TECHNICAL UNIVERSITY - SOFIA

ENGLISH LANGUAGE FACULTY OF ENGINEERING

RESEARCH PROJECT

MEng DEGREE

TITLE:

RENEWABLE ENERGIES AND

CONNECTION TO THE GRID OF WIND TURBINES IN BAIKAL

SUPERVISOR: Svetlana Tzvetkova

STUDENT: Álvaro Itoiz Donamaría

SOFIA 2013

INDEX

ABSTRACT

The renewable energies have experienced a big increase in all the development world in the lasts 25 years. They have consolidated like an alternative source of energy with an impact to the environment so much less than the conventional ones.

For the development of renewable energies has been made a legal marc to ensure the economic viability of the installations and have as a result something attractive to the investors.

However, in the lasts years of economic crisis, the most part of projects related to these energies have suffered an important stop, as well as the grants and the inversions.

Nevertheless we have to continue investing money in these projects because they are a great solution to the global crisis (economic crisis, financial crisis and environmental crisis). They are offering us a national supply, accessible and clean energy.

To have a bigger knowledge about renewable energies we have made a study of the most important energies, the ways of exploitation, the nowadays technologies, data of implantation, laws and advantages and disadvantages.

The most important part of this study is related to the wind energy due to we made the second part of the project of a wind turbines installation and the different elements to connect them to the net.

After these we have made the study of the technical aspects that we need to take care for the implantation of a wind park in the province of Pleven (Bulgaria), more concrete, in the local town of Baykal. The park is an alignment of three turbines of 600 kW of unitary power. The energy that we have calculated that we will produce is around 3.6 GWh per year, with 2218 equivalent hours of annual efficiency.

In this part of the project we have boarded first the viability of the wind park location from the wind data of the area. These data have been studying technically to known the potentiality of it and have could decide the best turbines to use there.

Also, we make an important study of the elements necessaries to the turbines connection to the net, the transformation centers, the protections of them, the types of wire that connect the elements and the switchgear necessary for this kind of installations.

The project has three principal parts interrelated: first, the introduction and the study of the most important renewable energies, then, the wind park memory where we have included the technical aspects and the calculations, and finally the planes, the part most visual.

RENEWABLE ENERGIES

Renewable energies are called to these types of energy that are obtained from a natural source virtually inexhaustible (because the quantity of energy is so high or because the energy is able to be regenerated by natural ways). The renewable energies are known also as green energies owing to these energies are obtained of a sources that are respectful with the environment.

We must differentiate between alternative energies and renewable ones due to, the first ones are energies that can substitute the actual (either by their less contaminant emission or principally for their regeneration capacity) and the second ones only have the regeneration capacity, and usually they don´t emit gas contamination.

Some of the renewable energies and their advantages and disadvantages are explain below.

1. WIND POWER

1.1. Introduction

The wind energy is part of the ensemble of the renewable energies. It is the most extended internationally due to the power installed and the energy generated.

This energy becomes from the sun power because, it generates the change of pressure and the change of atmosphere temperature, that cause the movement of the air (wind). The wind turbines use this movement of the air to produce electricity by the kinetic energy of its blades (they are moved by the wind). Before the applications for produce electricity we have lots of examples of the wind uses: windmills to have a mechanical power, windpumps to water pumping, sails to propel ships…

Almost every source of the renewable energies comes in the last term from the sun. The sun irradiates 174.423.000 million kWh to the Earth. With the wind power energy we use approximately 1% or 2% of the energy that comes from the sun, around 50 or 100 times less than it´s transformed into biomass by all the plants of the world.

1.2. A little bit of history

In 1888 Brush built the first wind turbine (as we believe today) that generates electricity automatically. The machine had a rotor diameter of 17 meters and it had 144 blades made in wood.

Despite of the size of the machine, it only had a power of 12 kW because the turbines with a slow gyre have bad efficiency (Pour la Cour found later that the turbines with faster gyre and with less blades are more efficiency to produce electricity). The turbine works 20 years charging batteries.

Pour la Cour is considered one the pioneer of the modern wind turbines that generate electricity. He was also the pioneer of the aerodynamic and built his own wind tunnel to make experiments.

Between 1891 and 1897 he built different wind turbine with diameters around 20 meters and power of 35 kW.

More or less during the Second World War, the Danish company F.L. Smidth built different wind turbines with 2 and 3 blades. The turbines that had 2 blades generated direct current and the turbines that had 3 blades generated alternate current due to the incorporation of an asynchronous generator.

J. Juul built a revolutionary wind turbine for the company SEAS from Denmark; it was called Gedser and had 200 kW of power. It was turbine with 3 blades, a windward rotor with electro-mechanic orientation system and an asynchronous generator.

The turbine had regulation by aerodynamic loses (really similar that actual system). J. Juul also invented the aerodynamic breaks in the top of the blade that actuate due to the centrifugal force when the speed is so high.

It worked 11 years without maintenance.

In the seventies, after the first crisis of the petrol in 1973, lots countries started to investigate about wind energy. In Denmark, Germany, Sweden, United Kingdom and EE.UU. the energy companies putted their attention in the big wind turbines.

In 1979 were built 2 wind turbines of 630 kW with different regulation each one. One had a regulation by blade pitch change and the other had a regulation by aerodynamic loses.

This turbines were really expensive, so that, the price of the electricity was high too, big reason against the wind turbines.

Bonus 30 kW

In the eighties the Bonus 30 kW machine was built and was an example of one of the firsts wind turbines (as the actual).

Nordtank 55 kW

The generation of wind turbines of 55 kW suppose the industrial and technology rise in 1981. The price of the kWh fall down around a 50% and the industry of the wind turbines became more professional.

The technology has advanced so much until nowadays and the industry became more professional but the concept and the way of investigation started in those wind turbines of the eighties.

1.3. Wind turbine types

1.3.1. Depend on the position of the axis

Depending on the position of the axis around the blades gyre we have two different types of wind turbines:

1.3.1.1. Vertical axis

The axis around the blades gyre is perpendicular to the floor due to this we don´t need orientation system to put the rotor against the wind. We don´t need to know where the wind comes. We can also save the cost of the tower and put the rotor near the ground, but we have to remember that in this high the wind speed is less than in 40 meters as we can see in the graphic (Figure 1.1):

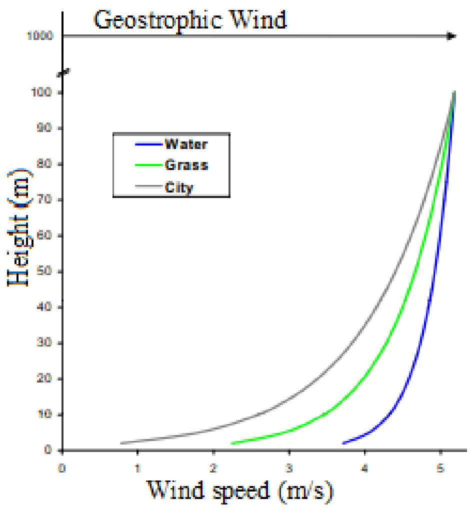


Figure 1.1: Height of the rotor against wind speed

In the graphic (Figure 1.1) we see that we have different types of curve depending on the place we are, and this is because the wind speed is influence by the roughness of the ground, the stability of the atmosphere and the orography.
One of the most important advantages over the horizontal axis turbine is that we can situate the generator, multiplier and the parts that usually are in the nacelle, in the ground. However it has a big disadvantage: if we want to change the bearings or some parts of the multiplier we have to disassemble the entire turbine.

The turbines that have the rotor elevated usually needs cables to ensure the machine, and they need many space, so that, sometimes we haven't got enough space to establish the turbine.

This type of turbine has two most commons prototypes:

- Darrieus rotor (Figure 1.2): it works by aerodynamic force.
- Savonius rotor (Figure 1.2): it works just by the force of the wind (pushed).

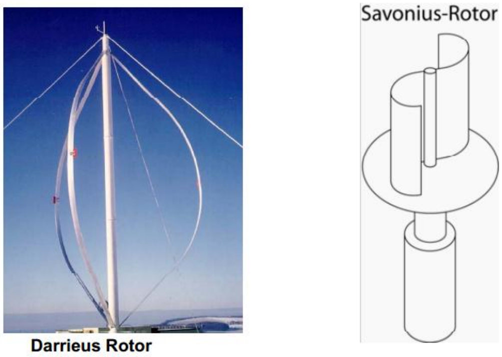


Figure 1.2: Darrieus and Savonius rotor

1.3.1.2. Horizontal axis

The wind turbines that use this system, unlike the previous, take more advantage about the wind speed. The high that the axis is situated is more elevated than the previous, so that, they have more wind speed and it is, join with the more efficiency, the main reasons of use more this type of turbine. Thus, the quality of the components and the technology of these turbines are growing up continually.

This system has many disadvantages too:

- They have problems to work near the ground due to the turbulences.
- The big tower and the large blades are difficult to transport (really expensive).
- The high turbines are difficult to install and need big cranes.
- They have a big visual impact in the environment.
- They have to orientate itself against the direction of the wind to work.
- They need a carefully control, otherwise they are prone to have fatigue in the material and structural damages.

We are going to forgot a little bit the vertical axis system and centre in this technology because as we said before, it´s the most common nowadays.

1.3.2. Depend on the number of blades

The wind turbines can have different number of blades depending on the technology they use, the rate speed that we have in the location…

We can classification them in four groups:

- 2 blades: this wind turbines save one blade and obviously its weight and price. However it has a bad part, these wind turbines need more speed of gyre to produce the same energy and with more speed of gyre they generate more noise and worse visual aspect.
  They need, as the turbines with 1 blade, an oscillating hub (the rotor has to can incline a little bit) to avoid the strong shocks every time that one of the blades passes by the tower. They can need dampers to decrease the shocks too. The inclination of the rotor is to avoid the collision of the blades against the tower.

- 1 blade: These wind turbines save the cost of another blade, but not of the weight because they need a counterweight. Also, the problems that we have seen in the turbines with 2 blades are applicable to these, and even more.
- Multi-blades: it isn´t usual to produce electricity, usually it is use to pump water. The gyre speed is low, so the components have less wear and also it can be installed in places with low wind speed (between 2 and 5 m/s).
- 3 blades: it is the most common model of turbines and the most efficient (as we can see in the next image: Figure 1.3). The three blades equilibrate the forces when one of the blades passes by the tower, so the hub can be less flexible. The speed of gyre can be less than the 2 and 1 blade turbines, therefore the noise, the vibrations and the visual impact are less. The gyre is also more uniform due to the proprieties of the moment of inertia, hence, minimizes the stress on the structure.

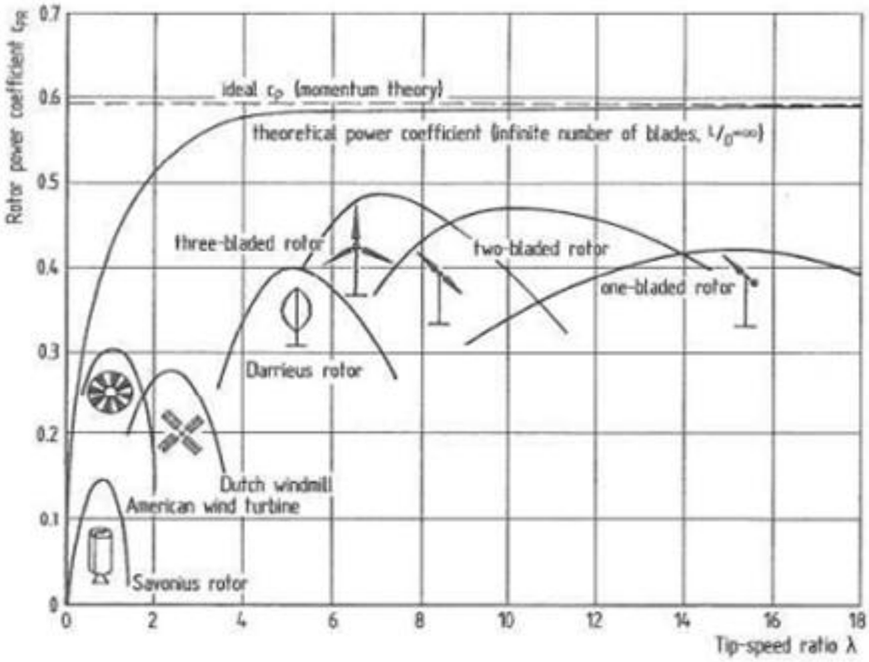


Figure 1.3: Theoretical power coefficient curve and power coefficient of different wind turbines

1.3.3. Depend on the position of the rotor

1.3.3.1. Upwind (Figure 1.4)

Figure 1.4: Upwind turbine

The wind turbines with upwind rotor has the rotor faced to the wind, so that, they avoid the shade of the tower, but not all of the turbulences created in the wind by the tower (the wind starts to deviate before the tower even if the tower is smooth and round. The energy generated by the wind turbine has downs when the blades pass in front of the tower.

The principal inconvenient is that upwind turbines must have an inflexible (almost) rotor and this must be situated with some distance to the tower. Also, this machine needs an orientation system.

1.3.3.2. Downwind (Figure 1.5)

The machines with downwind rotor have the rotor behind the tower in the direction of the wind. The advantage of this system front the other is that we don´t need to incorporate an orientation technology because if the design is adequate the nacelle will follow the wind passively. However, in big wind turbines for electricity generation are some doubts about the advantage because we needs cables to transport the energy and we will have problems if the machine has been orientated all the time in the same direction (the slip rings and the brush aren´t a good idea working with current around 1000 A).


Figure 1.5: Downwind turbine

A bigger advantage is that the rotor could be more flexible, so is a good thing for weight of nacelle (we don´t need much weight) and the blades can bend when the wind speed is high clearing part of the load to the tower.

The biggest disadvantage is that we have power fluctuations every time that one blade passes for the shade of the tower. This could generate more fatigue in the turbine than one upwind tower.

1.3.4. Depend on the control

All the wind turbines need a control system to regulate the gyre speed of the blades, because if not they can achieve a high speed and destroyed.

1.3.4.1. Passive stall (figure 1.6)

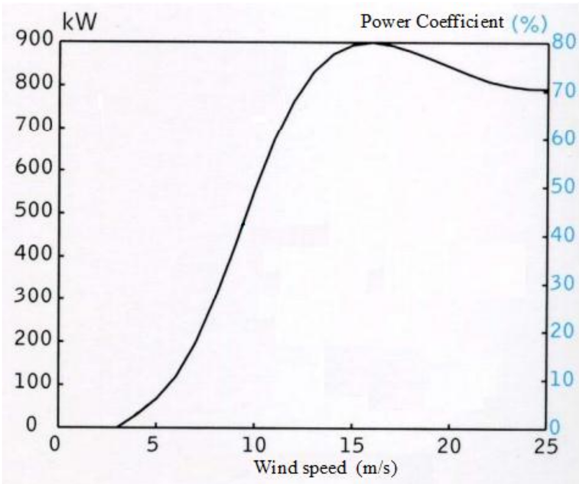


Figure 1.6 – Power curve of a wind turbine with passive stall

This is a system of control based on the aerodynamic of the blades. The blades are always in the same position respect the hub, they don´t move. When the speed of the wind become higher, the angle that the wind form with the movement of the blades changes and make the blades to increase their speed until arrive to the boundary layer separation. In this point, the gyre speed of the blades starts to decrease and if the wind raises more, the angle will be so big and the blades stop.

1.3.4.2. Active stall (Figure 1.7)

The idea is the same like the previous system but the difference is that with this technology we can move the blades a little bit (around 8 degrees) to increase or decrease the attack angle. With the change of the angle we can obtain better power curve and due to this, better energy in each moment.

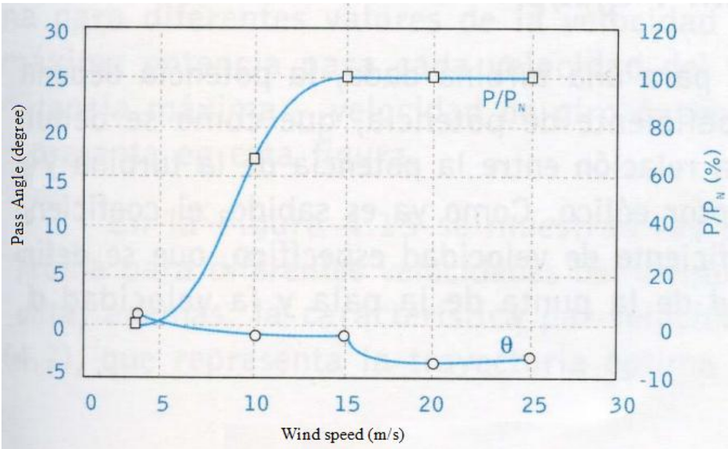


Figure 1.7 – Curve of wind turbine power and pass angle with active stall

1.3.4.3. Pitch (Figure 1.8)

With this technology we can move the pass angle of the blades between -5 degrees till 110 more or less. We can limit the power to its nominal value increasing the pass angle (θ) of the blades (decreasing the attack angle) when the wind speed is more than the nominal. The blades never will start to gyre when the blades are in feathered position (the blades profile is against the wind):

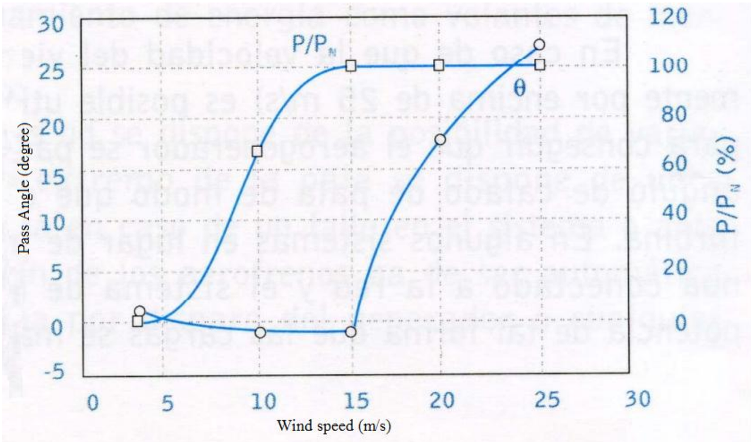


Figure 1.8 – Power curve of wind turbine and pass angle with pitch control.

1.4. General schema of a wind turbine

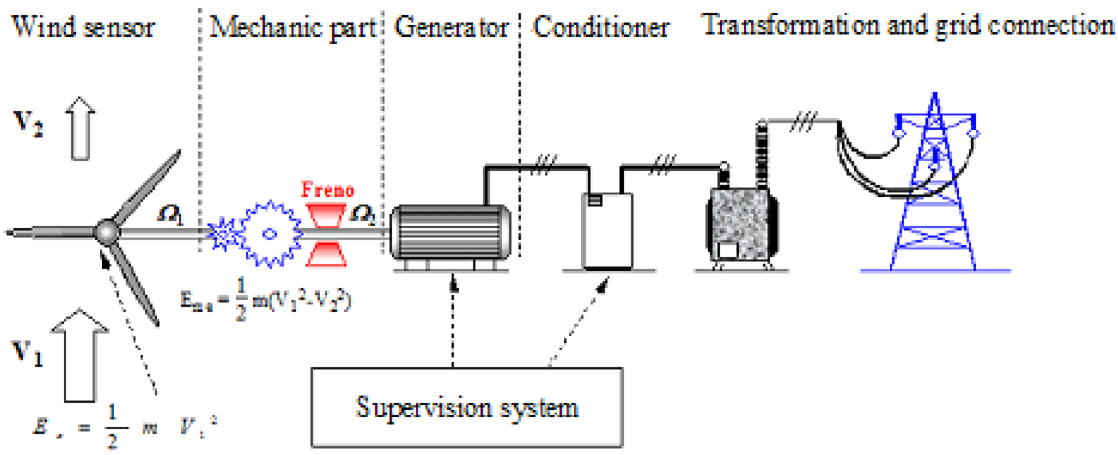


Figure 1.9: General schema of a wind turbine

- Wind sensor: it ensures of take part of the kinetic energy of the wind and transforms it in a gyratory movement. Depending in the technology of the wind turbine we can distinguish two types: vertical axis or horizontal axis.
- Mechanic part: transport and condition the mechanical energy. Usually it is composed by a low speed axe, a multiplier, a high speed axe and a mechanical break. With the multiplier we transform the low speed of the wind sensor (between 17 and 48 rpm) to the high speed that needs the generator (it needs approximately 1500 rpm). This transformation usually it is made by three steps with rates of 1:15, 1:15 and 1:3.
- Generator: converts the mechanical energy into electric energy. The generators usually are electric machines asynchronous or synchronous use in Electric Drives. These machines normally have a voltage under 1000 V and have 2, 3 or 4 pole pairs (1500, 1000 or 750 rpm respectively).
- Conditioner: it decouples the generator and the grid and gives power and speed control in the generator. This control is made to optimize the system.
- Transformer: Due to the high power that have the wind turbines and the low voltage, usually, it is necessary increase the voltage in the same place of generation of energy (the tower of the wind turbine) to decrease the current. Habitually in the wind turbines the energy is transformed into 22 kV and then in a substation the energy of all wind turbines is transformed into 66 kV to be introduced into the net.
- Supervisor system: The control of a generator commonly has two goals. In one hand we want to produce the more possible energy in a determinate speed, and in the other hand we want to attenuate the variation of the speed gyre in the mechanical part to decrease the fatigue and in the grid, to avoid disturbances. These possibilities of control are unit to the freedom degrees of the wind sensor, the generator and the conditioner.

1.5. Elements of a wind turbine

At first we have some schemas to over view all the important parts and then we will explain the different remarkable parts:

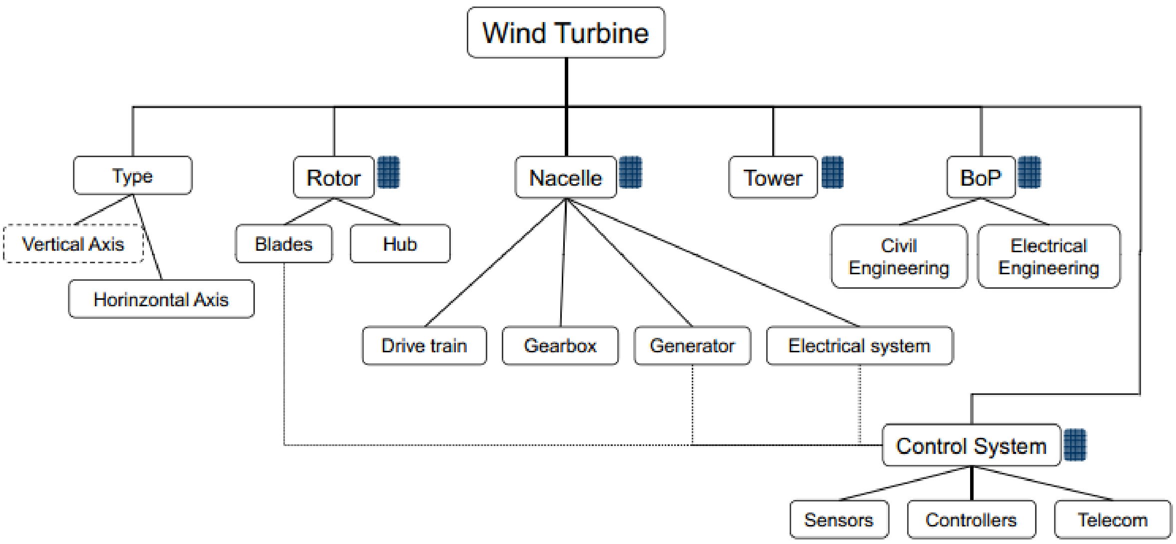


Figure 1.10: Principal elements in a wind turbine

- Rotor: it is the moving part (the nacelle moves but much less) of the wind turbines. It is composed by the blades and the hub.
- Nacelle: it is a cover housing that houses all of the electricity generating components in a wind turbine
- Tower: it is the largest part of the wind turbine, it holds the nacelle and the rotor elevate from the ground. It has the goal to hold the nacelle but also to brook the vibrations and movements of the machine.
- Balance of plant: It includes the civil and the electrical engineering, so that it includes all the preparative that a wind turbine needs to be built and to be connected to the grid.

1.5.1. Rotor

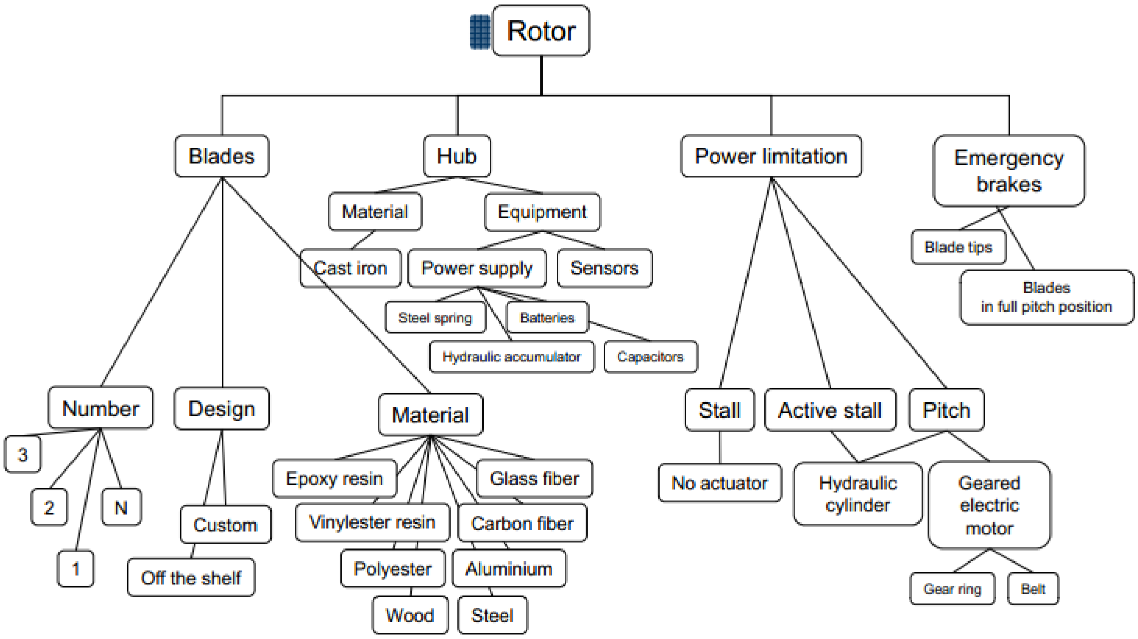


Figure 1.11: Principal elements that compose the rotor

1.5.1.1. Blades

Blades are one of the most complicated things in the design of a wind turbine. They must be perfects because they are the responsible of the transform the wind energy into mechanical energy. They have an aerodynamically form to take the lift force of the wind and gyre with the necessary speed to produce the best energy for each wind speed.

Usually in a wind turbine we have 3 blades made (the actual ones) with a structure of aluminium, the least, of carbon or glass fibre, the most, and recover of composite materials like epoxy resin. The oldest one usually had a heavier structure, therefore, they had more inertia moment so, they took more time to variety the speed when the wind speed change. The newest ones can change faster the speed keeping the tip speed ratio more nearly constant (the tip speed ratio is the ratio between the speed of the blade and the speed of the wind; usually it is near 6 or 7). The new blades have a disadvantage, as they can change easier the speed, the power fluctuate more and it worse to introduce it to the grid.

The cross section of a blade is the next (Figure 1.12):

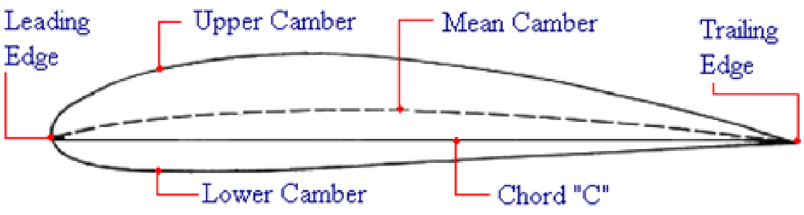


Figure 1.12: Section of a wind turbine blade.

- Leading Edge: Central point of the profile front.
- Trailing edge: Central point of the profile back.
- Chord: straight line that join the two previous points.
- Upper camber: it is the superior edge measured from the leading edge till the trailing edge.
- Lower camber: it is the inferior edge measured from the leading edge till the trailing edge.
- Mean camber: It is the line that joins the leading edge and the trailing edge passing for all the points with the same distance to the upper and the lower camber.
- Thickness: maximum distance between upper and lower camber.

There are lots of profiles depending on the application (Figure 1.13):

Figure 1.13: Different blade´s profiles

1.5.1.2. Hub

It is a really important piece in a wind turbine. Inside of it there are the elements that allow the angle of the blades change, in the modern versions, the hydraulic cylinders. Also, there are inside the mechanisms that let the possibility to stop the wind turbine, and if it has a pitch control, let to put the blades in feathered position.

Some wind turbines have inside of it the break system too.

The hub usually is made by alloy of steel, but the different components depend on the weather that the hub will be exposed.

1.5.1.3. Power limitation

This system is also known as the control systems. The main goal is to obtain the best energy for a determinate wind speed. As we have seen previously.

1.5.1.4. Emergency brakes

It is a system that provides high levels of reliability due to its importance. It has the aim of stop the gyre of the blades when the speed of the wind is too high. These brakes are sized to ensure adequate heat dissipation during an emergency stop and with an even pressure distribution across pad surfaces.

The brakes are usually mounted in the rotor shaft, between gearbox and generator. All units are engineered to handle the large output torque generated by the high ratios found in wind turbine gearboxes.

They come in a range of braking forces from 100 N to 1 MN to meet the torque requirements of the most common turbines.

1.5.2. Nacelle

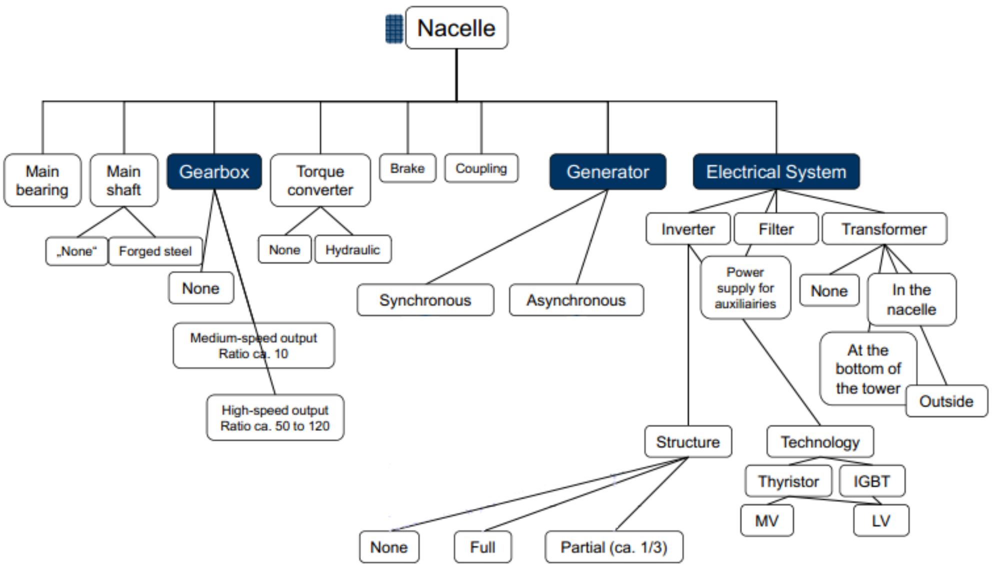


Figure 1 .14: Principal elements in the nacelle

1.5.2.1. Gearbox

The power from the rotation of the blades is transferred to the generator through the power train. It is composed by the main shaft, the gearbox and the high speed shaft.

If we don´t use a gearbox and we connect the generator directly to a 50 Hz alternant current three phase, with two, four or six poles, we would have an extremely high speed turbine. It would gyre between 1000 and 3000 rpm, and if the rotor has a diameter of 40 meters, that would imply a tip speed of rotor of far more than twice the speed of sound, something impossible.

Another idea to work without a gearbox is use a multiple poles generator, but it implies that the machine will have around 250 to have a blades speed of 30 rpm. Impossible too (the price will be huge). Also, a directly system would need a big and heavy shaft to support the torque of the blades.


Figure 1.15: Gearbox in construction

As we can see, the practical solution is to use a gearbox. With the gearbox you convert between slowly rotating, high torque power which you get from the rotor and high speed and low torque which you use for the generator. Normally, the gearbox doesn´t "change gears", it has a normal gear ratio between the rotation for the rotor and the generator.

The ratio of the gearbox depends on the power of the wind turbine. Per example, for a 750 kW machine the gear ratio is around 1 to 50.

1.5.2.2. Generator

The generator converts the mechanical energy into electrical energy. This generators are a little bit different than the others (those in the conventional plants to produce energy) because these have to work with a power source that supply a mechanical power so much variable.

