Palestine Polytechnic University
College of Engineering

GRADUATION PROJECT

Title

DESIGN A RESIDENTIAL VERTICAL WIND TURBINE FOR WATER HEATING

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Submitted to the College of Engineering
in partial fulfillment of the requirements for the
Bachelor degree in Electrical Engineering

Hebron, May 2017

جامعة بوليتكنك فلسطين

الخليل-فلسطين

كلية الهندسة الكهربائية والحاسوب

DESIGN A RESIDENTIAL VERTICAL WIND TURBINE FOR WATER HEATING

أسماء الطلبة

مصطفى عساف   داوود أبو يابس

بناء على نظام كلية الهندسة والتكنولوجيا واشراف ومتابعة المشرف المباشر على المشروع وموافقة أعضاء اللجنة الممتحنة تم تقييم هذا المشروع الى الهندسة الكهربائية وذلك للوفاء بمتطلبات درجة البكالوريوس في الهندسة تخصص هندسة تكنولوجيا الطاقة.

توقيع المشرف

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توقيع اللجنة الممتحنة

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توقيع رئيس الدائرة

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Acknowledgment

In the beginning, we thank God for blessing us with the mind

We would like to thank all those who have helped with their advice and efforts ...

We would like also to thank all the staff, especially our supervisor.

Abstract

Palestine needs to wind turbine compatible with the local weather and available wind speeds ,so we designed and built a small wind turbine meets this requirements and able to supply the most needed load in winter which is water heater.

In this project, need to deal with the design of three blades with 1.5m length and diameter between the blades 1.5m cyclone vertical wind turbine. The cyclone wind turbine is a type of Darriues vertical axis wind turbine, which is used to produce power. The turbine consists of three straight blades, which are represented by airfoils that are connected to the rotating main shaft. In this project, the components required for this wind turbine like airfoil, main shaft and bearing are designed properly. The power calculations with respect to the velocity of wind are included. The components are fabricated from steel, aluminum and wood then all parts are assembled together after manufacturing of blades.

This turbine capably to produce an electrical energy reach 300 Watt/hour at design point of 4 m/s.

الملخص

تحتاج فلسطين إلى توربينات رياح متوافقة مع الطقس المحلي وسرعة الرياح المتاحة، لذلك قمنا بتصميم وبناء توربين رياح صغير يلبي هذه المتطلبات وقادرة على توفير الحمل الأكثر حاجة في فصل الشتاء وهو سخان المياه.

في هذا المشروع، قمنا بتصميم ثلاثة شفرات بطول 1.5متر والقطر بين الشفرات 1.5متر ويعد السايكلون توربين هو نوع من انواع الداريوس توربين رياح المحور الرأسي، والذي يستخدم لإنتاج الطاقة. يتكون التوربين من ثلاثة شفرات مستقيمة، والتي يتم تشكيلها على شكل جناح محدد وهذه الجنيحات متصلة بمحور الدوران الرئيسي. في هذا المشروع، المكونات المطلوبة لهذا التوربين شكل الجناح، والعامود (المحور الرئيسي) والجزء الدوار بشكل صحيح. ويتم حساب الطاقة فيما يتعلق سرعة الرياح. المكونات هي الحديد والألومنيوم والخشب ثم يتم تجميع الأجزاء معا بعد تصنيع الجناح.

صمم هذا التوربين لإنتاج الطاقة الكهربائية تصل إلى 320 واط / ساعة عند نقطة تصميم 4 م / ث.

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List of symbols

m	mass (kg)
v	wind speed (m/s)
K.E.	Kinetic energy
ρ	air density (kg/m3)
α	friction coefficient
D	turbine diameter
H	turbine height
η	generator efficiency
Cp	Coefficient of power
λopt	optimum tip speed ratio
n	generator (RPM)
C	Chord length
X	Position through the chord from 0 to c
Y	Half of the thickness at a given position (centerline to surface)
t	Maximum thickness
a	gear ratio
D1	roller 1 diameter
D2	roller 2 diameter
c	the radius of rod (mm)
M	The torque at the point of connection between the base and the beam (N.mm)
I	moment of inertia of the column cross section (mm^4)
Δ	the stress on the rod (MPa or N/mm^2)

Contents

Chapter 1: Introduction

1.1 Overview

Currently the world's fastest growing renewable power source, wind energy is the transformation of the wind's kinetic force into mechanical power through a turbine. The mechanical power can be used for such tasks as grinding grain or pumping water, or converted into electricity through a generator for use by homes and businesses.

1.2 Wind turbine classification

1.2.1 According to Design

There are two kinds of wind turbines, the vertical axis design and the horizontal axis design. The vertical axis type is designed like an egg-beater. Darrieus, a French man, invented it. The horizontal wind turbine, on the other hand, has two to three blades. This type functions best when it is directly facing the wind. Farmers with great land area found out another source of income. When wind turbines became the newest source of electricity, these farmers leased their lands to power developers. Wind farms mushroomed all throughout the Midwest.

1.2.2 According to Size

Wind turbines vary not only with their designs but also with their sizes. Smaller turbines are usually lower than 100 kilowatts and they are most often found in homes. They are associated with simple diesel generators and water pumping needs. There are also the utility-scale wind turbines. They start at 100 kilowatts and reach up to even a few megawatts. There are also the really large turbines seen in wind farms. These turbines serve as the primary source of electricity in the electrical grid.[1]

1.3 VERTICAL AXIS WIND TURBINES

1.3.1 Definition

The vertical axis wind turbine is an old technology, dating back to almost 4,000 years ago. Unlike the HAWT, the rotor of the VAWT rotates vertically around its axis instead of horizontally. Though it is not as efficient as a HAWT, it does offer benefits in low wind situations wherein HAWTs have a hard time operating. It tends to be easier and safer to build, and it can be mounted close to the ground and handle turbulence better than the HAWT. Because its maximum efficiency is only 30%, it is only usually just for private use.

1.3.2 Types of vertical turbine

1. Darrieus Turbine

The Darrieus turbine in figure (1.1) is composed of a vertical rotor and several vertically oriented blades. A small powered motor is required to start its rotation, since it is not self-starting. When it already has enough speed, the wind passing through the airfoils generate torque and thus, the rotor is driven around by the wind. The lift forces produced by the airfoils then power the Darrieus turbine. The blades allow the turbine to reach speeds that are higher than the actual speed of the wind, thus, this makes them well suited to electricity generation when there is a turbulent wind.

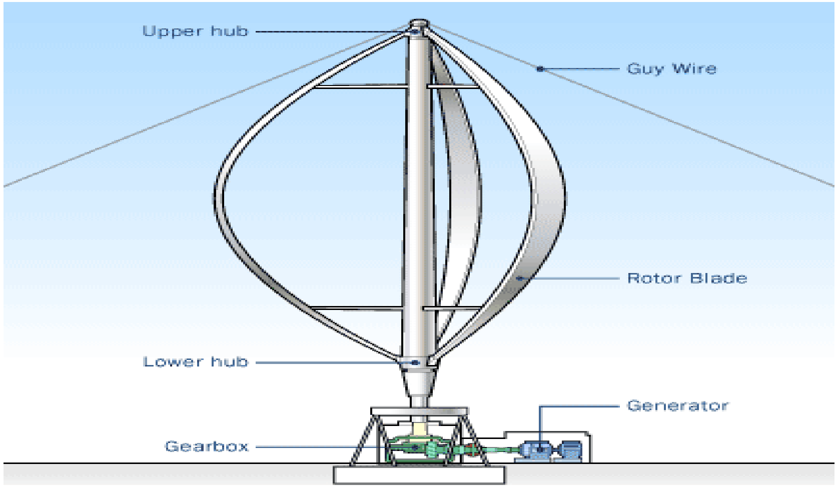


Figure 1.1: Darriues wind turbine

2. Giromill Turbine

The Giromill Turbine is a special type of Darrieus Wind Turbine. It uses the same principle as the Darrieus Wind Turbine to capture energy, but it uses 2-3 straight blades individually attached to the vertical axis instead of curved blades. It is also applicable to use helical blades attached around the vertical axis to minimize the pulsating torque.

A useful variant of the Giromill is the Cycloturbine figure (1.2) which uses a vane to mechanically orient the pitch of the blades for maximum efficiency. This gives the cycloturbine the advantage over other Darrieus wind turbines of self-starting.

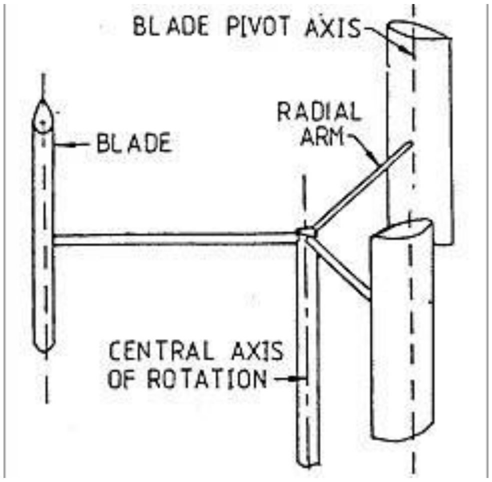


Figure 1.2: Cyclone wind turbine

3. Savonius Turbine

The Savonius wind turbine figure (1.3) is one of the simplest turbines. A drag-type device consists of two to three scoops. Because the scoop is curved, the drag when it is moving with the wind is more than when it is moving against the wind. This differential drag is now what causes the Savonius turbine to spin. Because they are drag-type devices, this kind of turbine extracts much less than the wind power extracted by the previous types of turbine. [2]

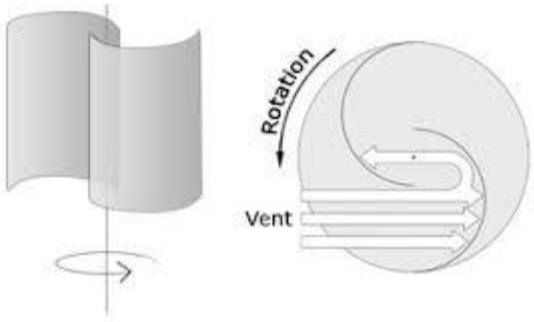


Figure 1.3: Savonius wind turbine

1.4 Advantages and Disadvantages

The VAWT also comes with a handful of advantages over the HAWT,

- Since VAWT components are placed nearer to the ground, it has an easier access to maintenance.
- Smaller cost of production, installation, and transport.
- Turbine does not need to be pointed towards the wind in order to be effective.
- VAWTs are suitable in places like hilltops, ridgelines and passes.
- Blades spin at a lower velocity, thus, lessening the chances of bird injury.
- Suitable for areas with extreme weather conditions like mountains.

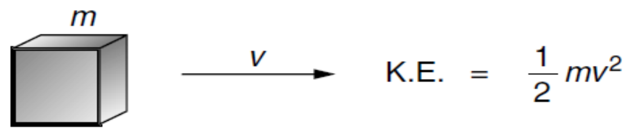
The disadvantages of the VAWT, on the other hand are:

- Most of them are only half as efficient as HAWTs due to the dragging force
- Air flow near the ground and other objects can create a turbulent flow, introducing issues of vibration
- VAWTs may need guy wires to hold it up (guy wires are impractical and heavy in farm areas).

Chapter 2: Power in the wind

2.1 Power in the wind

Consider a pocket "box" with mass "m" located in the wind stream as shown in figure (2.6).



The kinetic energy of this box is

$$K.E = 0.5 * m * v^2 \qquad (2.1)$$

Where:

m: mass (kg)

V: wind speed (m/s)

Power in the wind express by this equation;

$$P_w = \frac{1}{2}\rho A v^3 \qquad (2.2)$$

Pw is the power in the wind (watts); *ρ* is the air density (kg/m3) (at 15◦C and 1 atm, *ρ* = 1.225 kg/m3); *A* is the cross-sectional area through which the wind passes (m^2); and *v* = wind speed normal to A (m/s)

We have relation between power in the wind and power extracted by the wind turbine rotor is reduced by the power coefficient, *C*p:

$$P_m = C_p \, P_w \qquad (2.3)$$

Where:

Pm: mechanical power (W).

Pw: is the power in the wind (W).

The constant 16/27 = 0.593 from is referred to as the Betz coefficient. The Betz coefficient tells us that 59.3% of the power in the wind can be extracted in the case of an ideal turbine. However, an ideal turbine is a theoretical case. Turbine efficiencies in the range of 35-40% are very good, and this is the case for most large-scale turbines. It should also be noted that the pressure drop across the turbine blades is very small, around 0.02% of the ambient air pressure.

2.2 Affecting parameters

2.2.1: Air density

Consider a "packet" of air with mass (*m)* moving at a speed (*v*) its kinetic energy
K.E. is given by the familiar relationship:

$$K.E. = \frac{1}{2} m v^2 \qquad (2.4)$$

The kinetic energy of moving has proportional relation to its mass, so the effect on kinetic energy in wind is air density, in other words, the "heavier" the air, the more energy is received by the turbine. [3]

The wind power varies linearly with the air density sweeping the blades. The air density ρ varies with pressure and temperature in accordance with the gas law:

$$PV = nRT \qquad (2.5)$$

$$\rho = P/RT \qquad (2.6)$$

Where,

P = air pressure (atm)
T = temperature on the absolute scale (Kelvin)
R = gas constant

The air density is 1.225 kg/m3; it is assumed that air temperature is 15◦C (59◦ F) and pressure is 1 atmosphere.

Air density, and hence power in the wind, depends on atmospheric pressure as well as temperature. Since air pressure is a function of altitude, it is useful to have a correction factor to help estimate wind power at sites above sea level.

$$\rho = \rho_o - 1.194 \times 10^{-4} \times H_m \tag{2.7}$$

Air density varies with temperature and elevation. Warm air is less dense than cold air. Any given wind turbine will produce less in the heat of summer than it will in the dead of winter with winds of the same speed. For ready reference, the temperature varies with the elevation:

$$T = 15.5 - \frac{19.83\ H_m}{3048}\ {}^\circ\mathrm{C} \tag{2.8}$$

The average air density in Hebron city at 900-meter elevation while the annual average is 1.1141 kg/m^3.[see Appendix A.1].

2.2.2 IMPACT OF TOWER HEIGHT

To calculate the wind speed at the height of the hub, it is necessary to take care that the wind speed varies with height due to the friction against the structure of the ground, which slows the wind. This phenomenon is named wind gradient or wind profile and it is shown in Figure (2.1).

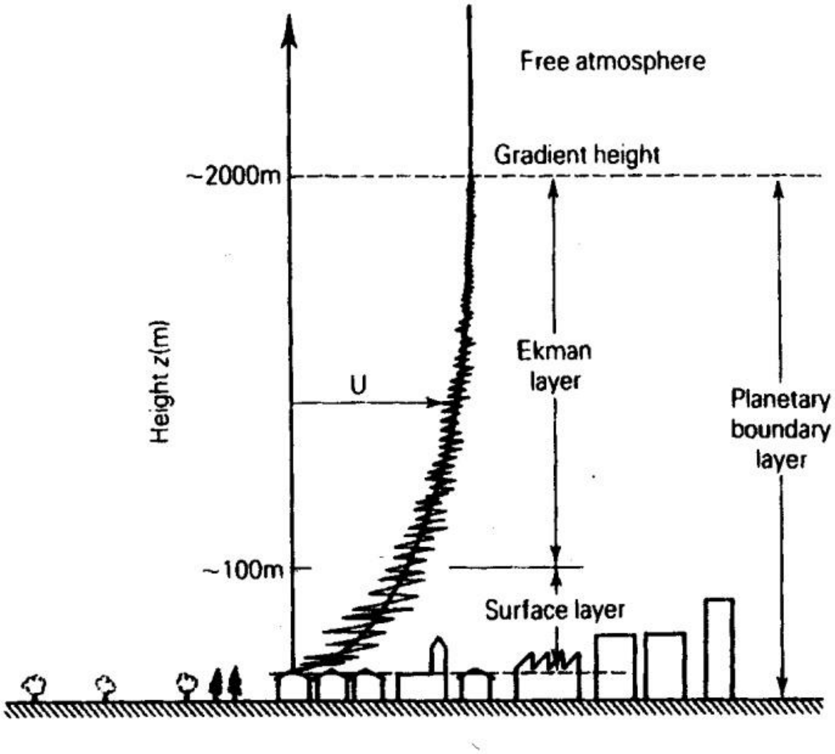


Figure 2.1: Variation of Wind Speed within the Atmospheric Boundary Layer [12]

power in the wind is proportional to the cube of the wind speed, one-way to get the turbine into higher winds is to mount it on a taller tower or install wind turbine on high buildings In the first few hundred meters above the ground, wind speed is greatly affected by the friction that the air experiences as it moves across the earth's surface. Smooth surfaces, such as a calm sea, offer very little resistance, and the variation of speed with elevation is only modest.

One expression that is often used to characterize the impact of the roughness of the earth's surface on wind, speed is the following:

$$\left(\frac{v}{v_0}\right) = \left(\frac{H}{H_0}\right)^{\alpha} \qquad (2.9)$$

Where v is the wind speed at height H, v_0 is the wind speed at height H_0 (often a reference height of 10 m), and α is the friction coefficient. The friction coefficient α is a function of the terrain over which the wind blows. Table (2.1) gives some representative values for rather loosely defined terrain types.

