**MENG 411 Capstone Team Project**

**Eastern Mediterranean University**

**Faculty of Engineering**

**Department of Mechanical Engineering**

# Micro Air-Borne Wind Turbine


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# ABSTRACT

Given all the problems and uncertainties with fossil fuels and nuclear fission such as environmental pollution, global warming that induces unhealthy state of the living organisms, there is an emergency to seek for alternative means for producing energy now for a better future. Indeed, here comes the situation wherein solar and wind energies are prominent. These two powers generation means are fully renewable because they renew themselves over a relatively short time due to natural causes and therefore cannot extinct over time. Besides, they are said to be environmentally friendly since they release almost no waste into the environment.

This project is to design and manufacture a small airborne wind turbine from low cost materials with an optimal output power of approximately 50 watts. Firstly, an overview of the past work done on the topic was carried out and this help in deciding on the helium balloon airborne wind turbine. Where a donut balloon type is inflated with helium gas and mounted on the frame to generate lift force. Later on, proper mathematical calculations are made to assure that the intended manufactured airborne wind turbine works properly. This includes power output evaluation with sample calculations to finally achieve a better design. In the main manufacturing section, all the parts procurement and manufacturing were explained giving flow charts and product breakdown structure and assembled together. Finally, testing of the manufactured airborne wind turbine helps in viewing the effect of the wind on system producing voltage from the generator.

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# NOMENCLATURE

P: power

P: air pressure

a: axial induction factor

$C_p$: Power coefficient

$C_T$: thrust coefficient

A: Rotor swept Area

$\rho$: Density of air

$\rho_0$: Density of dry air at standard temperature

$\dot{m}$: Mass flow rate

R: Radius of the rotor blades

$\omega$: Rotational speed of the rotor

T: Air temperature.

## ABBREVIATIONS

AWT: Airborne wind turbine

D.C: Direct current generator

GWEC: Global wind Energy council

HAWT: Horizontal Axis wind turbine

VAWT: Vertical Axis wind turbine

SWT: Small wind turbine

# CHAPTER 1

# INTRODUCTION

## 1.1 Background information

In the last decade, an increasing number of research groups and companies worldwide have been developing a new concept of wind energy generation, named airborne wind energy (AWE) [1]. Airborne wind energy systems aim at harnessing the wind blowing up to 1000 m above the ground, using tethered wings flying fast in crosswind conditions, i.e. roughly perpendicular to the wind flow as seen in figure 1.1. This recent interest in airborne wind energy is fostered by a series of factors, both technical and socio-political. On the technical side, the development of advanced solutions in fields like materials, mechatronics, and power conversion have made these concepts, which firstly appeared in the late 1970s, technically feasible today. On the socio-political and economical sides, the research and development of novel forms of renewable energy is driven by the actual energy situation and environmental issues, caused by the extensive use of fossil fuels that represent one of the most urgent challenges on a global scale but also an important market opportunity for renewable technologies. Despite the mentioned recent developments, several technical aspects of airborne wind energy still require research and development, in order to definitely assess the viability of this concept and to transform it into an industrial product [1]. Tether technology, aerodynamics and wing design, sensors, control and energy conversion are all fields where research activities specifically aimed at airborne wind energy are needed, either to solve technical bottlenecks or to improve off- the-shelf solutions that are being already used.

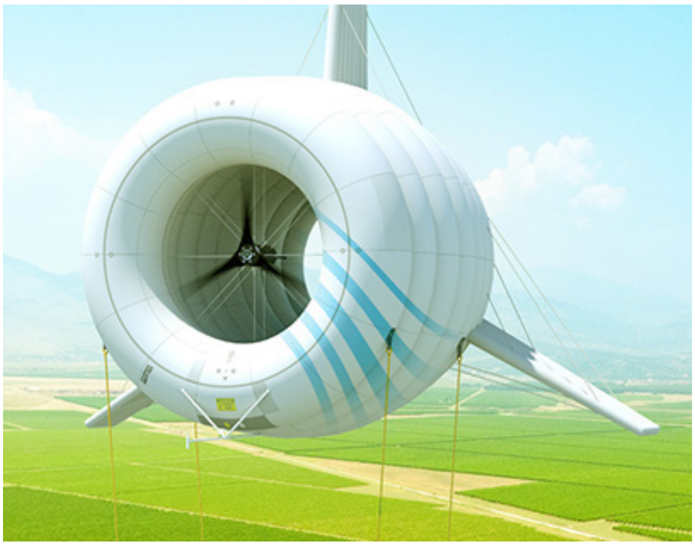


**Figure 1** Typical airborne wind turbine. Adapted from [3]

## 1.2 Aims, objectives and motivations

The purpose of this project is to design and construct a micro airborne wind turbine of minimum 50 watts output power. The design focus on the helium balloon type that will be able to fly at about 10 meters above the ground with the generator and rotor mounted on it in the sky.

Firstly, the motivation for this topic goes to the fact that conventional power generation systems such as fossil fuels and hydropower have been a serious problem for humanity. A reason for that are the high emission greenhouse gases that pollute decreasing therefore our lifespan. Fossil fuels (gas and coal) and water appear to be in extinction process. Airborne wind turbine provides more advantage from mechanical and aerodynamic options since the higher velocity and persistence of wind are found at high altitudes and airborne wind turbine goes to very high altitude to capture more consistence and predicted wind. The absence of a tower and yaw mechanism for vertical motion (along the z-axis) really have significant advance on the production cost of the airborne wind turbine. To conclude, the interest for this topic as our area of specialization in the future stands as one of the motivations.

### 1.3 Limitations of the design

This part consists of highlighting the different limitations of our design with respect to the weather conditions and the material available. Small wind turbines need low speed alternators and low speed alternator usually means low output power. Aside that, we have to mention that the more we go in altitude, the more wind we can find with higher density and speed; the more efficient the system will be (higher will be the output power) since the power in the wind blowing though the rotor is proportional to the air density and the wind speed. So, meteorological factors need to be watched alongside.

Furthermore, the number of blades with respect to the drag force has to be considered. Indeed, the power generated by the rotor is proportional to the torque and the rotational speed and more blades help the machine to start to turn slowly but as the speed increases, the drag force of all those blades will limit how much power it can produce. Multi bladed rotor work best at low speed.

### 1.4 Report Organization

Chapter one discussed on the general background information of the project. It described the aims, objectives and motivations as well as some limitations of the design process. Chapter two will be giving us information about the airborne wind turbine, its classifications and its components. More over, cause of wind, wind energy measurement and applications, and wind profile of Famagusta will be briefly discussed. Additionally, the third chapter, which consists of the design and manufacturing, will be carried out. This will account for the construction of the system with all the possible mathematical and engineering analysis considered. Material selection and cost analysis will also be discussed in chapter three. Manufacturing, fabrication, assembling and testing of the system is also going to be clearly discussed in chapter four. The results and the discussion on the results will be performed in chapter five, which will include the presentation of the results and the technical difficulties encountered during the construction and testing. Lastly, chapter six will help conclude on the report to acknowledge airborne wind turbine and provide eventual recommendations on future work of the airborne wind turbine.

# CHAPTER 2

# LITERATURE REVIEW

Airborne wind turbine is a non-static wind turbine that does not have tower, which are suspended in the sky. Much like the normal conventional wind turbine, the components and working principles are same with the airborne wind turbine. This type of wind turbine are mostly used/operated at high altitudes in order to take utilize the disadvantages of the conventional type, which altitude constrain produced a lot of disadvantages. More so, the airborne wind turbine reduces the cost of construction of wind turbine due to the absent of the construction of tower. Another key phrase in the wind energy sector is "collect as much wind as possible" as to get maximum power output. The conventional wind turbine, which is mostly operated at low altitude, faces challenges, which include:

- Inconsistent and unpredictable wind condition.
- Effects on flying animals (birds).
- Electromagnetic and noise pollution.

These give an opportunity and motivations to scientists and engineers have been working to provide energy from the wind at desired altitude and wind velocity.

This chapter will explain the general causes of wind and how it is conserved as wind energy and see the wind profile of northern Cyprus specifically for the design and test of Airborne Wind Turbine. We will be reviewing the different types of AWT; also we will select one based on our design objective for designing of airborne wind turbine that is cost effective and works with great efficiency. Lastly, in the next chapter, some state of art calculations and analysis are going to be shown for the design of the selected AWT. [6]

### 2.1 Advantages of Airborne Wind Turbine

Airborne wind turbine gives solution to all those problems facing the conventional wind turbine. The presence of enough consistence and easy predicted wind at high altitude makes it possible for AWT to generate more energy at maximum efficiency compare to the conventional wind turbine which is mostly at low altitude, with at least 100 times more kinetic energy according to research. Moreover, wind turbine at high altitude does not have any effect on birds, since they don’t fly to very high altitude of 100 meters to 10KM in the sky. This makes it safe for flying animals from being trapped by the turbine rotor of the suspended turbine, as the opposite is the case in conventional wind turbine. Additionally, noise produced by most wind turbines is minimized, as the generator and the rotor are not on the ground surface but several meters above the ground. Lastly, the cost of the turbine is drastically reduced, as the cost of construction of tower will not be considered. [10]

### 2.2 Classifications and concepts of airborne wind turbine

Although airborne wind turbine is a suspended system that is in the air, the electricity is transferred down using electric conductive wire called tether. There is different mythology used in Airborne Wind Turbine for energy generation and conversion namely;

- Flying aircraft, with many propellers, which is also used as the rotor to collect the energy from the wind.
- Suspended balloons carrying generator in the air to generate and convert energy.

Airborne wind turbine can be categories into two based on the mode used in generating and converting of the Kinetic Energy to electricity. In the ground-gen systems, the conversion of the mechanical energy into electrical energy is done on the ground while the fly-gen systems convert energy generated by the rotor to electrical energy in the sky. There are four types of Airborne Wind Turbine based on conceptual design, which is shown in the figure 2 below. (a) Fixed wing AWT (b) multi wing AWT, another type of fixed wing (c) Lifting balloon AWT (d) Rotorcraft AWT. Adapted from [5]

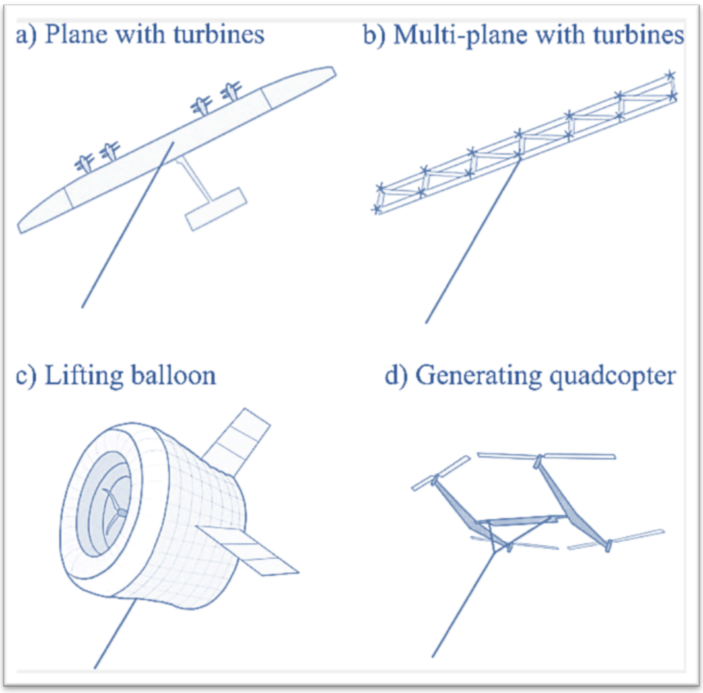



**Figure 2** Different concepts of airborne wind turbine. Adapted from [5]

The four main concepts of airborne wind turbine are named below:

1. Balloon type airborne wind turbine;
2. Kite type airborne wind turbine;
3. Rotorcraft type airborne wind turbine;
4. Fixed wing type airborne wind turbine.

### 2.2.1 Balloon type Airborne Wind Turbine

This concept is much like the conventional horizontal wind turbine, but without tower. A rotor held by a balloon filled with either helium gas or hydrogen suspended in the sky, much like a donut or swimming floating tube holding the rotor at the center as shown in figure 3. This type of wind turbine is classified under fly-gen types, which convert kinetic energy to electrical energy in the sky then transfer it through tether to the ground. Likely challenges of this concept are controlling of its motion at high altitude and its possibility to damage under strong wind, as it is light in weight. The concept was first lunched from MIT Energy Ventures class in 2009, and the concept won the 2011 ConocoPhillips Energy prize. [8]

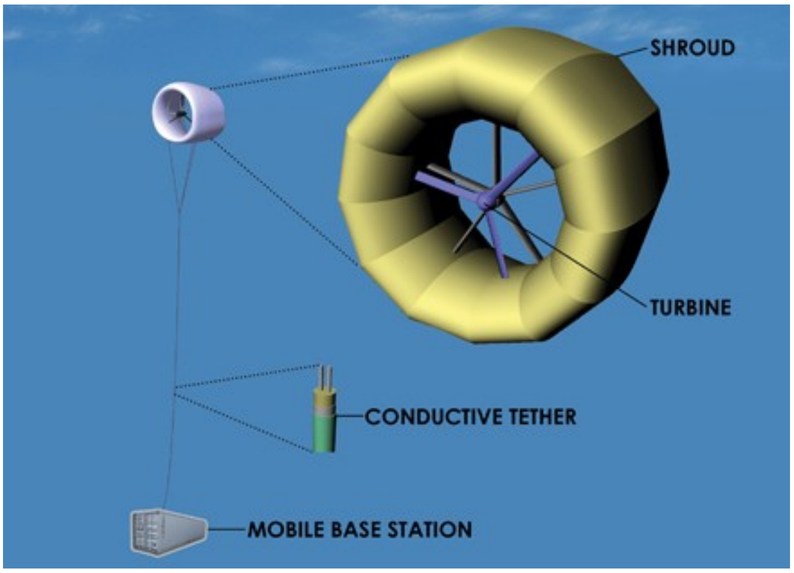



**Figure 3** Balloon type airborne wind turbine. Adapted from [10]

### 2.2.2 Kite type Airborne Wind Turbine

This is a kite like design that collect wind energy through wind turbines by following figure 8 trace suspended in the sky at high altitude. This is the most common type of AWT available and it is mostly ground-gen system. Kitegen, kitepower and kitenergy are the leaders in the kite type AWT research and development in the market for now. Although this is the most common AWT available, the design and manufacturing of the kite type AWT is required a lot of programming and calculations because it must be in constant motion, tracing the figure 8 shape in the sky makes it a hard choose for us to choose for our project. [10] Figure 4 below shows the different designs of the kite type AWT by different companies. (a) Flying kite using single wire for suspension (b) kite type with single wire suspension and control pod (c) kite AWT with double wire suspension (d) AWT with 3 wires suspension. [10]