Usually the generator of the wind turbines put out an electrical energy of 690 V of three phases current. After the generator in most of cases there is a transformer that high the voltage to a quantity between 10.000 and 30.000 V depending the region.

The generators need refrigeration during its work, and in the most wind turbines this refrigeration is made with air circulation, however, there are other machines that have water refrigeration (these machines have some advantages because the generator could be more compact, but the disadvantage is that it needs a radiator to evacuate the liquid heat).

There are different types of generator connection to the gird: directly or indirectly. The directly form is just join the three phases grid to the generator and the indirectly connection signify that the current passes through some electronic devices for adapt the generator and the grid current.

There are different types of generators:

- Synchronous: it can be winding or permanent magnet (both are similar) and it can gyre with different speed. When we gyre the magnet of the rotor induce alternant current of this frequency in the stator winding. Normally it isn´t connect to the grid directly because they need to adequate de frequency with electronic converters.

- Asynchronous (squirrel cage): The cage is magnetized generating current in the stator when it gyres. The speed is more or less fix, the range of work depends on the slip. In the normal industry they are more used like motor.
- With change of gyre speed: one example is the asynchronous generator doubly fed (the converter fed the rotor and the stator is connected directly to the grid). With this connection the frequency of the electric rotor can be change with the converter, so that, we can dissociate the mechanic and the electric frequency and make possible work with variable speed.
- With variable slip: with a slip of 10% we have enough capacity of speed variation for reduce 80% the torque and the electric power variation.

1.5.3. Tower

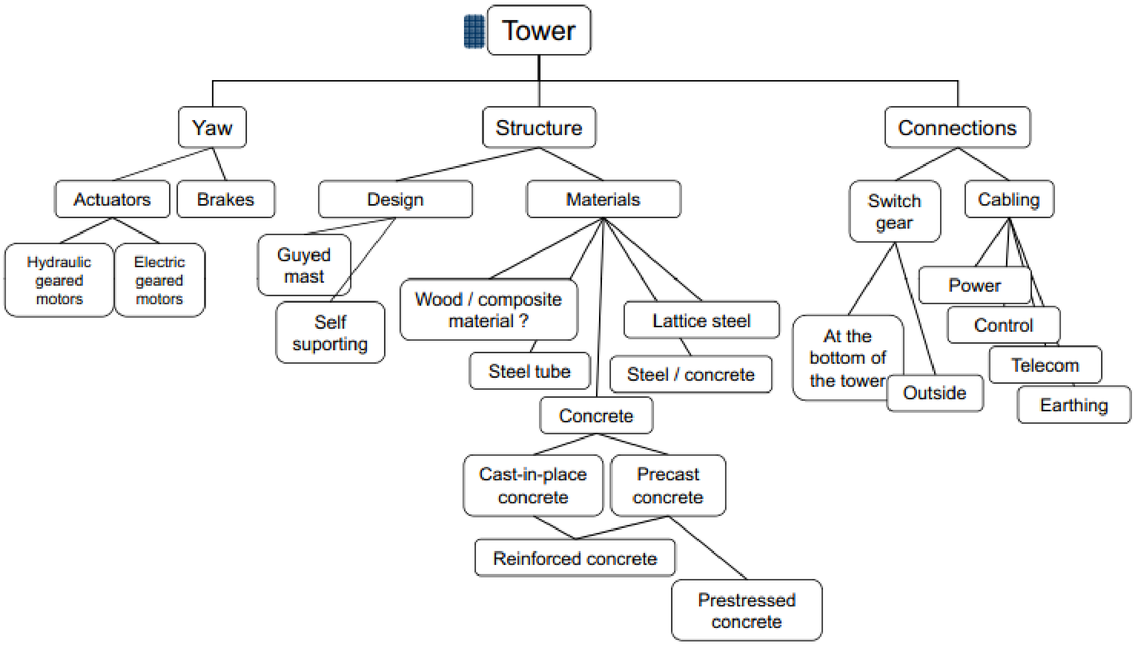


Figure 1.16: Principal elements of the tower

1.5.3.1. Yaw

The yaw system (Figure 1.17) of wind turbines is the component responsible for the orientation of the wind turbine rotor towards the wind.

The active yaw systems are equipped with some sort of torque producing device able to rotate the nacelle of the wind turbine against the stationary tower based on automatic signals from wind directions sensor.

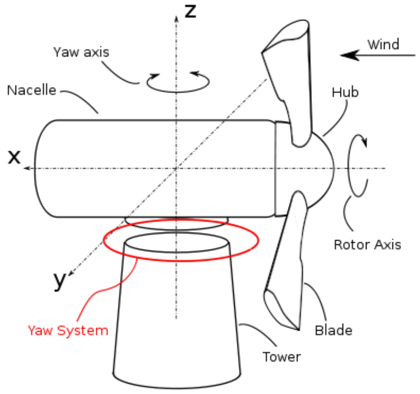


Figure 1.17 – Yaw system in a wind turbine

1.5.4. Balance of plant

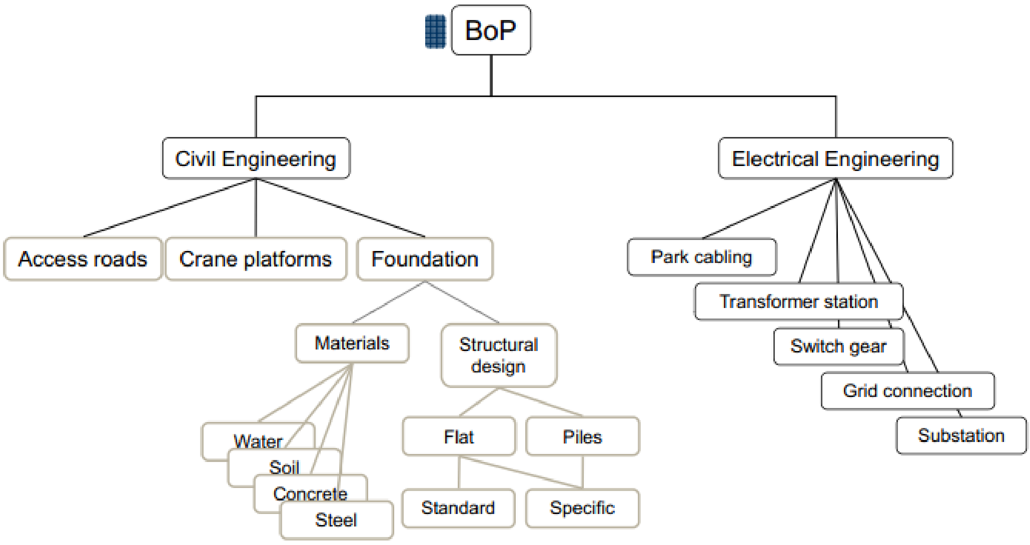


Figure 1.18: Principal elements of the balance of the plant

1.5.5. Control system

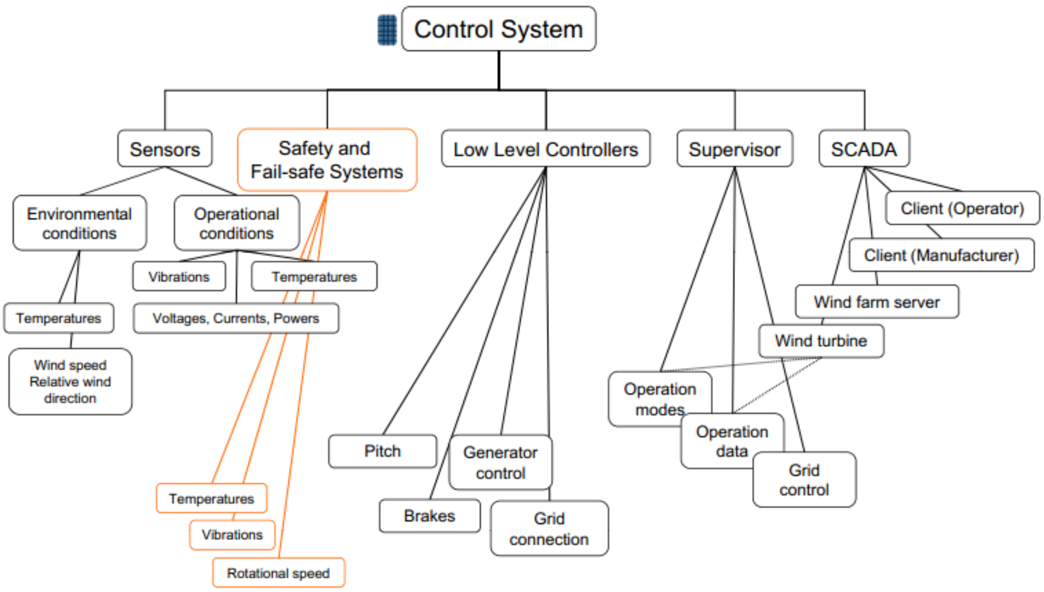


Figure 1.19: Principal elements of the control system

1.5.6. A picture to situate the most important parts

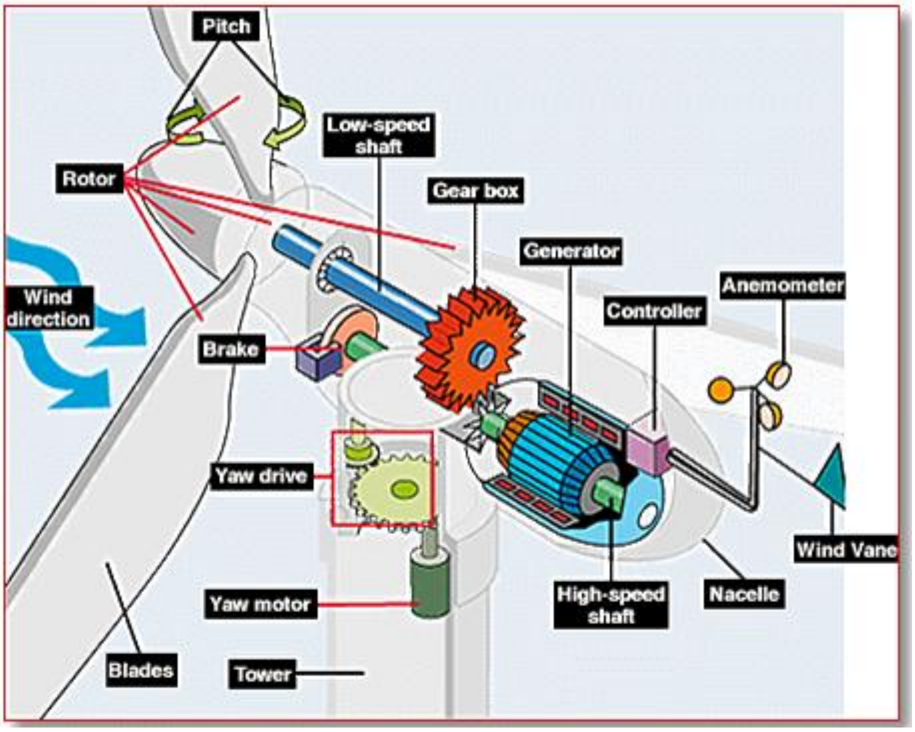


Figure 1.20: Elements of a turbine

1.6. Betz´s law

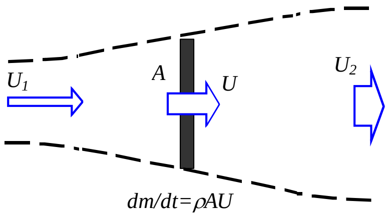


Figure 1.21: Schematic of fluid flow through a disk-shaped actuator.

Betz´s law is a theory about the maximum possible energy to be derived form a “hydraulic wind engine”, or a wind turbine such as the Éolienne Bollée (patented in 1868)… Betz´s law was developed in 1919 by the German physicist Albert Betz, and the conclusion is that any turbine can capture more than 59.3 % of the kinetic energy of the wind.

1.6.1. Proof

It shows the maximum possible energy (Betz´s limit) that may be derived by means of an infinitely thin rotor from a fluid flowing at a certain speed.

In order to calculate the maximum theoretical efficiency of a thin rotor (of, for example, a wind mill), one imagines it, to be replaced by a disc that withdraws energy from the fluid passing through it. At a certain distance behind this disc the fluid that has passed through will have a constant flow with lower speed than at first.

1.6.2. Assumptions

1. The rotor does not possess a hub; this is an ideal rotor, with an infinite number of blades which have zero drag. Any resulting drag would only lower this idealized value.

2. The flow into and out of the rotor is axial. This is a control volume analysis, and to construct a solution the control volume must contain all flow going in and out, failure to account for that flow would violate the conservation equations.

3. This is incompressible flow. The density remains constant, and there is no heat transfer from the rotor to the flow or vice versa.

1.6.3. Application of Conservation of Mass (continuity equation)

Applying conservation of mass to this control volume, the mass flow rate (the mass of fluid flowing per unit time) is given by:

$$\dot{m} = \rho A_1 v_1 = \rho S v = \rho A_2 v_2$$

Where v_1 is the speed in the front of the rotor, v_2 is the speed downstream of the rotor and v is the speed at the fluid power device. ρ is the fluid density, and the area of the turbine is given by S. The force exerted on the wind by the rotor may be written as:

$$F = m \cdot a = m \cdot \frac{dv}{dt} = \dot{m} \cdot \Delta v = \rho S v (v_1 - v_2)$$

1.6.4. Power and work

The work done by the force may be written incrementally as:

$$dE = F \cdot dx$$

$$P = \frac{dE}{dt} = F \cdot \frac{dx}{dt} = F \cdot v = \rho S v^2 (v_1 - v_2)$$

However, power can be computed another way, by using the kinetic energy. Applying the conservation of energy equation to the control volume yields:

$$P = \frac{\Delta E}{\Delta t} = \frac{1}{2} \dot{m} ({v_1}^2 - {v_2}^2)$$

Looking back at the continuity equation, a substitution for the mass flow rate yields the following:

$$P = \frac{1}{2} \rho S v ({v_1}^2 - {v_2}^2)$$

Both of these expressions for power are completely valid, one was derived by examining the incremental work done and the other by the conservation of energy. Equating these two expressions yields:

$$P = \frac{1}{2} \rho S v ({v_1}^2 - {v_2}^2) = \rho S v^2 (v_1 - v_2)$$

$$\frac{1}{2} ({v_1}^2 - {v_2}^2) = \frac{1}{2} (v_1 + v_2)(v_1 - v_2) = v(v_1 - v_2)$$

$$v = \frac{1}{2}(v_1 + v_2)$$

Therefore, the wind speed at the rotor may be taken as the average of the upstream and downstream speeds. This is often the most argued against portion of Betz' law, but as you can see from the above derivation, it is indeed correct.

1.6.5. Betz´s law and coefficient of performance

Returning to the previous expression for power based on kinetic energy:

$$\dot{E} = \frac{1}{2}\dot{m}({v_1}^2 - {v_2}^2) = \frac{1}{2}\rho S v({v_1}^2 - {v_2}^2)$$

$$\dot{E} = \frac{1}{4}\rho S(v_1 + v_2)({v_1}^2 - {v_2}^2) = \frac{1}{4}\rho S {v_1}^3\left(1 - \left(\frac{v_2}{v_1}\right)^2 + \left(\frac{v_2}{v_1}\right) - \left(\frac{v_2}{v_1}\right)^3\right)$$

By differentiating (through careful application of the chain rule) $\dot{E}$ with respect to $\left(\frac{v_1}{v_2}\right)$ for a given fluid speed v_1 and a given area S one finds the maximum or minimum value for $\dot{E}$ (figure 1.15):

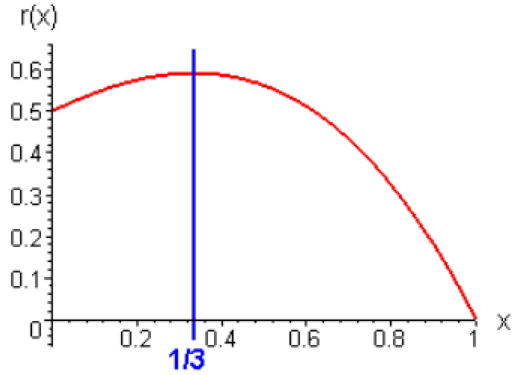


Figure 1.22: $r(x) = C_p$ (Power coefficient) against $x = \left(\frac{v_1}{v_2}\right)$

The result is that reaches maximum value when:

$$\left(\frac{v_2}{v_1}\right)_{opt} = \frac{1}{3}$$

Substituting this value results in Power expression:

$$P_{opt} = \frac{16}{27}\frac{1}{2}\rho S {v_1}^3$$

This implies:

$$(C_p)_{opt} = \frac{16}{27} = 0.593$$

The "coefficient of performance" (C_p) has a maximum value of: 0.593.

Rotor losses are the most significant energy losses in, for example, a wind mill. It is, therefore, important to reduce these as much as possible. Modern rotors achieve values for C_p in the range of 0.4 to 0.5, which is 70 to 80% of the theoretically possible.

1.6.6. Points of interest

Note that the preceding analysis has no dependence on the geometry; therefore S may take any form provided that the flow travels axially from the entrance to the control volume to the exit, and the control volume has uniform entry and exit velocities. Note that any extraneous effects can only decrease the performance of the turbine since this analysis was idealized to disregard friction. Any non-ideal effects would detract from the energy available in the incoming fluid, lowering the overall efficiencies.

There have been several arguments made about this limit and the effects of nozzles, and there is a distinct difficulty when considering power devices that use more captured area than the area of the rotor. Some manufacturers and inventors have made claims of exceeding the Betz´s limit by doing just this, in reality, their initial assumptions are wrong, since they are using a substantially larger A_1 than the size of their rotor and this skews their efficiency number. In reality, the rotor is just as efficient as it would be without the nozzle or capture device, but by adding such a device you make more power available in the upstream wind from the rotor.

1.7. Some figures and facts

1.7.1. Wind turbines in Spain the last years

The wind energy was, in Spain, the most important contribution to the Strategic of Renewable Energies with 20.676 MW installed at the end of 2010. This Strategic was valid from 2005 till 2010.

In the period that the Strategic of Renewable Energies was valid the contributed of the wind power energy change from the 7,4% to the 13,4% of the electricity consumed in Spain. In this period the wind power generated 138 TWh and received bonuses which sum 5.200 million of euros. It is more or less the price that would cost to the country the generation of this energy by fossil fuels according to the AEE (Wind Business Association) estimations.

With the change of the form of produce the energy we avoided more than 70 million of tones of dioxide of carbon. With this change also we save around 500 million euros due to Spain would have to buy emission rights because its quantity was completed. So that, we substituted more or less, 5.500 million euros destined to the exporter countries to 5.200 million to companies from Spain. These 5.200 million euros suppose a help to companies with world projection, companies that give thousands of jobs and have really good investigation programs to highlights in the market.

1.7.2. Wind power installed in Europe

Wind power installed in UE (MW)										
No	**Country**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**
-	UE	74.767	64.712	56.517	48.069	40.511	34.383	28.599	23.159	17.315
1	Germany	25.777	23.897	22.247	20.622	18.415	16.629	14.609	11.994	8.754
2	Spain	19.149	16.689	15.131	11.623	10.028	8.264	6.203	4.825	3.337
3	Italy	4.850	3.736	2.726	2.123	1.718	1.266	905	788	682
4	France	4.492	3.404	2.454	1.567	757	390	257	148	93
5	United Kingdom	4.051	2.974	2.406	1.962	1.332	904	667	552	474
6	Portugal	3.535	2.862	2.150	1.716	1.022	522	296	195	131
7	Denmark	3.465	3.163	3.125	3.136	3.128	3.118	3.116	2.889	2.489
8	Netherland	2.229	2.225	1.747	1.558	1.219	1.079	910	693	486
9	Sweden	1.560	1.048	788	571	509	442	399	345	293
10	Ireland	1.260	1.027	795	746	496	339	190	137	124
11	Greek	1.087	985	871	746	573	473	383	297	272
12	Austria	995	995	982	965	819	606	415	140	94
13	Poland	725	544	276	153	83	63	63	27	0
14	Belgium	563	415	287	194	167	96	68	35	32
15	Hungary	201	127	65	61	17	3	3	3	0
16	Czech Republic	192	150	116	54	28	17	9	3	0
17	Finland	146	143	110	86	82	82	52	43	39
18	Bulgaria	177	120	57	36	10	10	0	0	0
19	Estonia	142	78	59	32	32	6	2	2	0
20	Lithuania	91	54	54	51	48	6	6	0	0
21	Luxembourg	35	35	35	35	35	35	22	17	15
22	Latvia	28	27	27	27	27	27	27	24	0
23	Romania	14	11	8	3	2	1	1	0	0
24	Slovakia	3	3	5	5	5	5	3	0	0
25	Cyprus	0	0	0	0	0	0	0	0	0
26	Malt	0	0	0	0	0	0	0	0	0
27	Slovenia	0	0	0	0	0	0	0	0	0

Table 1.1: Wind power installed in Europe until 2010

1.8. Advantages and disadvantages

There are a range of advantages and disadvantages of wind energy to look at, including the many problems associated with wind turbines.

In this day and age, the world needs to look at the different natural energy sources available to us. Global warming could be due our energy lifestyle, so we should look into more environmentally friendly energy sources:

+ Wind energy is friendly to the surrounding environment, as no fossil fuels are burnt to generate electricity from wind energy.

+ Wind turbines take up less space than the average power station. Windmills only have to occupy a few square meters for the base, this allows the land around the turbine to be used for many purposes, for example agriculture.
+ Newer technologies are making the extraction of wind energy much more efficient. The wind is free, and we are able to cash in on this free source of energy.
+ Wind turbines are a great resource to generate energy in remote locations, such as mountain communities and remote countryside. Wind turbines can be a range of different sizes in order to support varying population levels.
+ Another advantage of wind energy is that when combined with solar electricity, this energy source is great for developed and developing countries to provide a steady, reliable supply of electricity.

– The main disadvantage regarding wind power is down to the winds unreliability factor. In many areas, the winds strength is too low to support a wind turbine or wind farm, and this is where the use of solar power or geothermal power could be great alternatives.
– Wind turbines generally produce a lot less electricity than the average fossil fuelled power station, requiring multiple wind turbines to be built in order to make an impact.
– Wind turbine construction can be very expensive and costly to surrounding wildlife during the build process.
– The noise pollution from commercial wind turbines is sometimes similar to a small jet engine. This is fine if you live miles away, where you will hardly notice the noise, but what if you live within a few hundred meters of a turbine?
– Protests and/or petitions usually confront any proposed wind farm development. People feel the countryside should be left in fact for everyone to enjoy its beauty.

2. SOLAR ENERGY

2.1. Introduction

The solar energy is obtained from the electromagnetic radiation of the sun. These radiations of the sun are captured by sensors that with different technologies can transform them into electric energy or thermal-energy.

The powerful of the sun´s radiations are different depend on the day of the year, the weather of the day (if it is cloudy, foggy…), the hour, the latitude... we can say that the good condition is when the radiation in the ground is around 1000 W/m^2 (irradiation).

We can differentiate two technologies in the solar energy:

- Photovoltaic (Figure 2.1): consist in take advantage of the shortest part of the spectrum (of the radiation) to make move the electrons from the valence shell to the conducting layer in a material previously prepared microscopically. The electrons can be maintained separately of the holes, so we can use this electric current with lots of systems.
- Thermal-solar (Figure 2.2): it needs a previous transformation of the solar radiation into term energy to later produce electricity in a conventional thermal-machine. This technology has the advantage that it can be saved like internal energy that is better than save as an electric one.


Figure 2.1: photovoltaic

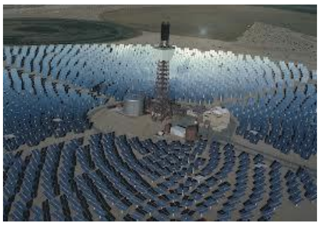


Figure 2.2: Thermal-solar

2.2. Photovoltaic

2.2.1. Introduction

Photovoltaic is a form of generate electrical energy by converting solar radiation into current electricity using semiconductors. The semiconductors are installed in solar cells that composed solar panels. We can use different types of materials to have semiconductors: monocrystalline silicon, polycrystalline silicon, amorphous silicon (the most common) and there are others under investigation like indium, gallium, selenide... This technology grows a lot in the last years by the demand increase of the renewable energies, but nowadays with the crisis it has stalled a little bit.

Photovoltaic is the third power among the renewable energies behind hydro and wind power. In 2011 a total of 67.4 GW of this technology had been installed in around 100 countries.


Figure 2.3: Photovoltaic system in a building wall.

The installation of this technology can be ground-mounted or mounted in the walls (Figure 2.3) or the roofs of the buildings. Actually, it is intended to be the second form of installation because it has less environmental impact and also it is a decentralized production that helps to the supply of the energy to everybody without increasing the capacity of the electrical lines.

The cost of photovoltaic has declined in the last years due to the advances in technology and increases in manufacturing scale and sophistication. Also, in the majority of the countries, the financial incentives, such as government feeds have supported photovoltaic installations. The figures say that photovoltaic technology recoups (with the actual technology) the energy needed to manufacture them in 1 to 4 years depending on the radiation, the weather...

2.2.2. Technology of a solar cell

Photovoltaic is best known as a method for generating electric power by using solar cells to convert the radiation from the sun into a flow of electrons. The photons of the light excite the electrons into a higher level of energy, allowing them to act as charge carriers for an electric current.

Solar cells produce direct current electricity from the sun radiation, which can be used to recharge a battery or to power equipment. The direct using of the electricity isn't much common due to the few equipment that works with direct current, but it is more common to store the electricity produced directly because the batteries works with direct current. However, the most common use is for grid connected power generation or for alternate current equipment, so that, we need an inverter to convert the direct current to alternate current.

Figure 2.4: Photovoltaic panel composed by 72 cells.

The cells require protection from the environment and have a glass sheet to cover the semiconductor material (Figure 2.4). When we need more power than a single cell we can connect them electrically to form photovoltaic modules or solar panels. Depending in the connections of the panel, the number of cells connects in parallel and in series we will have different voltage and current.

The actual power output of in a particular point in time is difficult to determine because it depends on the geographical location, time of day, weather conditions and other factors. Nevertheless we have to know that usually the photovoltaic panels have efficiency under 25%, which is lower than many other sources of electricity.

Nowadays the solar cells are made by silicon of high characteristics. The silicon is disposed in wafer of 300 nm approximately. A minimum part of this wafer is impregnated of phosphorus´ atoms (layer type-n) and the rest is impregnated of boron (layer type-p). Between this two layers appear an electrical field inside the wafer and near the area that see the sun radiation. This voltage between layers is the responsible of the separation of the loads photo-generated positives (holes) and negatives (electrons).

The cell has two output terminals and two faces. The over face has a lattice of silver or aluminium to equipotentialising the negative face and one of the output terminal is welding to it. The other face has an aluminium plate for the same reason and the other terminal is also welding to it. The negative face has also a thin layer to reduce the wastes of reflection in the cell.

2.2.3. Photovoltaic panels

The cells are mounted in series into the structure of the panel to achieve an adequate voltage for the electrical applications. The panels receive the solar radiation (directly or diffuse, so that, they can generate electricity even in cloudy days) and generate direct current to save it in accumulators or to use it directly.

The cells have usually power near 1 Wp (Watts of power), that it means: with a radiation of 1000 W/m^2 they give approximately voltage of 0.5 V and current of 2 A. With this specification if we want to use the electricity directly from the panel we have to join some panels to have the voltage and current necessaries.

The basic unit of the photovoltaic installations is the panel and usually it contains between 20 and 40 cells. The cells are interconnected and mounted between two layers of glass to protect them from the weather. The number of cells in series or in parallel depends on the voltage that we want to achieve. One example (Figure 2.5):

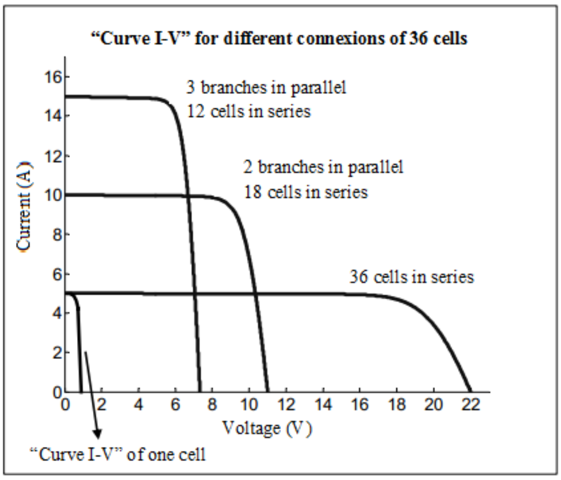


Figure 2.5: Different connections between the same numbers of cells.

2.2.4. Elements in a photovoltaic system

- Solar generator: It is the ensemble of photovoltaic panels that receive the solar radiation and transform it into direct current.
- Accumulator: Store the energy produces by the generator. After the store we have two possibilities:
  - Use the energy to elements that need direct current.
  - Transform the energy with an inverter into an alternate current to use it.
- Load regulator: The main function is to control and save the accumulator of overloads or excessive discharges (the damage could be irreparable). It has to ensure that the system works in the point of maximum efficiency.
- Inverter (optional): It transforms the direct current produces by the photovoltaic panels into alternate current.

A photovoltaic system doesn´t need to have all of these elements, it depends on the type and the size of the loads…

2.2.5. Type of photovoltaic systems

2.2.5.1. Non grid-connected

This type of system stimulated really the production of photovoltaic panels because it gave credibility to the possibility of has "cheap" energy in some places of the earth.

This system is used to generate energy in the same place or near the place that is consumed. One example is the picture above (Figure 2.6) but the most usual cases are:

- Give electricity to homes far away from the electrical conventional network.
- Public lights autonomous (each light has a small panel to produce the energy that it needs). With this lighting we save money because we haven´t got to dig, to connect each light to the network…
- Agricola and livestock applications: lighting of farms and greenhouses, water depuration, irrigation system, water pumping…

- Communications and signalling: Aerial, road (Figure 2.6), railroad signalling… Lighting signals like beacons, radio and television repeaters…

Figure 2.6: Example of non-grid connected system

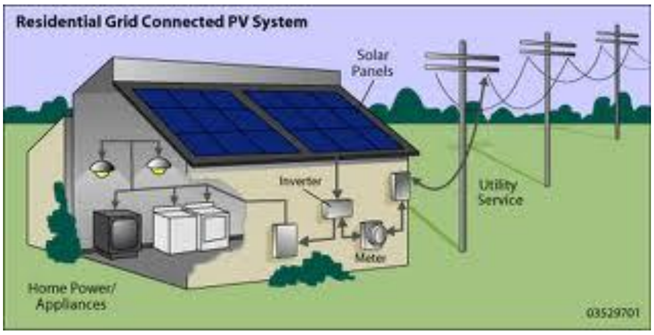


Figure 2.7: Grid-connected house that also use part of the energy produced.

2.2.5.2. Grid-connected

In this grid connection system (Figure 2.7) we can search two different cases: photovoltaic centrals (in this case the energy generated is giving to the grid directly as in a convectional central of electricity generation) and photovoltaic systems build in buildings or industries (part of the energy is inverted in the consume of the building and the rest of the energy is exported to the grid), as in the next picture (Figure 2.7):

Other possibility less used is in the second case export all the energy to the grid and consume from the grid like another user.

Different types of systems grid connected:

- Disperse generators: generators with low capacity of production (between 1-10 KW) that are installed in buildings.
- Central stations (figure 2.8): big plants of hundreds or thousands of kW operate by a support company. The interconnection with the grid is always by three phases due to the range of power.

Figure 2.8: Big plant of photovoltaic generation

- Network support stations: There are really similar to the central stations, but their aim is to help the networks of distribution that are near to the limit of capacity and to alleviate thermally some substations.

2.2.6. Graphics and equations characteristics of a module

The equation of a solar cell is the next:

$$I = I_L - I_0\left[e^{\left(\frac{eV}{mkT}\right)} - 1\right]$$

- I, V: Current and voltage gives by the cell
- T: Temperature of the cell (in Kelvin)

- I_L: Current generated by the impacts of the photons against the material. Directly proportional to the irradiation.
- I_0, m: Figures related to the union between both types of semiconductor.
- e: Constant of the charge of the electron.
- k: Constant of Boltzman.