Table 2.1: **Friction Coefficient of Various Terrains. [3]**

Terrain Type	Friction Coefficient α
Lake, ocean and smooth hard ground	0.10
Foot high grass on level ground	0.15
Tall crops, hedges, and shrubs	0.20
Wooded country with many trees	0.25
Small towns with some trees and shrubs	0.30
City area with tall buildings	0.40

When we install wind turbine above a tower of 10m the wind speed will increase as the following in the equation (2.9), for example; if we take wind speed 3m/s at reference then wind speed will be above tower 6m/s. The wind speed at tower of 10-meter over a year at Hebron city. [see Appendix A.2].

2.3: Swept Area & Betz' limit

2.3.1 Swept area of turbine blades

The wind turbine swept area is calculated in different way, according to the geometry of the rotor.

For a giromill VAWT, also named Cycloturbine, the swept area is:

$$A = h * d \tag{2.10}$$

Where:
D: Diameter
H: Height

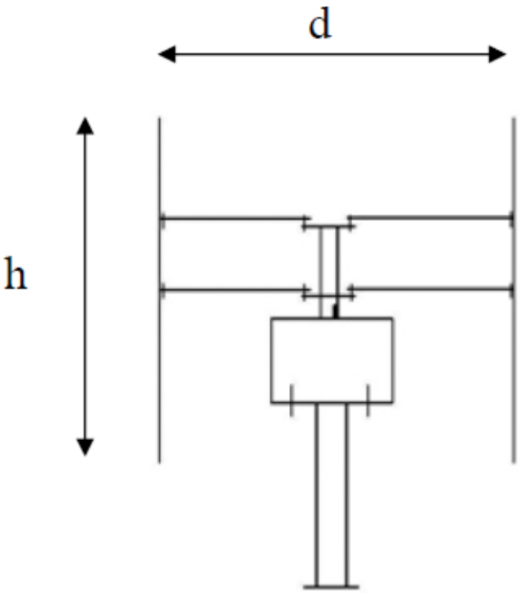


Figure 2.2: Swept area for cyclone

In our project and design height of blades is 1.5m and diameter between blades also 1.5m, by using equation (2.10) we get area of turbine is $2.25m^2$.

2.3.2 Betz limit

The original derivation for the maximum power that a turbine can extract from the wind is credited to a German physicist, Albert Betz, who first formulated the relationship in 1919. The analysis begins by imagining what must happen to the wind as it passes through a wind turbine. This conclusion, that the maximum theoretical efficiency of a rotor is 59.3%, is called the Betz efficiency or, sometimes, Betz law. [3] Figure (2.3)

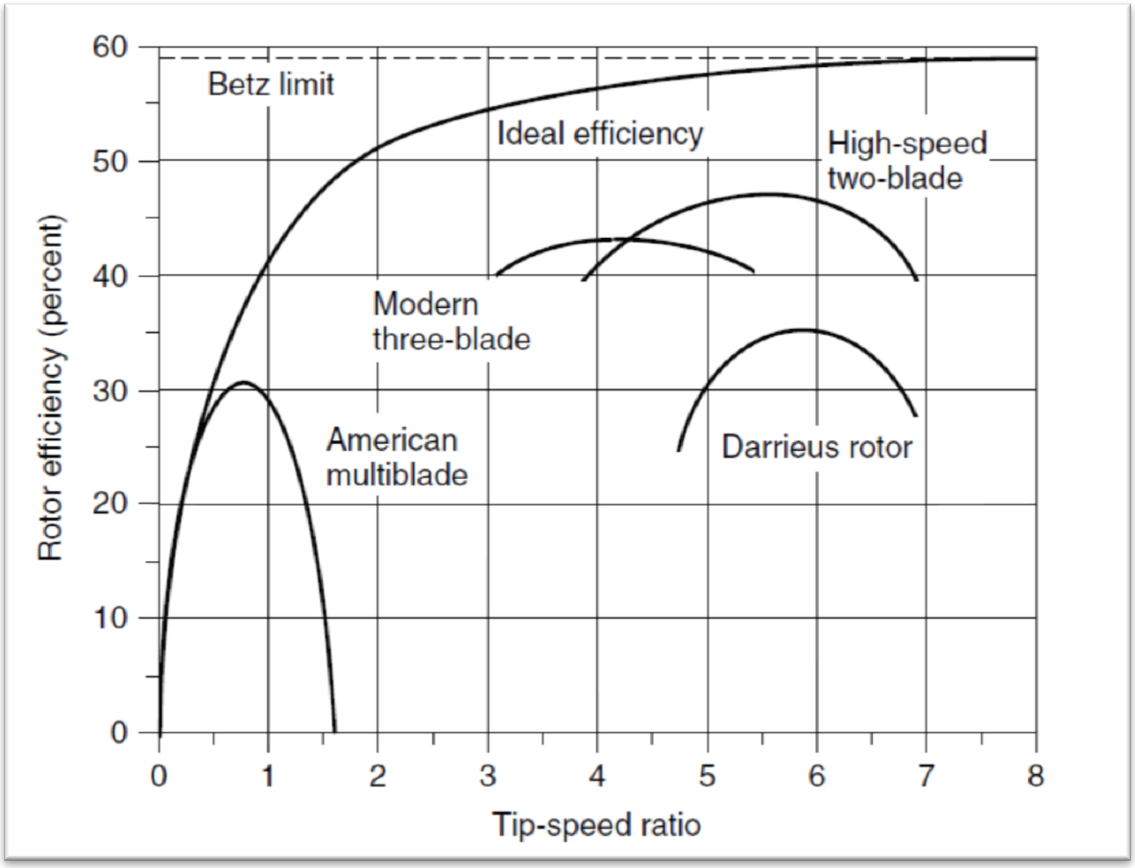


Figure 2.3: Betz efficiency [3]

Coefficient of power Cp:

The coefficient of power Cp of a wind turbine is a measurement of how efficiently the wind turbine converts the energy in the wind into electricity. By now, you already know how to calculate the amount of electricity a wind turbine is producing, and you also know how to calculate the total power available in a given area of wind. To find the coefficient of power at a given wind speed, all you have to do is divide the electricity produced by the total energy available in the wind at that speed. Wind turbines extract energy by slowing down the wind. For a wind turbine to be 100% efficient it would need to stop 100% of the wind - but then the rotor would have to be a solid disk and it would not turn and no kinetic energy would be converted. On the other extreme, if you had a wind turbine with just one rotor blade, most of the wind passing through the area swept by the turbine blade would miss the blade completely and so the kinetic energy would be kept by the wind.

$$C_p = \frac{Captured\ mechanical\ power\ by\ blades}{Available\ power\ in\ wind} \tag{2.11}$$

Cp value represents the part of the total available power that is actually taken from wind, which can be understood as its efficiency.

The power coefficient is strongly dependent on tip speed ratio, defined as the ratio between the tangential speed at blade tip and the actual wind speed.

Tip Speed Ratio:

A rotor rotating slowly will allow the wind to pass undisturbed through the gaps between the blades. In a fast rotating rotor, the rotating blades will act as a solid wall, which will obstruct the wind flow, again reducing the power extraction. Wind turbines have to be designed to operate at their optimal wind tip speed ratio to extract as much power as possible. Wind tip speed ratios are dependent on their designed turbine being used, rotor airfoil profile uses, and the number of blades being used [10].

The relationship between wind speed and the rotation rate, called the tip speed ratio:

$$\lambda = \frac{u}{v} = \frac{\omega r}{v} \tag{2.12}$$

Where

ω: rotational speed of the turbine rotor

r: radius of the rotor

v: wind speed

This table include Cp and TSR for each wind turbine type as the following:

***Table 2.2: Power Coefficients and TSR** [4]*

Rotor type	optimum Cp	range of tip speed ratio
Savonius	0.3	0.8 - 0.85
Dutch for arm	0.14	2.0 – 3.0
Darriues	0.32	5.5 – 6.5
Tow Blade	0.43	4.5 – 6.5
Propeller	0.55	3.0 – 7.0

For our cycloturbine, which is type of darriues turbine coefficient power is 0.32 and Tip speed ratio is 6 this parameters use to find out the electrical power of wind turbine.

2.4 Weibull probability density function

The benefit of weibull function is convert discrete of wind data, which you collect to continuous curve. A very general expression that is often used as the starting point for characterizing the statistics of wind speeds is called the Weibull probability density function:

$$F(v) = K * \frac{V^{(K-1)}}{C^{K}} * e^{-(\frac{V}{C})^{K}} \tag{2.13}$$

Where ***k*** is called the shape parameter, and ***c*** is called the scale parameter. As the name implies, the shape parameter ***k*** changes the look of the p.d.f. as figure (2.4).

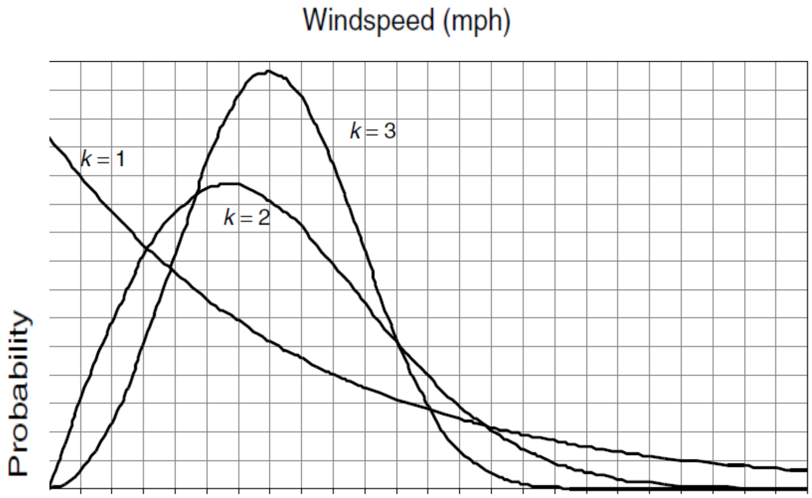


Figure 2.4: Weibull distribution [3]

For k = 1, it looks like an exponential decay function; it would probably not be a good site for a wind turbine since most of the winds are at such low speeds. For k = 3, the function resembles the familiar bell-shaped curve, and the site would be one where the winds are almost always blowing and doing so at a fairly constant speed, such as the trade winds do. For which *k* = 2, is the most realistic for a likely wind turbine site; that is, it has winds that are mostly pretty strong, with periods of low wind and some really good high-speed winds as well.

This calculation give me indication of how much hours I get any wind speed at a year. Weibull distribution at Hebron city area with shape factor ‘K’ of 1.81 and Weibull scale factor C = 4 at average wind speed of 3.1 m/s , this curve tell us that we have 1m/s wind speed for (500 hours) , 2m/s (1550 hours), 3m/s (2300 hours) , 4m/s (2100 hours) , 5m/s (1300 hours) , 6m/s (510 hours) , 7m/s (250 hours) , 8m/s (90 hours) , so if we observe these wind speeds we find that there is good wind speed that you can make your design which is 3 and 4m/s . [See Appendix A2].

2.5 Wind power

2.5.1 Lift and Drag Forces

Two types of aerodynamic forces are created when an air flows over any surface: drag forces and lift forces. Drag force is in the airflow direction while lift force is right-angled to the airflow. Both lift and drag can generate forces needed to rotate the blades of a wind turbine.

Drag forces are used to generate vertical based wind turbines with Savonius and Darrieus rotors are use lift forces in the same purpose, where the force of the wind pushes against the surface. As shown in figure (2.5).

- Lift turbines are those that have the blades designed as airfoils similar to aircraft wings. The apparent wind creates lift from a pressure differential between the upper and lower air surfaces. They are also more efficient than drag turbines [5].
- Drag turbines operate purely by the force of the wind pushing the blade [5].

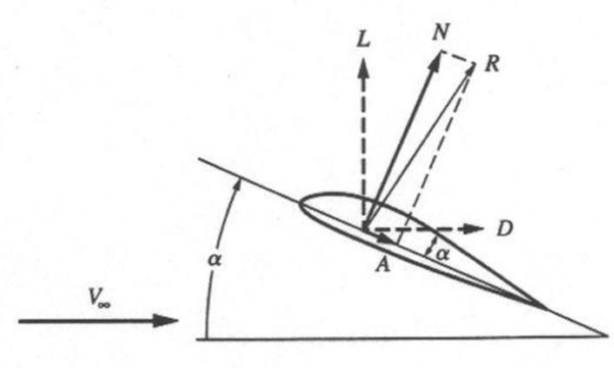


Figure 2.5: Lift and Drag force

2.5.2 Power of wind

$$P_{air} = \frac{1}{2}\,\rho\,Av^3 \tag{2.14}$$

Where:

ρ = air density (approximately 1.225 kg/m3*)*.

A = swept area of rotor, m2.

v = upwind free wind speed, ms−1.

$$P_{wind\ turbine} = C_p P_{air} = C_p \times \frac{1}{2}\,\rho\,Av^3$$

Although Equation (2.14) gives the power available in the wind the power transferred to the wind turbine rotor is reduced by the power coefficient, *C*p:

$$C_p = \frac{Captured\ mechanical\ power\ by\ blades}{Available\ power\ in\ wind} \tag{2.15}$$

Where

(2.16)

A maximum value of *C*p is defined by the Betz limit, which states that a turbine can never extract more than 59.3% of the power from an air stream. In reality, wind turbine rotors have maximum *C*p values in the range 25–45%. For cycloturbine Cp value is 0.32 and TSR value is 6.

2.6 Wind Turbine Power Curve

The most important technical information for a specific wind turbine is the power curve, which shows the relationship between wind speed and generator electrical output. See figure (2.5).

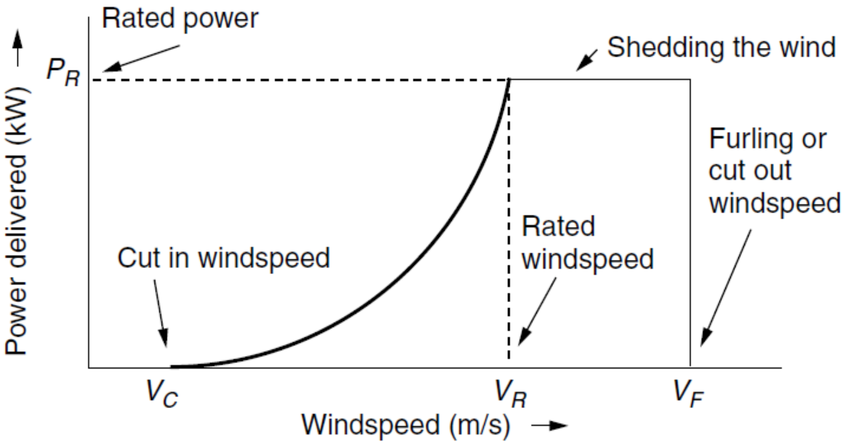


Figure 2.6: Power curve [3]

Cut-in Wind speed: Low-speed winds may not have enough power to overcome friction in the drive train of the turbine and, even if it does and the generator is rotating, the electrical power generated may not be enough to offset the power required by the generator field windings.

Rated Wind speed: As velocity increases above the cut-in wind speed, the power delivered by the generator tends to rise as the cube of wind speed. When winds reach the rated wind speed *VR*, the generator is delivering as much power as it is designed for.

Cut-out or Furling Wind speed: At some point, the wind is so strong that there is real danger to the wind turbine. At this wind speed *Vf* , called the cutout wind speed or the furling wind speed ("furling" is the term used in sailing to describe the practice of folding up the sails when winds are too strong), the machine must be shut down. Above *Vf*, output power obviously is zero. [3]

For our design, we find electrical power output at each wind speed, first we find cut-in wind speed at 1m/s, which produce 14 watt, and we find rated wind speed at 4.7 m/s, which produce 320 watt, And we find Cut-out or Furling Wind speed which is at 7.5 m/s, so at this wind speed we programming arduino to open relays which is already connected with water heater (electrical load) to protect generator coils which is (P.M. DC motor).

This power-speed curve show power output at every specific wind speed. Figure (2.8).

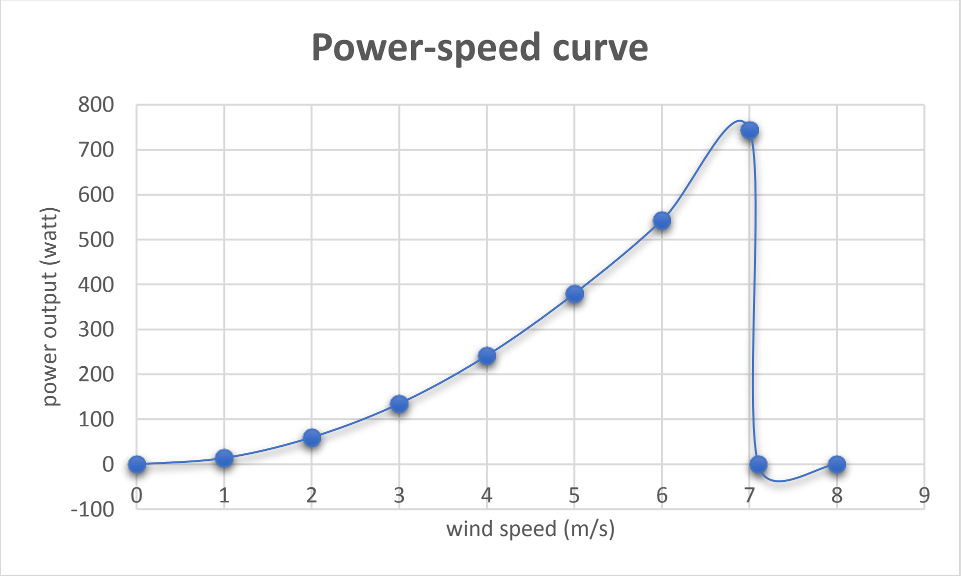


Figure 2.7: Output power related with wind speed

Chapter 3: System component losses

3.1 Efficiency Varies with Wind Speed

A given wind turbine has a "design point" that generally defines its peak efficiency at the wind speed for which the system is designed. At wind speeds above and below the design speed the efficiency is the same or less - maybe much less. If a turbine's best efficiency is 40% at a wind velocity of 9 meters per second, it will be 40% only at that wind speed. At all other wind speeds it will be something worse. That wind turbine will generally operate at lower than its best efficiency, because wind speeds are never constant or average.

