Power Quality and Utilisation Guide

Section 8 – Distributed Generation

Wind Power*

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Introduction

What is Wind Power?

General

Wind turbines 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 decennia a considerable scaling up has taken place in the wind power industry. Turbines have become larger, efficiencies and availabilities have improved and wind farms have become bigger.

The consumption of electricity keeps growing on a worldwide basis. Most European governments have set targets to reduce the emission of carbon dioxide in order to stop the Earth from warming up further. 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 application of renewable energy.

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

Basic principle

Wind turbines extract the energy from the wind by transferring the thrusting force of the air passing through the turbine rotor into the rotor blades. The rotor blades are aerofoils that act similarly to an aircraft wing; this is the so-called principle of lift. This can be seen in the cross-section of a rotor wing in figure 1.

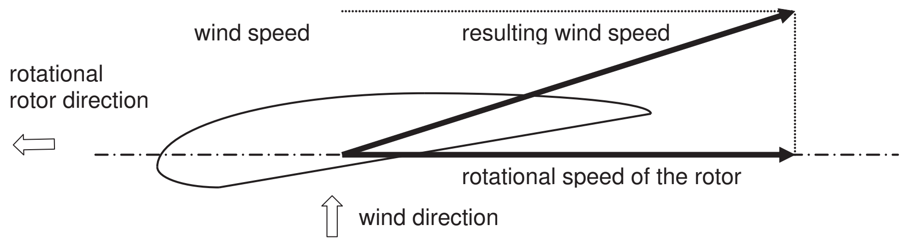

Figure 1: Cross-section of a rotor wing showing speeds and directions

As an effect of the resulting air flow, the windward side of the aerodynamic profile is over-pressured while the leeward side is under-pressured. This differential pressure creates a thrust force. This lifting force is perpendicular to the direction of the resulting force (resulting wind speed) reacted by the flowing wind towards the turbine wing and the local rotational speed of the wing. As a result, the lifting force is converted into a mechanical torque. The torque makes the shaft, as part of the turbine rotor, turn. The power in the shaft can be used in different ways. For hundreds of years it was used for the grinding of wheat or pumping water but the large machines of today, with integrated generators, convert the shaft power into electricity.

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:

$$P = 1/2 \cdot m \cdot V^2 \tag{1}$$

P power (Nm/s or Watt)

m air mass per second (kg/s)

V 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 cylindrical disc. The volume of the disc is equal to the surface area of the rotor and the length of the disc is equal to the wind speed.

Air mass through the turbine rotor per second is:

$$m = \rho \cdot A \cdot V \tag{2}$$

ρ density of air (kg/m3)

A rotor surface area (m2)

V wind velocity (m/s)

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

Both formulas combined make the theoretically power:

$$P = C_p \cdot 1/2 \cdot \rho \cdot A \cdot V^3 \tag{3}$$

C_p mechanical power coefficient (at slow shaft)

As an example:

At a wind speed of 6 m/s the energy content is 132 W/m^2 (Watt per square meter). When the wind is blowing at a speed of 12 m/s, the energy content is 1053 W/m^2. Summarized: twice as much wind speed gives eight times as much 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 proven that the theoretical maximum efficiency of wind power is limited at about 59

The net electrical power output of a turbine can be determined when mechanical and electrical performance rates are also taken into account.

Net electrical power output:

$$P_{elec} = C_e \cdot 1/2 \cdot \rho \cdot A \cdot V^3 \tag{4}$$

C_e electrical efficiency rate (%)

Today, large modern turbines are able to achieve a total net efficiency Ce 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. In operation there is no carbon dioxide emission or other air, water or soil pollution.

Other advantages of "Wind power fuel" are that it is free, it is inexhaustible and it is abundant. Wind turbines have a modular concept (reference to Section 8.4.2 "Standards" of this application note), are quick to install and are also independent of the importation of fuels and fluctuations in fuel prices caused by oil politics. Looking at the reliability of a modern wind turbine, the operating availability (the proportion of time in which a windmill is available to operate) is about 98%. 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 expansion of a grid with power produced by wind turbines is not as obvious as it seems. A certain percentage of the total generated power still needs to be provided by (central) "stable" conventional plants. This percentage depends on the composition and stability of the grid. If the instability of a grid is foreseen, it can be prevented by using intelligent control systems that interface between different kind of production units, consumers and the intermediate grid. In many EU countries, grid companies or (independent) associations are carrying out research into this.

