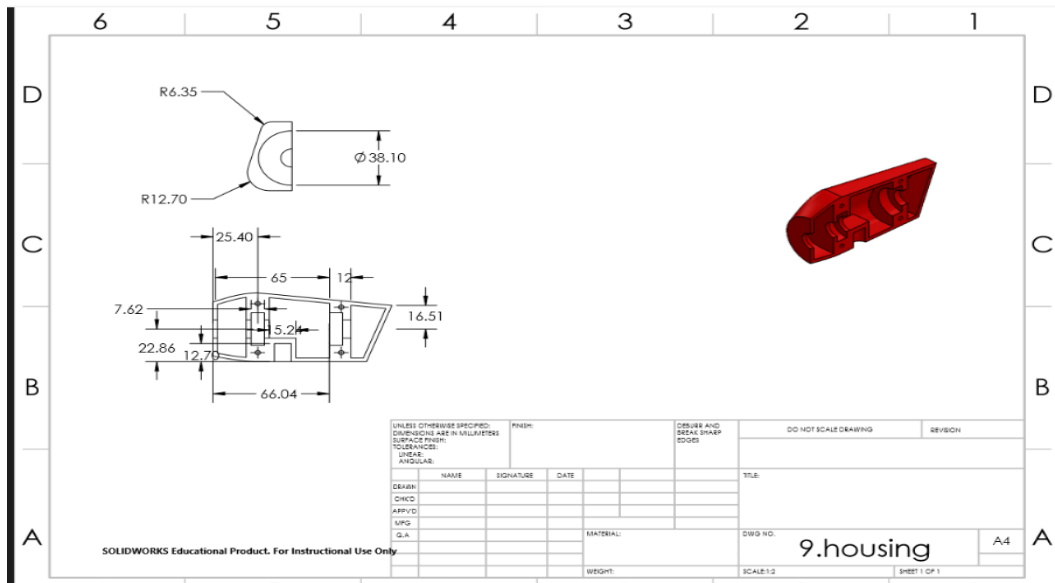
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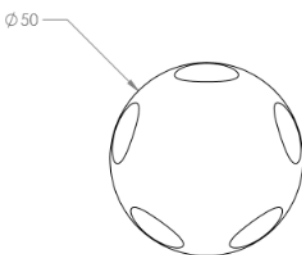
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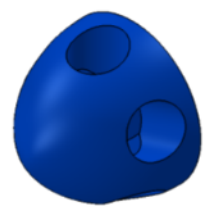
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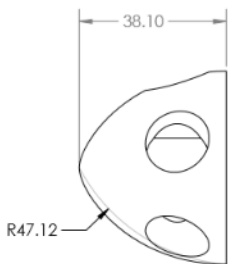
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WEIGHT:				SCALE: 1:1		SHEET 1 OF 1			

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