The characteristic curve of a cell is the "curve I-V" (current-voltage) for parameters of irradiation and temperature determinate. The "curve P-V" (power-voltage) is obtained by changing power by current (Figure 2.9):

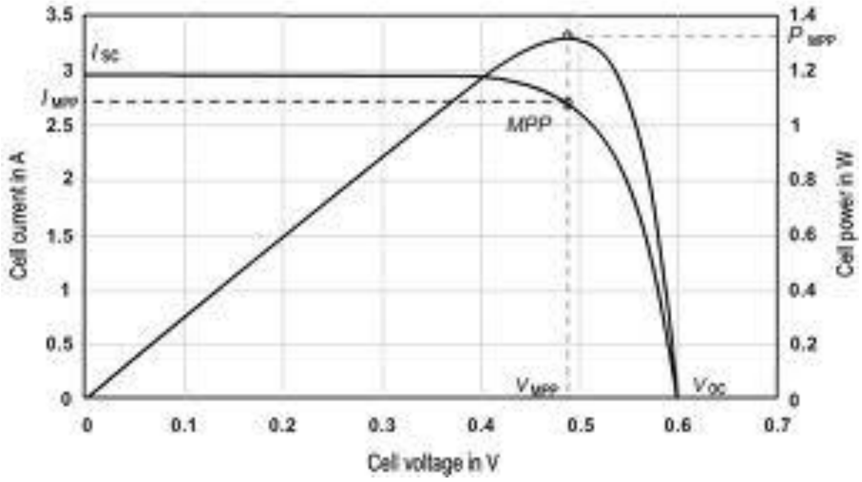


Figure 2.9: Curve of power and current against voltage in a cell

- I_{sc}: Short circuit current
- V_{OC}: Open circuit voltage
- MPP: Maximum Power Point (the product current by voltage is the best).
- V_{MPP} and I_{MPP}: Voltage and current in the Maximum Power Point.

Different facts that modified the "curve I-V":

- Irradiation (Figure 2.10): It affects principally to the current. The short circuit current is modified:

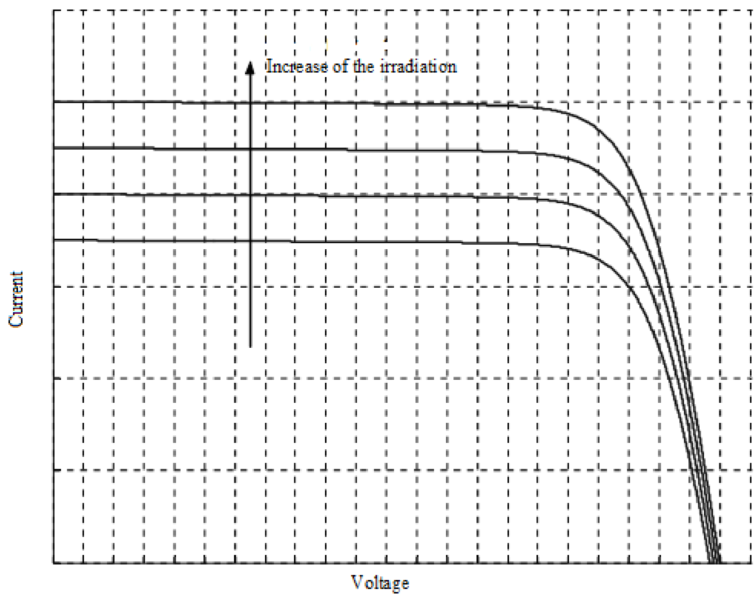


Figure 2.10: Variation of the curve by the increase of the irradiation.

- Temperature (Figure 2.11): It influences principally in the voltage, however it influences less in the voltage than the irradiation in the current. The open circuit voltage is modified:

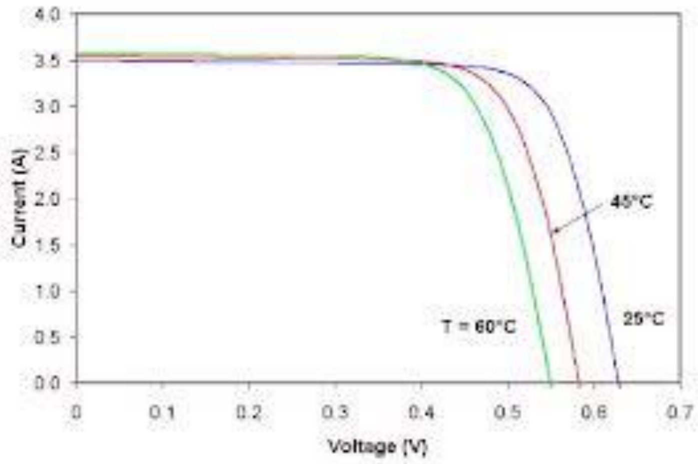


Figure 2.11: Variation of the curve by the increase of the temperature.

2.2.7. Some figures and facts

German nowadays is the second biggest producer of photovoltaic energy in the world, behind Japan with around 5 million of square meters, but this energy only represents a low percentage of the energy produce by German. In the European Union, German has more or less the 80% of the installation of photovoltaic energy.

The increase of the installations of photovoltaic plants nowadays is complicated due to two facts: the world crisis and the shortage of silicon. Actually there are other materials been studying to increase the performance of this type of energy.

Another problem that we have in Spain in relation with the renewables energies is the fault that puts the electrical companies to allow a new grid connection of renewable energies. The connection to the net has a strict normative by the government, also, the electric company has to give you the permission. These companies are obligated to connect the new generators (with renewable energy) that enforce the law, although, you have to do many papers to can connect to the grid, and these trammels are difficulting the growth.

The companies give excuses like the saturation of the net or others to stop the initiative of small producers, due to this the companies can control better the price of the electricity produce by other energies. This is a big contradiction between the aims that the European Union to increase the renewable energies and the low liberation of the energies market in Spain. It difficulties too much the competitiveness of the renewable energies and the price of their electricity.

Spain is in Europe one of the countries with more solar radiation (Figure 2.13), so we have to work to change all the problems that these energy have to do possible an increase of the self-production of the most part of the energy, because Spain depends a lot of the foreigner energy. However we have to distinguish that Spain is the second producer of photovoltaic energy in 2009.

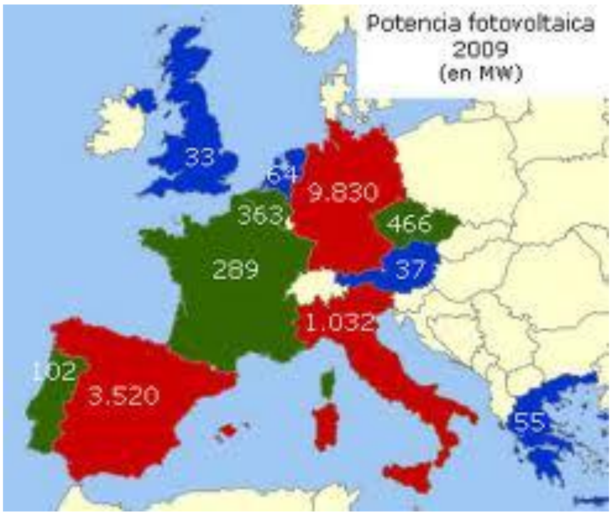


Figure 2.12: Photovoltaic power installed in 2010 in some of the European countries

Photovoltaic power installed in Europe (MW)(20 firsts)						
#	**Country**	**2005**	**2006**	**2007**	**2008**	**2009**
-	UE-27	2.170	3.420	4.940	10.380	15.860
1	Germany	1.910	3.063	3.846	6.019	9.830
2	Spain	58	118	733	3.421	3.520
3	Italy	46	58	120	458	1.032
4	Czech Republic	0	1	4	55	466
5	Belgium	2	4	22	71	363
6	France	26	33	47	104	289
7	Portugal	3	4	18	68	102
8	Netherland	51	51	53	57	64
9	Greek	5	7	9	19	55
10	Austria	24	29	27	32	37
11	United Kingdom	11	14	19	23	33
12	Luxemburg	24	24	24	25	26
13	Sweden	4	5	6	8	9
14	Slovenia	0,2	0,4	1	2	8
15	Finland	4	4	5	6	8
16	Bulgaria			0,8	1	6
17	Denmark	3	3	3	3	5
18	Cyprus	0,5	1	1	2	3
19	Malt	0,1	0,1	0,1	0,2	2
20	Poland	0,3	0,4	0,6	1	1

Table 2.1: Photovoltaic power installed in Europe

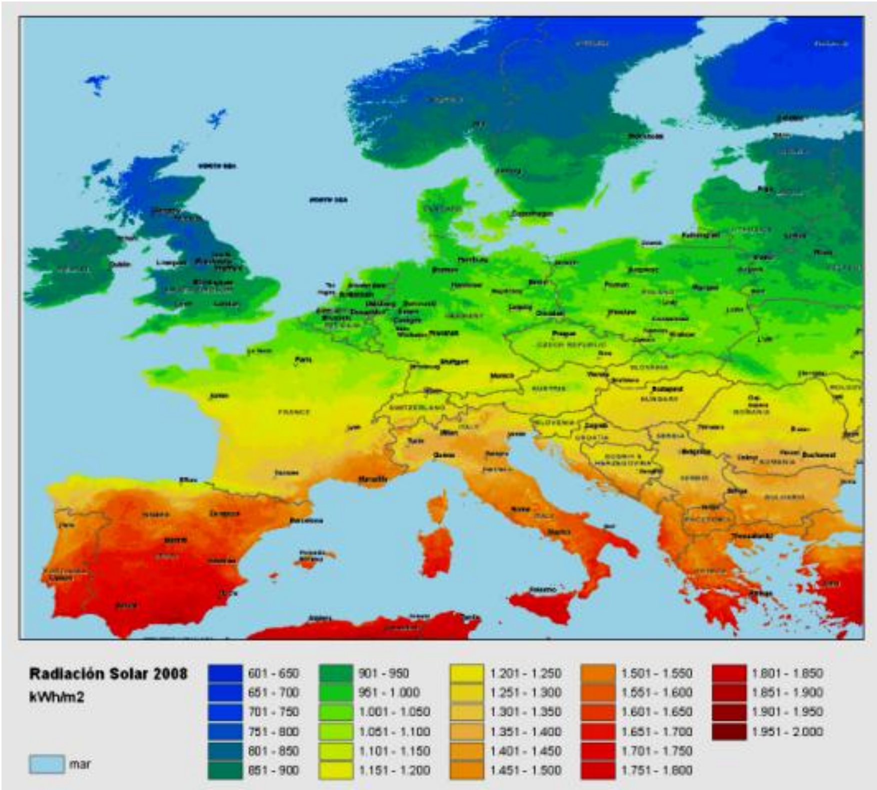


Figure 2.13: Solar irradiation in Europe

2.2.8. Advantages and this advantages

This energy, as the other renewable energies is inexhaustible, clean and respectful with the environment. It also helps to reduce the emission of greenhouse effect gases and protect our planet against the climatic change.

+ This energy don´t need any combustion so it doesn´t generate atmospheric contaminants, doesn´t help effects like the acid rain or the greenhouse effect…
+ The silicon is an abundant material in the environment.
+ We don´t need big extension to produce energy for one house, we can put the panels in the roof, we have enough space.
+ We produce the energy almost in silence.
+ We don´t need any combustible or other exterior things, due to this is an inexhaustible source.
+ The panels have a long live (around 25 years), their installation is simple and they have a low maintenance.
+ We can use this energy in places that the net doesn´t arrive and in isolated places.
+ We can increase the power that we have only incorporating new panels, we haven´t got to change the installation unless the increase is too big.
+ We can use the energy produce by the panels and sell the excess production or sell all the production.

– In the process of extraction of silicon for the cells we have big wastes and some of them are really contaminant.

– For have an exploitation of photovoltaic panels to connect to the grid we need lot of space so it has a big visual impact, and also, sometimes, this fields could be cultivated.
– The initial inversion that this energy needs is high.
– The technology could be better, so that, the efficiency is really low (we only take around 25% of the energy of the sun radiation).
– In the world, the places with more solar radiation are in deserted places and far away from the city (place with more consume).

2.2.9. Some applications

In the beginning of this energy we usually used it to supply energy to that place that there wasn´t profitable to put a grid connection (principally isolated places). With the pass of the time its use stars to diversify.

Nowadays we can find solar panels almost everywhere: in roads, in aerial applications, in the sea, in oil platforms, in fields to be connected to the grid…

Some applications:

- Electrify of rural houses.
- Supply of water to populations (pump of water from wells).
- Livestock buildings (the chicken farms need too much energy).
- Electric fences in the mountain to do not escape the cattle.
- Telecommunications.
- Water treatments.
- Signalisation.
- Grid connection
- Systems of satellite remote, fire detection…

2.2.10. Groups and organisms of investigation

- Institute of solar energy (Madrid): www.ies-def-upm.es
- CIEMAT (Madrid): www.ciemat.es
- IDAE (Madrid): www.idae.es
- CENER (Pamplona): www.cener.es
- Association of Photovoltaic Industry: www.asif.org
- European Association of Photovoltaic Industry: www.epia.org
- Sandia Laboratories EEUU: www.sandia.gov/pv
- International Energy Agency: www.iea.org

2.2.11. Normative in Spain

2.2.11.1. Royal Decree 661/2007 (BOE 26/05/07)

In this law is regulated all activity of electrical energy production with special characteristics (renewable energies).

2.2.11.2. Royal Decree 1578/2008 (BOE 27/09/08)

Law of remuneration for electricity production through solar photovoltaic technology.

2.2.11.3. Royal Decree 1663/2000: connection to the low voltage grid

- Chapter I: Scope and definitions
  - Scope: photovoltaic installations until 100 KVA and with low voltage connection
  - In the second article are defined all the elements: installation, nominal power, automatic switch of interconnection…
- Chapter III: Technical conditions of the connection to the low voltage grid.
  - General conditions: Article 8.
  - Specific conditions: Article 9.
  - Measures and billing: Article 10.
  - Protections: Article 11.
  - Ground connection conditions: Article 12.
  - Harmonics and electromagnetic compatibility: Article 13.

2.3. Solar thermal

2.3.1. History

The heat of the sun is an element really used since the prehistory by the human. Since the antiquity the humanity invent different artefacts for try to use usefully the sun radiation. The elements that try to produce fire by solar concentration were ones of the first elements that were invented.

Greeks and Romans could make fire in III century B.C. using parabolic reflective containers. A major milestone of the antiquity is the used of the solar concentration to repel an attack of the Roman army against Greeks in 213-211 B.C. The history said that the Greek savant, Arquimedes, putted some mirrors in the walls of the city and when the Roman boats closed to the city he focused them and the boats started to burn (Figure 2.14).

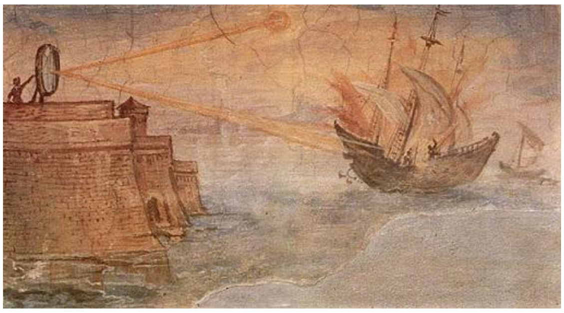


Figure 2.14: Image of the Arquimedes story.

Leonardo da Vinci, one of the biggest names in the Renaissance, also showed his interest in the solar concentration in one of his project. It consisted in a circle with a diameter of 6 km with parabolic mirrors that concentred the radiation. Unfortunately this project didn't be realised.

Since the Renaissance and until the XX century appear lots of invents related to the sun concentration that as time passed they were more sophisticated.

In 1900 was founded the first company of solar thermal energy in north-America. The founder was Auberey G. 4 years later another company was founded in Arizona. In 1909 was created a big project by a Germany engineer that hopes to supply electricity for all the world by a solar concentration plant in Sahara desert. The plant would have 198 MW, but this project was interrupt by the First World War, and after it the project was forgotten.

In the decade of 60s the low price of the fossil fuels made stop all the advances in the renewable energies. This type of energy recovered strong when in 1973 the OPEP increase so much the price of the fuels, and it took more strong when we realised that the fossil fuels aren't going to supply our energy much time, and also when we realised about the environmental problem.

In June of 2007 the Spanish company Acciona built a solar plant thermal-electric in USA with 64MW.

These types of projects were made also in Spain, and in 2009 built 2 plants in Granada. These plants consist in transform the solar energy in electric energy with a field of parabolic collector. The average efficiency in these plants is around the 16% of the solar energy and they can have peaks of 28% of efficiency.

We have to remark also the 2 plants built by Abengoa Solar that consist in a lots of mirror that reflect the sun to a collector tower. Between both of them can supply heat to more or less 16.000 homes (Figure 2.15).

Figure 2.15: Solar concentration plants

2.3.2. <u>Introduction</u>

Systems of solar thermal of concentration is called to some technologic devices think to transform the direct component of the solar radiation into thermal-energy with high temperature. This high temperature can be used directly or store it like heat or it can be used to produce electricity. In all the cases we generate this heat with concentration devices based on mirrors or lenses.

These systems of solar concentration aloud a use more efficient than the system without concentration, due to they can achieve higher temperatures and better thermodynamic performance. Usually these systems use mirrors by their high reflectivity.

The solar concentration only can use the direct radiation but not the diffuse because it can't be concentrate.

To generate electricity in these types of plants we usually use a Rankine cycle. This cycle is use to water vapour that at high temperature and pressure moves (doing a mechanical work) turbines that at same time move one solidary axis that moves an electric generator. The electric generator induces a balanced three-phase voltage which after is increased in a substation to have less losses in the transport.

The Rankine cycle has the next schema (figure 2.16):

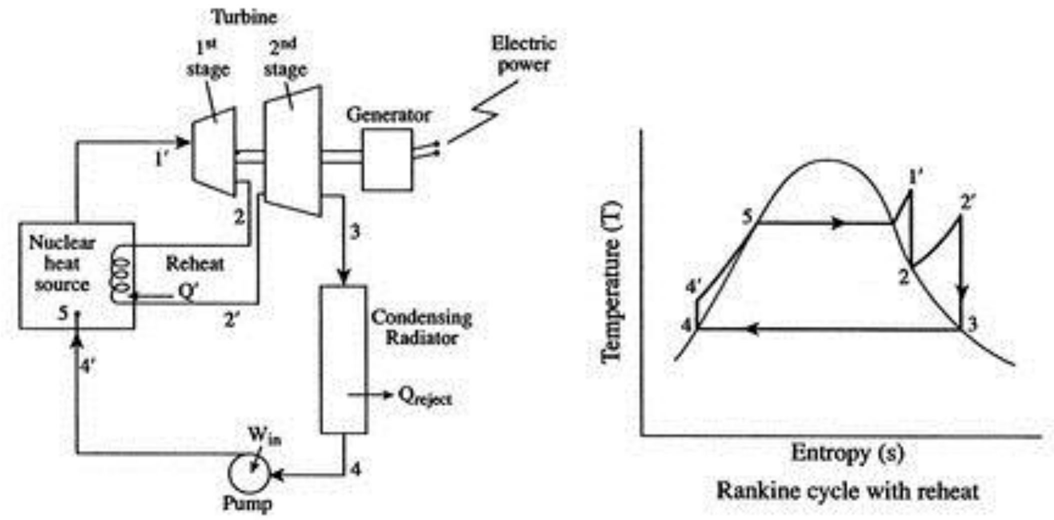


Figure 2.16: Rankine Cycle

2.3.3. Classification and types of solar thermal devices

The solar concentration can be punctual or lineal. The lineal concentration is easier because it has less degree of freedom but it has less concentration factor, so it can achieves less temperatures than the punctual concentration.

The lineal concentration technical can be cylindrical-parabolic (figure 2.17) and Fresnel (figure 2.18), and the central receptor (figure 2.19) and parabolic (figure 2.20) discs are based in the punctual concentration.

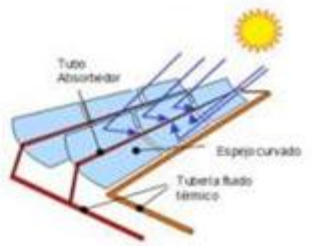


Figure 2.17: Cylindrical-parabolic

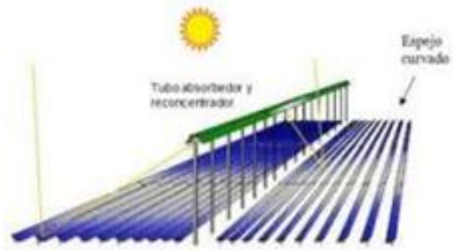


Figure 2.18: Fresnel

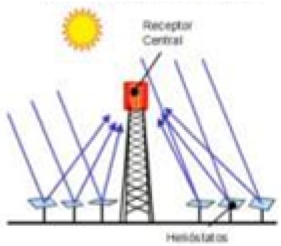


Figure 2.19: Central receptor

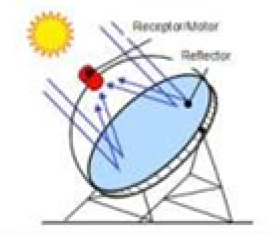


Figure 2.20: Parabolic discs

Relationship between concentration guidance (left), performance (right), temperature (below) and applied technology (in the graphic) (Figure 2.21):

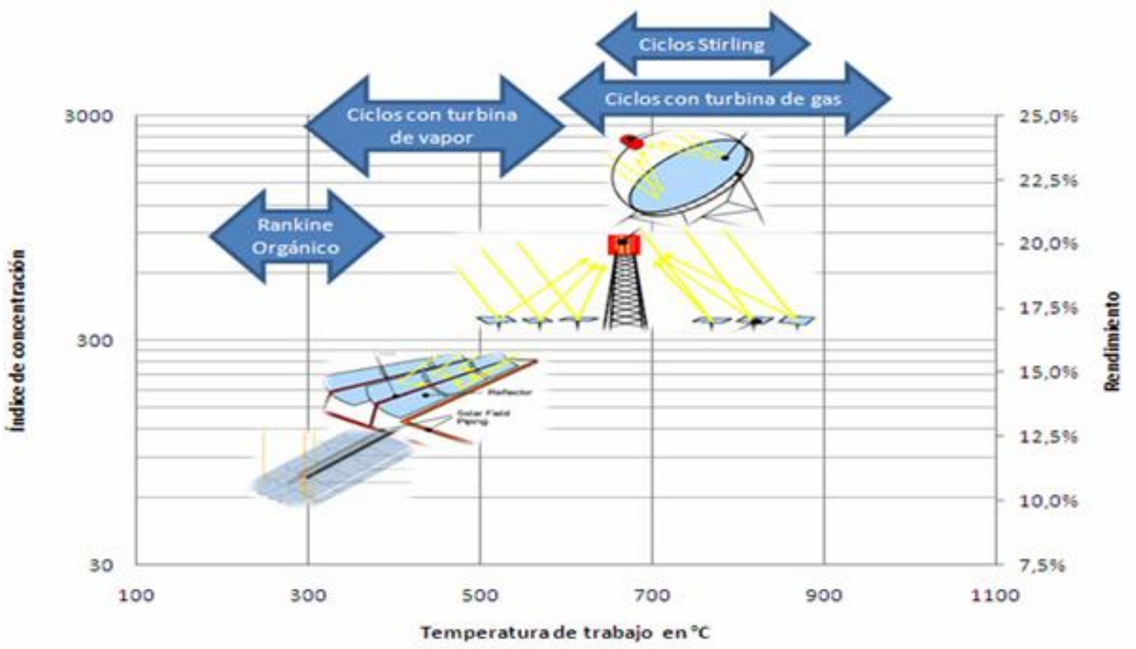


Figure 2.21: Concentration index against work temperature and against performance of the solar thermal devices

2.3.3.1. Technology of Cylindrical-parabolic

This technology is based in the tracing of the sun and in the concentration of the sunlight in a receptor tube of high term efficient located in the focal line of the cylinders.

In this central tube there is a transmission of heat fluid (synthetic oil…) that is heat near 400 ºC by the sunlight concentrate. This fluid is pumped by some exchangers to produce vapour with high pressure that will generate electricity in a normal Rankine cycle.

The systems and the equipments that compose this technology are:

- Receptor of sunlight (Figure 2.23): the mission of these cylindrical-parabolic devices is to reflect and concentrate the solar radiation in the tube that absorbs the radiation solar direct. The area has to reflect as much as possible the direct sunlight so usually it is made of silver, aluminium... or mirrors.

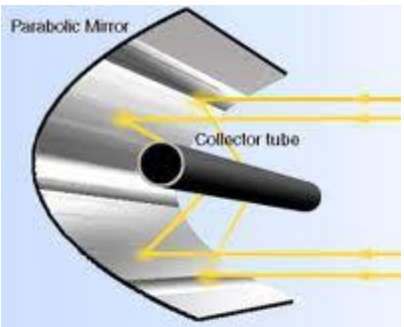


Figure 2.22 – Tube and parabolic mirror

Figure 2.23 – Receptor

- Tube that catches the concentration sunlight (Figure 2.22): the collector tube is made by two concentric tubes separated by a vacuum layer. The inside tube is made by metal and the outside one is made by glass. Components of the tube:

- Metallic tube: it has a black covering to search the most absorption of the ultraviolet spectrum and the less losses in the emission of the infrared spectrum. We search an element that is as similar as a black perfect body.
- Glass tube (Figure 2.24): the principal objectives are that it allows the less losses of heat by conduction as possible and that it makes a similar action like the greenhouse effect. To improve its characteristics we make the vacuum layer between both tubes.

Figure 2.24: Picture of the tube that heats the fluid.

- Welding of the ends: it must ensure the tightness for don't lose the vacuum.

- Structure: it has to support the weight of the tubes and of the mirrors, so that, the structure is made in metal. It must be anchored to the ground to support the weather inclement (rain, wind...). Also it must be light and easy to mount.
- Module: it is the equipment form by the structure, the mirrors and the absorbents tubes.
- Tracing system (Figure 2.25): like every system concentration solar, this technology only use the direct radiation and this forces to the equipment to have a tracing system of the sun during the hours of light. The most common system of orientation is that which only moves the equipment around one axis.

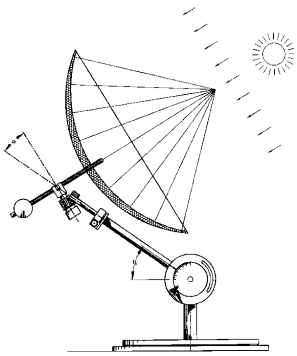


Figure 2.25: Whole system of cylindrical-parabolic.

Figure 2.26: Fields with cylindrical-parabolic installations.

- Collector: usually is very expensive to outfit each module with a tracing system, so that, we join different modules (8-12) and we put only one tracing system that moves all the modules together (that is called collector).
- Loop: We call loop to an ensemble of 4-8 modules in series, and this join is called loop because the fluid that goes inside the collector tube is the same for all of the modules and because the input and the output are always the same. This loop usually has a thermal-power of 1.57 MW, a length of 600 metres and a gain of temperature near the 100 ºC.
- Solar field (Figure 2.26): it is compound by the ensemble of loops that the plant has. This field is calculated by the thermal-power of each loop (1.57 MW), by the performance of the transform of the thermal energy and the electrical energy and the electric power desired. Normally the field is split in smaller fields to make easier the operation when there is too much radiation and we don't need all the loops.
- Work fluid: It is the fluid that goes inside the collector tube and it is the attendant to transport the heat until the vapour generator. The fluid that we use determinate the

temperature range of the solar field, and so that, the maximum performance that we will have in the power cycle.

There are some investigations to work in a different range of temperatures, but now the ideal temperature to work with this technology is between 150 and 400 ºC. If we work with high temperatures the losses in the collector tube are higher so the efficient decreases.

Actually, the fluid uses synthetic oil, but the problems are:

- With more than 400 ºC it loses the properties.
- The freezing point is 12 ºC, so we have to maintain all the oil circuit over this temperature.
- Risks of contamination and fire.

Three new fluids are been investigated actually: molten salts, direct vapour generation and pressured gases. Advantages and disadvantages of these fluids against synthetic oil (Table 2.2):

Fluid	Advantages	Disadvantages
Molten salts	Better thermal-store	More thermal losses at night
	Higher work temperature	More complicated design of the solar field
	Non environmental risks	More electricity consumption
Direct generation of vapour	Simple design of the plant	Lack of thermal storage system
	Higher work temperature	More difficult in the control of the solar field
	Non environmental risks	More pressure in the solar field
Pressured gases	Better thermal-store	Worse transference of heat in the collector tubes
	Higher work temperature	More difficult in the control of the solar field
	Non environmental risks	More pressure in the solar field

Table 2.2: New fluids for the cylindrical-parabolic system (advantages and disadvantages)

2.3.3.2. Tower collector technology

In this technology (Figure 2.27) we have a field with heliostats or movable mirrors that change their orientation depending where is the sun to reflect the solar radiation to a receptor situated in the top of a tower. This heat is transmitted to a fluid with the objective of produce vapour and this vapour moves a turbine to generate electricity.

The highest temperatures that the fluid achieves (over 1000 ºC) allow having high performances, even more than 25% in the transformation of the sun energy to electricity.

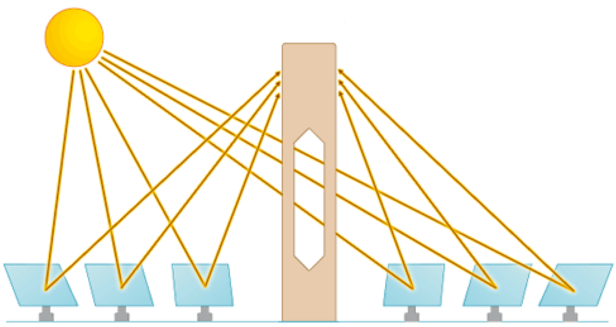


Figure 2.27: Tower collector technology.

The principal components are:

- Heliostats (Figure 2.28): they have the function of capture the solar radiation and focus it to the receptor. The heliostats has a reflector area (usually glass mirrors), the structure to maintain the reflector area and the tracing system (orient the mirror to focus the light well to the receptor in the top of the tower).

Figure 2.28: Example of heliostats in a tower collector system.

- The receptor (Figure 2.29): It transfers the heat to the work fluid (water, molten salts...). The fluid is the attendant to transmit the heat to a deposit of water to boil it and have vapour with high temperature that can move the turbine and generates electricity.

Figure 2.29: Tower receptor.

- The tower: It is just a support of the receptor because it has to be in high to avoid as much as it can the shadows between heliostats, blockages...
- The accumulation (figure 2.30): In this type of technology we can incorporate a system to store energy for use it when we have bad weather or at night. Actually the most common solution is to save the energy in water, vapour or molten salts tank, due to this, the plant has to be oversized. The installation is shown on figure 2.30.

There are two types of tower technologies:

- With carrier fluid: we use molten salts like fluid due to they support the high temperatures that we have and also the store of energy is good. We can store energy to supply 7 extra hours.
- Direct generation of vapour: we don’t need exchanger but the disadvantage is that we store worse than in the before technology the energy (we only can store energy to supply 2 extra hours).

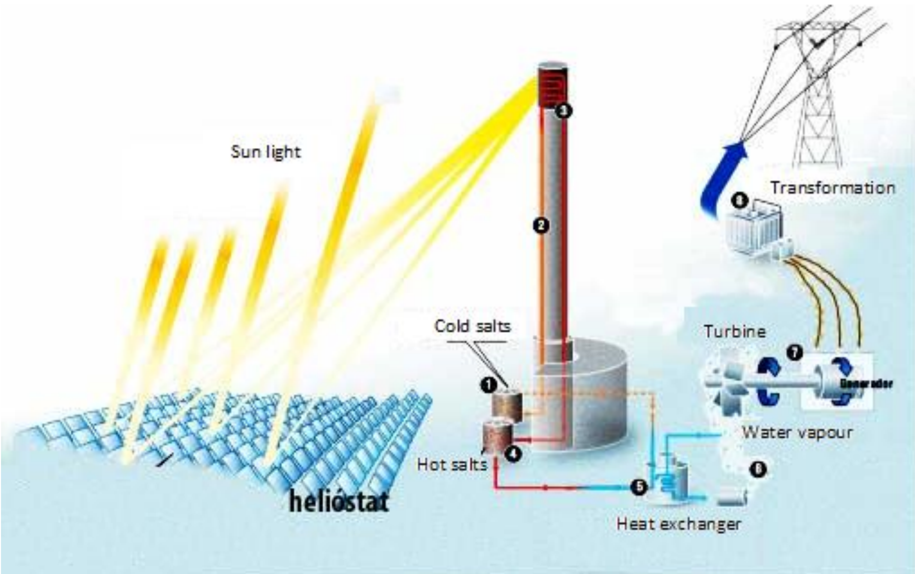


Figure 2.30: Complete system of tower receptor.

2.3.3.3. Fresnel technology

One of the new forms of thermal use of the sun energy is the lineal concentration Fresnel. This technology highlights by its simplicity of construction and its low cost. It consists in a use of flat reflectors that simulate a parabolic mirror with an adjustable angle of each line of individual mirrors in relation with the absorption tube.