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. A characteristic that represents a typical power output in relation to the wind speed is given in figure 2. At low wind speeds, no electrical power is generated. From 2 Beaufort (approx. 3 m/s) and above the turbine is rotating, and at about a wind force 6 Beaufort (12 - 13 m/s) the turbine is supplying its maximum power.

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

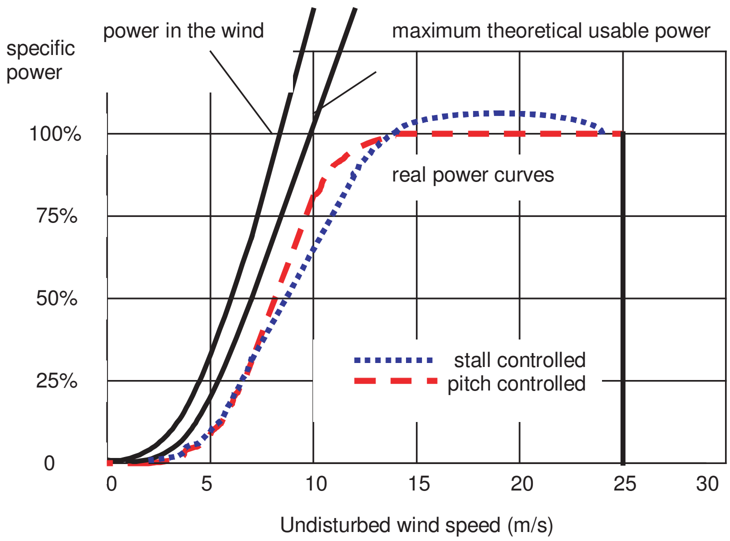

Figure 2: Typical turbine characteristic; power output in relation to wind speed

An average turbine in an ideal location can deliver an electrical power output on an annual basis of about 850 kWh per square meter 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 about 2000 full load hours and at high wind sites approximately 3000 hours.

For example, on average a 1.5 MW wind turbine produces 3.106 MWh, consisting of 2000 hours at 1.5 MW.

Costs of wind energy

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

Wind Energy cost breakdown	2000 full load hours [EUR/MWh]	2500 full load hours [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: daily management, insurance, land lease, compensation for visual or noise nuisance 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 renewable energy, including wind energy. Although each country or state applies its own rules, common features are:

- Tax benefits on investments in new renewable energy (wind) assets;
- Grants on installing new renewable energy (wind) assets;
- Lower interest rates from green funds for financing renewable energy (wind) assets;
- Incentives on the production (kWh) of renewable energy (wind).

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

Site selection wind energy

Next to issues such as sufficient space for an envisaged wind farm site, accessibility by heavy equipment such as cranes, limited nuisance to the neighborhood and the presence of a medium voltage substation with sufficient capacity, the most important issue is the presence of sufficient wind.

As a first guide, investors and developers may use 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. In case of wind farms installed in the surrounding, say less than 5 to 10 km, these production data may also serve as a good starting point.

More in detail the site wind speed and subsequently the envisaged wind farm output can be predicted with the WAsP software tool [3]. WAsP needs the long-term wind speed distribution of at least three surrounding meteorological stations. The accuracy of the results increases when the met stations are located close to the potential site. Subsequently the envisaged site and its surroundings, more precisely the surface roughness, are modeled as accurately as possible. The output is the long-term wind climate at site.

In case of doubt, certainly for complex terrain like hilly and mountainous areas, additional wind measurements are required. The measurement period has to be at least a 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 phase. As a result of the cubic law relation between the wind speed and the power, a relatively small decrease in the long-term wind speed may have a large effect on the energy output. A significant lower energy yield, i.e. more than 10 to 15%, may result in cost recovery times of more than 12 to 15 years instead of less than 10 as estimated. 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, use a lower value with an 80 or 90% probability of being exceeded. By doing this, in 8 to 9 out of 10 years one is assured of a wind speed, and therefore an energy output, higher than estimated.

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

- There must be sufficient space and plenty of wind. Nearby the applicable area many deflections can occur. These deflections can, for example, be caused by hill slopes or obstacles
- The territory must have a permit to operate a wind farm. In practice, this means that mostly territories that are marked as industrial areas are to be considered. Otherwise it is necessary to change the local zoning scheme
- The territory 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 possible 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 a transmission grid. For more details, refer to Section 8.3.5 "Integration and interconnection".