The electric power actually produced will be still lower because the generator efficiencies are also less than 100% (generally in the mid- or low-90's at best), and there are further losses in the conversion electronics and lines. However, this is true of all power technologies. When all these losses are figured in, you might, if you are lucky, be getting 35% or so of the wind's energy actually delivered as useful electrical energy to the end user in the very best conditions. The average might only be in the twenties

3.2 Losses Add Up

In reality, the power coefficient will depend on how much is lost at each stage of the energy conversion process. Some is even lost before it can begin. Shown in figure (3.1). [6]

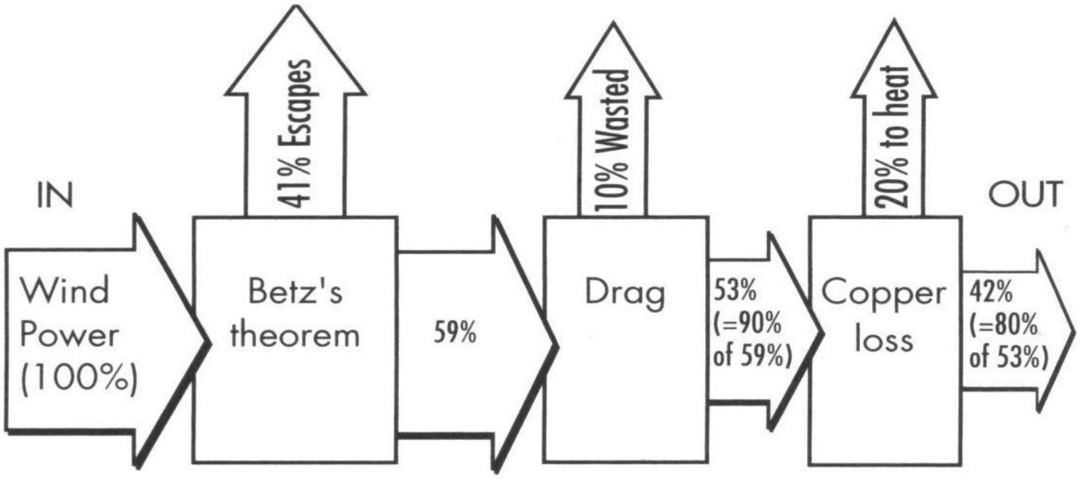


Figure 3.1: losses in wind turbine [6]

3.3 Betz's Theorem

Albert Betz (1926) is credited with figuring this out, so his name is always used to refer to this theory. In order to extract power from the wind, it must be slowed down. To remove all the wind's power would involve bringing the air to a halt. However, this would cause a pile-up of stationary air at the windmill, preventing further wind from reaching it. The air must be allowed to escape with some speed, and hence with some kinetic energy (which is lost).

According to Betz, the best power coefficient we can hope for is 59.3%, but in practice, this figure will be whittled down further by other losses described next.

3.4 Drag

The rotor blades convert the energy of the wind into shaft power. Later we discuss the advantages of using a few, slender blades which rotate fast, compared with many wide blades, rotating slowly. Fast moving blades will experience aerodynamic 'drag'. Drag holds the blades back, wasting some of the power they could be catching from the wind, so we need to make the blades as 'streamlined' as possible. Even the best designed 'airfoil section' blades will lose about 10% of the power they handle this way. Home built blades may lose a lot more.

3.5 Mechanical Friction

There will also be friction losses in the bearings, brushes and any sort of mechanical drive, such as a gearbox or pulley system. These will only increase slightly with increasing speed.

Therefore, when the windmill is working hard, in a strong wind, the friction losses may be only a tiny percentage of the total power. But in light winds, friction losses can make an enormous difference, especially in very small windmills, which have relatively low rotor torque.

3.6 Copper Losses

The next stage is to make electricity. This takes place in the coils of the generator. Electric current suffers from its own kind of friction, which heats the wires.

This 'friction' is in proportion to the 'resistance' of the copper wires carrying the current. You can reduce the resistance (and so the 'copper loss') by using thicker wires. This makes the generator heavier and more expensive, but it may be worth it. The resistance of a copper wire increase with rising temperature. Copper losses heat the coils, which increases temperature, thereby increasing resistance and causing more copper loss. This vicious circle can lead to burn out in the worst case, and will certainly lower the efficiency of the machine, so it will be important to look at the cooling of the generator, in the overall design. Copper losses increase with the square of current. When the generator is working at 'part load', in other words in light winds, losses in the main windings are very small. Some generators also have 'field coils' carrying an almost constant current. In light winds, they may consume all the power that blades can produce, leaving you with nothing.

Finally, do not forget about copper loss in the cable from the windmill. Where the cable is very long, it also need to be very thick.

If the cost of thick cable becomes ridiculous, then it is worth changing the system voltage. At higher voltages, less current will be needed to transmit the same amount of power. High voltage means much lower copper loss in cables, which is why it is used, in spite of the safety problems it may cause. A 12-volt system will lose 400 times as much power as a 240-volt system, when using the same cable.

3.7 Iron Losses

The fact that the flux is changing in the core all the time affects not only the coils around it, but also the steel in the core itself. We do not want these 'side-effects' in the core; they waste power. Iron losses occur for two reasons:

1- The iron is being magnetized and demagnetized at a rapid rate. This process involves hysteresis, and so takes energy. Special steels, which are easily magnetized, can be used to reduce hysteresis loss.

2- The flux changes tend to produce circulating currents in the steel, following any conductive path, which links around the changing lines of flux. A core built from flat laminations can be used to break up any such large circuit paths, minimizing these 'eddy currents'.

3.8 Rectifier Losses

Very often, small windmills are built with permanent magnet alternators, which produce alternating current (A.C.). The power is then fed into a battery, for use as direct current (D.C.). A converter is required, which changes the A.C. into D.C. This is the 'rectifier'. Modern rectifiers are simple, cheap, reliable semiconductor devices, based on silicon diodes. They work very well, but like everything in this world, they need their percentage. (One begins to wonder if there will be any power left at the end of all this!) In this case, the rule is simple: each diode uses about 0.7 volts. In the course of passing through the rectifier, the current passes through two diodes in series, and about 1.4 volts are lost. In other words, to get 12 volts D.C. out, we need to put 13.4 volts in. This represents another energy loss, representing about 10% of the energy passing through the rectifier. Again, changing to a higher voltage will reduce this loss. For example, in a 24 volt, system the voltage lost in the rectifier will be the same as in a 12-volt system (1.4 volts), but it is now less than 5% of the total. [6]

CHAPTER 4: Turbine Component Design

When designing a Wind turbine, many considerations must be kept in mind, both general and very specific. The design process involves a large number of mechanical and electrical components that are used to convert wind power into electrical power.

4.1 Design Procedure

Some approaches can be made when designing a wind turbine and many issues have to be considered. This section outlines the steps in one approach. The key design steps are as follows [7].

1. Determine application

The first step when designing a wind turbine is to determine the application. Wind turbines that are being used for large-scale power production have a different design than those used in more remote areas. Major factor in choosing the size of the turbine is the application or the usage. The type of generator, method of control, and how it is to be installed and operated are also major factors.

2. Review previous experience

Step 2 is reviewing previous experience, mainly when it comes to building a turbine for similar applications. Older turbines give useful information in how they were built and tested. Helping the designer narrow the options. General previous experiences have shown that the, maintenance, and service to the turbine must be safe and straightforward.

3. Preliminary loads estimate

It is vital to estimate the loads the turbine must be able to withstand, which is done early in the design process. Those estimated loads influence individual components in the turbine. At this stage, it is important to keep in mind all the loads that the turbine will be able to withstand in operation.

4. Develop tentative design

A preliminary design can be developed after the layouts have been chosen and loads have been estimated. The design consist of number of subsystems, which are:

1- Rotor (blades, hub, aerodynamic control surfaces)

2- Drive train (shafts, couplings, gearbox, mechanical brakes, generator)

3- Nacelle and mainframe.

4- Yaw system

5- Tower, foundation and erection

5. Predict performance

It is also important to predict the performance of the turbine done by using the power curve. Even though the rotor of the turbine is the main contributor in performance, the type of generator, efficiency of the drive chain, the method of operation (constant speed and variable speed), and the choices made in the design of the control system are important.

6. Evaluate design

The turbine must be able to withstand any expected loadings – this is where the preliminary design is evaluated. The turbine must be able to withstand any loadings that can take place in normal operation. The turbine must also be able to withstand extreme loads that can occur in abnormal circumstances. Various stress levels will generate fatigue damage occurring in a periodic manner proportional to rotor speed, a random manner, or because of transient loads. The loads that the turbine must be able to withstand are as follows:

1-Static loads (not associated with rotation)

2- Steady loads (associated with rotation, for example centrifugal force)

3- Cyclic loads (due to wind shear, blade weight, yaw motion)

4- Impulsive (short duration loads, such as blades passing through tower shadow)

5- Stochastic loads (due to turbulence)

6- Transient loads (due to starting and stopping)

7- Resonance induced-loads (due to excitations near the natural frequency of the structure)

The loads most important to keep in mind are those that affect the rotor, especially at the blade roots. But any load that effect the rotor distributes through the rest of the structure, so the loadings of each component must be evaluated.

7. Estimate costs and cost of energy

How much the turbine produces and the cost of the turbine itself are key factors in the cost of energy. It is therefore important to evaluate the cost of the turbine when it comes to the prototype stage and production. The components of the turbine can be both standard from the manufacturer custom made for the project in question, custom-made usually being more expensive in the prototype. But if there is a mass production of the component in question, the price can drop to the same level as the standard item of similar material, complexity and size.

8. Refine design

The next step is to refine the design according to the previously mentioned factor and analyze in a similar way to the processes summarized above. This refined design is used in building a prototype.

9. Build a prototype

A prototype should be built after the prototype design is completed. The prototype verifies the assumptions in the design, tests new concepts and make sure the turbine can operate as expected.

10. Test the prototype

After the prototype has been built and installed, tests are done to verify the performance predictions where the power is measured and a power curve is developed. The estimated strain is applied to critical components and the actual loads are measured and compared to predicted values.

11. Design production machine

The production of the machine is the final step in the design process. The final design should be as close to the prototype as possible. However, improvements from the prototype and lower cost for mass production are acceptable.

4.2 Structural components design

4.2.1 Blade design

The blades are carved from wood with hand tools and Carpenter Tools; we choose wood material because it is light, strong and resistant to fatigue. And it is less cost and available.

The blades produce mechanical power to drive the alternator. The alternator will convert this into electrical power. The diameter between the blades is very important so if we increase diameter we will get more extracted power from turbine.

Number of blades in the turbine rotor and its rotational speed must be optimized to extract the maximum energy from the available wind.

Put more blades will produce more torque (turning force), but that does not equate to more power. Mechanical power is speed multiplied by torque. For electricity production, you need speed more than you need torque. Extra blades help the machine to start to turn slowly, but as the speed increases, the extra drag of all those blades will limit how much power it can produce. Multiplied rotors work best at low tip speed ratios. Fast turning blades generate much more lift per square inch of blade surface than slow ones do. A few, slender blades spinning fast will do the same job as many wide ones spinning slowly.

The notion of the Tip Speed Ratio (TSR) is a concept used by wind turbine designers to optimize a blade set to the shaft speed required by a particular electricity generator while extracting the maximum energy from the wind.

Blade shape

There is many airfoil which designer can shape and carve blades; Figure (4.1) shows different types of NACA airfoils. Each type has different properties such as coordinates and chord length.

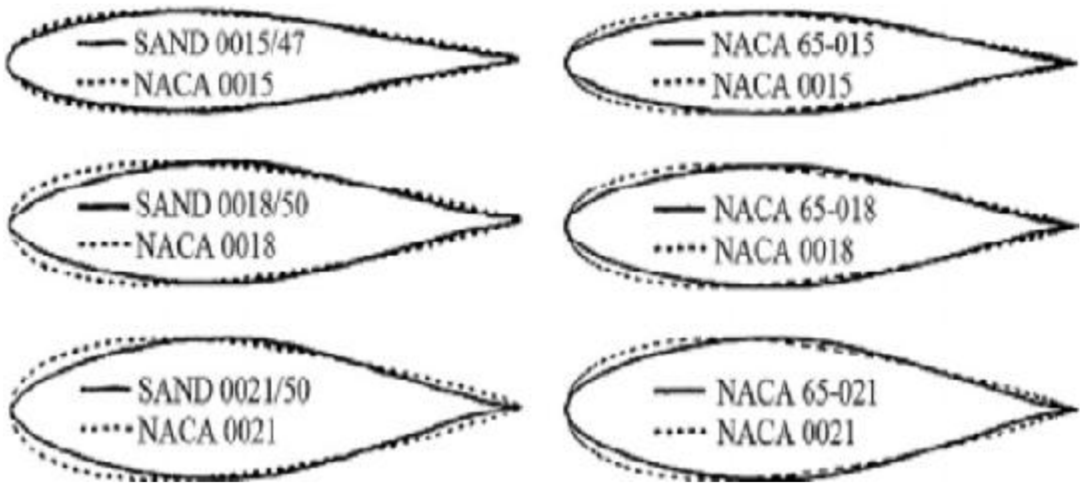


Figure4.1: NACA airfoils [13]

The main three NACA airfoils that have been chosen are NACA 0012, NACA0015 and NACA 0020, because these airfoils gave many good results according to the past studies about the cyclo VAWT. In our design, we choose NACA 0012 airfoil shown in figure (4.2) which is most useful in vertical wind turbine.

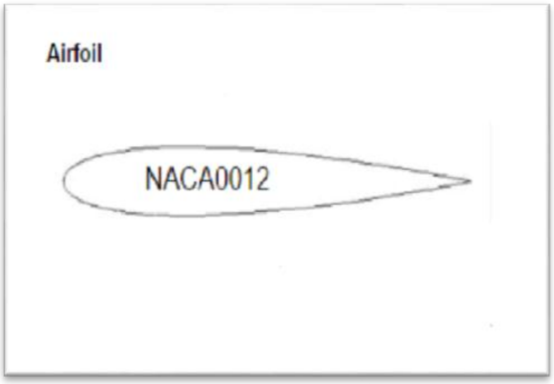


Figure 4.2: NACA 0012 airfoil [8]

In particular, the NACA airfoil, which studied in the project, is a uniform four numbers NACAs airfoil. The main property of these airfoils is that it starts with two 0 numbers. Equation 4.1 expresses the equation of NACA shape of 00xx model, which replaces the xx by a thickness percentage to tension:

$$y = \frac{t}{0.2}c\left[0.2969\sqrt{\frac{x}{c}} - 0.1260\left(\frac{x}{c}\right) - 0.3516\left(\frac{x}{c}\right)^2 + 0.2843\left(\frac{x}{c}\right)^3 + 0.1015\left(\frac{x}{c}\right)^4\right]$$

(4.1)

Here:

C: Chord length

X: Position through the chord from 0 to c

y: Half of the thickness at a given position (centerline to surface)

t: Maximum thickness

If we use NACA 0012 for this project, we have the following coordinates by applying equation (4.1) using excel:

X	Y(UPPER)	Y(LOWER)
16.67	0.021	-0.021
15.1545	0.222326	-0.222325799
13.7768	0.387594	-0.387594478
12.5244	0.524436	-0.524436317
11.3858	0.637859	-0.637859202
10.3507	0.731322	-0.731321521
9.4097	0.807407	-0.807406702
8.5543	0.868189	-0.868188614
7.7766	0.915452	-0.915452327
7.0697	0.950772	-0.950772125
6.427	0.975602	-0.975601949
5.8427	0.991268	-0.991267786
5.3115	0.998992	-0.998991556
4.8287	0.999893	-0.999893003
4.3897	0.994991	-0.994990606
3.9906	0.985201	-0.985200888
3.6278	0.971345	-0.971345068
3.298	0.954151	-0.954151204
2.9982	0.93426	-0.934259849
2.7256	0.912224	-0.912224004
2.4	0.880309	-0.880309274
1.8	0.80201	-0.802009627
1.2	0.688698	-0.688698382
0.9	0.612028	-0.612028097
0.6	0.513497	-0.513496834
0.3	0.374496	-0.374495593

0.15	**0.270016**	**-0.270015559**
0	**0**	**0**

# of piece	Material	Length	width	Max thickness

Fig (4.3) shows the excel sketching of the NACA 0012 airfoil:

