TECHNICAL UNIVERSITY OF SOFIA

VIRTUAL SENSOR for power measuring of an AEROGENERATOR

DEGREE IN ELECTRICAL AND ELECTRONICAL ENGINEERING

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INDEX

MEMORY

1. INTRODUCTION

1.1. OBJECT OF THE PROYECT

The purpose of the following project is to monitor the operation of a wind turbine for personal use. Realizing two types of studies, one focused on simulating in a real way, the operation of the wind turbine for a specific wind speed, being this collected from a study carried out for a city. And, on the other hand, studying the behavior of the system for different wind speeds being chosen interactively by the user. Thanks to the interface, it is possible to calculate the power captured by the wind rotor, as well as its power coefficient for different ranges of wind speeds.

2. VIRTUAL SENSORS

2.1. DEFINITION

A virtual sensor is a mechanism that allows the use of available information to calculate or estimate variables in order to reduce the number of physical sensors in a given process. The variables are estimated because they present technical difficulties to be measured or because they can reduce costs.

2.2. SCOPE

The sensors maybe require maintenance, be calibrated and can be very delicate, in addition to needing a "hardware" that connects them to the monitoring unit.

In the industrial sector there are processes, which must work without interruption and whose operating conditions are complex; In these cases, advanced systems of supervision, control and fault detection are required to guarantee an operation according to the needs of the users. A current trend is the automation of processes, which requires sensors to measure key variables and generate electrical signals to be processed in digital media.

His study over the next few years of these technological developments in the field of process engineering will similarly revolutionize the process industry.

2.3. OPERATING PRINCIPLE

Virtual sensors base their operation on the use of the available information of a process to deduce variables whose measurement presents technical or economic restrictions. In Fig. 1 a schematic of a virtual sensor is shown.

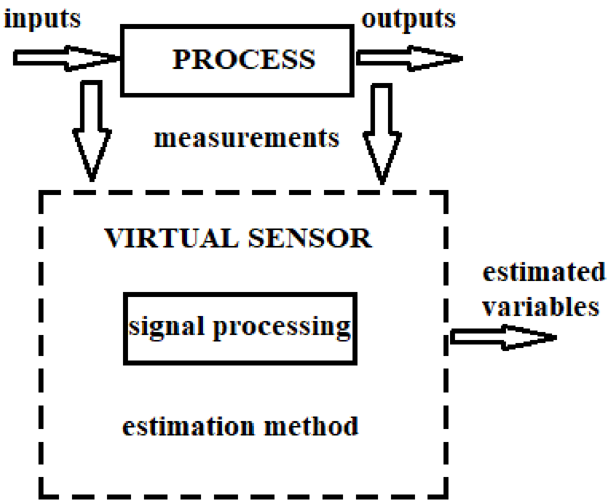

Fig. 1. General scheme of the virtual sensors.

The virtual sensor is programmed in a digital device, so the measured signals go through a processing and normalization stage. From this we obtain a representation of the process in general or in particular of the measured variables.

These representations are dynamic models (linear, non-linear), statistical or based on artificial intelligence concepts.

- Dynamic models allow to represent the phenomena that happen in a determined process by means of differential equations, its complexity is a function of the level of approximation that is required to reach.
- Statistical models need large amounts of data from the process considered; The objective is to classify them and find correlations between variables to find patterns of behavior.
- The models obtained by artificial intelligence have the objective of deducting the structure of a process from input and output signals or from empirical knowledge.

The estimation method is based on the model; for dynamic models, the acceleration of dynamics is commonly used by observers of states.

If statistical models are used, statistical deduction is recommended through multivariate analysis, such as analysis of principal components or projection to latent structures.

For models based on artificial intelligence techniques, diffuse and neural inferences are used.

Sometimes these methods are combined with other techniques to improve the quality of the estimation using virtual sensors.

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3. LabVIEW

3.1. INTRODUCTION

LabVIEW (*Laboratory Virtual Instrument Engineering Workbench)*, is a system design platform and development environment for a visual programming language from National Instruments in which you create programs using a graphical notation.

It differs from traditional programming languages like C, C++, or Java, in which you program with text. However, LabVIEW is much more than a programming language. It is an interactive program development and execution system designed for people, like scientists and engineers, who need to program as part of their jobs. The LabVIEW development environment works on computers running Windows, Mac OS X, or Linux. LabVIEW can create programs that run on those platforms, as well as Microsoft Pocket PC, Microsoft Windows CE, Palm OS, and a variety of embedded platforms, including Field Programmable Gate Arrays (FPGAs), Digital Signal Processors (DSPs), and microprocessors.

You will find LabVIEW applications improving operations in any number of industries, from every kind of engineering and process control to biology, farming, psychology, chemistry, physics, teaching, and many others.

3.2. WHAT IS LabVIEW AND WHAT IT CAN DO

LabVIEW offers more flexibility than standard laboratory instruments because it is software-based. You, not the instrument manufacturer, define instrument functionality. Your computer, plug-in hardware, and LabVIEW comprise a completely configurable virtual instrument to accomplish your tasks. Using LabVIEW, you can create exactly the type of virtual instrument you need, when you need it, at a fraction of the cost of traditional instruments. When your needs change, you can modify your virtual instrument in moments.

It has extensive libraries of functions and subroutines to help you with most programming tasks, without the fuss of pointers, memory allocation, and other arcane programming problems found in conventional programming languages.

LabVIEW also contains application-specific libraries of code for data acquisition (DAQ), General Purpose Interface Bus (GPIB), and serial instrument control, data analysis, data presentation, data storage, and communication over the Internet.

The Analysis Library contains a multitude of useful functions, including signal generation, signal processing, filters, windows, statistics, regression, linear algebra, and array arithmetic.

Because of LabVIEW's graphical nature, it is inherently a data presentation package. Output appears in any form you desire. Charts, graphs, and user-defined graphics comprise just a fraction of available output options. This book will show you how to present data in all of these forms.

LabVIEW's programs are portable across platforms, so you can write a program on a Macintosh and then load and run it on a Windows machine without changing a thing in most applications.

3.3. DATAFLOW PROGRAMING

LabVIEW use a very powerful graphical programming language call "**G**" (for *graphical*), LabVIEW can increase your productivity by orders of magnitude. Programs that take weeks or months to write using conventional programming languages can be completed in hours using LabVIEW because it is specifically designed to take measurements, analyse data, and present results to the user. And because LabVIEW has such a versatile graphical user interface and is so easy to program with.

If there is enough data available to a subVI or function, that subVI or function will execute. Execution flow is determined by the structure of a graphical block diagram (the LabVIEW-source code) on which the programmer connects different function-nodes by drawing wires.

Graphical programming eliminates a lot of the syntactical details associated with text-based languages, such as where to put your semicolons and curly braces.

Graphical programming allows you to concentrate on the flow of data within your application, because its simple syntax doesn't obscure what the program is doing.

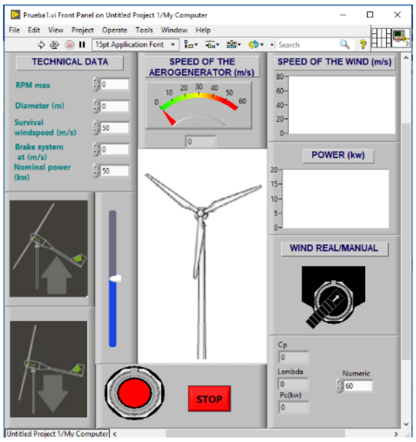
It is ideal for scientists and engineers. It relies on graphical symbols rather than textual language to define a program's actions. Its execution is based on the principle of **dataflow**, in which functions execute only after receiving the necessary data. Because of these features, you can learn LabVIEW even if you have little or no programming experience. However, you will find that a knowledge of programming fundamentals is very helpful.

3.4. VIRTUAL INSTRUMENTS

A LabVIEW program consists of one or more **virtual instruments (VIs)**. Virtual instruments are called such because their appearance and operation often imitate actual physical instruments. However, they are analogous to main programs, functions, and subroutines from popular programming languages like C or Basic. Also, we will refer to a LabVIEW program as a "**VI**".

A VI has two parts: a **front panel** and a **block diagram**.

- The **front panel** is the interactive user interface of a VI, so named because it simulates the front panel of a physical instrument (see Figure 1.1). The front panel can contain knobs, push buttons, graphs, and many other controls (which are user inputs) and indicators (which are program outputs). You can input data using a mouse and keyboard, and then view the results produced by your program on the screen.



RPM max 0

Diameter (m) 0

Survival windspeed (m/s) 50

Brake system at (m/s) 0

Nominal power (kw) 50

0

Cp 0

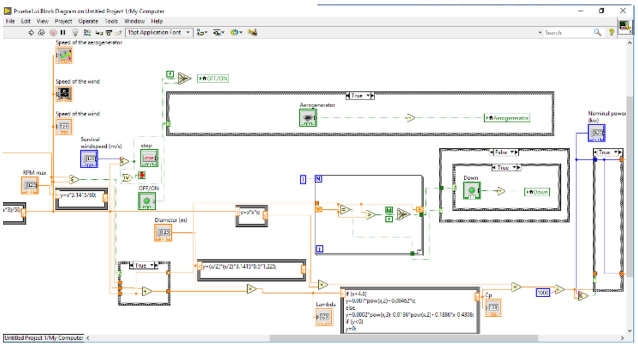
Lambda 0

Pc(kw) 0

Numeric 60

Fig. 2. Front panel

- The **block diagram** is the VI's source code, constructed in LabVIEW's graphical programming language, G (see Figure 1.5). The block diagram is the actual executable program. The components of a block diagram are lower-level VIs, built-in functions, constants, and program execution control structures. You draw wires to connect the appropriate objects together to define the flow of data between them. Front panel objects have corresponding terminals on the block diagram so data can pass from the user to the program and back to the user.



```
if (x<4.8)
y=0.007*pow(x,2)-0.00462*x;
else
y=0.0002*pow(x,3)-0.0136*pow(x,2)+0.1886*x-0.4308;
if (y<0)
y=0;
```

Fig. 3. Block diagram

In order to use a VI as a subroutine in the block diagram of another VI, it must have an icon with a connector. A VI that is used within another VI is called a subVI and is analogous to a subroutine. The icon is a VI's pictorial representation and is used as an object in the block diagram of another VI. A VI's connector is the mechanism used to wire data into the VI from other block diagrams when the VI is used as a subVI. Much like parameters of a subroutine, the connector defines the inputs and outputs of the VI.

Virtual instruments are modular. You can use them as top-level programs or subprograms. With this architecture, LabVIEW promotes the concept of modular programming. First, you divide an application into a series of simple subtasks. Next, you build a VI to accomplish each subtask and then combine those VIs on a top-level block diagram to complete the larger task.

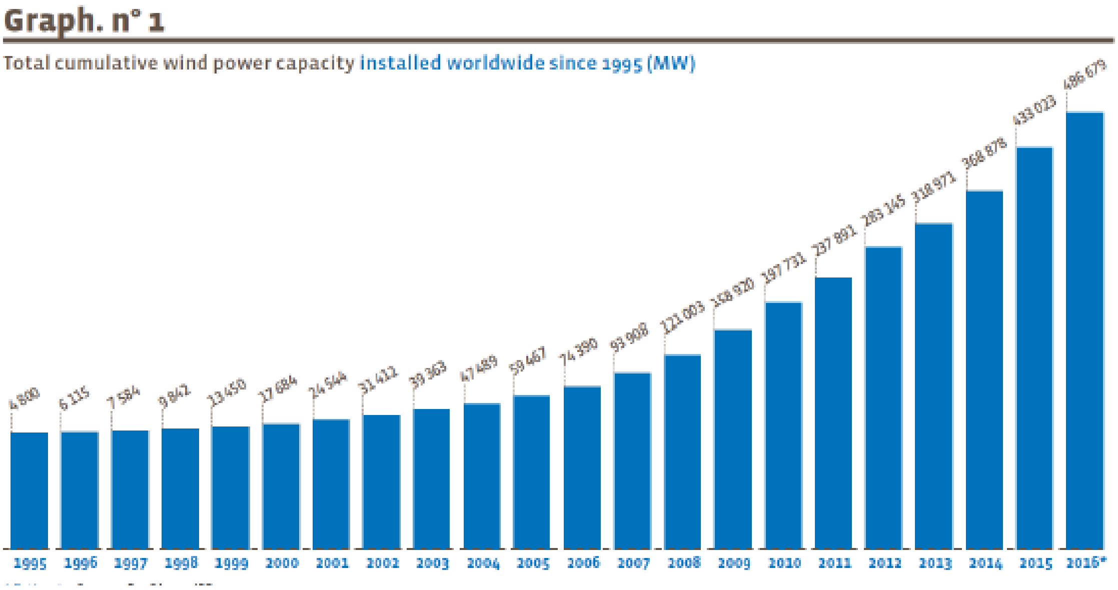
4. AEROGENERATORS

Wind energy is one of the oldest forms of energy used by the humanity. From the beginning of time, men used windmills to grind cereals or pump water. With the arrival of electricity, at the end of the 19th century, the first wind turbines were based on the shape and operation of windmills. However, until recently, the generation of electricity through wind turbines has not played a great role.

With the first oil crisis in the 70s, especially from the moves against nuclear energy in the 80s in Europe, increased interest in renewable energy. New ways were found to exploit Earth's resources both ecologically and economically profitable. The wind turbines of that time were too expensive, and the high price of the energy that was obtained through them was an argument to be against its construction. Because of this, international governments promoted wind energy in the form of research and grant programs, most of them provided by regional governments.

Modern wind turbines currently generate a significant part of the world's electricity. Germany, USA and Spain are the three countries with the most installed wind energy in the world.

The graph 1 shows the global evolution of installed wind power:



Graph. 1. Total cumulative wind power capacity

4.1. WIND POWER

Wind power is the use of air flow through wind turbines to mechanically power generators for electricity. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water, and uses little land.

At present, wind energy is mainly used to produce electricity through wind turbines connected to large electric power distribution networks. Wind farms built on land represent a source of energy that is increasingly cheaper and more competitive, and even cheaper in many regions than other conventional energy sources.

On the other hand, small wind farms can, for example, provide electricity in remote and isolated regions that do not have access to the electricity grid. The electricity distribution companies are increasingly acquiring surplus electricity produced by small domestic wind installations.

4.2. AEROGENERATOR / WIND TURBINE

A wind turbine is an electrical generator that works by converting the kinetic energy of wind into mechanical energy through a propeller and into electrical energy thanks to an alternator. Its direct precedents are the windmills that were used for the milling and obtaining of flour.