Wind turbine power control

The previous chapter demonstrated that the power 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.

Wind turbine technology applies the following methods to control the power above the rated wind speed (see also figure 2):

1. **Stall controlled rotors**
   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 flow angle-of-attack reaches a certain limit (stall point), the lifting force and subsequently the rotor torque stabilizes 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. In early days of modern wind technology, the 80s and 90s of the last century, stalling was the most widely used power control system. The Danish wind turbine manufacturers in particular gained extensive experience in this control principle. Currently stall control is not often applied any longer. The main reason is that when stall control is applied to a wind turbine greater than 1 to 1.5 MW, this 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.

2. **Variable speed rotors**
   Although this concept was already known and also applied on limited scale in the 80s and 90s, this control mechanism has been developed further and used widely since the end of the 90s. 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. By pitching the blades into the wind direction, the angle-of-attack is lowered and the lifting force and rotor torque are reduced. The synchronous generator is connected to the grid using a converter or other power electronics that can deal with alternating 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 together with up-to-date control techniques may lower design loads and may serve as a good starting point for further up-scaling activities. Last but not least, modern, IGBT or IGCT-based, converter technology improves the quality of the generated power.

3. **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. A power control mechanism applied in the 90s by a limited number of manufacturers is the so-called "active stall" control. This method combines stall control including constant rotor speed with blade pitch to optimize the stall characteristics. Another variation is the combination of stall/constant speed and power electronics to optimize the power quality.

More details are given in reference [1].

Wind power applications & opportunities in different sectors

The owner or operator of a wind turbine mostly sells the electricity produced to the utility company. Various systems of price rates have been determined in the EU to structure the trade in electrical power. Owners or operators can be:

- Initiatives from private persons or companies. They finance wind projects with own money or loan capital. Many taxation regulations are applicable for companies
- Cooperatives; private persons create a legal structure to set up a wind turbine or wind farm together. Shareholders participate in profits according to the efficiency of the turbine
- Utility companies; as turbines grew in capacity, more utilities became interested in the wind industry. The companies 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 2,900 in 1991 to 21,000 by 2002.

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

Other facts of wind power worldwide and in Europe are:

- By the end of 2005, worldwide 60,000 MW wind power capacity had been installed
- Over the last few years, the worldwide yearly increase has been approximately 25%, worldwide in 2004 7,500 MW and in 2005 11,600 MW wind power capacity has been installed
- The majority, 60 to 704
- It is estimated that 15,000 MW of wind power will be installed worldwide in 2006
- Outside Europe, most wind power is installed in USA and the last years China and India are 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, who account for 84% of the total European wind capacity. Emerging markets include Austria, Italy, Portugal, Sweden and the UK. All ten Member States that joined the EU in May 2004 have also adopted targets for the level of renewable energy they are expected to achieve
- In Germany last year, the wind industry turnover was € 4.2 billion