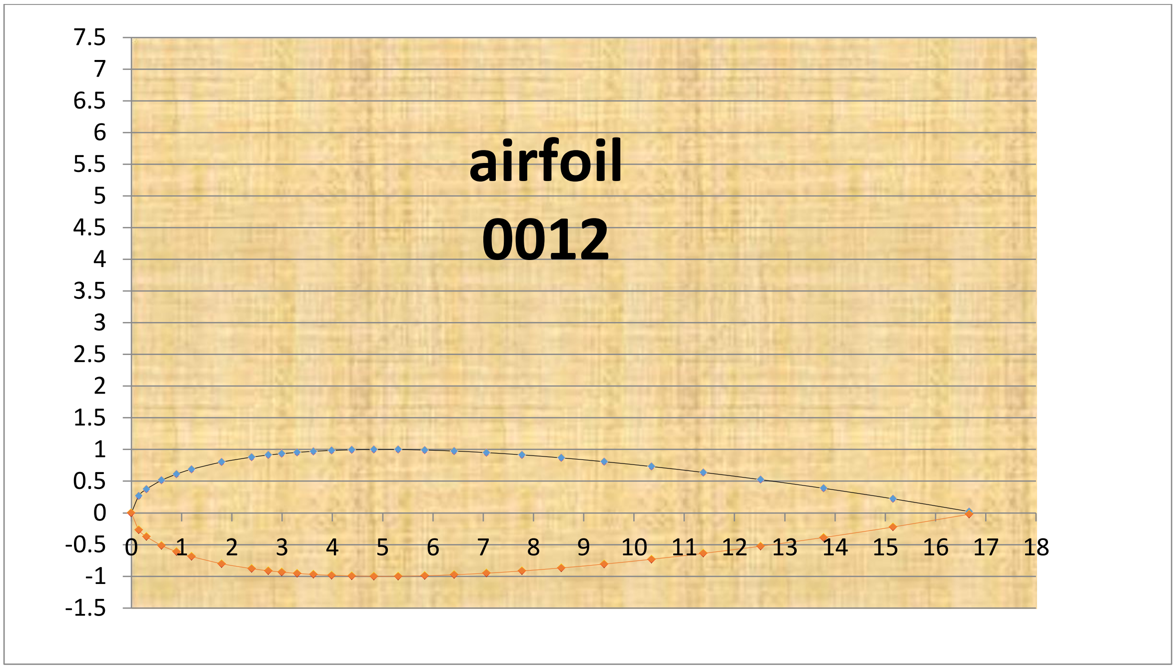


Figure4.3: Excel sketching of NACA 0012

Three Pieces	Light wood Straight strong	150 cm	16.6 cm	2 cm

Table 4.1: The dimension of carved blade

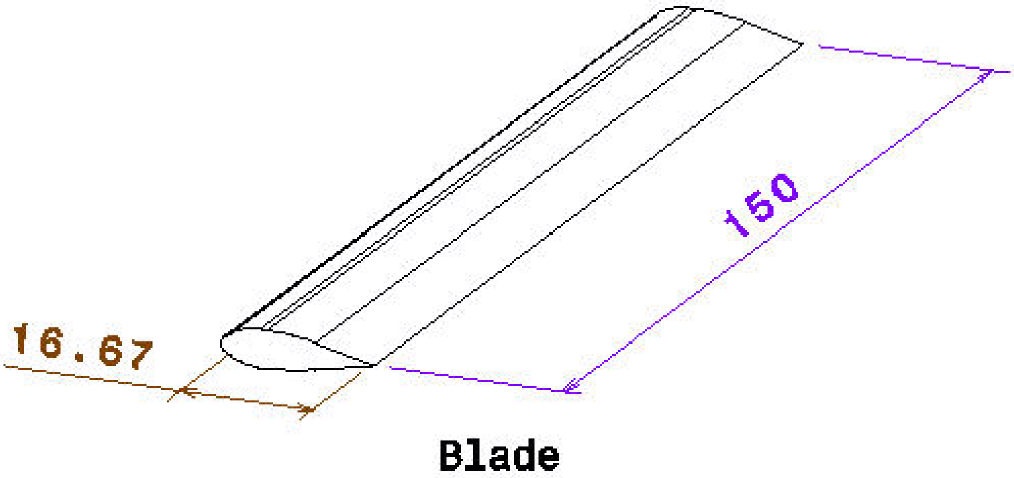


Figure 4.4: The dimension of carved blade using CATIA

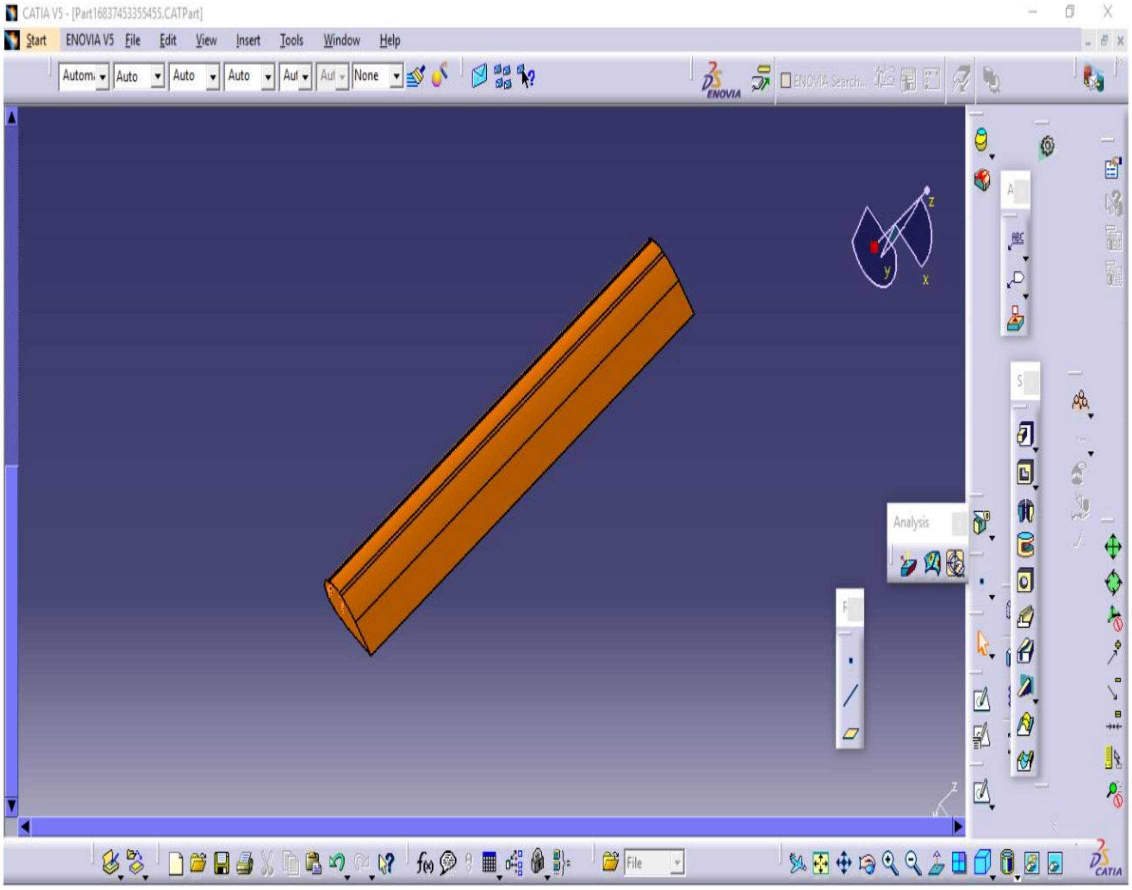


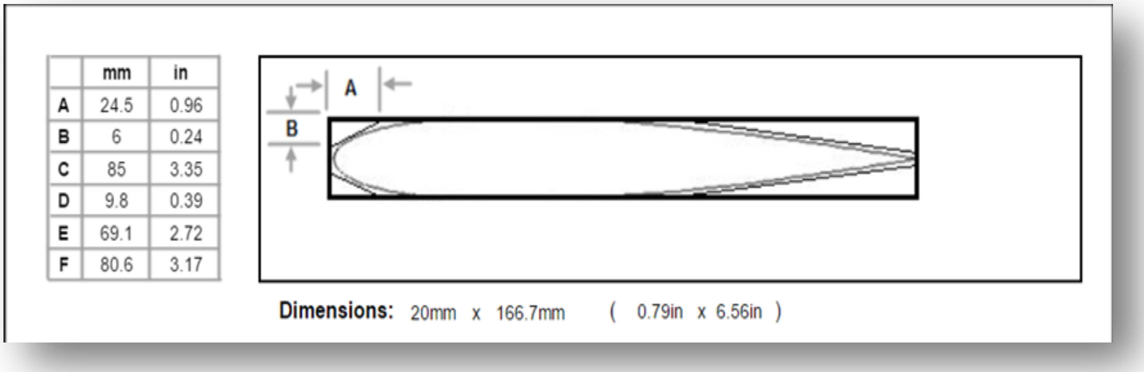
Figure 4.5: Shaped blades designed using CATIA

To carve wood we visited CNC factory process, which is specialized in this work, but if we carve blades in CNC, it will be very expensive one blade to be carve will cost 400 (NIS), so we search on method which give the same configuration and at a much lower cost than CNC, which is include seven steps to reach blade design.

Blade design steps

Initially we set the length 150cm, width 16.67cm, and thickness 2cm of the wood, which we will carve it as steps that will we show. [11]

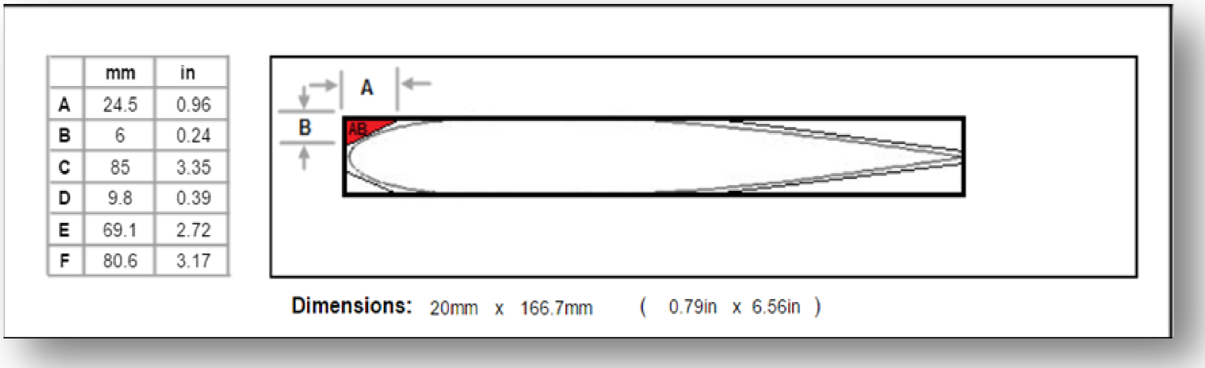
Step 1: draw A and B lines shown in figure (4.6) on your piece of wood with a pencil.



	mm	in
A	24.5	0.96
B	6	0.24
C	85	3.35
D	9.8	0.39
E	69.1	2.72
F	80.6	3.17

Figure 4.6: draw A and B lines

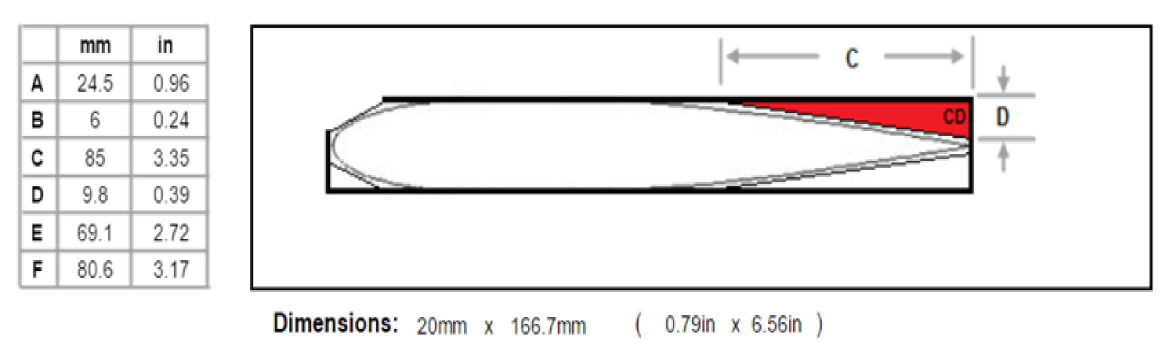
Step 2: Use a belt sander to remove section AB from your piece of wood by sanding between lines A and B as shown in figure (4.7).



	mm	in
A	24.5	0.96
B	6	0.24
C	85	3.35
D	9.8	0.39
E	69.1	2.72
F	80.6	3.17

Figure 4.7: remove section AB

Step 3: Draw lines C and D on your piece of wood then remove section CD from your piece of wood by sanding between the lines as shown in figure (4.8).

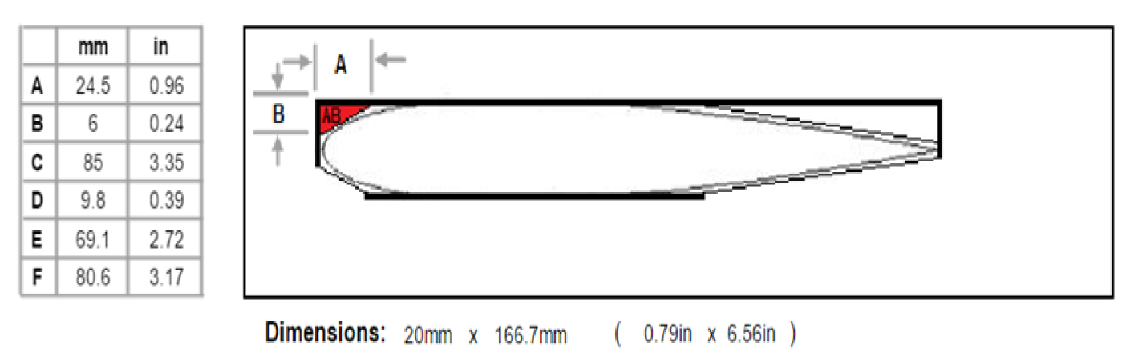


	mm	in
A	24.5	0.96
B	6	0.24
C	85	3.35
D	9.8	0.39
E	69.1	2.72
F	80.6	3.17

Dimensions: 20mm x 166.7mm (0.79in x 6.56in)

Figure 4.8: Draw lines C and D

Step 4: Flip your wood around 180 degrees, Draw lines A' and B' on your piece of wood then remove section AB' from your piece of wood by sanding between the lines as shown in figure (4.9).

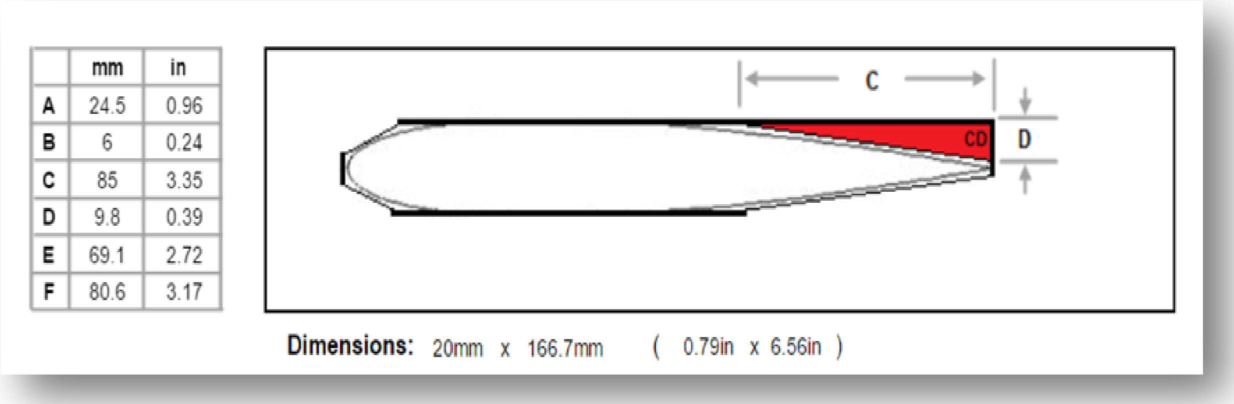


	mm	in
A	24.5	0.96
B	6	0.24
C	85	3.35
D	9.8	0.39
E	69.1	2.72
F	80.6	3.17

Dimensions: 20mm x 166.7mm (0.79in x 6.56in)

Figure 4.9: Flip your wood around 180 degrees, Draw lines A' and B'

Step 5: Draw lines C' and D' on your piece of wood then remove section CD' from your piece of wood by sanding between the lines as shown in figure (4.10).

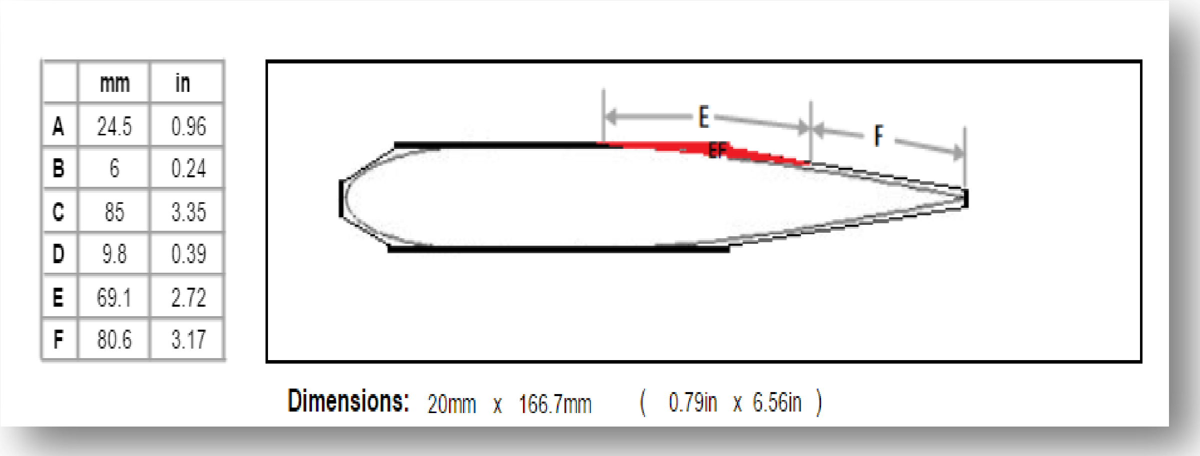


	mm	in
A	24.5	0.96
B	6	0.24
C	85	3.35
D	9.8	0.39
E	69.1	2.72
F	80.6	3.17

Dimensions: 20mm x 166.7mm (0.79in x 6.56in)

Figure 4.10: Draw lines C' and D' on your piece of wood then remove section CD

Step 6: Draw lines E' and F' on your piece of wood then remove section EF' from your piece of wood by sanding between the lines as shown in figure (4.11).

