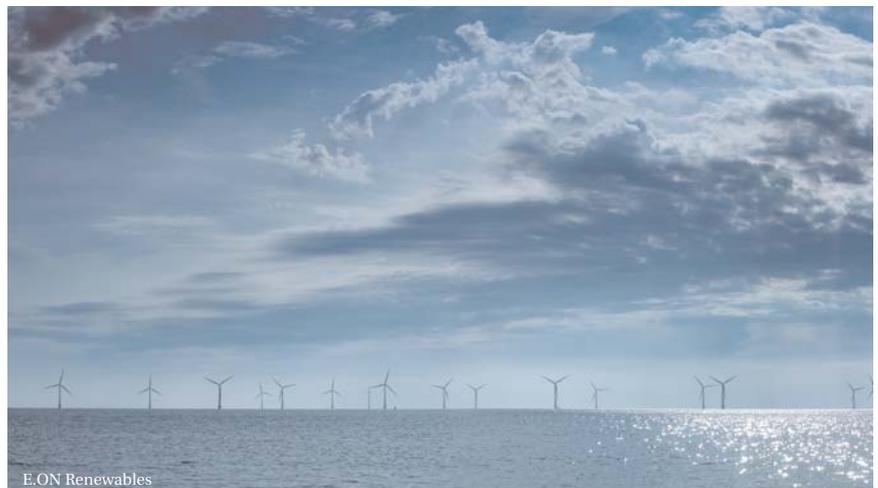
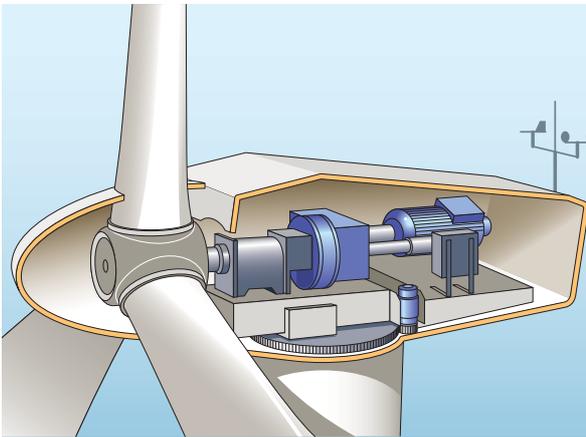


Power Quality and Utilisation Guide

Distributed Generation and Renewables

8.3.2 Wind Power



Distribution Generation and Renewables

Wind Power

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KEMA Nederland BV
November 2006

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Distributed Generation and Renewables

Wind power

General

Wind turbines can make a major contribution to the production of renewable energy. When the oil crisis occurred in the 1970s in Europe, the development and commercial production of wind turbines for generating electricity was strongly stimulated. Developments in harnessing wind power continually improved and during the last decade a considerable expansion of the wind power industry has taken place. Turbines have become larger, with improved efficiency and availability, and wind farms have become bigger.

Worldwide consumption of electricity continues to grow. Most European governments have set targets to reduce the emission of carbon dioxide in order to reduce the rate of global warming. The widely accepted opinion is that these targets can only be met, on the one hand, by energy-saving incentives and, on the other hand, by the large-scale exploitation of renewable energy.

The use of wind turbines is a serious option for achieving these aims. Several European countries have impressive plans for installing large amounts of wind power generation in the coming years. Some governments support these actions by providing tax or investment incentives. The north-west of Europe, with its windy coastal waters and fine-meshed but strong electric grid, provides promising opportunities for investment and wind farm development.

Basic principle

Wind turbines extract the energy from the wind by transferring the thrusting force of the air passing the turbine rotor into the rotor blades. The rotor blades are aerofoils, as shown in the cross-sectional drawing in Figure 1.

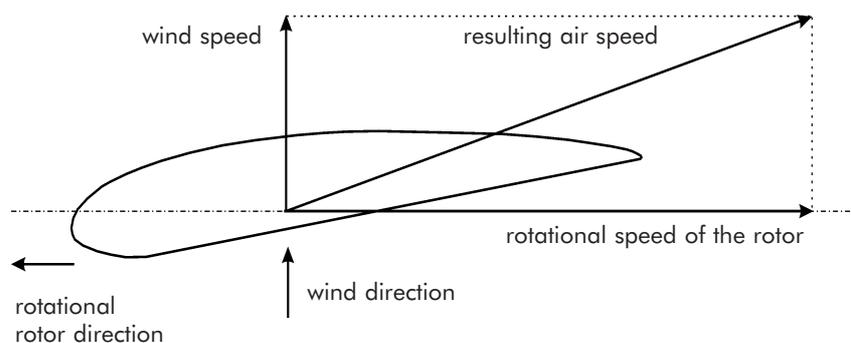


Figure 1 - Cross-section of a rotor wing showing speeds and directions

The rotational plane of the rotor is controlled to be perpendicular to the wind direction. The resultant air flow (i.e. the vector sum of the wind speed and the rotor local speed) over the rotor blade produces a differential pressure between the windward and leeward sides of the blade. (Air flowing over the leeward side has further to travel and so must do so at a higher speed and consequent lower density and pressure.) This differential pressure causes a thrust perpendicular to the resultant air flow. The resolved component of this thrust produces a mechanical torque to rotate the rotor and the shaft. The power in the shaft can be used in different ways. For hundreds of years it was used for the grinding of wheat or the pumping of water but the large machines of today, with integrated generators, convert the shaft power into electricity.