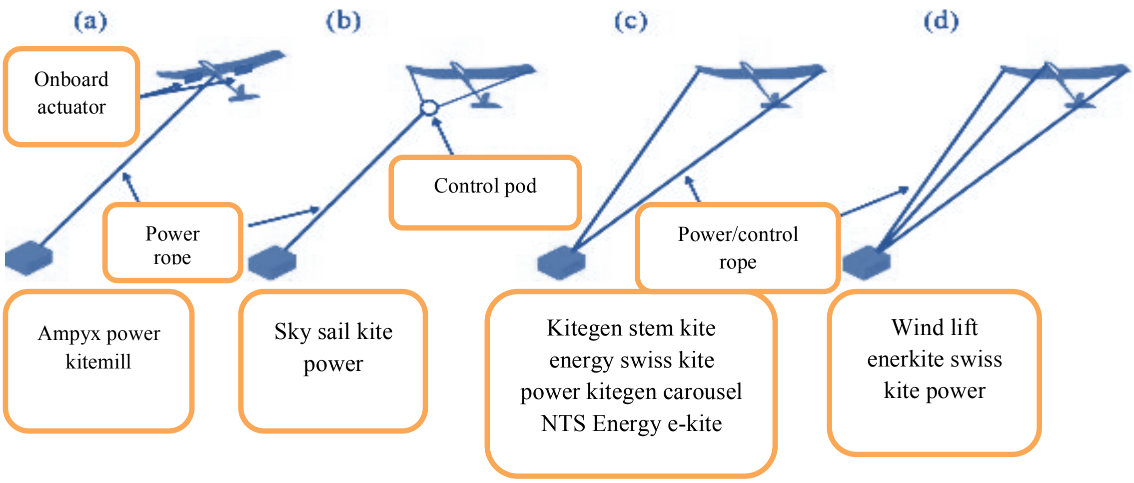



**Figure 4** Design of different types of kite airborne wind turbine. Adapted from [10]

### 2.2.3 Fixed wing type Airborne Wind Turbine

This concept is also in the ground-gen class, it is design with several propellers mounted on the wing, travelling in a circle trying to copy the motion of conventional wind turbine to generate energy. Unlike the kite type that has a motion in figure 8 forms, this concept is about mimicking the conventional turbine circular rotation of the blades, using principles of blade tip theorem to generate power. In low wind conditions, the turbine uses power from the power generated for threshold to maintain elevation. MaKani power is the leading company in this concept investment. The controlling mechanism and the cost of designing a simple small scale fixed wind type AWT has been the major hindrance for student research. [11]

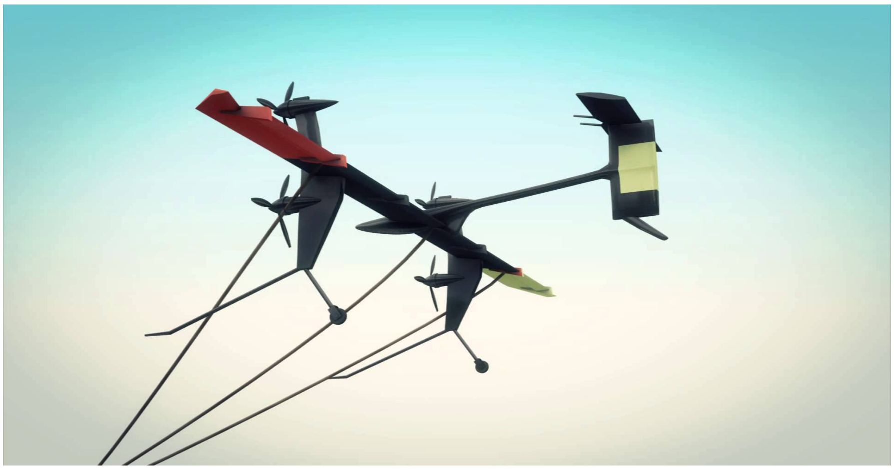


**Figure 5** Makani power model of fixed wing airborne wind turbine. Adapted from [11]

### 2.2.4 Rotorcraft type Airborne Wind Turbine

This is a four rotor aircraft that is much like a drone with similar principles like the fixed wing AWT that uses the principle of blade tip to generate power. More so, it is also classified underground-gen, which uses the tether wire from the rotors to carry the wind power for energy conversion. During low or zero wind velocity, it uses some of the power generated to maintain elevation as in the fixed wing AWT type. [11]

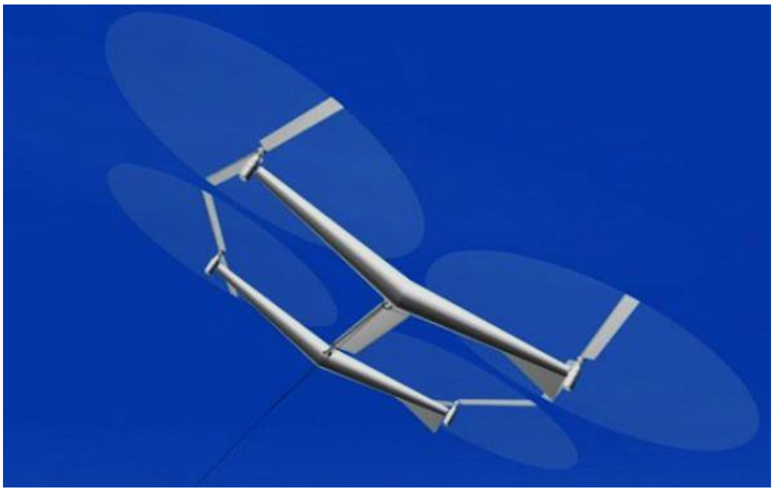


**Figure 6** Rotorcraft airborne wind turbine concept. Adapted from [11]

### 2.2.5 Comparison Table of Different Types of Airborne Wind Turbine

**Table 1** Analysis of different concepts of airborne wind turbine

| | Balloon AWT | Kite AWT | Rotorcraft AWT | Fixed Wing |
|---|---|---|---|---|
| Cost benefits | Average | Average | High | Average |
| Manufacturing (fabrication) | Medium | Medium | Difficult | Difficult |
| Controller | Low | Average | High | High |
| Feasibility | Easy | Easy | Difficult | Medium |
| Ground generation | No | Yes | Yes | Yes |
| Fly generation | Yes | No | Yes | No |

Based on this comparison table we shown in the table 1 and our project limitations, the balloon type AWT has the upper hand over the other types of AWT. Rotorcraft and the fixed wing AWT required high programming for its control and the manufacturing (fabrication) and assembling of its part is difficult than the kite and the balloon type. The balloon type was because of its upper hand in benefits. [8]

### 2.3 Airborne wind turbine components

The airborne wind turbine (AWT), much like the conventional wind turbine has similar components and working principle. Although there are several types of airborne wind turbine; the kite type, rotorcraft, winged type and the floating type. They all share a lot of components like the conventional wind turbine. In this project after several analyses, the floating type airborne wind turbine to design, Hence the rotor (blades), generator, transformer, storage are all like the conventional wind turbine, which shown in figure 7 schematically. In the airborne type of wind turbine we are going to have control mechanism for taking it up and bringing it down. We are going to show how we optimized our options on choosing each component, and the standard criteria to follow to design a simple, efficient, costless small scale AWT.

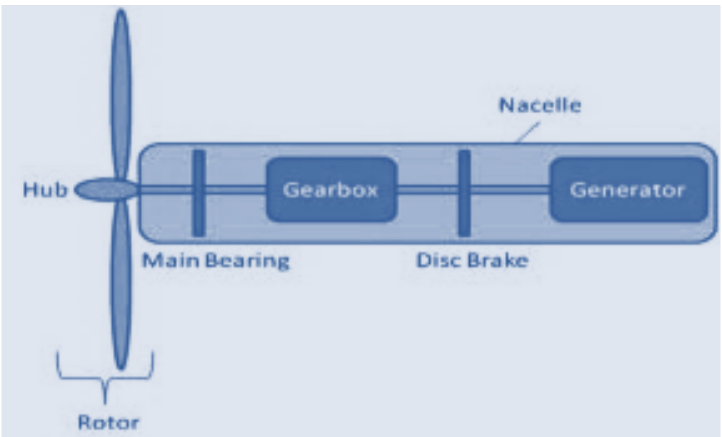



**Figure 7** Ideal diagram of Wind turbine components. Adapted from [12]

I. ROTOR: - rotor is the most important component in generating wind energy. The rotor is a metal blades design with aerodynamics principles to deal with the aerodynamics forces of the wind. These blades are connected to a rotating shaft and the momentum force generated by the rotating blades moves the shaft. A gearbox that regulates the revolution of the shaft to that generator's rpm is used to increase the rpm of the shaft and the generator. The generator is an important component in converting mechanical energy to the electrical energy. The shape, material and radius of a rotor are the main criteria to consider when designing a wind turbine. We will use the air profile and data of northern Cyprus to design our AWT in this project, using simple good material that will resist the air flow turbulence and speed to attend our required energy production target for this project. We are going to use some numerical analysis and software to analyze the stability and strength of our design respectively to able to understand problems and constrains of AWT. A schematic idea of general wind turbine the rotor is shown below in figure 8.

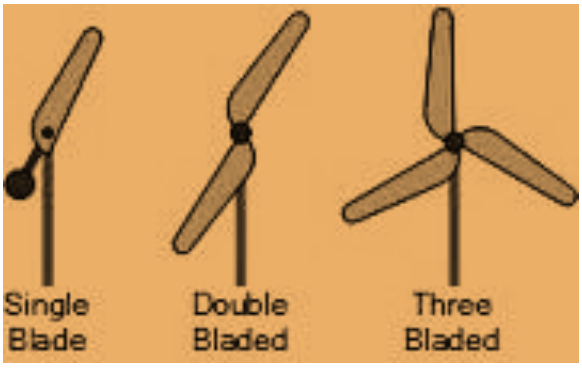



**Figure 8** Schematic drawing of turbine rotor. Adapted from [15]

I. GENERATOR: - the generator is the one of the most crucial component in our project, without the generator we cannot be able to convert the energy generated by the rotor mechanically to electricity. There are several varieties of generators in the market to select from depending of your limitation. Figure 9 shows the DC generator internal components. In the project a small-scale generator is use in the design of AWT with electricity output of 50W, which doesn't require a big generator. We will select a generator that can give us our required output with minimum cost and a very simple generator, as its complexity will create additional problems to our design.

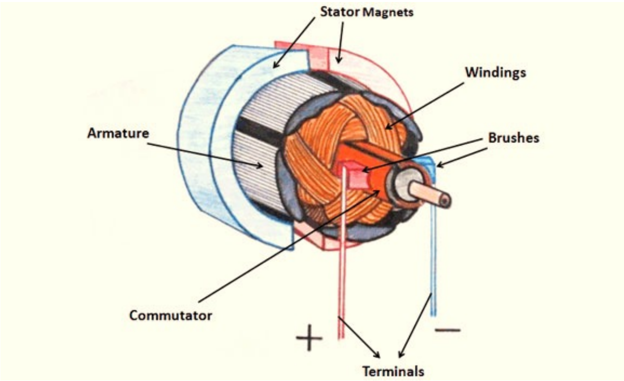



**Figure 9** Internal part of a generator. Adapted from [16]

II. STORAGE: - this is a domain part that stores the converted generated energy to be use another time. We are using a short-term storage device to store the energy we generated from the generator for later usage. We will be selecting the storage capacity based on the design output productivity.

III. AIR BALLOON: - Airborne wind turbine, much like the conventional wind turbine is in operational principles but not in stationary position. Although there're four types of wind turbine as discussed before, this project is the floating balloon. We selected the floating type AWT because, based on our limitation in the project and our research, the floating type is the simplest, costless, and most feasible to get our required electric output.

**Figure 10** 3D printed Balloon type AWT. [13]

In this project, noble gas was used to fill the balloon because; helium is one of the noble gases with less than 4 amu, which makes it easy float in the air carrying some masses in the sky. Much like hot air balloon, which use helium gas to fly with some weight on it. This floating tube is designed to carry the weight of the rotor and generator using helium gas.

IV. CONTROL MACHANISM: - Control mechanism of AWT is an important system in designing AWT, since is a flying turbine that takes off and stay in the sky at high altitude to capture enough energy for maximum production of electricity. A design of AWT should be made to control its motion from leaving the ground to landing back and its control whiles on the air. If we design a flying wind turbine and we cannot control its position in the air or we cannot bring it down then there is a problem. In this project we will not be going into more details of nacelle control (YAW control and wind vane) wind speed control because we are only designing a small scale AWT that is just going to be used for some limited time.

In a commercial or industrial design of AWT, these control mechanism are very essential because the turbine is going to stay for a while in the sky to capture enough energy for maximum production of electricity. More so, the turbine must work during low and high wind speed, and be able to maintain the blade speed in high speed to avoid damage of the turbine. Additionally, in this project we are going to be concerned about the takeoff and landing of the turbine. This control can be made using compact disc recordable (CDR) controller using a lot of programming and mathematics, which can be control wirelessly and can be automatic depending on the programming. To minimize cost and to simplify the design of the project, we choose to use mechanical control process to take it off and be able to bring it down. Using a pulley mechanism this is very feasible and easy to make. [15]

## 2.4 Wind Resources

### 2.4.1 Causes of wind

Wind is being cause by unequal heating of the earth surface by the sun which effect the movement of air flows from the area of high atmospheric pressure to the area of low atmospheric pressure on earth surface. Winds tend to be strong when the high and low pressure is closer together. The lines or contour on the weather map, which shows the constant pressure, are called isobars. These isobars represent the different values of pressure levels, which are usually in mill bars (mb). There are two main causes of large-scale air pressure circulation; difference in heating of the earth surface between the equator and the poles, and the rotation of the earth also known as Coriolis Effect. The mechanism of wind circulation has being used by to transform the energy to provide the power source of various forms of energy for different purposes. [6]

### 2.4.2 Wind energy measurement and application

Wind speed is measured by anemometer, and the most common type is the cup type anemometer. Anemometer measures the direction and the speed of the wind. Cup type anemometer gives high accuracy of wind data with accuracy of +- 3.5% by study (Curvers and Van Der Werff, 2001). Weibull created a standard method of analyzing wind speed data in 1951. A two parameter Weibull distribution gives a very simple data for wind speed distribution for an average of 10 minutes. [7]

The main purpose is of the design is to convert kinetic energy of the wind to electrical energy. To evaluate wind energy we need to calculate the wind power of the rotor speed and the velocity of the wind. Air in the space is a moving gas, which categories the type of energy in it to kinetic energy. From the kinetic energy equation, the formula for the energy is proportional to the square root of the velocity of the moving particle and directly proportional to the particle's mass. [7]

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

This equation is going to be used to determine the wind power required to design AWT for this project. By using software application called wind energy resource analysis, the total energy constitutes of all the wind power and density function (Weibull distribution) can be resolved analytically using this expression: [7] figure 11 below shows the schematic representation of the energy conversion in wind turbine.