The reflectors are built with normal glass mirrors, so that, the raw material is very cheap. The cylindrical-parabolic technology is 15% more efficient than the Fresnel, but with the saving of money that we have in the construction of these reflectors the design compensates the price.

Different advantages of the Fresnel technology:

- The collector tube is always fixed, so it hasn't got movables parts.
- The reflectors are situated in the level of the ground, so we reduce the wind load and are easier to clean and maintenance.
- The vapour is generated directly, we don't need exchangers.
- Automatic construction of the fundamental components.
- We need less area than other technologies because we don't need a regular place.

2.3.3.4. Cycle Stirling technology

A solar parabolic hub puts all of the sun lights in a point where is situated the receptor that is a hot reservoir of a Stirling motor. This motor transforms the heat into mechanical energy and we need an alternator that becomes it in electric energy.

One of the most important elements is the reflector because it needs good curvature and it needs a small relation between focal distance and diameter. With these restrictions we are able to work in temperatures between 650 and 800 ºC. The reflector is made by glass mirrors.

Another important element is the receptor of the reflective lights that has a small hole and an isolation system.

The process of the Stirling cycle is (figure 2.31):

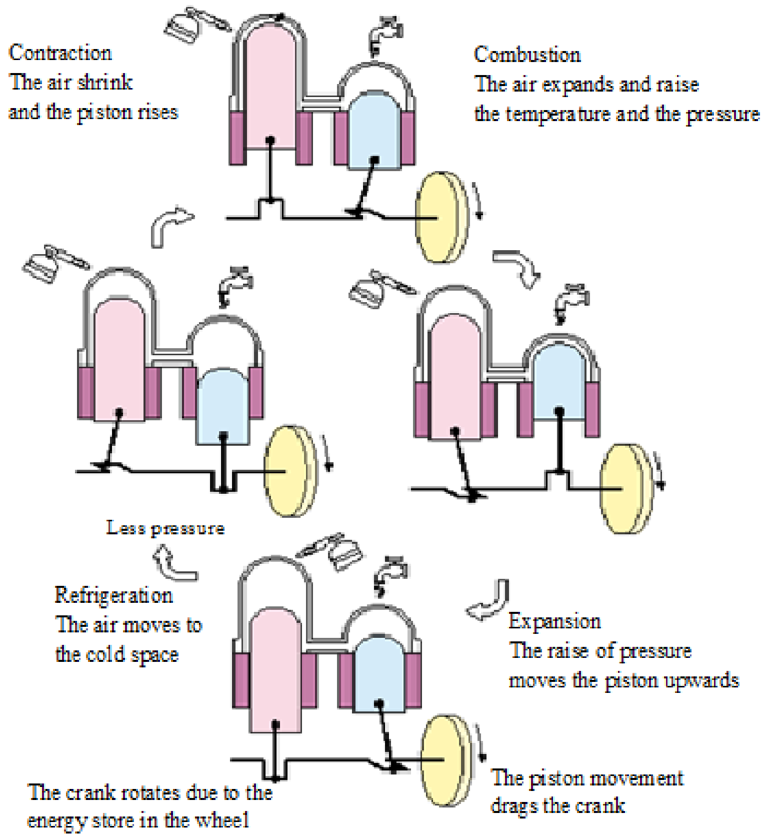


Figure 2.31: Process in the Stirling cycle.

The Stirling cycle has two processes made with constant volume and other two with constant temperatures (figure 2.32):

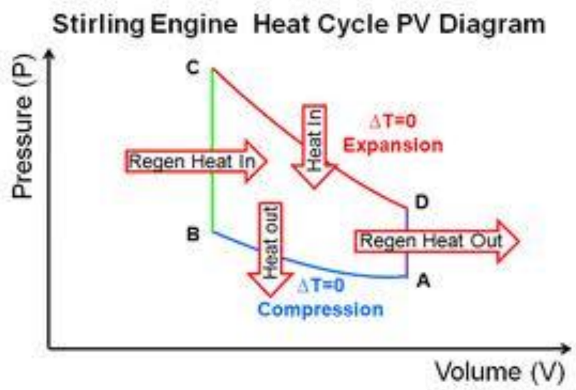


Figure 2.32: Stirling cycle represent in two axes, pressure against volume.

2.3.4. Storage system

2.3.4.1. Introduction

In the thermal-solar energy we have a problem due to the time of the day without sun light. Usually, this type of plants has burners of fossil fuels to solve the problem, but also we can solve it with a thermal-storage system.

The thermal-storage system takes the thermic-energy when there is sun light and too much generation of electricity and then we use it when the solar irradiation is too low. This system supplies energy when there are clouds and also, when there isn´t sun light.

This system prolongs the time of use of the plants, so it increases the efficiency of the plant and also helps in the life cycle of the plant because it reduces the thermal transient.

The period of supply of extra energy depends directly in the plant and in its solar field. If we have more capacity of collect sun we will have more extra heat so we can store more thermal energy. The normal extra time that the plants have is between 6 and 9 hours.

We have to differentiate between active and passive systems.

2.3.4.2. Active systems of storage

In the active systems the form of store the heat is with a circulating fluid that store and gives sensible heat. We can differentiate inside of this system: directly or indirectly and with one tank or with two. Now we are going to see the different between the second pair:

- Two tanks: we have one tank that has the cold fluid and in the other the hot one. When we have irradiation we take the cold fluid that is heated by the fluid that travels by all the receptors and we send it to the hot tank and it waits there until we need an extra thermal power. When we need extra power we take the fluid hot, we use this energy to produce energy and we send the fluid to the cold tank.
- One tank: in this system the cold and the hot fluid are stored in the same place, but not mix, because with the different temperature it is related the different of density, so the cold fluid is stored in the bottom of the tank and the hot fluid at the top. Inside the tank we have also other component that helps to separate the two layers. This system needs a more sophisticate device to load and unload the fluid.

Now we are going to see the first pair of difference and some example:

- Direct: the system is known with this name because the same fluid that travels by the receptors is which is used to store the thermal energy. Not all of the fluid goes to the stock, just a part of it. As transfer fluid we can have synthetic oils that support high temperature or molten salts. We can also have saturated water in the cases that we have directly a vapour generator, but it is less normal because we need more complex installations.
  Examples:
  - SEGS I: In this plant they used synthetic oil in the circuit and to store the energy they needed two tanks one a 240 ºC (cold) and another one with more than 307 ºC (hot). The problem that they had is that the oil has too high pressure of vapour and high costs. To solve these problems a possible solution is to use molten salts.
  - Solar Two and Three: they were two plants of tower technology, and the first one used a mix of salts that has the fusion point in 207 ºC. Due to this, they needed two tanks, one a 290 ºC and the other one a 565 ºC and the capacity of extra supply was

of three hours. Instead of this fluid the Solar three had molten salts like transfer fluid and storage. With this difference they were able to have extra supply during 15 hours without solar irradiation.
    - PS10 y PS20: these two plants use as fluid water that boils in the receptor and that is stored like saturated water. The big problem of these plants is that without radiations they are able only the supply extra energy during 50 minutes and only with half of the power.
- Indirect: in these systems the fluid of store and the fluid of transfer are different. Here we need an exchanger between both fluids, and then the fluid of store is saved in isolated tanks that are used only if we need more power. The fluid of transfer usually is water vapour.
  This technology is applied in the plants that have synthetic oil as fluid of transfer, because it isn´t good to store but it is to transfer. Due to that, they continue using the oil as fluid of transfer and in an exchanger they give the energy to the other fluid (molten salts). They continue using two tanks (one cold and one hot), but with this fluid they can have them with normal pressure.
  Examples:
    - Andasol I: it is a plant in Granada that use mix salts and molten salts. The cold tank has 290 ºC and the hot one has 380 ºC and when is completely full the hot tank we have extra energy to supply 7.5 hours, working normal.
    - Solar one (Figure 2.33): it was a plant of EE.UU that used this system of storage. The transfer fluid was water and the store fluid was oil with stones to improve the capacity. The store was realized only with one tank. During the unloading the oil went out by the top of the tank with a temperature of 302 ºC and returned with 218 ºC. The worst part of this installation is that the vapour of water in the unloading only achieves the temperature of 277 ºC.

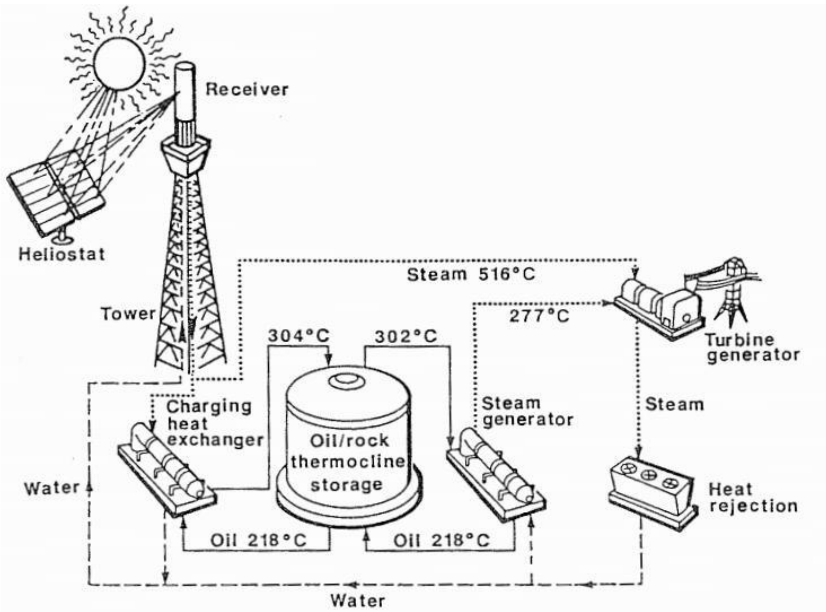


Figure 2.33: Schema of an indirect storage system with one tank.

2.3.4.3. <u>Passive systems of storage (sensible or latent heat)</u>

- Sensible heat: this system uses solid storage means (concrete or ceramic) where we pump the fluid of transfer to pass its energy.

This system don´t need high initial investment and need low cost of maintenance. Also it is recommended to plants that have direct generation of vapour.

Examples:

- The plant of Jülich in Germany (tower technology) (Figure 2.34): It is based on the storage of air-concrete that is connected in parallel to the vapour generator. During the load the hot air gives energy to the generator and to store it.

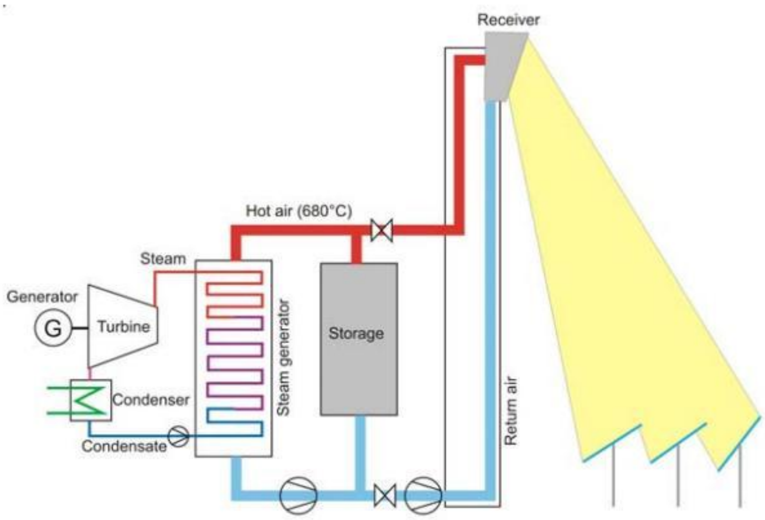


Figure 2.34: Solar plant of Jülich

In this technology is better to use air-concrete or air-ceramic than use molten salts or oil as store fluid. The reasons are:

- We haven´t got limit of temperature or solidification risk.
- The store can be installed directly after the solar receptor, we don´t need exchanger.
- The cost of build is less because the materials are conventional.

The disadvantage of the system is the high losses of pressure due to the low volumetric capacity and due to the mass of the circulation air is bigger than the other case.

We have to take care about the temperature of unload because in this case the temperature oscillates too much and the concrete only gives thermal stability until 500 ºC.

Latent heat (Figure 2.35): this system of storage uses the latent heat that is given almost a constant temperature during the phase change of the appropriate material of storage.

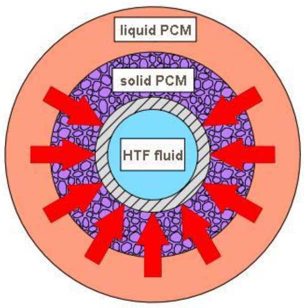


Figure 2.35: Schema of a Latent heat system.

The layout of the plant is really similar to those we have seen before.

In this system, the fusion point of the storage material is a value between the temperature of the load process and the temperature of the unload process. It can give the same capacity of storage as the before passives systems but with lower value and lower cost. The reason is that the fusion point (latent) is bigger than the sensible heat.

The units of storage of latent heat give thermal energy almost constant. The different temperatures between the transfer fluid and the storage mean can be staying low to limit the exergy losses.

The mix of the passive storage, latent and sensible (Figure 2.36), seems to be the best option for apply this system in the plants of direct generation of vapour. We can use the storage with modules of concrete for the preheating and the overheating, and the system of storage of latent heat for the evaporation zone.

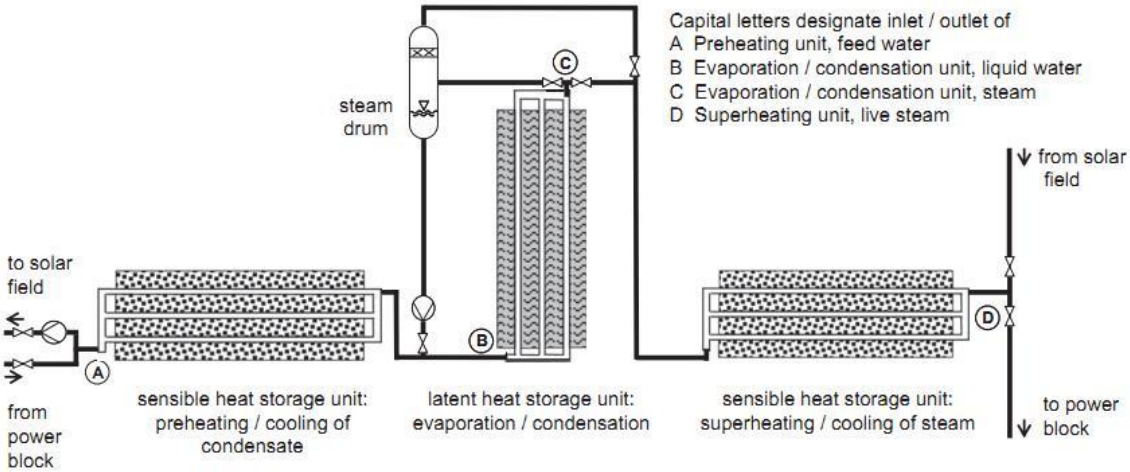


Figure 2.36: Mix system of latent and sensible storage for the direct generation of vapour

2.3.4.4. Thermal-chemical systems of storage

Other concept of thermal storage that has been proposed and tried is this type of system (Figure 2.37). It consists in endothermic and exothermic reactions that are reversible. During the load the endothermic reaction takes energy and during the unload the exothermic reaction gives the energy previously take.

This system gives a really stable period of storage, but it is underdeveloped and under investigation.

The processes more usual are the reactions with methane, dioxide of carbon, ammonia, metals and oxides of metals. Ammonia reaction:

$$NH_3 \pm \Delta H_{(reaction\ enthalpy)} \leftrightarrow 0.5 \cdot N_2 + 1.5 \cdot H_2$$

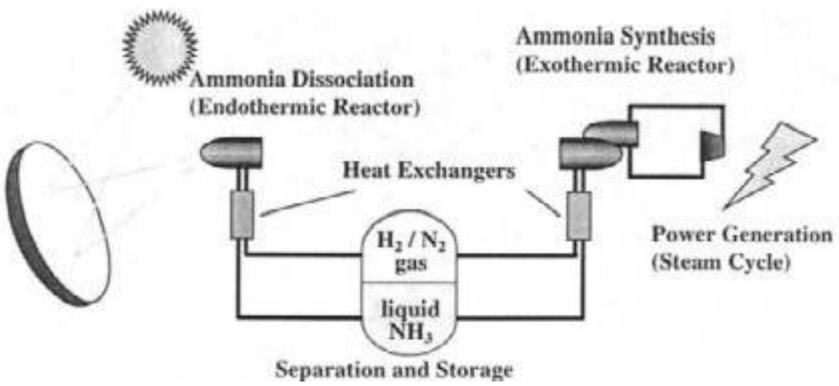


Figure 2.37: Schema of storage with thermal-chemical energy

3. BIOMASS

3.1. Introduction

The biomass is called to the grouping of organic material from trees, plants and animal´s wastes that can turn into energy. These organic materials can come from the agriculture (coffee, straw…), the organic wastes of the society (organic wastes, sewage…), and the wastes of the process that the industries make with their goods or from the nature.

The biomass is one of the oldest form of energy that the humanity knows due to the first utilization goes back to the fire discover. In the antiquity they used the biomass to burn it in bonfires at open sky, later they started to us the fire-kitchen, stoves… Actually this form of use are still used but in its most in the third world countries, however, the occidental society is inventing new forms of use it: transform the biomass to bio-fuel and then burn it, burn it to evaporate water and move turbines,…

We can consider the biomass like a renewable energy because its value comes from the sun. For take the organic material the plants have to do the photosynthesis (consume dioxide of carbon and expulse oxygen), and we can considerate this like a close circle because the dioxide of carbon that we generate when we burn the organic material has been consume before (Figure 3.1) (this reason is not completely true because we generate dioxide of carbon also when we plant and recollect the plants, but the balance is almost null).

We have to clarify that de fossil fuels, although they are formed by a transformation of organic material, they aren´t classified like renewable because they need thousands of years to be formed and the transformation give them non organic products. Also, the fossil fuels are being burned in a short period of time, so the planet can´t assimilate all the emissions and for this reason appear the greenhouse effect and other problems in the planet.

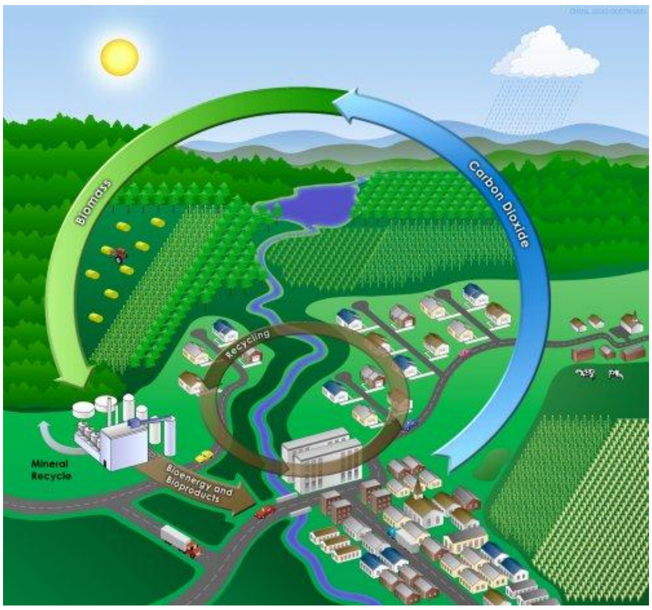


Figure 3.1: Biomass circle of recycling (The reason that converts it in a renewable source)

3.2. Origin of the biomass and approximate figures

The energy of the biomass has its first step in the radiation of the sun, and then the plants are able to use it, join to inorganic material of the ground and convert everything in organic material which has more energy than inorganic one.

If we are able to use all the biomass of the Earth, we will have more or less 5 times more than the energy that humanity needs nowadays. However, we know that it´s very difficult take all the biomass of the planet because it´s very disperse, for this reason, we only use a minimum part of its.

In the developed countries the biomass contributes only in the 3% of the energy, however, in the villages of the underdeveloped countries (50% of the world population) it contributes in the 35% of the consume, so that in the world is a 14%.

3.3. Sources of biomass

These sources of biomass that we are going to numerate below are used mostly to generate electricity in big scale or to substitute the fossil fuels:

- Agriculture´s wastes: they are so much, more in the field than in the industrial process, but we have to remember that part of the wastes of the field we have to leave there to protect the ground against the erosion.
- Livestock´s wastes: these are usually manure of the animals and we use to burn them after drying.
- Forest´s wastes: these wastes can come for the maintenance of the forest or for the wastes of the timber industry.
- Urban´s wastes: they can be sewage after drying, organic garbage…
- Industries organic wastes
- Energy plantations: They are plantations of trees or plants that when we recollect them we will use for energy production. We select plants or trees with quickly grow and low maintenance insomuch as we want to have the most profitability that we can. Also, we use for this kind of crops the fields that are less fertile for other plants.
  For these crops we need big areas because if not, we usually don´t arrive at the profitability that we want. Another way of arriving to the profitability is use a parallel crop (for example: use energetic plants and in the same time, plants that we can use to eat).
- Etc.

3.4. Important factor for use it

- Kind of biomass: it depends on the characteristic of each waste or plant.
- Physic and chemical composition: depending on these characteristic we will do one or other process to take the most of its energy.
- Humidity percentage (mass of water per kilogram of dry material): It is really important its determination because we will know if we need to reconditioning or not for the destination process.

- Ash percentage: this fact says us if the process is complete or if we can use another time as fuel the ash.
- Calorific power: it´s important to know how much energy we will obtain of the volume of material that we have. This fact is inversely proportional to the humidity percentage.
- Density: this datum gives us the known of how much weight we have in a volume of material. It depends on the other characteristics (humidity, kind of biomass…), and it´s better if we have high density because we will need less space for store the material.
- Recollect, transport and use: they are steps really important to know how we must build the plant of biomass and if the entire project will be profitable or not.

3.5. Use it processes

- Direct burn

  Like the name says, in this process we burn the material directly. It is the oldest process and usually, the most used. The systems to use this process could be rudimentary ones like stoves, chimneys… or could be more sophisticated like plants with fluidized bed.

  These types of processes are very inefficient because big part of the energy generated is non-used and also, they could be dangerous if we don´t make them in a controlee form, due to the contaminant emission that they produce. We can improve the efficiency with better equipment and better raw material.

  - Densification: is one possible operation to improve the efficiency that consists in compact all the material in briquettes. It helps also in the transport and in the store of material. The raw material for this process can be sawdust, agricultural wastes and charcoal particles.
- Term-chemical (figure 3.2)

Figure 3.2: The two firsts' types of ovens and the final product.

  In these processes we transform the biomass in a product of more value (more density and calorific power), so it´s more profitable to transport and burn it.

  When we burn the biomass the structure of products breaks in different forms: solids, liquids and gasses. Depending on the technology that we use we while obtain fuels in one state or in other. The usual process is pyrolysis or carbonization and includes:

  - Charcoal production: biomass is burned in an incomplete combustion. The solid residue is used as charcoal, which has a higher energy density than the original biomass, smokeless and is ideal for home use.

We can produce coal by different ways: earth ovens (we dig a hole in the ground, introduce the biomass and when it starts to burn we cover it with ground and vegetables to force the process into an incomplete combustion), masonry ovens (are constructed with earth, clay and brick) or modern ovens (made of steel and more sophisticated and expensive than the others, although they increase the efficiency of the product, the production capacity and the product quality.

- Gasification: is a process that consists in introducing pure oxygen when we have high-temperature combustion to produce syngas.

  This gas is constituted by monoxide of carbon, hydrogen, dioxide of carbon, methane and nitrogen. It can be used to generate electricity, hot and we can use it also in diesel motors.

  Exist different gasification technologies and their applications depend on the raw material.

- Bio-chemical: these processes are used to make gas and liquid fuels. They are better than the Term-chemical processes to transform wet biomass. Some important processes are:
  - Anaerobic digestion: the digestion of wet biomass by bacteria without oxygen produces biogas (it is a mix of methane and dioxide of carbon). We put the biomass into a hermetic container and wait some days (depending on the weather) for its putrefaction, finally we have biogas, also it is known as swaps gas because in them occurs a similar process.
  - Alcohol fuels: with biomass we can produce liquids as ethanol (fermentation of sugar) and methanol (destructive distillation of wood).
  - Biodiesel: it is made of fatty acids and alkyl esters that usually are derived from vegetable oils, animal fats and recycling fats.

    The best advantage is that we reduce bad emissions, black smoke and the smell.
  - Landfill gas: a gas is produced from the fermentation (natural process of the organic material with humidity and hot) of the solid urban wastes. We can use it to produce energy and also we reduce de gas emissions to the atmosphere and the explosions in these places (dumps).

3.6. Energy ways

We can obtain different kind of energies depends on the biomass that we have. We can burn directly and obtain hot for a domestic use or with the same process, we can obtain vapour to move turbines and produce electricity. Also, we can obtain both, hot and electricity if we us a cogeneration system.

If we make other type of processes we can obtain gas fuels or biofuels to be burn, but not in the same use of the previous paragraph.

3.7. Plant of biomass in Navarra (Spain) (Figure 3.3)

The plant of Sangüesa is one of the first operative central of biomass in Spain. It has a power installation of 25 MW and works approximately 8000 hours per year, so it consume is around 160.000 Tn. of straw. The cost of the plant is around 51 million Euros and it prevents the emission of 200.000 Tn. per year of dioxide of carbon if we generate this energy with fossil fuels.

The straw has a low energetic power so the company needs more raw material than if it uses other ones. The calculate is that the plant needs 45 trucks of straw per day, but also the plant needs to regulate the humidity of the bales (these bales have a standard measures, because the discharge is done with a bridge crane), so it has to have a big store. The store has space to save the fuel to supply the plant during 3 days, 24 hours per day.

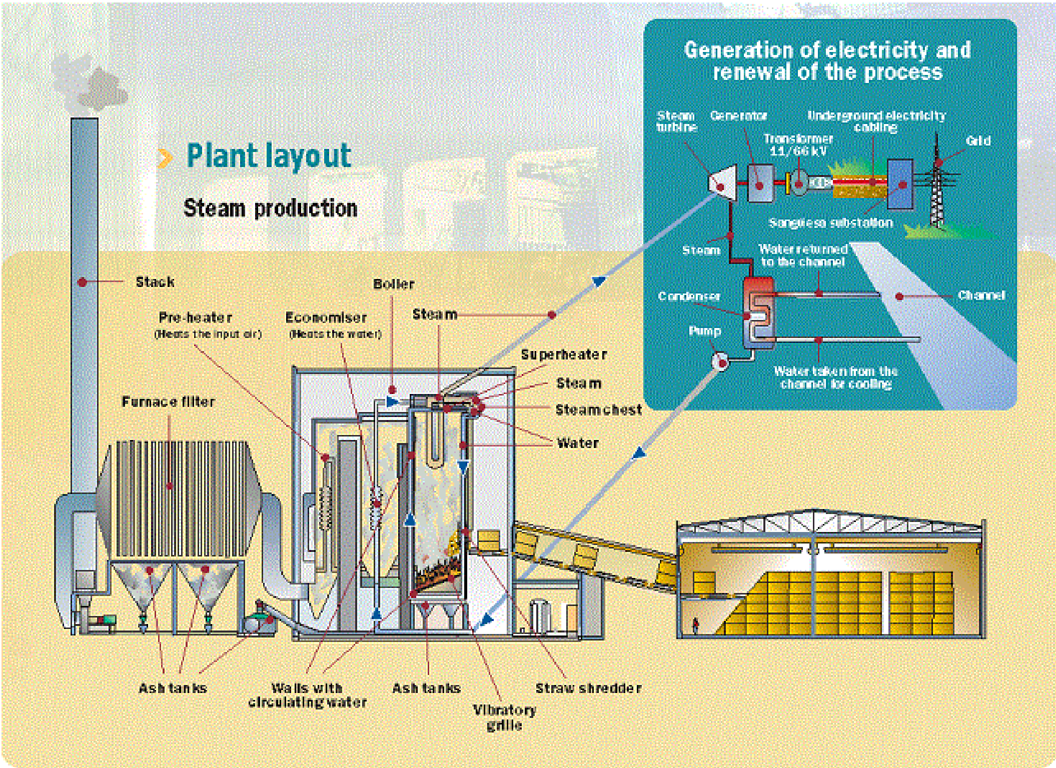


Figure 3.3: The process of a biomass plant in Sangüesa.

One of the most important parts of the plant is the boiler and it is design to use only straw, but you can also use part of wood in the fuel with some modifications of the system. The most difficult part to control is the corrosion because the straw has some components so aggressive for the boiler.

The raw material must have some parameters to be use, due to the boiler needs specific conditions to generate the maximum heat to evaporate the water which circulates from pipes inside the boiler. One of the most important parameters is the humidity, so that, it is really important the weather that they have between the harvest and the packaging and transfer.

The term cycle that the plant uses is a Rankine regenerative with 4 extractions of vapour in the turbine for the preheating of the condensed and the water for the boiler feed. The vapour is refrigerated by a river near the plant.

The electricity that is generated in the turbine has 11 kV and the company transforms into 66 kW to introduce it in the electric network.

The plant has to solve lots of problems to ensure the profitability of the operation:

- Difficulty of transport of the raw material.
- Difficulty of ensure the quantity, quality and price of the straw.
- Difficulty of logistic of fuel: recollect, store, transport and treatment.
- High cost of the inversion.

- High cost of operation and maintenance.
- Complexity of the installations.
- Lack of support to this “new” energy.

3.8. Plants of biomass in Spain

In Spain at the end of 2011 had installed 154 plants of biomass with a power of 706 MW, spread in 533 MW for solid biomass and 173 MW for biogas. With these numbers Spain reached the 45% of the objective that the Energies Renewable Plan has written until this year (to fulfil the objective the power should be 1567 MW).

If we classify these energy depending on the raw material the results most important will be these: 23% of the energy was generated with wastes of agriculture and forest, 20% with the wastes of the paper industry and 16% with biogas.

3.9. Plants of biomass in Bulgaria

The first and important biomass plant (to produce heat) was built in the center of Bansko Mountain. It has a power of 10 MW and gives energy to hotels, residential and administrative buildings, particular houses…

Another plant of similar characteristics started in 2009 in the city of Ihtiman, where the fossil fuels and the solids fuels were been substitute by briquettes of biomass. In this plant the cost of the energy production has been reduce with the change of fuel.

In March of 2012 the first minister and the Agriculture’s minister have expressed the position of the government pro the biomass energy and that the government won’t promote the installation of new wind power parks or solar plants.

3.10. Advantages and Disadvantages

+ The biomass is a renewable source of energy and is used don´t contributed to the global warming.
+ If we use the methane that the agriculture and livestock wastes emit when they rot we help to mitigate the greenhouse effect and to clean the aquifers.
+ The emissions of the biomass when it´s burned haven´t got almost sulphides, so that, we aren´t contributing to the acid rain.
+ If we use forestall, agricultural and urban wastes for obtain energy we solvent the problem of how to store them.
+ The biomass is everywhere and due to this, its price isn´t change by the movements of the international market.
+ The use of the biomass can increase the rural jobs and the economic activity in these areas.
+ The energy plantation can reduce the desertification areas and increase the biodiversity.
– The biomass has low density relative to the energy, so that, we need big volumes for produce the same energy that with the fossil fuels.
– An incomplete burn produces more dioxide of carbon and other gases.

- Less energetic efficiency than the fossil fuels.
- The price for a biomass plant is really high.
- The calorific power of the biomass varies so much with the changes in humidity, density…
- We need to put accord our plant the different types of wastes.

4. RENEWABLE ENERGIES NORMATIVE

4.1. Bulgarian normative

In this link we can read all the points of the new Bulgarian normative about renewable energies, including the new quotes and restrictions:

http://translate.google.com/translate?hl=es&sl=es&tl=en&u=http://www.suelosolar.com/newsolares/newsol.asp?id=6040&idp=3 May 2011

4.2. Spanish normative

On 23rd of November of 2010 was published in the BOE (Official State Newsletter) Royal Decree 1565/2010, where the government regulates and modifies some aspects of the activity of the electricity production in special regimen.

The Real Decree modifies principally the bonus that received due to the sale of energy generated in photovoltaic centrals and others.

On 7th of December of the same year, they published another Royal Decree (1615/2010) making changes in the conditions of the production of electricity through thermo-electric and wind power.

With these Decrees the government wants to stabilize the market of the energy and improve its generation with these special sources.

