

Wind

Introduction

Man has been using wind energy for thousands of years. The Egyptians were the first to experiment sailing on the Nile 5,000 years ago, while the first wind mills were made by the Babylonians and date back to the seventeenth century B.C. In the centuries that followed, wind mills spread all over the Middle East. Between 1200 and 1300 they were used in Europe too, especially in the northern countries. Even Leonardo da Vinci worked at perfecting these machines. In 1887, the French Duc de La Peltrie built the first aero generator to produce electrical energy. Today aero generators are utilised to obtain energy from the wind. These modern wind mills exploit the wind to make the blades of a big propeller rotate: the latter is connected to a generator that transforms mechanical energy (deriving from the movement of the blades) into electrical energy. Aero generators vary in size and shape. In fact, they can have one, two or three blades of varying lengths: those with 50-centimetre-long blades are used as battery chargers; those with 30-metre-long blades are capable of producing energy to satisfy the daily electricity requirements of about 1000 households. When many aero generators are connected they form a wind-farm, which are real power stations. There are both on shore and off-shore wind farms.

Aeolian knowledge

What is it

Aeolian energy is the energy that derives from the wind.

Men have used its power since ancient times to navigate or to move windmill blades, to grind cereals, to squeeze olives or pump water. Only in the last few decades wind energy has been used to produce electricity.

The word "Aeolian" comes from Aeolus, the Greek god of wind, whose name "aiolos" means "fast".

Electric power is obtained by exploiting the kinetic energy of the wind that makes the propeller blades move. These are connected to a generator that transforms mechanic energy (blade rotation) into electric power. These modern windmills are called aerogenerators.

Wind formation

Wind is an atmospheric phenomenon due to the heating of the sun. The sun radiates on the Earth a power of 1.74×10^{17} Watts: about 2% of it is converted into wind energy.

The Earth releases the heat received from the Sun, but this is hardly homogeneous. In those areas where less heat is released, the pressure of atmospheric gases increases, while in those areas where more heat is released, the air becomes hot and the gas pressure is reduced. As a consequence, high-pressure areas and low-pressure areas are formed, which are also influenced by the Earth's rotation. When different masses of air get in contact, the area with a higher pressure tends to transfer air towards the area with lower pressure. It is the same as when we let a balloon deflate. The high pressure inside the balloon tends to transfer air outside, where the pressure is lower, originating a small airflow. Therefore wind is a more or less rapid air transfer between different pressure areas. The higher is the pressure difference, the faster is the air displacement and the stronger is the wind.

How to measure the wind

A wind is described by two parameters: the strength (related to speed) and direction.

We all know that the wind is not constant, as its strength and direction change.

The wind direction can be observed by simply using a weathercock. In order to class the wind according to its direction people name it after the place the wind comes from. Sometimes the name refers to the geographical origin (Grecale if it comes from Greece; Libeccio if it comes from Libia, Scirocco if it comes from Siria). Some other times, like in the "Wind

rose", winds are referred to by using cardinal points (North-eastern wind, South-western wind).

The wind strength can be indicated either by measuring its speed, i.e. in knots that correspond to miles per hour (1 knot = 1 mile per hour = 1.85 km/h), or by the Francis Beaufort scale.

Speed is measured by the anemometer, a simple wheel exposed to the strength of the wind to measure its rotation speed.

Cup anemometer

One of the most used anemometers is the cup anemometer, where the wind, blowing into the cups, makes them rotate around a vertical axis. An electric or mechanic meter measures the number of turns that take place in a certain time interval. By means of adequate calibration charts it is possible to calculate the wind speed

Wind circulation on the Earth

Air masses are moved by solar heating and in particular by the difference in temperature (gradient) between equatorial and tropical areas.

Solar radiation in equatorial areas is more intense than in tropical areas.

Tropical air, warmer and less dense, tends to go up attracting cold air from tropical areas. When it arrives at the tropics, the warm air cools down and starts to go down. And in this way a continuous equator-poles cycle takes place. Without any other factor, the circulation of winds on the Earth would follow a regular process, like the one that has just been described.

Factors that affect wind circulation

In reality, other geographic-astronomic factors act on air circulation, modifying its movement.

The inclination of the Earth's axis and the revolution of the Earth around the Sun seasonally displace the areas of higher irradiation between the two tropics. Moreover, the Earth's rotation contributes to the alternation of solar irradiation and its surface, scarcely homogeneous, has a different absorption capacity and heat exchange. The Earth's rotation causes another factor that is fundamentally important to understand the wind circulation: Coriolis' acceleration, that produces the typical spiral or rotation movement of air masses.