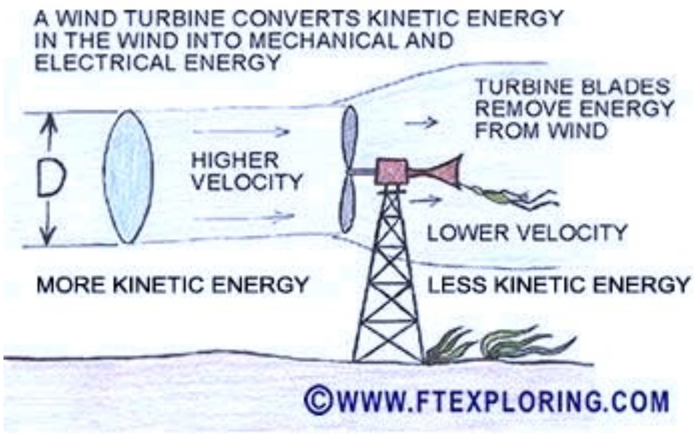



**Figure 11** Schematic representation of Energy conversion in wind turbine. Adapted [8]

### 2.4.3 Wind Profile for Northern Cyprus

The island of Cyprus is in the Mediterranean sea, has a very sunny climate with 75% average bright sunlight hours for a year mostly the sun above the horizon. The island is among the countries with longest sunlight period with 6 months of summer and the sun intensity is one of the greatest worldwide. The wind potential of Cyprus has not been encouraging over the years. The average wind speed of many part of the island is at about 5-6 m/s while in some region is 6.5-7 m/s [9]. For these two reasons, there is very little investment in wind farms in the southern Cyprus while there is no any wind farm in the northern part of the island. High cost of installation and low wind speed in many part of the island has affected invest in the wind energy sector. Technology is moving faster; the airborne wind turbine can make Cyprus realize its full potential in the wind energy. With consistence and predictable wind condition at high altitude, the AWT can generate 10 times more electricity than the conventional wind turbine. The only barriers the AWT can have are the lack of experience and technology in the field, which will make its cost, go high and can create investment risk for large-scale offshore installation. [9]

# CHAPTER 3

# DESIGN AND ANALYSIS

Some of the required parts necessary to design and manufacture a micro air-borne wind turbine are small turbine generator, transformer, conductive wires, floating tubes, and pulley. Since it is an air-borne wind turbine it is necessary to select light material parts, table 2 shows the major part required for design and manufacturing with specification.

**Table 2** Design tasks and manufacturing

| | |
|---|---|
| Generator | Type: direct current (D C) generator<br>Size<br>Weight<br>Power conditioning<br>Excitation<br>Maximum speed |
| Balloon | Material selection<br>Maximum expansion (Elasticity)<br>Fluid requirement |
| Rotor (blades) | Tip speed ratio, number of blades<br>Material selection<br>Center of gravity installation<br>Static and dynamic operation loads |
| Current storage | Reliable battery |
| General | Structural dynamic<br>Frame<br>Installation methods<br>Maintenance<br>Conductive wire<br>Light ropes |

### 3.1 System overview

Air-Borne wind turbine was design to have high efficiency and reliability compared to a normal wind turbine, a normal wind turbine have a maximum height of 100 meters but the air borne wind turbine can have its height raised up to 300 meters, which is quite higher than a normal wind turbine. One of the most important parts required for a wind turbine design is the D.C (Direct current) generator that is required for power production.

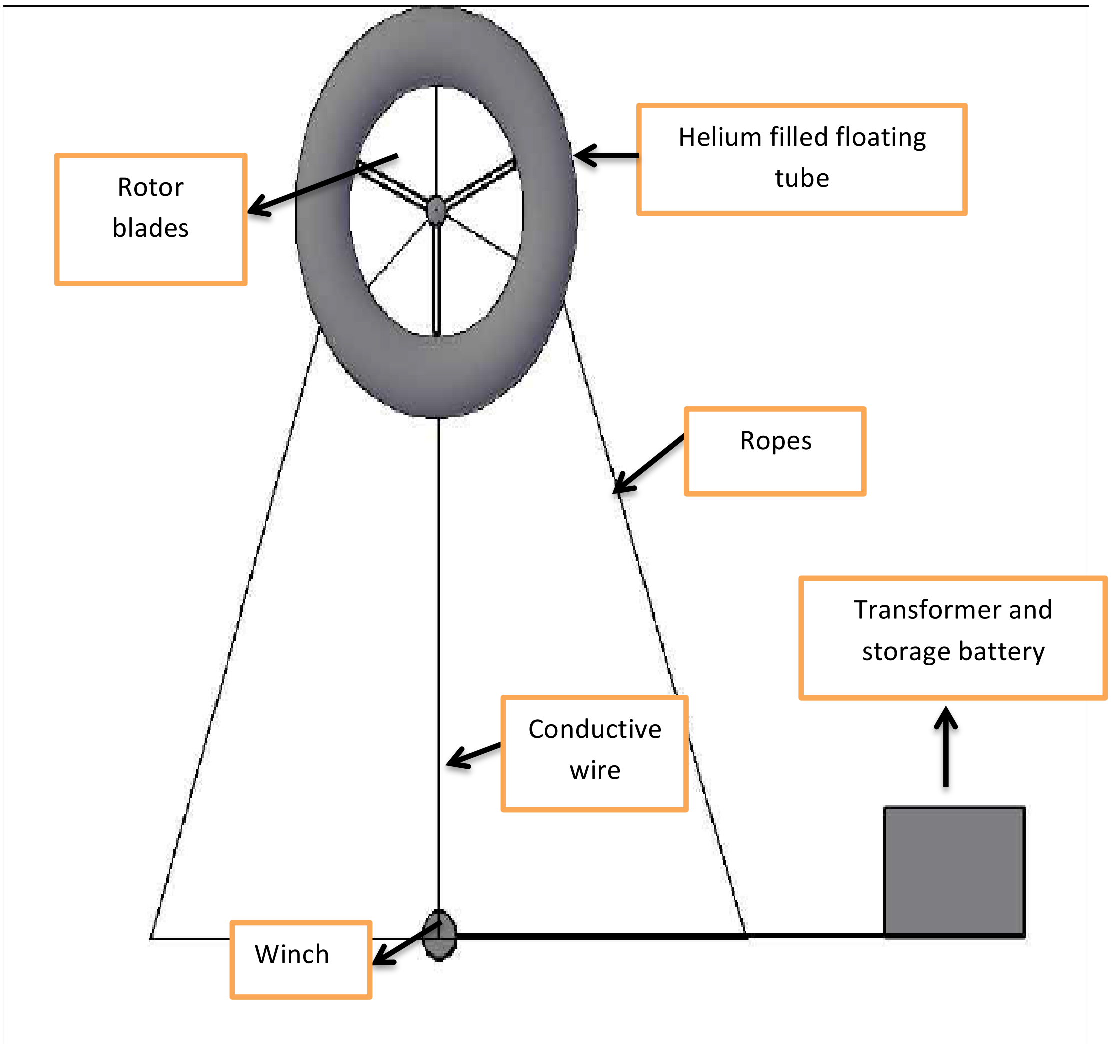



**Figure 12** AutoCAD drawing of complete balloon type AWT

Figure 12 shows an aerostat helium filled balloon suspended and kept stable by ropes. This above system shows a simple design that is capable of power production.

### 3.1.1 Wind turbine theory

One of the most common wind turbines is based on linear momentum theory developed centuries ago to predict the performance of ship's propellers. The turbine was being represented by an actuator disc which creates some pressure discontinuity in the stream tube of air flowing through the area of the actuator disc, which was used to determine the power generation of an ideal turbine rotor, the thrust of the wind, and the rotor operation effect on the local wind field [18]. In other to have an ideal test, there were some assumptions, which are;

- Infinite number of blades
- Constant down stream flow over the stream tube section with no pressure
- The air is assumed to be in a steady state, incompressible and in viscid flow
- No frictional drag
- Uniform thrust the disk. [18]

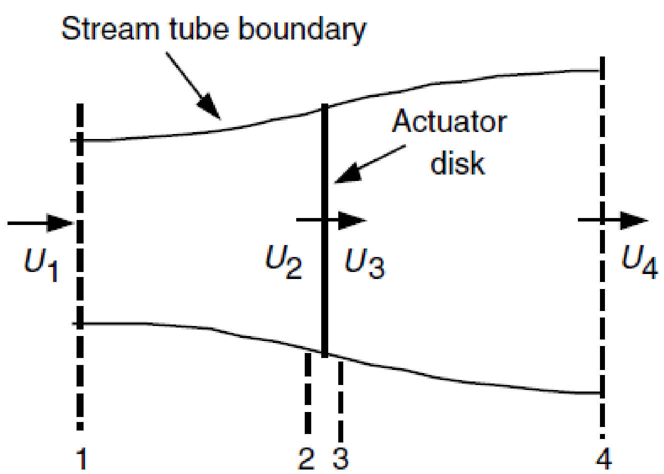



**Figure 13** Actuator model for AWT. Adapted from [18]

The figure 13 above gives a clear understanding of an ideal wind turbine also in the application of the linear momentum to the control volume, the air mean velocity for 1, 2, 3, and 4 are represented as U. and the net force of the wind is equal and opposite to the thrust T and this thrust equal and opposite to the rate of change in momentum and can be represented as

$$T = U_1(\rho AU)_1 - U_4(\rho AU)_4 \tag{3.1}$$

Where $\rho$ is the density, A is the cross-sectional area and U is the air velocity in different stages of the stream tube and numbered as the subscript. These equations were abducted from the linear momentum theory for wind energy. [18]

For steady state flow, $(\rho AU)_1 = (\rho AU)_4 = \dot{m}$ (3.2)

Therefore: $T = \dot{m}(U_1 - U_4)$ (3.3)

Since the thrust T is positive the upstream velocity $U_1$ is greater than the downstream velocity$U_4$. Since no work occurs either in the up or down stream Bernoulli function can be use in both sides of the actuator disc in the control volume. [18]

Bernoulli equation for upstream is given as:

$$p_1 + \frac{1}{2}\rho U^2{}_1 = p_2 + \frac{1}{2}\rho U^2{}_2 \tag{3.4}$$

The downstream Bernoulli equation is given as

$$p_3 + \frac{1}{2}\rho U^2{}_3 = p_4 + \frac{1}{2}\rho U^2{}_4 \tag{3.5}$$

Assuming the up and down far stream pressure are equal $p_1 = p_4$ and the velocity across the disc remains constant $U_2 = U_3$ therefore solving equation (3.4) and (3.5) simultaneously using the given assumptions, [18]

$$p_2 = \frac{1}{2}\rho U^2{}_1 \tag{3.6}$$

$$p_3 = \frac{1}{2}\rho U^2{}_4 \tag{3.7}$$

The net sum of forces on the actuator disc can be expressed as

$$T = A_2(p_2 - p_3) \tag{3.8}$$

Solving for $(p_2 - p_3)$ form equation (3.6) and (3.7) the net force, which is also the thrust, is given to be: [18]

$$T = \frac{1}{2}\rho A_2(U^2{}_1 - U^2{}_4) \tag{3.9}$$

Let equation (3.3) be equal to equation (3.9), solving this equation the mass flow rate was gotten to be:

$$\dot{m} = \rho A_2 U_2 \tag{3.10}$$

Obtained from the average upstream and downstream wind speeds [18]

$$U_2 = \frac{U_1 + U_4}{2} \tag{3.11}$$

The reduction in the wind velocity between the free stream and the rotor plane can be defined as the axial induction factor, a. where:

$$a = \frac{U_1 - U_2}{U_1} \tag{3.12}$$

$$U_2 = U_1(1 - a) \tag{3.13}$$

Finally, equating (3.11) to (3.13) [18]

$$U_4 = U_1(1 - 2a) \quad (3.14)$$

$U_1$ Is referred to the induced velocity of the rotor, which is the combination of the free stream velocity and the induced wind velocity. With an increase in the induction factor from zero, the wind speed behind the rotor decelerates, if $a = 1/2$, then the wind velocity behind the rotor is zero, which means the linear momentum theory is no longer applicable.

Thrust times the velocity of the disc is equal to the power output: [18]

$$P = \frac{1}{2}\rho A_2({U^2}_1 - {U^2}_4)U_2 = \frac{1}{2}\rho A_2 U_2(U_1 + U_4)(U_1 - U_4) \quad (3.15)$$

Substituting equation (3.13) and (3.14) for $U_2$ *and* $U_4$ to equation (3.15) gives:

$$P = \frac{1}{2}\rho A U^3 4a(1 - a)^2 \quad (3.16)$$

$A_2$ Is replaced by $A$ and the free stream velocity $U_1$ is replaced by $U$.

Equation (3.16) shows the output power of an ideal wind turbine system, where the free stream velocity is either constant or changes gradually. [18]

Now, wind turbine rotor performance is characterized by $C_p$:

$$C_p = \frac{P}{\frac{1}{2}\rho U^3 A} = \frac{Power\ extracted\ from\ the\ wind}{Available\ wind\ power} \quad (3.17)$$

[18]

Power coefficient $C_p$ is a dimensionless ratio coefficient of the power extracted to the power available. Putting equation (3.16) to (3.17) the power coefficient is then: [18]

$$C_p = 4a(1 - a)^2 \quad (3.18)$$

The maximum $C_p$ can be determined by the derivative of equation (3.18) equating it to zero with respect to $a$. Therefore since the axial induction factor (a) cannot be greater than or equal to 1 therefore $a = 1/3$. Calculating the maximum power coefficient inputting the value of $a$,

$$C_{P,max} = 16/27 = 0.5926 \tag{3.19}$$

Since power is equal to thrust multiplied by velocity therefore:

$$T = \frac{1}{2}\rho A U^2[4a(1-a)] \tag{3.20}$$

Also the dimensionless thrust coefficient can be given by:

$$C_T = \frac{T}{\frac{1}{2}\rho U^2 A} = \frac{\text{Thrust force}}{\text{Dynamic force}} \tag{3.21}$$

Therefore the thrust coefficient $C_T$ for an ideal system is equal to: $4a(1-a)$.