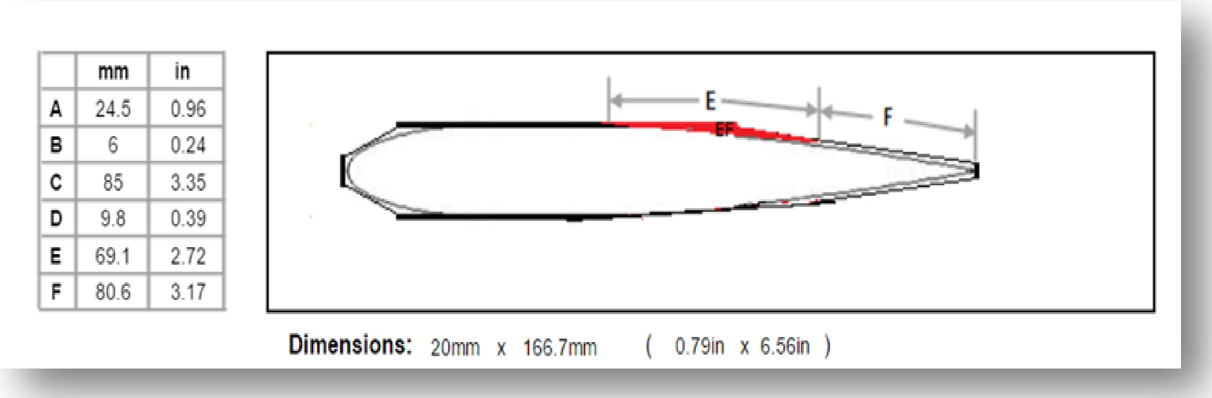


	mm	in
A	24.5	0.96
B	6	0.24
C	85	3.35
D	9.8	0.39
E	69.1	2.72
F	80.6	3.17

Dimensions: 20mm x 166.7mm (0.79in x 6.56in)

Figure 4.11: Draw lines E' and F' on your piece of wood then remove section EF'

Step 7: Flip your wood around 180 degrees, Draw lines E and F on your piece of wood then remove section EF from your piece of wood by sanding between the lines as shown in figure (4.12).



	mm	in
A	24.5	0.96
B	6	0.24
C	85	3.35
D	9.8	0.39
E	69.1	2.72
F	80.6	3.17

Dimensions: 20mm x 166.7mm (0.79in x 6.56in)

Figure 4.12: Flip your wood around 180 degrees, Draw lines E and F on your piece of wood then remove section EF

After we know, all dimension:

1) We must Mark out the stations by measurement from the root of the work piece.

2) Draw a line around the work piece at each station, using a square (lines shown dotted).

3) Mark the correct width at each station, measuring and join the marks up with a series of pencil lines, shown in figure (4.13).

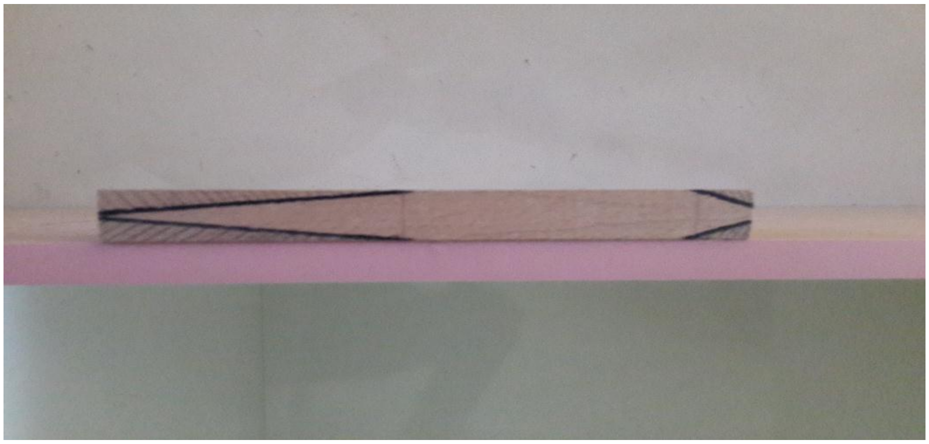


Figure 4.13: Dimensioned work piece

Figure (4.14) shows the performance of the blade due to change in wind speed.

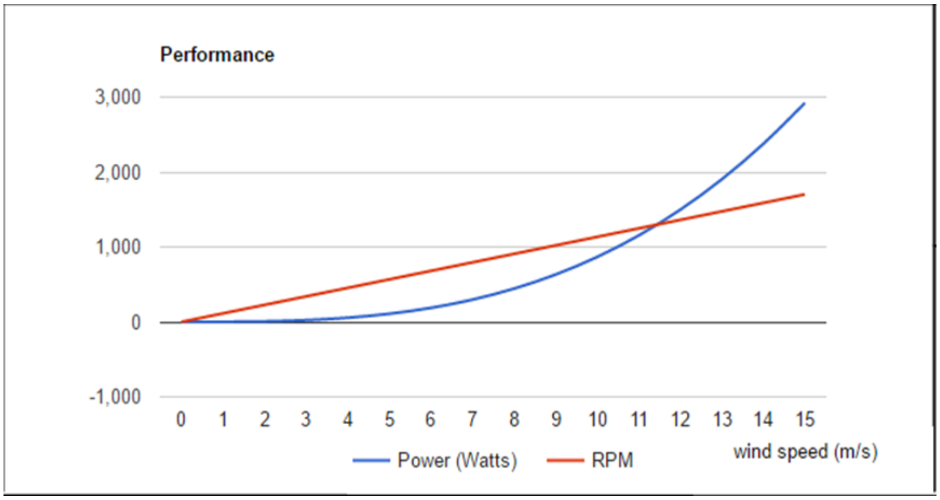


Figure 4.14: Performance of the blade

4.2.2 Radial Arms

The distance between center shaft and the airfoil is called radial arm. Specific systems are needed to be installed for easy assembling. The material used for fabrication of radial arms is aluminum because of its light weight and high strength.

For our design, we have assumed a 65 cm length for each arm as shown in figure (4.15).

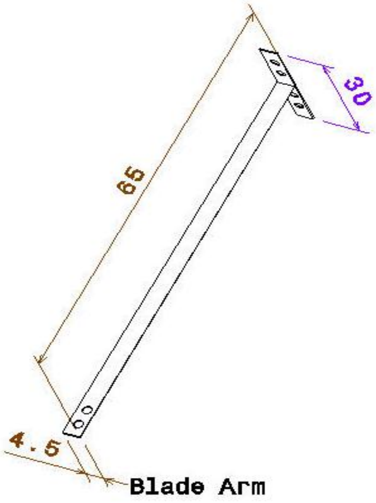


Figure 4.15: Radial Arm dimensions

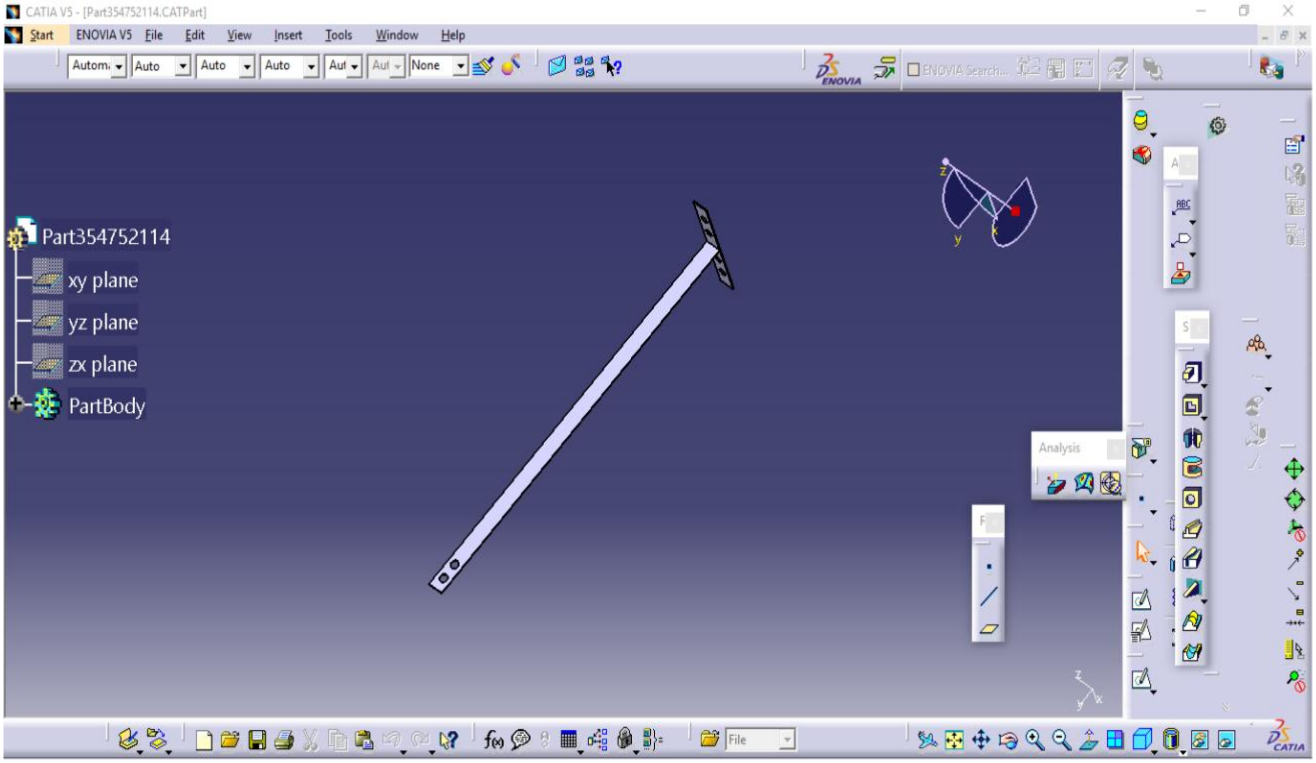


Figure 4.16: Radial arm design using CATIA

This radial arm carry blades as shown in figure (4.17).

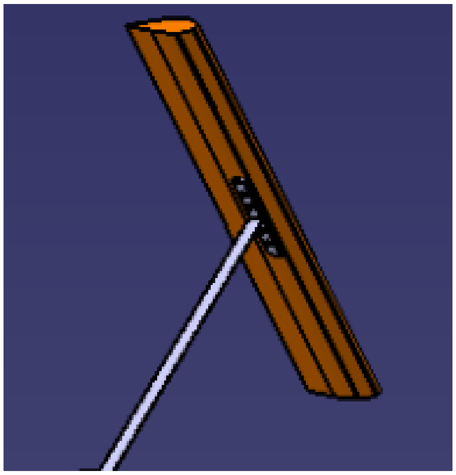


Figure 4.17: radial arm carry blades

4.2.3 Bearing

Bearing is a device used to permit constrained relative motion between two parts, typically rotation or linear movement. In our project, we will use plate bearing with diameter of the shaft is 35mm as shown in figure (4.18).

Figure 4.18: Plate bearing

Dimension of bearing is shown in figure (4.19).

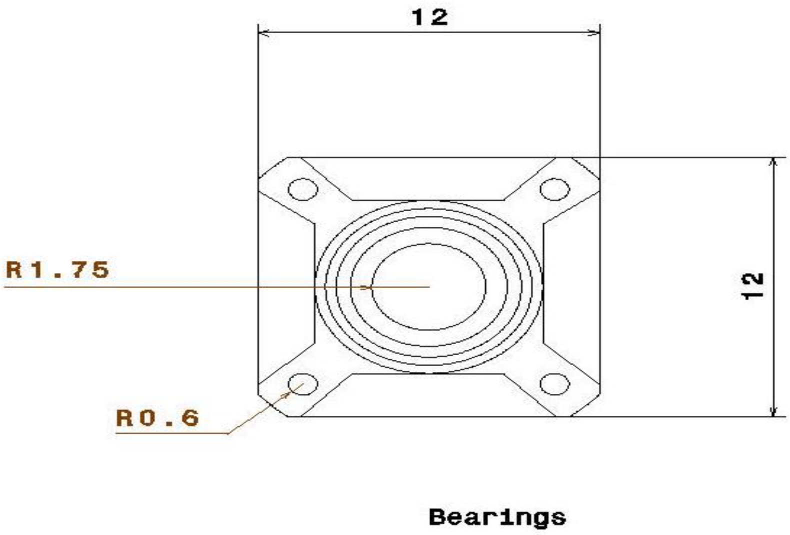


Figure 4.19: dimension of bearing using CATIA

4.2.4 Coupling disk

Initially we choose steel plate. Draw a circle at the plate during CNC plasma has 32 cm diameter and 0.7 cm thickness, plate bearings in the middle of coupling disk and three holes with 120 degree between them. Coupling disk mounted on shaft, figure (4.20) show coupling disk dimension.

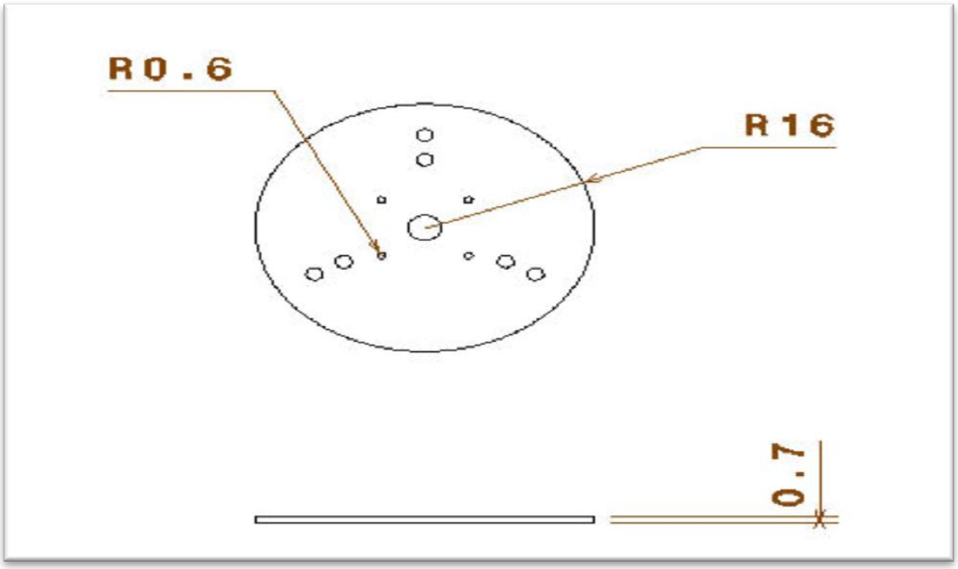


Figure 4.20: coupling disk dimensions

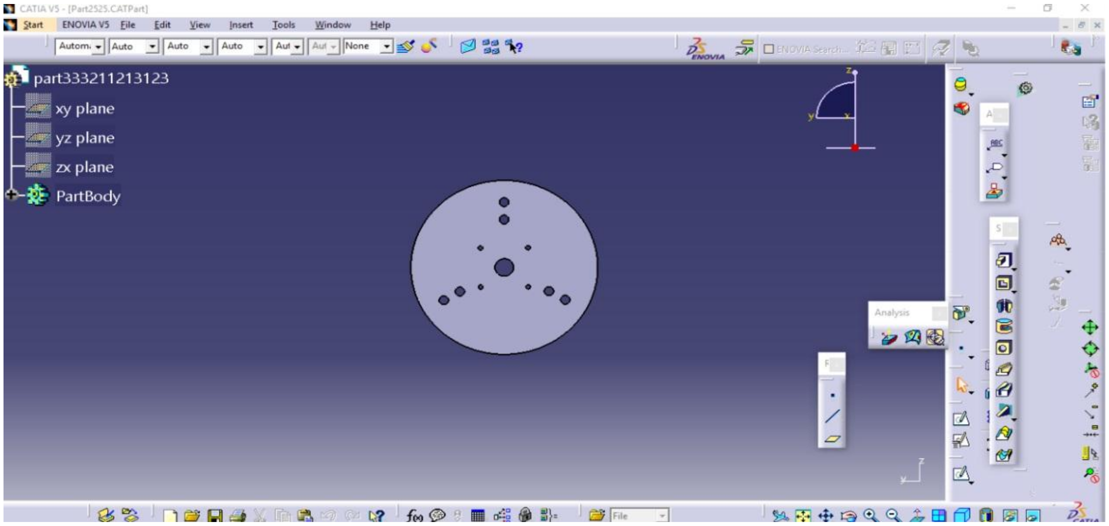


Figure 4.21: coupling disk using CATIA

After we couple blades and radial arms and bearings on coupling disk as shown in figure (4.22).