Another factor determining the direction and the power of the wind is the friction on the Earth's surface, as the wind uses energy to overcome it, as well as the presence of mountain chains, that block or divert the wind path.

The wind and land roughness

The speed of the wind depends, as well as on atmospheric parameters, on land conformation. The rougher the land, the more sudden inclination variations it has, the more forests, buildings and mountains, the more obstacles the wind will meet, the more its speed will be reduced.

In order to define the conformation of a land, four types of roughness have been detected:

- **roughness 0:** the soil is flat, such as the sea, the beach and the snow
- **roughness 1:** open soil with non-farmed land, low vegetation and airports
- **roughness 2:** agricultural areas with few buildings and few trees
- **roughness 3:** rough soil with many variations in soil inclination, forests and villages.

Usually the best position for an aerogenerator is on a land with a low roughness degree.

A bit of history

Man learned how to use the kinetic energy of the wind thousands of years ago. Sailing dates back to at least 10,000 years ago. The first wind mills of which rests were found were Persian and date back to 200 B.C. They were built in a very simple way, with sails mounted on wooden frames. During the following centuries, windmills became common all over the Middle East and became a commonly used machine in the agricultural sector.

Then, between 1200 and 1300 they reached Europe, especially the northern countries. Leonardo da Vinci himself contributed to the evolution of such machines.

More sophisticated technologies were introduced around 1600: the shape of the vanes was improved, and the vanes were streamlined to exploit the wind strength better.

In the Encyclopedie by Diderot and D'Alambert, written towards the end of the 1700s, contains a picture of them. At that time wind power was not exploited to grind cereals but rather to reclaim flooded land.

The invention of the dynamo by the Belgian Gramme in the mid-twentieth century opened up new horizons to the use of water- and wind-energy, and in 1887 the French Duc de La Peltrie built the first aerogenerator in Europe for the production of power: the exploitation of wind energy for the industry was born. In the same period, the United States produced the first "windmill" for the production of electricity (Charles Brush, Ohio, 1890).

The production of electric power from wind energy developed between 1920 and 1930, after the creation of turbines for the processing of hydraulic energy

After a period of oblivion, the oil crisis of 1973 led to a revival of the interest in renewable energy sources, including wind power, which in certain cases is competitive against fossil fuels. Modern mills are faster and more efficient than at the beginning of the 20th century. They have fewer blades and can reach a speed up to five times greater than that of the wind, with an energy output doubled as compared to traditional wind mills.

Aeolian plants

Wind generator

The most important way to use wind power is to produce electric power through wind generators, namely aerogenerators.

Electric power is obtained by exploiting wind kinetic energy: airflows move at more than 10 km/h speed making the blades of a propeller turn. They are connected to a generator that transforms mechanic power into electric power. There are different types of aerogenerators, that differ in shape and dimension. They can have one, two or three blades, of different length. Those with 50 cm length are used as battery chargers, while those with 30 cm blades can supply 1,500 kW power, managing to satisfy the daily power need of around 1000 households.

The most popular aerogenerator is made up of a steel tower of 60-100 meter height, with two or three blades that are around 20 metres long. It generates a power of 600 kW, which equals the daily power need of 500 families.

The blades of the wind generator are fixed on a mechanical element called hub and form the rotor. According to the position of the axis, it is possible to distinguish between horizontal and vertical axis rotors. The first ones are the most common and popular; while the second ones have been used since ancient times but only recently they have been subject to studies and researches to improve their efficiency (the main advantages of vertical axes are: their constant functioning regardless of the wind direction, a better resistance even when the wind is strong and turbulent).

The structure of a wind generator with horizontal axis is simple: a support (foundations and tower) with a gondola or nacelle on the top. Inside there is a slow-driving shaft, as well as a turn multiplier, the fast shaft, the power generator and auxiliary devices (braking system and control system).

The rotor (consisting of the hub, on which the blades are mounted) is fixed at the extremity of the slow shaft.

The shape of the blades is designed in such a way that the incoming airflow activates the rotor.

From the rotor, the wind kinetic energy is transmitted to a power generator. The wind generator works according to the strength of the wind. Under 4/5 metres per second it cannot start. The minimum speed allowing the device to provide power is 10/12 metres per second to produce a few hundred kilowatts. When the speed is high (20/25 m/s) the generator is switched off for safety reasons.

The progress made in the design of aeolian rotors in the last 10 years allow them to work at lower wind speed, catching a higher quantity of energy also at higher levels, increasing the quantity of wind power that can be exploited.