Given an ideal graph representation of this dimensionless coefficient over the axial induction factor when $C_T$ has a maximum value of 1.0 at $a$ = 0.5 and the downstream velocity is zero. [18]

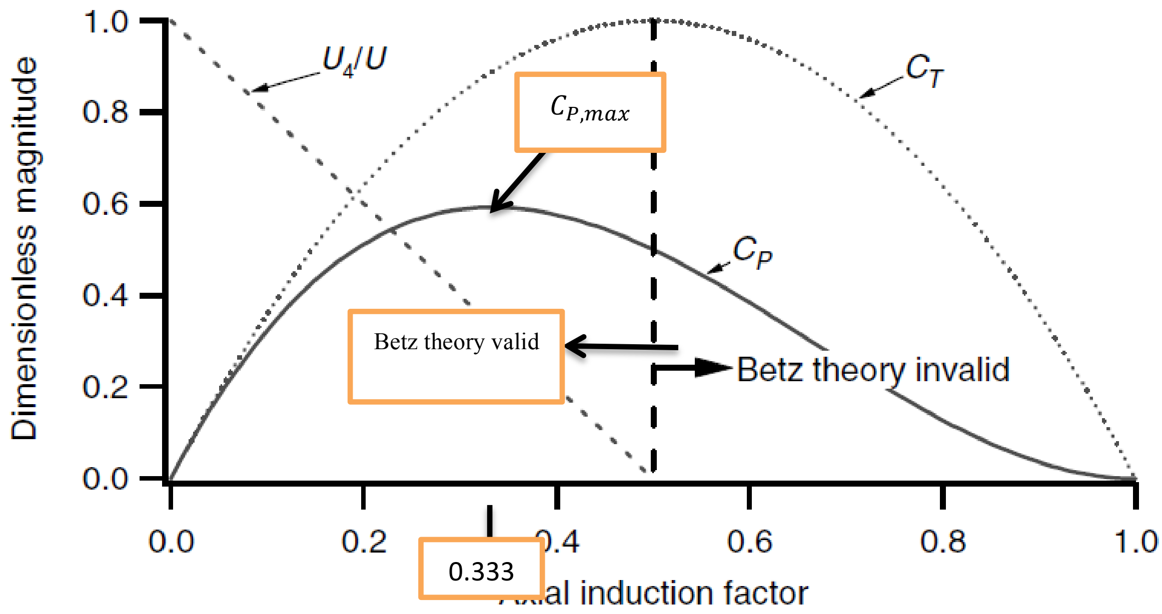



**Figure 14** Graphical presentation of Betz turbine theory. Adapted from [18]

From figure 14 above the maximum power output is obtained when the axial induction factor is $(a = 1/3)$ and $C_T = 8/9$. Also the maximum power coefficient, $C_{P,max} = 16/27$. [15]

The overall mechanical efficiency of the wind turbine:

$$\eta_{overall} = \frac{P_{out}}{\frac{1}{2}\rho A U^3} = \eta_{mech} C_P \tag{3.22}$$

$$P_{out} = \frac{1}{2}\rho A U^3 (\eta_{mech} C_P) \tag{3.23}$$

Finally, there are some factors that cause a decrement in maximum power coefficient in practical experimentation. [18]

- Non-zero aerodynamic drag
- Rotation of the wake
- Finite number of blades
- Tip losses

### 3.1.2 Tip speed ratio

The tip speed ratio can be explained as how fast the tip of the turbine rotor can rotate in proportion to the applied by convection. Tip speed ratio λ can also be defined as the linear speed of the blade tip to the wind where R is the fixed radius of the blades and ω varies with time as well as V velocity of the wind. [19]

Tip speed ratio (TSR) λ = ωR/ V (3.26)

- The distance the travel in one revolution =2∏D
- Revolution per sec = rpm/60
- Blade tip velocity (m/s)= distance blade tip travel in revolution/revolution/sec

### 3.1.3 Efficiency

The aerodynamic efficiency ($C_P$) of a wind turbine is the ratio of output power to the wind power.

$$C_P = \frac{P}{P_{WIND}} \tag{3.27}$$

$$P_{WIND} = \frac{1}{2}\rho A U^3 \tag{3.28}$$

$\rho$ = Density of air

A = cross-sectional area

U = velocity of the wind

### 3.1.4 Power Calculation

These calculations are based on assumed value. The reason is to have a clear view of power generated

Diameter of rotor: 500mm or 0.5m

Height: 10m

Power coefficient. $C_P$: 0.59259

Density of atmosphere at 10m heights: $1.225\,{}^{kg}/_{m^3}$

Area of rotor blades

$$A = \frac{\pi D^2}{4} = \frac{3.142 \times 0.25}{4} = 0.1963m^2$$

Wind velocity U= $5\,{}^{m}/_{s}$

From equation (3.24),

$$\text{Power, P} = \frac{1.225 \times 0.1963 \times 0.59259 \times 5^3}{2} = 8.91\text{W}$$

This result shows that the output power for an AWT with a wind speed of $5\,{}^{m}/_{s}$ produces 8.91Watt. Given the rotor diameter to be 0.5meters and at 10meter altitude.

### 3.1.5 Wind Turbine Generators

Wind turbine generator can be classified into three different types, and they are direct current (DC), alternating current (AC) synchronous and (AC) asynchronous generators. Each of these generators can run on both fixed and variable speed. But since it is impossible to have a 99% constant wind speed from nature, it is profitable to put a direct current (DC) variable speed wind generator into consideration in other to reduce physical stress of the turbine blades.

Turbine generator is responsible for converting mechanical rotation into electrical power. In chapter 2, the average wind speed data of Cyprus was given and from there a specific wind generator was picked due to the climate conditions of Cyprus.

Judging from these conditions, a DC wind turbine generator was considered with some specifications.

- Rated voltage: 120volt
- 115 degree motor overheating protection
- Power: 500watt
- Weight: 600gr

Power parameter measurement

**Table 3** Power measurement relative to input speed

| Speed (rpm) | Voltage (v) |
|---|---|
| 1000 | 50 |
| 2000 | 100 |
| 3000 | 150 |

Although fixed speed wind turbines are cheap, reliable, robust and simple to maintain. Due to the fact that a maximum power production from the wind is required, a variable speed wind turbine generator is applied in this project.

### 3.2 Material selections based on Ashby chart

This section would give a brief detail about material used in this design and their properties, which would also include reasons for selection, advantages and their limitations. The parts/components for this project are selected based on the best material with the favorable rating on a scale of 1-10 to be discus in this section. The rating would be starting from 1 as the minimum rating to the maximum rating, 10. In each component cost and availability are our main criteria to look for; subsequently other criteria's are going to be added based on the function of the part. The main criteria for our material selection are cost availability and quality. Our selection was based on these three themes; keep the price low, get it in the nearest market and get it a best quality as possible. The quality of each material was selected from the ASHBY material selection chart. The strength of the material, its toughness, durability, material for the manufacturing of that part for the purpose of that functions were the major criteria considered to classify the quality of each part short-listed. Below in figure 15 the picture of the Ashby chart used in determines the quality of the materials is shown.

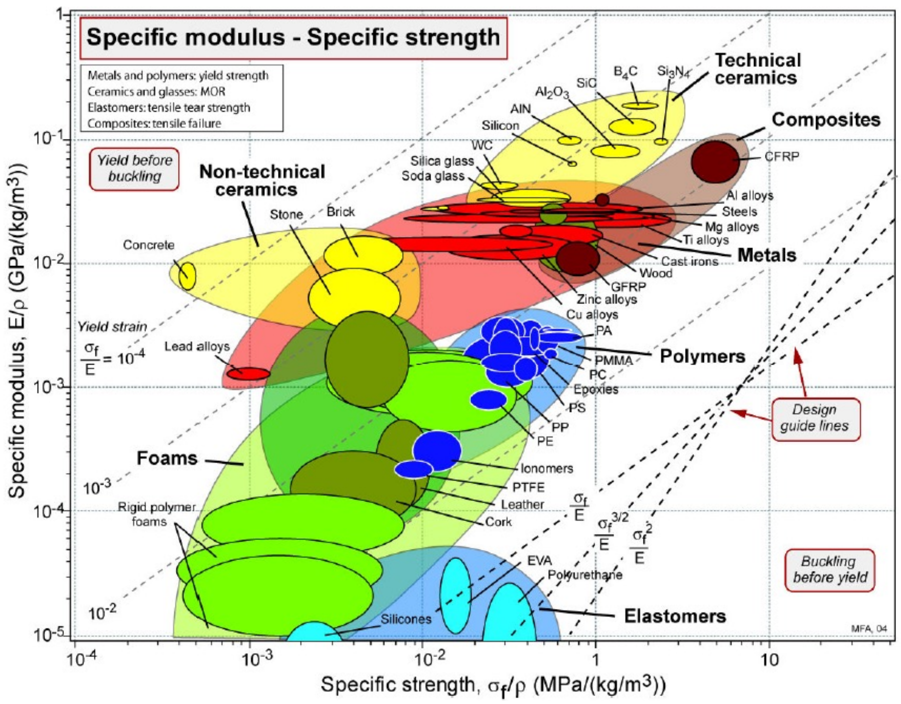



**Figure 15** Ashby standard chart for strength of material. Adapted [21]

### 3.2.1 Balloon

The balloon was selected based on five criteria, which was shown in table 4. Tire tube was our best option because it is available in Famagusta and affordable. The weight of the tire tube was a concern but its life span of 6 years and the material quality is better than our other options.

**Table 4** selection of balloon

| **Criteria** | **Floating tube** | **Tire tube** | **Tethered balloon** |
|---|---|---|---|
| Cost | 8 | 8 | 4 |
| Available | 8 | 10 | 2 |
| Quality | 4 | 8 | 6 |
| Weight | 10 | 6 | 8 |
| Life span | 4 | 8 | 6 |
| **TOTAL** | **34** | **40** | **26** |

### 3.2.2 Generator

The generator that was chosen also was based on five criteria, which was shown in table 5. The DC type is our best option for this type of project.

**Table 5** Selection table for generator

| **Criteria** | **AC generator** | **DC generator** |
|---|---|---|
| Cost | 4 | 7 |
| Available | 5 | 8 |
| Performance | 8 | 8 |
| Weight | 5 | 6 |
| Flow direction | 5 | 8 |
| **TOTAL** | **27** | **37** |

### 3.2.3 Frame material

Based on five criteria relative to each other we decide to use two of the materials selected for the framing. Table 6 shows the materials shortlisted and it's rating. The goal of this part is to minimize the weight and cost while gets the one that is easy to get. Plastic pipe and low carbon steel were chosen to construct the frame. The cost, available, formability and weight of those two materials are the major criteria considered.

**Table 6** Frame material selection table

| **Criteria** | **Plastic pipes** | **Copper wire** | **Low carbon Steel** |
|---|---|---|---|
| Cost | 10 | 6 | 10 |
| Available | 10 | 8 | 10 |
| Quality | 8 | 8 | 6 |
| Weight | 6 | 8 | 8 |
| Formability | 6 | 8 | 8 |
| **TOTAL** | **40** | **38** | **42** |

### 3.2.4 Battery

The battery is chosen based on the major four (4) primary criteria plus the power output of it. From table 7 we can see that the lead type battery has the higher total rating number of criteria value. Although the overall quality of the lithium water battery is batter, the cost of the lithium type battery is one of the major points that made us go for the lead acid battery type.

**Table 7** Battery selection

| **Criteria** | **Lead acid** | **Lithium** |
|---|---|---|
| Cost | 8 | 3 |
| Available | 9 | 5 |
| Quality | 5 | 7 |
| Life span | 8 | 9 |
| **TOTAL** | **30** | **24** |

### 3.2.5 Conductive wire

The conductive wire that was chosen also was based on five criteria from two options, which was shown in table 8. The copper conductive wire has the highest number of material selection as shown in the table below. It is also our best option because it is available in Famagusta.

**Table 8** Selection of conductive wire

| **Criteria** | **Silver** | **Copper** | **Aluminum** |
|---|---|---|---|
| Cost | 4 | 7 | 8 |
| Available | 6 | 8 | 7 |
| Conductivity | 7 | 8 | 9 |
| Quality | 8 | 7 | 4 |
| Resistance | 7 | 7 | 5 |
| **TOTAL** | **32** | **37** | **33** |

### 3.2.6 Robe

The robe that was chosen also was based on 3 criteria, which was shown in table 9. Synthetic was chosen between the two options we had based on its cost and quality as this made its total number goes up.

**Table 9** Selection of rope

| **Criteria** | **Synthetic robe** | **Natural fiber robe** |
|---|---|---|
| Cost | 7 | 7 |
| Available | 5 | 7 |
| Quality | 9 | 4 |
| **TOTAL** | **21** | **18** |

### 3.2.7 Gas

Helium gas was chosen based on four criteria. Based on the requirements of the purpose of the gas in the project, the quality and density of the three gases was used as our primary criteria here. The cost of helium was very high but it has the best quality. It has low density and doesn't react with temperature, and importantly is not a dangerous gas to work with. As seen in table 10 below, helium has a reasonable total rating number and was subsequently chosen for the project.

**Table 10** Gas selection table

| **Criteria** | **Hydrogen gas** | **Helium gas** |
|---|---|---|
| Cost | 4 | 2 |
| Available | 7 | 5 |
| Density | 10 | 9 |
| Quality | 4 | 9 |
| Combustion | 2 | 8 |
| Buoyancy | 9 | 8 |
| **TOTAL** | **36** | **41** |

**Figure 16** Picture of the helium gas and its valve regulator

### 3.2.8 Control mechanism

The control mechanism that is to be use for the control of the height of the system from the ground was selected based on two options and 5 criteria shown in table [3.10]. We have chosen the pulley control mechanism to control the height of the system based on availability and reasonable cost and time management for the system. Also, the complex nature of creating and controlling the remote controller is high since it requires programming and some control units that will add weight to the system in the sky than the simple pulley mechanism.

**Table 11** Control mechanism selection table

| **Criteria** | **Pulley mechanism** | **Controller remote** |
|---|---|---|
| Cost | 5 | 7 |
| Available | 8 | 4 |
| Easy to control | 8 | 5 |
| Simplicity | 9 | 3 |
| **TOTAL** | **30** | **19** |

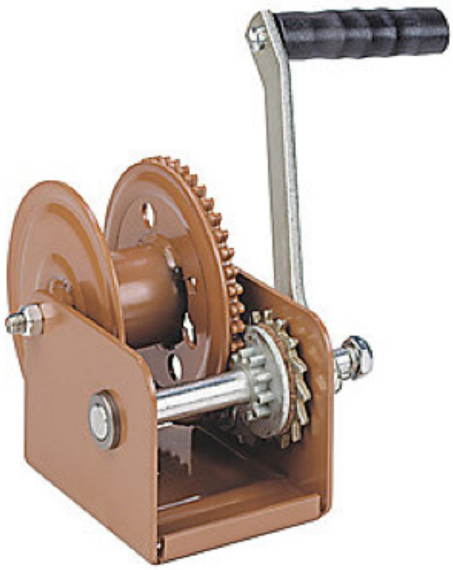


**Figure 17** Winch picture

### 3.3 Cost analysis

Bill of materials table 12 below shows the parts details, quantity, sources and cost of all the materials procured for this project.

