Saimaa University of Applied Sciences
Technology, Lappeenranta
Degree Program in Mechanical Engineering and Production Technology

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RESEARCH AND UTILIZATION OF WINDMILL

Bachelor’s Thesis 2010

ABSTRACT

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Research and Utilization of Windmill, 60 pages
Saimaa University of Applied Sciences, Lappeenranta
Technology, Mechanical Engineering and Production Technology
Instructor: Mr Jukka Nisonen, Saimaa University of Applied Sciences

The thesis researches the characteristics of the wind power, the operation and design of the windmill. The design part involves the strength calculation and the method of placing and fixing the windmill on a high building. The methods applied in the thesis include preliminary study of the wind power, functional specification of the wind mill and technical specification of the design of wind mill.

The environment aspect should be considered more when designing something as an engineer in the future.

Keywords: wind power, renewable, environment, batteries, design, strength and drawing.

CONTENTS

1 INTRODUCTION

The global Greenhouse effect has been taken seriously and frequently over the world nowadays. To meet the worldwide promotion of reducing pollution and better utilizing the renewable sources, the final thesis is about the wind mill mainly in China. China has kept strong economic growing in recent years. The industry is the key contribution on growing factor, but the electric crisis is still remaining behind the big contribution, so the authors hope this small design could relief electric crisis and meet the civilians' daily electric consumption at least.

To distinct the common wind wills we could see around wild place far away the urban area, the design is to place the wind mill on the roof of a high building in an urban area, school campus building or three-storied civilian building so that we can better catch and utilize the wind power in the higher place.

The thesis first introduces the energy aspect worldwide briefly and mentions the wind mill utilization in China. And the authors know how to better utilize wind power according to its character we have analyzed. Then the authors list the impact of wind mill to the environment even if it is minor, the controversy of wind power because of the instability of wind power. Next, the authors focus on design of wind mill including blade and rotors, how wind mill sores electric to the batteries, and design the beam structure that can fix the wind mill firmly on the roof. Last, the authors draw the parts of wind mill with parameter by using CAD and Solidworks.

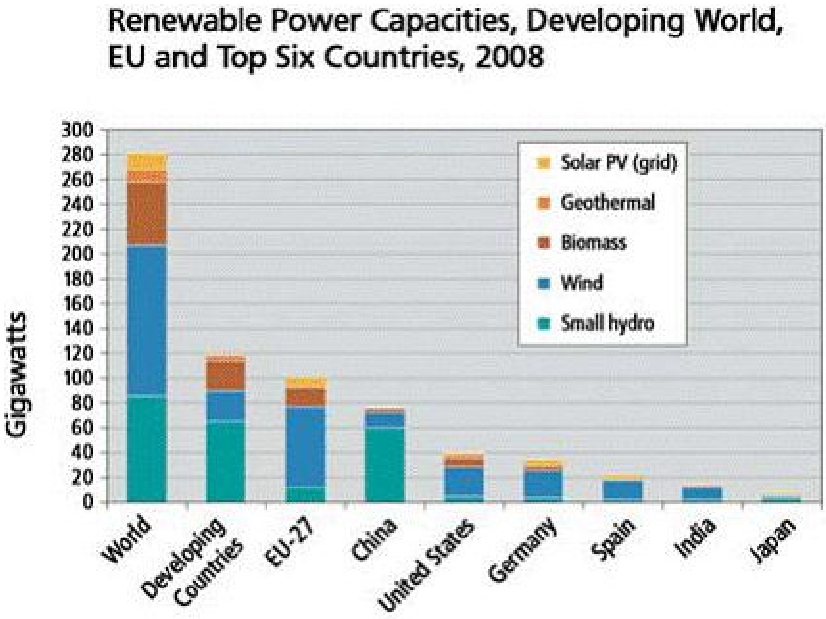
The thesis is about the research how the wind works, impacts related to it, and mainly focus on the design of wind mill. While with the process to finish the final thesis, the authors were also studying the wind power and wind mill which were a new subject. Also the authors understood deeply the environment issues, especially when the authors design something as engineers the authors should take environment into account.

2 ENERGY INTRODUCTION

2.1 Energy in the world

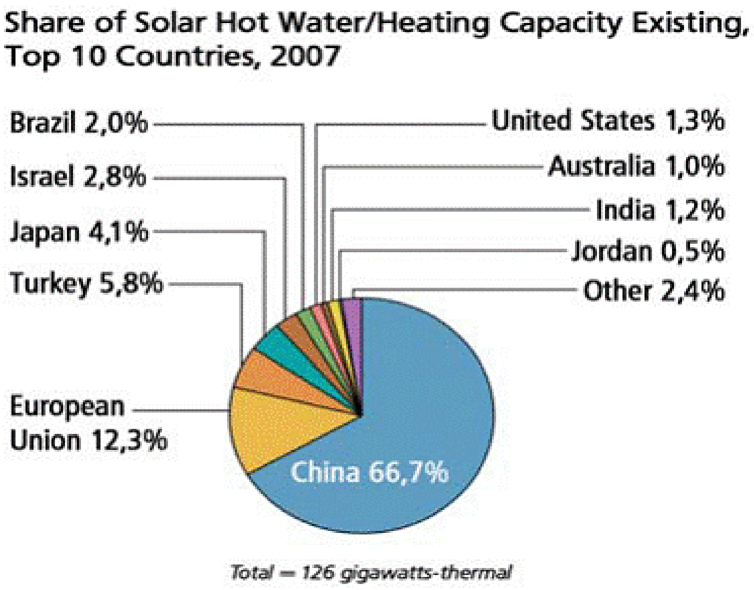
Nowadays renewable energy source is more widely utilized that can replace fossil fuel resources over the long run to reduce greenhouse gases and other pollutants. Growth in demand for renewable energy in industrialized countries is leading to economies of scale such as China. The deployment of renewable energy requires appropriate economic, market and regulatory instruments. The Chinese government carried out the policy to support the innovation of diversity of renewable energy.

Figure 1



Renewable Power Capacities, Developing World, EU and Top Six Countries, 2008

Figure 2



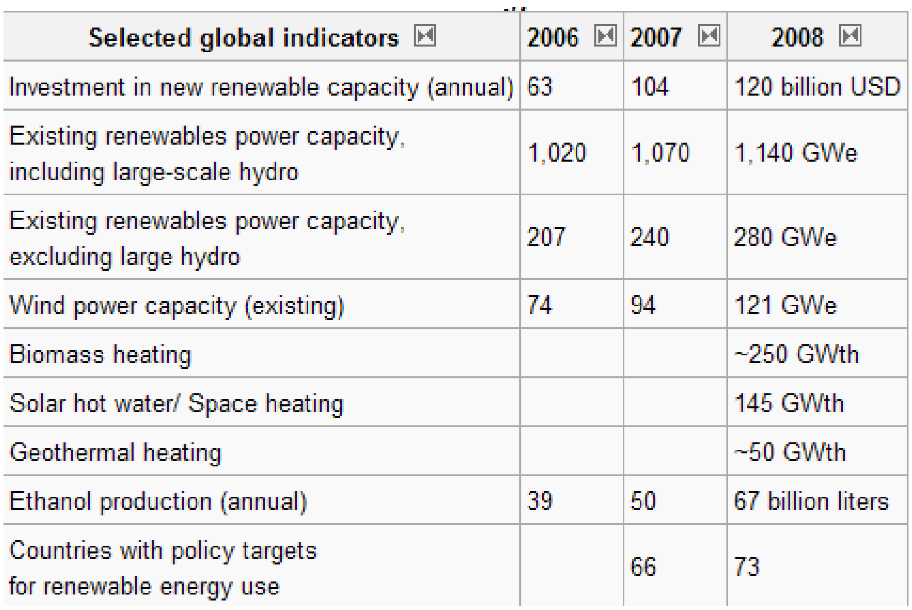
Share of Solar Hot Water/Heating Capacity Existing, Top 10 Countries, 2007

Total = 126 gigawatts-thermal

2.2 Globe growth of renewable energy

From the end of 2004 to the end of 2008, solar photovoltaic (PV) capacity increased six fold to more than 16 gig watts (GW), wind power capacity increased 250 percent to 121 GW, and total power capacity from new renewable increased 75 percent to 280 GW. During the same period, solar heating capacity doubled to 145 gig watts-thermal (GWth), while biodiesel production increased six fold to 12 billion liters per year and ethanol production doubled to 67 billion liters per year. (http://en.wikipedia.org/wiki/Renewable_energy, 05.01.2010)

Figure 3



Selected global indicators	2006	2007	2008
Investment in new renewable capacity (annual)	63	104	120 billion USD
Existing renewables power capacity, including large-scale hydro	1,020	1,070	1,140 GWe
Existing renewables power capacity, excluding large hydro	207	240	280 GWe
Wind power capacity (existing)	74	94	121 GWe
Biomass heating			~250 GWth
Solar hot water/ Space heating			145 GWth
Geothermal heating			~50 GWth
Ethanol production (annual)	39	50	67 billion liters
Countries with policy targets for renewable energy use		66	73

2.3 Wind power in China

In 2009, China became the third largest wind energy provider worldwide (behind USA and Germany), with the installed wind power capacity reaching 20 GW at the end of 2009. According to the Global Wind Energy Council, the development of wind energy in China, in terms of scale and rhythm, is absolutely unparalleled in the world. The National People's Congress permanent committee passed a law that requires the Chinese energy companies to purchase all the electricity produced by the renewable energy sector. (http://en.wikipedia.org/wiki/Wind_power_in_China, 05.01.2010)

2.4 Future wind farms

The Gansu Wind Farm proposed for western Gansu province is one of the six national wind power megaprojects approved by the Chinese government. It is expected to grow to 20,000 MW by 2020, at an estimated cost of 120 billion Chinese Yuan ($17.5 billion). In 2008, construction began on a 750 kV AC power line to carry electricity from the wind farm (http://en.wikipedia.org/wiki/Wind_power_in_China, 05.01.2010)

3 WIND

When the sunrays warm up the surface of the Earth, the regions near the equator are heated the most. As a result, when at these areas the density of the air of higher temperature decreases, air begins its movement upward and towards the poles. However, this movement is complicated by the Coriolis effect which deflects all paths of moving object to the left in the southern hemisphere and do the right in the northern one. The general formula that governs this inertia-related factious force is:

$$\mathbf{a_c} = -2\mathbf{\Omega} \times \mathbf{v}$$

Where:
$\mathbf{a_c}$ – vector of the Coriolis acceleration,
$\mathbf{v}$ – vector of the velocity of the object
$\mathbf{\Omega}$ – vector of the angular velocity of the Earth

Due to this phenomenon, the air, which blows parallel to the isobars, tends to get twisted anticlockwise when looking form above near low-pressure areas, or depressions, in the northern hemisphere, and by analogy - clockwise in southern one. Near high pressure areas, or anticyclones, wind is deflected clockwise in the northern hemisphere and anticlockwise in the southern one.

Because of the Coriolis force, it can be observed, that as a general rule, the wind at given latitude blows predominantly according to the following list:

Latitude:	90-60°N	60-30°N	30-0°N	0-30°S	30-60°S	60-90°S
Direction:	NE	SW	NE	SE	NW	SE

For example, the coordinates of Lappeenranta are 61°04′N 28°11′E, so wind blowing from south-western direction can be expected. This is important for the right choice of the site of the windmill, because any obstacles in the direction of the wind should be avoided. However, the above considerations apply mostly to so-called geotropic winds, i.e. winds in the higher atmosphere driven exclusively by temperature and pressure differences and unaffected by objects on the surface of the Earth. For the operation of a windmill, much more important are the surface winds, i.e. wind in the first kilometer, and especially – within the first 100 meters, above ground level. In their case local topography and obstacles might alter these general directions applicable to the geotropic winds and should be always taken into consideration. The impact of the object on the surface of the Earth on the performance of the turbine will be described later on. (http://www.eoearth.org/article/Wind Lead Author: Michael Pidwirny 05.01.2010)

3.1 Wind changeability

Wind is always changing. Exactly how large the variation is depends both on the weather and on local surface conditions and obstacles. Energy output from a wind turbine will vary as the wind varies, although the most rapid variations will to some extent be compensated for by the inertia of the wind turbine rotor. In most locations around the globe it is windier during the daytime than at night

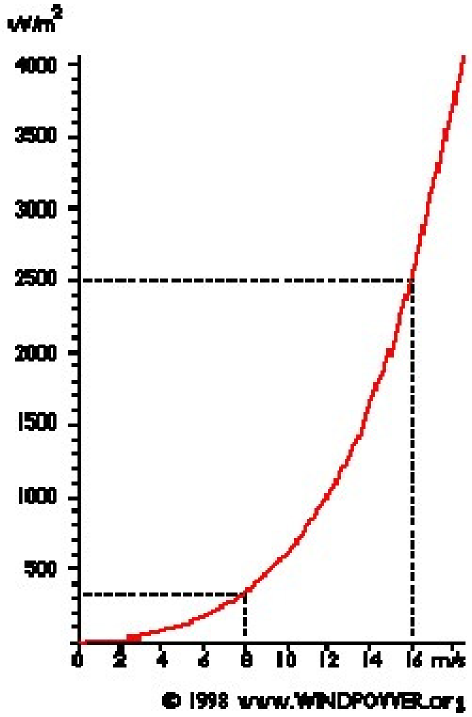
This variation is largely due to the fact that temperature differences e.g. between the sea surface and the land surface tend to be larger during the day than at night. The wind is also more turbulent and tends to change direction more frequently during the day than at night. From the point of view of wind turbine owners, it is an advantage that most of the wind energy is produced during the daytime, since electricity consumption is higher than at night. Many power companies pay more for the electricity produced during the peak load hours of the day (when there is a shortage of cheap generating capacity).
(http://www.windpartnersbg.com/thewindpower.php 12.02.2010)

3.2 Wind energy and measurements

The wind speed is extremely important for the amount of energy that a wind turbine can convert to electricity. The energy content of the wind varies with the cube (the third power) of the average wind speed, e.g. if the wind speed is twice as high it contains $2^3 = 2 \times 2 \times 2$ = eight times as much energy. Now, why does the energy in the wind vary with the third power of wind speed? From everyday knowledge you may be aware that if you double the speed of a car, it takes four times more energy as to break it down to a standstill. (Essentially this is Newton's second law of motion).

In the case of the wind turbine we use the energy from breaking the wind, and if we double the wind speed, we get twice as many slices of wind moving through the rotor every second, and each of those slices contains four times energy as much as we learned from the example of braking a car.

Figure 4



The measurement of wind speeds is usually done using a cup anemometer, such as the one in Figure 4 to the above. The cup anemometer has a vertical axis and three cups which capture the wind. The number of revolutions per minute is registered electronically. Normally, the anemometer is fitted with a wind vane to detect the wind direction. Instead of cups, anemometers may be fitted with propellers, although this is not common. Other anemometer types include ultrasonic or laser anemometers which detect the phase shifting of sound or coherent light reflected from the air molecules. Hot wire anemometers detect the wind speed through minute temperature differences between wires placed in the wind and in the wind shade.

The advantage of non-mechanical anemometers may be that they are less sensitive to icing. In practice, however, cup anemometers tend to be used everywhere, and special models with electrically heated shafts and cups may be used in arctic areas.

The best way of measuring wind speeds at a prospective wind turbine site is to fit an anemometer to the top of a mast which has the same height as the expected hub height of the wind turbine to be used. This way one avoids the uncertainty involved in recalculating the wind speeds to a different height. By fitting the anemometer to the top of the mast one minimizes the disturbances of airflows from the mast itself. If anemometers are placed on the side of the mast it is essential to place them in the prevailing wind direction in order to minimize the wind shade from the tower. Guyed, thin cylindrical poles are normally preferred over lattice towers for fitting wind measurement devices in order to limit the wind shade from the tower. The poles come as kits which are easily assembled, and you can install such a mast for wind measurements at (future) turbine hub height without a crane. Anemometer, pole and data logger (mentioned below) will usually cost somewhere around 5,000 USD.

The data on both wind speeds and wind directions from the anemometer(s) are collected on electronic chips on a small computer, a data logger, which may be battery operated for a long period.

An example of such a data logger is shown to the left. Once a month or so you may need to go to the logger to collect the chips and replace them with blank chips for the next month's data. If there is much freezing rain in the area, or frost from clouds in mountains, you may need a heated anemometer, which requires an electrical grid connection to run the heater. Wind speeds are usually measured as 10 minute averages, in order to be compatible with most standard software and literature on the subject. The result for wind speeds are different, if you use different periods for averaging, as we'll see later. (http://guidedtour.windpower.org/en/tour/wres/enrspeed.htm, 15.02.2010)

4 ENVIRONMENT IMPACTS OF WIND ENERGY

4.1 Shadow casting from windmill

Wind turbines that will be mounted on the roof of some high building, will cast a shadow on the neighboring area when the sun is visible. It may be annoying if the rotor blades chop the sunlight, causing a flickering effect while the rotor is in motion, especially for the people who live in the room of top floor which is close to the roof and the residents who live nearby the building.