Rotors with "mobile" blades have been created: by changing the blade inclination with a different wind speed it is possible to keep the quantity of power produced by the aerogenerator constant.

Onshore wind farm

Several aerogenerators connected together form the wind-farms, which are real electric plants. A wind farm is based on a group of aeolian turbines, placed in the same area, interconnected by a middle-voltage linking net. This net gathers the energy created by each turbine, conveying it to a collection station. Here a transformer converts the middle-voltage electric energy in high-tension electric current, introducing it in the distribution system. A large wind farm may have dozens of aeolian generators and more than one hundred of single turbines, being placed on an area of several km²: however, being the space of each generator very little, all the places between the turbines could be used for agriculture or livestock holdings.

United States of America currently own the most quantity of wind farms, followed by Germany, Spain and Denmark. Italy is on the fourth place; then we have the United Kingdom, Portugal, France and Ireland. World's largest wind farm onshore is placed in Roscoe, Texas. This plant owns 627 turbines with a power of 781 MW. The European largest plant is the new Glasgow (Scotland) farm, with 140 turbines, that will give their energy to 180.000 houses, with an effective power of 322 MW.

Offshore wind farm

The most recent wind farms are usually placed offshore, on the sea, far from the coasts, where it is possible to exploit the strong winds not delayed by obstacles. This happens on the sea surface, but also on the great lakes.

Unluckily, the realisation and maintenance costs of these offshore wind farms are more elevated than the onshore ones, because of the transportation costs, the great building problems, the difficulty to anchor their towers on the bottom and, in the end, the corrosive action of the sea water on their structures. For instance, it would be possible to work on a maximum depth of 200 meters, but usually no more than 20 m or not beyond than 20 km from the coast, to allow low costs. Anyway, these marine plants have great productivity advantages. On the sea surface, as matter of fact, winds blow without any obstacle, with a higher speed and with less changeableness. The offshore placement of great wind farms also solve the acoustic and aesthetical problems, the tower being placed beyond the line of the horizon, at least 3 km from the coast. This would solve the danger for the most part of bats and birds, migratory and birds of prey, too.

Some researchers affirm that the creation of undersea platforms and pylon and cable systems could realize, after some time, restocking and biodiversity areas on the sea bottom, like it currently happens with the anchorages of the offshore rigs.

Therefore, the offshore plants represent, according to the most part of the specialists of this sector, the true future of the aeolian energy, for what concerns both the environmental problem and the production potential.

In 2007, the offshore plants produced about the 3,5% of the European aeolian energy, owned for the most part from Denmark and United Kingdom, followed by Holland and Sweden; in 2008 the largest aeolian offshore production happened in the UK, followed by Denmark. At present, the largest offshore wind farm is placed off the Lincolnshire coasts (Great Britain), with an installation power of 194 MW.

Nowadays, we may see great projects for the offshore aeolian: the United Kingdom planned to enlighten every house of the country with the wind farm offshore energy within 2020, while Canada is planning to build an offshore wind farm on the Great Lakes. One of the world's largest offshore wind farm, called London Array, will be built on the estuary of the Thames, with an installed power of 630 MW (then, 1 GW). This plant will give energy to 750.000 houses, about ¼ of the London houses, with 341 turbines placed 12 nautical miles from the coast. Even this European offshore wind farm will be interconnected, also connected with all the onshore farms.

Wind map

In order to produce enough electric power the place where the aerogenerator is installed has to be very windy.

The assessment of the output potential of a wind power plant is a difficult and complex operation, depending on the characteristics of the winds that blow in the area where the plant is to be created. The conformation of a land affects the speed of the wind. Obstacles can strongly influence the speed, power, direction and distribution of winds. For example, as regards mountains, it has been shown that whereas steep slopes create turbulences that are dangerous in terms of stability and negative in terms of plant efficiency, more gradual slopes favour the concentration of the wind.

In general, the ideal position for an aerogenerator is a land with a limited number of obstacles with an inclination between 6 and 16 degrees.

The wind must be faster than 5.5 metres a second and blow constantly during most of the year.

As for the off-shore wind sites, the best are the ones where the wind exceeds 7-8 metres a second, which have shallow waters (between 4 and 40 metres) and are more than 3 km far from the coast.

The creation of a plant presumes the knowledge of the "wind map" of the area, that shows how and how much wind blows in the interested site.

Moreover, before building a plant, the power, speed and paths of the winds blowing in the selected areas are systematically recorded for extended periods of time.

Types of wind plants

Electric power can be used through two types of plants: plants for isolated users and plants to be connected to already-existing electric networks.