**Table 12** Cost analysis of material

| ITEM NO | PART NO | QUANTITY | NAME | SOURCE | COST ($) |
|---|---|---|---|---|---|
| **1** | C282108153 11 | 3 | Tire Balloon | Pirelli tire store, metropol, Lefkosia | **83.60** |
| **2** | NP1.3-12 | 1 | Battery | Ali express | **21.58** |
| **3** | | 1 | Voltage regulator | Ali express | **3.49** |
| **4** | Nil | 200bar cylinder | Helium gas | Linde sanayi bol. 6 sok. No.18, Lefkosia | **454.64** |
| **5** | ZYT51-1200083A | 1 | Generator | Hobby world mainland, China | **17.56** |
| **6** | Nil | 4 | Plastic pipes | Ali electric. | **3.44** |
| **7** | Nil | 6 | Rope | China bazar | **4.13** |
| **8** | Nil | 15 meters | Conductive wire | Ali electrical equipment ltd | **3.45** |
| **9** | Nil | 1 bunch | Metal wire | Ganc shop, industrial area Famagusta | **1.73** |
| **10** | W06-508-2 | 1 | Pulley | Sernaoglu, industrial area, Famagusta. | **41.32** |
| **11** | Nil | 10 | Nuts | | **3.00** |
| **12** | Nil | 25 | Celebration balloons | Deniz plaza EMU | **7.00** |
| **TOTAL** | | | | | **644.94** |

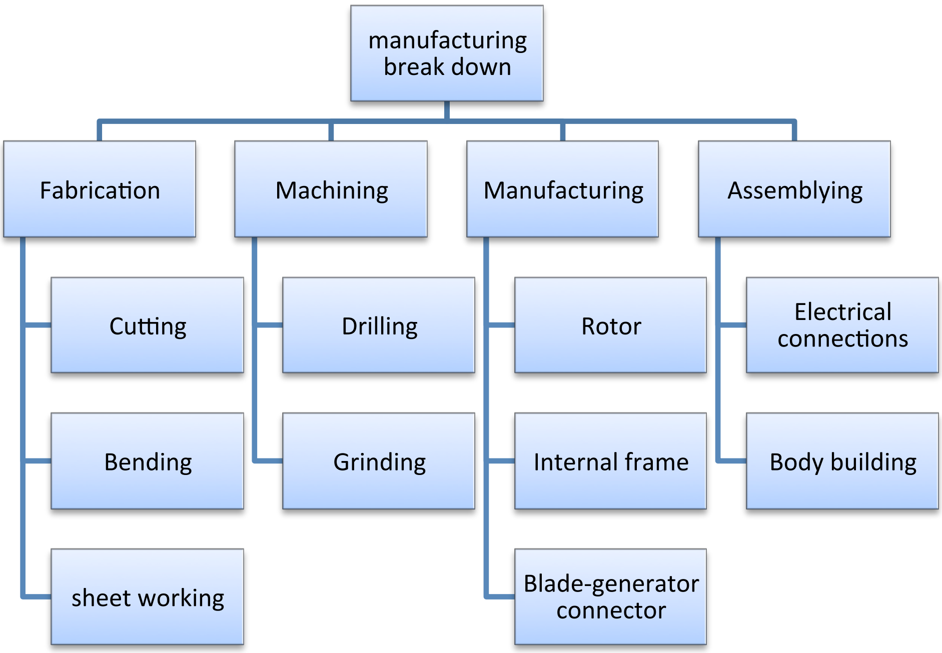
Cost of Transportation and Miscellaneous are estimated at $ 40.00

Grand total $649.72 + $40 = $684.94

# CHAPTER 4

# MANUFACTURING AND ASSEMBLING OF THE MICRO AWT

The materials procured online and locally have to be fabricated, machined before constructing the design. The internal frames, rotor, generator housing and electrical components were the components we had to work on before we got the desired part needed for the project. Below is the manufacturing break down of the manufacturing, fabrications and assembling flow chart.




## 4.1 Manufacturing, Fabrications and Machining

**Supportive frame:** Parts like the rotor and the supportive frame were fabricated from local materials procured in the workshop. PVC pipes of 10mm and internal diameter and 3 meter length were cut using electrical hand cutting machine. The pipes were first cut to 1.5 meter then bended to make a circle of 475 mm diameter.

Using the cutting length is equal to the circumference P, we can write: P=πD and since P=1500mm, the diameter is found to be D=P/π =475mm. Later on, the axial drilling machine of the workshop was used to drill equally 100mm spaced holes with the 2.5mm drill. This holes as stated earlier will undergo the passage of copper wires for connecting the tubes and the pipe with each other with a rollover repeated process. See figure 18 below showing the picture of the fabricated plastic pipe forming the frame support with the copper wire and blade support together.

**Figure 18** picture of the frame support

### 4.1.1 Blade Support Part

The blade support is just a high strength bolted plastic material that was manufactured and mounted on the rotor shaft in order to have the blade fixed. The material selection here account for the lightweight material. The main machining operations here are facing, drilling and turning with the use of Lathe turning machine. The support was drilled at the shaft diameter of 10mm through and then and across drilling at 2mm was also done to allow a 2mm bolt to pass through and reinforce its stability over the shaft. The top surface was facing worked at 45mm diameter and using a protractor, we divided it into three equally angle of 120 degree. After that, along each of the three lines, two holes of 2mm were drilled to achieve the stability of the blades with the use of nut and bolt system (see figure 19 below). Keeping the diameter of the top surface at 35mm and 3mm thickness, the remaining part down was turning- worked to reduce the diameter that will account for decreasing the weight and kept at 16mm. The total length of the support was kept at 50mm with facing operation.

**Figure 19** Picture of blade support with the rotors mounted on it

### 4.1.2 Rotor

PVC Pipes that are use for water drainage in a house building were used for the manufacturing of the rotor. Based on some videos from the YouTube and documents given to us by our supervisor we bought some pipes of 100mm diameter. We divided pipes longitudinally to get two semi circular parts on each pipe using electrical hand cutting machine. The design of the shape of the rotor was later drawn using a protractor, a divider and pencil the layout was able to be drawn on the semi circles keeping one edge straight and taking it as reference, we were able to cut the other edge to an angle of 45degree to achieve a twist as seen in figure 4.3 and 4.4 below. Importantly, the twist angle is fundamental in achieving high-pressure difference over the blades, which help in achieving high rpm. The bottom of the blades modified at an angle of 120degree from a shift of 10mm away from the reference edge layout. More over, using a drilling machine a 2mm holes were drilled o the bottom of the rotor which will be use to connect the rotor and the generator by the blade support part. Lastly a grinding machine was used on the designed rotor to smoothen and reduce the thickness of 2-3 mm of the rotor so that the weight will reduce (see figure 20 and 21 below).

**Figure 20** Picture of one of the manufactured rotors

**Figure 21** Mounted rotors (blades)

**Table 13** physical properties of polyvinyl chloride

| Property | Rigid PVC | Flexible PVC |
|---|---|---|
| Density [g/cm^3] | 1.3 -1.45 | 1.1 -1.35 |
| Thermal conductivity | 0.14-0.28 | 0.14-0.17 |
| Yield strength | 4500- 8700 | 1450 – 3600 |
| Young's modulus | 490000 | |

### 4.2 Assembling

The project parts assembling were divided into two categories: body building and electrical connections assembling.

#### 4.2.1 Frame building

After the procurement of the parts, fabrications and machining, we started connecting the generator with the blade support together to test run of the rotor and the generator together. Later on, we used 2 clamps (from the top and bottom) to assemble the generator and fabricated sheet metals. The sheet metals were arranged on top of the generator extending its bended section vertically so that it can be connected with the copper wire spokes. The copper wire were passed through the pipes and extended to the fabricated sheet metals and tighten up. Furthermore, we then passed the copper wires to the remaining drilled holes on the pipes. More so, we then inflate the tubes with helium gas until the reaches their maximum volume. Initially the total weight of the 7.6 kg and each tube was weighing 1.6 kg, which is a bad thing because after inflating them with helium, the weight only reduced by 0.4 kg. The tubes weight was a major hindrance for our work, instead of the tube to start fly after filling them with the helium gas; they remain static on the ground. We wanted to mount the rotor on the center of the 3 tubes, but this problem made us modified our design and reduced the number of tubes. We reduced the tubes number from 2 to 1 tube and re assembled the generator and the pipes on it. Two pipes were now used on both sides of the tube while the generator and the rotor were arranged at the center of the tube as seen in figure 22 below. Two Ropes were tired to the tube from left and right of the tube to provide support for the turbine when it's in the sky.

**Figure 22** Complete assembled AWT system

### 4.2.2 Electrical connections

A 15-meter conductive copper wire was used to connect the generator down to the battery. One end of the generator is to be connected to the conductive wire while the other end is going to be where the rotor is going to be mounted on. The wire was twisted and tired on one of the rope providing support to the system and passed down to the micro controller. All the power generated from the generator is then transferred to the micro controller. From the micro controller two wires goes out, one wire is passed and connected to the voltage regulator where it was passed and connected to the battery storage. The other wire is connected to the computer to read, record and process the data coming from the rotor.

### 4.2.3 Micro-controller programming

Math-lab software was used to help us in recording, storing, and processing the data. Making use of the micro- controller in this project was very helpful in read the voltage, revolution per minute (RPM) velocity and power of the system. Very accurate reading the micro-controller was programmed at a time leap of 0.1sec per reading, therefore after 100seconds the data that could be read in the system was about a thousand. The reason for making use of the micro-controller is that it is more reliable than the anemometer.

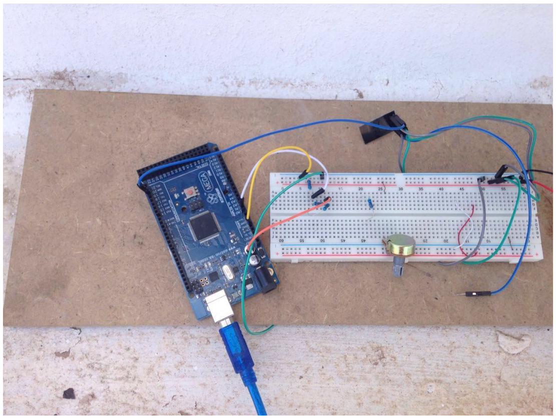


**Figure 23** micro controller pictures

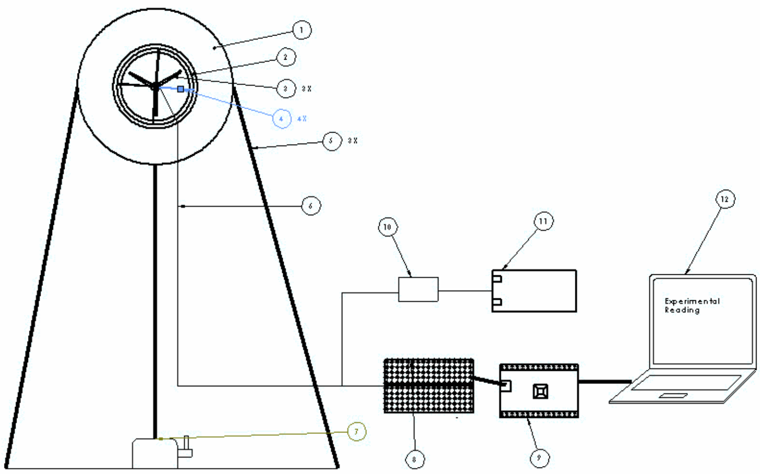



**Figure 24** Complete System connections

Figure 24 shows the complete assembled of all the mechanical components and the electrical connection. It shows how the wind energy generated by the rotor blades (3) is being transferred by the conductive wire (6) to the circuit breaker (9) to be stored b the battery (11).

1. Helium filled tire tube
2. Plastic pipe PVC
3. Rotor blades
4. Carbon steel wire
5. Ropes
6. Copper conductive wire
7. Pulley
8. Circuit breaker
9. Micro controller
10. Voltage regulator
11. Battery

# CHAPTER 5

# RESULTS, DISCUSSION AND TECHNICAL DIFFICULTIES

## 5.1 Results

After assembled the parts together, the Math lab code which is shown in appendix D was run as mentioned earlier in chapter 4 to achieve the graphs of the voltage, RPM and velocity with respect to time for three different heights of (8,10,12) meters.

### 5.1.1 First experiment

The first experiment was carried out at a height of 8 meter and the results are shown in table 14 below, it was recorded that at a very low wind speed the rotor stops. The actual readings from the math-lab coding were the RPM, and voltage. The tip speed ratio and power coefficient are calculated using equation 3.26 and 3.27 respectively. The result will be taken at a time differences of 100 millisecond.

**Table 14** Experiment one readings

| time (sec) | wind turbine velocity (m/s) | wind velocity (m/s) | Power coefficient (CP) | Tip speed ratio (TSR) | RPM | Voltage (V) |
|---|---|---|---|---|---|---|
| 0 | 10.097 | 13.012 | 0.5369 | 0.775976 | 438.28 | 21.914 |
| 10 | 15.227 | 18.12 | 0.451 | 0.840342 | 660.94 | 33.047 |
| 20 | 0.972 | 3.94 | 0.181 | 0.246701 | 42.19 | 2.1094 |
| 30 | 0 | 3.3 | 0 | 0 | 0 | 0 |
| 40 | 0 | 3.5 | 0 | 0 | 0 | 0 |
| 50 | 20.951 | 23.11 | 0.3071 | 0.906577 | 935.156 | 45.469 |
| 60 | 13.715 | 16.65 | 0.479 | 0.823724 | 595.313 | 29.765 |
| 70 | 0 | 2.34 | 0 | 0 | 0 | 0 |
| 80 | 1.259 | 4.4 | 0.2338 | 0.286136 | 39.844 | 1.99 |
| 90 | 8.315 | 11.11 | 0.564 | 0.748425 | 360.9375 | 18.0469 |
| 100 | 11.609 | 14.34 | 0.499 | 0.809554 | 503.91 | 25.196 |

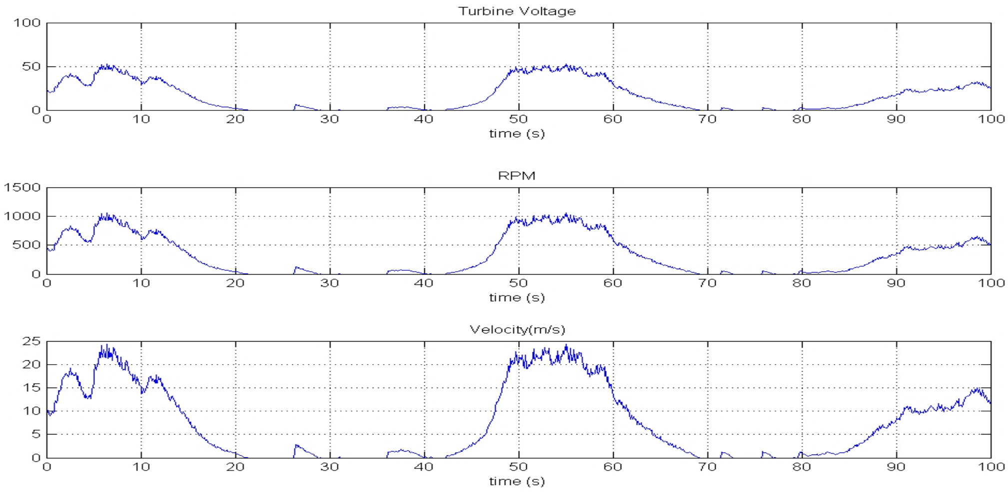



**Figure 25** Graphs of the voltage, RPM and velocity respectively.

As shown in figure 25 below is the power curve and Power coefficient Cp verses tip speed ratio TSR curve for Experiment one in figure 24 and figure 25 below.