Fig. 4. Old aerogenerator

Fig. 5. New aerogenerator

In this case, the wind energy (actually the kinetic energy of the air in motion), provides mechanical energy to a rotor propeller that, through a mechanical transmission system, rotates the rotor of a generator, usually a three-phase alternator, that converts rotational mechanical energy into electrical energy.

There are different types of wind turbines, depending on their power, the arrangement of their axis of rotation, the type of generator, etc.

The IEC 61400-1 standard classifies wind turbines according to the type of wind for which they are designed:

Turbine class	Average wind	Extreme wind
I: High wind	10 m/s	70,0 m/s
II: Medium wind	8,5 m/s	59,5 m/s
III: Low wind	7,5 m/s	52,5 m/s
IV	6,0 m/s	42,0 m/s

Table. 1. IEC 61400-1 standard classifies

Depending on the turbulence with which they can work, subclasses A and B are defined:

Subclass	Turbulence
A	18 %
B	16 %

Table. 2. Turbulence classifies

On the other hand, the position of the axes of the turbine, can be vertical or horizontal.

The most used vertical axis turbines are Darrieus, Savonius and H-Rotor.

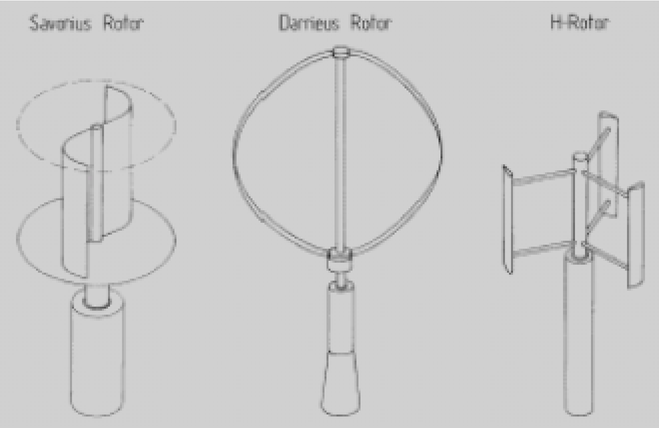


Fig. 6. Savonius, Darrieus, H-Rotor

Nowadays, with rare exceptions, the only vertical axis machines that are built are of low power and intended to be placed in buildings. In this type of application where the wind is very disturbed, the characteristic of being able to receive the wind in any direction is very interesting.

Wind turbines with the axis of the horizontal turbine are the most used today and offer the best features for the capture of wind power.

Wind turbines can work in isolation or grouped in wind farms or wind power plants, separated from each other, depending on the environmental impact and turbulence generated by the movement of the blades.

Another differentiation of a wind turbine is where the rotor is located, if the rotor is located in front of the nacelle (windward) or on the back (leeward).

The rotor wind turbines have the rotor facing the wind. The main advantage of the designs is that it avoids wind disturbances for the tower. The vast majority of wind turbines have this design.

The machines with leeward rotor have the rotor located on the leeward side of the tower. The theoretical advantage they have is that they can be built without an orientation mechanism, if the rotor and the nacelle have an appropriate design that makes the nacelle follow the wind passively. However, in large machines this is a somewhat dubious advantage, since cables are needed to conduct the current outside the generator.

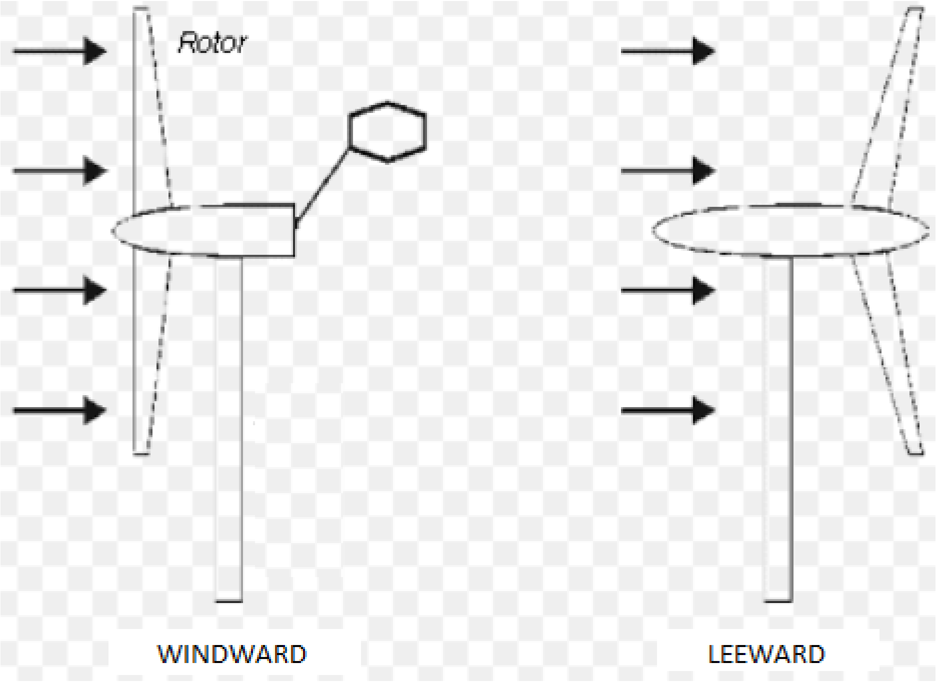


Fig. 7. Rotor located in an aerogenerator

To provide power to the electricity network, wind turbines must be equipped with a synchronization system so that the frequency of the generated current is perfectly synchronized with the frequency of the network.

4.2.1. PARTS OF THE AEROGENERATOR

The main components of a horizontal axis wind turbine are:

- Tower: Supports the gondola and the rotor. It has a height of between 40 to 60 meters, since the wind speed increases as we move away from the ground level, along it there is a staircase to access the gondola.

- Orientation system: It is activated by the electronic controller, monitors the direction of the wind using the vane and its speed with an anemometer.

- Electronic controller: It is a computer that continuously controls the conditions of the wind turbine and the orientation mechanism. In case of any anomaly it stops the wind turbine and warns the computer of the maintenance operator of the turbine.

- Nacelle: Contains the key components of the wind turbine, the multiplier and the electric generator. The service personnel can access the interior of the gondola from the tower.

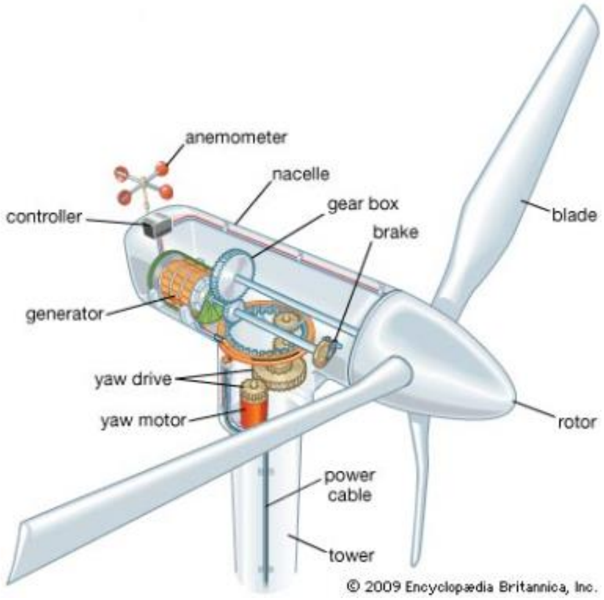
- Rotor blades: Capture the energy of the wind and transmit it to the rotor. Each blade measures between 25 to 35 meters in length and its design is very similar to the wing of an airplane, built of strong and lightweight material.

- Rotor: The rotor is where the kinetic energy of the wind is converted into rotating energy, it is coupled to the low speed shaft of the generator. In a modern 1 MW wind turbine the rotor rotates very slowly, at about 19 to 30 revolutions per minute (r.p.m.), it is equipped with an aerodynamic brake that stops the rotor when the wind speed can be dangerous for the equipment.

- Brake: It is equipped with an emergency mechanical disc brake, which is used in case of aerodynamic brake failure, or during maintenance work on the turbine.

- Multiplier: Allows the generator to rotate at a higher speed than the turbine (usually between 750 and 1500 rpm), so that its size is reduced (inside of the nacelle).

- Electric generator: In modern wind turbines the maximum power is usually between 800 and 1,500 kW.



Wind turbine

Fig. 8. Parts of the aerogenerator

4.3. SMALL WIND TURBINES

A small wind turbine is a wind turbine used for microgeneration, as opposed to large commercial wind turbines, such as those found in wind farms, with greater individual power output. The Canadian Wind Energy Association (CanWEA) defines "small wind" as ranging from less than 1000 Watt (1 kW) turbines up to 300 kW turbines. The smaller turbines may be as small as a 50 Watt auxiliary power generator for a boat, caravan, or miniature refrigeration unit.

Smaller scale turbines for residential scale use are available. Their blades are usually 1.5 to 3.5 metres (4 ft 11 in–11 ft 6 in) in diameter and produce 1-10 kW of electricity at their optimal wind speed. Some units have been designed to be very lightweight in their construction, allowing sensitivity to minor wind movements and a rapid response to wind gusts typically found in urban settings and easy mounting much like a television antenna. It is claimed, and a few are certified, as being inaudible even a few feet (about a metre) under the turbine.

The generators for small wind turbines usually are three-phase alternating current generators and the trend is to use the induction type. They are options for direct current output for battery charging and power inverters to convert the power back to AC but at constant frequency for grid connectivity. Some models utilize single-phase generators.

Some small wind turbines can be designed to work at low wind speeds, but in general small wind turbines require a minimum wind speed of 4 metres per second (13 ft/s).

Dynamic braking regulates the speed by dumping excess energy, so that the turbine continues to produce electricity even in high winds. The dynamic braking resistor may be installed inside the building to provide heat (during high winds when more heat is lost by the building, while more heat is also produced by the braking resistor). The location makes low voltage (around 12 volt) distribution practical.

Small units often have direct drive generators, direct current output and use a vane to point into the wind. Larger, more costly turbines generally have geared power trains, alternating current output and are actively pointed into the wind.

4.3.1. PARTS OF A SMALL TURBINE

Depending on the manufacturer, can have different components, then describe the components of a wind turbine of one of the largest brands (Bornay), with type of Furley braking.

The list of the different components is as follows:

1	Tail
1	Tail tube
1	Nacelle
1	Alternator
1	Hub
3	Blades
1	Frontal cone
1	Set of bolts
1	Fixation plate
1	Control box

The final structure of the wind turbine would be in Fig. 9:

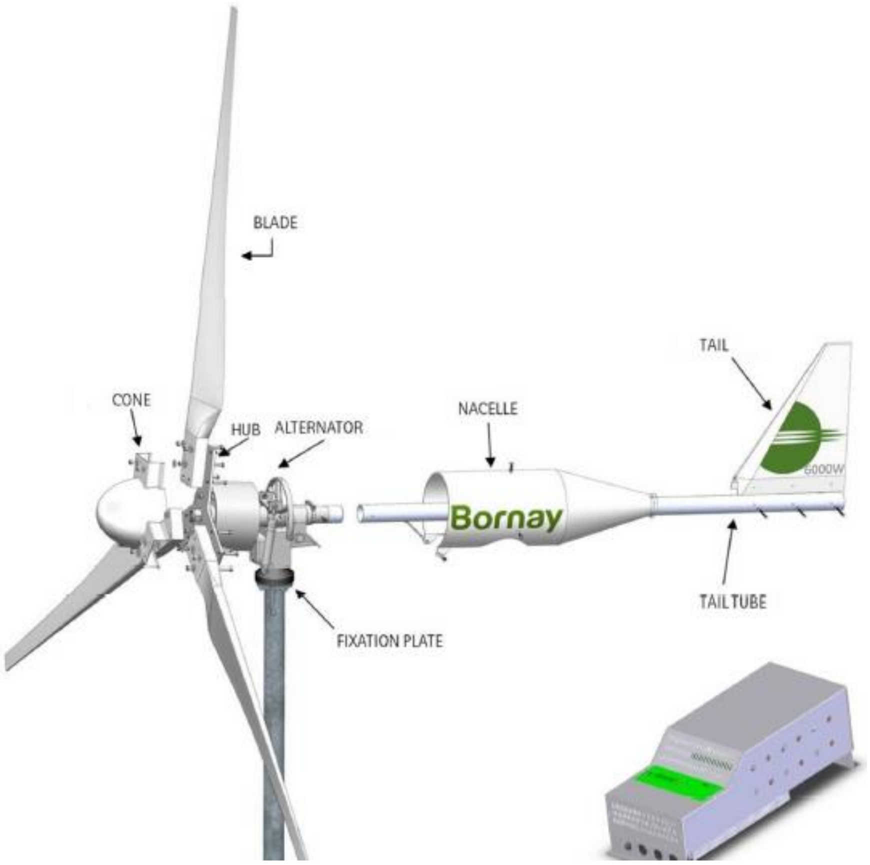
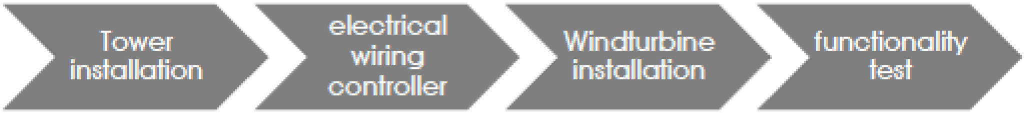


Fig. 9. Parts of the small aerogenerator

4.3.2. INSTALLATION

Before you begin, run through the steps to follow in order to correctly assemble your wind turbine and take a series of important precautions. All the following steps are carried out, they will be carried out with the help of the technical installation manual for each type of wind turbine.



The precautions to follow should be:

- Don't plan to carry out installation on windy days.
- Do not leave the generator running freely.
- With the generator running freely, the automatic leaning brake system
- does not work; this could cause irreparable damage to the wind turbine.
- Use the correct wiring.

The tower:

It is recommended to install the windmill on an Independent tower, and not next to the house to avoid turbulences.

Anchoring the tower is carried out according to the type for installation, and must be fixed securely to the ground, normally with concrete foundations. It must be totally vertical and leveled to avoid poor wind turbine functioning.

In the case of shorter-based towers requiring tensile guy cables: once the base is anchored and the tower is in place, 3 or 4 tensile guy cables are applied, their supports firmly anchored to the ground, generally in concrete foundations.

Check at all times that your tower remains perfectly vertical.

The guys ropes have to absorb all tower bend in windy conditions. Therefore, they must be 6-10 mm diameter steel cables. Attach the guy wires to the highest point of the tower but always beneath the diameter of the blades.