The first type of plant is the one to produce "utility" electric power supplied by small aerogenerators with less than 1 kilowatt power (1-2 metre rotor) to feed equipment in isolated areas, like radio relay stations, detectors, signalling systems, etc. these systems often compete or are used together with photovoltaic systems.

Moreover electricity is produced to supply isolated houses or settlements that are not connected to the network. These installations are made up of small aerogenerators (3-20 kilowatts) and a system (battery) that accumulates electric power when the wind is favourable.

These applications have a limited distribution in industrialized countries, but they could have interesting perspectives in developing countries with strong winds.

The second type of Aeolian installations is connected to the network and divided into two categories: one to produce power to supply small networks and one connected to the national network. The first are plants located on small islands or remote areas that are supplied by power systems not connected to the national network. Also for this type of systems it is possible to use wind power and photovoltaic power together (hybrid plants) that could integrate on an annual basis. The most interesting application for wind power is the supply of large national networks. For this reason medium-large sized machines or wind-farms have been used for a total power of some megawatts or a few tens of megawatts.

Aeolian distribution

Aeolian production worldwide

In the last years we have assisted at an exponential growth of aeolic power installed and production of electricity generated by wind. In 2010 a power of 39 GW has been installed worldwide, a 20% increase if compared to previous year, reaching a total power rising up to 198 GW: biggest contributors were China (44.7 GW), USA (40.2 GW), Germany (27.2 GW), Spain (20.7 GW), India (13.2 GW), with Europe as a whole covering 42% of world aeolic power. The 86.5% of installed power in the world is located in just ten countries: China, USA, Germany, Spain, India, Italy, France, Britain, Canada and Denmark. In 2010 the major efforts to boost wind power installed are from China, that, with an increase of 18.9% over 2009, reaches 27% of installed power in the world, and from the USA, that, with an increase of 5.1%, reach 24%.

Traditionally, since the beginning of aeolic era, the countries that invested and produced more have been Germany, Spain and the USA. In the last 5 years a new, important "outsider" has broken through, China, which in 2010 becomes the first countries with an installed capacity of 44.7% (18.9% more than previous year), becoming then the major emerging country in this field. Italy has always been on the cutting edge and in 2010 Italy occupies a honourable 6th place after China, USA, Germany, Spain, India.

In 2010 worldwide aeolic energy production covered 2-2.5% of the total amount of electricity produced; nevertheless, in some countries it is an important part of national electricity balance: as an example, at the end of 2010, in Denmark, 24% of power consumed was produced by aeolic sources, in Portugal 14.8%, in Spain 14.4%, in Ireland 10.1% and in

Germany 9.3 %, while while China, though at the top of the list, covers only 1% of electricity consumption with wind power.

(Source: *Renewables 2011 - Global Status Report e EWEA – Wind in power: 2010 European Statistics*)

Aeolic production in Europe

During 2010 in EU27 181.7 TWh of electricity have been produced by aeolic means, of which 171.1 TWh thanks to onshore wind farms and 10.6 TWh from offshore wind farm. 5.3% of the total consumption of electricity in Europe in 2010 (compared to 2% in 2002) was produced through wind power with about 71,620 turbines. The field is monitored, in Europe, by the European Wind Energy Association (EWEA), a non-profit NGO established in 1982, counting up to 15,000 members among which the main firms in aeolic plants making, and the most influential research institutes: it is the biggest sustainable resources association in the world.

From 1996 to 2010 aeolic power installed in Europe has grown at a yearly rate of 97%, passing from 6.1 GW in 1996 to 198GW in 2010. Despite this, there are still many disparities among different countries: Germany (27%), Spain (25%) Great Britain (8%) France (6.5%) and Italy (6.4%) sustain by themselves 72.9% of the entire European production.

A significant contribution

The EU Directive (2009/28/CE) establishes that 20% of total EU energy production has to come from renewable sources by 2020, indicating some common guidelines to reach this goal as well.

In 2009 sustainable sources have produced about 13% of the total amount of energy consumed in the world, with hydroelectric and solid biofuels having the biggest share (thanks to poorest countries' contribution, where use of solid fuels for heating, cooking and illumination purposes is widespread). In 2010 production of aeolic energy worldwide has covered about 2-2.5% of the total amount of energy consumed: it may look a very modest share, however the production of aeolic energy is expanding fast, playing a fundamental role in the delicate and difficult passage to an ever smaller reliance on fossil fuels.

The aeolic field is indeed the one, amongst all renewable sources, which is recording the biggest annual increases, with a growth higher than 7% a year between 1996 and 2010, and an even larger increase (38%) between 2006 and 2010.