The flickering effect is one of reasons to cause the adverse reaction of epilepsy; the people who have epilepsy are affected by the flickering effect when they are passing by the building. The problem can be solved by using astronomy and trigonometry.

4.2 Noise

Noise comes from the sound produced by the turning blades and the gearbox, generator. Quieter rotor blade tips are spent in slightly increasing the tip speed (the wind speed measured at the tip of the rotor blade), and thus increasing the energy output from the machines.

The design chooses 12 turbines, 10 kW of gearbox. The windmills will be mounted on the roof of a high building which is far away from the crowds. So the noise can be neglected because it is isolated and under low level.

4.2.1 Background noise: masking noise drowns out turbine noise

Birds and human activities make sound, and at wind speeds around 4-7 m/s and up the noise from the wind in leaves, shrubs, trees, masts etc. will gradually mask (drown out) any potential sound from wind turbines. This makes it extremely difficult to measure sound from wind turbines accurately. At wind speed of about 8 m/s and above, it generally becomes a quite difficult issue to discuss sound emissions from modern wind turbines, since background noise will generally mask any turbine noise completely.

4.2.2. The Influence of the surroundings on sound propagation

Sound reflection or absorption from terrain and building surfaces may make the sound picture different in different locations. Generally, very little sound is heard upwind of wind turbines. So the wind rose is important to chart the potential dispersion of sound in different directions. (http://guidedtour.windpower.org/en/tour/env/sound.htm 20.02.2010)

4.3 Birds and wind turbines

The main impacts on birds are deaths caused by the birds colliding with power lines and blades, and disturbance to migration routes.

The main causes are listed as follows:

- Death or injury caused by rotating blades.
- Electrocution from transmission lines.
- Change of migration habits.
- Reduction of available habitat.
- Disturbance to breeding, nesting and foraging

A bird collision is determined by wind speed, nature and height of wind mill, species, and age of bird and stage in its breeding cycle etc.

Figure 5

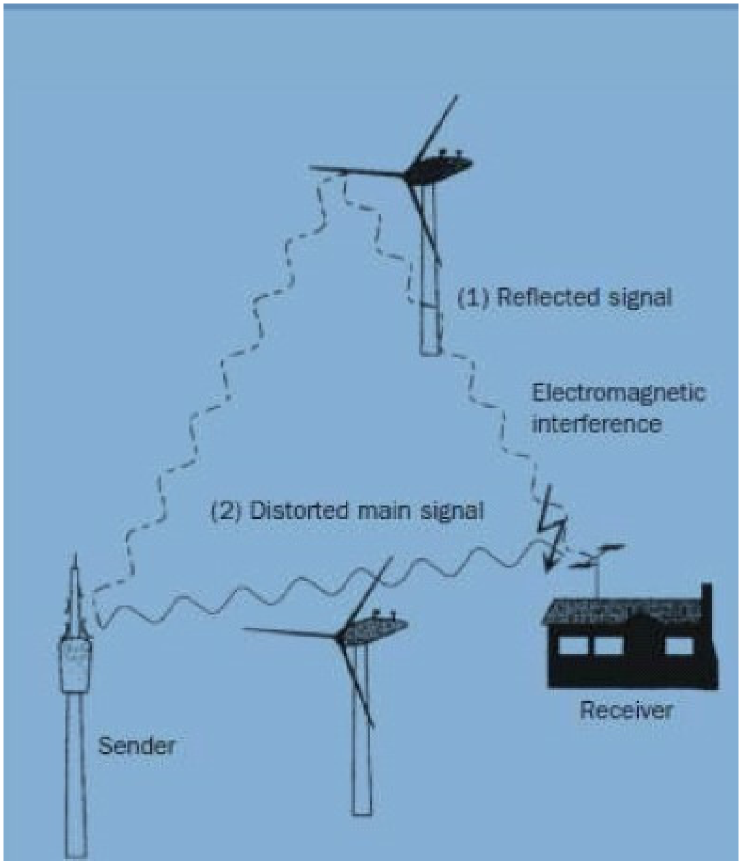
California, USA. The Altamont Pass Wind Park is characterized by a high density of turbines and the different types and size of turbines. At Altamont Pass, the main losses of birds such as hawks, eagles, storks and vultures were affected. This wind park is example of how poor sitting and tower technology can impact bird populations.

Figure 6: a undefined dead bird of prey illustrated

4.4 Electromagnetic interference (EMI)

Generation equipment can interfere with communication systems that use electromagnetic waves (see Figure 7). This is caused mainly by the turbine blades, which sometimes scatter the signals as they rotate. The tower may also reflect signals, so interfering with the original signal arriving at the receiver.

Figure 7 Electromagnetic Interference



EMI mainly affects television reception, aircraft navigation and landing systems, as well as microwave links. Interference with television reception is the most common effect but it can be easily and cheaply corrected. Other mentioned impacts are unlikely to happen unless the turbines are placed in close proximity to the transmitter or receiver. EMI effects on FM radio, cellular phones and satellite services are very unlikely to occur.

EMI is a site-specific issue. It is recommended that an onsite assessment is performed to identify any effects on radio services in the area as well as the interference zones.
(http://www.wind-energy-the-facts.org/en/home--about-the-project.html 23.02.2010)

5 CHARACTERISTICS OF THE WINDMILL

5.1 Choosing axis of turbine

Modern wind turbines fall into two basic groups:

- Horizontal-axis variety, as the traditional farm windmills used for pumping water
- Vertical-axis design, as the eggbeater-style Darrieus model, named after its French inventor.

Most large modern wind turbines are horizontal-axis turbines.

5.1.1 Vertical-axis windmill

- Savonius rotor

Figure 8a

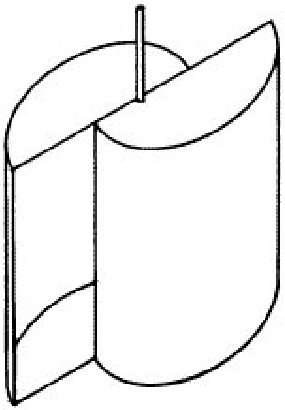


Figure 8b

- Darrieus rotor

Figure 9a

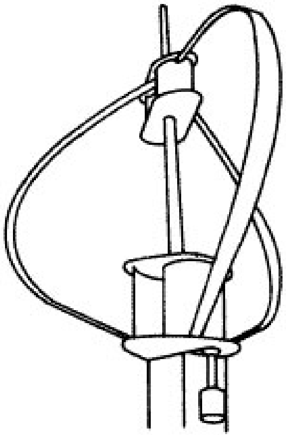
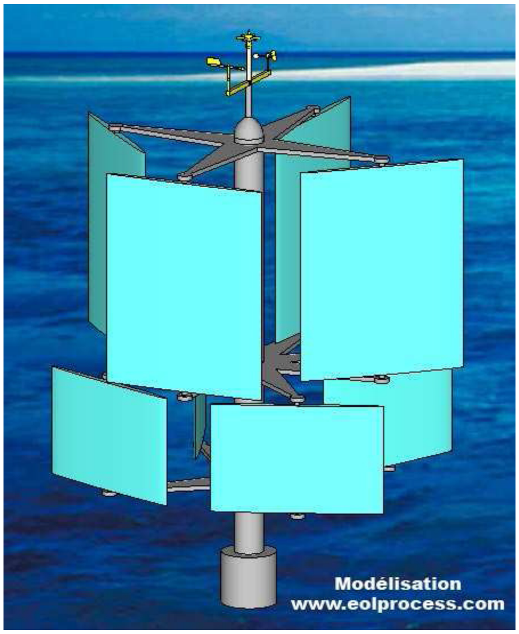


Figure 9b

- Rotary-wing windmill

Figure 10



5.1.2 Horizontal-axis windmill

Figure 11

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Horizontal-axis windmill was chosen because, nowadays, there are more horizontal-axis windmills than vertical-axis windmills.

5.3 Quantity of wind turbines

5.3.1 Reasons for choosing large turbines

Larger machines are usually able to deliver electricity at a lower cost than smaller machines. The reason is that the cost of foundations, road building, electrical grid connection, plus a number of components in the turbine (the electronic control system etc.), are somewhat independent on the size of the machine.

Larger machines are particularly well suited for offshore wind power.

In areas where it is difficult to find sites for more than a single turbine, a large turbine with a tall tower uses the existing wind resource more efficiently.

5.3.2. Reasons for choosing smaller turbines

- The local electrical grid may be too weak to handle the electricity output from a large machine. This may be the case in remote parts of the electrical grid with low population density and little electricity consumption in the area.

- There is less fluctuation in the electricity output from a wind park consisting of a number of smaller machines, since wind fluctuations occur randomly, and therefore tend to cancel out. Again, smaller machines may be an advantage in a weak electrical grid.

- Several smaller machines spread the risk in case of temporary machine failure, for example, due to lightning strikes.

- Aesthetical landscape considerations may sometimes dictate the use of smaller machines. Large machines, however, will usually have a much lower rotational speed, which means that one large machine really does not attract as much attention as many small, fast moving rotors.

6 BATTERIES

6.1 How to store the energy

Wind turbines have been used for household electricity generation in conjunction with battery storage over many decades in remote areas.

Grid-connected wind turbines may use grid energy storage, displacing purchased energy with local production when available. Off-grid system users can either adapt to intermittent power or use batteries, photovoltaic or diesel systems to supplement the wind turbine.

6.1.1. Intermittent power

Many renewable energy systems produce intermittent power. Other generators on the grid can be throttled to match varying production from renewable sources, but most of the existing throttling capacity is already committed to handling load variations. Further development of intermittent renewable power will require some combination of grid energy storage, and demand response. Intermittent energy sources are limited to at most 20-30%

of the electricity produced for the grid without such measures. If electricity distribution loss and costs are managed, then intermittent power production from many different sources could increase the overall reliability of the grid.
(http://www.kterra.com/kb/Energy_Storage-23.html 25.02.2010)

6.1.2. Batteries

Battery storage was used in the early days of direct-current electric power networks, and is appearing again. Battery systems connected to large solid-state converters have been used to stabilize power distribution networks. For example many "off-the-grid" domestic systems rely on battery storage, but storing large amounts of electricity in batteries or by other electrical means has not yet been put to general use.

Batteries are generally expensive, have high maintenance, and have limited life spans. One possible technology for large-scale storage are large-scale flow batteries. Sodium-sulfur batteries could also be inexpensive to implement on a large scale and have been used for grid storage in Japan and in the United States. Vanadium redox batteries and other types of flow batteries are also beginning to be used for energy storage including the averaging of generation from wind turbines. Battery storage has relatively high efficiency, as high as 90% or better.

Rechargeable flow batteries can be used as a rapid-response storage medium. These storage systems are designed to smooth out transient fluctuations in wind energy supply.
(http://en.wikipedia.org/wiki/Grid_energy_storage 25.02.2010)

6.1.3. Batteries' capacity and discharging

The more electrolyte and electrode material there is in the cell, the greater the capacity of the cell. Thus a small cell has less capacity than a larger cell, given the same chemistry, though they develop the same open-circuit voltage.

Because of the chemical reactions within the cells, the capacity of a battery depends on the discharge conditions such as the magnitude of the current, the duration of the current, the allowable terminal voltage of the battery, temperature and other factors. The available capacity of a battery depends upon the rate at which it is discharged. If a battery is discharged at a relatively high rate, the available capacity will be lower than expected.

The battery capacity that battery manufacturers print on a battery means a new battery can supply maximum constant currant for 20 hours at 68 F° (20 C°)

If a battery rated at 100 A·h, it will deliver 5 A over 20 hour period at room temperature. However, if it is instead discharged at 50 A, it will have a lower apparent capacity.For the reason, a battery capacity rating is always related expected discharge duration.

$t= Q / I$

Where:
Q is the battery capacity (typically given in mA·h).
I is the current drawn from battery (mA).
t is the amount of time (in hours) that a battery can sustain.

Theoretically, a battery should provide the same amount of energy regardless of the discharge rate, but in real batteries, internal energy losses cause the efficiency of a battery to vary at different discharge rates. When discharging at low rate, the battery's energy is delivered more efficiently than at higher discharge rates.

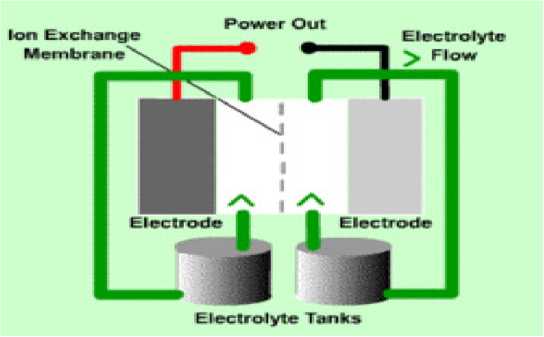
In general, the higher the ampere-hour rating, the longer the battery will last for a certain load. Installing batteries with different A·h ratings will not affect the operation of a device rated for a specific voltage unless the load limits of the battery are exceeded.
(http://en.wikipedia.org/wiki/Battery_(electricity) 25.02.2010)

6.2 Types of batteries

This part explains different types of battery, and the characteristics of each one. At the end there is a summary table with all the data for the calculations.

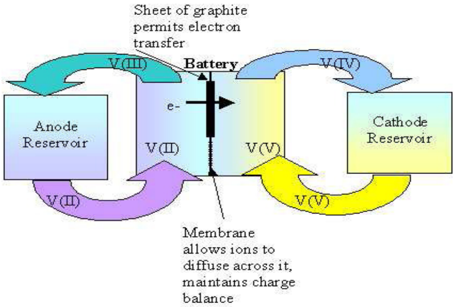
6.2.1. Vanadium redox batteries

Figure12



The vanadium redox battery in its present form (with sulfuric acid electrolytes) was patented in 1986. It is a type of rechargeable flow battery that employs vanadium redox couples in both half-cells, thereby eliminating the problem of cross contamination by diffusion of ions across the membrane. The Vanadium redox battery exploits the ability of vanadium to exist in solution in 4 different oxidation states, and uses this property to make a battery that has just one electroactive element instead of two. The main advantages of the vanadium redox battery is that it can offer almost unlimited capacity simply by using larger and larger storage tanks, it can be left completely discharged for long periods with no ill effects, it can be recharged simply by replacing the electrolyte if no power source is available to charge it, and if the electrolytes are accidentally mixed the battery suffers no permanent damage. The main disadvantages with vanadium redox technology are a relatively poor energy-to volume ratio, and the system complexity in comparison with standard storage batteries. Current production Vanadium redox batteries achieve an energy density of about 25 Wh/kg of electrolyte. More recent research indicates that the use of precipitation inhibitors can increase the density to about 35 Wh/kg. This energy density is quite low as compared to other rechargeable battery types, e.g. Lead-acid (30-40 Wh/kg) and Lithium Ion (80-200 Wh/kg).

Figure 13



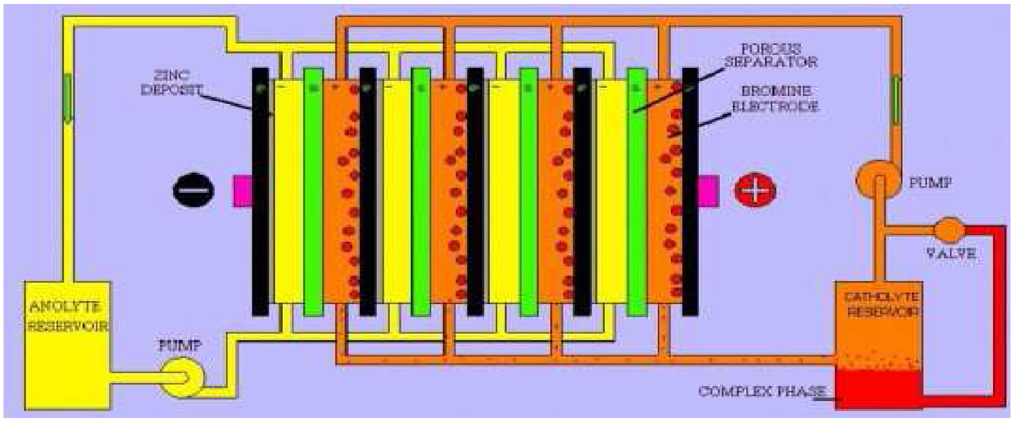
The extremely large capacities possible from vanadium redox batteries make them well suited to use in large power storage applications such as helping to average out the production of highly variable generation sources such as wind or solar power, or to help generators cope with large surges in demand.