We don’t recommend the installation of lighting arrestors near to or within the area occupied by the wind turbine.

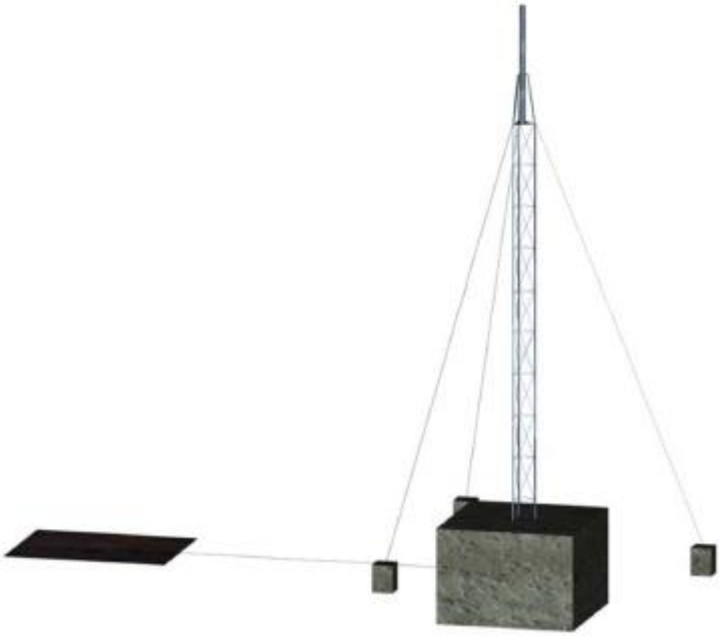


Fig. 10. Parts of the tower

Once the wind turbine has been installed on the tower, check that it can turn freely and that there are no obstacles within the diameter of the blades.

Under the pressure of the wind, the blades can have a torsion, so there must be a minimum distance between the blades and the nearest point.

Electrical wiring:

Full electrical wiring installation must be carried out prior to the installation of the wind turbine and once the tower has been installed.

In the case of using the wind turbine for domestic consumption, the first step in the electrical configuration is to place the correct battery bank, with its correct connection configuration and connected according the manufacturer's specifications, and obtain the right voltage and capacity for the installation to be carried out.

Different types of batteries exist. In the case of domestic hybrid wind energy/ solar energy installations, open lead-acid batteries are recommended and, to meet the installations charge capacities, certain minimum installation requirements are essential to assure correct running and durability of the installation.

With the correct battery selected and assembled in the installation, the regulator must now be installed on the wall.

The regulator must be placed in a well ventilated area and in vertical position.

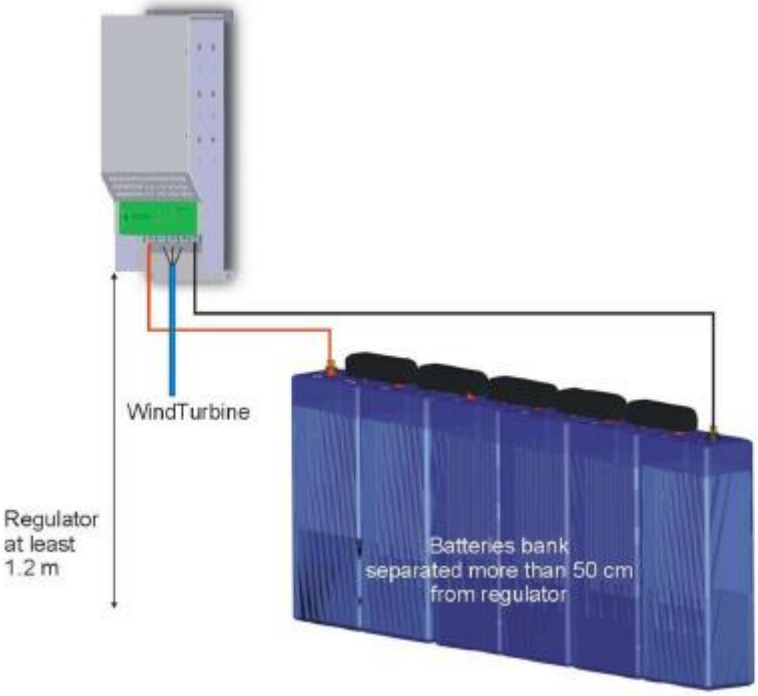


Fig. 11. Distribution of the regulator and batteries

Regulator:

The regulator uses the energy it obtains from the wind turbine to charge batteries and create electrical energy for the user's consumption. While batteries are uncharged, and with weather conditions allowing, the regulator supplies energy to the accumulators.

When the batteries are charged to the pre-programmed setting, the regulator will cause the wind turbine to go into braked mode to achieve perfect battery performance and to avoid their deterioration. The way it enters braked mode is via electrical impulses, i.e. by sending controlled charges to the wind turbine.

Installing the Wind Turbine:

Once we have the electrical wiring installed, we will proceed to assemble the wind turbine.

To ease installation of the wind turbine on the tower, a bracket and pulley system should be used.

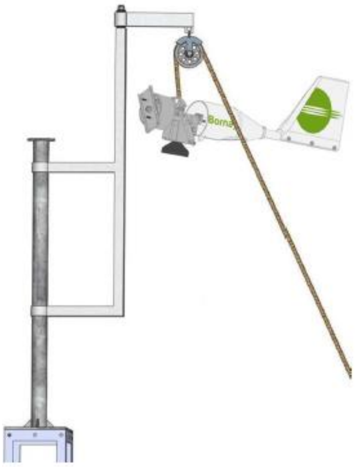


Fig. 12. Bracket and pulley system

The fixation plate is provided to be attached to the tower. Another one is assembled on the wind turbine base.

Its function is to secure wind turbine, offering an ease of installation and removal from the tower at any moment.

Fig. 13. Functions of the differents parts

The assembly of the generator also includes the placement of the steering rudder, which is attached to the alternator through a tube.

On the other hand, the nacelle is placed to protect the alternator from weather conditions.

Blades and frontal cone:

The blades, made reinforced carbon fiber/glass make direct contact with the wind. They are highly stressed. Their aerodynamics makes the alternator turn faster or slower depending on wind speed.

Blade assembly is carried out by securing them to the hub, with the relief logo towards the rear part, therefore, facing the alternator.

After performing the correct installation of the wind turbine, make sure that all the components are well connected, as well as check that the electrical circuit is working correctly.

4.3.3. APPLICATIONS

Isolated areas: the small wind turbines are used in isolated areas where there is a great cost or difficulty to carry power from the electrical network. Here there would be not only isolated houses, but also farms, telecommunication towers, water pumping, etc. In these cases the wind turbine is usually accompanied by photovoltaic solar panels that guarantee the optimal functioning of the system.

Facilities with a high index of electricity consumption: factories, desalination plants and other infrastructures that consume a large amount of energy can resort to the installation of wind turbines to reduce the electricity consumption of the electrical network.

Connection to the network: Individuals and companies that have a wind turbine can consume the energy they need and sell the surplus to the electrical network.

4.3.4. LOCATION

To know where to place a small power wind turbine, you have to know the prevailing winds that exist in the area and how they can vary throughout the year. Generally the highest point of the land is the one that receives more wind, although this rule can be altered by the presence of rivers, valleys or wooded zones, as well as the obstacles that exist around like buildings or trees. These can vary both the speed and the direction of the wind.

Measurements made in a wind tunnel have indicated that significant detrimental effects associated with nearby obstacles can extend up to 80 times the obstacle's height. However, this is an extreme case. Another approach to siting a small turbine is to use a shelter model to predict how nearby obstacles will affect local wind conditions.

Nowadays, it is recommended to install the small power wind turbine at least 10 meters above any obstacle and twice as high as it is.

Models of this type are general and can be applied to any site. They are often developed based on actual wind measurements and can estimate flow properties such as mean wind speed and turbulence levels at a potential turbine location, taking into account the size, shape, and distance to any nearby obstacles.

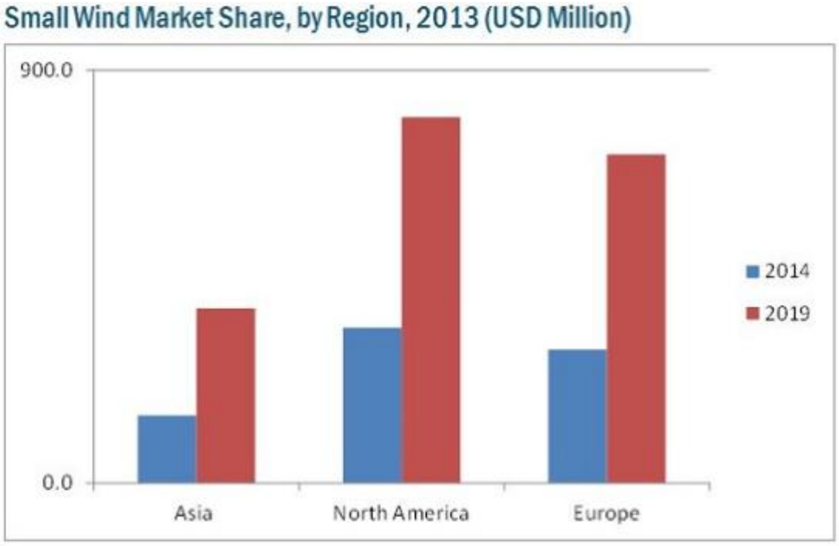
A small wind turbine can be installed on a roof. Installation issues then include the strength of the roof, vibration, and the turbulence caused by the roof ledge. Small-scale rooftop turbines suffer from turbulence and rarely generate significant amounts of power, especially in towns and cities.

4.3.5. MARKETS

The increasing demand for renewable sources for energy generation and rapid industrialization has played a huge part in providing the necessary boost to the global small wind market. Also expanded because of the increasing energy demand and growing concerns over environmental impacts of power generation through fossil fuel. The global small wind market is projected to grow 19.5% from 2014 to 2019.

The market is segmented based on type, application, and region in terms of value. The market segments by type include horizontal axis wind turbine and vertical axis wind turbine. The market segments for application include on-grid and off-grid. The regional segmentation includes market values for Asia-Pacific, North America, and Europe.

Companies such as Northern Power Systems Inc. (USA), Bergey Wind Power Co. (USA), Kingspan Group Plc. (Netherlands) and Xzeres Wind Corp. (U.K.) have greatly influenced this competitive market.



Source: Expert Interviews and MarketsandMarkets Analysis

Graph. 2. Small wind market share

The market was dominated by North America in 2014. Strong growth has been projected for the small wind market in the next five years, as demand for small wind turbines continues to rise in the wake of escalated use of renewable energy.

5. FOUNDATIONS OF WIND SYSTEM

To know the energy that we can extract from the wind, it is necessary to know the operation of an aerodynamic model.

Aerodynamics is the branch of fluid mechanics that studies the actions that appear on solid bodies when there is a relative movement between them and the fluid that bathes them, this being a gas.

Aerodynamics develops from Newton's equations. With the equations of continuity, momentum and energy you can obtain models that describe the movement of fluids.

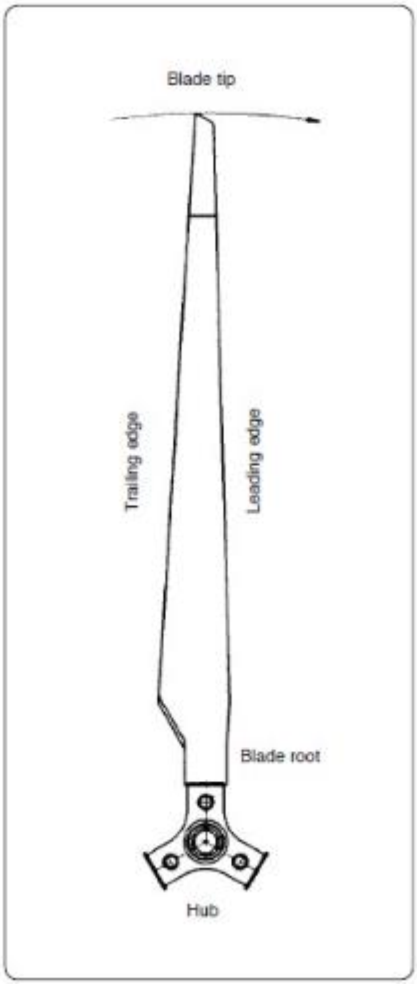


Fig. 14. Parts of one blade

Regarding the aerodynamic profile of the wind turbines, the front and rear sides of a wind turbine blade have a roughly similar shape to that of a long rectangle, with the edges bounded by the leading edge, the trailing edge, the blade tip and the blade root. The blade root is bolted to the hub.

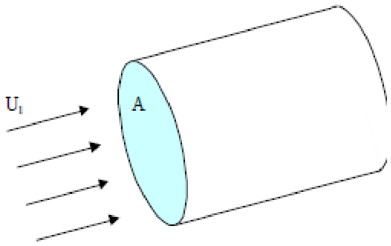
The radius of the blade is the distance from the rotor shaft to the outer edge of the blade tip. Some wind turbine blades have moveable blade tips as air brakes, and one can see the distinct line separating the blade tip component from the blade itself.

5.1. ACTUATOR DISC THEORY

To calculate the amount of power available in the wind, a balance of the input power is made based on the model of the actuator disc.

A model for the prediction of the characteristic parameters of a horizontal axis wind turbine is formulated.

The mass flow or mass of air per unit of time that passes through the wind rotor is (ρ is the density of the air, A the swept area and U1 the wind speed):



$$\frac{dm}{dt} = \rho \cdot A \cdot U_1$$

That mass has a kinetic energy: $E_c = \frac{1}{2} \cdot m \cdot U_1$

The available power of the wind is:

$$Pd = \frac{dEc}{dt} = \frac{1}{2} \cdot \frac{dm}{dt} \cdot U_1^2 = \frac{1}{2} \cdot \rho \cdot A \cdot U_1^3$$

We can draw the following conclusions:

- The available power is proportional to the density of the air. In standard conditions (sea level and 15° C) the density of the air is 1,225 Kg / m3.
- The available power is proportional to the surface swept by the blades (the square of the radius in horizontal axis wind turbines).
- The available power is proportional to the cube of the speed of the wind.