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Power and efficiency rates

Mass in motion carries a certain amount of energy. This kinetic energy varies in proportion to the product of the mass and the square of the velocity. In units of time, this energy is similar to the power.

Kinetic energy per second is:

$$P = \frac{1}{2}(mV^2)$$

where:

P is the power (Nm/s or Watt)

m is the mass per second (kg/s)

V is the wind velocity (m/s).

This physical law is also applicable to air in motion. The mass of air flowing through the rotor has to be imagined as a cylinder. The volume of the cylinder is related to the surface area of the rotor and wind speed, i.e the length of the cylinder passing the rotor per unit time.

Air mass through the turbine rotor per second is:

$$m = \rho AV$$

where:

ρ is the density of air (kg/m³)

A is the rotor surface area (m²)

V is the wind velocity (m/s).

This leads to an important characteristic; the amount of energy is related to the speed of wind raised to the third power.

$$P = \frac{1}{2}\rho AV^3$$

As an example, at a wind speed of 6 m/s the energy content is 132 W/m² (Watt per square metre). When the wind is blowing at a speed of 12 m/s, the energy content is 1053 W/m². Doubling the wind speed gives eight times the power.

Not all the energy present in the wind can be converted into usable energy at the rotor shaft. Using physical calculations it can be shown that the theoretical maximum efficiency of wind power is limited to about 59%. This limit is also called the power coefficient or C_p value. Consequently, the equation above must be modified to:

$$P = \frac{1}{2}C_p\rho AV^3$$

where:

C_p is mechanical power coefficient (at slow shaft).

(The C_p at 'slow shaft' is defined as the energy conversion efficiency from (undisturbed) wind power to mechanical rotating power at the main turbine shaft, which is located downstream of the rotor and before the gearbox. This shaft has a rotational speed equal to the wind turbine rotor and is therefore referred to as 'slow shaft'. C_p may also be defined after the gearbox transmission at the fast running generator shaft, so-called 'fast shaft', or at the transformer output, C_p 'grid'.)

The net electrical power output of a turbine, P_{elec} , taking mechanical and electrical efficiencies into account, is given by:

$$P_{elec} = \frac{1}{2}C_e\rho AV^3$$

where:

C_e is electrical efficiency rate (%).

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Today, large modern turbines are able to achieve a total net efficiency, $C_{e'}$ of 42 to 46% with respect to the energy of the undisturbed wind in a circular tube with a cross-sectional area equal to the gross rotor area.

Basic comparison with conventional electricity production and benefits of wind power

There are several reasons for the success of wind power over recent years. When compared to conventional electricity production, wind turbines produce clean energy with no carbon dioxide emission or other air, water or soil pollution in operation.

Other advantages are that the fuel – wind – is free, inexhaustible, abundant and independent of political sensitivities. Turbines are quick and easy to install and are very reliable with availabilities of 98%. (This is the availability of the turbine. However, wind is not always available so the operational availability is much lower). No other electricity generating technology has a higher availability rate.

A disadvantage of wind power is the unpredictability of wind. Storm fronts in particular can cause a sudden increase in the wind power. Furthermore, periods of low wind give little wind power.

The introduction of power produced by wind turbines into a grid is not as straightforward as it may seem. In order to maintain stability a certain percentage of the total generated power still needs to be provided by centrally controlled 'stable' conventional plants. This percentage depends on the composition and stability of the grid. If the instability of a grid is expected, it can be prevented by the use of intelligent control systems that interface between different kinds of production units, consumers and the intermediate grid. In many EU countries, grid companies, (independent) associations and academic institutions are carrying out research in this area.

Application of wind power

Description of typical situations in which wind power can be/is suitable

The amount of electrical power produced by a turbine depends on the size and type of the turbine and where the turbine is located. Figure 2 shows a characteristic curve that represents typical power output in relation to the wind speed. At low wind speeds, no electrical power is generated. From Beaufort 2 (approx 3 m/s) and above the turbine is rotating, and at about a wind force Beaufort 6 (12 – 13 m/s) the turbine is supplying its maximum power.

At wind speeds over 25 m/s early generations of wind turbines were designed to shut down in a controlled way to avoid overloading or damaging the turbine's installation or construction. Later designs are equipped with pitch control that changes the angle of the rotor wing in extreme weather. The result is that the power can be generated even in bad weather conditions. When very heavy storms occur it still is necessary to stop the turbine.