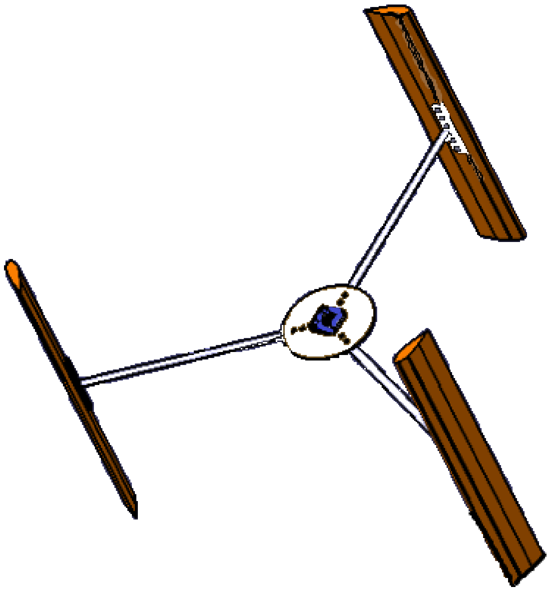


Figure 4.22: coupling disk consist components

4.2.5 Vertical holder arm

This component is from solid steel, which hold all component with 1.5m height and 3.5 diameter as shown in figures below.

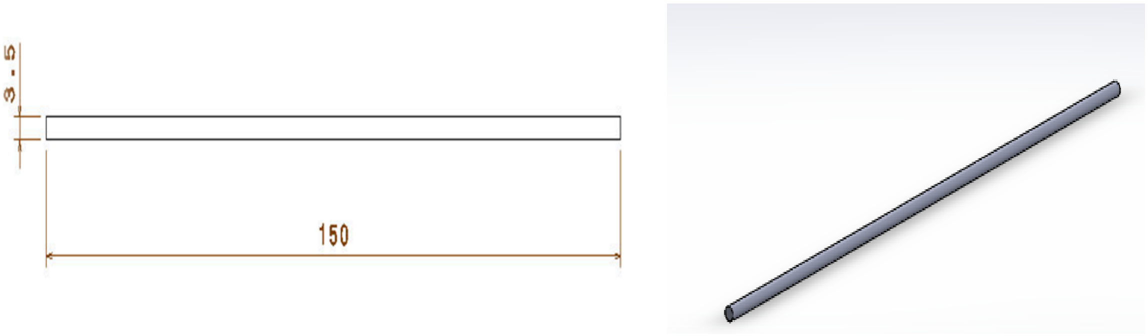


Figure 4.23: Vertical holder arm dimension

4.2.6 Alternator

To choose the generator we calculate the power. In our project we design simple gear consist two roller first one with 40cm diameter connect with coupling disk, second with 6.5cm connect with dc motor so by this method we increase rpm six times to get output power at design point, gear calculation shown in equation (4.2).

$$a=D1/D2 \qquad (4.2)$$

Where:

a: gear ratio

$D1$: roller 1 diameter

$D2$: roller 2 diameter

Our calculation:

$a= (40/6.5)=6.1$

We can increase rotation speed at alternator six time than the turbine rotation speed by the tow roller as shown in figure (4.24), (4.25).

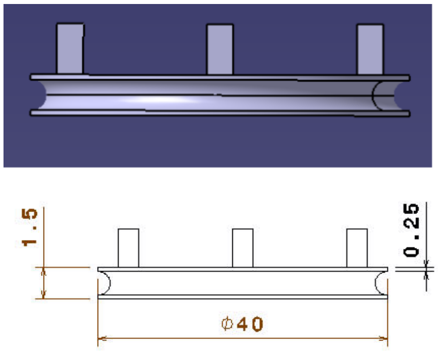


Figure 4.24: turbine roller

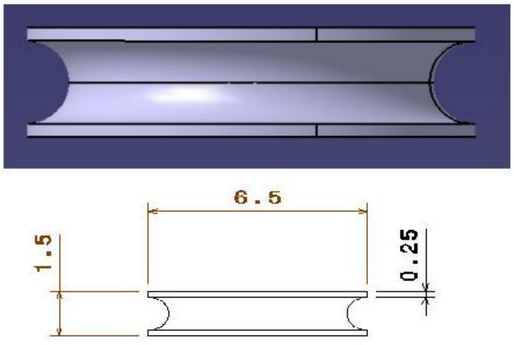


figure 4.25: motor roller

We use DC PM Motor as generator to produce electrical power, why we use DC motor?

We used DC motor to charge the thermal resistance because thermal resistance does not differentiate between it if the voltage is constant (DC) or alternating (AC) and depends on the power connected to it regardless of constant current or alternating current. Therefore, we found through research on the same subject that the DC motor meets the purpose and achieves the required.

Here is specification of electric water heater as show in figure (4.26).

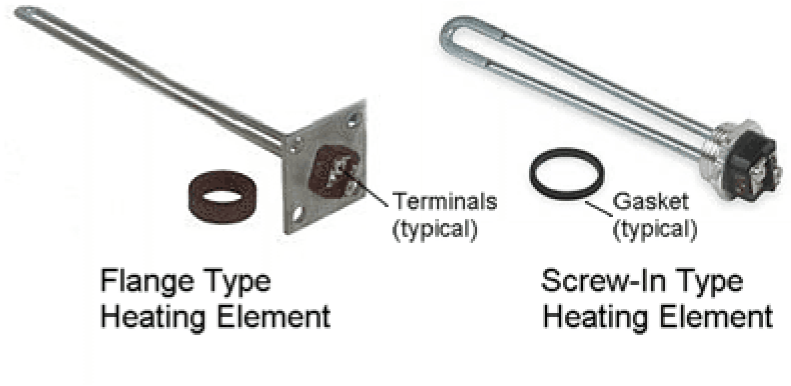


Figure 4.26: electric water heater

Electric water heater Specification:

Water boiler consumed = 2.5 kWh

Resistance = 19.9 Ω

Generator:

In the following table 4.2 for a VAWT generator data sheet.

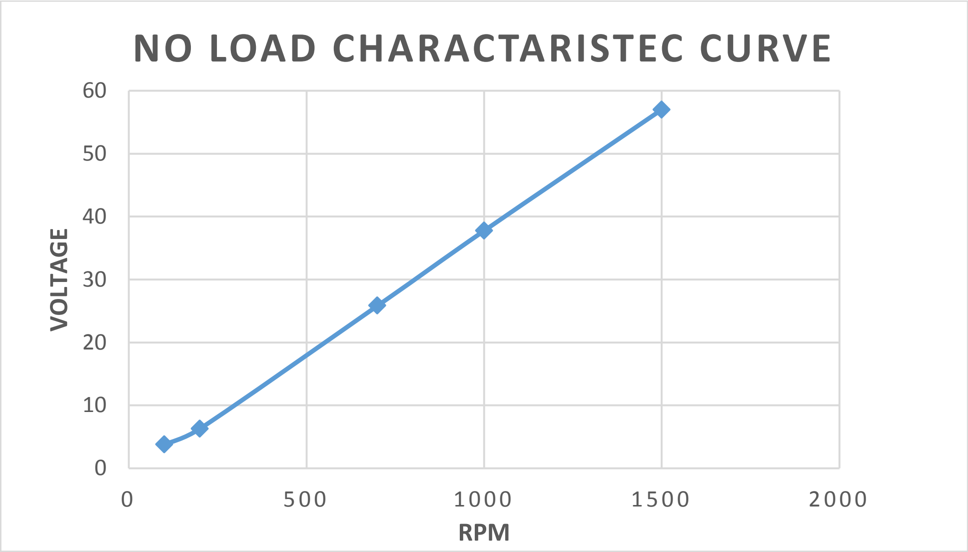
Table 4.2: Generator Data sheet.

Rated power	**1.2 hp**
Rated voltage	**180 volt**
Rated current	**6 A**
Field	**PM**

Figure (4.27) show generator.

Figure 4.27: DC motor

To find characteristic curve, we visited machine lab in our university to find the characteristic curve.



Therefore, we find value of voltage at different rotation speed during coupling generator with prime mover, which give different rotation speed.

At design point, wind speed is 4 m/s.

This wind speed in rpm before using simple gear is equal:

$$n = \frac{60 v_m \lambda_{opt}}{2\pi R_{turb}} \qquad (4.3)$$

$$\boldsymbol{n}\, nom = \frac{60 * 4 * 6}{2 * 3.14 * 0.75} = 359\, rpm$$

After gear rotating speed is:

$$a \times n = 6 \times 395 = 2155rpm \tag{4.4}$$

This rotation speed give us voltage:

$$v = \left(2155 * \frac{57}{1500}\right) = 80\ V \tag{4.5}$$

Current is:

$$\mathrm{I} = \frac{V}{R} = \frac{80V}{20\Omega} = 4\ A \tag{4.6}$$

Power is:

$$P = V*I = 80*4=320 \text{ watt} \tag{4.7}$$

In our design we have all the night to heat water , as we know in winter all consumer need warm water because in winter warm water convert to cold water quickly. If we deliver electrical power to the heater, it will remain hot water as much as possible for residential demand.

This equation express time required for heating water in hour

$$P \text{ x } t=m*Cp*(T_2-T_1) \tag{4.8}$$

Where:

P: electrical power (watts)

t: Time (hours)

T: water temperature (Celsius)

Cp: water specific heat (*4.187 kJ/kgK*)

m: water volume (L)

To protect generator coils from over current we use arduino which sense the (voltage and rpm) if the voltage is more than specific design point we connect normally close relay direct with the load which control turn on or off the load as shown in figure (4.28)

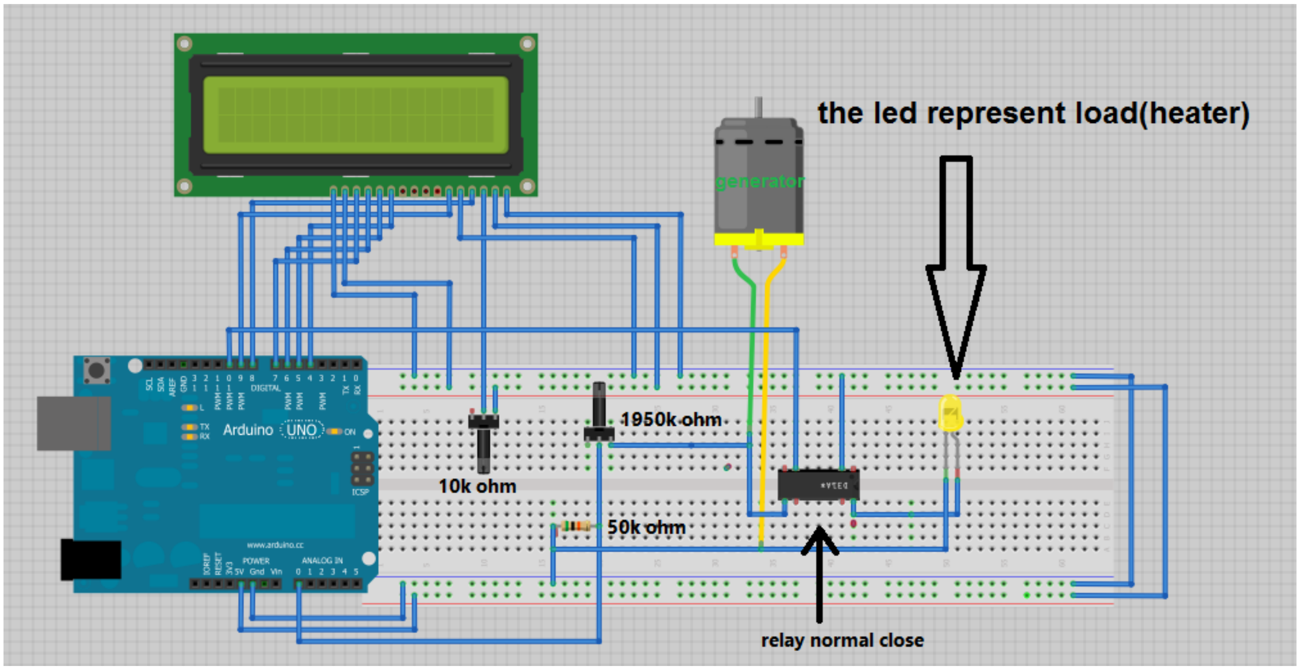


Figure (4.28): arduino control circuit

Code explained in appendix A4.

Figure 4.29 show whole wind turbine after assembling all component.

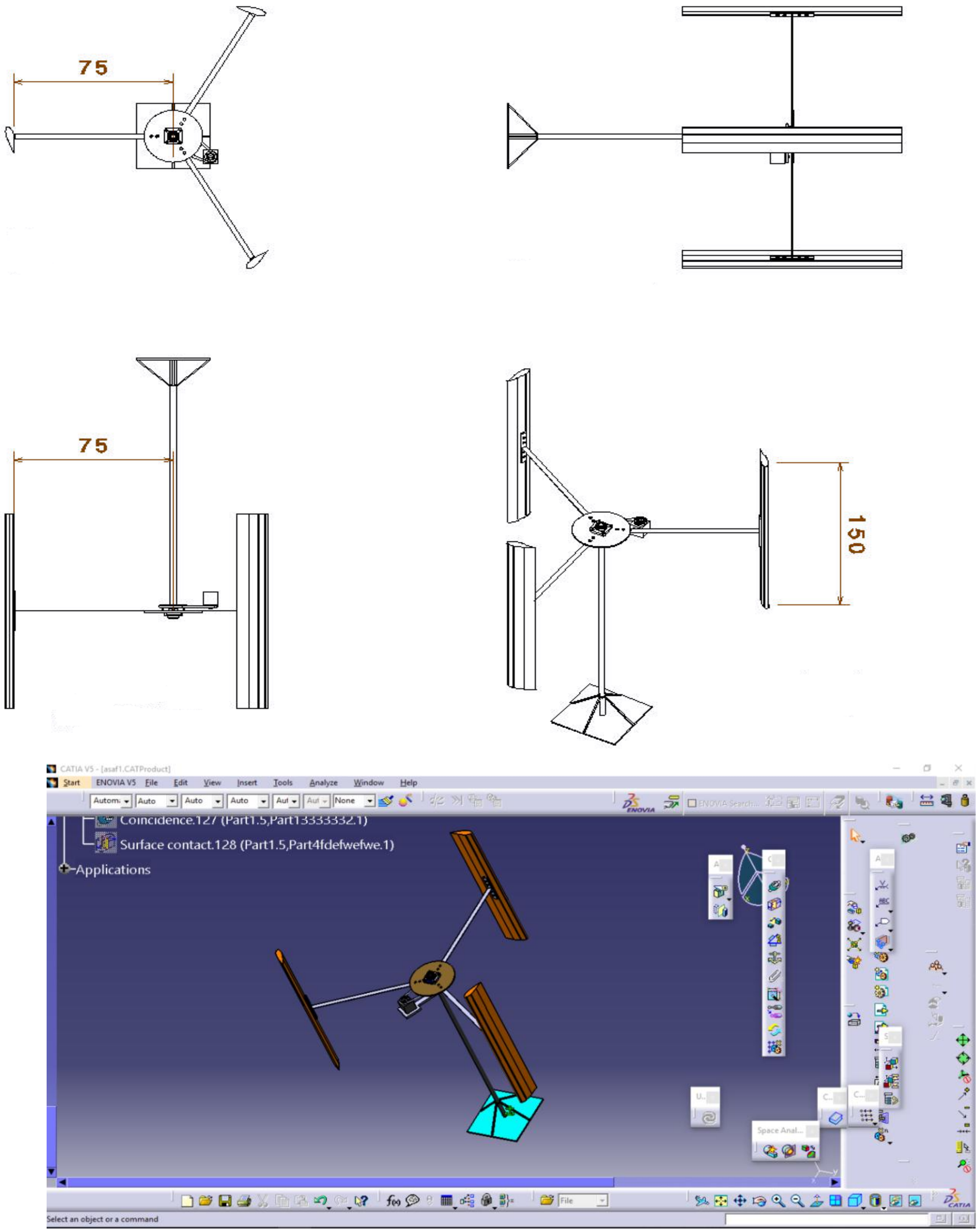


Figure 4.29: whole wind turbine

4.3 Mechanical Calculation:

For a security system, check the allowable deflection range due to vibration, an average of 0.5 cm, and the stress on the beam depend on type steel, we using high-speed steel type and the tensile strength reach to 800 to 1000 MPa.

To find the vibration resulting from the wind force effect on the rod.

$I = \frac{\pi}{64} [D^4\_d^4]$ (4.9)

I: moment of inertia of the column cross section (mm^4)

D: diameter outside of rod (mm).

D: diameter inside of rod (mm).

$I = \frac{\pi}{64} [35^4\_0] = 73624.5mm^4$

δ = FL3/3EI (4.10)

δ: the transverse deflection of the beam.

E: modulus of elasticity steel equal 207GPa and equal 207000 N/mm^2

To find wind force:

$F = 0.5*\rho*A*v^3$ (4.11)

F: wind force (N).

A: area of blade (m^2).

V: Wind speed at maximum probability (m/s).

ρ: air of density 1.12 (kg/m^3).

$F = 0.5*1.12*1.875*(13)^2 = 177.5$ N

If the beam is fixed directly with the ground using concrete or screws as figure, the deflection will reach 1.135cm.