(http://en.wikipedia.org/wiki/Vanadium_redox_battery 25, 02, 2010)

6.2.2. Zinc-bromine batteries

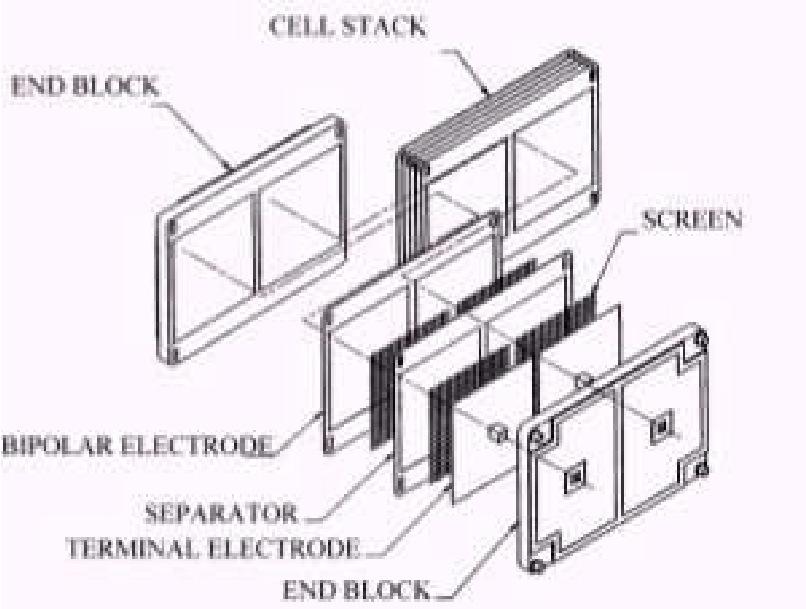
The zinc-bromine flow battery is a type of hybrid flow battery. A solution of zinc bromide is stored in two tanks. When the battery is charged or discharged the solutions are pumped through a reactor and back into the tanks. Zinc-bromine batteries have energy densities of 75 to 85 Wh/kg.

Figure 14



The primary features of the zinc bromine battery are superior energy density; depth of discharge; cycle life; large capacity scale (50 kWh) stackable to 500 kWh systems; and the ability to store energy from any prime mover generating source.(http://en.wikipedia.org/wiki/Zinc-bromine_flow_battery 28,02,2010)

Figure 15



6.2.3. Nickel-hydrogen batteries

A nickel hydrogen battery is a rechargeable electrochemical power source based on nickel and hydrogen. The difference with a nickel-metal hydride battery is the use of hydrogen in an up to 1.200 psi (82, 7 bar) pressurised cell.

The cathode is made up of a dry sintered porous nickel plaque, which contains nickel hydroxide, the negative hydrogen electrode utilizes a Teflon-bonded platinum black catalyst, the separator is in general a asbestos paper or untreated knit zirconium oxide cloth.

Figure 16

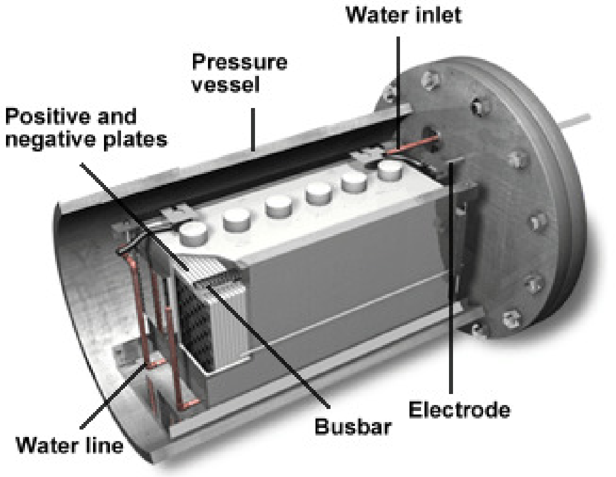


Figure 1

Nickel hydrogen cells using 26% potassium hydroxide as an electrolyte have shown a service life for 15 years or more at 80% depth of discharge (DOD). The energy density for LEO and GEO is 75 Wh/Kg, 60 Wh/dm3 specific-powers 220 W/kg. The open-circuit voltage is 1, 55 V, discharge voltage 1.25 V, the voltage under load 1.5 V. The cells handle more than 20,000 charge cycles on 85% efficiency.

NIH2 rechargeable batteries possess good electrical properties which make them attractive forthe energy storage of electrical energy in satellites and space probes. The Hubble Space Telescope leads with the highest number of charge/discharge cycles of any NiH2 battery currently in low earth orbit.(http://en.wikipedia.org/wiki/Nickel_hydrogen_battery 28,02,2010)

6.2.4. Nickel-iron batteries

The nickel-iron battery is a storage battery having a nickel(III) oxide-hydroxide cathode and an iron anode, with an electrolyte of potassium hydroxide. It is a very robust battery which is tolerant of abuse, (overcharge, overdischarge, short-circuiting and thermal shock) and can have very long life even if so treated. Its use has declined due to low specific energy, poor charge retention, and poor low-temperature performance, and its high cost of manufacture compared with the lead-acid battery.

Nickel-iron batteries have energy densities of 50 Wh/kg, and a 65% efficiency.

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Nickel-iron batteries have long been used in European mining operations because of their ability to withstand vibrations, high temperatures and other physical stress. They are being examined again for use in wind and solar power systems and for modern electric vehicle applications.

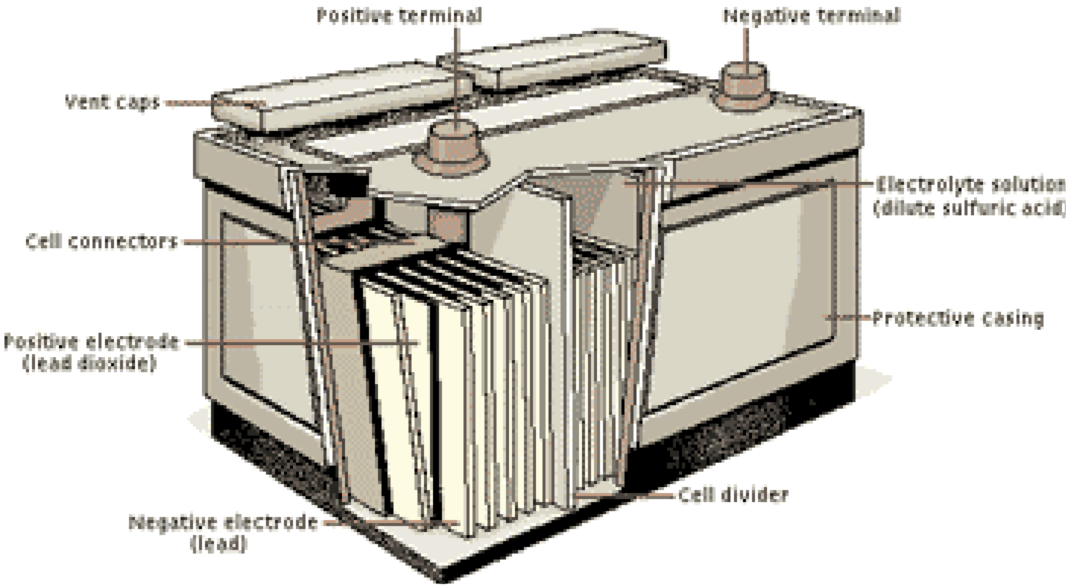
In many respects the nickel-iron battery was almost "too good." A battery that lasts for decades in many cases can outlast the equipment that it was originally designed to power. So from an economic standpoint lead acid, nickel-cadmium and other technologies have been deemed "good enough" and are the predominant technologies in use today even though they do not last as long as a nickel-iron counterpart.(http://en.wikipedia.org/wiki/Nickel-iron_battery 28,02,2010)

Figure 17

6.2.5. Lead-acid batteries

Lead-acid batteries are the oldest type of rechargeable battery. Despite having the second lowest energy-to-weight ratio and a correspondingly low energy-to-volume ratio, their ability to supply high surge currents means that the cells maintain a relatively large power-to-weight ratio. These features, along with their low cost, make them attractive for use.

Figure 18



One of their applications is as wet cell stand-by (stationary) batteries designed for deep discharge, commonly used in large backup power supplies for telephone and computer centers, grid energy storage, and off-grid household electric power systems.

Current production Lead-acid batteries achieve an energy density of about 30-40 Wh/kg of electrolyte, and 50%-92% of efficiency. (http://www.absoluteastronomy.com/topics/Vanadium_redox_battery 28, 02, 2010)

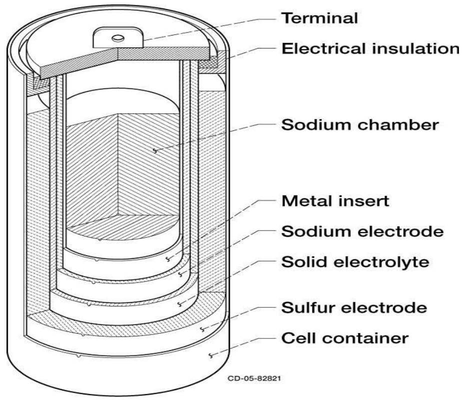
6.2.6. Sodium-sulfur batteries

A sodium-sulfur battery is a type of battery constructed from sodium and sulfur. This type of battery has a high energy density, high efficiency of charge/discharge (89-92%) and long cycle life, and is fabricated from inexpensive materials. Because, however, of the operating temperatures of 300 to 350 °C and the highly corrosive nature of the sodium polysulphides, such cells are primarily suitable for large-scale non-mobile applications such as grid energy storage.

Sodium sulfur batteries are a possible energy storage application to support renewable energy plants, specifically wind farms and solar generation plants. In the case of a wind farm, the battery would store energy during times of high wind but low power demand. This stored energy could then be discharged from the batteries during peak load periods.

In addition to this power shifting, it is likely that sodium sulfur batteries could be used throughout the day to assist in stabilizing the power output of the wind farm during wind fluctuations.

Figure 19



Sodium sulfur battery schematic

These types of batteries present an option for energy storage in locations where other storage options are not feasible due to location or terrain constraints. (http://en.wikipedia.org/wiki/Sodium-sulfur_battery 28, 2, 2010)

6.2.7. Summary data table

Here is a table with some of the characteristics of different batteries: the voltage, the energy density, the efficiency, energy/price, the cycles, the useful life and the cost per weight.

The main concern is the density of energy and the price of batteries. The density of energy is used to find kilograms we need to store the energy that we are going to use. That is, if a battery has an energy density of 30 kWh / kg means that for every kilogram is capable of storing 30 kWh.

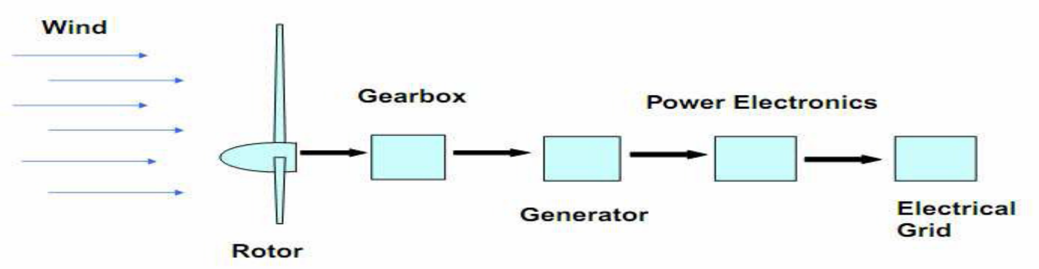
The different types of batteries with different features as follows:

Type	Voltage (v)	Energy Density (Wh/kg)	Efficiency(%)	Energy/e (Wh/e)	Cycles (#)	Life (years)	Cost (e/kg)
Vanadium redox	1.15-1.55	25-35	8-	217	14.000	10	Tank of liquid
Nickel-hydrogen	1.5	75	70	135	20000	15+	68
Nickel-iron	1.2	50	65	4.73	2000	50+	--
Lead-acid	2.1	30-40	70-92	5.1	500-800	20	--
Sulfur-sodium	2	150	89-92	86.6	30000	20+	60

7 DESIGN OF THE WINDMILL

Design of the windmill is a complicated subject, big companies are involved in this business, and in the design there is no aim to compete with them. The authors will try to describe the main aspects in the design of the windmill, make the same calculation of blade profile; and try to understand how the main parts of the nacelle, such as main low-speed shaft, bearings, gear box and generator are selected. This enable to understand in general how the wind turbine will convert the wind power to the electrical power. After all, the work will try to find approximate analog to the calculations on the market, because already made wind turbines will have much better parameters than the ones which will be designed, as the aim of the work is not to design a wind turbine from the zero, the aim is to find the best solution to the problem. When you are selecting to have a definition of how it is working and what you need; this is the aim of this part.

Figure 20



7.1 Rotor design

The rotor is the part of the wind turbine in charge of convert power taken from the wind flow to the rotational power of the main low-speed shaft.

One of the important decisions when considering the installation of the wind turbine is determining whether or not a chosen site has enough wind to generate the power needed. The power from the wind is proportional to the cube of the wind speed:

$P_{wind}=1/2\rho S\ V^3$

Where:

ρ is the air density [kg/m3]

S is a rotor area [m2]
V is the wind speed [m/s]

If the winds speed V doubles to 2V. The power of the wind or its ability to produce a power increases 23=8 times. This means that a 10 m/s wind has 8 times the power of a 5 m/s wind.

The power of the shaft is calculated by formula:

$P_{shaft}= M\omega$ [W]

Where:
M is moment of inertia [Nm]

ω is angular speed [rad/s].

The main variables that define the output rotor power, the axial force and the angular speed:

- pitch angle
- chord length
- tip speed ratio
- number of the blades
- length of the blades

To calculate those parameters, BEM theory will be used, according to the some requirements:

- Tip speed ratio must be lower than 8. This is the maximum value for a windmill
- Number of blades should be even, because of stability of the turbine
- The axial force on the rotor should be as low as possible
- Use the optimal blade profile

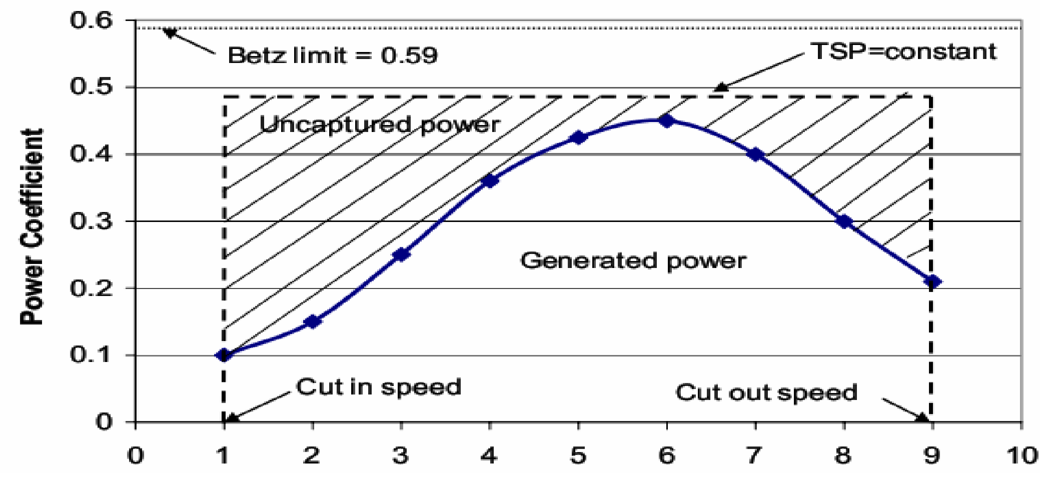
7.2 The Tip Speed Ratio

The tip speed ratio λ (lambda) or TSR for wind turbines is the ratio between the rotational speed of the tip of a blade and the actual velocity of the wind.

Tip speed ratioλ=speed of rotor tip / wind speed = $v / V = \omega r / V$

Where:
V is the wind speed [m/s]
$v = \omega r$ is velocity of rotor tip [m/sec]
r is rotor radius [m]
$\omega = 2\pi f$ is the angular velocity [radian/sec]
f *is* the frequency of rotation [Hz] or [sec_{-1}]

Figure 21



A higher tip speed ratio generally indicates a higher efficiency but is also related to higher noise levels and a need for heavier, stronger blades. High efficiency 3-blade-turbines have tip speed ratios of 6–7.