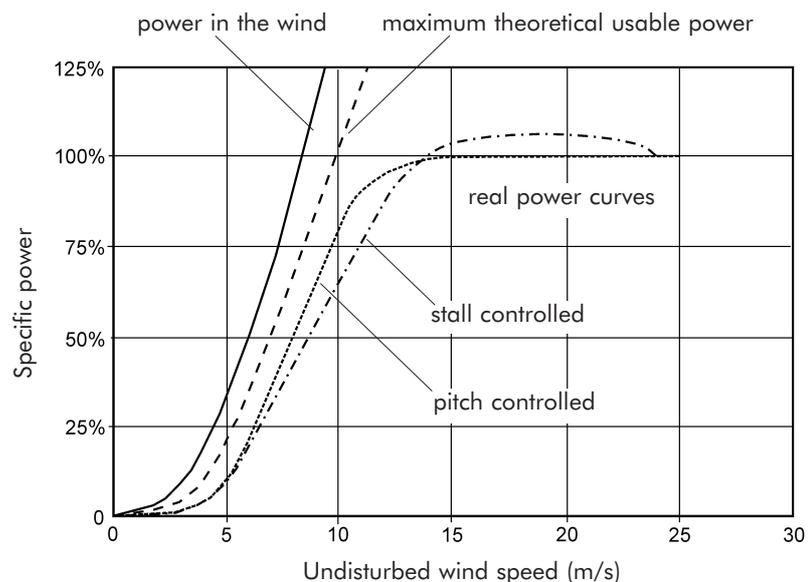


Figure 2 - Typical turbine characteristic; power output v wind speed

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An average turbine in an ideal location can deliver an annual electrical power output of about 850 kWh per square metre of rotor surface area. Another simple rule for estimating the annual energy yield of a wind turbine is that, on an average wind site, the output is equivalent to about 2000 full load hours and at high wind sites approximately 3000 hours. For example, on average, a 1.5 MW wind turbine produces 3×10^6 kWh, corresponding to 1500 kW for 2000 hours.

Costs of wind energy

Without taking into account tax benefits or other incentives on the production of wind energy, the costs of wind energy are summarised in Table 1.

Wind energy cost breakdown	2000 full load hrs [EUR/MWh]	2500 full load hrs [EUR/MWh]
Investment (12 year annuity at 4%)	40 to 50	30 to 40
Operation and maintenance including major overhauls	12	12
Other operational expenses	8	8
Total	60 to 70	50 to 60

Table 1 - Summary of wind energy cost breakdown

Included in 'Other operational expenses' are the costs of daily management, insurance, land lease, visual or noise nuisance compensation and taxes.

Currently, the costs of wind energy are slightly higher than the feed-in tariff for electricity produced from conventional fossil fuels or by nuclear power plants. However, most European countries have incentives to stimulate the production of wind and other renewable energy.

Although each country or state applies its own rules, common features are:

- ◆ Tax benefits on investments in new assets
- ◆ Grants on installing new assets
- ◆ Lower interest rates from green funds for financing assets
- ◆ Incentives for production (kWh related).

As a consequence of one or more of these incentives, investments in wind energy can be profitable. In the past, tax benefits of up to 50% of the investment costs were not uncommon. In the case of a feed-in tariff, including incentives, of 80 to 100 EUR/MWh, the cost recovery period is between 6 (> 2700 full load hours) and 10 (>1900 full load hours) years.

Site selection for wind energy

There are many issues to be taken into account when choosing the location for a wind generator, such as the availability of space, access for heavy construction plant, environmental considerations and the proximity to the medium voltage grid, but the most important factor is the availability of sufficient wind.

As a first guide, investors and developers may consult the European Wind Atlas [2] to estimate the long-term wind speed. A second source is wind data from meteorological stations located up to 30 to 40 km from the site.

More detailed estimates of the site wind speed and the predicted wind farm output can be obtained from the WAsP software tool [3]. WAsP requires as an input the long-term wind speed distribution from at least three surrounding meteorological stations. The accuracy of the results increases when the meteorological

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stations are located close to the proposed site. Subsequently the proposed site and its surroundings, more precisely the terrain, are modelled as accurately as possible. The output is the long-term 'wind climate' at the proposed site.

Where there is doubt, certainly for complex terrain like hilly and mountainous areas, additional wind measurements are required. The measurement period must be at least one year and, if possible, extended to two years.

Project risks

The main project risk is that the long-term wind climate at the potential site is lower than anticipated during the feasibility study phase. As a result of the cube law relationship between wind speed and power, a relatively small decrease in the long-term wind speed will have a large effect on the energy output. A significantly lower energy yield, e.g. more than 10 to 15%, may result in cost recovery times of more than 12 to 15 years instead of the typical 10 years. The result is a loss-making project.

It is therefore advisable to use a somewhat lower mean wind speed in the financial and economic calculations. Instead of using a wind speed with a 50% probability of being exceeded, a lower value with an 80 or 90% probability of being exceeded should be assumed. By doing this, in 8 or 9 out of 10 years, a wind speed, and therefore an energy output, higher than estimated should be obtained.

The following items need to be considered when building a wind turbine:

- ◆ There must be sufficient space and plenty of wind. Deflections caused, for example, by hill slopes or obstacles nearby can affect power output.
- ◆ The area must have a permit to operate a wind farm. In practice, this means that mostly areas that are designated as industrial areas should be considered. Otherwise it is necessary to seek changes to the local land-use planning scheme.
- ◆ The site must be accessible. During the erection of the wind turbine it is necessary for large hoisting cranes to be able to reach the construction site.
- ◆ It has to be practical and economic to connect the wind turbine to the electrical grid. The voltage level can be from 10 to 30 kV when connected to the local distribution grid. In the case of a wind farm, where the generated power is much larger, it is necessary to connect at the voltage level of the transmission grid.

Wind turbine power control

Power output increases with wind speed according to a cubic law. Most wind turbines reach maximum power, also called the rated or nominal power, at wind speeds between 12 and 14 m/s. At higher wind speeds, the power has to be kept constant in order not to overload the wind turbine structure or the electrical connection.

There are three methods that can be used to control the power output in situations where wind speed exceeds the design rating and these are discussed below (see also Figure 2).