However, not all this power is usable (the wind turbine does not absorb all the kinetic energy of the wind). The energy absorbed is the energy difference between the input and the output:

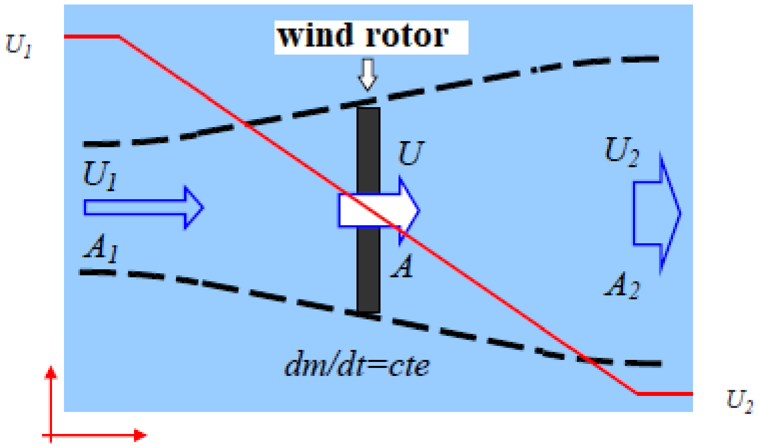


Fig. 15. Differentiation between input and output

Definition of the induced velocity coefficient (a), that is, the fall of speed from the entrance to the wind rotor:

$$U = U_1(1 - a)$$

Knowing that the principle of conservation of the mass is fulfilled:

$$\frac{dm}{dt} = cte$$

As the wind rotor extracts energy from the wind, the air decelerates (U2 <U <U1), and, because of dm / dt = cte, the section at the output must increase (A2> A> A1).

It is considered that the speed that crosses the wind rotor decreases linearly, and therefore corresponds to the arithmetic mean of U1 and U2 (Froude's theorem):

$$U = \frac{U_1 + U_2}{2} \Leftrightarrow U_2 = U_1(1 - 2a)$$

The power captured by the wind rotor (Pc) will be the difference between the powers of the air at the entrance and at the exit:

$$Pc = \frac{1}{2} \cdot \frac{dm}{dt}(U_1^2 - U_2^2) = \frac{1}{2} \cdot \rho \cdot A \cdot U(U_1^2 - U_2^2)$$
$$= \frac{1}{2} \cdot \rho \cdot A(\frac{U_1 + U_2}{2})(U_1^2 - U_2^2)$$

The power captured by the wind rotor (Pc) can be expressed as a function of the induced speed coefficient (a) in the following way:

$$U_2 = U_1(1-2a) \Leftrightarrow \quad P_c = \overbrace{\frac{1}{2}\,\rho A U_1^3}^{P_d}\, 4a(1-a)^2$$

5.2. POWER COEFFICIENT(CP), BETZ LIMIT

As previously developed the laws of physics, prevent that you can extract all the power available in the wind as it passes through the rotor of a wind turbine. The wind in its path slows down, leaving it with a lower speed than the one that entered. In practice, 40% of the available wind power is used. The maximum use of wind power is defined by the **Betz limit** and for this, a wind turbine can convert mechanical energy to a maximum of **59.26%** of the kinetic energy of the wind that falls on it.

This last value is calculated as follows:

The maximum power that can be obtained by the wind rotor is obtained by deriving Pc from a and equalling to zero:

$$\frac{dPc}{da} = 0 \Leftrightarrow a = \frac{1}{3} \Leftrightarrow Pc, max = \frac{1}{2} \cdot \rho \cdot A \cdot U_1^3 \cdot \frac{16}{27}$$

$$Pc, max = \frac{1}{2} \cdot \rho \cdot A \cdot U_1^3 \cdot 0.5926$$

The power coefficient Cp measures the fraction of the wind power that is used:

$$Cp, max(Theoretical) = 0.5926 = Betz\ limit$$

$$Cp, max(Real) < 0.5926$$

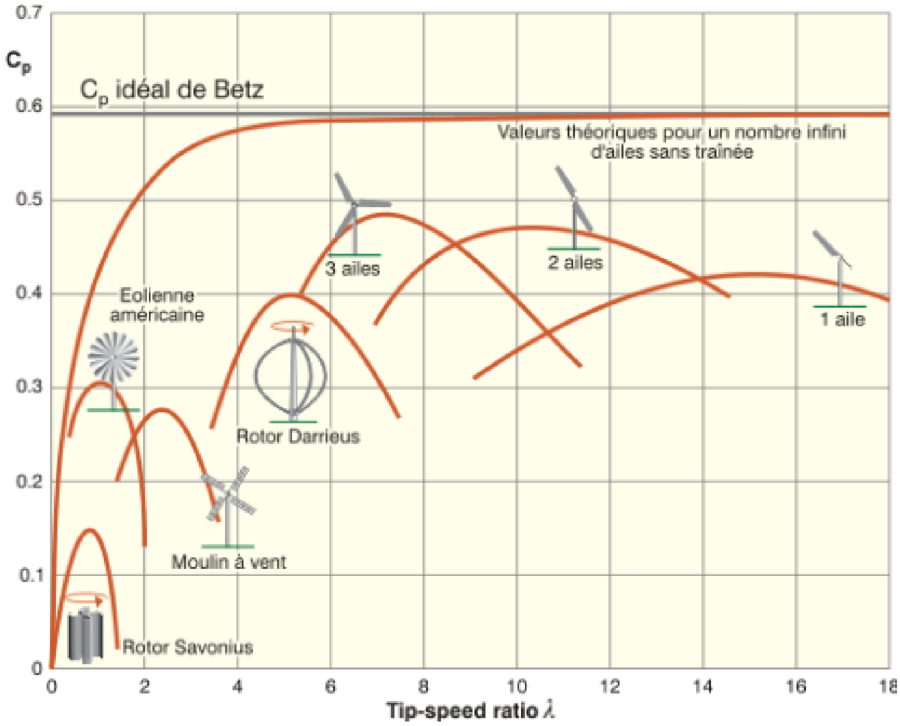
5.3. TIP SPEED RATIO (TSR)

The amount of energy obtained depends on the type of rotor of the wind turbine, as well as the ratio of speeds at the tip of the blade, called λ (specific speed or Tip Speed Ratio, TSR). The value of λ is:

$$\lambda = \frac{\omega \cdot R}{U_1}$$

(R is the radio of the wind rotor, ω the rotation speed and U1 the wind speed)

The Tip Speed Ratio of a wind turbine is an essential factor to how efficient that turbine will perform. The graph 3 shows the relationship between tip-speed ratio (TSR) and the coefficient of power (Cp) for wind turbines with different number of blades:



Graph. 3. Relationship TSR-Cp

The greatest efficiency is obtained with the turbines with a horizontal axis of two or three blades.

The smaller the number of blades are, the more level of Cp curves are. The interest of this characteristic is that it is not so important the adaptation of the speed of the turbine to the wind.

5.4. AERODYNAMIC PROFILE

If a blade were sawn in half, one would see that the cross section has a streamlined asymmetrical shape, with the flattest side facing the oncoming air flow or wind. This shape is called the blades aerodynamic profile.

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

Definition of the parts of an aerodynamic profile:

- Leading edge: Center point of the front of the profile.
- Trailing edge: Center point of the back of the profile.
- Upper surface: It is the top of a profile, measured from the leading edge to the trailing edge.
- Lower surface: It is the bottom of a profile, measured from the leading edge to the trailing Edge.
- Thickness: It is the maximum distance between the upper surface and the lower surface.
- Mean or camber line: It is the equidistant curve between the upper surface and the lower surface.

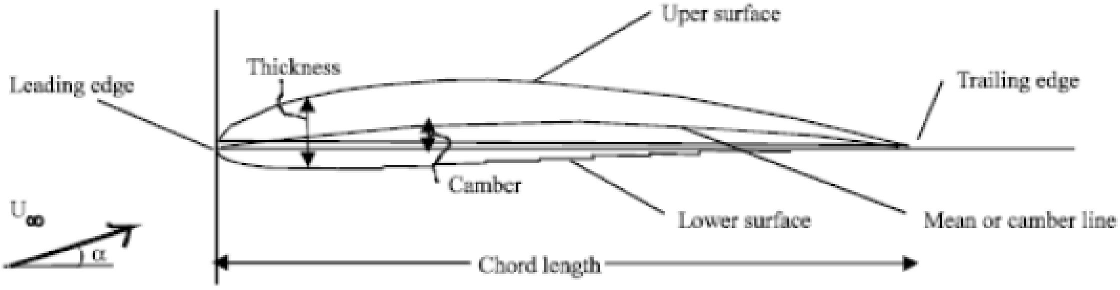


Fig. 16. Parts of an aerodynamic profile

5.5. LIFT AND DRAGING

An aerodynamic profile (airplane wing) when moving through the air, experiences a force that can be decomposed into two components:

Lift: Perpendicular to the direction of advance.

$$L=1/2\cdot Cl\cdot \rho\cdot A\cdot V_2$$

Drag: (parallel to the direction of advance)

$$D=1/2\cdot Cd\cdot \rho\cdot A\cdot V_2$$

The coefficients of lift **Cl** and of drag **Cd** are a function of the aerodynamic profile and the angle formed between the rope (straight line joining the leading edge to the trailing edge) of the profile and the direction of the wind.

The support of the profile is produced because when the wind current goes to the edge of the attack of the blade, deflects the current downwards, which drives the profile upwards.

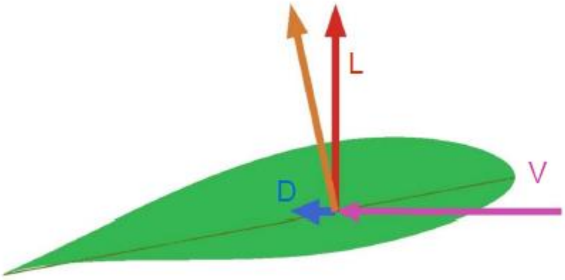


Fig. 17. Lift and drag

The aerodynamic profiles are designed to have minimum lift and maximum drag.

Each aerodynamic profile presents characteristic curves of Cl and Cd.

The coefficients of lift Cl and drag Cd are a function of the angle of attack of the profile (α). This angle represents the angle between the rope of each blade profile and the direction of the relative wind speed in that profile.

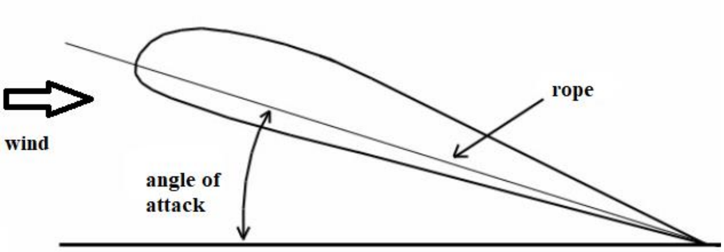


Fig. 18. Angle of attack

With an excessive angle of attack, the profile falls into aerodynamic loss:

- The flow at the top of the profile becomes turbulent and stops sustaining.
- The drag that the profile suffers increases.

The optimum angle of attack (greater lift) in wind profiles is between 10 and 15º.

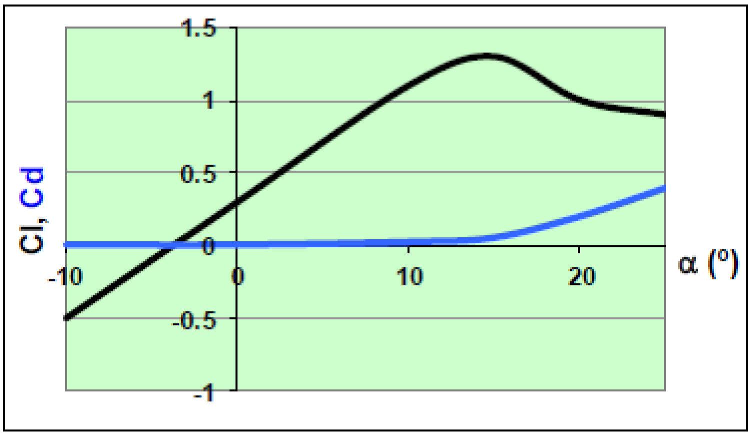


Fig. 19. Relation between Cl,Cd and α

To achieve an optimal angle of attack and achieve higher performance, it is advisable to turn the blade depending on the wind speed in order to maintain a constant angle of attack.

5.6 PASSIVE STALL CONTROL

Wind turbines controlled by loss (passive) have the rotor blades attached to the hub at a fixed angle.

The geometry of the rotor blade profile, however has been aerodynamically designed to ensure that the moment the wind speed becomes too high, it creates turbulence on the side of the rotor blade which is not facing the wind . This stall prevents the lifting force of the rotor blade from acting on the rotor.

It is used in small and medium size machines (less than 1 MW).

The performance of this machine is less than that of a variable-pitch machine. However, its cost is lower.

Around two thirds of the wind turbines currently being installed in the world are stall controlled machines.

5.7 ACTIVE STALL CONTROL

An increasing number of larger wind turbines (1 MW and up) are being developed with an active stall power control mechanism.

The machines of active stall control also have the denomination of machines with control of pitch, to the reference to the control that realizes the angle of step of the blades.

Variable pitch wind turbines regulate their power by rotating the blades on their axis.

The rotation of the blades allows a much tighter adjustment of the power than that achieved by aerodynamic loss, which allows the performance of a variable pitch machine to be greater than that of a fixed pitch machine.

The variable step system increases the cost of the machine.

At present, most of the wind turbines installed are of variable pitch.

Power curve of a variable pitch wind turbine and fixed pitch:

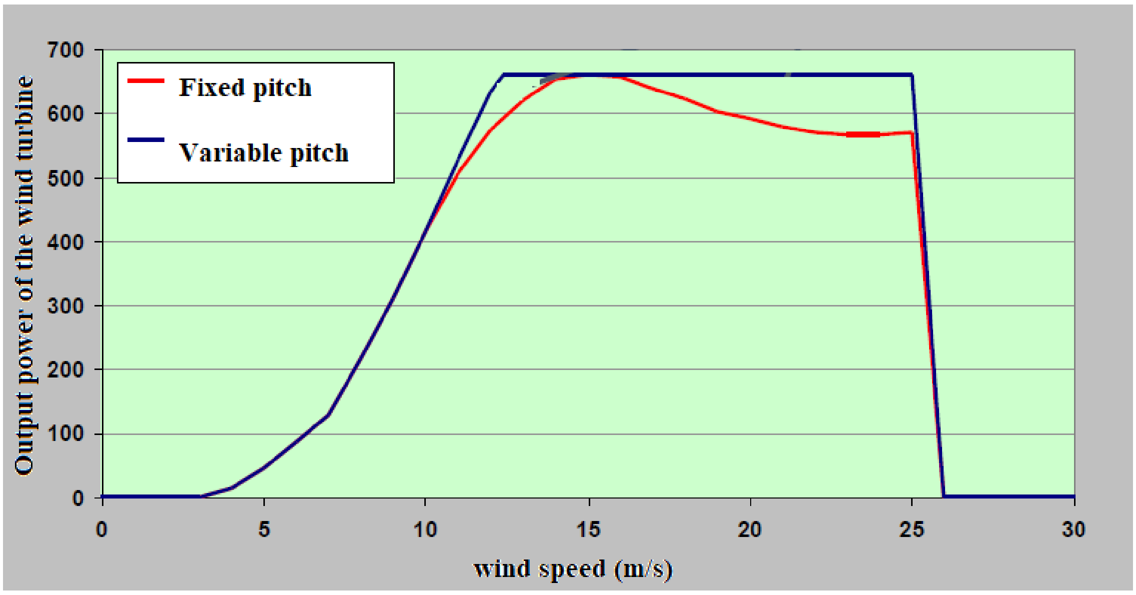


Fig. 20. Relation between fixed-variable pitch and wind speed

It can be observed, there is an improvement of production for the variable step machine.