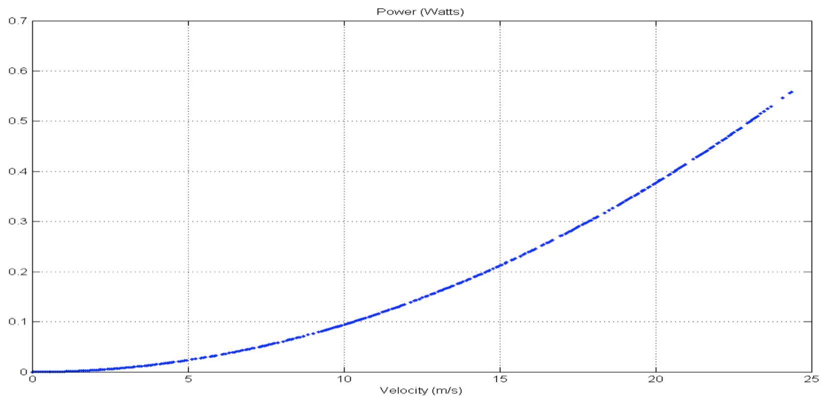



**Figure 26** Power versus time graph

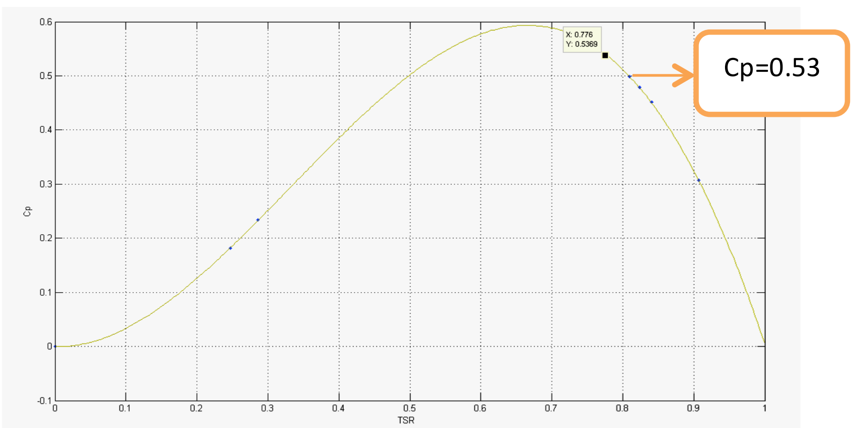



**Figure 27** Power coefficient versus tip speed ratio graph

The maximum power coefficient recorded from the system as shown in figure 27 was (Cp= 0.53) and this is considered valid since the maximum power coefficient recorded from an ideal wind turbine is approximately 0.59

### 5.1.2 Second experiment

At 10 meters height, we were able to achieve these results.

**Table 15** Readings for experiment two

| time (sec) | voltage(V) | RPM | wind turbine velocity(m/s) | wind velocity(m/s) | Cp | TSR |
|---|---|---|---|---|---|---|
| 0 | 24.726563 | 494.5313 | 11.39318211 | 14.393 | 0.52239 | 0.79156 |
| 10 | 21.445313 | 428.9063 | 9.881290643 | 12.8812 | 0.54818 | 0.76710 |
| 20 | 21.914063 | 438.2813 | 10.09727514 | 13.0972 | 0.54456 | 0.77094 |
| 30 | 21.679688 | 433.5938 | 9.989282891 | 12.9892 | 0.54637 | 0.7690 |
| 40 | 0.46875 | 9.375 | 0.215984495 | 3.44798 | 0.01471 | 0.06264 |
| 50 | 0 | 0 | 0 | 2.223 | 0 | 0 |
| 60 | 5.2734375 | 105.4688 | 2.429825568 | 4.52982 | 0.53356 | 0.5364 |
| 70 | 0 | 0 | 0 | 1.45 | 0 | 0 |
| 80 | 0.9375 | 18.75 | 0.43196899 | 1.55196 | 0.22363 | 0.27833 |
| 90 | 2.109375 | 42.1875 | 0.971930227 | 2.97193 | 0.28790 | 0.32703 |
| 100 | 6.796875 | 135.9375 | 3.131775177 | 6.33177 | 0.49455 | 0.49461 |

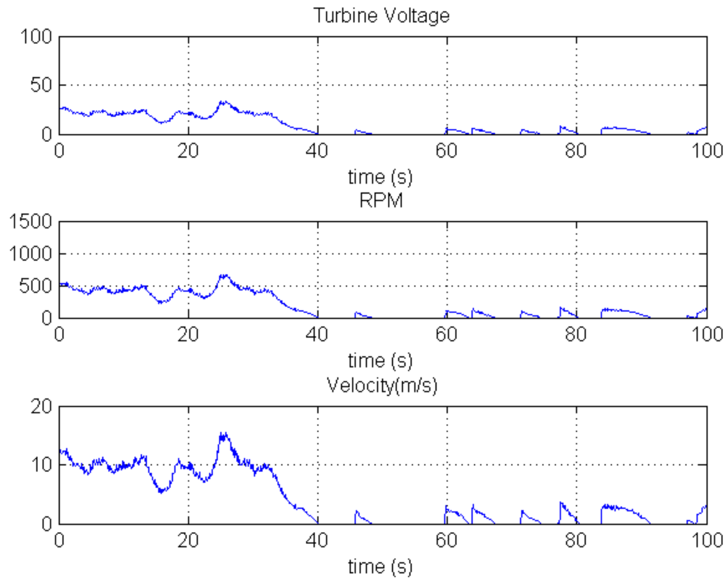



**Figure 28** Graphs of the voltage, RPM and the velocity respectively

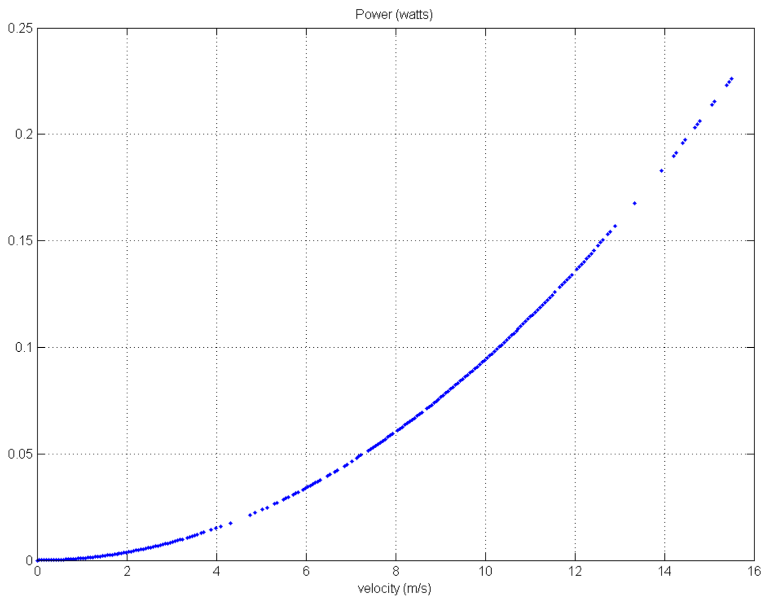



**Figure 29** Power versus time graph

### 5.1.3 Third experiment

At 12-meter height, the values gotten from the voltage regulator and MatLAB are shown below.

**Table 16** Experiment three readings

| Time (s) | Wind Turbine voltage (Volts) | RPM | wind turbine Velocity (m/s) | wind velocity | TSR | Cp |
|---|---|---|---|---|---|---|
| 0 | 4.3359375 | 86.718 | 1.997856 | 4.997856 | 0.399743 | 0.383671 |
| 10 | 0.234375 | 4.687 | 0.107992 | 2.107992 | 0.05123 | 0.00996 |
| 20 | 9.9609375 | 199.218 | 4.589670 | 8.129670 | 0.564558 | 0.555146 |
| 30 | 44.1796875 | 883.593 | 20.35653 | 22.65653 | 0.898484 | 0.327805 |
| 40 | 13.828125 | 276.562 | 6.37154 | 8.771542 | 0.726388 | 0.577474 |
| 50 | 0 | 0 | 0 | 2 | 0 | 0 |
| 60 | 4.1015625 | 82.031 | 1.889864 | 4.889864 | 0.386486 | 0.366566 |
| 70 | 4.8046875 | 96.093 | 2.21384 | 4.558841 | 0.485615 | 0.485213 |
| 80 | 0 | 0 | 0 | 2 | 0 | 0 |
| 90 | 0.234375 | 4.6875 | 0.10799 | 3.107992 | 0.034747 | 0.004662 |
| 100 | 0 | 0 | 0 | 1 | 0 | 0 |

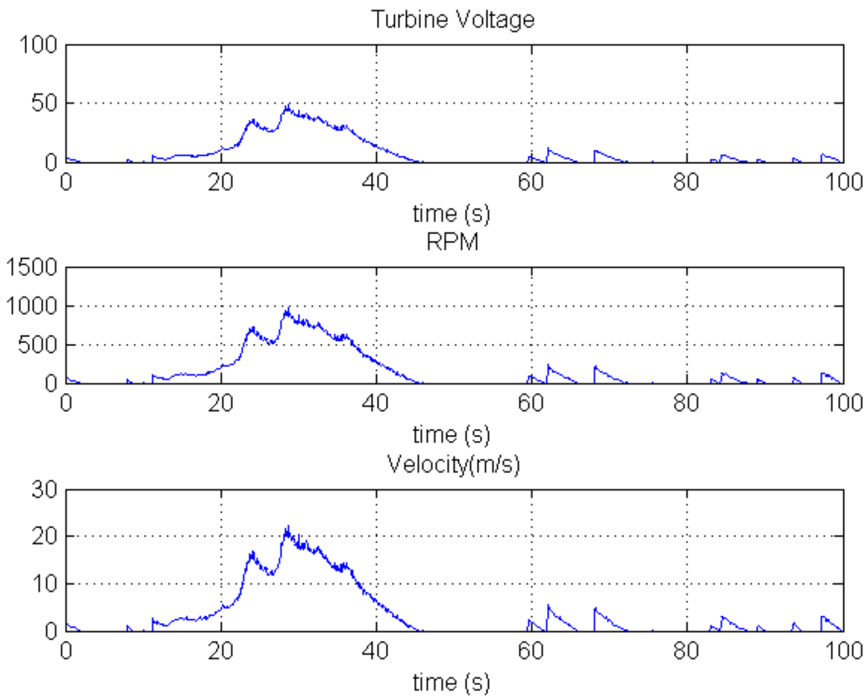



**Figure 30** Voltage, RPM and velocity graphs of third experiment

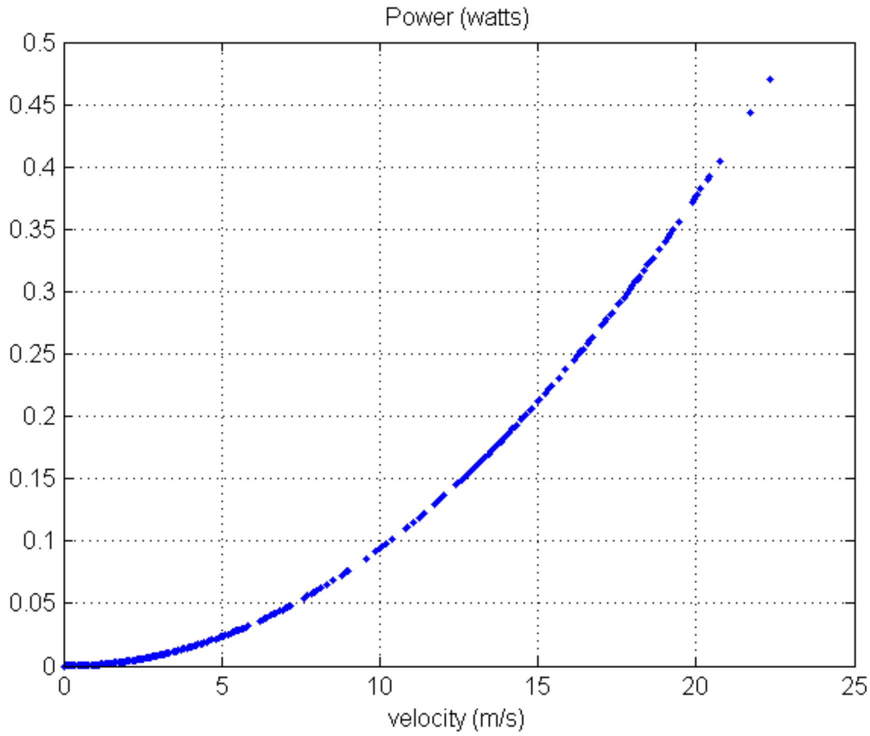



**Figure 31** Power versus time graph of the third experiment

### 5.2 Discussion

The mathlab graphs above help to understand the workability of the system as voltage, RPM, velocity and power are regarded for different heights. An observation of the graphs helps to understand that as there is a change in the wind speed , there is also changes in the power output. For this reason the voltage regulator is required to stablise the voltage flowing in to the battery. Also the result shows us how excellenct the micro-controller can be in storing datas. It records the voltage, power,RPM, and velocity of the blades every hundred millseconds (0.1sec) and very accurate. On the longer run airborne wind turbine can be one of the best renewable energy source in the history of man.