Stall controlled rotors

In the early days of modern wind technology, stalling was the most widely used power control system. The rotor is kept at a constant speed and the mostly asynchronous generator is connected to the 50 or 60 Hz public grid without the use of a converter or other power electronics. Power control is based on the aerodynamic principle that, if the air flow angle-of-attack reaches a certain limit (stall point), the lifting force, and consequently the rotor torque, stabilises or even decreases in magnitude. The main advantage of this concept is its simplicity; no mechanical or electronic systems are required to limit the power because this is a completely passive system.

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Stall control is now less often used because, when applied to a wind turbine greater than 1 to 1.5 MW, it may lead to resonance problems in the rotor blades and drive train. Another disadvantage is the relatively poor power quality obtained from stall wind turbines.

Variable speed rotors

Although this concept was already known and applied on a limited scale in the 1980s and 90s, it has been developed further since and is widely used. The rotor speed is variable and increases in proportion to the wind speed. At the rotor speed producing the nominal power the power is kept constant by pitching the blades towards the wind, lowering the angle-of-attack, the lifting force and rotor torque. The synchronous generator is connected to the grid using a converter or other power electronics that can deal with the different frequencies.

The advantage of this control mechanism is that it can be applied to MW wind turbines without introducing undesirable mechanical resonances. Applying blade pitch control, together with other up-to-date control techniques, may provide opportunities to lower design loads and serve as a good starting point for further size increases. Last but not least, modern, IGBT or IGCT-based, converter technology improves the quality of the generated power.

Intermediate power control solutions

In the past two decades, several power control methods have been introduced that are based in one way or another on the above-mentioned control mechanism. Some manufacturers have used the so-called 'active stall' control which combines stall control, including constant rotor speed, with blade pitch control to optimise the stall characteristics.

Another variation is the combination of stall/constant speed control with power electronics to optimise the power quality. More details are given in [1].

Wind power applications and opportunities in different sectors

The owner or operator of a wind turbine usually sells the electricity produced to a utility company. Owners or operators can be:

- ◆ Private individuals or companies who finance wind projects from their own resources or with loan capital. Many taxation regulations are applicable for companies.
- ◆ Cooperatives in which private individuals create a legal structure to set up a wind turbine or a wind farm together. Shareholders participate in profits according to the efficiency of the enterprise.
- ◆ Utility companies who are particularly interested in large wind farms and will probably participate in the development of new offshore wind farms.

Current status of wind power

The manufacture of commercial wind turbines started in the 1980s, with Danish technology leading the way. From units of 40-60 kW with rotor diameters of around 10 m, wind turbine generators have increased in capacities over 5 MW and rotor diameters of 120 m and above.

Continual improvements are being made in the ability of wind turbines to capture as much energy as possible from the wind. One result is that employment in the European wind energy sector has been growing rapidly. In Denmark, for example, the number of people employed both directly and indirectly in wind turbine manufacture increased from about 2900 in 1991 to 21 000 by 2002.

Estimates based on the EWEA scenario 'Wind Force 12' show employment in Europe could reach almost 200 000 by 2020, with double that number for global employment.

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Other facts of wind power worldwide and in Europe are:

- ◆ By the end of 2005, 60 000 MW wind power capacity had been installed worldwide
- ◆ Over the last few years, the global annual increase has been approximately 25%. The wind power capacity installed in 2004 was 7500 MW and in 2005 it was 11 600 MW.
- ◆ The majority, 60 to 70%, of the global wind power is installed in Europe, 5800 MW in 2004 and 6200 MW in 2005
- ◆ It is estimated that 15 000 MW of wind power will be installed worldwide in 2006
- ◆ Outside Europe, most wind power is installed in the USA, with China and India rapidly increasing wind power capacity
- ◆ Wind energy has grown most consistently in Europe, with capacity multiplied by 27 times over the decade between 1992 and 2002
- ◆ The leading nations in wind energy are Germany, Spain, Denmark and the Netherlands, which account for 84% of the total European wind capacity. Emerging markets include Austria, Italy, Portugal, Sweden and the UK. The ten Member States that joined the EU in May 2004 have also adopted targets for the level of renewable energy which they are expected to achieve.
- ◆ In Germany last year, the wind industry turnover was EUR 4.2 billion.