7.3 Characteristics of the blades

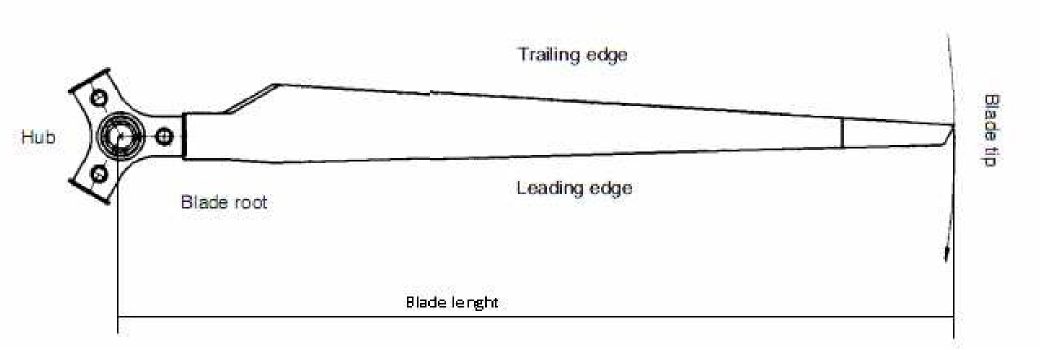
7.3.1. Number of blades

Usually flat objects are connected to a center shaft that converts the push of the wind into a circular motion in a wind turbine. Most wind turbines have three blades. Very small windmills may use two blades for ease of construction and installation. Vibration intensity decreases with larger numbers of blades. Noise and wear are generally lower, and efficiency higher, with three instead of two blades. This design tends to be a standard against which other concepts are evaluated. Finally, aesthetics can be considered a factor in that some people find that the three-bladed rotor is more pleasing to look at than a one- or two-bladed rotor. Considering all those aspects the numbers of blades have been selected as 3.

7.3.2. Length of the blades

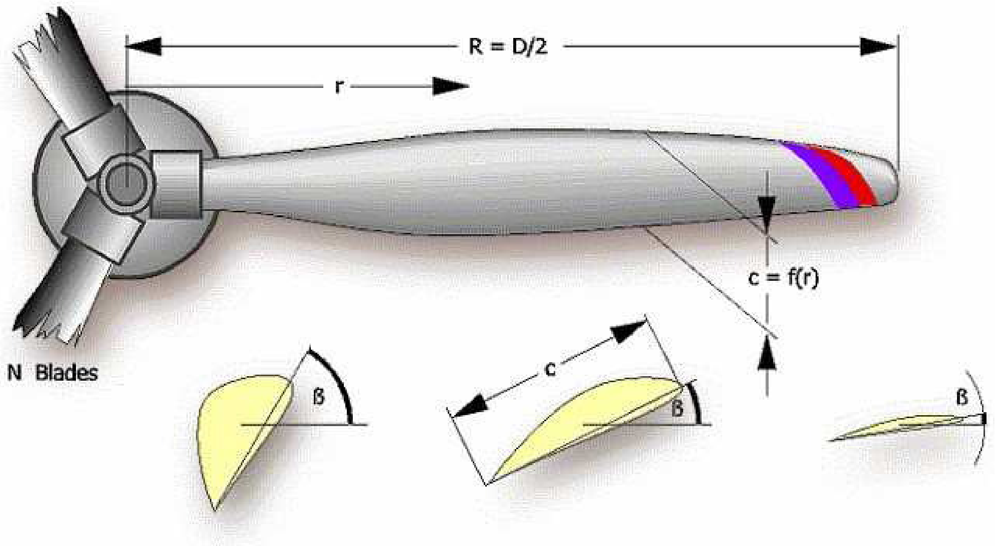
The length of the blade is a distance from the tip of the blade till the center of rotor.

Figure 22



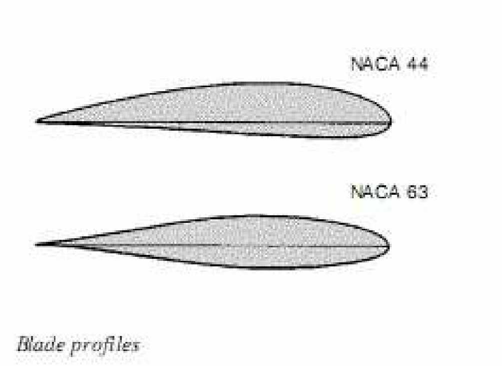
7.3.3. The aerodynamic profile of the blade

Figure 23



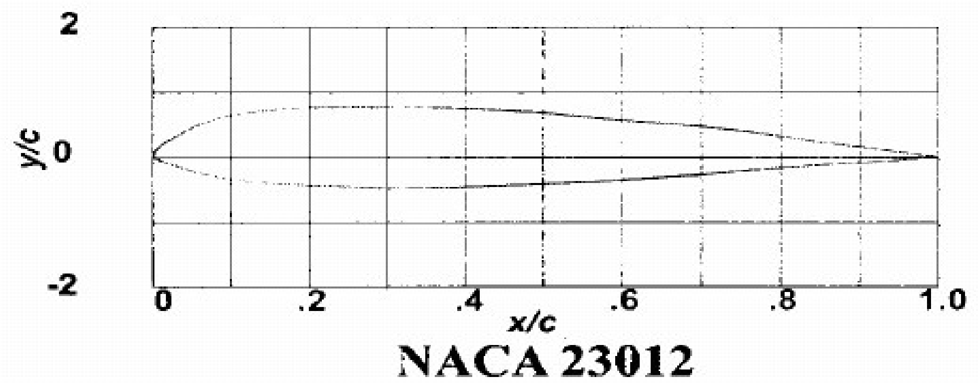
The shape of the aerodynamic profile is decisive for blade performance. Even minor alterations in the shape of the profile can greatly alter the power curve and noise level. Therefore a blade designer does not merely sit down and outline the shape when designing a new blade. The shape must be chosen with great care on the basis of past experience. For this reason blade profiles were previously chosen from a widely used catalogue of airfoil profiles developed in wind tunnel research by NACA (The United States National Advisory Committee for Aeronautics) around the time of the Second World War.

Figure 24



Modern turbines use more complicated aerodynamic principles to capture the wind's energy most effectively. The project tries to show the principle of calculations on a NACA 23012 profile, because the calculation tables and the main characteristics of that profile were available.

Figure 25



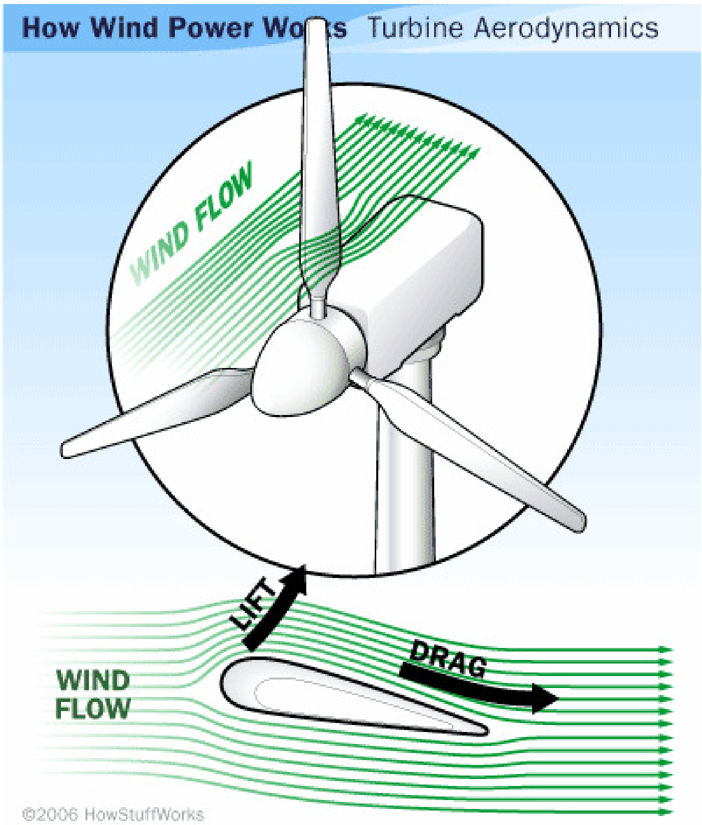
7.3.4. Rotor blade materials

Rotor blades are usually made using a matrix of fiber glass mats which are impregnated with a material such as polyester (GRP = Glass fiber reinforced polyester). The polyester is hardened after it has impregnated the fiber glass. Epoxy may be used instead of polyester. Likewise the basic matrix may be made wholly or partially from carbon fiber, which is a lighter, but costlier material with high strength. Wood-epoxy laminates are also being used for large rotor blades.

7.4 Aerodynamics

The two primary aerodynamic forces at work in wind-turbine rotors are lift, which acts perpendicular to the direction of wind flow; and drag, which acts parallel to the direction of wind flow.

Figure 26



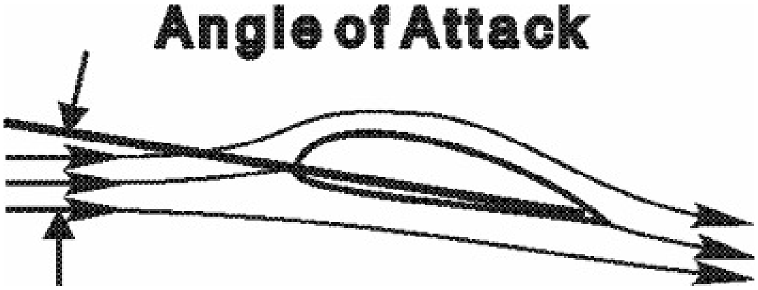
In an airfoil, one surface of the blade is somewhat rounded, while the other is relatively flat. Lift is a pretty complex phenomenon, but in general words when wind travels over the rounded, downwind face of the blade, it has to move faster to reach the end of the blade in time to meet the wind traveling over the flat, upwind face of the. Since faster moving air tends to rise in the atmosphere, the downwind, curved surface ends up with a low-pressure pocket just above it. The low-pressure area sucks the blade in the downwind direction, an effect known as "lift." On the upwind side of the blade, the wind is moving slower and creating an area of higher pressure that pushes on the blade, trying to slow it down. Turbine blades are twisted so they can always present an angle that takes advantage of the ideal lift-todrag force ratio.

Lift and drag forces depend on the coefficients CL and CD, which in turn depend on the cross section of the used blade, and of course on the angle of attack α, at with the wind strikes the blade. We cannot calculate the lift and drag coefficients. They are measured experimentally in the wind tunnels, and recorded in the table of the characteristic of the blade profile. (http://science.howstuffworks.com/wind-power3.htm 28,02,2010)

7.5 Angle of attack

The difference between where the wing is pointed and the direction of the air flowing over the wing is the angle of attack as shown in this schematic.

Figure 27



The graph below show how lift and drag change with the angle of attack for a typical wing design.

Figure 28

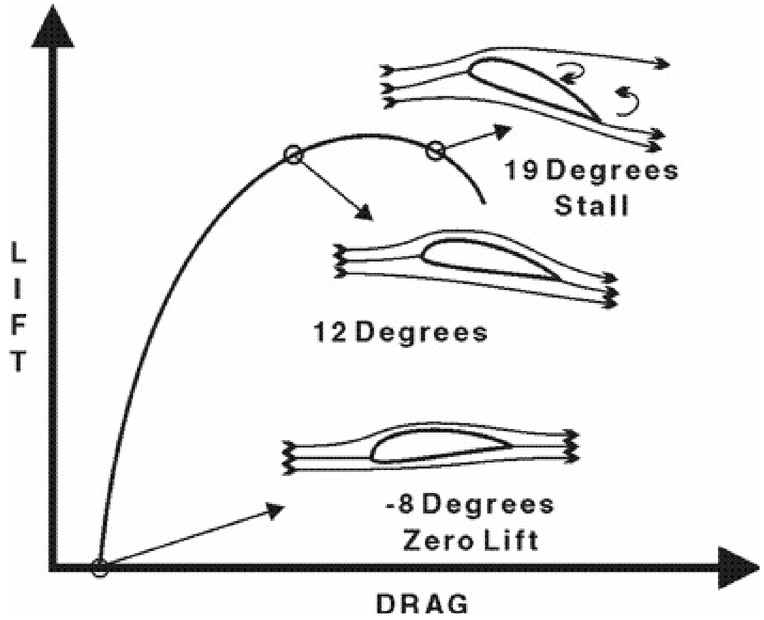
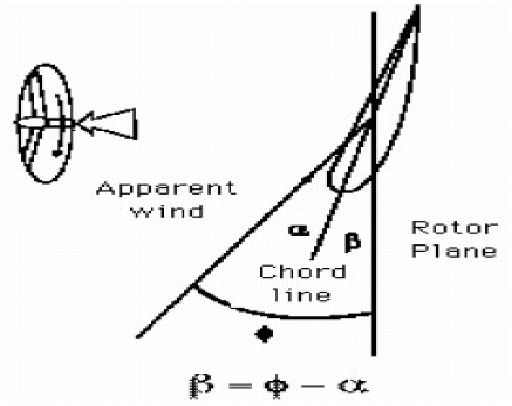


Figure.29

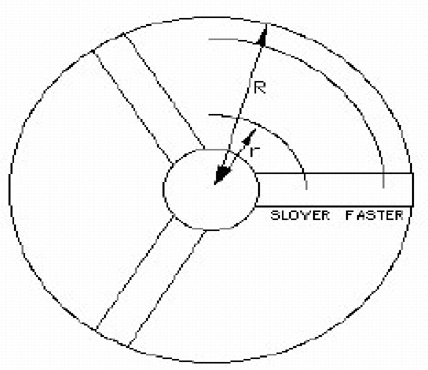


When designing a wind turbine rotor, the angle α depends on the angle of the apparent wind φ, and the blade angle β, also called as pitch angle. So we have control over α, and thus control over the lift and drug produced by the blade. We need to optimize the lift force, to satisfy the Betz criterion, but the blade will not work well unless the drag is minimized, so we have to choose a section and angle of attack, where the lift/drag ratio is high. Finding the exact best angle of attack can be an involved process, because the lift and drag coefficients depend on both the section and the Reynolds number. The Reynolds number is a measure of the size and speed of the blade.

In practice, most sections will produce their best lift/drag at the angle of attack around 5 degrees, so as a general rule, where detailed data is not available, we can say that the blade angle β should be set to give this angle of attack, thus: $\beta = \varphi - 5$

Having worked out β we still need to work out the chord width. The wider and shorter a blade is, the higher the angular speed is for the same power output at the same wind speed. Each blade element has a certain band of wind to process. As radius r grows smaller near the center, the amount of the wind in the band gets smaller too.

Figure 30



The external parts do the main work. The inner part is less important but it needs a different shape. To satisfy Betz, the wind in each part of the swept area of the rotor must be slowed down to 1/3 of its upstream velocity, and this slowing is done by the thrust force, which is very closely related to lift force.

The rough expression for the chord width C which will produce the right amount of trust to meet the Betz condition can be expressed by the formula:

$$C = 16\pi R(R/r) / 9\lambda^2 B$$

So according to the formula we can see, that chord width is:

·Proportional to radius r, so the blade shape should be tapered

·Proportional to blade number B, so fewer number blades will be wider blades

·Proportional to tip speed ratio λ, so doubling speed means cutting blade width down to ¼.

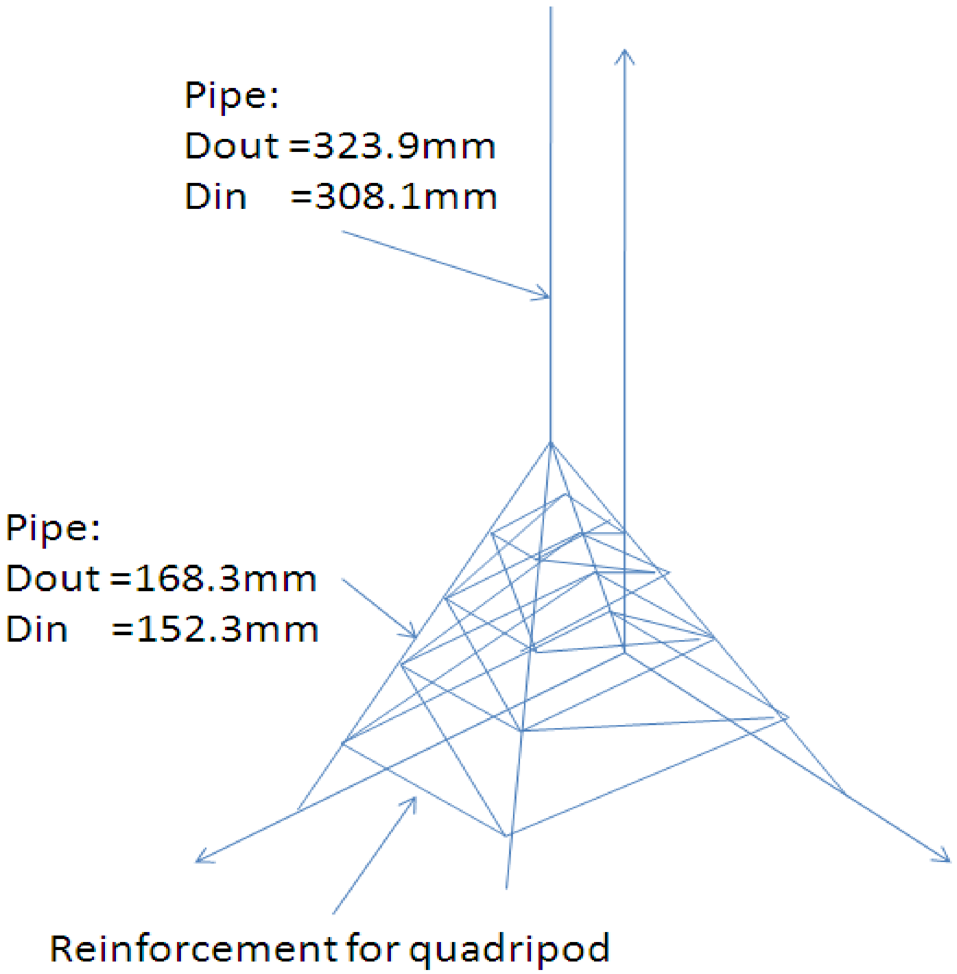
8 CALCULATION OF CONSTRUCTION

8.1 Dimension

It was decided to study deformation, forces, and stresses of the windmill and to check that the windmill can support force caused by the wind and other forces. Moreover, this study enables to know the reactions on the roof.

