WIND ENERGY KNOWLEDGE

___Index___

WIND ENERGY KNOWLEDGE

Introduction

Wind is a fundamental element on our planet and the main 'driving force' of the Earth's climate: there is no place on Earth where the wind does not blow, more or less intensely, for several days a year. In some areas of the planet, wind is one of the main agents of rock erosion, sediment transport and landscape shaping: think of desert and coastal environments, where the work of the wind leaves a strong imprint on the morphological characteristics of the landscape. Wind accompanies every meteorological disturbance, is responsible for the movement of waves in seas and oceans, and consequently for coastline morphologies, it determines the stability of the mantle of snow on high mountains and the morphologies of the snow- and ice-covered surfaces of Arctic and Antarctic areas. From the very beginning of history, man has realised the possibility of using wind power, first to move boats, then to run gears, move the vanes of windmills, and finally produce electricity.

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 windmills 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 time great than that of the wind, with an energy output doubled as compared to traditional windmills.

Wind energy in the world

Research is trying to solve what at present is the major problem of the production of wind energy: the discontinuous nature of the supply of energy due to the irregular wind regime. It must be pointed out that the gross efficiency of wind power plants, expressed in MW, defines the quantity of energy that can be produced in a determined period of time in which the plant operates, and it is the parameter that is considered in order to compare the productive possibilities of wind power generators with one another. However, it must be considered that due to various factors, and first of all the variability of the wind, a wind power generator never operates for 24 hours a day for the whole year, but only for a certain number of hours. When the wind blows at speeds that are too low ($v < 5$-4 m/s) the generator does not produce energy, while when the wind speed is too high ($v > 20$-25 m/s) the plants must be shut down for safety reasons. Therefore, a very important factor, in order to determine the productivity of the plants, is the number of hours of operation. In Italy the plants that operate for the greatest number of hours generally operate for about 3,200 hours a year (i.e.

for about 38% of the time, considering that in a year there are 8,760 hours). However, the Italian national average is much lower, it amounts to 1,700 hours a year. In order to solve this problem and increase the number of hours of utilization, research is trying to develop rotors that can produce energy and operate safely also with very low or very high-speed winds. However, there are limits beyond which no further improvement is possible, especially with regard to the efficiency at low speeds.

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 2021 a power of 102 GW has been installed worldwide, reaching a total power rising up to 845 GW: biggest contributors were China (282 GW), USA (178 GW), Germany (62 GW), India (38 GW), Spain (27 GW), with Europe as a whole covering 29% of world aeolic power. The 83.4% of installed power in the world is located in just ten countries: China, USA, Germany, India, Spain, Great Britain, Brazil, France, Canada and Sweden.

Traditionally, since the beginning of aeolic era, the countries that invested and produced more have been Germany, Spain and the USA: Germany has always been the first in the ranking, but in 2011 it was overtaken by China and the United States. In the last years a new important "outsider" has broken through, China, which from 2010 became the first country in the ranking, making it the main emerging country in the wind sector.

In 2021, the greatest effort to incentivize installed wind power came from China, which registered a 16.6% increase respect to 2020, and from the USA, which registered a 7% increase. Italy has always been in the vanguard in this sector and in 2021, it held the honourable 11th position in the classification of installed power, after China, USA, Germany, India, Spain, Great Britain, Brazil, France, Canada and Sweden.

Aeolic production in Europe

Wind power installed in Europe by end of 2020 reached 216,580 MW. The field is monitored, in Europe, by the European Wind Energy Association (EWEA), a non-profit NGO established in 1982, counting up to 700 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. In 2021, installed wind power in Europe increased of 15,947 MW, from 216,711 MW to 232,658 MW. However there still are great disparities in the various European countries: Germany (27.4% of the total in Europe), Spain (11.8%), Great Britain (11.6%), France (8%), Sweden (5.2%) and Italy (4.8%) and together account for 68.2% of the production of wind power in Europe.

A significant contribution. Directive 2009/28/EC of the European Parliament and Council (which replaced previous Directives 2001/77/EC and 2003/30/EC) aims to establish a common framework for the production and promotion of energy from renewable sources. For each Member State, the Directive sets a target, share of energy from renewable sources, out of the final overall consumption of energy before 2020, which is coherent with the global target "20-20-20" (which means a 20% reduction in greenhouse gas emissions, 20% energy saving and a 20% consumption of energy from renewable sources) of the EC. With regard to the transportation sector, energy from renewable sources must be equal to at least 10% of overall energy consumption, by the year 2020.

Aeolic production in Italy

In 2020 Italy was at 10th place of biggest aeolian energy producers' ranking, with an installed capacity of 10.8 GW. 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.
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.
At the end of 2020 there were 5,660 wind farms installed, with a total capacity of 10,907 MW, accounting for 19% of the entire park of installations fuelled by renewable sources. The latest data provided by the Energy Services Operator (GSE), updated to 31 December 2020, were used to get an idea of the distribution of wind farms in Italy. The graph above shows the evolution of installed power and the number of wind farms in Italy from 2006 to 2020. Some environmental and territorial characteristics of sites such as windiness, orography, and accessibility are particularly important for the construction and operation of wind farms. For these reasons, the presence of wind farms is uneven across the country: Southern Italy, in particular, is where 96.5% of the country's total wind power capacity and 92.4% of total installations in terms of numbers are concentrated.
Basilicata is the region with the highest percentage of wind farms in the country (25%), followed by Apulia (20.8%). In Northern Italy, which is generally characterized by limited windiness, the spread of such installations is generally modest; the most representative regions are Emilia Romagna and Liguria, with 1.3% and 0.6% of total national installations, respectively. In Central Italy, on the other hand, the region with the largest number of installations is Tuscany (2.1% of the total). The map showing the regional distribution of wind power plant capacity reflects, as is natural, that relating to numbers of wind farms: in the northern and central regions of Italy, installations at the end of 2020, taken together, cover only 3.5% of the total national capacity. Apulia (24.2%) and Sicily (17.7%) are in the lead for installed power among the regions.
How much energy is produced in Italy. Over the past 15 years, electricity production from wind power has increased significantly, from 2,971 GWh in 2006 to 18,762 GWh in 2020. Variations between individual years are generally related to windiness, which varies from year to year.

Most of the country's wind power is generated, as already mentioned, in the south and the islands; in the north, however, modest values are noted due to the limited installed power. With 4,802 GWh of electricity produced, Apulia is the leader for wind power production (25.6%), followed by Campania (3,209 GWh, 17.1%) and Sicily (2,765 GWh, 14.7%). Taken together, these three regions cover 57.4% of the total national figure.

***Future scenarios*.** According to *OWEMES* (*Offshore Wind and other marine renewable Energy in Mediterranean and European Seas),* future scenarios of wind energy systems indicate the Puglia Region as the region with the greatest extension in sq. km, that can be used for offshore plants (2,932 sq. km), followed by the Marche region (2,717 sq. km), Sicily (1,772 sq. km), Sardinia (1,270 sq. km), Abruzzo (952 sq. km), Tuscany (727 sq. km), Emilia Romagna (369 sq. km), Molise (292 sq. km) and Lazio (6 sq. km), for a total amount of 11,686 sq. km that can be dedicated to the development of wind energy. In the larger islands there is the possibility of counting on places where the speed of the wind is greater (approximately 7-8 m/s) than the average in other sites (6-7 m/s), and the Puglia region is one of the regions with the largest number of marine offshore wind parks being developed.

Text updated to August 2022