5.8. FURLING

The fundamental principle of this system is to reduce the area of the rotor in a position perpendicular to the current of incident air when the speed exceeds a certain value.

The system for the detection of excess energy and that of action is formed by the rotor itself and its connection to the tower through the nacelle.

When the wind hits the rotor, a force is generated in the direction of the air flow.

If the rotor axis, where this force is applied, does not belong to the vertical plane that contains the axis of the tower, where the nacelle-rotor assembly rotates according to the direction of the wind, there will be a moment that will misalign the rotor with respect to the direction of the wind.

If this rotation is limited by a calibrated spring attached on one side to the rotor and on the other to the structure of the rear part of the wind turbine, it is achieved that only when there are air currents at speeds higher than the nominal one, the nacelle is rotated, calling itself This system "furling".

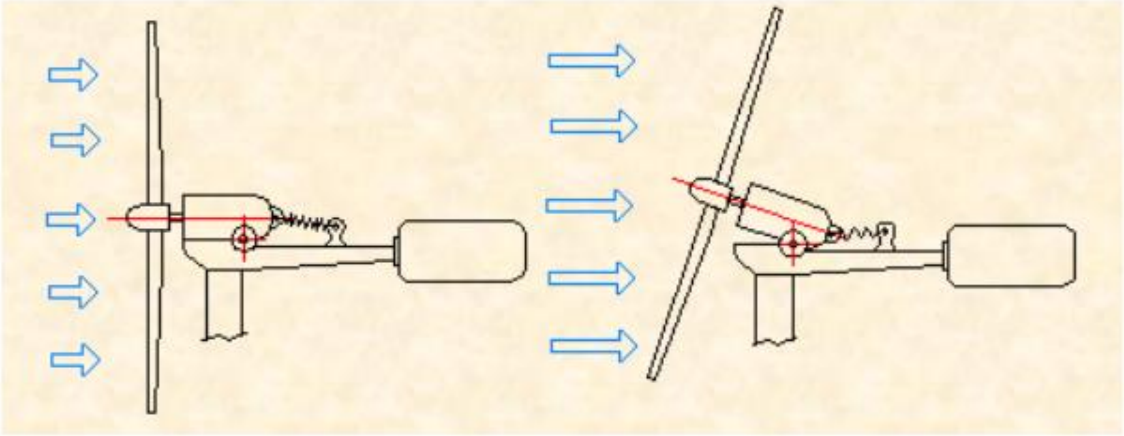


Fig. 21. Operation of the furling system

This type of system is used frequently in small wind turbines, for wind turbines of few Kw of power.

This will be the system used in the study carried out in this project.

6. INTERFACE AND PROGRAMMING

In this section, the different parts of the project carried out in the Lavbiew program will be explained, divided into two parts, on the one hand the interface and on the other hand the programming part.

6.1. INTERFACE

This will be the visual part of the program, with which the user will be able to interact and see the different results obtained.

The interface corresponds to the **front panel** part of the program.

This control panel has an interactive part, in which the user can enter the values of the data sheet of the wind turbine.

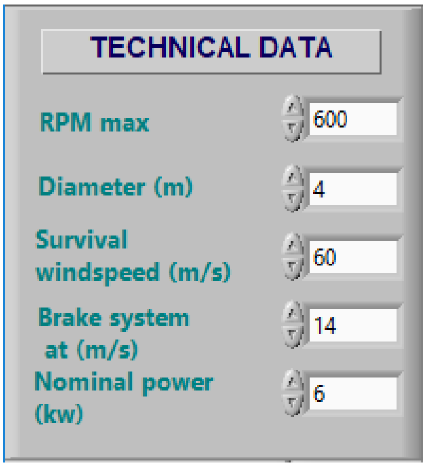
Within the electrical specifications, it is necessary to know the maximum revolutions of rotation of the wind turbine, this value will limit the maximum power extracted.

Another necessary value will be the nominal power, this value will be the objective to achieve for different wind speeds.

Regarding the technical specifications, it is necessary to know the diameter of the wind turbine.

Regarding the specifications depending on the wind speed, it is interesting to know the maximum speed of operation, as well as the speed at which the automatic braking comes into operation.

On the other hand it is not necessary to know the speed at which the nominal power is achieved, although if that speed is known, it is observed that it will correspond to the nominal power.



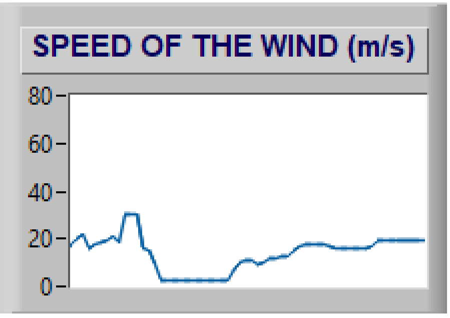
TECHNICAL DATA

RPM max	600
Diameter (m)	4
Survival windspeed (m/s)	60
Brake system at (m/s)	14
Nominal power (kw)	6

Fig. 22. Technical data

Also, in the control panel we can observe the evolution of different parameters in real time.

The input variable of the wind speed, thanks to a graph.



Graph. 4. Speed of the wind

The speed that supports the wind turbine, and which can never exceed the maximum of operation (before it stops turning).

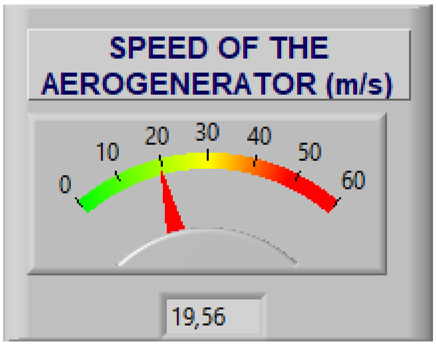
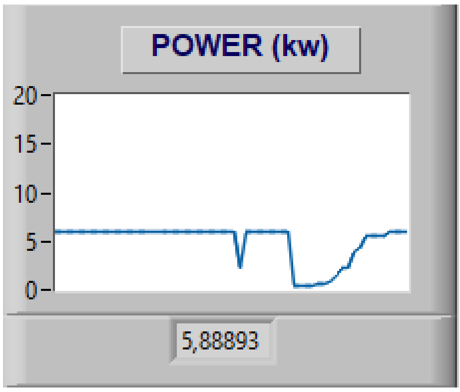


Fig. 23. Speed of the aerogenerator

In addition to the output variable of the power captured by the wind rotor, which will change depending on the different input variables.



Graph. 5. Power

6.1.1. DSC MODULE

The LabVIEW Datalogging and Supervisory Control (DSC) Module extends the LabVIEW graphical development environment with additional functionality for the rapid development of measurement and control of differents variables.

The DSC Module also improve the LabVIEW shared variable. Use the shared variable to access and pass data among VIs and devices on the local computer and across a network. With the DSC Module, you can log data automatically; add alarming, scaling, and security to the shared variable; and configure the shared variable programmatically.

The DSC Module also enhances the NI Distributed System Manager. You can use the System Manager to monitor, configure, and acknowledge alarms. You also can use the System Manager to monitor and acknowledge events.

To use DSC Module, launch LabVIEW and select Tools»DSC module »Image navigator.

The DSC Module also provides tools for graphing historical or real-time trends. The DSC Module provides solutions for supervisory control of a wide variety of distributed systems using graphical LabVIEW programming.

Regarding the images used, different interactive images were created:

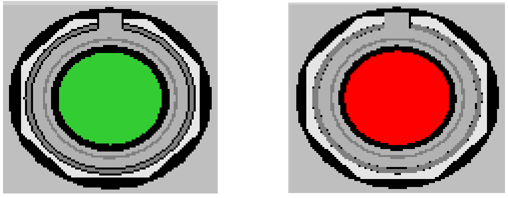


Fig. 24. On/Off

With a button we will be able to start the wind turbine, showing itself in green when it is in operation and in red when it has not yet started or on the other hand the wind speed is higer than the maximum.

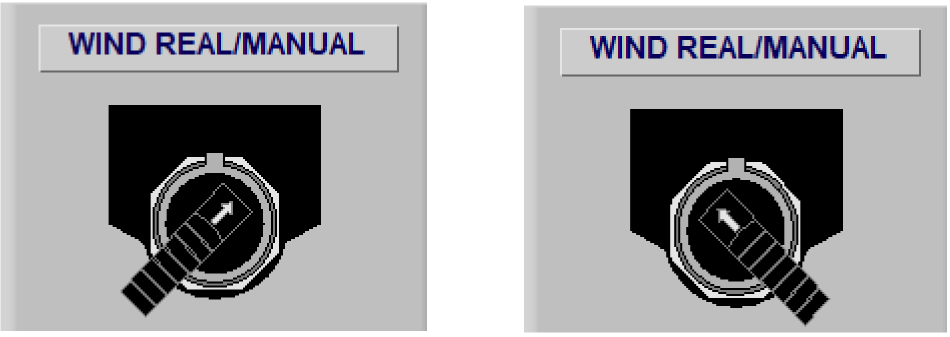
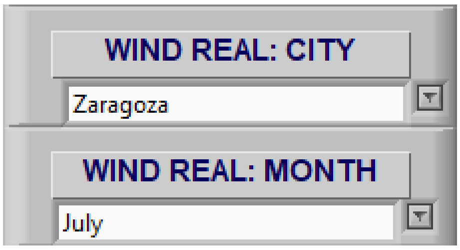


Fig. 25. Real/Manual

The switch selector image contains two variables for the use of the interface. On the one hand there is the manual option, through which the bar and pressing a pre-set letter (F1) can increase the wind speed or decrease it.

On the other hand, by choosing the real option, you access a database of a specific region or city, in which the different average monthly wind speeds are observed, and thanks to this you get a more accurate idea of the operation of the wind turbine in that location.

For now the option to choose the city of Zaragoza, belonging to the north of Spain has been loaded. Selecting this option and selecting the month to study, the power extracted for that monthly wind average is observed.



WIND REAL: CITY
Zaragoza

WIND REAL: MONTH
July

Fig. 26. Selection of the city and month

Another use for the real wind option, it must be added that if the program were actually used, for the "real wind" option an anemometer would be used, in order to monitor the operation of the wind turbine.

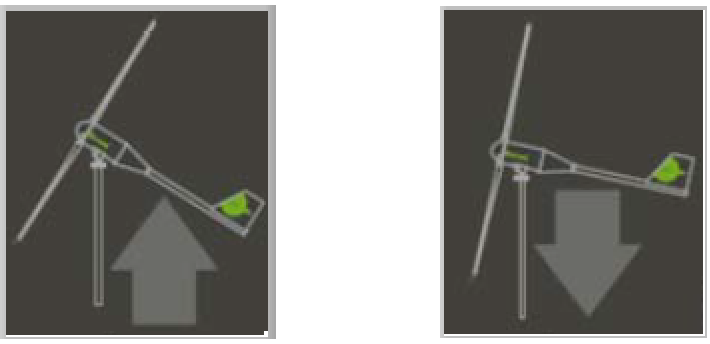
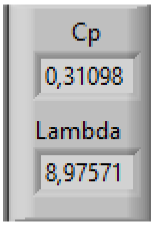


Fig. 27. Inclination of the aerogenerator due to the furling system

To achieve a maximum power, the inclination of the wind turbine will be regulated, this is achieved by the furling method, mentioned above, which will come into operation when exceeding the speed specified in the section "brake system".

In addition, you can see that the Cp will change from a maximum, which will be obtained when the wind turbine is to horizontal, that is, before starting with braking system. Also, the value of lambda.


Cp
0,31098
Lambda
8,97571

Finally, two images were implemented which represent the wind turbine working, these images will interlace faster or slower depending on the wind speed.

Fig. 28. Image of the aerogenerator in the interface

6.2. PROGRAMMING

The part used to perform all the calculations and implement all the data obtained corresponds to the "**block diagram**" part of the program. It is accessed through the Front panel»Window»Show block diagram.

This part is formed by different blocks which unite the variables or constants used to develop the program.

On the other hand, C programming is implemented in different parts of the program.

To explain the operation of the program in the first place you have to select an operation mode, real or manual, which will be done with a true / false structure.

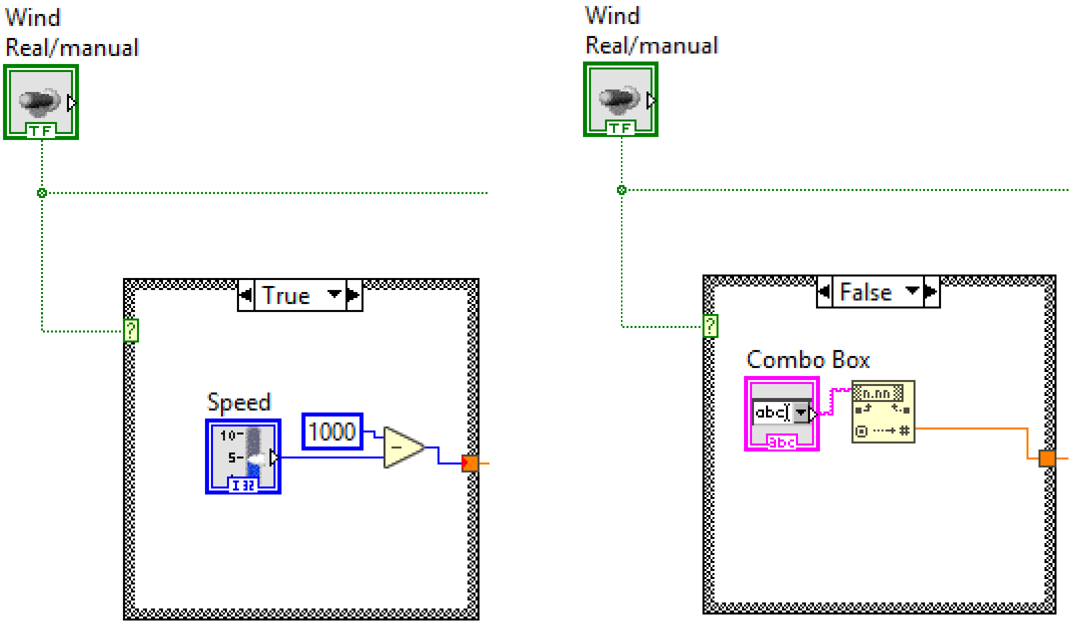
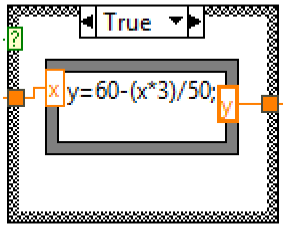


Fig. 29. Block diagram, operation mode

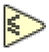
The structure true will correspond to the manual mode, in which we will enter the value by moving the bar, and the structure of the false will correspond to the real mode, selecting the chosen month from the interface.