$\delta = FL3/3EI = (177.5N*(1430mm)^3 / (3*207000N/mm^2*73624.5mm^4) = 11.35mm$

11.35 > 5mm the system is not suitable.

Draw using AutoCAD 2007

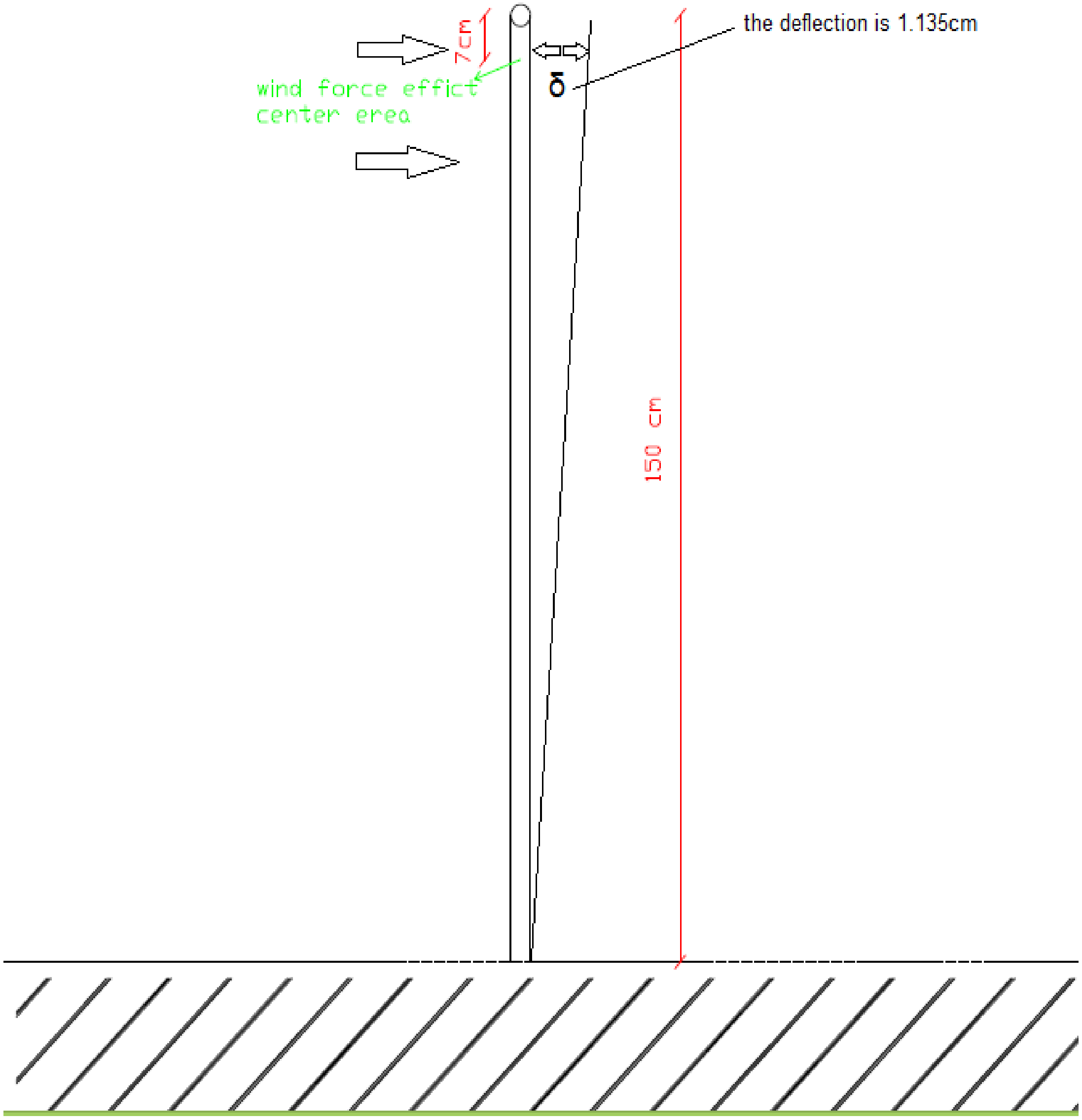


Figure 4.30: wind force effect on rod

If a base consist three arms is used to fixed as figure, it will reduce the beam length and affect the remaining length of the beam and become 53cm.

$\delta = (177.5\text{N}*53\text{mm}^3)/\ (3*207000\text{N/mm}^2*73624.5\text{mm}^4) = 0.6\text{mm}$

0.6mm < 5mm, the system is Suitable.

We using this model because the deflection is good.

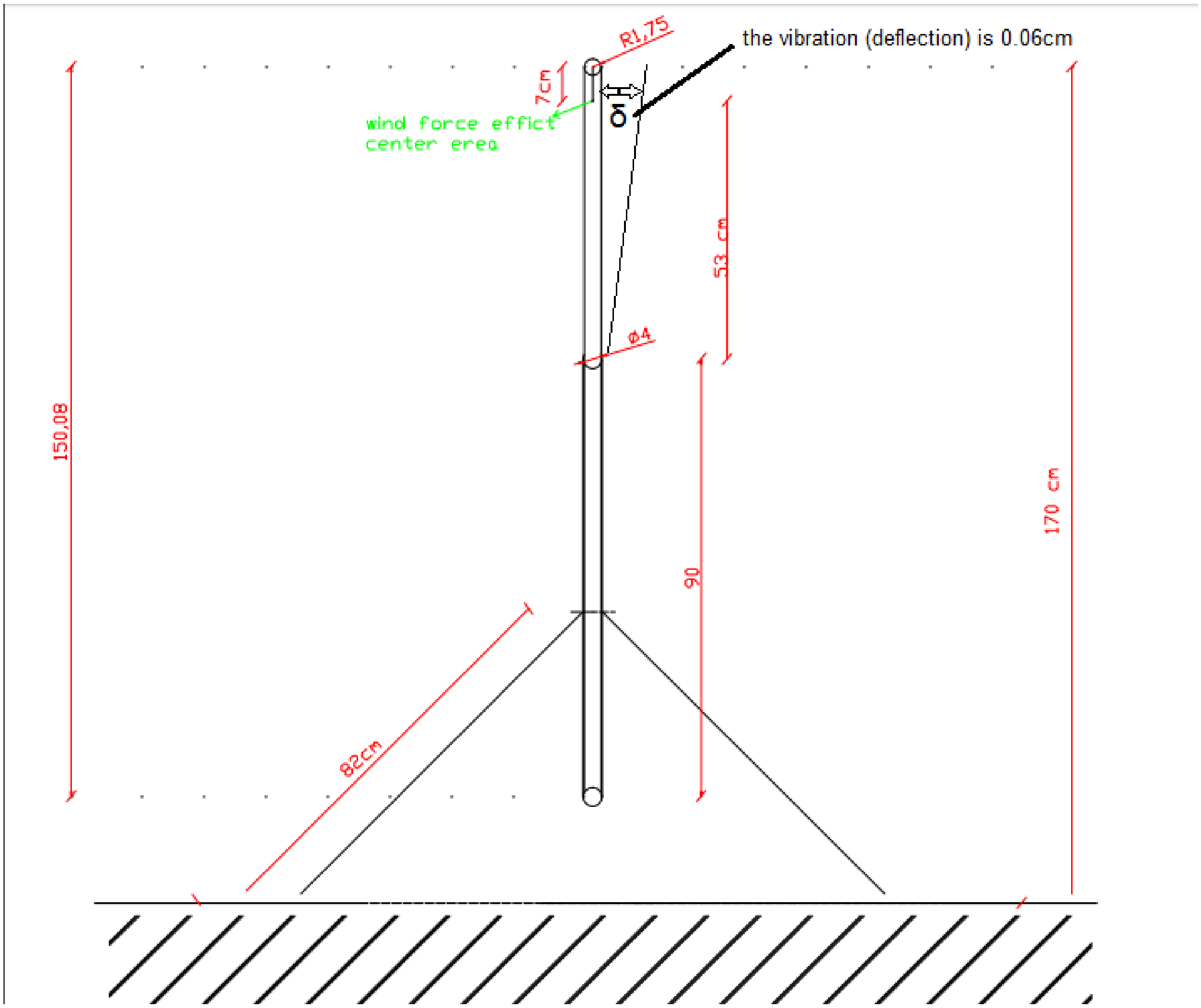


Figure 4.31: vibration deflection on rod

Check the stress on the beam (rod):

$\delta = M.\frac{c}{I}$ (4.12)

c: the radius of rod (mm)

M: The torque at the point of connection between the base and the beam (N.mm)

I: moment of inertia of the column cross section (mm^4)

δ: the stress on the rod (MPa or N/mm^2)

$\delta = (177.5N * 530mm * 17.5mm) /73624.5mm^4 = 22.4\ N/mm^4$

Factor of safety must large than 1, assume F.S 3,

$f.s = \frac{Sy}{\delta}$ (4.13)

Sy: the yield strength of the steel from type high speed steel =800 N/mm^2

$f.s = \frac{800}{22.4} = 35.71$

35.71 >> 3 , so the steel is very strong

Finally, the system is safety.

Table 4.3: Effect of weight on base:

Components	**unit (kg)**
blade	**0.9**
radial arm	**0.92**
bearing	**1.5**
disk	**4.380**
motor	**8**
beam (rod)	**12**
total screws	**0.5**

Total mass = 0.9 * 3+ 0.92*3+1.5*2+4.380+8+12+0.5 =33.34 kg

$\delta = \frac{w}{A}$

δ: the stress on the base (MPa or N/mm^2).

w: the weight effect on base (N)

A: area of base (mm2).

The resulting shape of the base is a triangle, the distance between each arms is 1050mm.

w = total mass * 9.81 m/s^2 = 328 N

δ = 328 N / (1050mm * 1050mm * 0.5) = 6*10^ $^{-4}$ N/mm^2

The type of steel for base is Stainless Steel (S31600), the Yield Strength is 205MPa.

f.s = 205/0.00006 = 3416666

3416666 >>> 3, so the weights are much larger than the existing load

System is (Very safety). [14]

CHAPTER 5: Economic Feasibility

In this chapter, our calculation depends on weibull distribution wind speed for Hebron city.

Average wind speed by statistical weibull function, this curve of weibull give us indication of number of hours per year that each specific wind speed may be expected. Wind speed distribution based on the statistical Weibull function with a shape factor of 2 and average wind speed of 4 m/s as shown in figure (5.1).

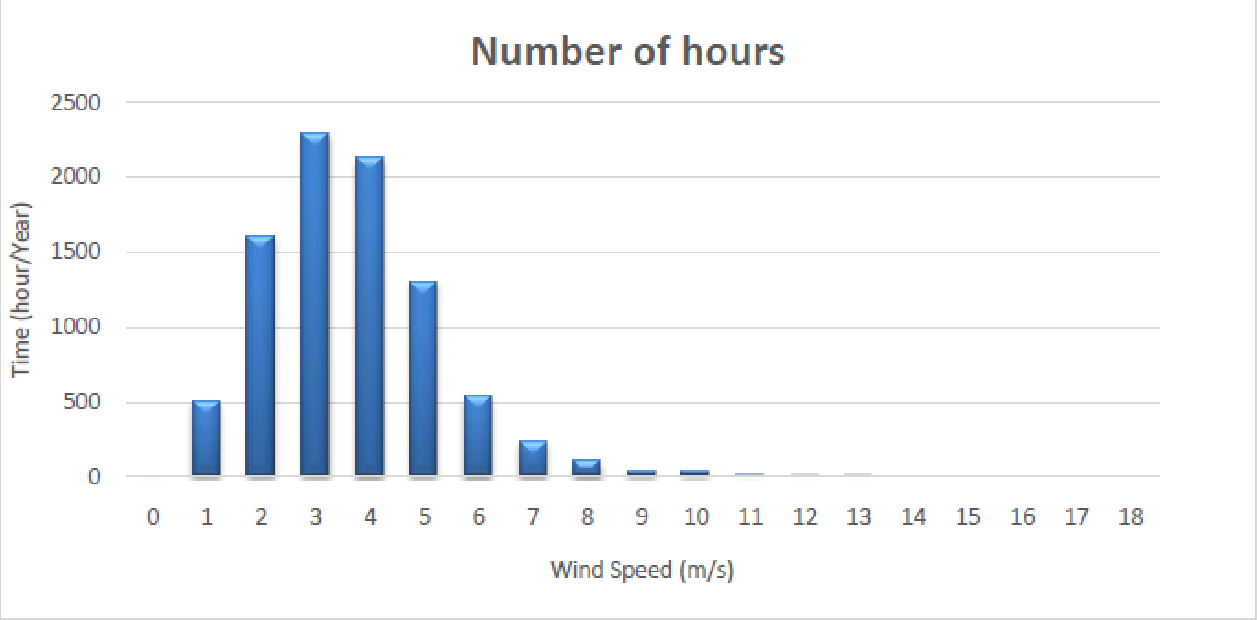


Figure 5.1: Weibull distribution at Hebron city [9]

In our design point which is at Vavg= 4 m/s which is available 2400 hours per year.

Calculation according weibull speed:

Vavg=4m/s

#of hour=2400 hour

Pout =300 watt

Annual energy=Pout*(#of hours) =300*2400=720 KWh/year

Water boiler consumed = 2.5 KWh

In the winter, the house turn on the water heater for 4-5 hours to heat the water so we assume the energy consumed in winter four month which is in (December , January , February , march).

Energy consumed by boiler in 4 month= 2.5*4*30*4 = 1200 KW (in 4 month), which equal 3600 KW /year.

The amount coverage of the turbine of the total energy consumption through water heater annually:

$$\frac{\boldsymbol{energy\ from\ turbine}}{\boldsymbol{the\ total\ boiler\ consumption\ energy\ at\ 4\ month}} \textbf{*100\%} = \frac{\mathbf{720}}{\mathbf{3600}} \textbf{* 100\% = 20 \%}$$

Which cover 20% from the whole year, but in winter especially in 4 months, it cover 60%.

Table 5.1: Capital cost

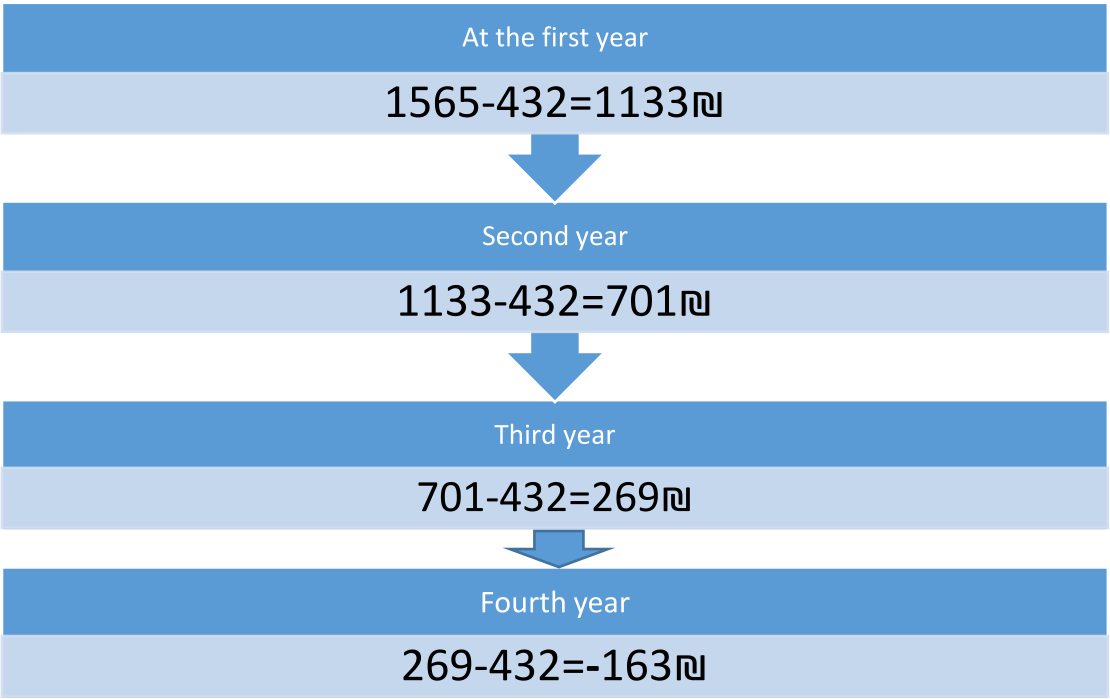
Item	# number	Cost (₪)	description
Shaft	*1*	185	1,5 meter length , 3.5 cm diameter
Bearings	2	70	12x12 cm, 3.5 cm diameter
Coupling disk	1	100	32 cm diameter, 0.7 cm thickness
Radial arms	3	340	75 cm arm length aluminum
wood blade	3	150	1.5 m length, 16.67 cm width, 2 cm thickness
DC motor	1	150	180v , 6 A
paint	2	40	White paint
Roller	2	50	40 cm , 6.5 com diameter
Screw	40	30	Different scale screw
Arduino and LCD	2	150	Arduino Uno , and lcd
Interconnection and transportation	1	300	
Total cost		**1565₪**	

This table express that if medium house which turn boiler on their Electric meter the price of Energy purchased, and energy sold by wind turbine as shown in (table 5.2).