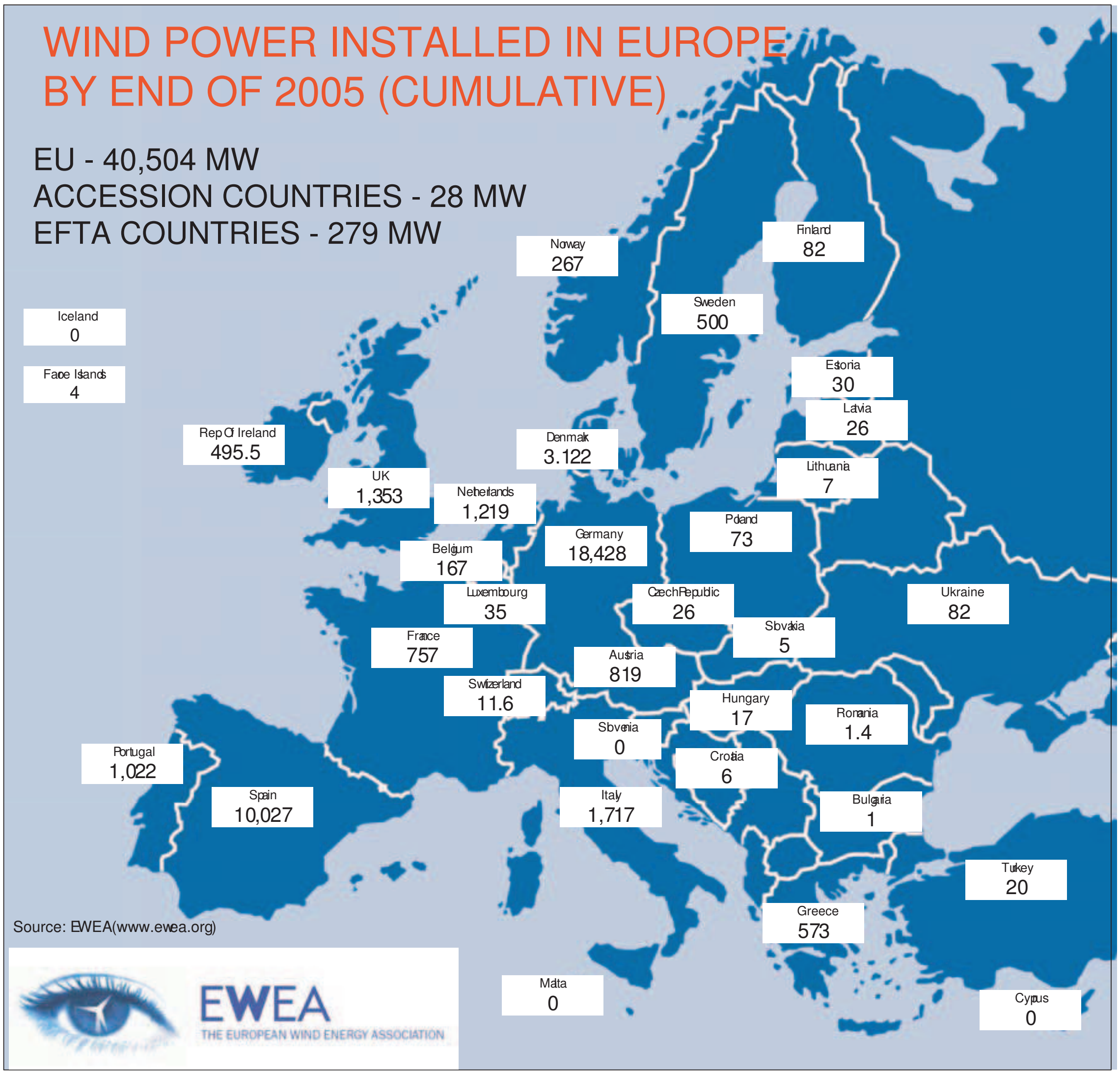

Figure 3: Map of Europe with installed amount of wind power per EU-member in MW

Wind turbine manufacturers

Worldwide, the market for wind turbine manufacturing and installation is dominated by a limited number of manufacturers. The leading ten manufacturers have a worldwide market share of 95% in wind turbine production and installation, see figure 4.

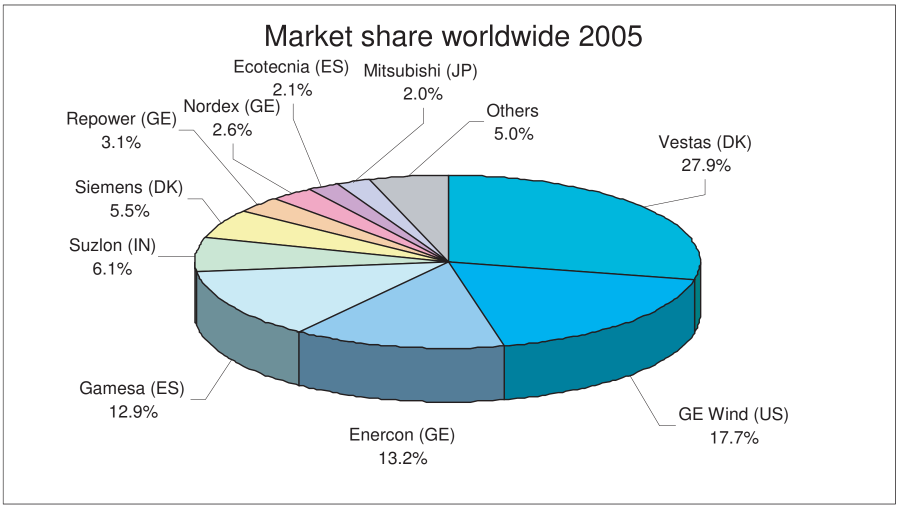

Figure 4: Worldwide market share of wind turbine manufacturers (production and installation).