Older Royal Decrees of Spain:

- Royal Decree 661/2007
- RD 436/2004
- RD 1578/2008

http://www.boe.es/

4.3. Studies

Spanish study about the renewable energies in Bulgaria. The best study I find to understand the position of Bulgaria for renewable energies. We can read a sum of the history about the energy position of Bulgaria, the energy politic of the country, the laws for renewable energies that they have, the production of these renewable energies, the conditions of the market…
http://www.icex.es/icex/cma/contentTypes/common/records/mostrarDocumento/?doc=4651244

WIND PARK PROJECT

5. LOCATION OF THE STUDYING AREA

At first we are going to situate the place that we are studying to put the wind turbines in the map of Bulgarian (Figure 5.1):

Figure 5.1: Map of Bulgaria

The wind potential measuring equipment has been installed in the Northern part of Danube Plain, 37 km North-West of Pleven town, in the region of Baikal village. The coordinates of the site are:

N43^{o} 42.254’ E24^{o} 24.742’, at altitude of 160 m above the sea level.

Next we are going to see two more maps of the location of this equipment of measure (Figure 5.2 and Figure 5.3):

Figure 5.2: Situation of the sensors near Baykal

Figure 5.3: Altitude over the sea level of the location

In the next picture (Figure 5.4) we can see in white the area that we have to the location of the wind turbines. The distances of the perimeter are 380, 260, 410 and 260 meters if we start from the north side. The area approximately is 128.000 square meters.

Figure 5.4: Area for the situation of the wind turbines

6. EQUIPMENT OF MEASURES

6.1. Introduction

Before erecting a wind turbine it is important to assess the amount of wind available over a prolonged period. Wind turbine sites are invariably financed on the basis of a return on investment, and this calculation requires extensive information on how much wind will be available all year round. Errors in this prediction can have an enormous effect on the amount of electricity produced and the viability of the investment.

Large towers are often erected with many anemometers mounted at varying heights to collect data (as we can see in the Figure 6.1).

Figure 6.1: Anemometers in a measuring tower

In this case the elements that we have to analyses all the characteristics of the wind are the next:

- Wind speed measuring sensor 3 units, calibrated, type Anemometer NRG Maximum # 40; these sensors are installed at height of 50 m, 40 m and 30 m.
- Wind direction measuring sensor 2 units, type Wind Vane NRG 200P; these sensors are installed at height of 48 and 38 m.
- Air temperature measuring sensor 1 unit, type SWI 10k Probe; this sensor is installed and height of 49 m.

The sensors are installed on a wind mast with height of 50 m, tubular and manufactured by NexGen UK company.

6.2. Study of the components

6.2.1. Wind speed sensor

Figure 6.2: Speed sensor

The first components that we are going to analyzed are the three sensors of speed that we have situated in different heights. We can see the sensor in the Figure 6.2.

These sensors are formed by 3 conical cups model in one continuous piece. The cups are equidistant one of the other and gyre around an axis. This axis induces a sine wave voltage by a four pole magnet. Two sine wave cycles are produced for each revolution of the cups, and the frequency of the signal is directly proportional to the speed of the wind.

Their low moment of inertia and unique bearings permit very rapid response to gusts and lulls. Also the material of the cups has thermal properties which resist and shed icing far more effectively than metal assemblies.

The maximum speed that we can measure with this anemometer is 96 m/s.

Because of their output linearity, these sensors are ideal for use with various data retrieval systems and controllers. The unique bearing system ensures that wind-blown dirt and moisture will not destroy the bearings or degrade performance.

We can see more characteristics of this sensor in the next page: http://130.226.17.201/extra/web_docs/instruments/nrg/1899.pdf

6.2.2. Wind vane sore

Figure 6.3: Wind direction sensor

The NRG #200P wind direction vane (Figure 6.3) is the industry standard wind direction vane used worldwide. The thermoplastic and stainless steel components resist corrosion and contribute to a high strength-to-weight ratio.

The vane is directly connected to a precision conductive plastic potentiometer located in the main body. An analog voltage output directly proportional to the wind direction is produced when a constant DC excitation voltage is applied to the potentiometer.

We can see more characteristics of this sensor in the next page: http://www.nrgsystems.com/sitecore/content/Products/1904.aspx

Datasheet: http://www.secondwind.com/PDFdocs/983SWI_WindVaneSS.pdf

6.2.3. Temperature sensor

Figure 6.4: Temperature sensor

The SWI Thermistor (Figure 6.4) is designed specifically for use with a data logger. It consists of a 10K type thermistor encased in an aluminum shaft. The thermistor's resistance changes with temperature, following a known but non-linear curve. The specific data logger measures the resistance of the thermistor and uses a lookup table with over 4000 values to determine the temperature. The sensor is wired to 2.5V excitation on the data logger's terminal strip, and will run on the 9V power being supplied to the logger.

We can see more characteristics of this sensor in the next page: http://www.secondwind.com/Sensors/other-environmental-sensors.html

6.3. Sensor that gives us speed and direction of the wind

We can use other type of sensor more sophisticated to make all the measures with one instrument (Figure 6.5).

The main function of this instrument is: the anemometer measures the time taken for an ultrasonic pulse to travel from one transducer to the opposite transducer and then compares it with the time taken for another pulse to travel in the opposite direction. Likewise, differences are measured between other pairs of transducers allowing calculation of both wind speed and direction.

Figure 6.5 New anemometer systems

This instrument is more robust than the previous ones because we eliminate the moving parts so we reduce the maintenance of the dispositive. Also, it detects better the fluctuations of the wind and the wind direction changes, so that, we have more exactly figures.

We can see more characteristics of this sensor in the datasheet:
http://www.gill.co.uk/data/datasheets/3_AXIS_web.pdf

7. DISTRIBUTION OF ENERGY IN THIS AREA

The distribution of the energy in Bulgaria is made by three power companies which are: Czech CEZ, Austria´s EVN and Germany´s EON (now in the final stages of the sale to Czech Energo-Pro).

In the next map we can show the distribution of the country by these three companies (Figure 7.1):

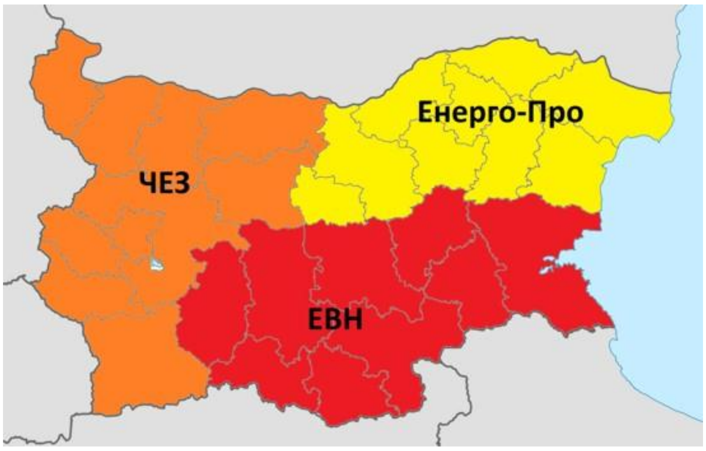


Figure 7.1: distribution of electrical companies in Bulgaria.

Now we know the region and the company at which belongs our place, so we can know the law and the characteristics of connection of the company.

In Bulgaria there are different types of networks apart of the control of the electricity companies. Usually, the country has some normalized voltages to supply the energy and to transport it to different places.

Normally they have the distribution in high-voltage (figure 7.2), that has the next normal values: 110 kV, 220 kV, 400 kV and 750 kV. There is only one network with 750 kV and actually isn´t used.

In the next map we can search the places near Baykal that has high-voltage networks.

Also we have to search the medium voltage connections near Baykal because it is a small village near the Danube river and as we can see in the previous map (Figure 7.2) we have to join the nearest high-voltage network with the place of generation.

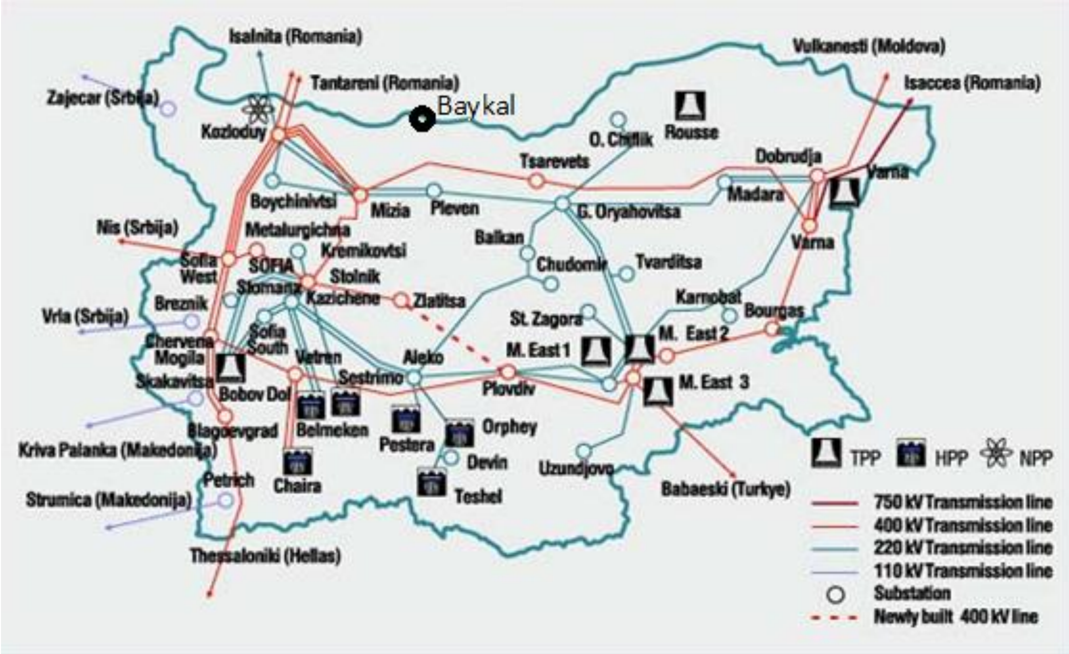


Figure 7.2: Networks of high-voltage of Bulgaria

The normalized medium voltage values are: 6 kV, 10 kV and 20 kV.
In the next map (Figure 7.3) we can see some networks of the Baykal region:

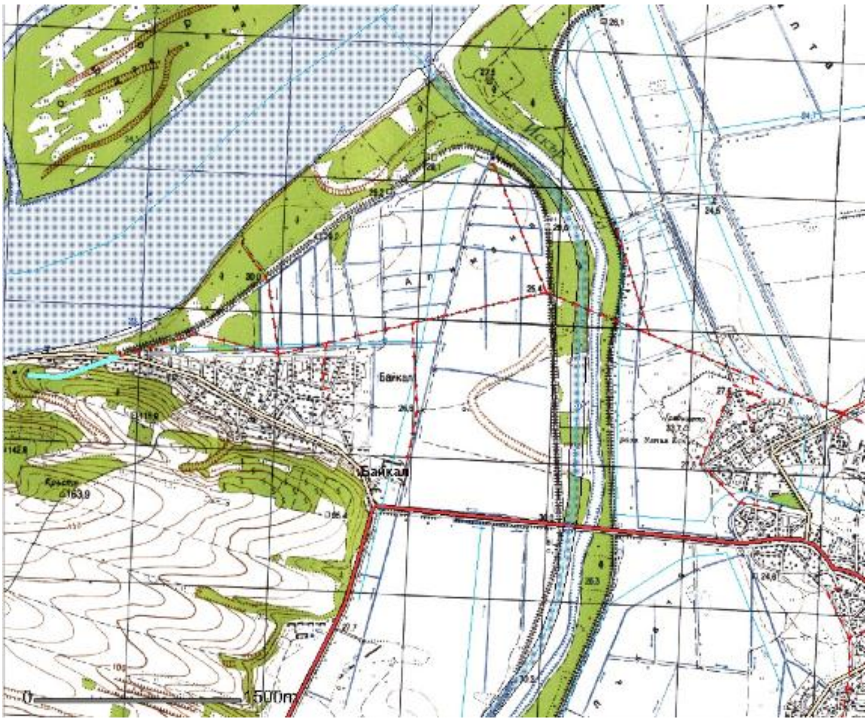


Figure 7.3: Networks in Baykal region

8. STUDY OF THE WIND CHARACTERISTICS

8.1. Coriolis power

Due to the rotation of the earth, a movement in the north part of the planet is deviated to the right, if we look from our position in the ground (on the contrary in the south hemispheric). This power is known as Coriolis power (due to the French mathematic Gustave Gaspard Coriolis 1792-1843).

The biggest expression of this power is seen when a fluid follow the direction of a terrestrial meridian. The fluid is moved in the East direction if it goes to the pole or to the West direction in the other case (in the North hemispheric). The contrary happened in the South hemispheric.

The Coriolis Effect has to be studied always that we have a movement of a fluid or an object in a sphere or in a plane with gyre. This norm predicted that always that we see the gyratory movements, the vortex will follow the next rule: the fluid in the South of the planet will turn in the direction of clockwise and in the North in the contrary direction.

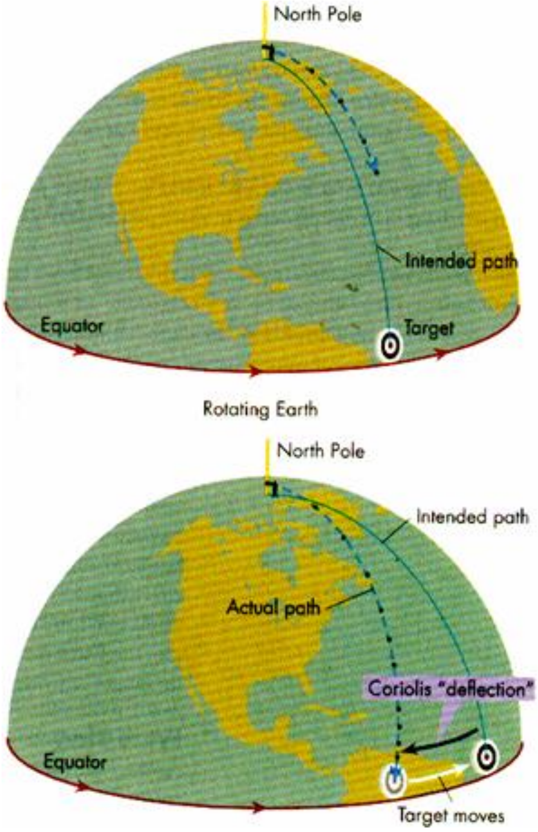


Figure 8.1: Coriolis Effect

8.2. Local winds

Usually, the global winds are more important than the local ones, but also, these local characteristics can change the most common wind direction. Normally, the wind direction is influence by the global plus the local effects.

When the global winds are low the local ones can dominate the wind regimen.

8.2.1. Sea winds

During the day, the ground is heated faster than the sea for the effect of the sun. The air of the ground become less heavy so goes up and let a hole in the floor that is occupied by the fresh air of the sea. Usually there is a period every day that this circulation stop, when the temperature of the sea and the ground are the same.

During the night the winds go in the other direction because the ground loses the heater before the sea. Also, these winds are lower than the day ones because the difference of temperature is less.

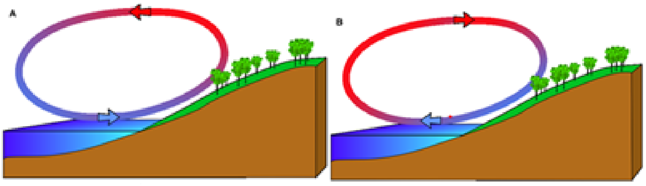


Figure 8.2: Direction of the sea wind depending if is day (A) or night (B)

8.2.2. Mountain winds

One example of this is when the hot air of the valley goes up (due to lose of density) from the hillside of the mountain. During the night the process usually is in the other direction, the air of the mountain become cooler and goes down.

This type of wind can be really powerful and we have lot of examples: The Sirocco, a wind from the Sahara to the Mediterranean, the Fhon in Alpes, the Mistral in the valley of the Rhone…

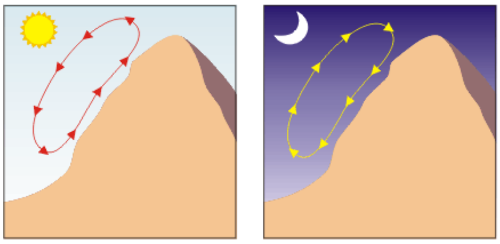


Figure 8.3: Fluency of the wind in a hillside

Also we have to know that the speed of the wind increase in the top of the mountain due to the tunnel effect. The area where the wind pass, is smaller at the top than in the hillside, so that, the speed of it rise.

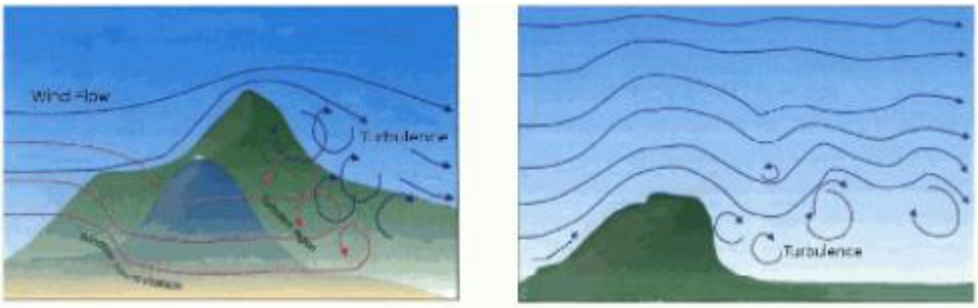


Figure 8.4: More near the lines of wind in the top of the mountain, so, more speed of wind

8.3. The energy of the wind

One wind turbine takes the power that produces by the conversion of the wind power into a torque realized by the blades. The quantity of energy transfer to the rotor depends on the air density, on the wind speed and on the area of the rotor.

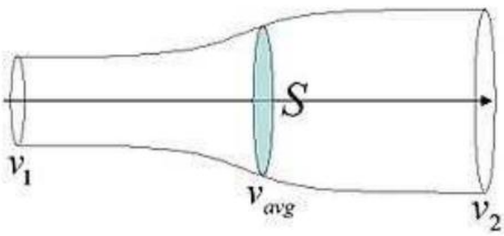


Figure 8.5: Tube of fluid that passes from the rotor of the turbine and the variation of wind speed

8.3.1. Wind density

The kinetic energy of a body in movement depends on the mass, so, in the density. In the case of the air, it depends on the mass per volume unit.

When the air is heavier, its density is bigger; more energy will bring to the turbine. The air density with normal pressure atmospheric and with 15ºC is 1,225 kg/m^3, but it changes a lot with the humidity.

The air is more density when is colder and when is more down, because the pressure is bigger.

8.3.2. Rotor size

The rotor size determines how much energy of the wind is able to take the turbine. This is easy to see, because the area of the rotor rises with the square of the diameter, so a double bigger area will take four times more of energy.

In the next figure (Figure 8.6) we can have an idea about the relation between rotor size and power that can take by the wind:

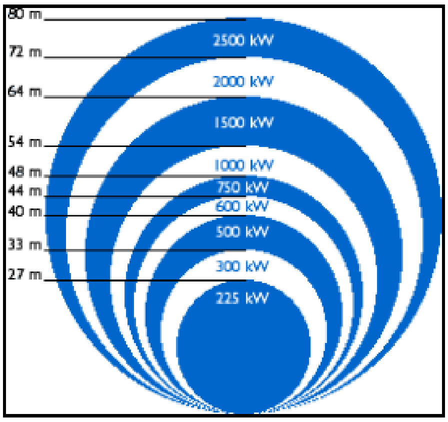


Figure 8.6: Relation between size of the rotor and power

8.3.3. Reasons for choose big or small wind turbines

For choose a big wind turbine:

- The biggest machines can produce more electricity so they can give the electricity with lower price than the small ones. The reason of this is because the road construction, the connection to the grid, the electronic control systems are more or less independents of the size of the machine. The price of maintenance is almost independent of the size too.
- The biggest machines are well adapted to be installed in the sea, where can produce more than in the ground.
- In areas where is difficult to install lots of wind turbines, one big turbine uses the wind resource with better efficiency.
- We attend also to aesthetic considerations, and it is better a park with a few wind turbines that gyre with low speed, than lot of wind turbines that are gyring with high speed.

For choose a small wind turbine:

- The electrical network maybe is so small to support the capacity of production of a park of big wind turbines. It could be in places with low density of inhabitants and with low electrical consume.
- The fluctuations of the wind are less harmful because if we have more than one or two wind turbines the fluctuations aren´t going to affect to the wind turbines at the same time, so the electricity hasn´t got finally big fluctuation.
- In some areas is really difficult to construct big roads that allow the transport of big turbines, so in some areas is easier and cheaper the use of small wind turbines.
- The problem of the stop of the machine is lower when we have installed more than one. Usually we install more when they are small.

8.3.4. Deviation of the wind by the wind turbine (Ley de Betz)

One wind turbine diverts the wind before it passes through the rotor. So that, we can´t take advantage of all of the energy of the wind, and also, the wind has to continue after the rotor, so it needs kinetic energy. We can see in the next image the picture that explains this (Figure 8.7):

Figure 8.7: Deviation of the wind after and before a turbine.

The rotor of the turbine slows the wind taking advantage of the kinetic energy of it to transform this energy into electricity.

Due to the conservation theory the air that entry in the rotor has to goes out, and as the kinetic energy is less in the out, the section has to be bigger. This imaginary tube we can see in the previous image (Figure 8.7).

The speed of the wind doesn’t suffer a suddenly variation, it slows progressively until a constant speed.

The Betz law gives the maximum power that we can take advantage from the wind with an ideal wind turbine. (Page 17-19).

8.3.5. Wind rose

It is a system to show the information of the distribution of wind speeds and the frequency of wind direction variation. It is really useful to know the priority wind direction and where we can put the wind turbines for the best energy efficiency.

In our case we have to select the high of the wind turbines and the direction. We can select the way of install them with the next picture (Figure 8.8):

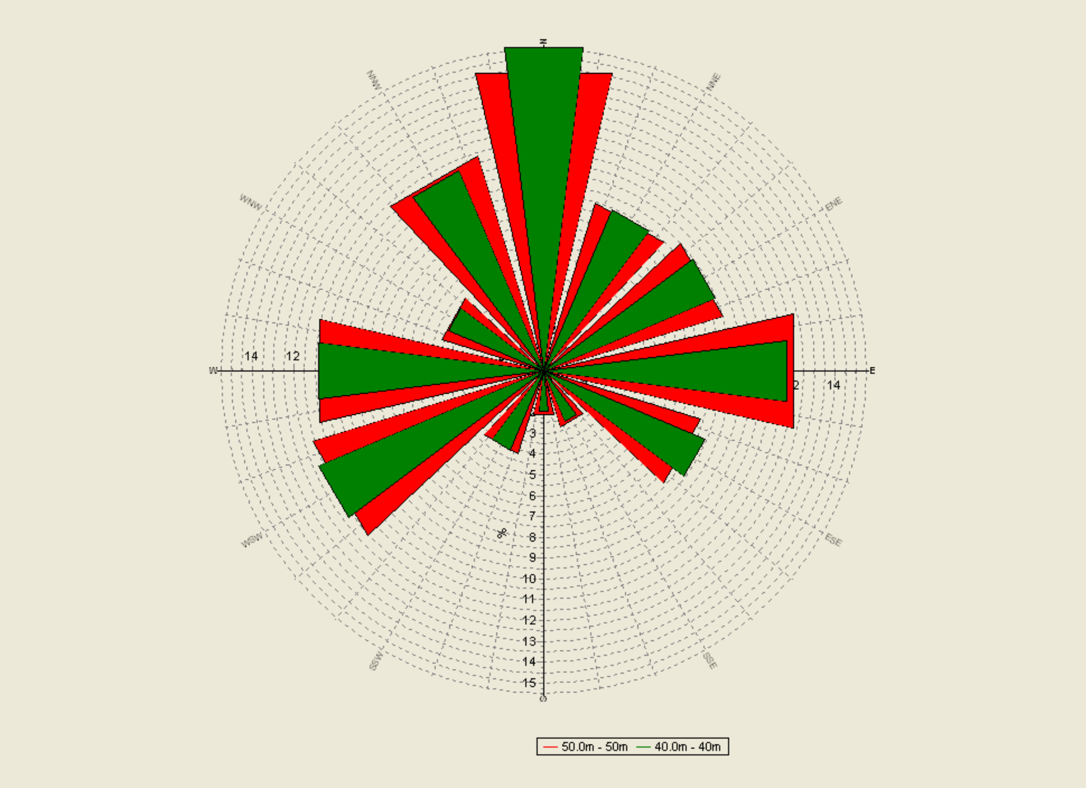


Figure 8.8: Wind frequency by directions at 50m and 40m

The wind rose, as we can see, it´s a circle divide in 16 and each line of division represent the direction of the wind. The dates to form the wind rose at 50 meters are the next (Table 8.1):

	Frequency (%)	Average speed (m/s)
N	14,674	7,43
NNE	8,440	5,2
ENE	9,001	4,47
E	12,305	4,8
ESE	7,866	4,43
SSE	2,795	3,43
S	2,169	2,86
SSW	4,169	3,63
WSW	11,578	4,24
W	11,055	4,92
WNW	5,117	5,44
NNW	10,831	7,85

Table 8.1: Dates of the wind rose at 50 m.

In case that the wind rose has a predominant direction, we will want to have the fewer obstacles possible in this direction, a smooth terrain and the turbines rotor orientate perpendicular to the wind direction.

However, in our case (Figure 8.8) we have three predominant directions so we are going to get advantage of all of them situating the turbines in a direction that don´t disturb the others in no one of the cases.

This wind rose (Figure 8.8) has been made by the dates of one year; nevertheless it´s preferable to be made by more years because the wind changes from one year to other, but in our case we haven´t got more dates.

9. SELECTION OF THE HIGH OF THE TURBINE

We have to select the high of the turbines with the data that we have. These data is taken by the measurements equipment during one year (Table 9.1, 9.2 and 9.3):

50.0m NE – Mean wind speed	**2007**	**2008**	**Mean**
January		5.58	5.58
February		6.07	6.07
March	5.28	6.05	5.87
April	4.38		4.38
May	4.27		4.27
June	4.83		4.83
July	5.07		5.07
August	5.20		5.20
September	5.62		5.62
October	5.10		5.10
November	6.90		6.90
December	5.15		5.17
Mean, all data	**5.17**	**5.90**	**5.34**

Table 9.1: Average wind speed at 50m by months, [m/s]

40.0m NE – Mean wind speed	**2007**	**2008**	**Mean**
January		5.20	5.20
February		5.85	5.85
March	5.01	5.94	5.73
April	4.18		4.18
May	4.03		4.03
June	4.47		4.47
July	4.77		4.77
August	4.92		4.92
September	5.16		5.16
October	4.71		4.71
November	6.49		6.49
December	4.92		4.92
Mean, all data	**4.85**	**5.67**	**5.05**

Table 9.2: Average wind speed at 40m by months, [m/s]

30.0m NE – Mean wind speed	**2007**	**2008**	**Mean**
January		5.09	5.09
February		5.70	5.70
March	4.77	5.67	5.47
April	4.14		4.14
May	3.99		3.99
June	4.50		4.50
July	4.80		4.80
August	4.82		4.82
September	5.05		5.05
October	4.67		4.67
November	6.31		6.31
December	4.91		4.91
Mean, all data	**4.80**	**5.49**	**4.96**

Table 9.3: Average wind speed at 30m by months, [m/s]

Just with the first look of these tables (9.1, 9.2 and 9.3) and the wind rose (Figure 8.8) we can see that the best measures have been taking at 50 m.

We say this because in this height we have the biggest average speed in the year and as the variation per month in the different height is very similar we can confirm that due to the height, 50 meters is the best in our location.

10. STUDY OF THE WIND CHARACTERISTICS AND LOCATION OF THE TURBINES

10.1. Study of the wind

For the location of the wind turbines we use the winds rose and the data that we have.

Speed (m/s)	% Frequency
0	4,708
1	6,62
2	9,866
3	12,201
4	12,658
5	12,494
6	10,487
7	8,418
8	6,117

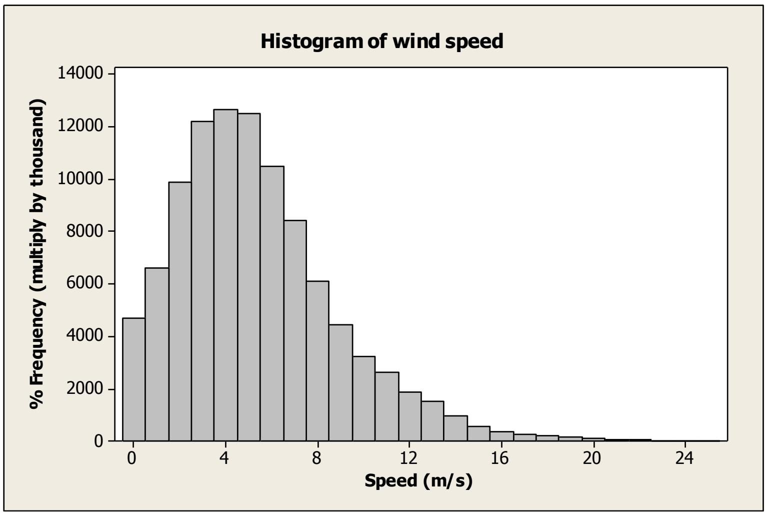
Speed (m/s)	% Frequency
9	4,439
10	3,237
11	2,604
12	1,886
13	1,53
14	0,969
15	0,567
16	0,332
17	0,257

Speed (m/s)	% Frequency
18	0,203
19	0,16
20	0,112
21	0,071
22	0,035
23	0,015
24	0,013
25	0,002
26	0

Table 10.1: Wind speed and direction distribution at 50 m.

With this table (Table 10.1) we can make a graphic (Figure 10.1) where we can see the most common values of wind speed and the frequency. It is called Weibull due to the similar form with this type of graphic. Also we can calculate the average speed with the next equation (10.1), the modal value looking the table (Table 10.1) (it is the value with more frequency, in our case, 4 m/s) and the value that divide the graphic (Figure 10.1) in two equal areas. To create this graphic (Figure 10.1) we are going to use Minitab.

$$Average\ Speed = \sum_{i=0}^{26} frecuency_i * speed_i = 5{,}34\ m/s \qquad (10.1)$$



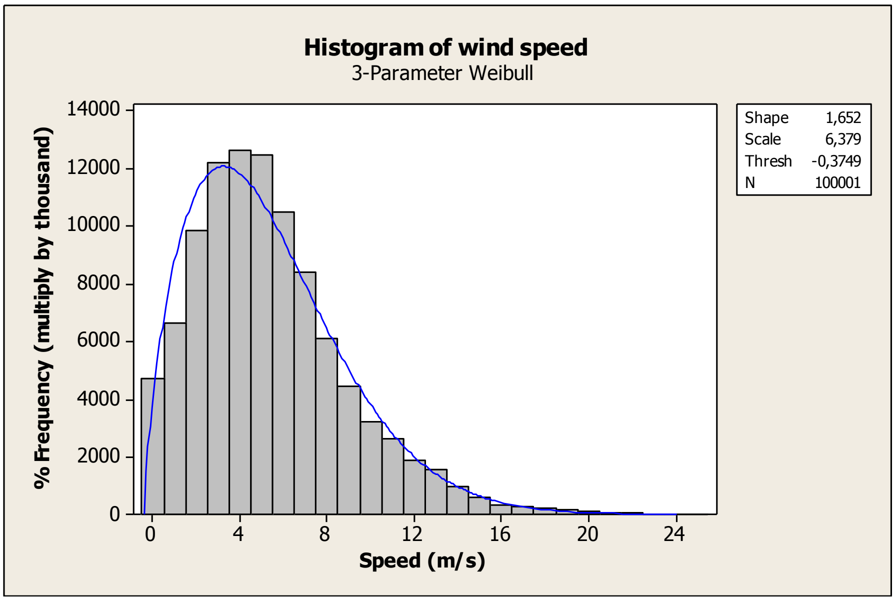


Figure 10.1: Weibull

The most important think in this graphic (Figure 10.1) are the parameters of shape and scale of the Weibull curve. In this case the values are: k (parameter of shape) = 1,652 and A (parameter of scale) = 6,379.