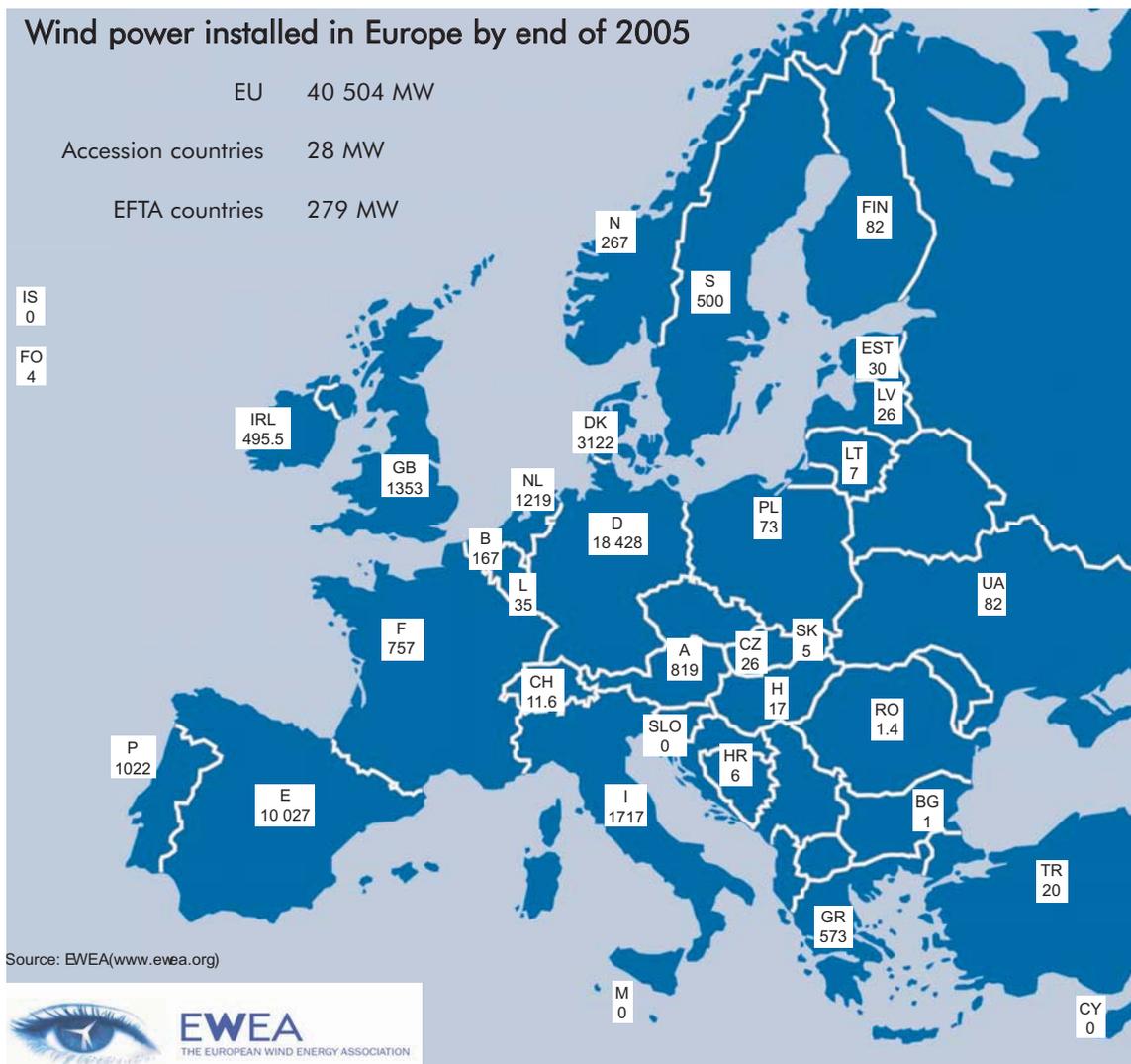


Figure 3 - Map of Europe with installed amount of wind power per EU-member in MW

Trends

Three major trends can be recognised in recent years concerning economical and technological aspects of grid connected wind turbines:

Turbines have grown larger and taller

The average capacity of turbines installed in Germany and Denmark increased from approximately 200 kW in 1990 to almost 1.5 MW during 2002. Turbines in the 1.5 to 2.5 MW range have more than doubled their share of the global market from 16.9% in 2001 to 35.3% in 2003.

Investment costs have decreased

The average cost per kW of installed wind power capacity currently varies from 900 Euro/kW to 1200 Euro/kW. The turbine itself comprises about 80% of this total cost. Foundations, electrical installation and grid connection mainly account for the remainder of the cost. Other costs are land, road construction, consultancy and financing costs.

Turbine efficiency has increased

A mixture of taller turbines, improved components and better siting has resulted in an overall efficiency increase of 2 - 3% annually over the last 15 years.

In addition to the previously mentioned trends, there is also the fact that offshore wind farms have become larger in number and size. In the beginning, offshore turbines were 'sea-adjusted' versions of land-based technology, with extra protection against sea salt incursion. Present generations include more substantial changes, such as higher peripheral rotor speeds and built-in handling equipment for maintenance work. The turbines must be firmly positioned on the sea bed, based on a precise design. Many kilometres of cables have to be laid, both between individual turbines and back to shore to feed the generated power into the grid. To ensure a high reliability of wind turbines, it is of great importance to perform effective maintenance on turbines. This requires service vessels that can transport maintenance crews in extreme weather to the turbine platforms.

By the end of 2003, a total of almost 600 MW of offshore wind farms had been constructed around Europe in the coastal waters of Denmark, Sweden, the Netherlands and the UK.

Wind turbine technology

Technology

The technology of modern wind turbines has developed rapidly during the last two decades. The basic principle of a wind turbine has remained almost unchanged and consists of two conversion processes performed by the main components:

- ◆ The rotor that extracts kinetic energy from the wind and converts it into generator torque
- ◆ The generator that converts this torque into electricity and feeds it into the grid.

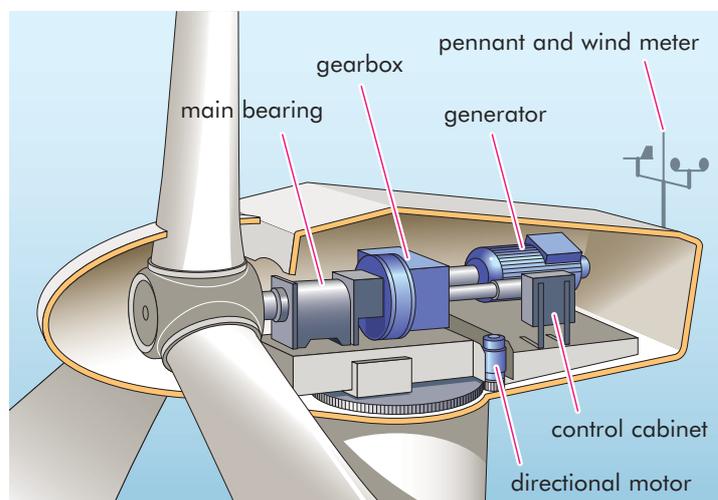


Figure 4 - Cutaway drawing of a wind turbine

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Although this sounds rather straightforward, a wind turbine is a complex system in which knowledge from the areas of aerodynamics and mechanical, electrical, and control engineering is applied.