Table 5.2: The price of Energy purchased and Energy Sold

	Quantity (KW)	KW cost ₪	Total cost₪
Energy Purchased	1200	0.6	720
Energy Sold	720	0.6	432

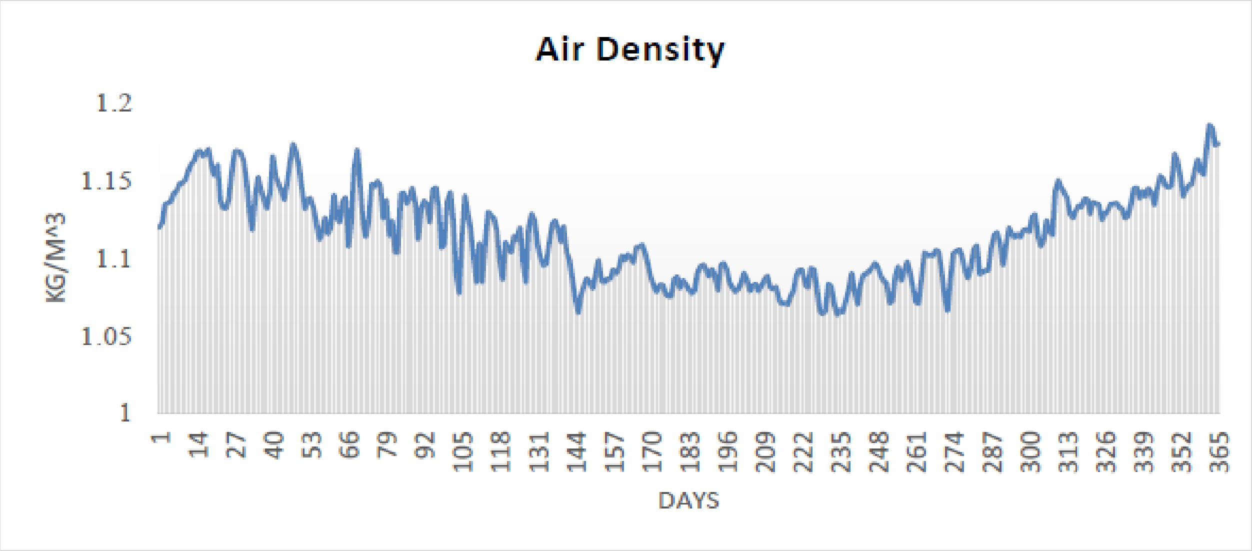
For sure from this table we can assume after which year I can get my capital and start make profit, so we explain it in this cash flow.



From net cash flow the capital cost is decreasing gradually until it has reach the fourth year; after this year all of the cost will be recovered and the project will be start to income the profit throughout the period of work.

Appendix [9]

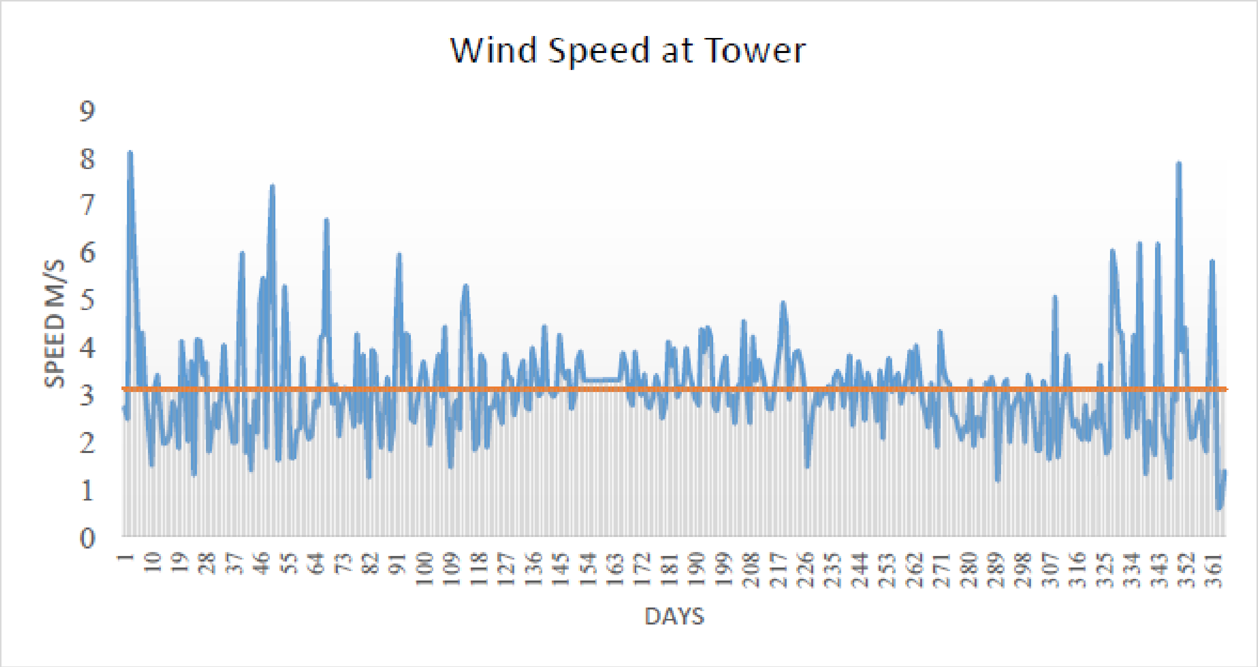
Appendix A1: shows the average air density in Hebron city at 900-meter elevation while the annual average is 1.1141 kg/m3.



the average air density in Hebron through a year.

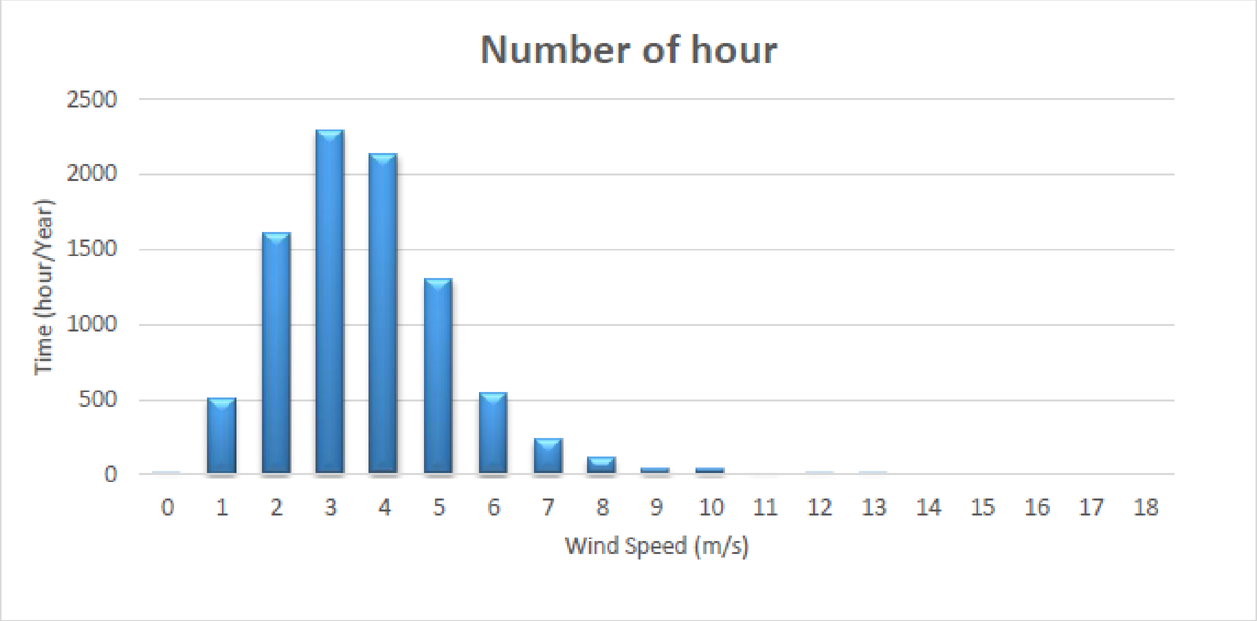
Source: Palestine Polytechnic university anemometer unit.

Appendix A2: shows the wind speed at tower of 10-meter over a year at Hebron city.



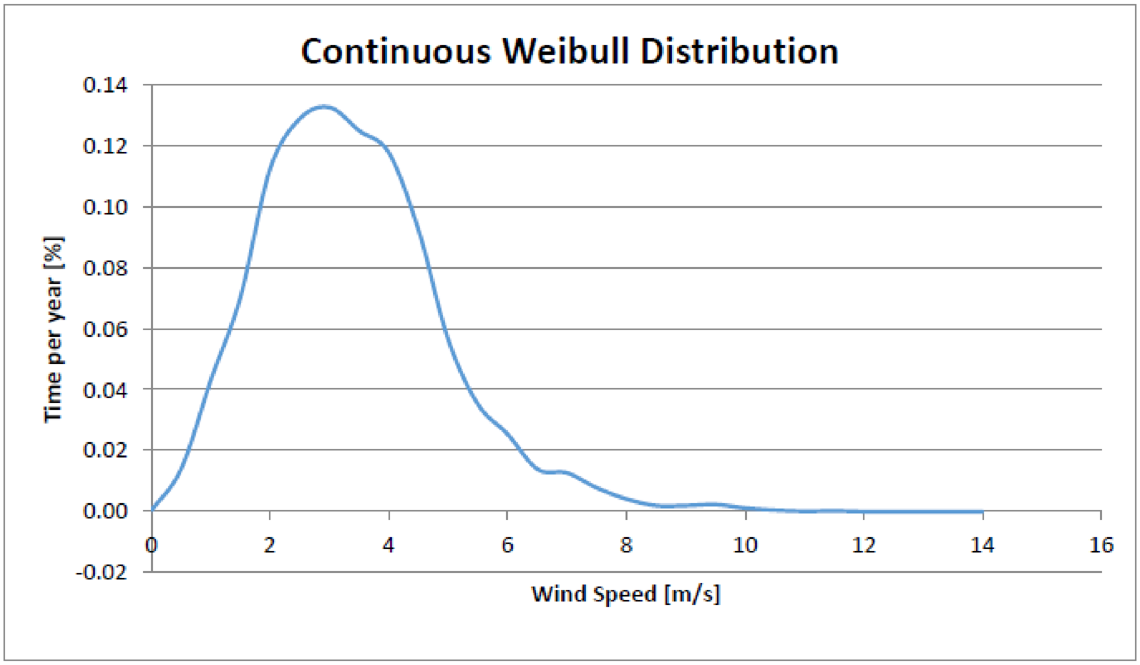
Wind Speed with 10-meter tower above reference anemometer.

Appendix A3: Weibull distribution at Hebron city area with shape factor 'K' of 1.81 and Weibull scale factor C = 4.

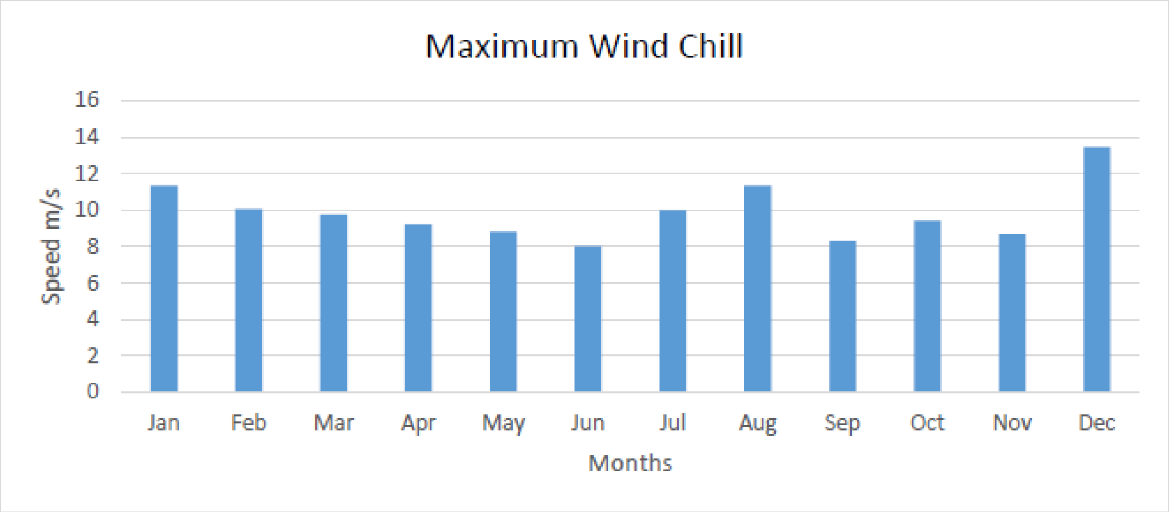


Number of hours per year for each wind speed range- Average of (2006-2010)–site at

Weibull distribution at Hebron city area with shape factor 'K' of 1.81 and Weibull scale factor C = 4.

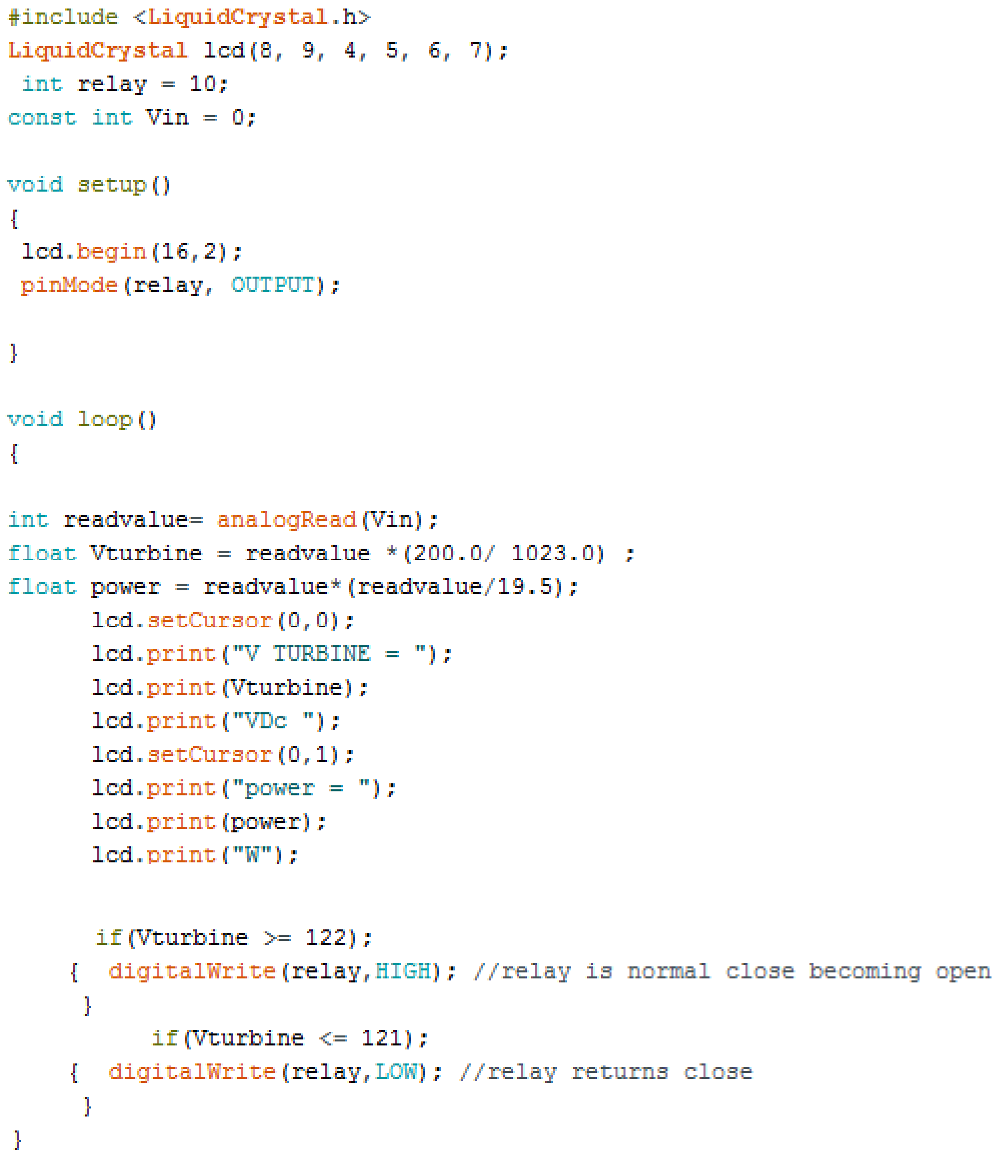


Monthly maximum wind speed is important parameter to show the turbine safety limits



Wind chill by month, wind recorded every fifteen minutes.

Appendix A4: Arduino code for generator protection



```
#include <LiquidCrystal.h>
LiquidCrystal lcd(8, 9, 4, 5, 6, 7);
 int relay = 10;
const int Vin = 0;

void setup()
{
 lcd.begin(16,2);
 pinMode(relay, OUTPUT);

}

void loop()
{

int readvalue= analogRead(Vin);
float Vturbine = readvalue *(200.0/ 1023.0) ;
float power = readvalue*(readvalue/19.5);
      lcd.setCursor(0,0);
      lcd.print("V TURBINE = ");
      lcd.print(Vturbine);
      lcd.print("VDc ");
      lcd.setCursor(0,1);
      lcd.print("power = ");
      lcd.print(power);
      lcd.print("W");


      if(Vturbine >= 122);
     {  digitalWrite(relay,HIGH); //relay is normal close becoming open
      }
          if(Vturbine <= 121);
     {  digitalWrite(relay,LOW); //relay returns close
      }
 }
```

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