Another form to calculate these parameters is to take some values of the frequency accumulate and the speed and makes a line adjusted by least squares. The example is here (Table 10.2 and Figure 10.2):

Speed (v)	Frequency	F(v)	Ln(v)	Ln(-Ln(1-F(v)))
1	11,327	0,11327295	0	-2,118447954
6	69,034	0,69033509	1,79175947	0,158937336
10	91,245	0,91244549	2,30258509	0,890149482
15	98,800	0,98799806	2,7080502	1,486747458
20	99,864	0,99863953	2,99573227	1,887058499

Table 10.2: Different parameters to make the figure 10.2

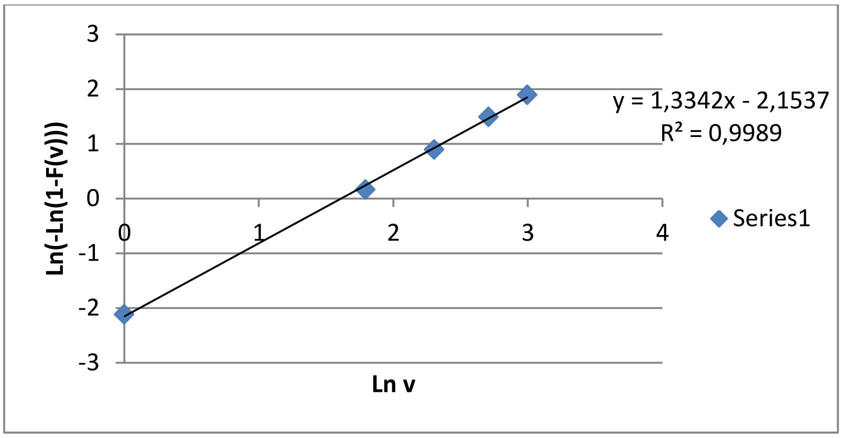


Figure 10.2: Line adjusted by minimum squares to obtain the parameters of shape and form

Now, with the following equation we are going to obtain the parameters:

$$y = 1{,}3342x - 2{,}1537 \;\rightarrow\; k = 1{,}3342$$

$$y = 1{,}3342x - 2{,}1537 \rightarrow y = 0 \rightarrow x = Ln(A) = \frac{2{,}1537}{1{,}3342} = 1{,}6142 \rightarrow A = exp^{Ln(A)} = 5.024$$

With these parameters we can calculate the average speed, so we are going to compare between both methods to know which one of them are more near of the reality. The real value is the 5.34 m/s that we have calculated with the data take by the meteorological station.

$$\bar{u} = A \cdot \Gamma\left(1 + \frac{1}{k}\right)$$

Γ: It is an Euler function called Gamma

With the parameters obtain by the curve (Figure 10.1):

$$\bar{u} = A \cdot \Gamma\left(1 + \frac{1}{k}\right) = 6.379 \cdot \Gamma\left(1 + \frac{1}{1.652}\right) = 6.379 \cdot 0.8941 = 5.7036\, m/s$$

With the parameters obtain by graphic (Figure 10.2):

$$\bar{u} = A \cdot \Gamma\left(1 + \frac{1}{k}\right) = 5.024 \cdot \Gamma\left(1 + \frac{1}{1.3342}\right) = 5.024 \cdot 0.919 = 4.617\, m/s$$

With both results here we can see that is better to use the Weibull curve because is more near the value of the average speed to the reality (5.34 m/s). We will use from here to the end of the calculations the values of: k=1.652 and A=6.379.

We are going to calculate the mode and the median:

$$u_{mode} = A \cdot \left(1 - \frac{1}{k}\right)^{\frac{1}{k}} = 6.379 \cdot \left(1 - \frac{1}{1.652}\right)^{\frac{1}{1.652}} = 3.6337\ m/s$$

$$u_{med} = A \cdot \left(Ln(2)\right)^{\frac{1}{k}} = 6.379 \cdot \left(Ln(2)\right)^{\frac{1}{1.652}} = 5.1098$$

Then we are going to show the graphics of the cumulative function and the probability function (Figure 10.3 and 10.4) with our data. We calculate these distributions with the following equations:

$$F(u) = 1 - exp^{\left[-\left(\frac{u}{A}\right)^{k}\right]}$$

$$f(u) = \frac{k}{A} \cdot \left(\frac{u}{A}\right)^{k-1} \cdot exp^{\left[-\left(\frac{u}{A}\right)^{k}\right]}$$

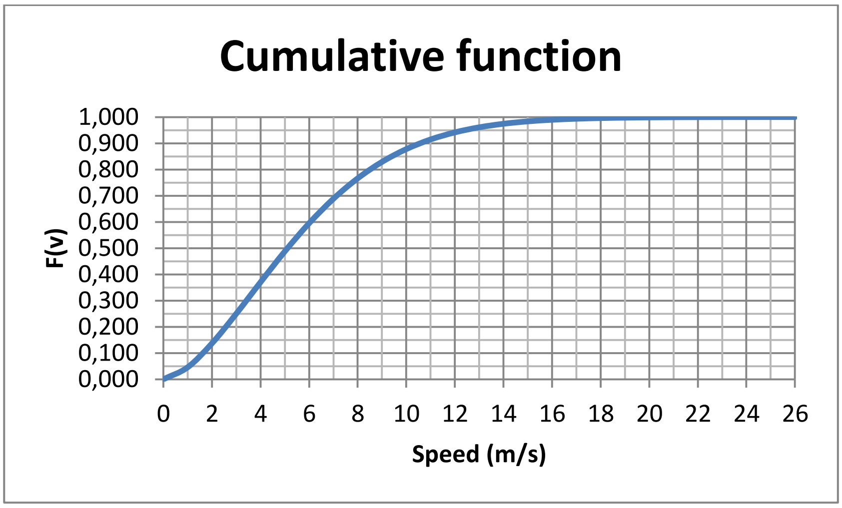


Figure 10.3: Cumulative function with the data at 50 m.

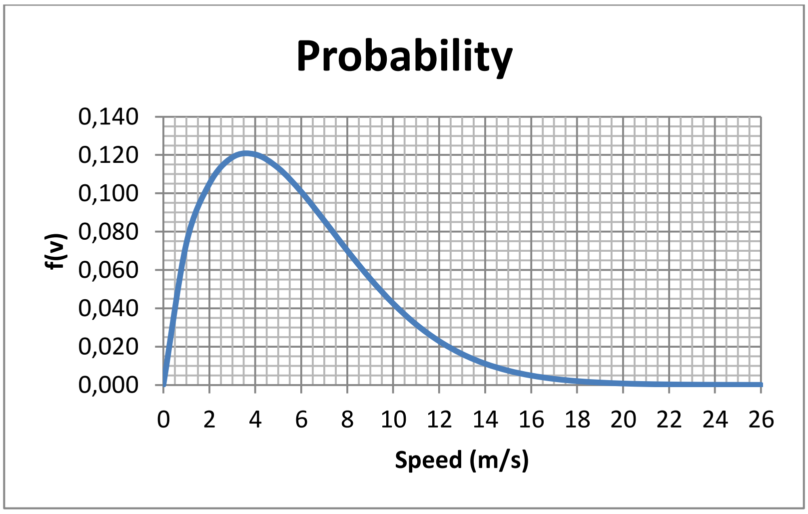


Figure 10.4: Probability function with the data at 50 m.

Other parameter that we can calculate with these data is the power density available for area:

$$\overline{\left(\frac{P}{S}\right)} = \frac{1}{2}\,\rho A^3 \Gamma\left(1 + \frac{3}{k}\right) = \frac{1}{2}\,1.2 \cdot 6.379^3 \Gamma\left(1 + \frac{3}{1.652}\right) = \frac{1}{2}\,1.2 \cdot 6.379^3 \cdot 1.6993$$
$$= 264.6544\ w/m^2$$

The density of the air in these conditions will be approximately 1.2 Kg/m3 with the data that we have: height of 150 m above the sea level and average temperature during the year of 13.3 ºC.

10.2. Location of the turbines

We can see in the graphics (Figure 8.8 and Table 8.1) that the direction of the wind in this area is not defined. We have three principal lines where the wind comes. Due to this we decide to install the wind turbines in a line from north-west to south-east (Figure 10.6), for solve the problem of the shadows of the wind turbines. We will separate the turbines a distance of 3 times the diameter of the rotor, so we will know the number of turbines that we can put when we select the machine.

We have to decide if we are going to put one or more than one lines of turbines, but we are conditioned by the turbulences that can produce one of each other. If we put more than one line the turbines must be alternating staggered and the distance between lines must be more than 10 times the diameter of the rotor and between turbines in the same line three times (figure 10.5).

With this data we can confirm that we are going to put only one line because our area isn´t enough to situate the distance between lines (around 500 meters or more) and introduce more numbers of turbines than in only one line.

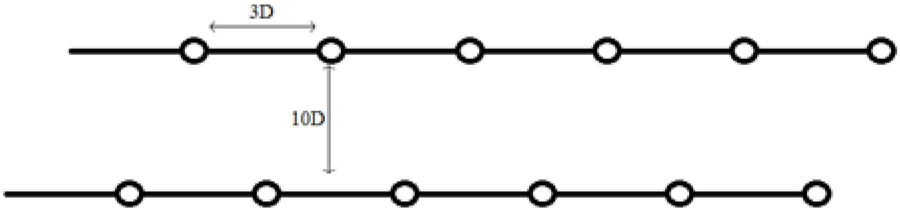


Figure 10.5: Ideal position of the separation between turbines

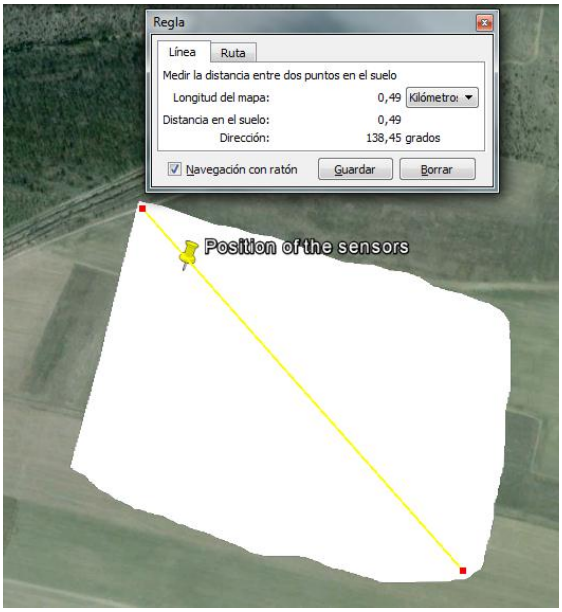


Figure 10.6: Line where we will install the wind turbines

We have to stand out that our area is more than 300 meters far from a place habited because if not we wouldn´t build the generators. Also we have to distinguish that the high of the location is 150 meters over the sea level, and near the river Danube.

11. SELECTION OF THE TURBINE AND NUMBER

11.1. Dates that we have

Now we have to compare the different characteristics of the turbines and choose the most convenient for us, considering the dates that we have calculated:

- We know the average speed in a height of 50 m, which is the best between the three measures that we have.
- The turbines must be separated three times the diameter of the rotor.
- The turbines must be situated in the line (Figure 10.6) and inside our area.

11.2. Different companies producers of turbines

Catalog of the different type of big wind turbines that offer some companies:

- Acciona: http://www.acciona-energia.es/areas_actividad/aerogeneradores/ modelos.aspx
- Gamesa: http://www.gamesacorp.com/es/productos-servicios/aerogeneradores/
- Vestas: http://www.vestas.com/en/media/brochures.aspx
- Repower: http://www.repower.de/

Catalog of the some turbines which can fix in our location:

- Vestas: http://www.iufmrese.cict.fr/concours/2002/CG_2002STI_lycee/Pour_en_savoir_plus/Vestas_V47.pdf
- Different turbines: http://www.alcion.es/Download/ArticulosPDF/en/11articulo.pdf

11.3. Calculate the wind speed in other high

As we can see in the different companies, it is very difficult to have the rotor high just in 50 meters as we want and also have the best turbine to get advantage of the wind speed that we have. Due to this, we maybe need to calculate the average speed in the rotor high that we select. For this calculates we have the next equation:

$$\frac{v}{v_o} = \left(\frac{H}{H_0}\right)^{\alpha}$$

v is the wind average speed at the high of H.
v_o is the wind average speed at the high of H_0.
H is the high of the center of the rotor.
H_0 is the high of the measurement equipment
α is the friction coefficient or Hellman exponent.

In the next table (Table 11.1) we have the approximate values of the Hellman exponent depending on the landscape:

Type of landscape	Friction coefficient
Lakes, seas, soft and hard surfaces	0,10
Grass	0,15
Cropland, hedges or fences and shrubbery	0,20
Fields with lots of trees	0,25
Small village with some shrubberies and trees	0,30
Area of the city with high buildings	0,40

Table 11.1: Hellman exponent depending on the landscape

11.4. Type of location that we have

Also we have to control depending on the average speed of the wind the class of the location that we have. The location can be classified in four classes due to the IEC 61400 normative. This classification allows us to select the best wind turbine for our location. At first we have to know the wind average speed in the center of the rotor and to calculate the class with this table (Table 11.2):

Average speed (m/s)	Class
v < 6	IV
6 < v < 7,5	III
7,5 < v < 8,5	II
8,5 < v < 10	I

Table 11.2: Class of location depending on the average speed

All the turbines can work in a location with lower class, but never in higher class. For example: a class I turbine can operate in all of the locations, but a class III turbine can operate in a location III and IV but never in a class I or II location.

The fabricants make smaller turbines if the class increases: a class I will be smaller than a class II. It is because a smaller turbine has a small rotor size and can support better the efforts make by the highest speed of the wind.

11.5. Final election and dates

With all of these elements and considering that our wind average speed in the high of 50 meters is a little bit low (5.34 m/s), but the best of the three that we have, we are going to select the wind turbine that we consider the best for our location. We have made the next table (Table 11.3) to know the class of the location depending on the height of the rotor:

Average speed in the measurement high (m/s)	Hellman exponent for our landscape	High of the measurement equipment (m)	High of the rotor (m)	Wind average speed (m/s)	Class of the location
4,96	0,2	30	30	4,96	IV
5,05		40	40	5,05	IV
5,34		50	50	5,34	IV

Table 11.3: Class of the location depending on the high of the turbine

Finally we have selected the **turbine D48-600kW of Dewind Iberia, S.A. that has the power of 600 kW**.

This selection has based:

- In the class of the turbine (class III).
- In the height of the turbine (50 meters), we have selected this height because give as a bigger average speed and the shearing of the wind is less, as we can see in the next figure (Figure 11.1). Also we have made the calculations to know which of the heights give us is the best (Table 11.4 and Figure 11.2) depending on the price that cost increase the height:

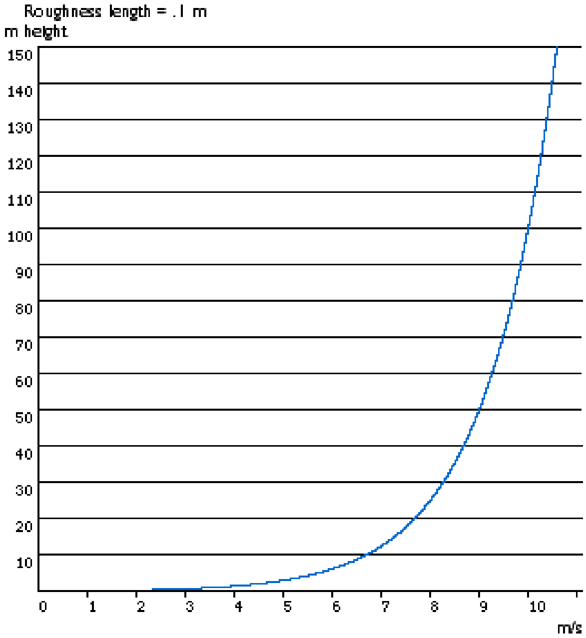


Figure 11.1: High against speed for a Hellman exponent of 0.1

The calculations of the best height depending on the increase of the price when the height is bigger are the next (Table 11.4):

Height	Average speed	(Average speed)^3	% Power increase	% Price increase
30	4,96	122,02	100,00	100,00
40	5,05	128,79	105,54	102,50
50	5,34	152,27	124,79	105,00

Table 11.4: Relation between increase of power, price and wind speed

Explanation of the table:

- The first file is the average dates that we have measured in one year. We consider these figures the 100% of the value, and if we increase the high we will get better results.
- We have the data of the average speed.
- To calculate the power increase we make a normal rule, the example of the second file:

$$122.02 \rightarrow 100\%$$
$$128.79 \rightarrow X$$
$$X = \frac{128.79 * 100}{122.02} = 105.54\%$$

- To calculate the increase of the price we have to consider that the price of the turbine increase the 25% per meter of tower. If we know that the 100% is when we have 30 meters the equation is the next (7.2):

$$\%p.i = 100 + (0.25 * \Delta h) = 100 + \left(0.25 * (40 - 30)\right) = 102.5\ \%$$

In the next graphic (Figure 11.2) we can see these figures visually:

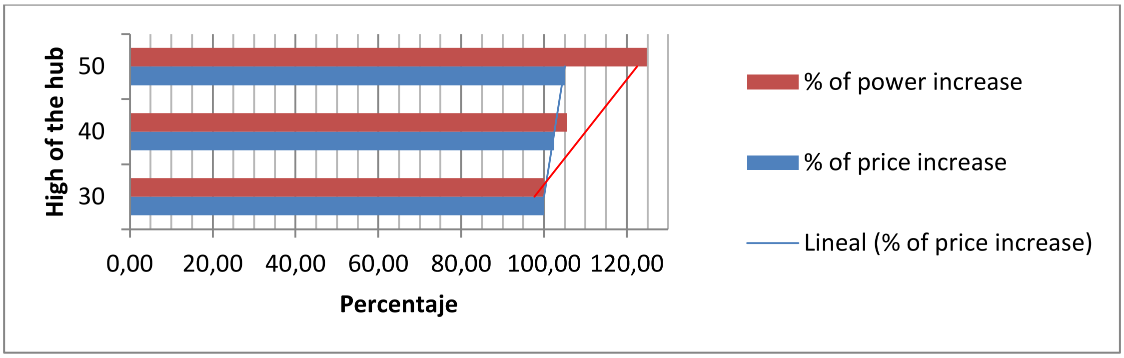
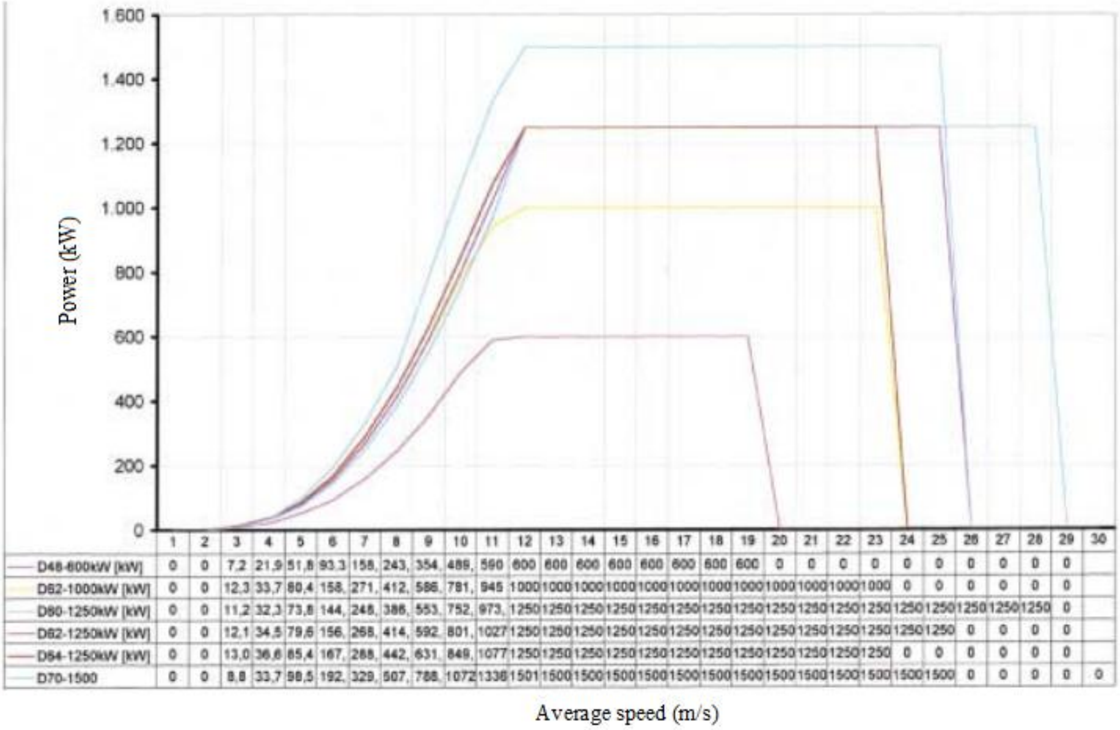


Figure 11.2: Relation between the increase of power percentage and price percentage

- In the diameter of the rotor (48 meters), because we can situate three turbines of this size in our area with a separation of three times the diameter between turbines and without overstep our field limits.
- In the graphic of power against average speed (Figure 11.3). We can see how this machine gets more advantage from the low wind speed than others turbines because it starts to move with 2.5 m/s.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
D48-600kW [kW]	0	0	7,2	21,9	51,8	93,3	158,	243,	354,	489,	590	600	600	600	600	600	600	600	600	0	0	0	0	0	0	0	0	0	0	
D62-1000kW [kW]	0	0	12,3	33,7	80,4	158,	271,	412,	586,	781,	945	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	0	0	0	0	0	0	
D60-1250kW [kW]	0	0	11,2	32,3	73,8	144,	248,	386,	553,	752,	973,	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	0	
D62-1250kW [kW]	0	0	12,1	34,5	79,6	156,	268,	414,	592,	801,	1027	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	0	0	0	0	
D64-1250kW [kW]	0	0	13,0	36,6	85,4	167,	288,	442,	631,	849,	1077	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	0	0	0	0	0	0	
D70-1500	0	0	8,8	33,7	98,5	192,	329,	507,	788,	1072	1336	1501	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	0	0	0	0	0

Figure 11.3: Power against average speed in different turbines of Dewind Iberia, S.A.

- In one of the best getting advantage of the low power density, ensuring the biggest energy production with a low level of noisy emission.

The characteristic of this turbine can be read in the next web site in page 152:

http://www.google.es/url?sa=t&rct=j&q=dewin+iberia+d48-600&source=web&cd=1&ved=0CDMQFjAA&url=http%3A%2F%2Fbiblioteca.uns.edu.pe%2Fsaladocentes%2Fdoc_abrir_archivo_de_curso.asp%3Fid_archivo%3D488%26archivo%3Dfabricantes_de_aerogeneradores_espa%25F1a.pdf&ei=AVF2UZC0JoiJPeGPgPgL&usg=AFQjCNFPxh5CYBz6t9jIoOlhgu7iLacvGg

12. ENERGY PRODUCTION

In this section we are going to calculate the power of the turbines (Figure 12.1) and the power and energy of one turbine in one year (Figure 12.2):

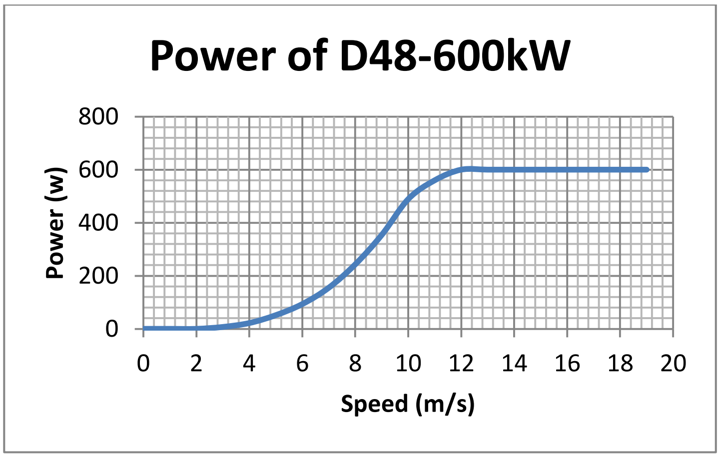


Figure 12.1: Curve of the power of the generator.

Speed (m/s)	Probability	Turbine power (w)	Power electric of the wind turbine (w)
0	0	0	0
1	0,075	0	0
2	0,106	0	0
3	0,119	7,2	0,8568
4	0,121	21,9	2,6499
5	0,113	51,6	5,8308
6	0,103	93,3	9,6099
7	0,086	155	13,33
8	0,075	243	18,225
9	0,056	354	19,824
10	0,042	489	20,538
11	0,033	560	18,48
12	0,024	600	14,4
13	0,016	600	9,6
14	0,012	600	7,2
15	0,008	600	4,8
16	0,005	600	3
17	0,003	600	1,8
18	0,002	600	1,2
19	0,001	600	0,6
20	0	0	0
Total	1		151,9444

Table 12.1: Calculation of the power of one generator

$$Power\ electric\ of\ the\ wind\ turbine = Turbine\ power \cdot Probability$$

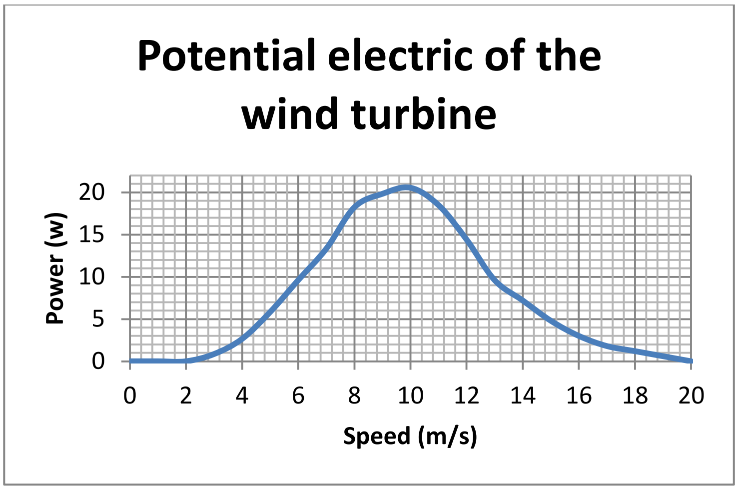


Figure 12.2: Power generated by one turbine apply the probability of the wind speed (by unit of area)

Now we are going to calculate different parameters of the wind and the turbine in the next table (Table 12.2):

v(m/s)	f(v)	Electric power (KW)	Power of the wind (KW)	Electric power before the generator	Energetic power of the wind	Power coefficient (Cp)
0	0	0	0,000	0,000	0,000	0,000
1	0,075	0	1,086	0,000	0,081	0,000
2	0,106	0	8,686	0,000	0,921	0,000
3	0,119	7,2	29,315	0,857	3,488	0,246
4	0,121	21,9	69,487	2,650	8,408	0,315
5	0,113	51,6	135,717	5,831	15,336	0,380
6	0,103	93,3	234,519	9,610	24,155	0,398
7	0,086	155	372,407	13,330	32,027	0,416
8	0,075	243	555,896	18,225	41,692	0,437
9	0,056	354	791,500	19,824	44,324	0,447
10	0,042	489	1085,734	20,538	45,601	0,450
11	0,033	560	1445,113	18,480	47,689	0,388
12	0,024	600	1876,149	14,400	45,028	0,320
13	0,016	600	2385,359	9,600	38,166	0,252
14	0,012	600	2979,255	7,200	35,751	0,201
15	0,008	600	3664,354	4,800	29,315	0,164
16	0,005	600	4447,168	3,000	22,236	0,135
17	0,003	600	5334,213	1,800	16,003	0,112
18	0,002	600	6332,003	1,200	12,664	0,095
19	0,001	600	7447,052	0,600	7,447	0,081
20	0	0	8685,875	0,000	0,000	0,000

Table 12.2: Different parameters of the wind and the turbine

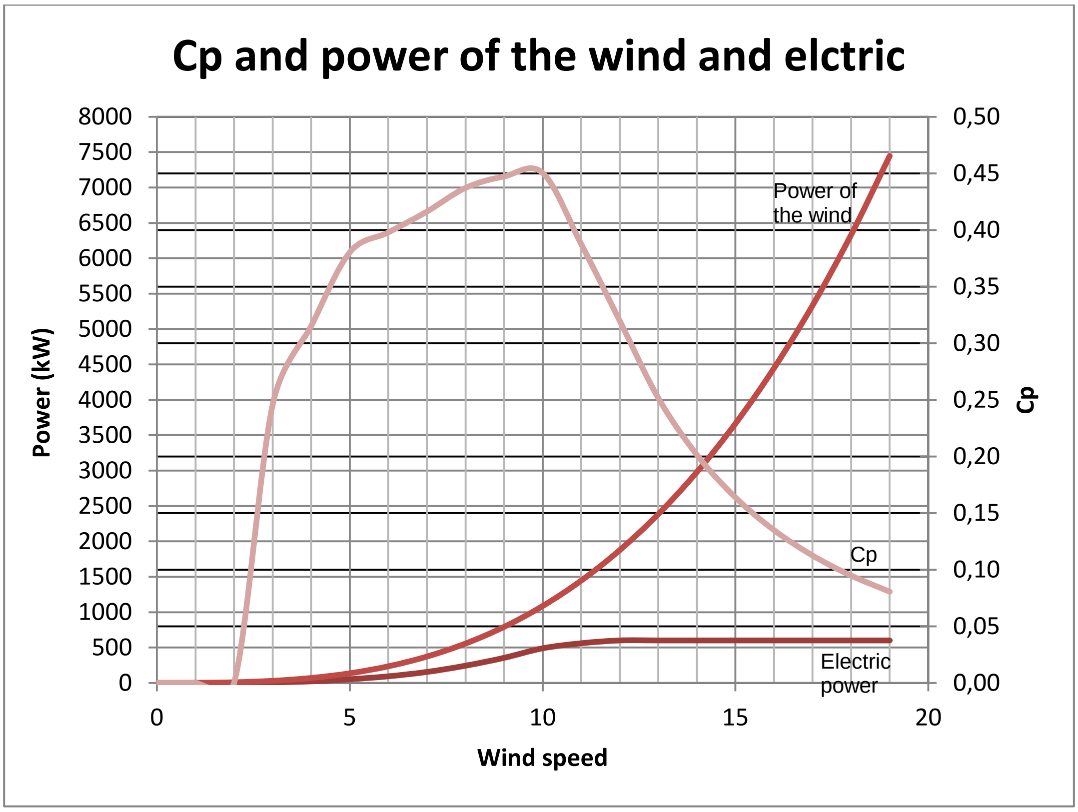


Table 8.3: Power coefficient and power of the wind and electric power depending on the wind speed

In the following paragraph we are going to put the different equations that we use in the last table (Table 12.2) and that we are going to use to calculate the energy of one turbine during a year (Table 12.3):

- $Power\ of\ the\ wind = \frac{1}{2} \cdot \frac{\rho \cdot \pi \cdot r^2 \cdot v^3}{1000}$
- $Electric\ power\ before\ the\ generator = Electric\ power \cdot f(v)$
- $Energetic\ power\ of\ the\ wind = Power\ of\ the\ wind \cdot f(v)$
- $Power\ coefficient\ (Cp) = \frac{Electric\ power}{Power\ of\ the\ wind}$
- $Average\ electric\ power = \sum_{i=0}^{20} Elec. power\ before\ the\ generator_i$
- $Average\ \ wind\ power = \sum_{i=0}^{20} Energetic\ power\ of\ the\ wind_i$
- $Electrical\ energy\ in\ one\ year = \left(Average\ electric\ power \cdot \frac{8760}{10^6}\right)$
- $Wind\ energy\ in\ one\ year = \left(Average\ wind\ power \cdot \frac{8760}{10^6}\right)$
- $Equivalent\ hours = Average\ electric\ power \cdot \frac{8760}{Max.power\ of\ the\ turbine}$
- $Average\ Cp = \frac{Average\ electric\ power}{Average\ \ wind\ power}$
- $Average\ efficiency = \frac{100 \cdot Average\ Cp}{0.593}$
- $Maximum\ efficiency = \frac{100 \cdot Maximum\ Cp}{0.593}$

Average electric power (kW)	Average wind power (kW)	**Electric energy in one year (GWh)**	Wind energy in one year (GWh)	**Equivalent hours**	Average Cp	Maximum Cp
151,944	470,331	**1,33103294**	4,12010364	**2218,38824**	0,32305812	0,45

Average efficiency (%)	Maximum efficiency (%)
54,4786041	75,9504864

Table 12.3: Energy production of one turbine in a year

All of these data (Table 12.3) are for only one turbine and we have 3 in our park so we will have the next numbers (Table 12.4):

Average electric power (kW)	**455,832**
Electric energy in one year (GWh)	**3,99309883**

Table 12.4: Data of the theoretical park

To the data of energy we have to apply the different coefficient of loses due to the machine and substations failures (0.98), transport loses (0.97), maintenance loses (0.96)… to have the real energy value that we are going to generate:

$$Electric\ energy\ real\ (MWh) = 3.99309883 \cdot 1000 \cdot 0.98 \cdot 0.97 \cdot 0.96 = 3644.006$$

13. Calculation of the transformer

13.1. Cables between the turbines and the transformers

The transformers will be situated in an intermediate point of the three turbines to have the least losses possible in low voltage. Also, they will be located in a safe point, in a distance of the central turbine and in the north part of the area that we have because they will be nearer of the net.

They will be situated more or less 250 meters far from the extremes turbines and 100 meters far from the centre one.