The work presented a simplified model of the windmill because it is very complicated to study the real model. The windmill is composed of 4 legs (called quadripod), 44 reinforcements for the quadripod and the tower of the windmill.

Figure 31



We can see on the picture above the dimensions of all the parts for the structure. The diameter of the tower in the windmill (CYCLONE 10kW) is 325 mm. But, the standard diameter for the software is Dout=323.9mm and Dint=308.1mm.Then the parameter of the pipe of the quadripod as follows: Dout=168.3mm and Dint=152.3 mm (standard diameter for the software) and we have chosen pipe of 20mm for the reinforcement of the quadripod.

The eight of the quadripods are fixed at 3 meters (H=3m), the height of the tower is 4 meters and the angle between one leg of the tripod and the vertical axis of the quadripod is 30° shown in the figure:

Figure 32

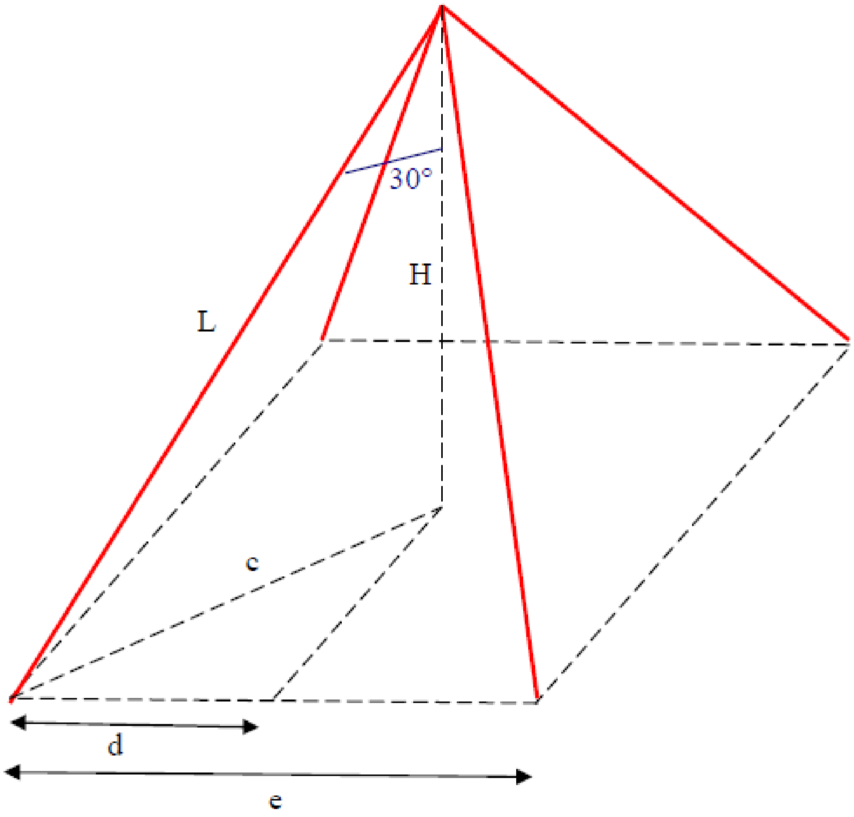
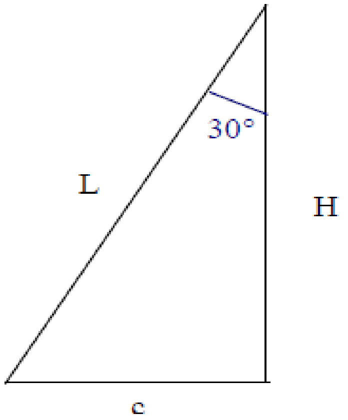
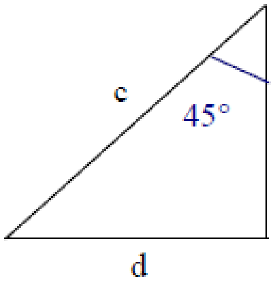


Figure 32 (a)



cos30=H /L
cos30=3/L
L=3/cos30
L=3.4641m (length of the quadripod leg)
tan30=c/3
=> c=3tan30=1.73205m

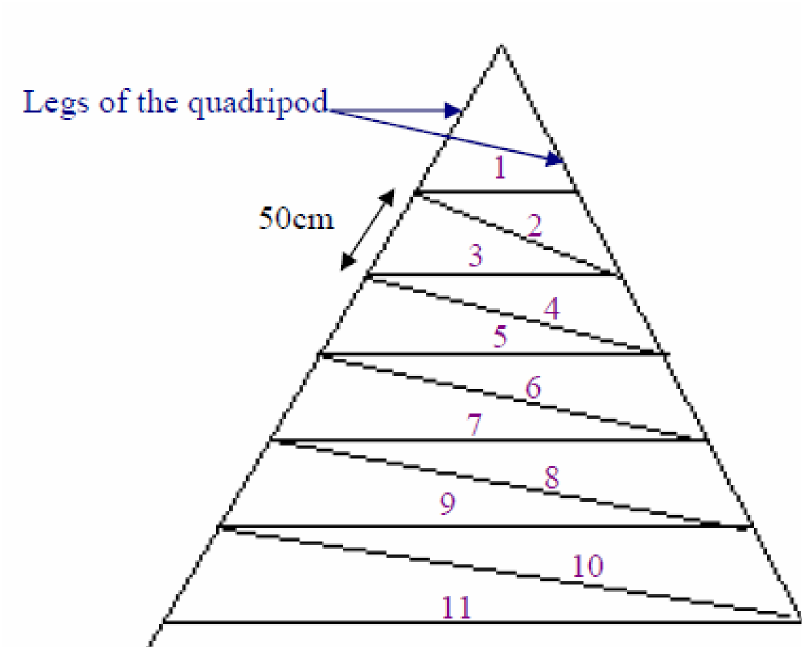
Figure 32 (b)



sin45 =d /c
d=c*sin45
d=1.73205*sin45
d=0.866025 m
e=2d=2,4495m (width between two beam)

There are 11 reinforcements between two legs. The distance between two reinforcements is 50 cm and the length of them is represented on the picture below.

Figure 33



8.2 Material

For each pipe of the structure, the same material will be used, a structural steel ASTM-A36:

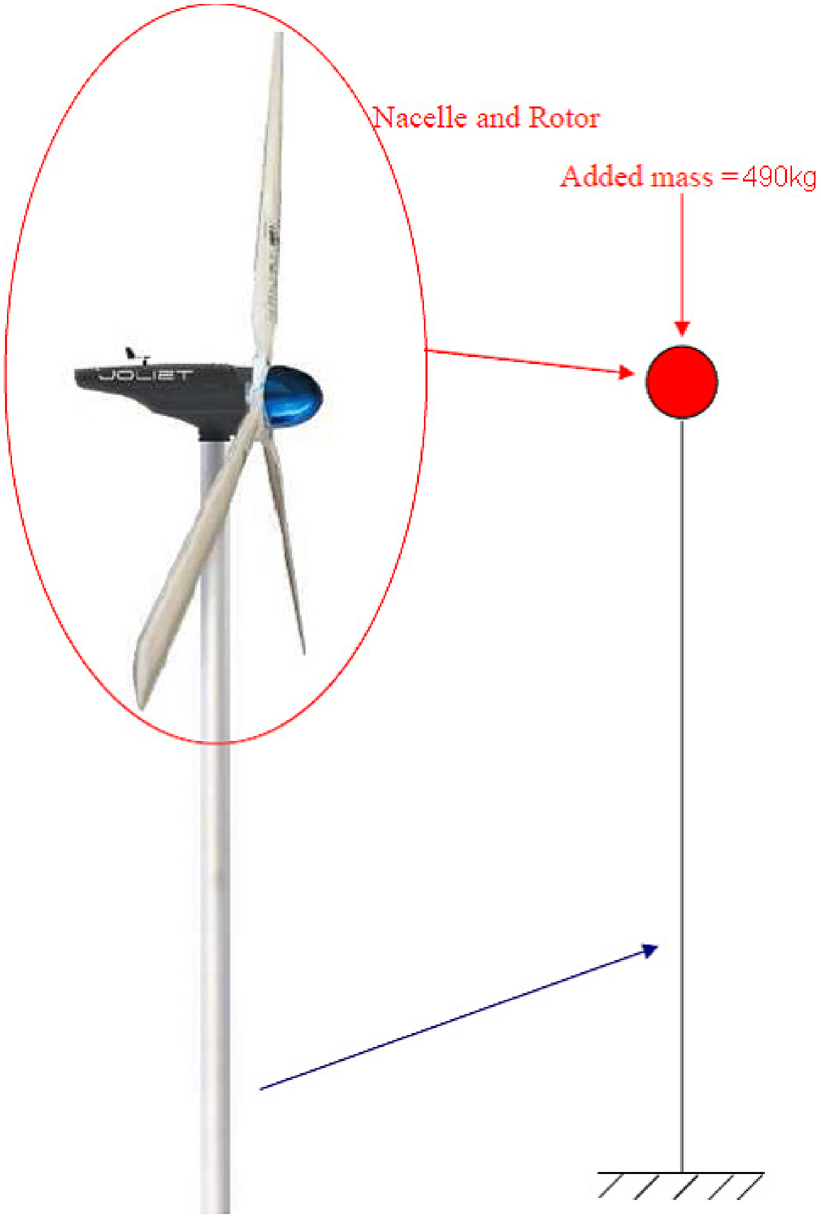
Figure 34

Density	kg/m^3	7860
Young's Modulus	N/m^2	200*10^9
Ultimate Strength Su	N/m^2	400*10^6
Yield Strength Sy	N/m^2	250*10^6
Shear Constraint	N/m^2	125*10^6

8.3 Strength calculation

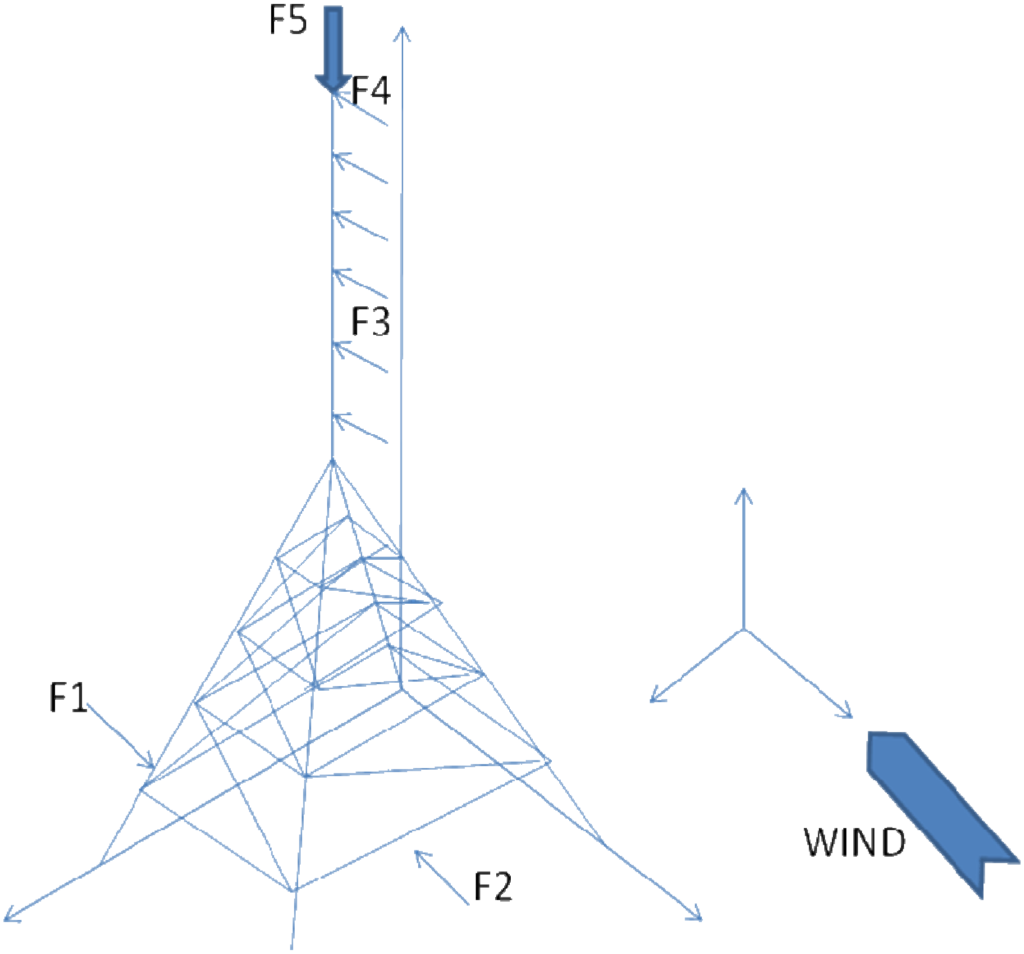
The real model of a windmill has been simplified: the nacelle is considered as an added mass. A wind turbine in finite element method is presented in the picture below.

Figure 35



Let the direction of wind speed = 0°, the wind speed direction is “y”.

Figure 36



There is:

- One force linearly repartee on the 4 parts of the quadripod: F1
- One force linearly repartee on the reinforcement on the quadripod: F2
- One force linearly repartee on the tower: F3
- One force caused by the wind on the blades: F4
- One force caused by the weight of the nacelle and the rotor: F5

The forces F1, F2, F3, f4, F5 are presented in the picture above. To calculate all these forces, we take for wind speed 25 m/s, because it is the extreme case for the windmill. The forces F1, F2, F3, and F4 are caused by the wind. The forces of the wind depend on its' speed, the air density and the superficies such as

F wind= F1=0.5*ρ*S*V2

Where:
ρ is the density of the air = 1,225 kg/m3
S is the section (m2)
V is the wind speed (m/s) => V=25 m/s (maximum wind speed)

F1=0.5*ρ*S1*V2
When the wind act on a pipe, the superficies is the diameter of the pipe multiply by the height of the pipe.