(Source: *ewea.org*)

Aeolic production in Italy

In 2010 Italy was at 6th place of biggest aeolian energy producers' ranking, with an installed capacity of 5,797 MW. A placement that deserves respect, if we think at country's smallness if compared to "giants" like USA, China or India. Moreover, conditions for aeolian production in Italy aren't the most favourable, given the peculiar shape of the country with this long and stretched territory, presence of high mountains such as the Alps which offer a barrier to winds; however there are many ideal places locally, especially on the Adriatic side of the Apennines and on the islands, and there are big potentials for offshore plants.

In Italy many associations care about management, research and diffusion of aeolic energy, as the "Associazione Nazionale Energia del Vento", ANEV (National Association Energy of the Wind, NAEW), which has subscribed agreements with Greenpeace and Legambiente for a sustainable and environmentally respectful development, or the "Associazione Produttori Energia da Fonti Rinnovabili", APER (Association of Producers of Energy from Renewable Sources, APERS) and an important cooperation is on stage with the "Gestore Servizi Elettrici", GSE (Electric Services Manager, ESM), to integrate aeolic-generated electricity with the national grid.

The aeolian energy production actually started in 1994, just with pilot plants or experimental ones, in the national energy balance. From this year, it persevered to give significant increases. In 1994, the aeolian energy (with a production of 6 GWh) represented the 0,02 % of the total renewable source energy amount, while in 2001, with a production of 1.179 GWh, this amount increased to the 2,14% and, in 2006, to the 5,6%, producing 2.971 GWh. In 2007 we saw the real "quality leap": the aeolian energy produced, 4.034 GWh, representing the 8% of our renewable sources energy, and the 1,2% of the national electric balance, based on the produced and imported energy. The growth of wind power has continued in the years 2008 and 2009 and in 2010 reached 9,126 GWh per share.

In the end of 2010, Italy owns 487 installed aeolian plants. Anyway, because of the morphological features of our land

and the consequent wind rate, their distribution is not uniform for every region. The highest concentration of aeolian plants is in Puglia (134 farms), followed by Campania (76), Sicily (62), Sardinia and Calabria (31), Basilicata (28), Abruzzo (25), Molise (23), Toscana (17), Liguria and Emilia Romagna (15), Veneto and Trentino (5) Marche (3) Umbria, Valle d'Aosta and Lombardia (1), while Friuli Venezia Giulia has no aeolian plants.

About the efficient gross power, in 2010 it was of 5,814 MW, so distributed: Sicily (1,436 MW, the 24.7% of the national aeolian power), Puglia (1,288 MW, equal to the 22.1% of the national aeolian power), Campania (803 MW, the 13.8%), Calabria (672 MW, the 11.5%), Sardinia (639 MW, the 11 %), Molise (367 MW, the 6.3 %), Basilicata (280 MW, the 4.8%), Abruzzo (218 MW, the 3.8 %), Toscana (45 MW, the 0.8 %), Liguria (19 MW, the 0.3 %), Emilia Romagna (18 MW, the 0.3%), Piemonte (15 MW, the 0.2%), Lazio (9 MW, the 0.2%), Trentino (3 MW, the 0.1%), Umbria (2 MW, the 0.1%) e Veneto (1 MW, the 0.1%).

In 2010, the produced energy was equal to 9.126 GWh, coming from: Sicily (2.203 GWh, equals to 24.1% of the total amount), Puglia (2.103 GWh, equals to 23% of the total amount), Campania (1.333 GWh, the 14.6 %), Sardegna (1036 GWh, the 11.4 %), Calabria (952 GWh, the 10.4%), Molise (532 GWh, the 5.8 %), Basilicata (458 GWh, the 5 %), Abruzzo (329 GWh, the 3.6%), Toscana (76 GWh, the 0.8 %), Liguria (35 GWh, the 0.4%), Emilia Romagna (25 GWh, the 0.3%), Piemonte (21 GWh, the 0.2%), Lazio (15 GWh, the 0.2%), Umbria (2,3 GWh, the 0.1%), Trentino (2,2 GWh, the 0.1%), e Veneto (1,7 GWh, the 0.1%).

Therefore, we can easily see how the regions of Southern and Central Italy are the most productive ones, thanks to the propitious wind conditions along the Apennine Crest and on the islands' relieves, while the Alps negatively influence the wind exploitation in the regions placed under this mountain chain.

(Source: *Rapporto statistico 2010, Impianti a fonti rinnovabili - GSE 2011*)