In the case that manual mode is used, an equation must be implemented to adjust the velocity values.



```
y=60-(x*3)/50;
```

The next step will be to check if the operating speed is higher than the speed at which the braking system comes into operation. For this, we will use a comparator less or equal.



If it is true that the braking speed is lower than the wind speed, it means that the furling system must come into operation, therefore by means of another true / false structure, we select the suitable operations.

The wind turbine must move to continue contributing the nominal power. In this way, we implement a structure to indicate if, being above the braking speed, the speed is increasing or decreasing.

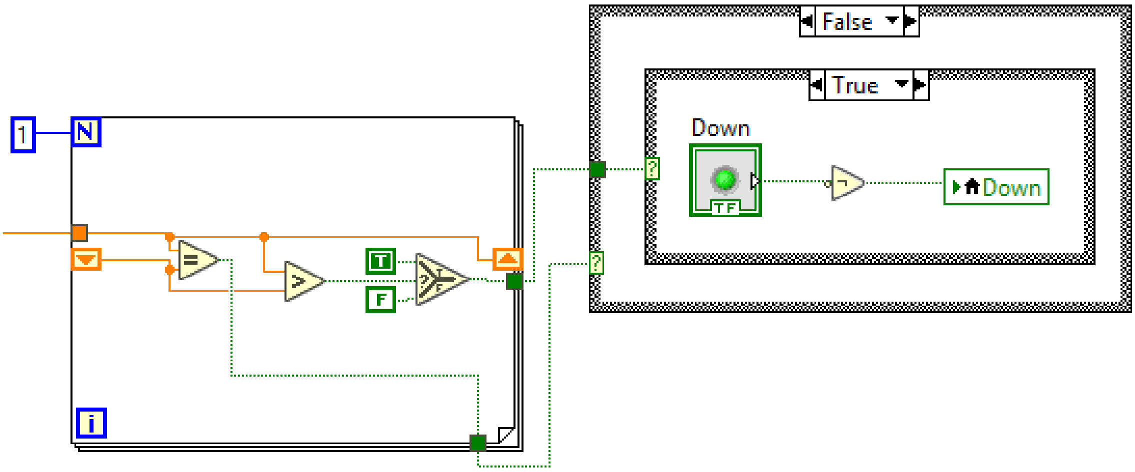


Fig. 30. Block diagram, brake system operation mode

For this, we will compare the input value with the previous value and in this way we will know if it increases or decreases. We will implement all this in a for loop and then in a double true / false.

On the other hand, we will compare the maximum speed of operation with that of the wind turbine, if at some time it exceeds the maximum, the program will stop.

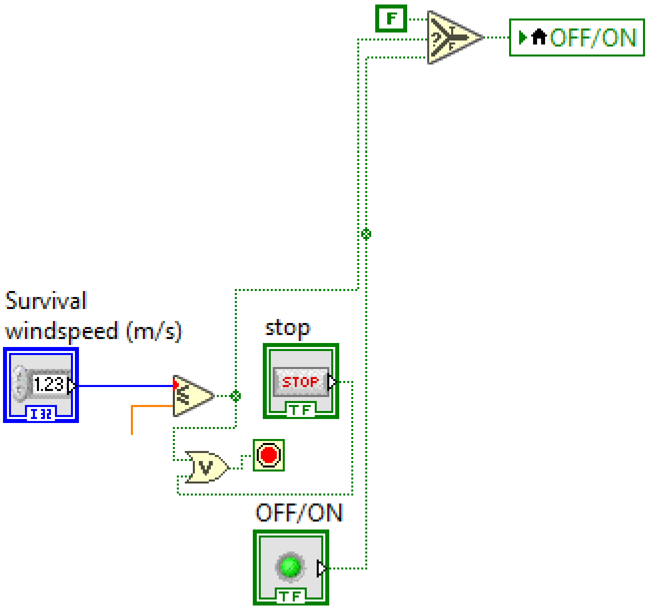


Fig. 31. Block diagram, operation mode with maximum speed

To represent the wind turbine in motion, a loop was implemented in which it would only exit as previously seen.

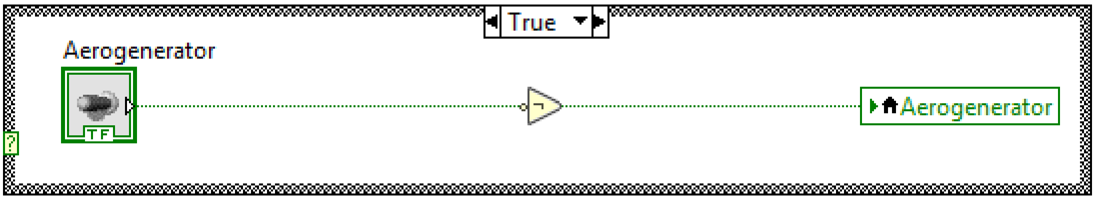
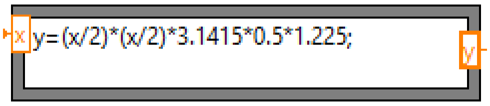


Fig. 32. Block diagram, loop to represent the wind turbine in motion

After performing the different schedules depending on the wind speed, the other variables and constants are implemented.

Using the block “formula node”, is possible to use evaluates mathematical formulas and expressions similar to C on the block diagram.



```
y=(x/2)*(x/2)*3.1415*0.5*1.225;
```

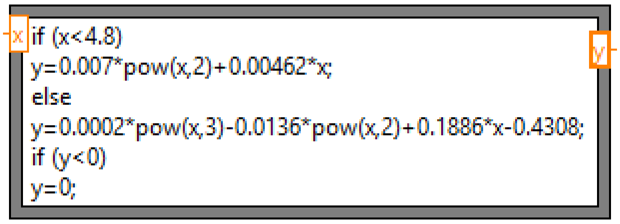
This equation represents the product of the area swept by the blades, multiplied by the radius (the variable "x") and the density of the air. For which we assume that it is in standard conditions (sea level and 15º C) 1,225 Kg / m3.

The blades and the power developed by the wind in the axis of the wind turbine will be simulated by means of a curve that will characterize its power coefficient Cp.

The Cp is calculated from the value of the blade tip coefficient λ, tip speed ratio, defined as:

$$\lambda = \frac{\omega \cdot R}{V}$$

Knowing this value of Lambda and knowing the direct relationship between it and the Cp, it will be calculated with the following equation:



```
if (x<4.8)
y=0.007*pow(x,2)+0.00462*x;
else
y=0.0002*pow(x,3)-0.0136*pow(x,2)+0.1886*x-0.4308;
if (y<0)
y=0;
```

This expression is approximate since it takes a long time to calculate for each particular wind turbine and does not change the result obtained much.

Finally, by multiplying the different values we get the power captured by the rotor, as shown below:

$$Pc,real = \frac{1}{2} \cdot \rho \cdot A \cdot V^3 \cdot Cpreal$$

The maximum power that can be obtained corresponds to the nominal power, we will achieve that this value does not increase thanks to the inclination of the wind turbine, "furling".

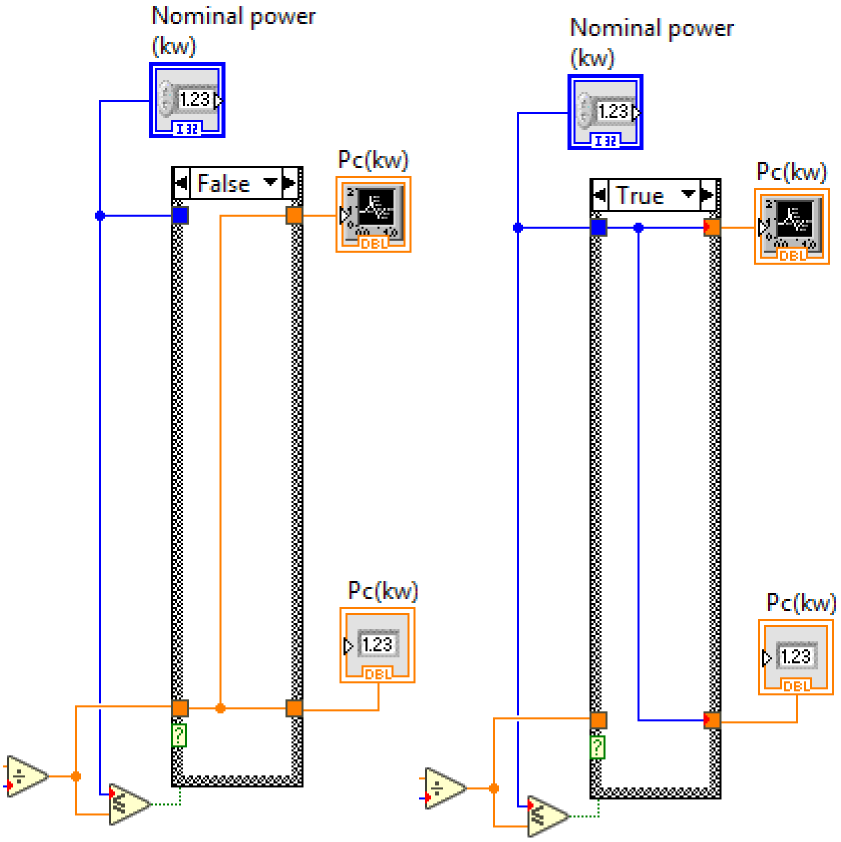


Fig. 33. Block diagram, operation mode of the power obtained

TESTS AND RESULTS

7. TESTS AND RESULTS

The simulation of the operation of the low power wind turbine will be done with a prototype that is currently on the market, the **Bornay 6000** wind turbine.

Bornay is a Spanish company dedicated to renewable energies, with more than 40 years of experience in the sector. Its branch of wind energy is one of the strongest in the sector, combining performance with resistance, which makes its wind turbines one of the best in the world.

The Bornay 6000 wind turbine is the largest in the Bornay family. With 6000 watts of power and 48 volts this wind turbine is designed to work in conjunction with solar systems that work with high energy demands such as water pumping, farms, telecommunications and many more.

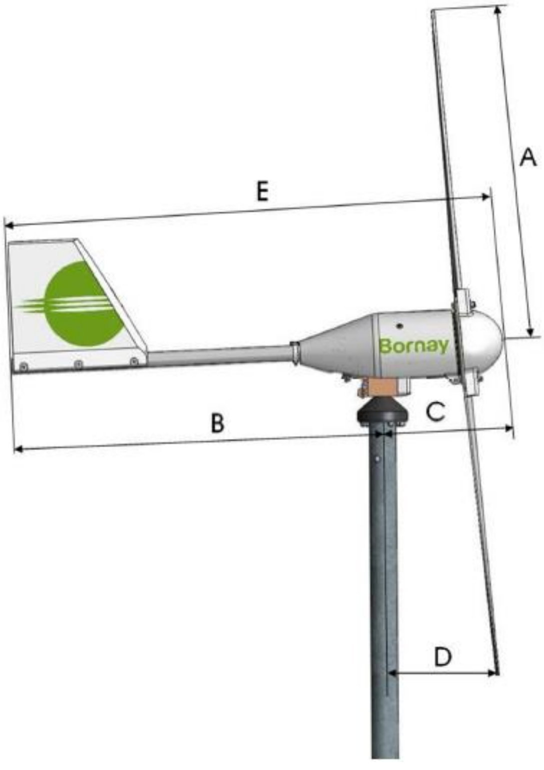
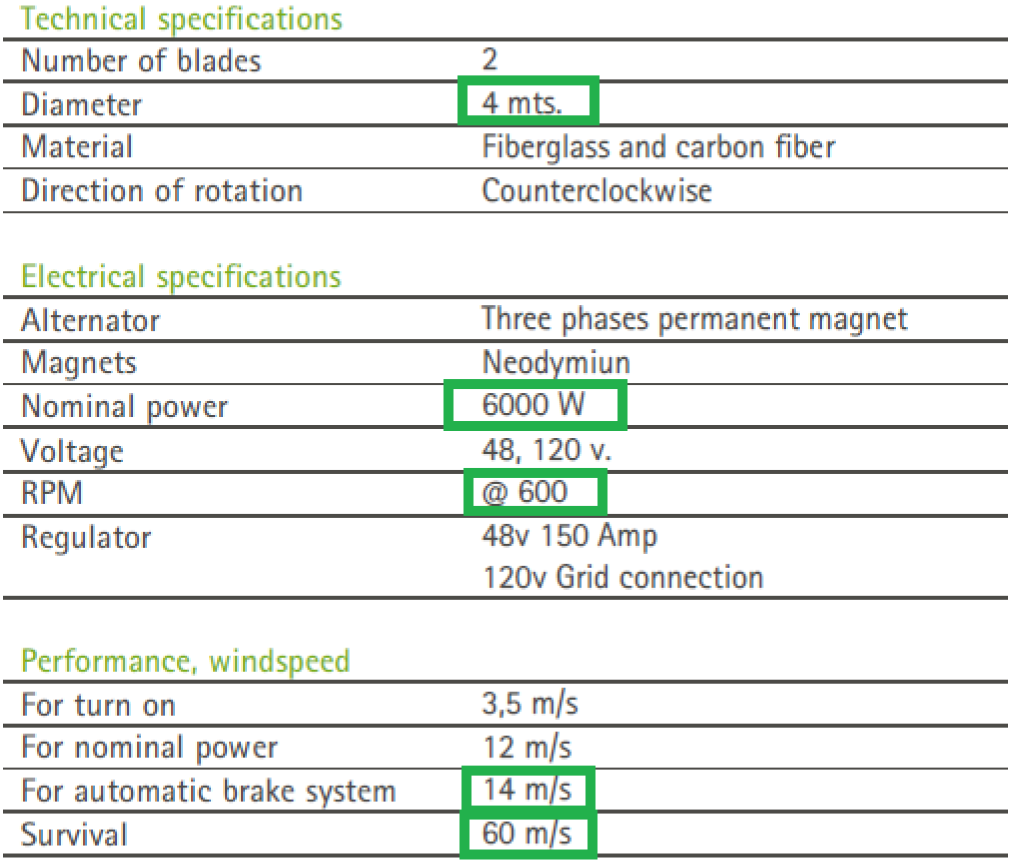