S1=D1*L=0.1683*1 and D1=168.3mm
S1=0.1683 m2
F1=0.5*1,225*0.1683* 252
F1= -64.43 N/m

F2=0.5*ρ*S2*V2 => F2=0.5*ρ*D2*L2*V2 and D2=20mm=0,02m, L2=1m
F2=0.5*1.225*0.02*1*252
F2= -7.65625 N/m

F3=0.5*ρ*S3*V2 => F3=0.5*ρ*D3*L3*V2 and D3=323.9mm=0.3239m, L3=1m
F3=0.5*1,225*0.3239*1*252
F3= -123.99 N/m

F4=0.5*ρ*S4*V2
To calculate the force caused by the wind on a blade, we assume its length = 4m and its width
= 20cm. So, S4=L4*W4=0.2*4=0.8m2
F blade-wind is the force caused by the wind on 1 blade.
F blade-wind =0.5*1.225*0.2*4*252
F blade-wind=306, 25
But, we have 3 blades. So,
F4 = 3* F blade-wind
F4=3*306.25
F4= -918.75 N

We know that the mass of the nacelle + rotor = 490kg
So, F5=m5*g
m5 is the mass of rotor+nacelle (kg)
g is the gravity. g= 9.81m/s2
F5=m5*g=490*9.81= **-4806.9 N**

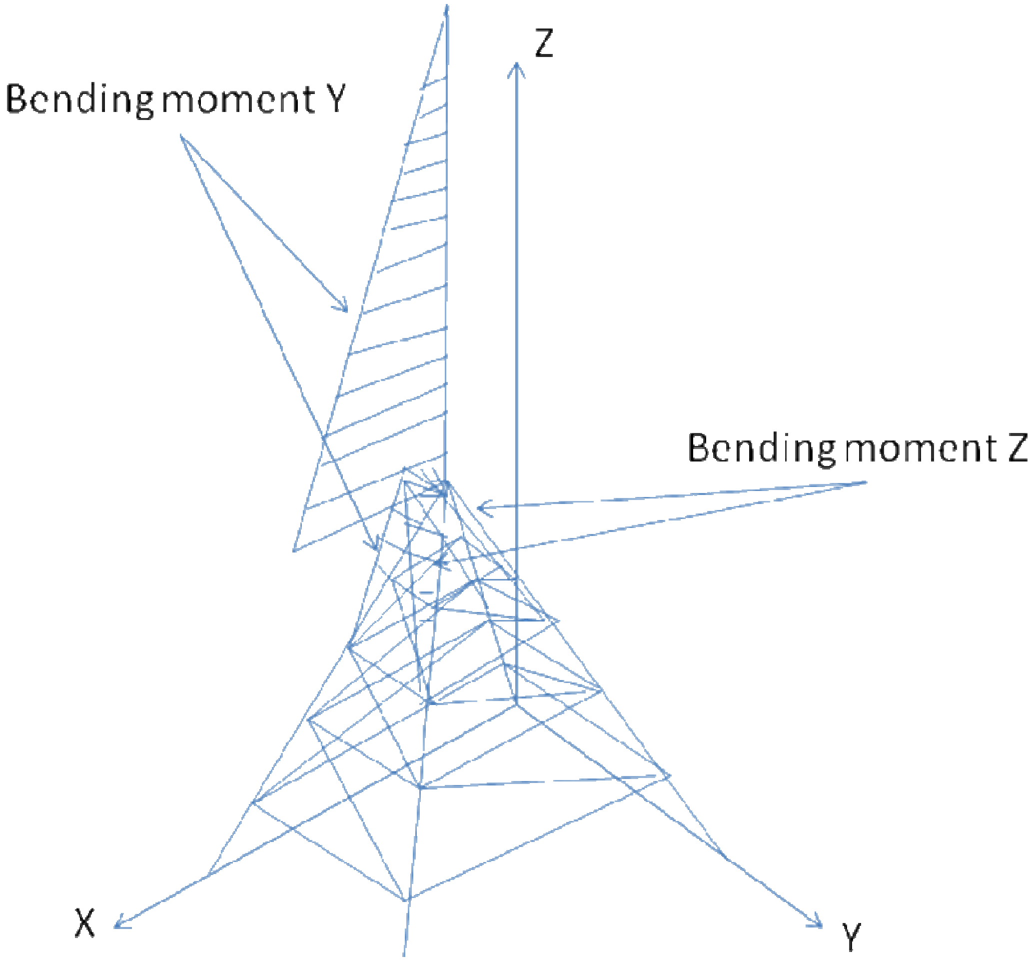
Now, all the forces on each knot, weight of the structure and the position of the center of gravity can be calculated.

Weight of the structure = 794.2319 kg

Center of gravity: x=1224.750 y=1224.750 z=2418.451 (mm).

Interior actions – Strength of the structure

Figure 37



The presentations of the bending moments on the structure are presented in the picture above. the maximum bending moment is calculated as follows:

Mfymax = 4666920 N.mm (MFymax is the Bending moment Y max)
Mfzmax = 994338.42 N.mm (MFzmax is the Bending moment Y max)

Strength of the tower in bending:

σMfmax is the constraint caused by the maximum bending moment.
σMfmax t=(Mfmax*ymax)/I
I is the quadratic moment of a section (mm4) such as:
I pipe = (Π*(De^4-Di^4))/64

ymax is the radius of the section for a pipe
De is the exterior diameter and Di is the interior diameter of the section.
Tower: De=323,9mm Di =308,1mm
We call it, the quadratic moment of the tower
$It = (\Pi*(323.9^4-308.1^4))/64$
$It = 97953413.31\ mm^4$
=>σMfmax t = (4666920*161.95)/97953413.31
σMfmax t=7.72 MPa
If σMfmax < σmax, the pipe of the tower that we have chosen is appropriate.
σmax =250 MPa
σMfmax t=7,72 MPa< σmax
So, the tower pipe is appropriate in Bending.

Strength of the quadripod in bending:

Mfmax quadripod is the maximum bending moment for the quadripod
Mfmax quadripod= 994338.42 N.mm
σMfmax =(Mfmax*ymax)/I
We call Iq, the quadratic moment of the quadripod
Quadripod:
De=168.3mm Re=84.15mm Di=152.3mm
$Iq = (\Pi*(168.3^4-152.3^4))/64$
$Iq =12972711.83\ mm^4$
σMfmax q is the constraint caused by the maximum bending moment on the quadripod
=>σMfmax q= (994338.42 *84.15)/12972711.83
σMfmax q = 6,45 MPa
σMfmax q = 6,45 MPa< σmax
So, the quadripod pipes are appropriate in Bending.

Strength of the reinforcement quadripod in bending:

Mfymax reinforcement and Mfzmax reinforcement are the bending moment for the reinforcement of the quadripod.
Mfymax reinforcement= 2923.3 N.mm
Mfymax reinforcement= 1349.2 N.mm
σMfmax=(Mfmax*ymax)/I

We call Ir, the quadratic moment of the quadripod
Reinforcement: D=20mm R=10mm
$Ir = (\Pi*(20^4))/64$
Ir=7853.98 mm4
σMfmax r is the constraint caused by the maximum bending moment on the reinforcement.

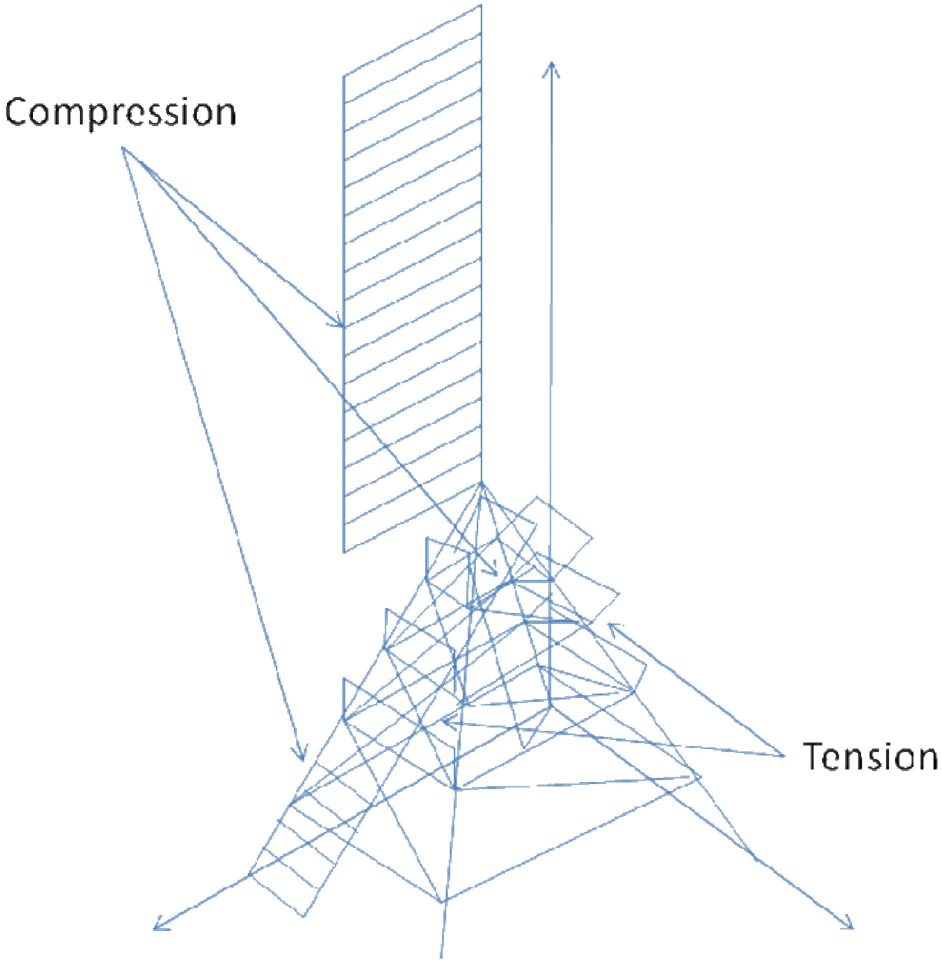
=>σMfmax r= (2923.3 *10)/7853.98

σMfmax r =3.72 MPa < σmax

So, the reinforcement quadripod pipes are appropriate in Bending.

Normal force:

Figure 38



The presentation of normal stresses is presented in the picture above. We can see that the two pipes of the quadripod exposed at the wind are in traction. Logically, the two others pipes of the quadripod are in compression. The normal forces are maximum in between a part of the quadripod and the reinforcement of the quadripod: Nmax is the maximum normal force for the structure (Nmax is given)

Nmax can be positive (tensile)

Nmax can be positive (compression)

Nmax = -6209.25N (Compression)

Strength of the quadripod in normal forces:

σNmax is the constraint caused by the maximum normal force.
σNmax =Nmax/S
S is the surface of the section.
Quadripod:

De= 168.3mm Re=84.15mm
Di= 152.3mm Ri=76.15mm
Sq is the section area of the leg of the quadripod
Sq = $\Pi^*(Re^2-Ri^2)$
Sq= $\Pi^*(84.15^2-76.15^2)$
Sq= 4028.77 mm^2
σNmax q is the constraint caused by the maximum normal force on the quadripod.
σNmax q=6209.5/4028.77
σNmax q=1.54 MPa
If σNmax q<σmax, the pipe of the quadripod that we have chosen is appropriate/
σmax =250 MPa
σNmax q=1.54 MPa< σmax
So, the quadripod pipes are appropriate in tensile, compression

Strength of the tower in normal forces:

Nmax = -4806.9 N
It is the quadratic moment of the tower
It =12972711.83 mm^4 (already calculated).
St = section area of the tower
St = $\Pi^*(Re^2-Ri^2)$
Tower: De=323.9mm Re=169.95mm
Di=308.1mm Ri =154.05mm
St= Π*(169.952-154.052)
St= 7842.67 mm2
σNmax t is the constraint caused by the maximum normal force on the tower.
σNmax t=4806/7842,67= **0.61 MPa**
σNmax t=0.61 MPa< σmax
So, the tower is appropriate in tensile, compression

Strength of the reinforcement quadripod in normal forces:

Nmax = 1547.6 N
Sr =section area of the reinforcement

Reinforcement: D=20mm R=10mm
Sr= Π*102
Sr=314.15 mm^2
σNmax r is the constraint caused by the maximum normal force on the reinforcement.
σNmax r= 1547/314.15= **4.92 MPa**
σNmax r=4.92 MPa< σmax
So, the reinforcement quadripod pipes are appropriate in tensile, compression

Calculation of buckling on the reinforcement quadripod:

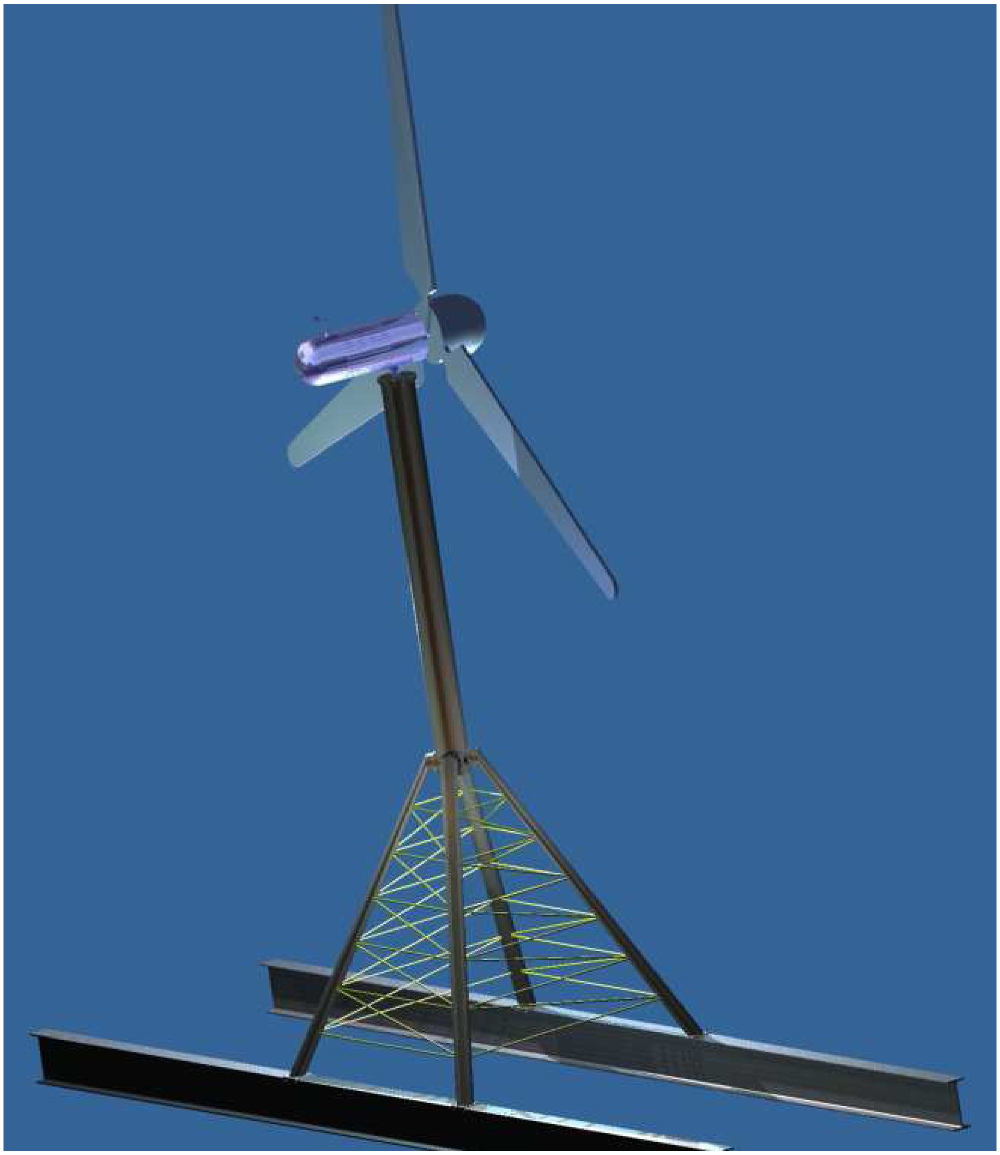
We have a diameter of 20mm for the reinforcement of the quadripod (D=20mmm).
We consider that Nmax (Normal forces) for the reinforcement of the quadripod is applying on the longer reinforcement (the maximum length for the reinforcement is 2.121m).
So, if there is no buckling for this pipe (length=2.121m), there will not have bulking for none.
Fc is the maximum forces that we can apply before have buckling.
Nmax must be inferior at Fc to avoid buckling of the material.
Fc = (Π2*E*Igz)/L2
E is the Young modulus of the material.
L= length of the pipe
Igz= Quadratic moment of the section.
The material for the reinforcement is Structural steel ASTM-A36 (E=200MPa)
Igz = $(\Pi*(De^4))/64$
Igz = $(\Pi*(20^4))/64$
Ir=7853.98 mm4
We take Lmax. Lmax=2.121m=2121 mm
Fc = (Π2*200*7853.98)/21212
Fc =7309.35 N
Nmax = 1547.6 N
So, Nmax = 1547.6 < 7309.35 N
So, **we will have none buckling for all the reinforcement of the quadripod.**

9 DETAILS OF THE CONSTRUCTION

After finishing all the theoretical works, a 3D-model was built, reflecting all previous calculated values and chosen standard parts.

This 3D-model will show the details of the construction which will put the theory into practice. The rotor and blades showed on this model are just only for complete view. The main model is of course the tower.