The maximum power of the turbines is a 5% more of the nominal power:

$$P_{Max} = 600 \cdot 5\% + 600 = 630\ kW$$

Now we are going to calculate the section of the cables attending to different aspects:

- Intensity criteria

$$I = \frac{P}{\sqrt{3} \cdot V \cdot Cos\phi}$$

This aspect is the same for all the turbines, so the calculation is:

$$I = \frac{P}{\sqrt{3} \cdot V \cdot Cos\phi} = \frac{630000}{\sqrt{3} \cdot 690 \cdot 1} = 527{,}15\ A$$

With this intensity we take the regulation of buried lines and we select the section that supports the current:

If we check the REBT-ITC-07 we see that with a 500 mm^2 we can support the current (we have considerate different factors to apply to the table). The cables won´t be in the same tube, they will go separately.

- Voltage that falls down criteria

$$S = \frac{2 \cdot L \cdot P}{c \cdot u \cdot V}$$

$S =$ Section (mm^2)
$L =$ Length of the line (m)
$P =$ Power connected (W)
$c =$ Conductivity of the copper (S/m=56)
$u =$ Tension that can falls down (3%)
$V =$ Nominal voltage (V)

In the extremes turbines:

$$S = \frac{2 \cdot L \cdot P}{c \cdot u \cdot V} = \frac{2 \cdot 300 \cdot 630000}{56 \cdot 3\% \cdot 690 \cdot 690} = 472{,}59\ mm^2$$

In the central turbine:

$$S = \frac{2 \cdot L \cdot P}{c \cdot u \cdot V} = \frac{2 \cdot 150 \cdot 630000}{56 \cdot 3\% \cdot 690 \cdot 690} = 236{,}29\ mm^2$$

After these calculations we have to check which are the upper sections normalized in the regulation of buried lines.

We add 50 meters due to the height of the turbine.

- Thermal criteria

$$T_{x\,mm^2} = T_0 + (T_{Max} - T_0) \cdot \left(\frac{I}{I_{adm}}\right)^2$$

$T_{x\,mm^2}$: Temperature that is going to be in the cable with section "x".
T_0: Temperature of the cable (25ºC for be buried).
T_{Max}: Maximum temperature that the cable can support (250ºC for be XLPE insolating and in short circuit case).
I: Current that is going to pass for the cable in normal conditions.
I_{adm}: Current maximum that the cable support.

$$T_{500\,mm^2} = 25 + (250 - 25) \cdot \left(\frac{527{,}15}{615}\right)^2 = 190{,}31\ ºC$$

$$T_{300\,mm^2} = 25 + (250 - 25) \cdot \left(\frac{527{,}15}{485}\right)^2 = 290{,}81\ ºC$$

With these results we can see that the section of 500 mm^2 will support the current due to the thermal criteria (because the temperature is less than 250 ºC that supports the XLPE) but not the 300 mm^2 cable.

- Short circuit current criteria

$$S = \frac{I \cdot t^{0,5}}{k}$$

I: Intensity of short circuit in the secondary
t: Time that the protections actuate.
k: Density of short circuit current for cables with XLPE insulation. (143 for copper cables and 94 for aluminium ones).

The short circuit current in the secondary and the section of the cable to support it are calculated here:

$$I_{scs} = \frac{S}{\sqrt{3} \times (\frac{U_{sc}}{100}) \times U_s} = \frac{1}{\sqrt{3} \times (\frac{6}{100}) \times 0.69} = 13{,}946\ KA$$

$$S = \frac{13946 \cdot 1^{0,5}}{143} = 97{,}52\ mm^2$$

When we have finished the calculations we have to choose the bigger normalized section and appoint the neutral and the protection conductor:

- The cables of the three turbines will be: RV-K 0,6/1kV 3x500 Co + 2x300 Co

These cables aren´t definitive because they depend on the low voltage protections too. So that, we will put a final paragraph with the definitive values.

13.2. General information of the transformer

The transformer will be installed in a prefabricated building, so it will be interior refrigerated with oil. For its control we will install cells with metallic surrounding.

The high voltage cables arrive aerially to the center and after the transformer we will buried them till the different turbines. The high voltage net will be of 20 kV and the low voltage of 690 V, both of them with a frequency of 50 Hz. The supplier electric company will be CHEZ.

The transformer will be installed in the same field of the turbines, near the north east corner as we can see in the figure (Figure 13.1):

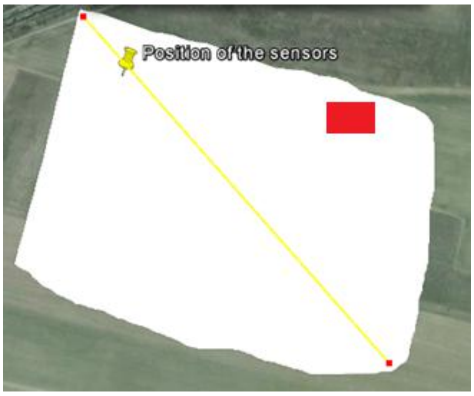


Figure 13.1: Situation of the transformer center (red square) inside our field.

13.3. Calculation of the transformers

Once that we have the power of the park we have to choose the transformer or transformers that we want to put. In our case, the power that our plant has is calculated in the next paragraph:

$$S_{calc} = \frac{P_{calc}}{Cos\phi} \cdot F = \frac{455832W}{1} \cdot 2 = 911664\ VA$$

P_{calc}: Power of the turbines taking care of the wind speed of the last year.
$Cos\phi$: Gap between current and tension vector.
F: Factor of oversize.

In this case, the $Cos\phi$ is 1 because our turbines have each one a capacitor bank that correct the difference between vectors to zero. The factor of oversize we have putted two because we want to foresee an increase of wind in our region.

However finally we are going to dimensioning the transformer with the maximum power that we can have in our park, because we want to obtain the maximum energy if one day the three of them are working in the maximum power together.

$$S_{calc} = 600\ W \cdot 3 \cdot 0.05 = 1890\ kVA$$

The factor 0.05 is because our turbines can produce 5% more than the nominal power with the right conditions.

With this figure we finally decide to put three transformer of 800 kVA each one. We decide to put three instead of one because if we would have a problem in one of them we can continue producing energy with the others.

The tension of the generators of the turbines give in the output is 690V, a no-normal tension that forces us to ask a special transformer to the company. However, we are going to work with the data of a normal transformer (0.4/20 kV and 800 kVA). We can make this because the data of the special one will be similar and also, the losses will be smaller due to the current will be smaller too. The characteristics are in the next table (Table 13.1):

Series B-B' Hermetic		
Rated Power	kVA	800
Type		TMXB
Rated Voltage HV	kV	20
Rated Voltage LV	V	400
Vector-group symbol		Dyn5
No-load losses	W	1450
Load losses	W	10500
Impedance voltage	%	6
Weight of oil	kg	490
Weight of transformer	kg	2420
Transformer dimensions		
A	mm	1680
B	mm	1030
C	mm	1565
D	mm	1180
N1	mm	385
N2	mm	290
K1	mm	380
K2	mm	170
E	mm	820
G	mm	150
F	mm	50

Table 13.1: Characteristics of the transformer

These characteristics belong to a transformer of Elprom Trafo CH, with 800 kVA of power. The characteristics are copied from a catalog of this company.

13.3.1. Intensity of short circuit in primary and secondary of the transformers

The intensity of short circuit can be calculated in both cases with the next expressions:

$$I_p = \frac{S}{\sqrt{3} \times U_p}$$

$$I_s = \frac{S - L_{NL} - L_L}{\sqrt{3} \times U_s}$$

I_p = Intensity of primary (A)
S = Power of the transformer (KVA)
U_p = Voltage primary (KV)
I_s = Intensity of secondary (A)
L_{NL} = No-Load loses (KW)
L_L = Load loses (KW)
U_s = Voltage secondary (KV)

$$I_p = \frac{S}{\sqrt{3} \times U_p} = \frac{800}{\sqrt{3} \times 20} = 23{,}094\ A$$

$$I_s = \frac{S - P_{fe} - P_{cu}}{\sqrt{3} \times U_s} = \frac{800 - 1{,}45 - 10{,}5}{\sqrt{3} \times 0{,}69} = 659{,}393 A$$

13.3.2. Short circuit current in the low voltage site

The short circuit current can be calculated in the primary and in the secondary with the follow equations:

$$I_{scn} = \frac{S_{sc}}{\sqrt{3} \cdot U_p}$$

$$I_{scs} = \frac{S}{\sqrt{3} \cdot (\frac{U_{sc}}{100}) \cdot U_s}$$

I_{scn} = Short circuit intensity of the net (KA)
S_{sc} = Short circuit power of the net (MVA)
U_p = Primary voltage (KV)
S = Power of the transformer (MVA)
I_{scs} = Short circuit intensity in the secondary (KA)
U_{sc} = Short circuit voltage of the load (KV)
U_s = Secundary voltage in load (KV)

$$I_{scn} = \frac{S_{sc}}{\sqrt{3} \cdot U_p} = \frac{400}{\sqrt{3} \cdot 20} = 11{,}547\ KA$$

$$I_{scs} = \frac{S}{\sqrt{3} \cdot (\frac{U_{sc}}{100}) \cdot U_s} = \frac{0{,}8}{\sqrt{3} \cdot (\frac{6}{100}) \cdot 0{,}69} = 11{,}157\ KA$$

13.3.3. Calculation of the transformer busbar

The Medium Voltage busbar is calculated by current density, electrodynamics solicitation and thermal solicitation:

13.3.3.1. Checkout by current density

The current that passes by the busbar normally is I, and the density is:

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

A: Area of the cable. In this case:

We will try with a copper busbar of 25x4 mm. The section used will be:

$$A = a \cdot b = 25 \cdot 4 = 100\ mm^2$$

The density will be:

$$\delta = \frac{I}{A} = \frac{23{,}094}{100} = 0{,}231\ A/mm^2$$

Now we have to check if the cable is able to support this density. We can search in the next web in the page 16:

http://www.unileon.es/ficheros/servicios/prevencion/d3151_1968.pdf

We see in this Article 22 of Aerial electric lines that the next section supports 3,70 A/mm^2, so is totally valid.

Also, as we can see in the next table (Table 13.2) of the fabricant, the busbar that we selected is the second one and supports the intensity in the primary of our transform (24 A):

Size (mm)	AC allow (A)	Ohmic resistance
25x25x3	155	1,01
25x25x4	163	0,78
30x30x4	193	0,64
35x35x4	226	0,54
40x40x4	260	0,47
40x40x5	278	0,38
45x45x5	312	0,34
50x50x5	345	0,27
60x60x6	416	0,17
75x75x8	545	0,08

Table 13.2: Current admissible, Ohmic resistance and size of different copper busbar

13.3.3.2. Checkout by electrodynamics solicitation

The forces electrodynamics in the busbar will be:

$$\frac{F}{L} = 0{,}2 \cdot \frac{{I_s}^2}{a} \qquad \left(\frac{kg}{cm}\right)$$

I_s: Secondary peak intensity (kA)
a: Separation between busbar (cm)

$$\frac{F}{L} = 0{,}2 \cdot \frac{\left(11{,}547 \cdot \sqrt{2}\right)^2}{40} = \ 1{,}333 \ \left(\frac{kg}{cm}\right)$$

We can consider the busbar like an object supported by the two extremes, so that, the maximum bending moment is:

$$M_{max\ b} = \frac{1}{8} \cdot \frac{F}{L} \cdot L^2 \qquad (kg \cdot cm)$$

L: Length of bars between supports (cm).

$$M_{max\ b} = \frac{1}{8} \cdot 1{,}333 \cdot 2{,}5^2 = 1{,}041 \ (kg \cdot cm)$$

The resistant moment of:

- A solid circle bar is: $W = \frac{\pi \cdot d^3}{32}$
- A tubular section bar: $W = \frac{\pi \cdot (D^4 - d^4)}{32 \cdot D}$
- A solid square bar: $W = \frac{a \cdot b^2}{6}$

$$W = \frac{a \cdot b^2}{6} = \frac{2{,}5 \cdot 0{,}4^2}{6} = 0{,}0667 \ cm^3$$

The maximum tension of the bar material will be:

$$\sigma = \frac{M_{max\ b}}{W}$$

Considering that $\sigma < \sigma_{break}$

$$\sigma = \frac{M_{max\ b}}{W} = \frac{1{,}041}{0{,}0667} = \frac{15{,}613 kg}{cm^2} = \frac{0{,}15613 \text{kg}}{\text{mm}^2} \ll \frac{21 \text{kg}}{\text{mm}^2}$$

The mechanical characteristic of the copper are: density 8.900 kg/m^3, elasticity model 13.000 kg/mm^2 and traction strength 21 kg/mm^2.

13.3.3.3. Checkout by thermal solicitation

Thermal and resistivity characteristics of copper: specific heat 383.3 J/kg*ºC and resistivity 1.78x10^{-8} Ω*m.

In case of short circuit there is an overheating of the busbar, admitting higher temperatures than in the normal service due to the short duration of it. For this phenomenon we have to check if our section of busbar supports the current (copper):

$$I_{th} = a \cdot S \cdot \sqrt{\frac{DT}{t}}$$

I: Average intensity (A).
a: 13 for copper.
S: Section of the busbar (mm^2).
DT: Maximum increase of temperature, (150ºC copper).
t: Time of during of the short circuit.

$$I_{th} = 13 \cdot 100 \cdot \sqrt{\frac{150}{1}} = 15921{,}68\ A$$

With the characteristics of this busbar it can support almost 16 kA in 1 second for the short circuit, so in our case we haven´t got any problem.

13.3.4. Calculate of the ground installation

The place that we are going to put the transformer centre is the same where we will install the turbines, so that, it is a growing field with a resistivity of 500 Ω · m. We can check the resistivity of the ground in the next table (Table 13.3):

Nature of the terrain	Resistivity (Ωxm)
Wetlands	0-20
Silt	20-100
Humus	10-150
Moist Peat	5-100
Plasticines	50
Marl and shale	100-200
Jurassic marls	30-40
Loamy sand	50-500
Silica sand	200-3000
Stony soil covered with grass	300-500
Bare stony ground	1500-3000
Soft limestone	100-300
Compact limestone	1000-5000
Cracked limestone	500-1000
Slates	50-300
Mica and quartz rocks	800
Granite and sandstone from alterations	1500-10000
Granite and sandstone very altered	100-600
Concrete	2000-3000
Ballast or gravel	3000-5000

Table 13.3: Materials and its resistivity

13.3.4.1. Maximum current of ground connection and maximum time of elimination of this defect.

In installation with tension the same or less than 30 kV the different aspects to take care are the next:

- Type of neutral connection

The calculations are different if the neutral wire is isolated, directly connect to the ground or join with impedance.

- Type of line protection

If we have a short circuit in the net it will be eliminated with the open of an element that is commanded by a current measurer.

The maximum time of elimination of the defect is 1 second, and the values of the impedance of the ground connection of the neutral wire will not be less than 20 **Ω**.

With these data and the normative of the MIE-RAT 13 we can obtain the values of “K” and “n”. With these values we can calculate the maximum intensity of ground connection.

$$Id_{máx} = \frac{U_{p\ máx}}{\sqrt{3} \cdot Z_n} = \frac{20000}{\sqrt{3} \cdot 20} = 577.35A \ \approx 570A$$

Id_{max} = Maximum defect of intensity (A)
$U_{p\ max}$ = Maximum tension in the primary (V)
Z_n = Value of the ground connection impedance (Ω)

13.3.4.2. Design of the ground installation

For the different operations that we have to make we will use the expressions, procedures and equations of the “Calculate method and project of ground connection installations for transformer center of third category”, edited by UNESA.

- Protection ground

To this system will be connected the metallic parts of the installation that haven´t got tension in a normal use but can have due to breakdowns or other accidental causes. For example: metal enclosures of the cabins, ventilation grids, transformer housings…

- Code of the protection ground (UNESA): 70-60/5/46
  - The firsts 2 numbers (70) mean the length of the ground protection in dm.
  - The next 2 numbers (60) mean the width of the ground protection in dm.
  - The number between bars (5) means the deep of the ground protection spikes in dm.
  - The penultimate number (4) means the number of spikes that we are going to put.
  - The last number (6) means the length of the spikes in meters.
- Characteristic parameters:

$$Kr = 0.056 \left(\frac{\Omega}{\Omega \times m}\right)$$
$$Kp = 0.0113 \left(\frac{V}{\Omega \times A}\right)$$

- Description:

  The installation will be constituted by 4 spikes in rectangular disposition join with a horizontal conductor of copper of 50 mm^2.

  The spikes will have a diameter of 14 mm and a length of 6 m. They will be buried vertically in a 0.5 m deep, and the space between them will be 6 and 7 meters, depending on the side. With this configuration the horizontal conductor will have 26 m long.

We can choose other configuration always that the parameters Kp and Kr will have a smaller values than before.

The connection from the transformer center to the first spike will be made by a cooper isolated wire of 0.6/1kV, protected against mechanical damages.

- Service ground

To this system we are going to connect the neutral wire of the transformers and ground of the transformers of tensions and current form the measure cell.

- Code of the service ground (UNESA): 5/44
  - The first number (5) means the deep that the spikes are going to be installed in dm.
  - The second number (4) means the number of spikes that we are going to put.
  - The last number (4) means the length of the spikes in meters.
- Characteristics parameters:

$$Kr = 0.0572\left(\frac{\Omega}{\Omega \times m}\right)$$

$$Kp = 0.00919\left(\frac{V}{\Omega \times A}\right)$$

- Description:

The service ground will be constituted by 4 spikes in a row join with a conductor horizontal without cover and a 50 mm^2 section.

The spikes will have a diameter of 14 mm and a length of 4 m. They will be buried vertically in a deep of 0.5 m and a separation between them of 6 m. With this configuration the length of the bare cable from the first spike to the last will be 18 m.

We can use other configurations always that the parameters Kp and Kr have a less value than before.

The connection from the transformer center to the first spike will be made by a cooper isolated wire of 0.6/1kV, protected against mechanical damages.

The value of the resistance has to be less than 37 Ω (the electrode with the connection cable). With this rule we make that a defect to ground in a low voltage installation protected against indirect contacts with a differential interrupter of 300 mA of sensibility doesn´t generate a tension bigger than 24 V (maximum permitted).

We have to take care about the separation between the spikes of the protection ground and the service ground ones. This is because if they are too close, could be a defect in high voltage and transfer big tensions to the low voltage net.

13.3.4.3. Calculation of the ground installation resistance

- Protection ground

For calculate the resistance of the ground connection (R_t), the intensity and the tension of defect (Id, Ud) we will use the following equations:

$$R_t = Kr \cdot \rho$$

$$Id = \frac{U_{p\,máx}}{\sqrt{3} \cdot \sqrt{(R_n + R_t)^2 + {X_n}^2}}$$

$$Ud = Id \cdot R_t$$

R_t: Resistance of ground connection (Ω)

$Kr = 0{,}056 \left(\frac{\Omega}{\Omega \times m}\right)$

$\rho = 500\ (\Omega \cdot m)$

Id: Defect intensity (A)

$U_{p\,max}$: Maximum tension of the primary (V)

R_n and X_n: Give the value to the impedance of ground connection of the neutral wire: $Z_n = \sqrt{{R_n}^2 + {X_n}^2} = \sqrt{20^2 + 0^2} = 20\Omega$

Ud: Defect tension (V)

$$R_t = Kr \cdot \rho = 0{,}056 \cdot 500 = 28\Omega$$

$$Id = \frac{U_{p\,máx}}{\sqrt{3} \cdot \sqrt{(R_n + R_t)^2 + {X_n}^2}} = \frac{20000}{\sqrt{3} \cdot \sqrt{(20 + 28)^2 + 0^2}} = 240{,}563\ A$$

$$Ud = Id \cdot R_t = 240{,}563 \cdot 28 = 6735{,}753\ V$$

The isolation of the installation in low voltage of the transformer center has to be the same value or bigger than the maximum defect tension calculated (Ud), so that, the protection will be 10 kV. With protections of this value we ensure that the low voltage elements aren´t going to suffer any damage due a defect in the high voltage part.

Also, with the current of defect calculate we can see that the normal protection will actuate normally because the value is bigger than 100A.

Sum:

- Configuration: 70-60/5/46
- Geometry: Ring
- Dimension: 7x6 m
- Deep of the spikes: 0.5 m
- Number of spikes: 4
- Resistance Kr = 0.056 $\left(\frac{\Omega}{\Omega \times m}\right)$
- Step voltage Kp = 0.0113 $\left(\frac{V}{\Omega \times A}\right)$
- Contact voltage Kc = 0.0215 $\left(\frac{V}{\Omega \times m \times A}\right)$

- Service ground

The resistance of the service ground is calculated by the multiplication of the electrode value and the ground resistance:

$$R_t = Kr \cdot \rho = 0.0572 \cdot 500 = 28.6\Omega < 37\Omega$$

Sum:

- Configuration: 5/44
- Geometry: spikes in a row
- Deep of the spikes: 0.5 m

- Number of spikes: 4
- Length of the spikes: 4 m
- Distance between spikes: 6m
- Resistance Kr=0.0572 $\left(\frac{\Omega}{\Omega\times m}\right)$
- Step voltage Kp=0.00919 $\left(\frac{V}{\Omega\times A}\right)$

13.3.4.4. Calculation of the exterior tension of the installation

With the goal of avoid the high contact tension in the exterior of the installation, the doors and metallic grids that have contact with the exterior haven´t got direct contact with conductor mass that in case of breakdown can have tension.

The walls of the transformer center will have a resistance of 100 kΩ.

With these security measures we haven´t got to calculate the contact tension in the exterior, it will be near to zero.

However we have to calculate the step tension in the exterior with the next equation:

$$U_{p\ ext} = Kp \cdot \rho \cdot Id = 0{,}0113 \cdot 500 \cdot 240{,}563 = 1359{,}19\ V$$

13.3.4.5. Calculation of the interior tension of the installation

In the floor of the transformer center will be installed a welded grid of a metallic material which diameter is not less than 4 mm. The material will form squares no bigger than 0,3x0,3 m. This grid will be connected to at least two opposite points of the transformer center protection ground. That grid will be covered by a concrete layer of 10 cm at least.

With this measure the person who must touch a part of the transformer center that could be in tension due to a breakdown or a defect, haven´t got any problem because she/he will be above an equipotential area, so the risk to suffer a contact tension or a step tension inside the center disappears. They will be near zero, so that, we haven´t got to calculate them.

Nevertheless, the existence of an equipotential area connected to the ground electrode makes that the step tension of access to the center is the same as the contact exterior tension:

$$U_{p\ access} = Kc \cdot Id \cdot \rho = 0{,}0215 \cdot 240{,}563 \cdot 500 = 2586{,}05\ V$$

13.3.4.6. Calculation of the maximum applied tension

The maximum contact tension that can be suffered according to the MIE-RAT 13 is:

$$U_{ca} = \frac{K}{t^n}$$

U_{ca}: Maximum contact tension that can be applied. (V).

$K = 78.5$

$t = 1s$: Duration of the defects (s)

$n = 0.18$

$$U_{ca} = \frac{K}{t^n} = \frac{78.5}{1^{0.18}} = 78.5\ V$$

To calculate the maximum values admissible for the step tension in the exterior and the access tension we will use the next equations:

$$U_{p\ exterior\ max} = 10 \cdot \frac{K}{t^n} \cdot \left(1 + \frac{6 \cdot \rho}{1000}\right)$$
$$U_{p\ access\ max} = 10 \cdot \frac{K}{t^n} \cdot \left(1 + \frac{3 \cdot \rho + 3 \cdot \rho_c}{1000}\right)$$

ρ: Resistivity of the ground ($500\Omega \cdot m$)
ρ_c: Resistivity of the concrete ($3000\Omega \cdot m$)

$$U_{p\ exterior\ max} = 10 \cdot \frac{K}{t^n} \cdot \left(1 + \frac{6 \cdot \rho}{1000}\right) = 10 \cdot \frac{78.5}{1^{0.18}} \cdot \left(1 + \frac{6 \cdot 500}{1000}\right) = 3140\ V$$
$$U_{p\ access\ max} = 10 \cdot \frac{K}{t^n} \cdot \left(1 + \frac{3 \cdot \rho + 3 \cdot \rho_c}{1000}\right) = 10 \cdot \frac{78.5}{1^{0.18}} \cdot \left(1 + \frac{3 \cdot 500 + 3 \cdot 3000}{1000}\right)$$
$$= 9027{,}5\ V$$

Now we check if the values that we have obtained are less than these:

$$U_{p\ ext} = 1359{,}19\ V < U_{p\ exterior}\ (MIE - RAT) = 3140\ V$$
$$U_{p\ acceso} = 2586{,}05V < U_{p\ acceso\ max}\ (MIE - RAT) = 9027{,}5\ V$$

13.3.4.7. Investigation of the tension transferable to the exterior

We haven´t got any way of tension transference to the exterior, so, we don´t need a study for this.

Nonetheless, we have to calculate the minimum distance between the service ground and the protection ground for in case a defect appear the service ground doesn´t experiment a big increase of its tension. If the service ground would have a big tension the workers will have risk of electrocuted. The distance minimum is:

$$D_{mín} = \frac{\rho \cdot Id}{2 \cdot 1000 \cdot \pi} = \frac{500 \cdot 240{,}563}{2000 \cdot \pi} = 19{,}15\ m$$

This distance will separate the protection ground and the service ground but also, as we have more than one prefabricated transformation center, the distance between them must be bigger than this.

13.3.4.8. Correction and adjust of the starter design establishing the definitive

We don´t consider any correction in the design system because it passes all the calculations and rules.

Something could happen when we will install the service and the protection ground, is that the value of them increase, so, generate some risks. In that case we will put some extra material in the floor of the transformer center to increase the resistivity.

13.3.5. Dimension of the ventilation of the Transformer Center

The ventilation of the Centre will made with natural ventilation in the walls of it. To prevent the entry of elements we will put grids. The space open will be calculated:

$$Q = \frac{L_{NL} + L_L}{1{,}16 \cdot \Delta T}$$

L_L: Load loses (10.5 KW).
L_{NL}: No-Load loses (1.45 KW).
ΔT: Difference of temperature between the air that come inside and the air that leaves the Centre. (15ºC)
Q: Airflow (m^3/s)

Now we are going to calculate the area of the grid, but first the speed of the wind that entry in the transformer cabin:

$$w_s = 4{,}6 \cdot \frac{\sqrt{H}}{\Delta T}$$

H: Difference of height between the grids of input and output (2 meters)
w_s: Wind speed (m/s)

$$A_{minimum} = \frac{Q}{w_s}$$

$A_{minimum}$: Minimum area for the ventilation grid (m^2)

$$A_{grid} = 1{,}4 \times A_{minimum}$$

A_{grid}: Area of the gird (m^2)
1,4: Coefficient of mayoration of the gird, due to that 40% is the space ocupated by the grid lamas.

Now we are going to substitute the different values in the equations and obtain the area of the grid:

$$Q = \frac{L_{NL} + L_L}{1{,}16 \cdot \Delta T} = \frac{1{,}45 + 10{,}5}{1{,}16 \cdot 15} = 0{,}687\ m^3/s$$

$$w_s = 4{,}6 \cdot \frac{\sqrt{H}}{\Delta T} = 4{,}6 \cdot \frac{\sqrt{2}}{15} = 0{,}434\ m/s$$

$$A_{minimum} = \frac{Q}{w_s} = \frac{0{,}687}{0{,}434} = 1{,}582\ m^2$$

$$A_{grid} = 1{,}4 \cdot A_{minimum} = 1{,}4 \cdot 1{,}582 = 2{,}215\ m^2$$

Finally, we are going to put in the walls of the transformer center 6 grids of 1 meter of length and 0.5 meters of width. We can put a smaller grid but we prefer to have a good ventilation and refrigeration of the transformers.

13.3.6. Well fire-fighting dimension

The well of collecting oil has to be big enough for store all the volume of the transformer. In this case, we are going to install a prebuild building, so that, the company has dimensioned the well to store all the dielectric of the transformer without problem.

In the superior part of the well will be installed a system that extinguish the flames in case of have them. It consists in metal gratings that produce the auto-extinguish of the oil flame.

13.3.7. Cells SM6

The cells that we are going to use are from the SM6 series of Merlin Gerin. They are modular cells air-insulated that use sulphur hexafluoride as the cutting and arc extinction element.

The differentiated cells are:

13.3.7.1. Lift cell

We are going to use a Merlin Gerin cell of switch-disconnector with three positions, range SM6. It allow to communicate the busbar with the cables, switch off the nominal current, disconnect this union or derivate to ground at the same time the three terminals of the High Voltage wires.

- Bars of 400 A.
- Switch-disconnector of SF6 of 400 A, tension of 24 kV and 16 kA.
- Earthing disconnector of SF6.
- Voltage presence indicators.
- Earthing busbar.
- Terminals of wire connection.

Electric characteristics:

- Nominal tension 24 kV
- Nominal current 400 A
- Short duration current (3s) 16 kA
- Isolation level
  - Industrial frequency (1 min)
    - To ground and between phases 50 kV
    - For disconnecting distance 60 kV
  - Lightning impulse
    - To ground and between phases 125 kV
    - For disconnecting distance 145 kV
- Close capacity 40 kA
- Cut capacity
  - Principally activate current 400 A
  - Capacity current 31.5 A
  - Inductive current 16 A
  - Earth fault 63A

13.3.7.2. Protection cell

Merlin Gerin cell with fuses and switch protection.

Electric characteristics:

- Nominal tension 24 kV

– Nominal current of the busbar	400/630 A
– Output nominal current of the transformer	600A
– Short duration current (3s)	16 kA
– Isolation level	
o Industrial frequency (1 min)	
To ground and between phases	50 kV
For disconnecting distance	60 kV
o Lightning impulse	
To ground and between phases	125 kV
For disconnecting distance	145 kV
– Cut capacity	
o Principally activate current	400/630 A
o Capacity current	31.5 A
o Inductive current	16 A
o Earth fault	63A
– Combination breaking capacity of switch and fuses	20 kA
– Transference current	600A

13.3.7.3. Measuring cell

Merlin Gerin cell of tension and current measuring with a lateral input by bars and lateral output by wires, range SM6.

- Bars of 400 A, tension of 24 kV and 16 kA.
- Lateral input by bars and lateral output by wires.
- 3 intensity transformers with relation 20/5 A, 15 VA (loses in the cables and in the measuring elements), CL: 0.5 (for be a billing use) and 24 kV isolation.
- 3 tension transformers with relation Ft= 1.9 Un, CL: 0.5 (for be a billing use) and 24 kV isolation.

The factor tension is determined by the maximum tension when the transformer is working. The factor depends on the neutral wire of the net and of the earthing connection of the primary winding.

- 1.9 Un during 30 s, if the network isn´t neutral effectively grounded, with automatic removal of the defect.
- 1.9 Un during 8 h, if the network has isolated neutral or it´s compensate by an extinction winding, without automatic removal of the defect.