Fig. 34. Bornay 6000

The wind turbine specification sheet is as follows, the data that we must take into account are in green:



Technical specifications	
Number of blades	2
Diameter	4 mts.
Material	Fiberglass and carbon fiber
Direction of rotation	Counterclockwise

Electrical specifications	
Alternator	Three phases permanent magnet
Magnets	Neodymiun
Nominal power	6000 W
Voltage	48, 120 v.
RPM	@ 600
Regulator	48v 150 Amp 120v Grid connection

Performance, windspeed	
For turn on	3,5 m/s
For nominal power	12 m/s
For automatic brake system	14 m/s
Survival	60 m/s

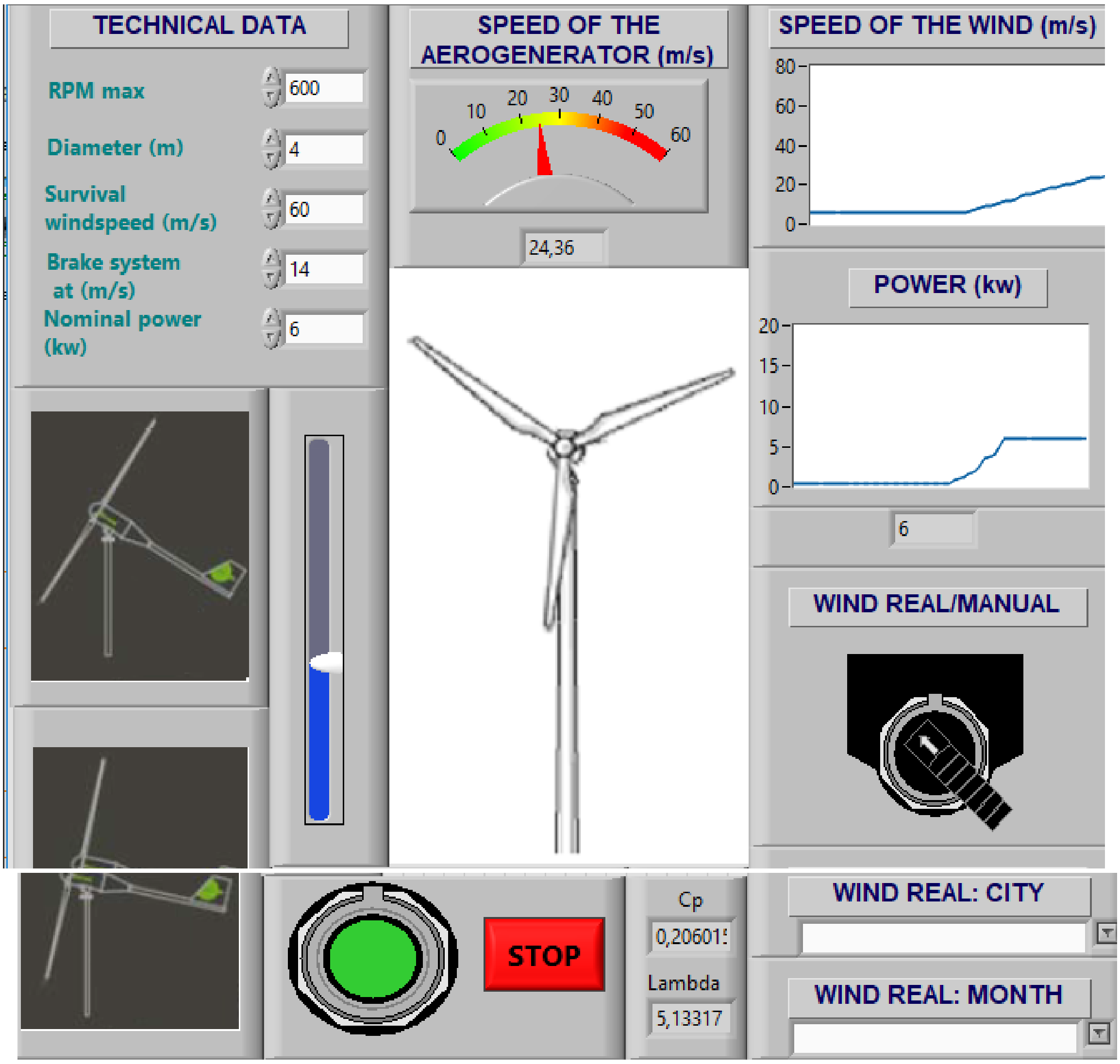
Table. 3. Specification sheet

These values are entered in the interface, for all the possible models that are used.

The next step will be to choose an operating mode, that is, simulate the wind speed or use real data from a specific location.

7.1. SIMULATING WIND

Manual wind mode is activated, the red button is pressed to change to green and start the wind turbine turn, and then F1 is pressed and the wind speed is increased with the help of the keyboard.



TECHNICAL DATA

RPM max: 600
Diameter (m): 4
Survival windspeed (m/s): 60
Brake system at (m/s): 14
Nominal power (kw): 6

SPEED OF THE AEROGENERATOR (m/s): 24,36
POWER (kw): 6
Cp: 0,20601
Lambda: 5,13317

Fig. 35. Front panel, interface

As long as the wind speed is lower than the braking speed, the value of the Cp will be constant. This means that the wind turbine remains horizontal and has not started to turn.

Knowing that the brake system starts at 14 m/s, we simulate two cases with lower speeds (in green colour the speed):

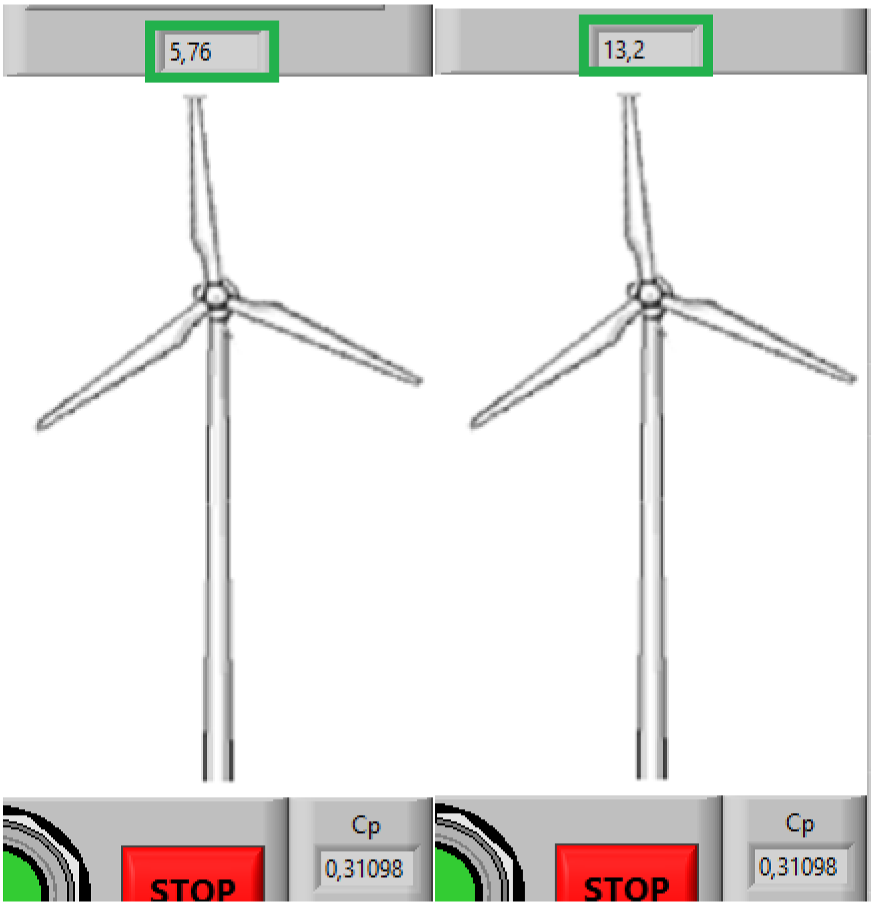
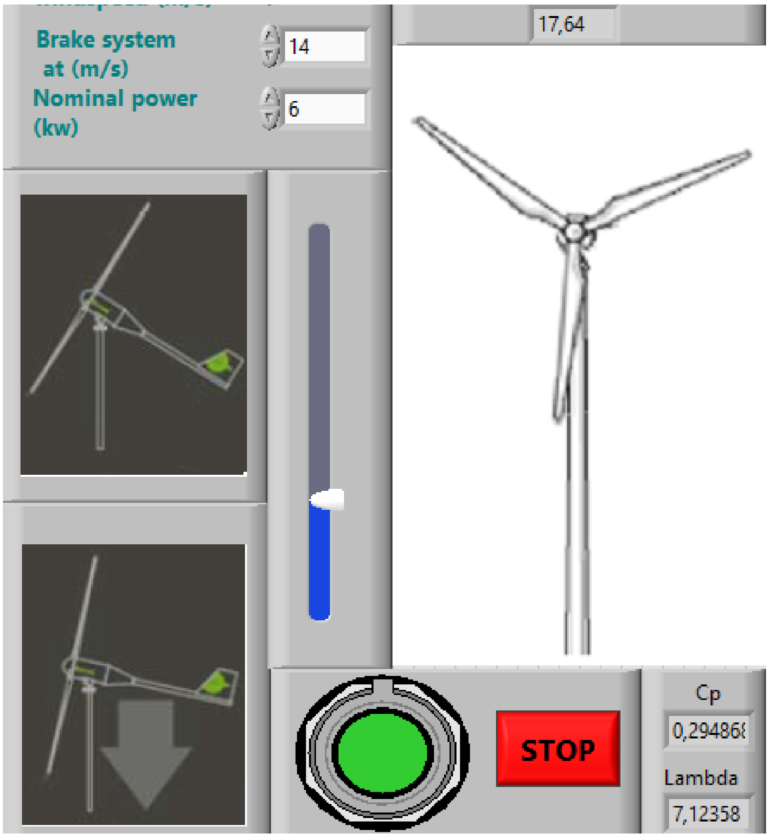


Fig. 36. Front panel, simulation of the aerogenerator with low wind

As we can see in this case, the maximum Cp value is 0.31098.

By the Betz limit, it is known that the maximum value theoretical of this coefficient is 16/27. In large wind, optimizing the design of the blades can achieve power coefficients greater than 0.45. As will be seen later, for small wind turbines, the practical values of this coefficient are considerably smaller.

In the case that the wind speed is higher than the braking speed, we see that the Cp decreases, therefore the wind turbine has begun to tilt. This is indicated by the arrow on the left side.


Brake system at (m/s) 14

Nominal power (kw) 6

17,64

Cp 0,29486

Lambda 7,12358

Fig. 37. Front panel, simulation of the aerogenerator with normal wind

On the other hand, if the speed is greater than the braking speed, but decreases, it will be indicated by an arrow going up.

Also, analyzing the power captured by the wind rotor, it is observed that the nominal power value is obtained with the wind value specified in the characteristics sheets, with a small mismatch.

In the technical data, it specifies that the nominal power is obtained for a wind speed of 12 m/s while we see that in the test a power of 5.21 kw has been obtained for said speed. That power obtained can be considered close to the nominal power.

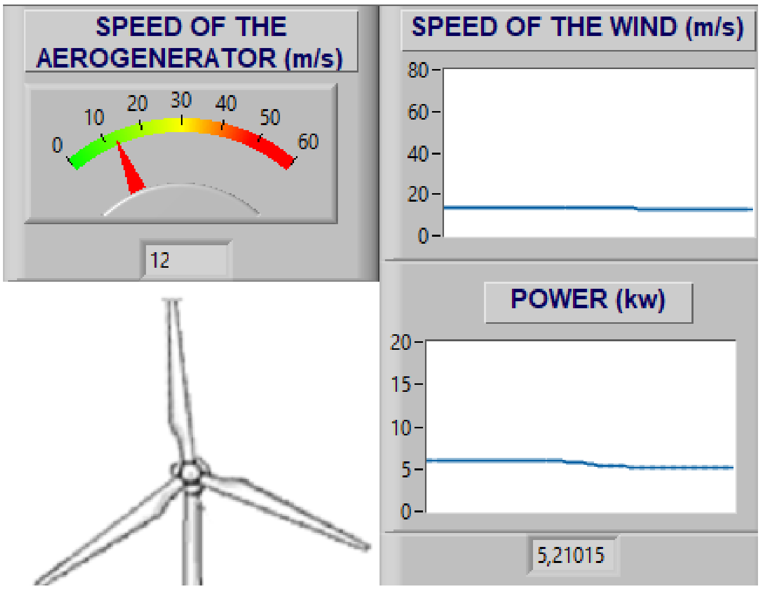


Fig. 38. Front panel, relation 1 between speed of the wind and power

For higher speeds, we see that the power remains constant even if the wind speed varies.

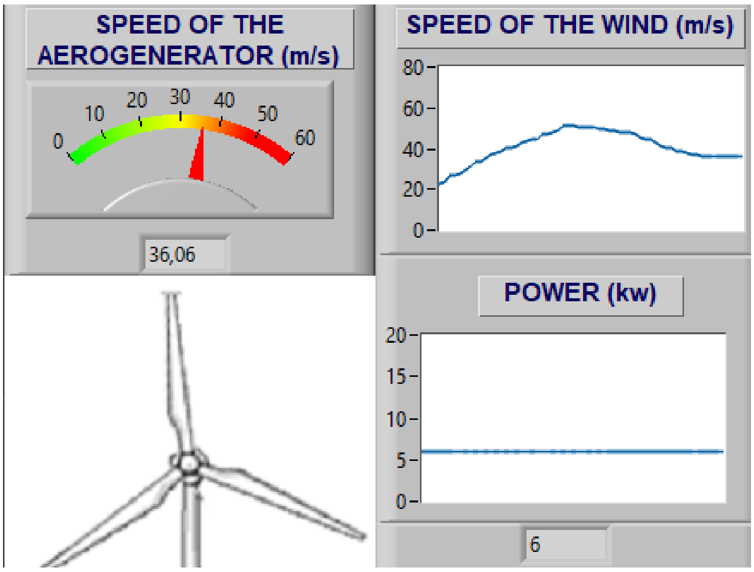


Fig. 39. Front panel, relation 2 between speed of the wind and power

And finally, it is observed that if the wind speed is higher than the maximum, the wind turbine will stop, placing it completely vertical.