### 5.3 Technical difficulties and innovation in the design

The micro AWT was successfully manufactured. But, it is also important to acknowledge the difficulties that were encountered during the manufacturing and assembling. Initially, the design was meant to be with three tubes as shown in figure 5.1. The reason for initially selecting a three-tube design was for stability and to increase the lift force, but that was skipped early stage of the production due to weight of the system ranging at about 5.7kg in total. Secondly, two tubes –design was adopted as shown in figure 24 as a considerable design but still there was no improvement since no matter much volume we inflated the tubes with helium, it could not fly. Finally, the idea was to use only one tube and inflate it enough with having around it a series of balloons inflated with helium as shown in figure 5.8.Aside that, we have to say that tire tubes idea was adopted because we could not find very light balloon material as we thought initially.

**Figure 32** initial concepts of three tubes

Figure 32 shows the initial design of three tubes filled with helium but since the tube were very heavy, restricting the vertical elevation of the system, also figure 32 and figure 33 shows the modification of this design in other to come up with a more appropriated design.

**Figure 33** Two tubes concept


**Figure 34** Final design concept

## 5.4 PRODUCT BREAKDOWN STRUCTURE

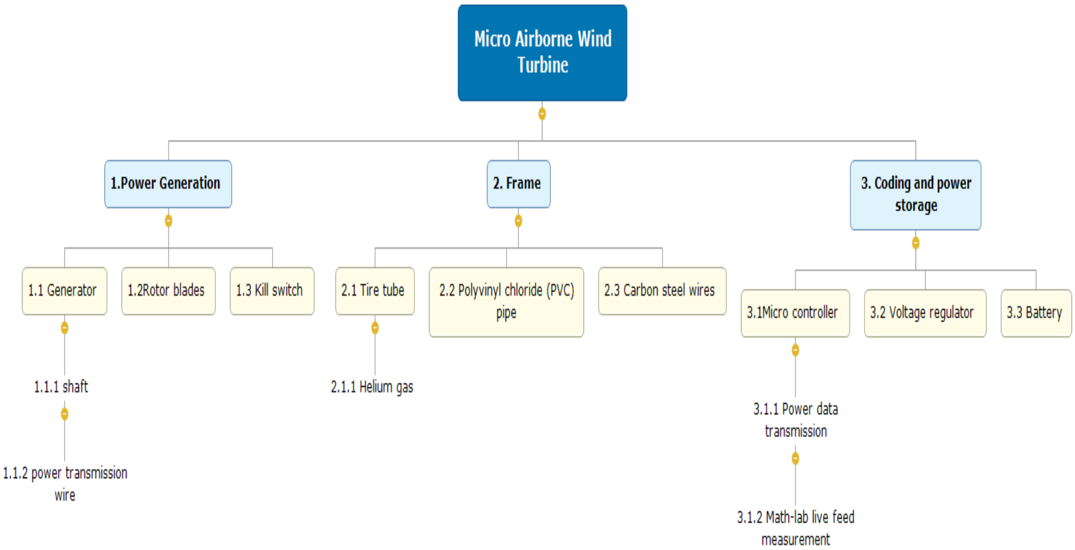



**Figure 35** Product break down structure of the system

# CHAPTER 6

# CONCLUSION AND FUTURE WORK

## 6.1 Conclusion

This project was about design and manufacturing of a small-scale airborne wind turbine from cost efficient material with a target output power of about 50 watts. After all the tasks carried out notably the mathematical calculations, parts drawing and assembling of the parts, parts procurement and at last manufacturing and assembling that helps to achieve a testing at various heights with the department roof taken as reference (2 meters, 4 meters and 6 meters from the roof level where the roof is at about 6 meter above the ground) we come to a conclusion with no risk of mistake that an airborne wind turbine is implementable in the real life and appear to have more advantage than the conventional static wind turbine. In fact, it is cheaper than the conventional one at the investment (investment cost), but may have more maintenance cost on the long run in the sense that as it flying in the air, it can encounter collision with flying object and bird that may affect the balloon and the blades necessitating maintenance. Besides, at high altitudes on a sunny day all the balloons might explode due to expansion of the confined helium. Moreover, as they go in altitude, the wind speed increase and this will account for more power output which is desired. However, we have to mention that this manufactured AWT could be made more sophisticated depending on some factors and this is opened to potential volunteer for future work that will be explained in the next part.

## 6.2 Future work

After the testing, we have seen the manufactured airborne wind turbine working at the expected power of 50 watts. As we earlier mentioned, the small scale manufactured AWT was achieved based on the materials we were able to procure easily here in Cyprus and from online sales. However, this project could be made perfect to be able to have a full design for manufacturing that will be massively produced and marketed at commercial surfaces for domestic, office and industrial use.

Consequently, we have to take into account some parameters namely the control mechanism as well as the materials selection. Indeed, as the control mechanism is concerned, the height control could be managed using a small AC motor that will be electrically powered to unfold and fold the tether on the pulley gear-connected to motor shaft. A kite could also be used to on top of the tube still for the purpose of increasing the lift and the floating of the system in the air. Regarding the material selection, a striving for more lightweight materials so that the pressurized helium in the balloons and tube will be able to reduce the weight and this will allow the system to float better and move in desired higher altitudes. To account for this, the tired tube could be replaced by more light tube meaning that the tube should have less thickness. This will be a supportive driving force in increasing the number of tubes. For a three tubes design for example that we had initially, the motor could be mounted on the middle PVC pipe to have more balance of the system. In our project, we used a passed semester group's anemometer cup type with a rotating wind vane behind to know the wind direction that we could not implement directly into our design during the production due weight increment. Therefore, light plastic or wooden sheet could be mounted at the back of the generator attached on the backside copper wire supports in the same direction to act like fin for direction control (two sheets for example in two diametrically opposite supports). Aside that, to account for more torque input at the generator, a small plastic material gear mechanism can be machined with a convenient gear ratio and mounted between the blade support shaft and the generator shaft.

# REFERENCE


[1] US Department of Technology (March 2014). *Wind Power Today and Tomorrow* .Retrieved on May 25, 2016 from: http://www.nrel.gov/docs/fy04osti/34915.pdf

[2] Theresher M. & Robinson M. (March 1-2, 2008). *Wind Energy Status and R& D Future.* Retrieved on May 25, 2016 from: http://www.nrel.gov/docs/fy08osti/43374.pdf

[3] Behance (Oct 22, 2012). Retrieved on December 28, 2015 from https://www.behance.net/pikcells/appreciated

[4] Wind Energy Outlook 2015: Could Total Installed Wind Capacity Reach 2,000 GW by 2030? By David Appleyard. http://www.renewableenergyworld.com/articles/2015/02/wind-energy-outlook-2015-could-total-installed-wind-capacity-reach-2000-gw-by-2030.html

[5] Airborne wind turbine http://windturbinezone.com/wind-turbine/airborne-wind-turbine

[6] Wikipedia https://en.wikipedia.org/wiki/Airborne_wind_turbine

[7] Z. Zong, H. L. (2006). A three-dimensional human head finite element model and power flow in a human head subject to impact loading. *Journal of Biomechanics 39* , 284–292.

[8] Samuel P., "wind turbine selection" A case studies for Búrfell, Iceland. January 2014.

[9] David S., "An investigation into integration of renewable energy source for electricity generation a case in Cyprus'' Thesis report. February 2013. Pp35-40

[10] alternative energy., upadated December 2015., www.alternative-energy-tutorials/wind-energy/wind-turbine-design.html.

[8] M Ragheb, 2010 Airborne wind turbine concepts. Retrieved on 11, November 2015. http://mragheb.com/NPRE%20475%20Wind%20Power%20Systems/Airborne%20%20Wind%20Turbine%20Concepts.pdf

[11] World's First Airborne Wind Turbine to Bring Renewable Energy and WiFi to Alaska

http://inhabitat.com/worlds-first-airborne-wind-turbine-to-bring-renewable-energy-and-wifi-to-alaska/

[12] M.L. Loyd **Crosswind kite power (for large-scale wind power production)** J Energy, 4 (3) (1980), pp. 106–111. Full Text via CrossRef. View Record in Scopus. Citing articles (141)

[14] Airborne Wind Energy Systems: A review of the technologies Copyright 2015 by The Authors. http://www.sciencedirect.com/science/article/pii/S1364032115007005

[15] Abo-Khalil, A. G. (2011). A new wind turbine simulator using a squirrel-cage motor for wind power generation systems. *IEEE Ninth International Conference on Power Electronics and Drive Systems (PEDS)*, 750-755.

[16] Argatov, I., Rautakorpi, P., Silvennoinen, and R: Estimation of the mechanical energy output of the kite wind generator. Renewable Energy 34(6), 1525–1532 (2009).

[17] Furkan E. Mehmet Y. & Murat F (Oct 2013). *Method and Case Study for Wind Power Assessment in Cyprus*. Retrieved on May 28, 2016 from https://www.researchgate.net/publication/264858404_Method_and_Case_Study_for_Wind_Power_Assessment_in_Cyprus

[18] Fundamentals of Physics 6th ed, Halliday, Resnick & Walker p. 330

[19] Cartier, A., Murphy, E., Perullo, T., Tomasko, M. (2010). *Re-Design and Testing of the WPI Kite Power System.* (MQP Report, Worcester Polytechnic Institute).

[20] Meteorological Service Website, Climate of Cyprus [online], Ministry of Agriculture and Natural Resources, Republic of Cyprus, Available at: http://www.moa.gov.cy/moa/ms/ms.nsf/All/DA0B0C1B609E174FC22578E2002BCF6B?OpenDocument&highlight=wind

[21] Material process selection chart. Ashby chart. 2009. Retrieved 04 June 2016. http://www.mie.uth.gr/ekp_yliko/2_materials-charts-2009.pdf

# APPENDIX

## APPENDIX A

**LOGBOOK**

NAME: **LUKMAN MAISHANU**

STUDENT NUMBER: **118427**

| **Accomplished** | Dates |
|---|---|
| Project proposal to ASSIST. PROF. DR. NERIMAN OZADA. | 14-10-2015 |
| MEETING: FIRST MEETING WITH GROUP MEMEBERS. | 22-10-2015 |
| MEETING: DISCUSSION ON DESIGN CONCEPT SELECTON. | 23-10-2015 |
| MEETING: WORK DISTRIBUTION BETWEEN MEMBERS. | 03-11-2015 |
| MEETING: ENGINEERING AND MATERIAL SELECTION MEETING. | 20-11-2015 |
| WRITING OF CHAPTER TWO. LITERATURE REVIEW. | 11-11-2015 |
| WRITING OF CHAPTER TWO. LITERATURE REVIEW CONTINUED. | 02-12-2015 |
| MEETING: COST ANALYSIS. | 22-12-2015 |
| REPORT CHECKING AND COMPLILATION BY MEMBERS. | 25-12-2015 |
| MATERIAL ACQUIRING: ONLINE ORDER. | 20-02-2016 |
| MATERIAL ACQUIRING: PULLEY MECHANISM, PIPES AND TUBES IN MAGUSA. | 02-03-2016 |
| MEETING: DESIGN FABRICATION AND ASSEMBLY WITH MEMBERS. | 08-03-2016 |
| MEETING: MEMBERS MEETING WITH SUPERVISOR ASSOC. PROF. DR. QASIM. | 20-03-2016 |
| FABRICATION: CONSTRUCTION OF ROTOR AND INTERNAL FRAME. | 27-03-2016 |
| MATERIAL ACQUIRING: HELIUM GAS IN LEFKOSIA | 26-04-2016 |
| FABRICATION AND ASSEMBLING OF PARTS. | 04-04-2016 |
| MEETING: FINDING SOLUTION ON PROBLEMS FACED FROM THE DESIGN; HELIUM AND TUBE. | 15-04-2016 |
| MATERIAL ACQUIRING: FLOATING TUBE BALOON FROM SOUTH CYPRUS | 06-05-2016 |
| FABRICATION: DESIGN MODIFICATION | 10-05-2016 |
| REPORT REVIEWED | 17-05-2016 |
| WRITING: CHAPTER FOUR. MANUFACTURING AND ASSEMBLING PROCESS | 24-05-2016 |
| ASSEMBLING OF DESIGN | 31-06-2016 |
| FABRICATION: CONCEPT MODIFICATION | 3-06-2016 |
| TESTING BY MEMBERS, SUPERVICED BY DR. PROF.QASIM | 07-06-2016 |
| WRITING: REPORT COMPILATION AND REVIEWED | 07-06-2016 |

NAME: **EMMANUEL CHIWUZIE**

STUDENT NUMBER: **118318**

| **Accomplished** | Dates |
|---|---|
| Project proposal to ASSIST. PROF. DR. NERIMAN OZADA. | 14-10-2015 |
| MEETING: FIRST MEETING WITH GROUP MEMEBERS. | 22-10-2015 |
| MEETING: DISCUSSION ON DESIGN CONCEPT SELECTON. | 23-10-2015 |
| MEETING: WORK DISTRIBUTION BETWEEN MEMBERS. | 03-11-2015 |
| MEETING: ENGINEERING AND MATERIAL SELECTION MEETING. | 20-11-2015 |
| WRITING OF CHAPTER THREE. DESIGN MANUFACTURING AND DESIGN. | 11-11-2015 |
| MEETING: COST ANALYSIS. | 22-12-2015 |
| REPORT CHECKING AND COMPLILATION BY MEMBERS. | 25-12-2015 |
| MATERIAL ACQUIRING: ONLINE ORDER. | 20-02-2016 |
| MATERIAL ACQUIRING: PULLEY MECHANISM. | 02-03-2016 |
| MEETING: DESIGN FABRICATION AND ASSEMBLY WITH MEMBERS. | 08-04-2016 |
| MEETING: MEMBERS MEETING WITH SUPERVISOR ASSOC. PROF. DR. QASIM. | 20-03-2016 |
| FABRICATION: CONSTRUCTION OF ROTOR AND INTERNAL FRAME. | 27-03-2016 |
| MATERIAL ACQUIRING: HELIUM GAS IN LEFKOSIA | 26-04-2016 |
| FABRICATION AND ASSEMBLING OF PARTS. | 04-04-2016 |
| MEETING: FINDING SOLUTION ON PROBLEMS FACED FROM THE DESIGN; HELIUM AND TUBE. | 15-04-2016 |
| MATERIAL ACQUIRING: FLOATING TUBE BALOON FROM SOUTH CYPRUS | 06-05-2016 |
| FABRICATION: DESIGN MODIFICATION | 10-05-2016 |
| REPORT REVIEWED | 17-05-2016 |
| WRITING: CHAPTER FOUR. TESTING CODES (MATLAB) | 24-05-2016 |
| DRAWING: DRAWINGS MODIFICATIONS | 26-06-2016 |
| ASSEMBLING OF DESIGN | 31-06-2016 |
| FABRICATION: CONCEPT MODIFICATION | 3-06-2016 |
| TESTING BY MEMBERS, SUPERVICED BY DR. PROF.QASIM | 07-06-2016 |
| WRITING: CHAPTER FIVE. RESULTS AND DISCUSSIONS | 07-06-2016 |