13.3.8. Protections in low voltage

In the low voltage part of the transformers we are going to put different elements to protect our installation and the security of the persons. We will put a magnetothermal switch, a differential switch, a manual cutting switch and a measuring of energy production system:

13.3.8.1. Magnetothermal switch

This switch is going to work for cut the current in case of short circuit or overload, so that, we have to calculate the nominal current, the cut power and the curve. First we will put all the equations and define the different things:

$Z_{H.V.}(j) = \frac{u_{H.V.}^2}{S_{sc}}$ $\quad Z_{L.V.}(j) = Z_{H.V.}(j) \cdot \frac{u_{L.V.}^2}{u_{H.V.}^2}$ $\quad Z_{Transformer}(j) = U_{cc} \cdot \frac{u_{L.V.}^2}{S_n}$

$Z_{Aparament1}(j) = nº \cdot 0.00015$

$Z_{Line} = \phi \times \frac{L}{s}$ $\quad |Z_d| = \sqrt{(Z_{Lines})^2 + (Z(j))^2}$

$|Z_o| = \sqrt{(3 \cdot Z'_{Lines})^2 + (Z_{Transformer}(j) + 3 \cdot Z_{Aparament}(j))^2}$

$t_{mcicc} = \frac{C_c \cdot s^2}{I_{ccf}^2}$

$u_{H.V.}$: High voltage tension.
$u_{L.V.}$: Low voltage tension.
S_{sc}: Short circuit power.
$Z_{H.V.}$: Impedance of the high voltage line.
$Z_{L.V.}$: Impedance reference to the low voltage part.
S_n: Power of the transformer.
U_{sc} (%): Short circuit tension that could be search in the next table (Table 13.4):

Power of the transformer	$\boldsymbol{U_{sc}}$
$S_n \leq 630KVA$	4%
$630KVA \leq S_n \leq 800KVA$	4.5%
$800KVA \leq S_n \leq 1000KVA$	5%
$1000KVA \leq S_n \leq 1600KVA$	6%

Table 13.4: Short circuit tension depending on the transformer power

$Z_{Aparament1}$: Impedance of the elements before the switch.
Z_{Line}: Impedance of the line between the transformer and the switch.
$|Z_d|$: Direct impedance
$|Z_o|$: Homopolar impedance
$nº$: Number of elements
ϕ: Resistivity of copper (0.018).
L: Length of the line.
s: Section of the line.
$I_{cc\,max}$: We are going to calculate the maximum short circuit current depending on the line (Table 13.5):

Triphase short circuit	$I_{sc\,max} = \frac{c \times u_{L.V.}}{\sqrt{3} \times \lvert Z_d \rvert}$
Biphase short circuit	$I_{sc\,max} = \frac{c \times u_{L.V.}}{2 \times \lvert Z_d \rvert}$
Phase-ground short circuit	$I_{sc\,max} = \frac{c \times u_{L.V.} \times \sqrt{3}}{\lvert 2 \times Z_d + Z_o \rvert}$

Table 13.5: Different type of short circuit

$I_{cc\,min}$: Minimum short circuit current. It is use to be the phase-ground one.
c: It is calculated by the next table (Table 13.6):

	$I_{sc\,max}$	$I_{sc\,min}$
230/400 V	1	0.95
Other tension	1.05	1

Table 13.6: Different values for the c parameter

t_{mcicc}: Maximum time that the conductor is able to support the short circuit current.
C_c = Conductor coefficient. We can see in the next table (Table 13.7):

	PVC	XLPE/EPR
Cu	13225	20449
Al	5476	8836

Table 13.7: Values of the parameter C_c depending on the material and the isolation

$$I_{ccf} = I_{sc\,min}$$

Now we are going to calculate our switch:

$$Z_{H.V.}(j) = \frac{u_{H.V.}{}^2}{S_{sc}} = \frac{20000^2}{400000000} = 1\,j\Omega$$

$$Z_{L.V.}(j) = Z_{H.V.}(j) \cdot \frac{u_{L.V.}{}^2}{u_{H.V.}{}^2} = 1 \cdot \frac{690^2}{20000^2} = 0{,}00119\,j\Omega$$

$$Z_{Transformer}(j) = U_{sc} \cdot \frac{u_{L.V.}{}^2}{S_n} = \frac{6}{100} \cdot \frac{690^2}{8 \cdot 10^5} = 0{,}0357\,j\Omega$$

$$Z_{Aparament1}(j) = n^{\underline{o}} \cdot 0{,}00015 = 1 \cdot 0{,}00015 = 0{,}00015\,j\Omega$$

$$Z_{Line} \approx 0$$

$$\lvert Z_d \rvert = \sqrt{(Z_{Lines})^2 + (Z(j))^2} = \sqrt{(0{,}00119 + 0{,}0357 + 0{,}00015)^2} = 0.037$$

$$I_{sc\,max} = \frac{c \times u_{L.V.}}{\sqrt{3} \times \lvert Z_d \rvert} = \frac{1{,}05 \times 690}{\sqrt{3} \times 0{,}037} = 11305\ A$$

The cut power of this switch will be 22 kA, because it is the next upper normalized value.

Nominal current: $545\ A < I_N < I_{adm} = 615A \rightarrow$ There isn´t a normalized current of magnetothermal between these two values, so that, we have to increase the section of the low voltage wire. The conductor will pass to 630 mm^2 and the neutral and the protection cable 400 mm^2.

Nominal current: $545\ A < I_N < I_{adm} = 690A \rightarrow\ I_N = 630A$

Now we are going to calculate the curve and if the switch supports the short circuit current:

$Z_{Aparament}(j) = n^{o} \cdot 0{,}00015 = 3 \cdot 0{,}00015 = 0{,}00045 j\Omega$
$Z_d = Z'_{Lines} + Z(j) = (0{,}00119 + 0{,}0357 + 0{,}00045)j = 0.0373j$
$Z_o = 3 \cdot Z'_{Lines} + Z_{Transformer}(j) + 3 \cdot Z_{Aparament}(j) = (0{,}0357 + 3 \cdot 0{,}00045)j = 0{,}0371j$
$|2 \times Z_d + Z_o| = \sqrt{(2 \cdot 0{,}0373j)^2 + (0{,}0371j)^2} = 0{,}0833$

$$I_{sc\,min} = \frac{c \cdot u_{L.V.} \cdot \sqrt{3}}{|2 \times Z_d + Z_o|} = \frac{1 \cdot 690 \cdot \sqrt{3}}{0{,}0833} = 14347{,}12A$$

$I_{scF} = I_{sc\,min} \geq 5 \times In = 3150 \rightarrow$ Curva B
$I_{scF} = I_{sc\,min} \geq 10 \times In = 6300 \rightarrow$ Curva C
$I_{scF} = I_{sc\,min} \geq 20 \times In = 12600 \rightarrow$ Curva D y MA

We are going to choose the curve C, but all of them are available.

Finally we check if the switch supports the short circuit current the time that we need.

$$t_{mcicc} = \frac{C_c \times s^2}{{I_{ccf}}^2} = \frac{20449 \times 630^2}{14347{,}12^2} = 39{,}43s > 0{,}1s \rightarrow Valid$$

13.3.8.2. Differential switch

The differential switch will be between the transformer and the magnetothermal switch. The main goal of it is to open the circuit if there are some losses. The nominal current will be like the magnetothermal, 630 A, and the residual current 300 mA.

13.3.8.3. Manual cutting switch

After these two protections we will install a switch that works manually. We will use it to cut the current in the low voltage if we have to make some reparations or some change in the line between turbines and transformers.

13.3.9. Elements in the transformer center

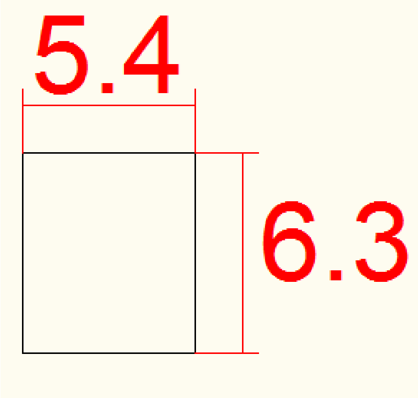
13.3.9.1. Lights

In this section we are going to calculate the different elements of low voltage in the center of transformation. These elements will be connected to another transformer that will be calculated here too.

The illumination of the centers:

- The characteristic of the prefabricated center are the next:

a=6.3 m b=5.4 m h´=2.75 m h´´=0.85 m d´=0.38 m h=1.9m n=2 E=350lm
$\Phi_L = 5800$



We obtain the next data:

$$k = \frac{a \cdot b}{h \cdot (a+b)} = \frac{6,3 \cdot 5,4}{1,9 \cdot (6,3+5,4)} = 1,53 \approx 1,5 \rightarrow \eta = 0,33$$

$$\Phi_T = \frac{E \cdot S}{\eta \cdot f_m} = \frac{350 \cdot 6,3 \cdot 5,4}{0,33 \cdot 0,8} = 45102,27$$

$$N = \frac{\Phi_T}{n \cdot \Phi_L} = \frac{45102,27}{2 \cdot 5800} = 3,88 \rightarrow N = 4\ lamps$$

The final power of the lights will be:
$Power = Lamps \cdot number \cdot watts = 4 \cdot 2 \cdot 58 = 464\ W$

This power is installed in each transformer center so we will have, rounding, 1,5 kW.

Also, we are going to install two emergency and signalling lights inside each center. They will have 60 Lm and 4 w per light (24 W).

13.3.9.2. Power point

We are going to install two monophasic power points inside each center with low voltage tension for help the maintenance work and the work in a possible emergency.

13.3.9.3. Electricity meters

Inside the transformer center we are going to put measuring elements in low voltage too. The main element will be a cupboard with double isolation HIMEL model PLA-753/AT-ID with the next dimension: 750 x 500 x 320 (all in mm). The cupboard will contain: Connection switch approved by the Electric Company (CZEC) and active energy meter.

13.3.9.4. Transformer for supply the centers

We are going to install a small transformer in a cabin next to the wall of one of the centers to supply in low voltage to them. The power that we are going to need is low, so the transformer will have a power of 50 kVA.

It will be a vacuum encapsulated dry transformer situated in a cabin to protect against the weather inclemency. The characteristics are the next (Table 13.8):

Series B-B' Hermetic		
Rated Power	kVA	50
Rated Voltage HV	kV	20
Rated Voltage LV	V	400
Vacuum losses	W	350
Load losses 75ºC	W	1230
Load losses 120ºC	W	1400
Impedance voltage	%	4
Noise	dB	58
Transformer dimensions		
Length	mm	1000
Width	mm	770
High	mm	1080
Weigh	Kg	520
Distance between wheels	mm	520
Length of the wheels	mm	125

Table 9.8: 50 kVA transformer characteristics.

This small transformer will have manual switch to stop the supplier in high voltage and also in low voltage. The low voltage one will be after the electrical meters, a differential magnet and a magnetothermal (in that order after the transformer).

The metallic part of the cabin and of the transformer will be connected to the ground of the center that has more near.

The protection will have a nominal current of 125 A, the sensibility of the differential will be 30 mA and the power of cut of the magnetothermal 3 kA.

The protections of the low voltage and the electrical meters will be situated in other cabin next to the transformer.

14. SUMMARY OF ELEMENTS

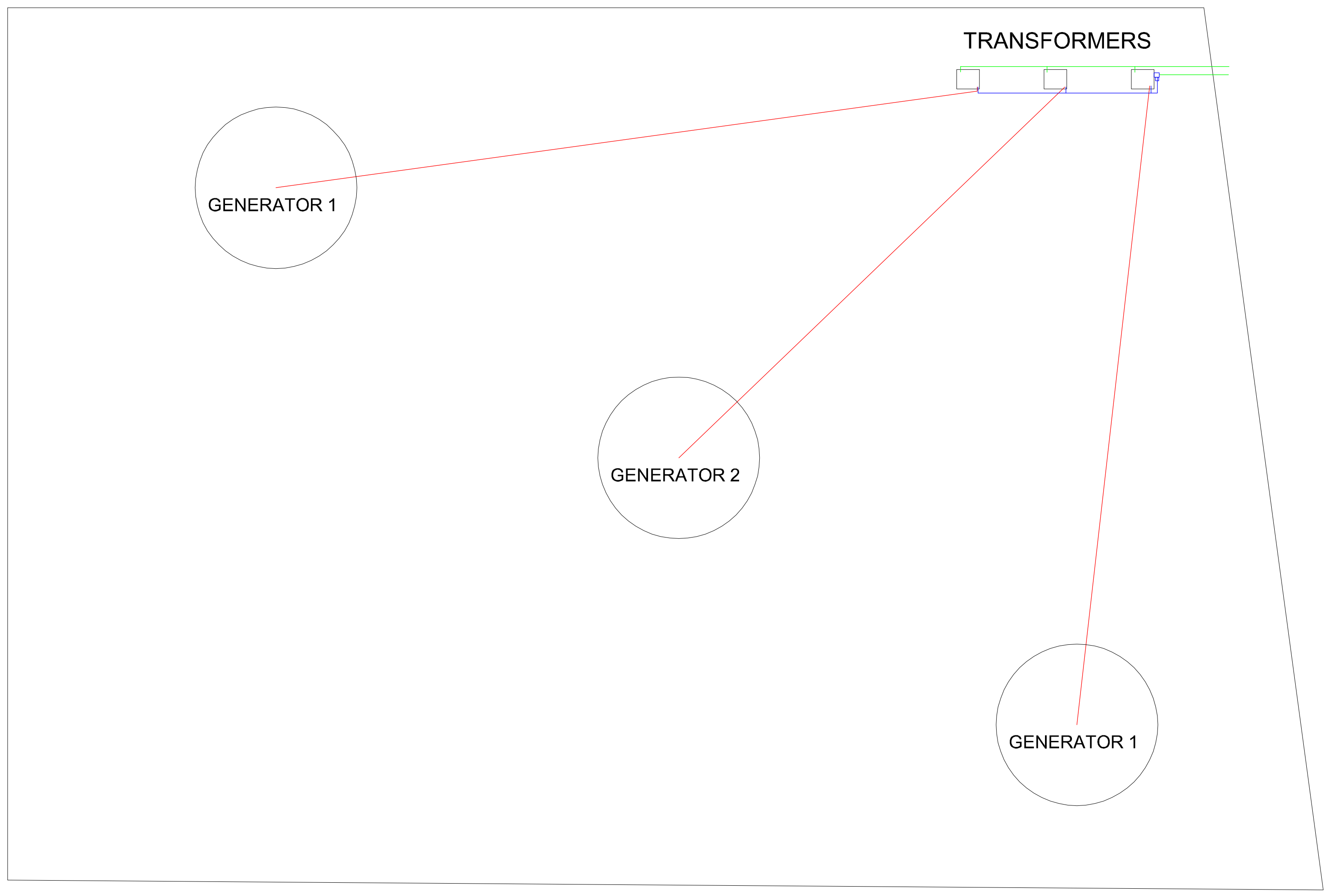
Element	Quantity	Description
Turbine	3	Turbines D48-600kW of Dewind Iberia, S.A.
Connection between turbine and transformers	2	Cables RV-K 0,6/1kV 3x630 Co + 2x400 Co 250 m
	1	Cables RV-K 0,6/1kV 3x630 Co + 2x400 Co 300 m
Transformation centers non-electric elements	3	Prefabricated buildings
	3	Protection grounds 70-60/5/46 (UNESA)
	3	Service grounds 5/44 (UNESA)
Transformation centers HV elements	3	Transformers Elprom Trafo CH 800 kVA 690V/20kV
	3	Lift cell
	3	Measuring cell
	3	Protection cell

Transformation centers LV elements	3	Magnetothermal 630A 22kA ©
	3	Differential 630A 300mA
	3	Manual switch
	3	Measuring panel low voltage to control the energy that we produce (3 current transformer and 3 voltage transformer for each one)
	6	Monophasic power points
	12	Lamps 2x58W
	3	Switch for the light
	12	Emergency lights
Elements to protect and control the energy spend in LV	1	Transformer Elprom Trafo CH 50 kVA 20 kV/400V
	1	Measuring panel low voltage to control the energy we spend
	1	Differential 125A 30mA
	3	Magnetothermal 125A 10kA C

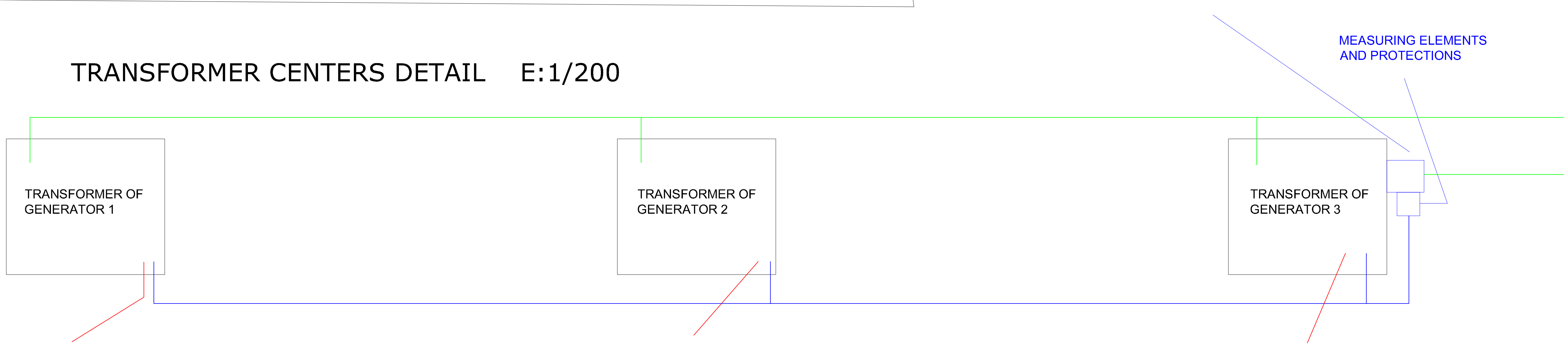
Table 14.1: Summary of elements to realize the project

15. PLANES

GENERAL SIUATION   E:1/2000



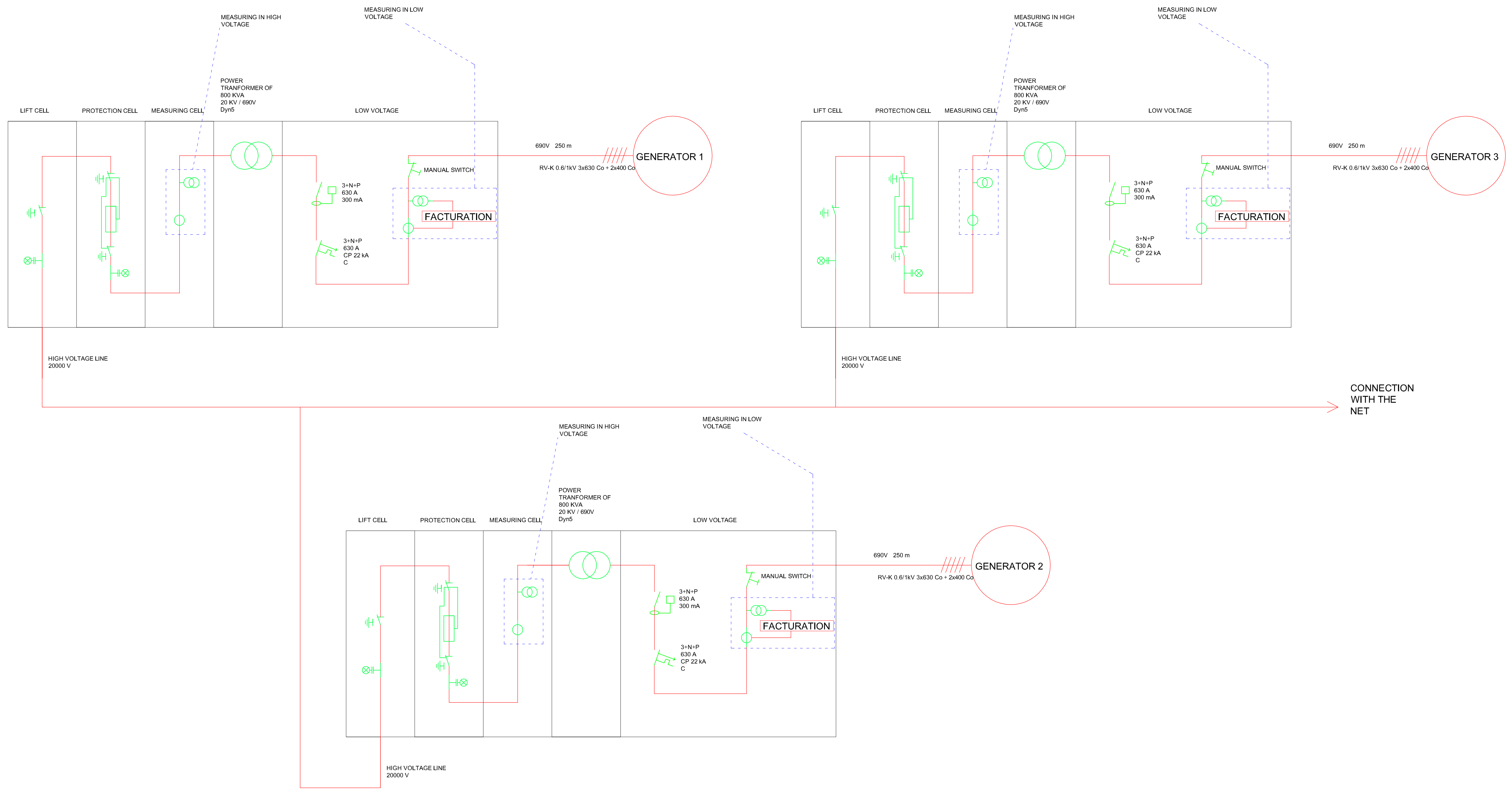
TRANSFORMER CENTERS DETAIL   E:1/200



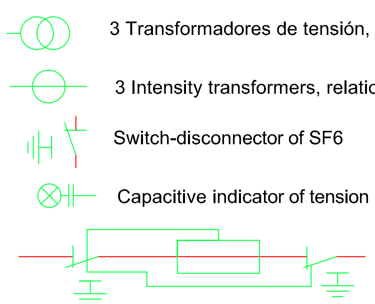
LEGEND:

- Line of LV between turbines and transformers
- Line of LV between transformer and transformation centers
- Line of HV to connect the park with the net

TECHNICAL UNIVERSITY OF SOFIA	E.T.S.I.I.T. INDUSTRIAL ENGINEER	FACULTY OF ELECTRICAL ENGINEERING
PROJECT: RENEWABLE ENERGIES AND CONNECTION TO THE GRID OF WIND TURBINES IN BAIKAL		MADE BY: ITOIZ DONAMARÍA, ÁLVARO SIGN:
PLANE: LOCATION OF THE TURBINES IN THE FIELD AND CONNECTION WITH THE TRANSFORMERS		DATE: 30/04/2013 · SCALE: 1 : 200 · Nº PLANE: 1



LEGEND:



3 Transformadores de tensión, 13200/110 V, de relación Ft=1.9. CL.0.5. y aislamiento 24 KV

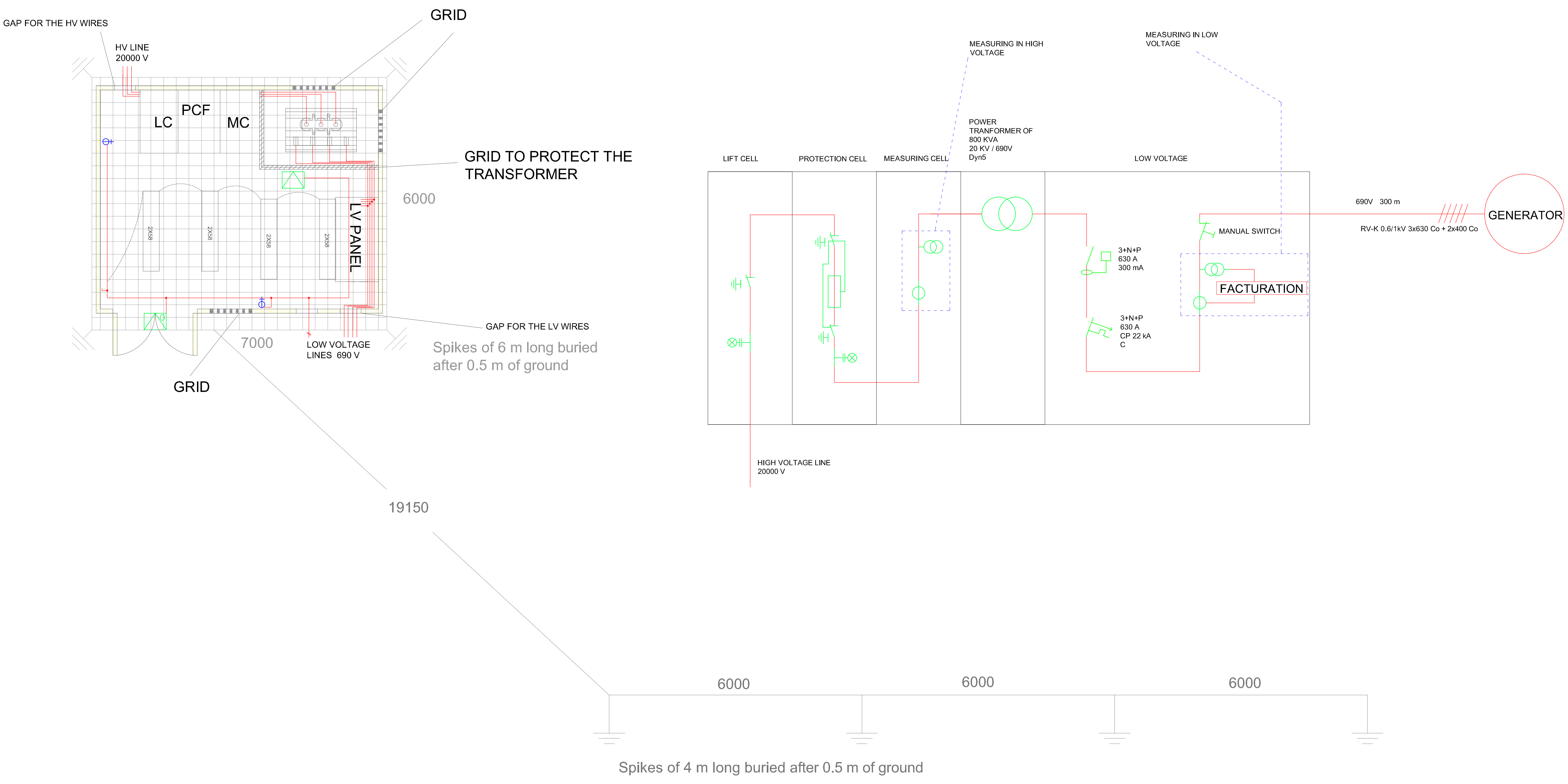
3 Intensity transformers, relation 20/5 A, 15 VA, CL.0.5 and isolation 24 KV

Switch-disconnector of SF6

Capacitive indicator of tension

Fuses and switch protection

TECHNICAL UNIVERSITY OF SOFIA	E.T.S.I.I.T. INDUSTRIAL ENGINEER	FACULTY OF ELECTRICAL ENGINEERING
PROJECT: RENEWABLE ENERGIES AND CONNECTION TO THE GRID OF WIND TURBINES IN BAIKAL		MADE BY: ITOIZ DONAMARÍA, ÁLVARO SIGN:
PLANE: CONNECTION SCHEMA OF THE THREE TRANSFORMERS WITH THE NET		DATE: 30/04/2013 · SCALE: · Nº PLANE: 2



LEGEND:

COPPER MESH OF 7x6 m
ELECTRO ROD MAKING SQUARES OF 0.3x0.3 m
DIPSTICK OF 6 mm OF DIAMETER

- POWER POINT
- EMERGENCY OUTPUT LIGHTS
- EMERGENCY LIGHTS OF SIGNALINNG
- 2X58 LIGHTS, 2x58W
- MC - MEASURING CELL
- PCF - PROTECTION CELL WITH FUSES
- LC - LIFT CELL

- 3 Transformadores de tensión, 13200/110 V, de relación Ft=1.9. CL.0.5. y aislamiento 24 KV
- 3 Intensity transformers, relation 20/5 A, 15 VA, CL.0.5 and isolation 24 KV
- Switch-disconnector of SF6
- Capacitive indicator of tension
- Fuses and switch protection

TECHNICAL UNIVERSITY OF SOFIA

E.T.S.I.I.T.

INDUSTRIAL ENGINEER

FACULTY OF ELECTRICAL ENGINEERING

PROJECT: **RENEWABLE ENERGIES AND CONNECTION TO THE GRID OF WIND TURBINES IN BAIKAL**

MADE BY: **ITOIZ DONAMARÍA, ÁLVARO**

SIGN:

PLANE: **GROUND CONNECTION OF TRANSFORMATION CENTER AND PROTECTION SCHEMA**

DATE: **30/04/2013**

SCALE: **1 : 100**

Nº PLANE: **3**

CONCLUSION

The renewable energies are an important alternative energy source against the fossil resource depletion. Therefore, in recent years there has been increased the number of studies about them and their different forms of exploitation.

We have seen how these studies have led to breakthrough in technology since a couple of decades to the present, which has allowed the best use of these energies. There is still much to be done to ensure that these energies can unseat the fossils, and it is therefore necessary to continue investing in studies and development.

Nowadays the renewable energies are an expensive generation form, but its development will be lowering its price, and of course, they are the way to a sustainable world.

As we have seen in the initial study, the renewables energies are still having many problems, but with their investigation should be resolved most of them in top form.

With the second part of the project we were able to visualize the complexity of carrying out a project of this nature. In turn, these projects take lot of time to be performed mainly by the need to study the wind for a long period to ensure the viability of locations.

After seeing that the location is appropriate, by the wind conditions, and also by the surrounding environment, would pass to the choice of the wind turbines, task, also complicated mainly by the wide variety of wind turbines on the market.

Perhaps this point is the most complex of the installation, in my point of view, as you must evaluate many factors to determine whether the product you are selecting is the best fit to the conditions that have your location and characteristics of air.

Once these first steps have been done the rest I found that it can become more systematic and consequently, easier.

To finish, the implementation of the plans has been important to capture visually for everyone the final distribution facilities as well as to observe the end connections and the different components of the transformation centers and protections.

The final idea that I have is the complexity of this type of project and the many factors that must be analyzed for its development technically, without going to the economic and amortization parts.

BIBLIOGRAPHY

Books and magazines:

- GUTIÉRREZ MONTES, José Luis, et al. *El proyecto del centro de transformación*. Valencia: UPV, 2006. ISBN 84-9705-959-X
  Available on internet:
  http://books.google.bg/books?id=V_P9uNUWjKIC&hl=es&source=gbs_navlinks_s

- *Wind Turbine Grid Connection and Interaction*. Deutsches Windenergie-Institut GmbH. 2001. Denmark
  Available on internet:
  http://ec.europa.eu/energy/technology/projects/doc/2001_fp5_brochure_energy_env.pdf

- *Celdas modulares, Gama SM6* (Modulated cells, Gamma SM6). MERLIN GERIN, Schneider Electric.
  Available on internet:
  http://es.scribd.com/doc/81532204/Celdas-Sm6-Media-Tension

- *Centros de Transformación Prefabricados hasta 36 kV* (Prefabricated transformation centers till 36 kV). ORMAZABAL. CA-101-ES-0209
  Available on internet:
  http://dugi-doc.udg.edu/bitstream/handle/10256/2267/6.1_Documents_Cataleg_C.T._ORMAZABAL.pdf?sequence=7

- *Sistemas Modulares de Celdas de M.T. Aisladas en gas SF_6, Serie CGM* (Modulated systems of cells in Medium Voltage Isolated with SF6, Series CGM). ORMAZABAL.
  Available on internet:
  http://www.clas-sa.com/documentos/productos/471.pdf

- *Oil Immersed Distribution Transformers 25-2500 kVA*. ELPROM TRAFO CH. 2003, number 63. Kiustendil (Bulgaria).

- Fabricantes de aerogeneradores y características de sus máquinas (Wind turbines fabricants and characteristics of their machines). Especial Energía Eólica. 2003, year nº 29, number 174. ISSN 0210-2056.
  We have selected our turbine in this article, page 152. Available on internet:
  http://www.google.es/url?sa=t&rct=j&q=dewin+iberia+d48-600&source=web&cd=1&ved=0CDMQFjAA&url=http%3A%2F%2Fbiblioteca.uns.edu.pe%2Fsaladocentes%2Fdoc_abrir_archivo_de_curso.asp%3Fid_archivo%3D488%26archivo%3Dfabricantes_de_aerogeneradores_espa%25F1a.pdf&ei=AVF2UZC0JoiJPeGPgPgL&usg=AFQjCNFPxh5CYBz6t9jIoOlhgu7iLacvGg

- *Las Energías Renovables en Bulgaria* (The renewable energies in Bulgaria). ICEX. 2012. Sofía (Bulgaria).
  Available on internet:
  http://www.icex.es/icex/cma/contentTypes/common/records/mostrarDocumento/?doc=4651244

Notes from subjects that I studied in my career:

- Energetic Technology from 5th of Industrial Engineering (UPNA (Spain)).
- Master of Renewable Energies (UPNA (Spain)).
- Raw Materials for a Sustainable Development (UPNA (Spain)).
- Renewable Energies (optional subjects for all the careers in UPNA (Spain)).

Internet pages

- Different sums of energies (Wind power, biomass, renewable energies and solar (in this order)):
  http://en.wikipedia.org/wiki/Wind_power
  http://en.wikipedia.org/wiki/Biomass
  http://es.wikipedia.org/wiki/Energ%C3%ADa_renovable
  http://www.monografias.com/trabajos61/energia-fotovoltaica/energia-fotovoltaica2.shtml#xpanel

- Some advantages and disadvantages of wind energy:
  http://www.clean-energy-ideas.com/articles/advantages_and_disadvantages_of_wind_energy.html

- Process of a Wind Turbine Park:
  http://www.adurcal.com/mancomunidad/viabilidad/56.htm
  http://www.adurcal.com/mancomunidad/viabilidad/57.htm

- Wind energy in Bulgaria and some future projects with Spanish companies:
  http://www.evwind.com/2009/05/21/la-energia-eolica-en-bulgaria-158-mw-instalados-y-3-000-mw-previstos-en-2020/

- How calculate the transformation center:
  http://upcommons.upc.edu/pfc/bitstream/2099.1/11353/3/Transformador.pdf

- Calculations of a transformation center and how to draw the schemas:
  http://www.upv.es/electrica/material_tecno/Transparencias03/Tema9/T9.pdf