7.2. REAL WIND

To choose a good location for the wind turbine, it must be taken into account that the energy that can be captured from the wind is proportional to the cube of its speed, that is, when the wind speed doubles, the power that can be produced with a Wind turbine is up to eight times higher.

For this reason, it is important to install the wind turbine in a place where the wind blows with the greatest speed and constancy possible. The speed of the wind depends to a great extent on the land on which the air moves; the vegetation, type of terrain, nearby constructions, etc., slow the wind and produce turbulence.

To perform this simulation, with large wind speeds, I had two options, or choose a small town, which would be the ideal place to place a smart wind turbine, with little data on wind speeds, or, on the other hand, choose a big city.

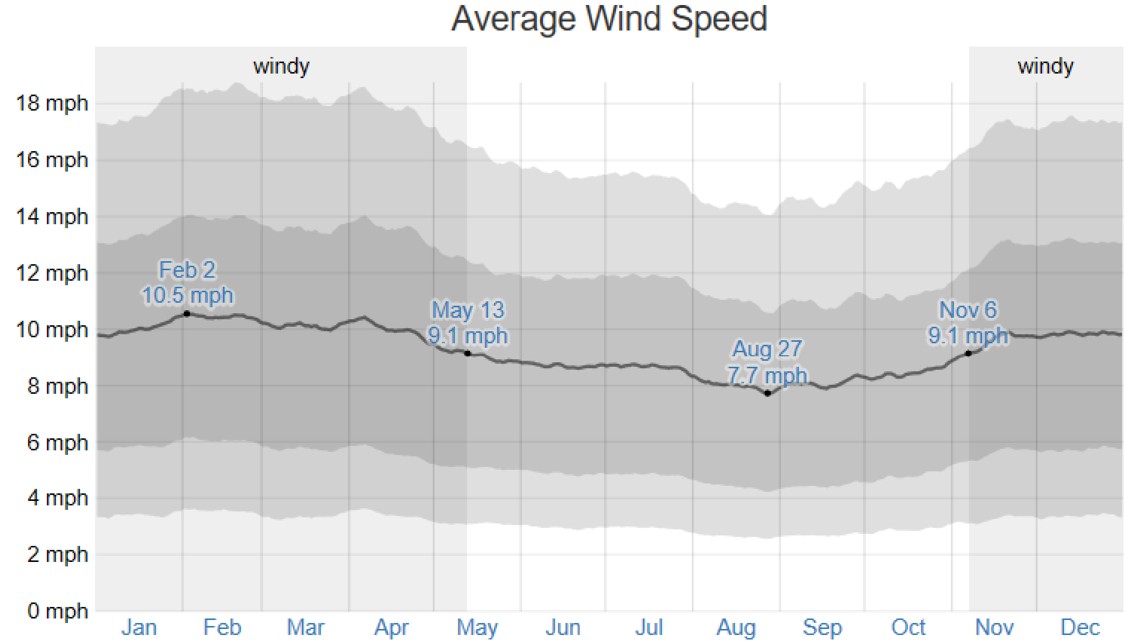
Choosing a big city, one of the highest annual wind speeds is Zaragoza. Zaragoza is a city and a municipality of Spain, located to the north of this, and capital of the autonomous community of Aragon. It is a city in which the wind blows constantly throughout the year, with more or less acceptable gusts.

The average hourly wind speed in Zaragoza experiences mild seasonal variation over the course of the year.

The windier part of the year lasts for 6.2 months, from November 6 to May 13, with average wind speeds of more than 9.1 miles per hour. The windiest day of the year is February 2, with an average hourly wind speed of 10.5 miles per hour.

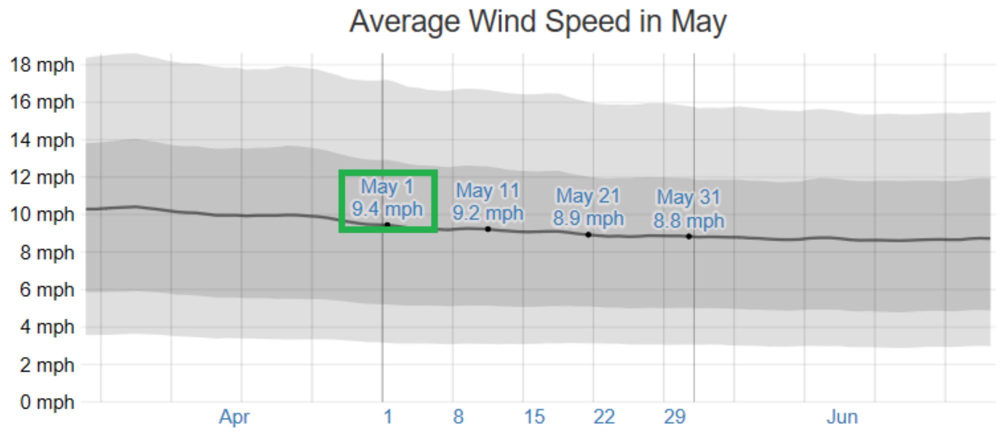
The calmer time of year lasts for 5.8 months, from May 13 to November 6. The calmest day of the year is August 27, with an average hourly wind speed of 7.7 miles per hour.

All the wind values collected during the year in Zaragoza are represented in the graph 4:



Graph. 6. Average wind speed in Zaragoza in 2017

To select a representative speed per month, the highest speed of each month has been selected, for example, for May:



The average of mean hourly wind speeds (dark gray line), with 25th to 75th and 10th to 90th percentile bands.

Graph. 7. Average wind speed in May in Zaragoza in 2017

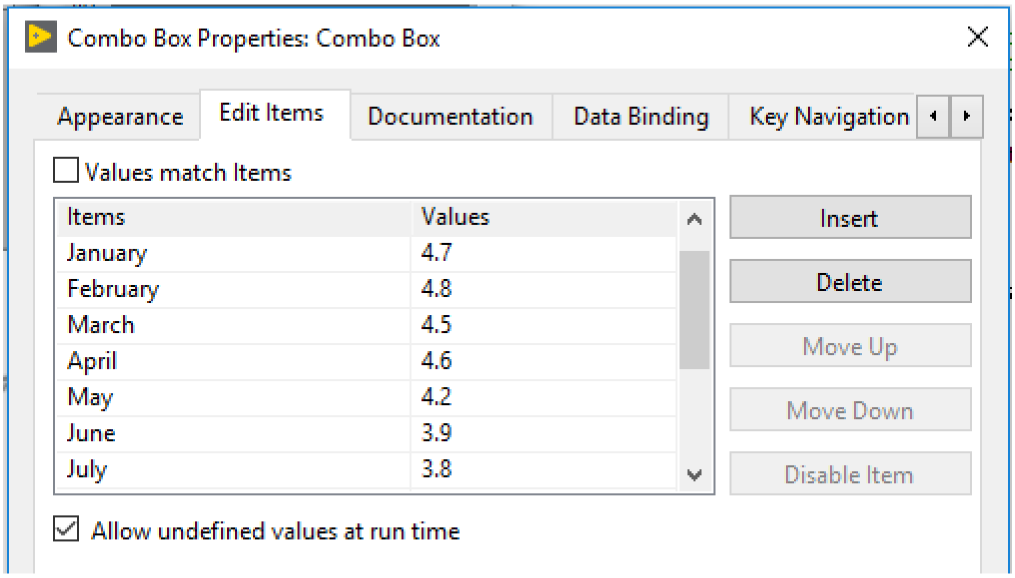
The data obtained are shown in the table 4:

1 mph = 0.44704 m/s

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mph	10,5	10,5	10,3	10,4	9,4	8,8	8,7	8,3	8,3	8,8	9,7	9,9
m/s	4,7	4,7	4,5	4,6	4,2	3,9	3,8	3,7	3,7	3,9	4,3	4,4

Table. 4. Data of the speed of the wind

Selecting a block "Combo box " Enter the different data in Labview, for the city of Zaragoza.



☐ Values match Items

Items	Values
January	4.7
February	4.8
March	4.5
April	4.6
May	4.2
June	3.9
July	3.8

☑ Allow undefined values at run time

Fig. 40. Front panel, block "Combo box"

To join these data in string mode with the rest of the program, we use a string to number converter, which will be within a true / false structure, selected when choosing manual or real mode.

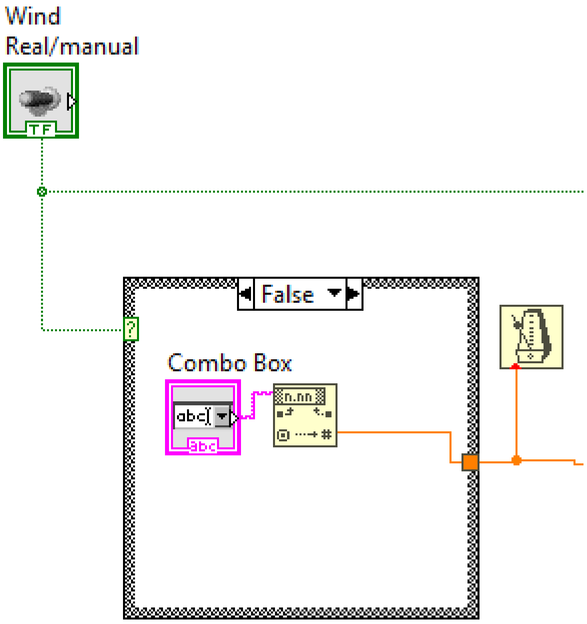


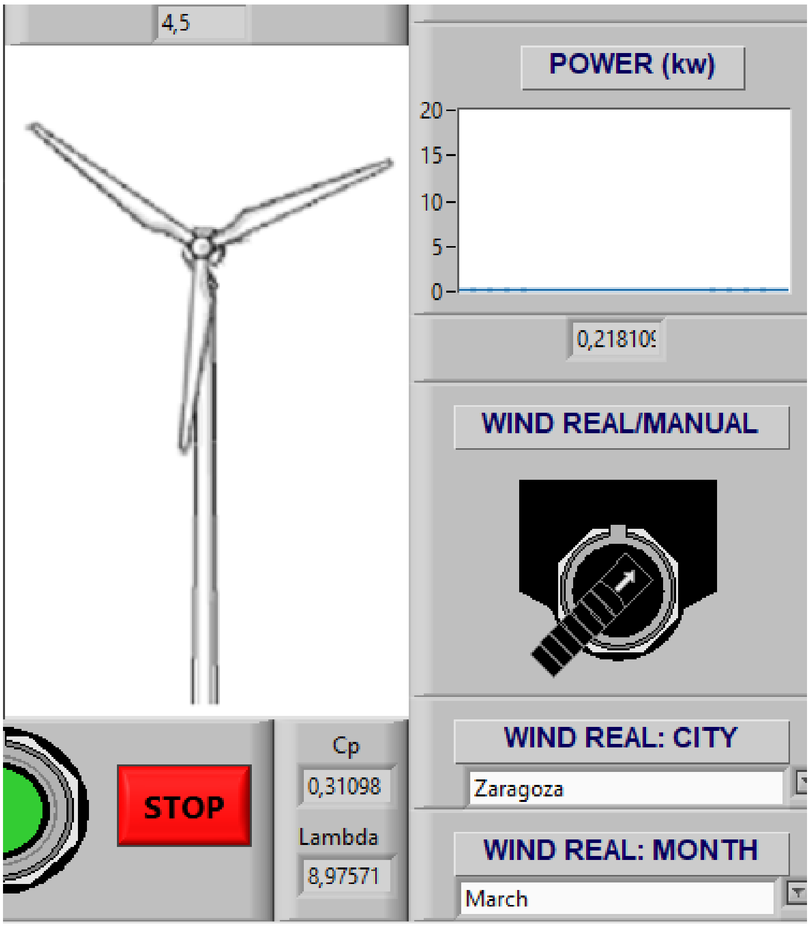
Fig. 41. Diagram block, block "Combo box"

The steps to follow when carrying out the simulation are indicated below.

First, we will introduce the data of the previously selected wind turbine (Bornay 6000) in the interactive part of the interface. And select the real mode of operation.

Fig. 42. Front panel, wind real

Then select the city to study (Zaragoza) and select a month, finally press the red button to change to green, and study the data obtained.



4,5

0,21810

Cp 0,31098

Lambda 8,97571

WIND REAL: CITY Zaragoza

WIND REAL: MONTH March

Fig. 43. Front panel, part of the interface during the operation

We see that the wind speed coincides for the month of the year, on the other hand we observe that the Cp is the maximum that this wind turbine can give.

In the next part, we will calculate by means of the application of the different used formulas, if the power obtained equals the real one.

$$Pc,real = \frac{1}{2} \cdot \rho \cdot A \cdot V^3 \cdot Cpreal$$

Knowing that the radius is 2m, and the density is1,225 kg/m3, with the values of the interface we calculate the power captured:

$$Pc = \frac{1}{2} \cdot 1.225 \cdot 2^2 \cdot \pi \cdot 4.5^3 \cdot 0.31098 = 218.11\ w = 0.2181\ kw$$

In this way we verify that the results are correct.

8. CONCLUSIONS

With the realization of this project, a study has been made for the use of wind energy, from how to take advantage of it, to go through the different types of wind turbines, to reach the low power, on which this work has focused.

Through the Labview program, the operation of a low-power wind turbine has been visualized for, generally, domestic use

The purpose for which this interface has been made is to provide the user with an idea of the operation of their wind turbine, in a simple and practical way. Obtaining different values, being the most representative the power captured by the wind turbine depending on the wind speeds.

On the other hand, when working in a real way, a database of the different wind speeds has been created for a specific city, a way to develop this project further, it would be creating a database of different cities through which by clicking on a certain city, you get a real example of wind conditions, for a specific month.

Another thing that could also be done, is the implementation of a sensor to the wind turbine, an anemometer, so, automatically, take the calculation of the power that is being generated in real time.

9. LIST OF IMAGES, TABLES AND GRAPHS

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