Rotor and blades

A modern wind turbine consists of two, preferably three, blades or wings. The blades are made of polyester strengthened with glass or carbon fibres. On a commercial basis, blades are available from 1 metre up to 100 metres and more. The blades are mounted on a steel construction, called the hub. As mentioned, some blades are adjustable by pitch control.

Nacelle

The nacelle can be considered to be the machine room of the turbine. This housing is constructed in such a way that it can revolve on the (steel) tower so that the rotor is perpendicular to the wind direction. This is accomplished by a fully automatic system controlled by a pennant on the turbine housing. The machine room is accessible from the tower and contains all the main components such as the main shaft with bearing, gearbox, generator, brakes and revolving system. The main shaft transfers the rotor torque to the gearbox.

Gearbox

A gearbox is required to convert the relatively slow speed of the rotor (about 20 revolutions per minute for a diameter of 52 m) to that required by the generator (1500 rpm).

Generator

Currently, there are three main wind turbine types available. The main differences between these concepts concern the generator and the way in which the aerodynamic efficiency of the rotor is limited during wind speeds above the nominal value in order to prevent overloading. As for the generator, nearly all wind turbines currently installed use one of the following systems (see Figure 5):

- ◆ Squirrel-cage induction generator
- ◆ Double-fed (wound rotor) induction generator
- ◆ Direct-drive synchronous generator.

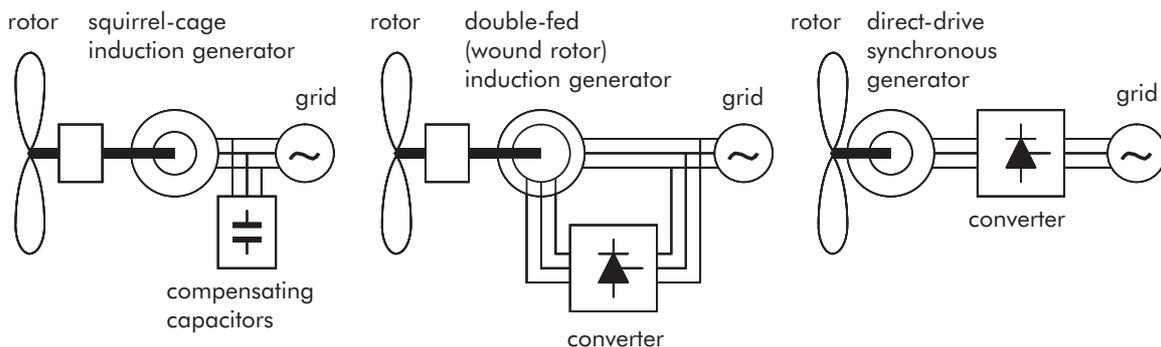


Figure 5 - Commonly applied generating systems in wind turbines

Wind turbines of the first generation used asynchronous squirrel cage generators. Because of the great difference between the rotation speed of the turbine and that of the generator, a gearbox is used to couple them. The stator windings are connected to the grid. This concept is called a constant speed wind turbine, although the squirrel cage induction generator allows small variations in rotor speed (approximately 1%).

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Since a squirrel cage generator consumes reactive power, which is undesirable, especially in a weak grid, capacitor compensation is required.

The other two generating systems allow for about a factor of 2 between the minimum and maximum rotor speed. These different speed levels are accommodated by the use of power electronics to decouple the grid and rotor frequencies.

The double-fed induction generator system uses power electronics to inject a current into the rotor windings of the generator. The frequency of the rotor current is varied such that the frequency of the current generated in the stator winding matches that of the grid to which it is directly connected. A gearbox is required to match the rotor and generator speeds.

The direct drive synchronous generator does not have a gearbox. The generator and grid is fully decoupled from the grid by power electronics. The generator speed is much lower than in indirect systems so special low revolution generators may be used; these are recognisable by their relatively large diameters and their close proximity to the turbine rotor.

As can be concluded from this description, there is a fundamental difference between wind power and conventional thermal or nuclear power generation; in wind turbines, synchronous generators are not used.

Braking system

Wind turbines are equipped with a robust safety system including an aerodynamic braking system. For emergency use, or for parking the turbine during maintenance, a (disk) brake is usually fitted.

Control system

Wind turbines have sophisticated computer control systems which can also provide detailed information on the status of the turbine. Often this information can be retrieved and some control functions performed remotely via a communications link.

Future developments

At the moment (2006), wind turbines with proven technology are available in the range of 1.5 to 3 MW. In Western Europe the focus is mainly on wind turbines in the 2 to 3 MW range. All leading manufacturers have one or more wind turbines in the MW+ market segment.

In some regions, e.g. in Southern Europe, Asia and Latin America, with a less developed transport infrastructure or where mountainous areas dominate, physically smaller wind turbines are more appropriate. For this reason, wind turbines in the 0.8 to 1.3 MW range are most in demand worldwide.