NAME: **ERIC LE ROY NGWOPE**

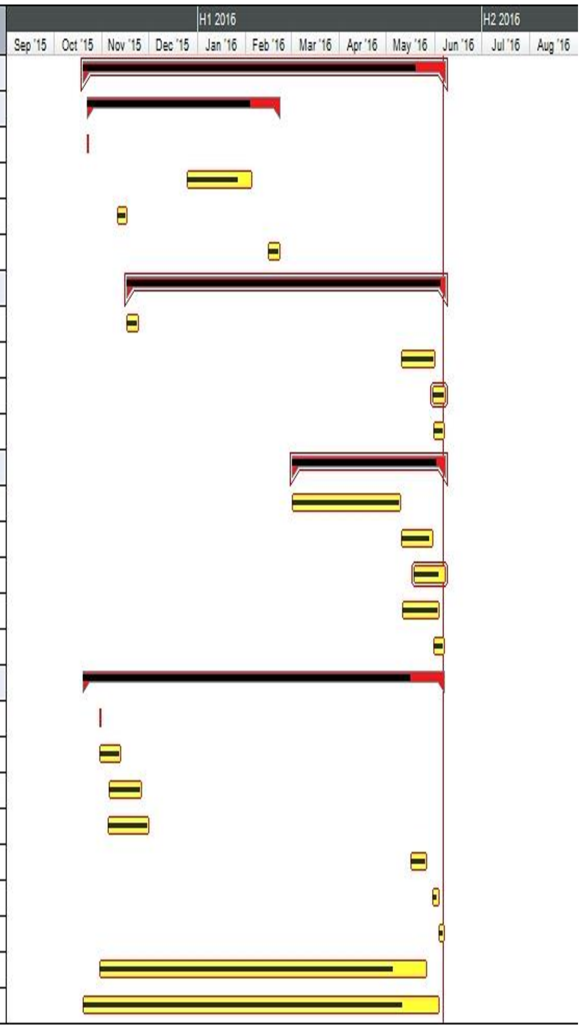
STUDENT NUMBER: **118328**

| **Accomplished** | Dates |
|---|---|
| Project proposal to ASSIST. PROF. DR. NERIMAN OZADA. | 14-10-2015 |
| MEETING: FIRST MEETING WITH GROUP MEMEBERS. | 22-10-2015 |
| MEETING: DISCUSSION ON DESIGN CONCEPT SELECTON. | 23-10-2015 |
| MEETING: WORK DISTRIBUTION BETWEEN MEMBERS. | 03-11-2015 |
| MEETING: ENGINEERING AND MATERIAL SELECTION MEETING. | 20-11-2015 |
| REPORT WRITING: CHAPTER ONE. INTRODUCTION REVIEW. | 11-11-2015 |
| REPORT WRITING: DESIGN DRAWING USING SOLID WORKS. | 19-12-2015 |
| MEETING: COST ANALYSIS. | 22-12-2015 |
| REPORT CHECKING AND COMPLILATION BY MEMBERS. | 25-02-2016 |
| MATERIAL ACQUIRING: ONLINE ORDER. | 20-02-2016 |
| MATERIAL ACQUIRING: PULLEY MECHANISM IN MAGUSA. | 02-03-2016 |
| MEETING ON DESIGN FABRICATION AND ASSEMBLY WITH MEMBERS. | 08-03-2016 |
| FABRICATION: CONSTRUCTION OF ROTOR AND INTERNAL FRAME. | 27-03-2016 |
| FABRICATION AND ASSEMBLING OF PARTS. | 10-05-2016 |
| REPORT REVIEWED | 17-05-2016 |
| ASSEMBLING OF DESIGN | 31-06-2016 |
| FABRICATION: CONCEPT MODIFICATION | 3-06-2016 |
| TESTING BY MEMBERS, SUPERVICED BY DR. PROF.QASIM | 07-06-2016 |
| WRITING: CHAPTER SIX. CONCLUSION. | 07-06-2016 |

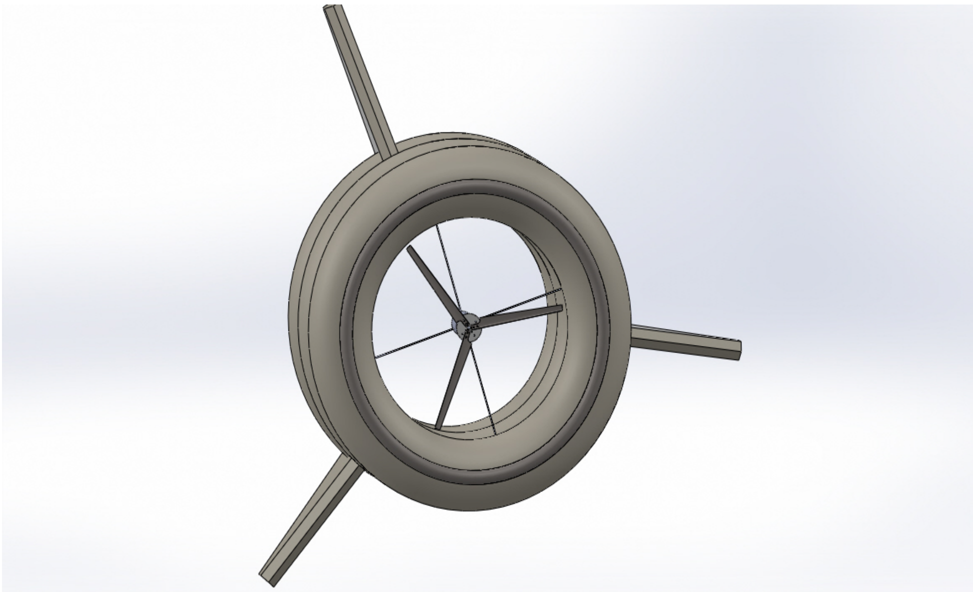
APPENDIX-B

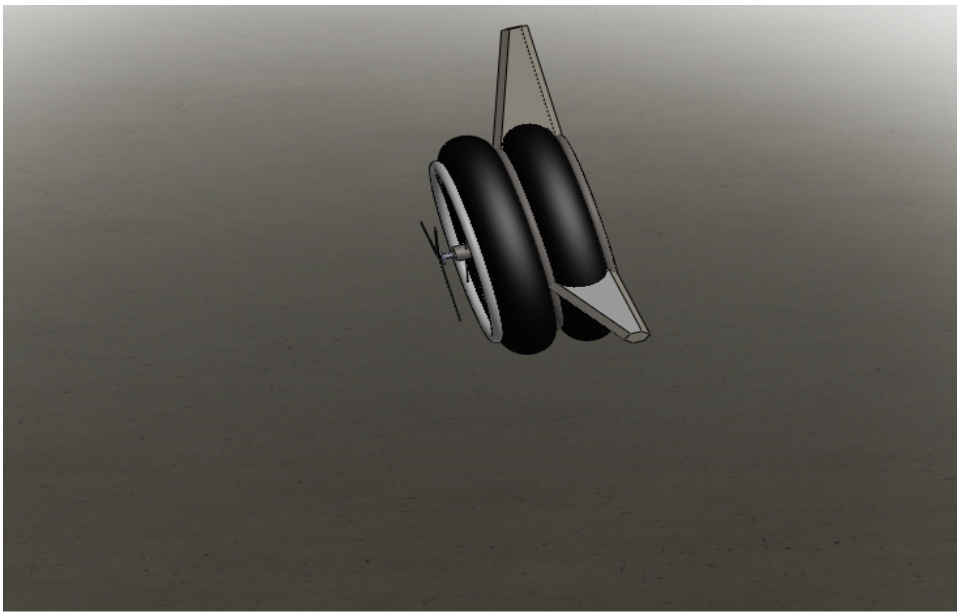
Gantt chart

| | | Task Mode | Task Name | Duration | Start | End | Completion |
|---|---|---|---|---|---|---|---|
| 1 | | | Micro airborne wind turbine. | 167 days? | 10/19/2015 | 6/7/2016 | 92% |
| 2 | | | Project analysis | 88 days? | 10/22/2015 | 2/22/2016 | 85% |
| 3 | | | Aim and objectives | 1 day? | 10/22/2015 | 10/22/2015 | 100% |
| 4 | | | Material selections | 30 days | 12/25/2015 | 2/4/2016 | 80% |
| 5 | | | Engineering solution | 5 days | 11/10/2015 | 11/16/2015 | 90% |
| 6 | | | Cost analysis | 6 days | 2/15/2016 | 2/22/2016 | 100% |
| 7 | | | Design | 147 days | 11/16/2015 | 6/7/2016 | 99% |
| 8 | | | Design concept | 6 days | 11/16/2015 | 11/23/2015 | 100% |
| 9 | | | Design drawing using solidworks | 16 days | 5/10/2016 | 5/31/2016 | 100% |
| 10 | | | Design modifications | 7 days | 5/30/2016 | 6/7/2016 | 100% |
| 11 | | | Design drawing modifications | 5 days | 5/31/2016 | 6/6/2016 | 90% |
| 12 | | | Fabrications | 71 days | 3/1/2016 | 6/7/2016 | 95% |
| 13 | | | Material purchases | 50 days | 3/1/2016 | 5/9/2016 | 100% |
| 14 | | | Manufacturing | 15 days | 5/10/2016 | 5/30/2016 | 90% |
| 15 | | | Machining of parts | 15 days | 5/18/2016 | 6/7/2016 | 80% |
| 16 | | | Assembling of parts | 18 days | 5/11/2016 | 6/3/2016 | 100% |
| 17 | | | Testing | 5 days | 5/31/2016 | 6/6/2016 | 90% |
| 18 | | | Report writing | 166 days? | 10/19/2015 | 6/6/2016 | 91% |
| 19 | | | Abstract | 1 day? | 10/30/2015 | 10/30/2015 | 100% |
| 20 | | | Chapter 1- Introduction | 10 days | 10/30/2015 | 11/12/2015 | 100% |
| 21 | | | Chapter 2- Literature Review/ Bac... | 15 days | 11/5/2015 | 11/25/2015 | 100% |
| 22 | | | Chapter 3- Design and Analysis | 19 days | 11/4/2015 | 11/30/2015 | 100% |
| 23 | | | Chapter 4- Manufacturing Assemb... | 9 days | 5/16/2016 | 5/26/2016 | 100% |
| 24 | | | Chapter 5- Result and Discussion | 5 days | 5/30/2016 | 6/3/2016 | 80% |
| 25 | | | Chapter 6- Conclusions and Futur... | 2 days | 6/3/2016 | 6/6/2016 | 90% |
| 26 | | | References | 150 days | 10/30/2015 | 5/26/2016 | 90% |
| 27 | | | Log Book | 165 days | 10/19/2015 | 6/3/2016 | 90% |



**APPENDIX-C**





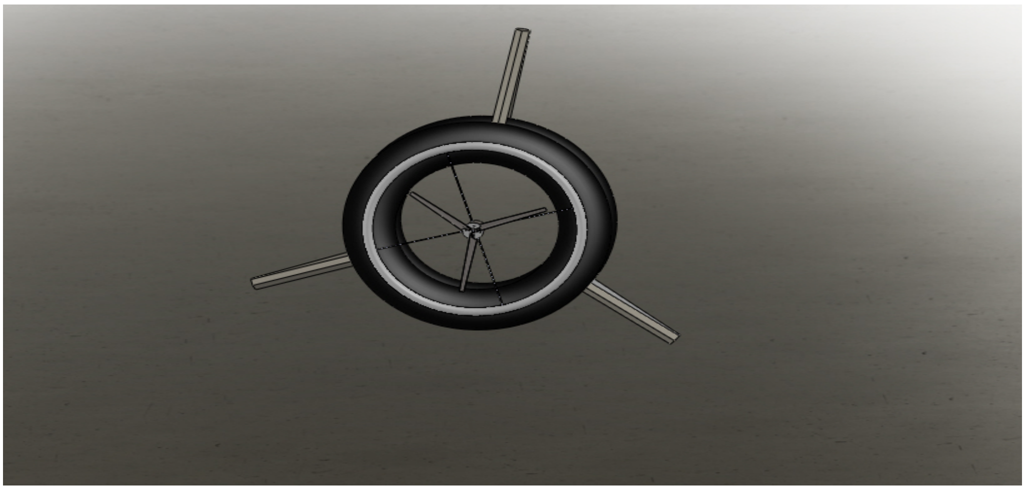


Figure solid work drawing

**APPENDIX D**

Math-lab coding of the microcontroller

```
%% WindTurbine
% This script establishes a serial connection with the arduino at a
% specified comPort and recursively reads the ADC values from the
arduino
% and modifies it with some specific equations to obtain the voltage
and RPM
% of the wind turbine

clear all
close all

%% Setup and open serial communication with arduino
comPort = 'COM6';
serialObj = setupSerialArduino(comPort);

%% Loop parameters
t = 0;
maxIterations = 1000;
dt = 1;
ADC_GAIN = 204.8;
windTurbineVolVec = 0;
rpmVec = 0;
tVec = 0;
velVec = 0;
r = 0.22;
%% loop
while(t < maxIterations)

    inputVol = fscanf(serialObj, '%u')/ADC_GAIN;
    windTurbineVol = 24*inputVol;
    rpm = 20*windTurbineVol;
    vel = (2*pi*r/60)*rpm;
    windTurbineVolVec = [windTurbineVolVec windTurbineVol];
    rpmVec = [rpmVec rpm];
    velVec = [velVec vel];
    tVec = [tVec t/10];

    fprintf('turbine voltage = %f, rpm = %f, velocity = %f\n\n',
windTurbineVol, rpm, vel);

    subplot(3, 1, 1), plot(tVec, windTurbineVolVec), title('Turbine
Voltage'), xlabel('time (s)'), axis([0, 100, 0, 100]), grid;
    subplot(3, 1, 2), plot(tVec, rpmVec), title('RPM'), xlabel('time
(s)'), axis([0, 100, 0, 1500]), grid;
    subplot(3, 1, 3), plot(tVec, velVec), title('Velocity(m/s)'),
xlabel('time (s)'), axis([0, 100, 0, 160]), grid;
    drawnow;

    t = t + dt;

end

average = mean(windTurbineVolVec);
fprintf('\nAverage voltage over run time = %f\n\n', average);
```

```
%% Close serial port Object
fclose(serialObj);
fprintf('serial port has been closed');
```

## APPENDIX D

**AWEA 9.1 -2009** Strength and safety standards.

AWEA 9.1 -2009 report and certificate.

BWEA small wind turbine standards: power performers and safety.

ASME design drawing standards.

IEC standards.

APPENDIX-E

WEB PAGE: http://students.emu.edu.tr/118427

## SYSTEM FLOW CHART