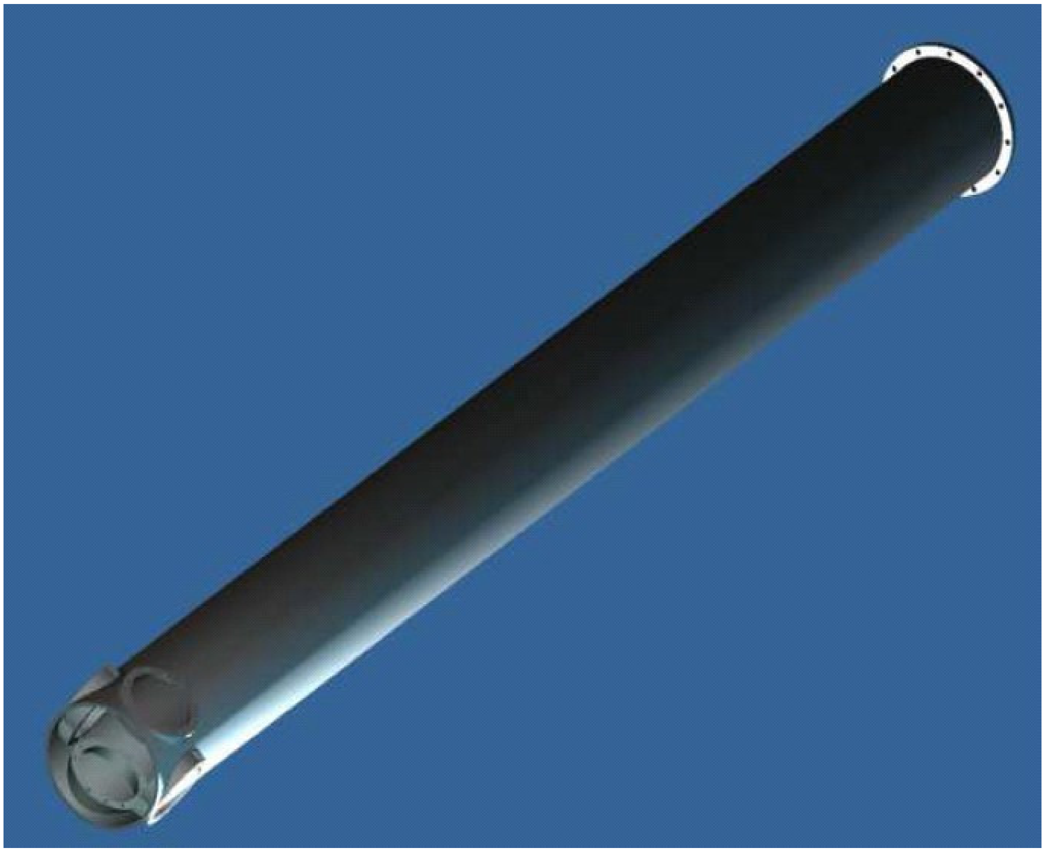
Figure 39



The main assembly consists of the tower and two supporting beams.

9.1 The main segment

Figure 40



Dimensions of the main segment of the tower were taken from the wind turbine manual. The main segment is of steel. The main segment consists of a pipe with the 330 mm outer and 310 mm inner diameter. A flange of pipe is used for connecting a wind turbine by welding. There are 12 holes around the flange for the connection with the bolts. 15 mm bolts are chosen for the connection of wind turbine, 10 mm bolts are chosen for the connection of leg.

Figure 40

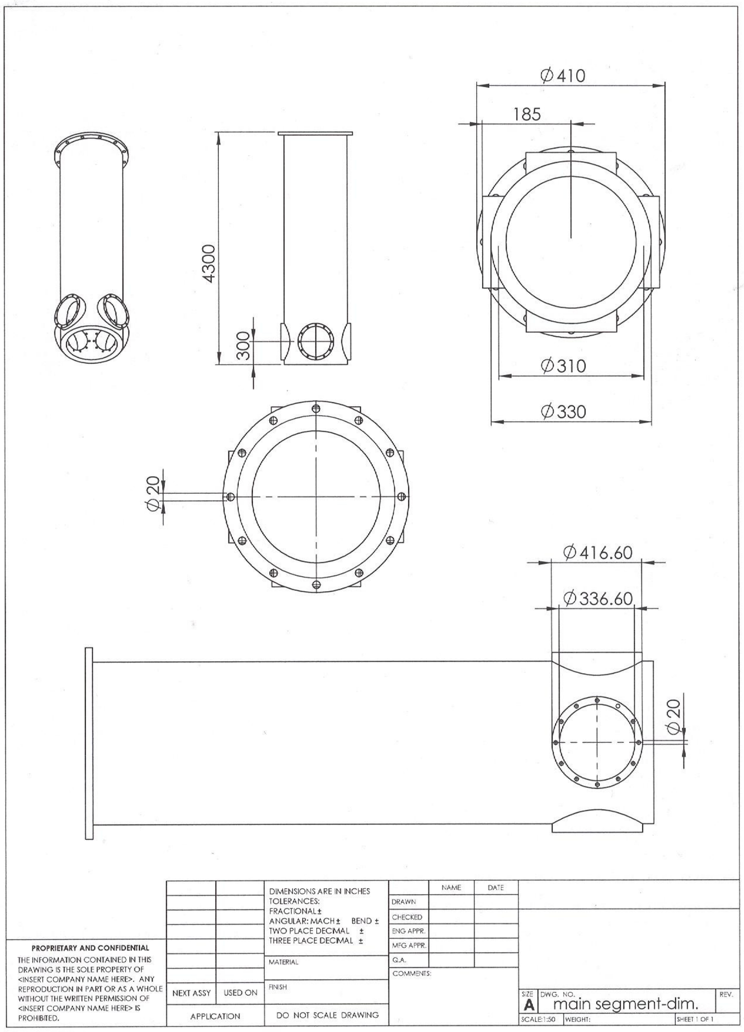


Figure 40 illustrates the drawing view of the main segment with parameter by the Solidworks.

9.2 Legs

Figure 41

Four legs are used in the tower to spread the weight of the wind generator, in the reasons of safety. Legs are made of pipes as well. Two flanges from each side of the pipe are welded.

Figure 42

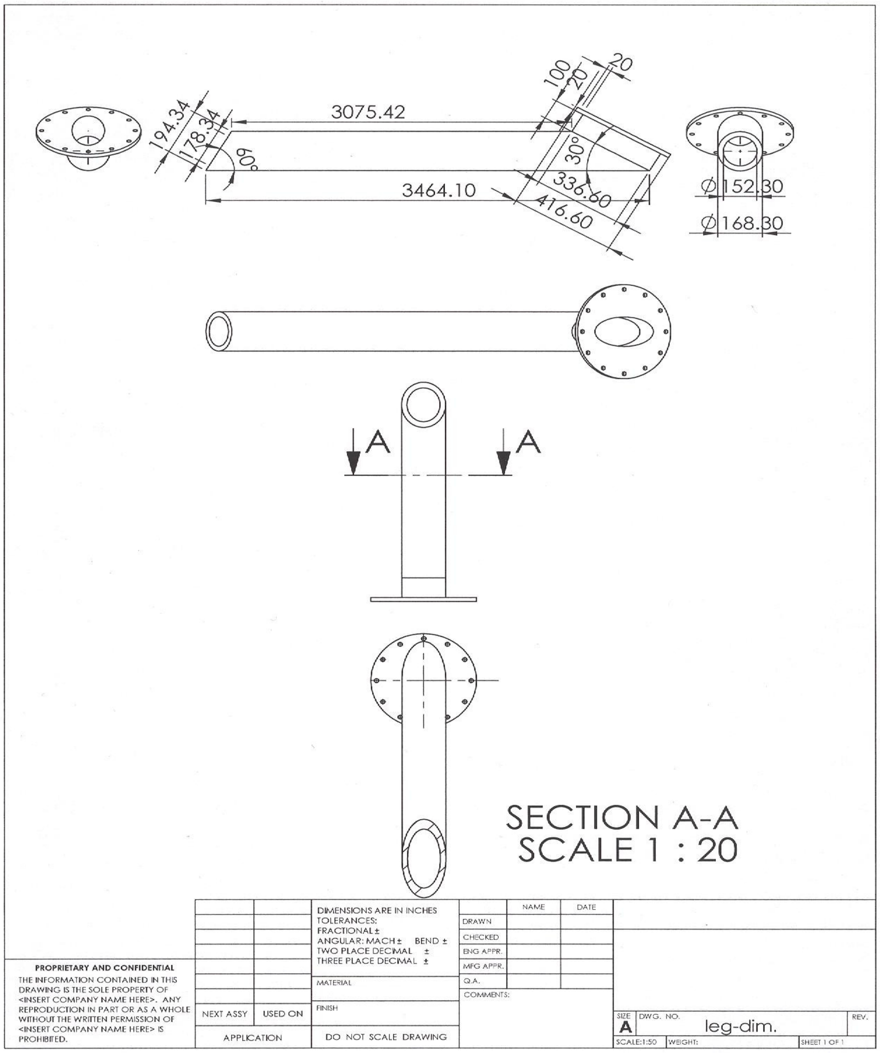
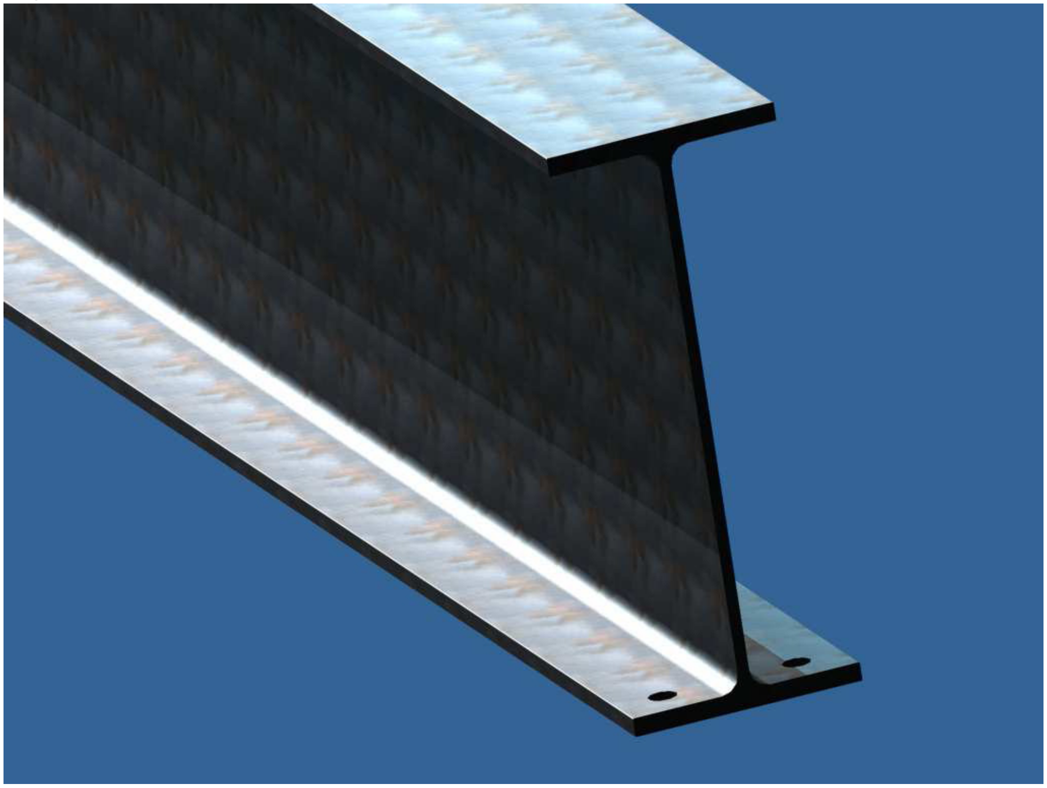


Figure 42 illustrates the drawing view of construction of leg part with parameter by the Solid works.

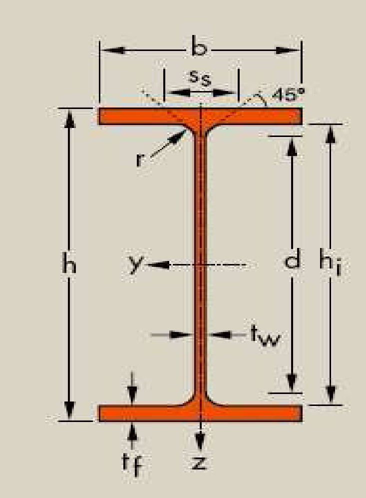
9.3 Supporting beam

Figure 43



Supporting beam is made of steel. Eight holes of different diameters are drilled in each beam to connect the four legs of the tower. Beam also have holes for the roof connection