Wind turbine prototypes are available up to 5 to 6 MW and are expected to become commercially available from 2006. These turbines are characterised by a shaft height of 120 metres or more and rotor diameters of more than 110 metres. Apart from the continued high per-installed-MW costs of these 5+ MW turbines, the main problem is the weight and overall dimensions of the components that are hard to transport over the Western European road infrastructure. Some manufacturers solve this problem by offering these turbines only for offshore sites or sites accessible by waterways. Others manage this logistic problem at least partly by building and installing the towers from prefabricated concrete parts or in-situ concrete tower structures instead of tubular steel segments.

In wind turbine technology, the following developments are under preparation, or are anticipated:

- ◆ The market share of variable speed rotor technology, including modern power electronics, will increase.
- ◆ In the >1 MW segment, the gearbox is one of the weakest links, requiring frequent maintenance, or expensive refurbishment or replacement. Some manufacturers offer gearless wind turbines which use large (diameters up to 5 metres) multi-pole synchronous generators. Hybrid designs are also obtainable, e.g. a one-stage step-up gearbox followed by a less massive multi-pole generator. In the next 5 to 10 years it is anticipated that these different concepts will continue to be developed.

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- ◆ The development of >1 MW wind turbines will focus on saving weight and limiting dimensions in order to simplify road transport and limit the required capacity of building cranes on site. Ways to achieve this are the optimisation of the control strategy leading to less heavily loaded, and therefore less massive, components. Another strategy is to increase the level of integration of components and systems leading to fewer or more compact parts.
- ◆ Currently offshore wind turbines are either similar to, or derived from, onshore turbines but, in the near future, each type will be developed to better suit its application environment. Offshore wind machines will focus on reliability, remote control and high installed power per unit (up to or more than 10 MW). Onshore wind machines will concentrate on low and acceptable nuisance (i.e. noise) for the neighbourhood, high efficiency, easy and low cost transport to the site, installation by easily available building cranes and limited installed power (up to 6 to 8 MW).

Costs and benefits

Costs of wind power

Cost prices of wind power depend to a considerable degree on the location of the turbine. The wind speed and costs for the connection to the grid can vary according to location. For commercial use (budget and depreciation over ten years), cost prices vary from 5 Eurocent/kWh on good windy areas up to 8 Eurocent/kWh inland. In comparison, the cost price of electricity generated by fossil fuels is approximately 4 Eurocent/kWh. Payment for the delivered energy consists of avoided fuel costs, partly ecotax (grants for green energy) and a part that is determined by the market for renewable power.

The wind cost figures above are based on the following assumptions:

- ◆ A new medium-sized wind turbine of 850 - 2500 kW capacity
- ◆ Operating and maintenance (O&M) costs averaging 1.2 Eurocents/kWh over a lifetime of 20 years. The aggregated operational expenses (land rent, taxes, insurance, daily operation, maintenance) are approximately 2 Eurocents/kWh.

During the last twenty years, the investment costs of wind generation have dropped by about 80% to between EUR 900 and EUR 1200 per kW installed power. It is expected that this trend will continue with a reduction of a few percent each year.

The other principal cost element is that of operation and maintenance (O&M). Obviously, there are no fuel costs. O&M costs include regular maintenance, repairs, insurance, spare parts and administration. Because there are few machines older than 20 years, reliable data is not always available, or comparable. For a new machine, O&M costs might average, over the lifetime of the turbine, about 20-25% of the total amortised cost per kWh produced. Manufacturers are aiming to reduce these costs significantly through the development of new turbine designs requiring fewer regular service visits and reduced downtime. The trend towards larger wind turbines also reduces O&M costs per kWh produced.

Costs for the following items also have to be taken into account in addition to investment and O&M costs:

- ◆ Project development
- ◆ Preparation of the building site
- ◆ Foundation of the turbine
- ◆ Connection to the grid
- ◆ Real estate taxes.

Benefits of wind power

The owner of a wind turbine sells the electricity generated to a utility company. The value of wind power, as seen by the utility, is to be determined by the equivalent cost of its generation by coal or gas. If the wind

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farm owner were only to be compensated to this extent, wind power would not be an economic proposition.

Utility companies also pay for a guaranteed supply of power. 'Back up' power is not needed if the power supplied has a high level of availability. Statistics have shown that wind power can, in slow wind speeds, represent approximately 25% of the guaranteed power.

Future costs

Can wind power compete with existing conventional power plants? In this comparison, wind power does not have an advantage because the existing plants are partly written off.

The real question is how electricity generated by wind will compare in, say, ten years time, with that produced by the then newly built conventional fossil fuels plants? By that time, it may be expected that all exhaust gases will need to be cleaned and, probably, all CO₂ emissions will have to be sequestered. Because sources of fossil fuels are being exhausted, there is a realistic chance that the prices of fossil fuels will remain high. On the other hand, the costs of wind power are expected to continue to drop.

If wind power continues to develop positively for the next ten years, it is likely to become a serious competitor to conventional energy sources.

Taxes and incentives

In most European countries wind power has, at present, no chance of surviving economically without an incentive from government.

A substantial reason for providing incentives is that wind power, as an (almost) clean energy source has almost no external costs. The European Union states that "external costs are incurred when the social or economic activities of one group influence another group, and when this influence is not entirely being compensated or taken into account". For example, a conventional power plant produces SO₂, which causes a shortness of breath in people who are asthmatic and damage to building materials. However, the owner of the plant does not pay for the extra health care or the repair of buildings; the owner shifts these costs to others such as the taxpayer or individual building owners. The EU could introduce an ecotax to cover this damage and, as a consequence, the price of energy would rise by 2 to 7 Eurocent/kWh.

Alternatively, clean energy sources can be encouraged by incentives, so social and environmental costs are avoided. These subsidies are allowed, if not encouraged, by the EU. In some European countries for example, wind power is rewarded with subsidy rates of approximately 8 or 9 Eurocent/kWh depending whether it is located on land or in the sea.

Policy and regulation

Regulations, EU policies and directives concerning wind power

As sources of fossil fuel become depleted and their prices fluctuate, being dependent on oil imports becomes a major disadvantage. The environment is also becoming a major issue in terms of, for example, CO₂ emissions or the storage of nuclear waste.

Many industrialised countries are making major efforts to develop renewable energy sources, especially solar, biomass, hydro and wind power. Shell expects that one third of all energy demand worldwide will be provided by renewable sources by the year 2050.

Some European Union member states have set individual targets for (for example) 9% of all electricity to be generated from renewable sources by the year 2010, of which half might be from wind.

Wind Power

These ambitions are very modest compared with the targets that have been set by the European Union as a whole. Most EU member states already have a higher share of power generation from renewable sources in the form of hydropower, biomass and wind power. By 2010, in the EU-15, 22% of all generated electricity must be produced from renewable energy sources. EU policy constantly encourages both new (EU-25) and former members to achieve this goal.

Local effects of wind power

Wind power has an inevitable effect on the local environment, but this can be limited to an acceptable level by careful planning.

Birds

Birds can collide with the rotor blades of a turbine or become trapped by the turbulence behind the rotor. The estimated number of 'collision-victims' is relatively small at approximately 21 000 victims for an installed power of 1000 MW per year (in the Netherlands). Although this seems high, it is relatively small compared to the number of birds that are killed each year by traffic (2 million) or that die because of power lines (1 million)[9].

Most wind turbine casualties are caused at night, during twilight or in bad weather situations. Birds know their forage and resting grounds very well; they avoid wind turbines. When installing turbines, the known breeding and foraging areas of the birds have to be carefully considered.

Fish

Off-shore wind farms also have positive effects. Over-fishing is a well-known problem and the stocks of many species of fish are threatened. Since sailing, and therefore fishing, is prohibited in and around wind farms, marine biologists expect that these areas will develop into breeding grounds for many species of fish. Recent research in the vicinity of wind farms confirms this positive effect on fish stocks.

Noise

Wind turbines produce noise. The rotor makes a zooming sound and mechanical noise from the generator and gearbox is also audible. Careful design of the rotor blades, limiting the rotational speed and providing effective sound insulation of the gearbox and generator can limit noise emission. By maintaining a sufficient distance from residential or other sound-sensitive areas, noise pollution can be avoided.

Shadow

The rotating blades of a turbine create moving shadows which can cause annoyance when, for example, the shadow from a low winter sun falls onto a window. Appropriate sighting of turbines with respect to housing can be sufficient to prevent this problem. If the problem is confined to a few hours per year, the turbine can be stopped at these times without excessive loss of energy.

Blending into the landscape

Wind turbines are striking structures in the landscape. They can be made to blend in by, for example, arranging them in lines along natural features such as a dyke or waterway. Research has shown that positioning wind turbines in clusters is more accepted when it is clear to people in the neighbourhood that a great yield can be generated by doing so. Whether alignment of several turbines is liked or not is, and always will be, a matter of taste. More important is the relationship between the height of the shaft and the diameter of the rotor. Another significant item is the size of the rotor – rotors that have larger diameters are slower and consequently quieter.

Summary

For thousands of years, wind power has been used for various purposes. Since the oil crisis substantial development has taken place and impressive wind farm projects have been realised.

Wind technology is still developing. Turbines are becoming more efficient, power rates are increasing and intelligent power electronics are being introduced. In the meantime, impressive wind farms are rising out of the sea.

The continuous reduction in the investment and maintenance costs of wind turbines makes this technology interesting for investors and wind farm developers.

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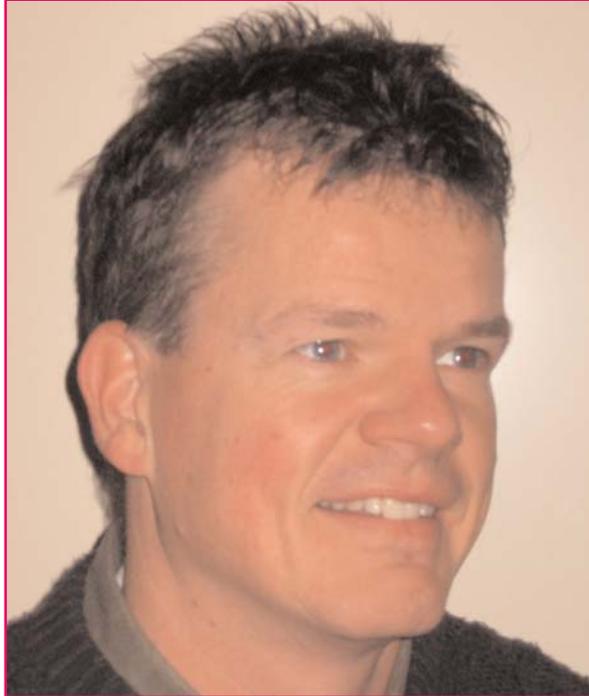
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