Figure 43 (a) I-beam with parameter



b= 500mm

h =800mm

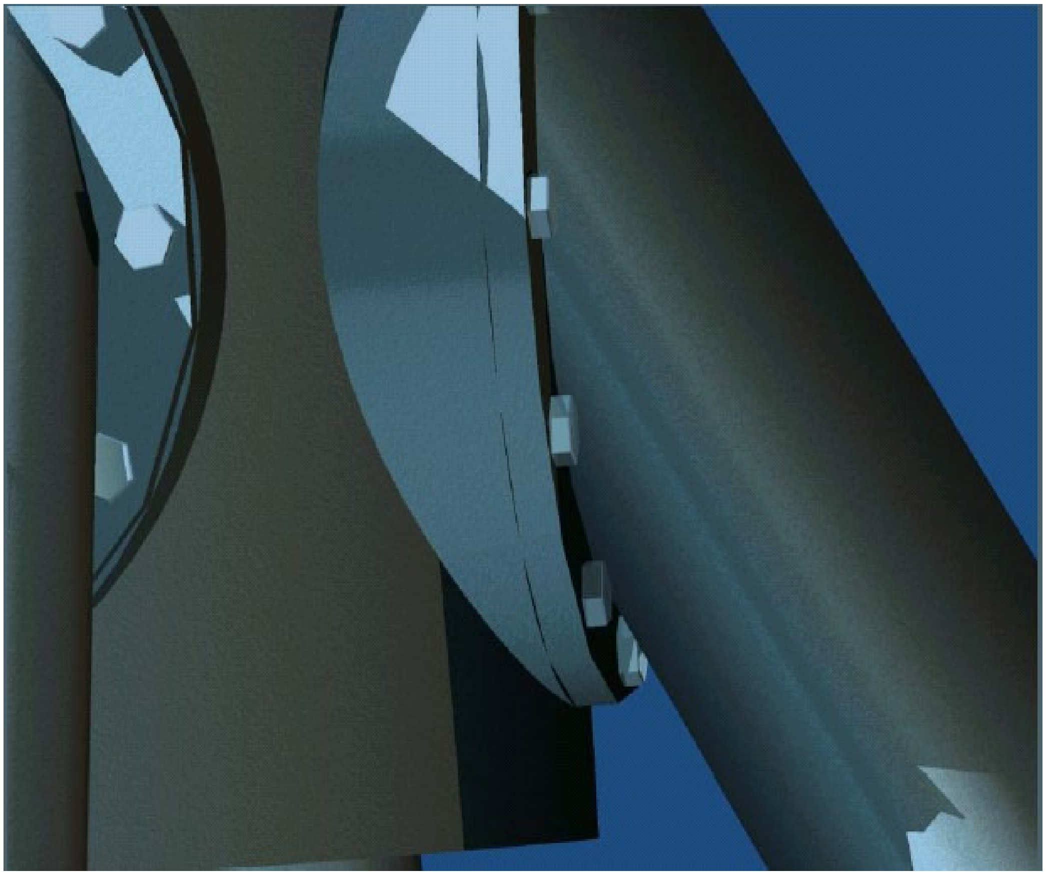
tw =100,2mm

tf= 160mm

r = 160mm

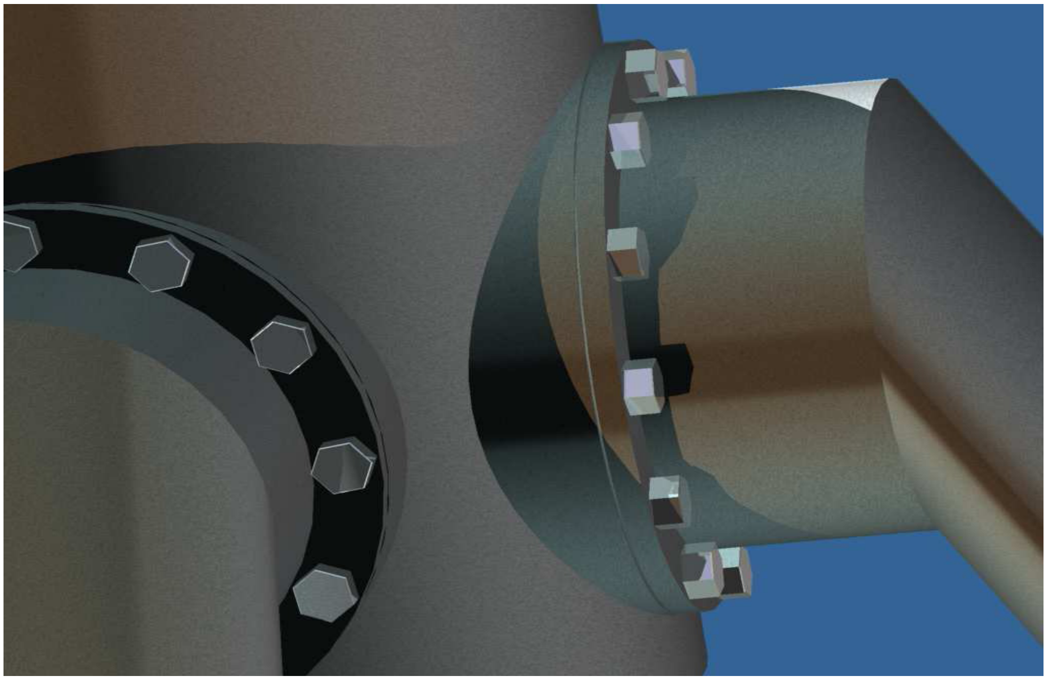
9.4 Connections

Figure 44



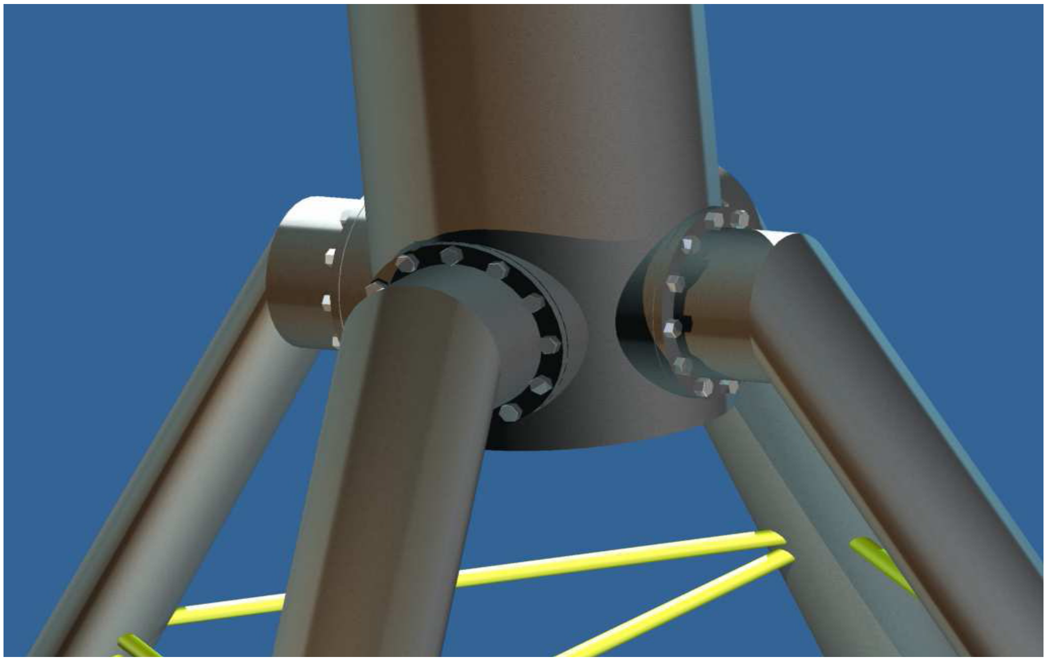
The first idea was to weld the pipe of the leg directly to the flange. But during the modeling, the problem of the intersection of the bolts occurred. There were several ways to correct it. But we decided to weld 80 mm part of the pipe, between the flange and leg.

Figure 45



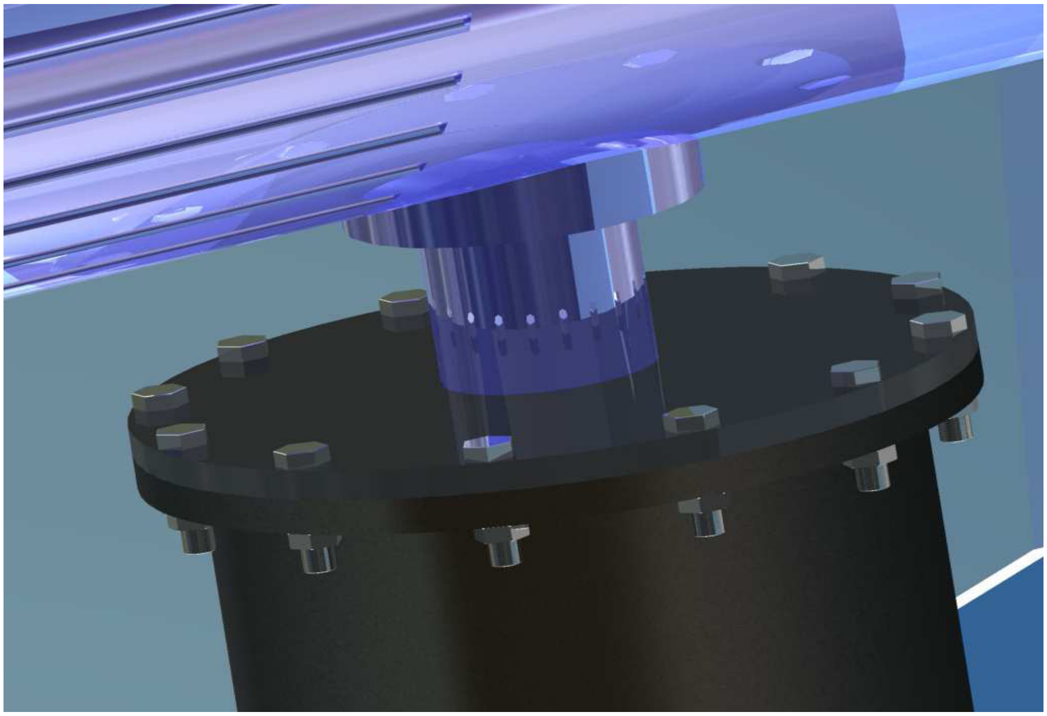
The legs are connected with twelve 10 mm bolts.

Figure 46



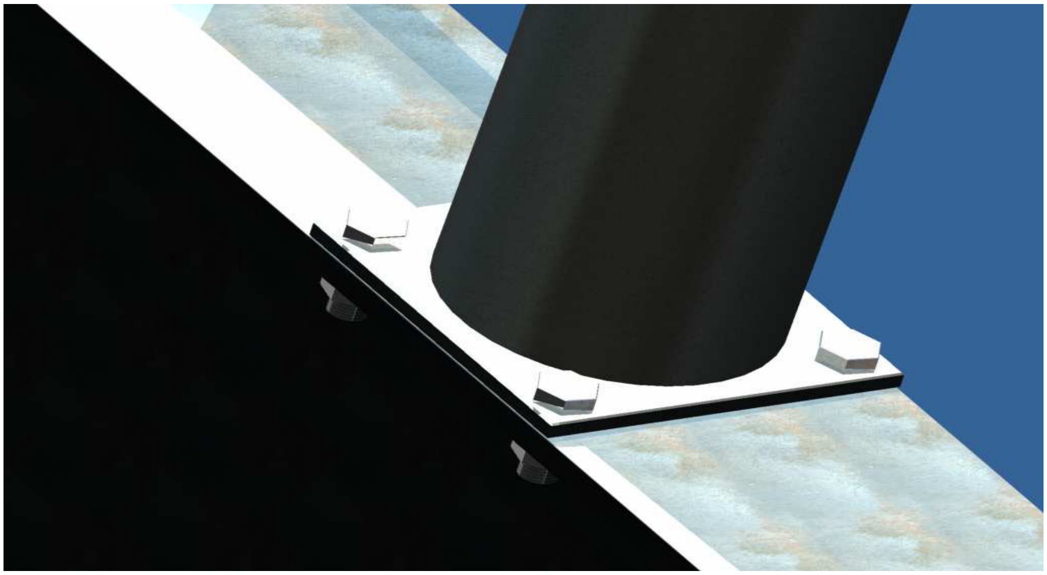
This is a general view of the leg connection.

Figure 44



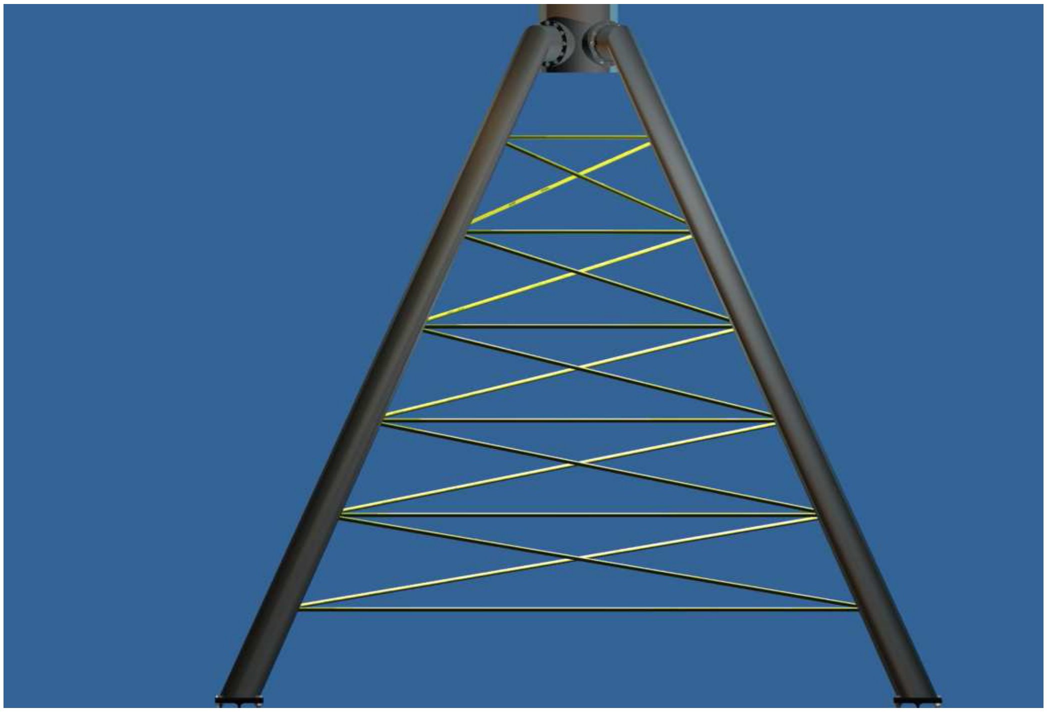
This picture shows the way of connection between wind turbine and the main segment of the tower. Twelve 15 mm bolts are holding wind turbine.

Figure 45



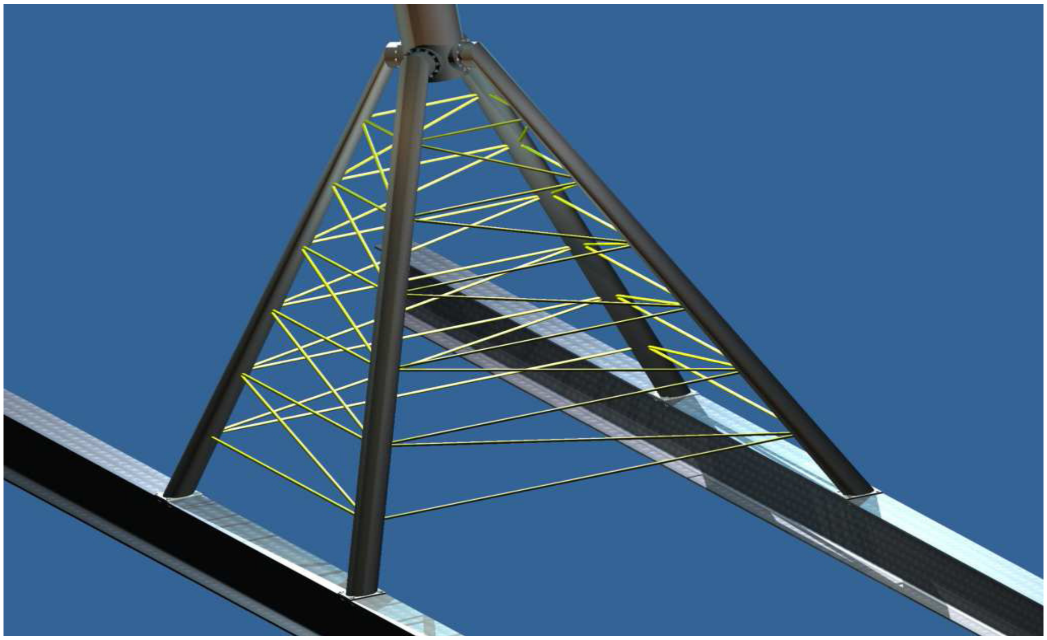
Legs are fixed to the supporting beam with four 20 mm bolts.

Figure 46



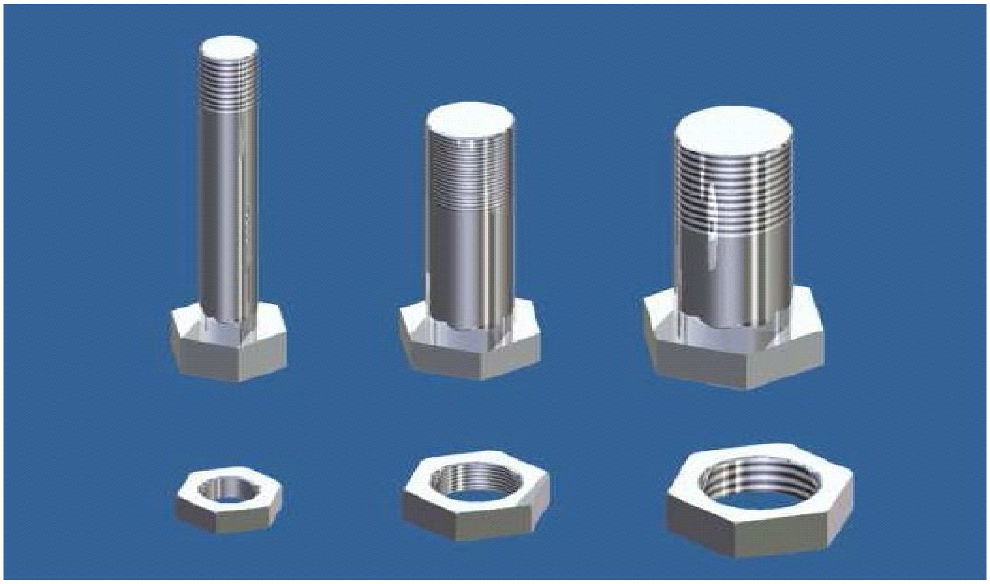
Eleven bars for each two legs were welded. Bars have 20 mm diameter.

Figure 47



Free view of tension bear bars and supporting beams.

Figure 48



Bolts and nuts are used in the construction.

9.5 Setting on the roof

Figure 49

Model of a high building roof was modeled as well, to have general view of the setting of the windmills on it.

10 CONCLUSION

Due to the fact that renewable sources of energy are gaining popularity as a substitute of traditional fossil fuels, our group had the idea of supplying a high building with electrical energy from a windmill, so that it could be independent in terms of electricity.

At the beginning, it was considered to design an energy supply solution for a household and not for a high building. Moreover, an idea arose to use not only wind energy, but also solar energy. However, the use of solar cells was rejected because of the slightly inadequate weather conditions for efficient use of that kind of device.

It was agreed to design the most popular type of a horizontal-axis, three-blade turbine, instead of for example American multi-blade, vertical axis windmill. The reason for that was the higher efficiency of a traditional turbine in comparison to Darrieus or Savonius-type turbines.

The next step was to decide how many windmills are needed and how large they should be. The first concept was to install a single, large turbine either on top of the roof or near the building. During the performing of extensive research and analysis of the situation, we realized that in this particular case, that kind of turbine would be unsuitable. Instead of that, it was predicted that several smaller windmills could provide comparable amount of energy, without producing so much noise, changing the landscape, or casting large shadows.

In order to make them less visible, it was decided that the roof of the building is an appropriate placement for the wind farm.

As we were gaining more knowledge about this subject, it was realized that it could not be possible to cover all the energy needs of one building with windmills sufficiently small for aesthetic reasons. It was concluded that our design will just cover a percentage of the required energy.

Initially, this design was meant to consist of designing the main components of the windmill from sketch. Due to the fact of the complexity of design even a single part such as the blade, or a gear box (which can takes several months), and our insufficient skills in aerodynamics, it was decided to simplify the aim of the design and to focus on what kind of condition should be fulfilled to enable the installation of a windmill.

During the whole process of working on our final thesis, we have not only gone through what we have learnt based on our major of mechanical engineering. It especially reflected on the design part of the wind mill, but also how to utilize the wind power that is one of the renewable energies. In our thesis, we solve the problems under our assumptions, but in the real life, we are going to encounter more difficulties that require us to accumulate more experience to handle these problems. But also we should consider more the environment aspect when designing something as an engineer in the future.

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