Market leader is Vestas Wind Systems (VWS) with a market share of almost 30%. Since approximately 2000 there is growing tendency for large multi-national operating companies in power generation equipment and plants to expand their activities towards wind energy. Examples are Mitsubishi, GE and Siemens with the takeover of Bonus from Denmark.

Trends

In perception of economical and technological aspects, three major trends can be recognized in recent years concerning 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
- **Investment costs have decreased**
  The average cost per kW of installed wind power capacity currently varies from

900 €/kW to 1 200 €/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

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 kilometers 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 crew 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

The technology of modern wind turbines has developed rapidly during the last two decennia. The basic principle of a wind turbine has remained almost unchanged and consists of two conversion processes. These processes are performed by its 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.

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 wings

A modern wind turbine consists of two, preferably three wings or blades. The blades are made of polyester strengthened with glass fiber or carbon fibers. On a commercial basis, wings are available from 1 meter up to 100 meter and more. The wings are mounted on a steel construction, called the hub. As mentioned, some wings 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 its (steel) tower to face the rotor into the right wind direction. This facing into the wind is controlled by a fully automatic system and is set 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.

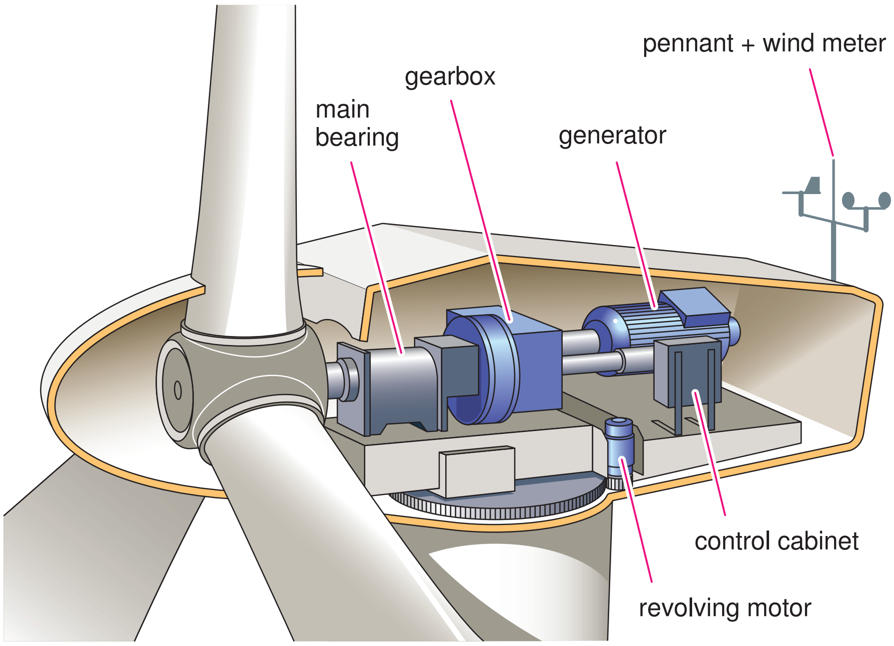

Figure 5: Cross-section of a wind turbine nacelle

Gearbox

A gearbox increases the number of revolutions from the shaft to the desired number of revolutions of the generator. A turbine with a capacity of 1.0 MW and a rotor diameter of 52 m turns at about 20 revolutions per minute and the generator at 1 500 rpm. The necessary transmission rate will be: 1 500 divided by 20 is 75.

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 either one of the following systems (see figure 6):

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

An asynchronous squirrel cage generator is a wind turbine with the first generating system. Because of the great difference between the rotation speed of the turbine and 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%). A squirrel cage generator does consume reactive power from the grid. This is not a desirable situation, especially in a weak grid. For this reason, the generator's need for reactive power is compensated for with capacitors.

The other two generating systems allow for about a factor of 2 between the minimum and maximum rotor speed. These different speed levels are intercepted by the decoupling of grid frequency and rotor frequency. For this, decoupling power electronics is used.

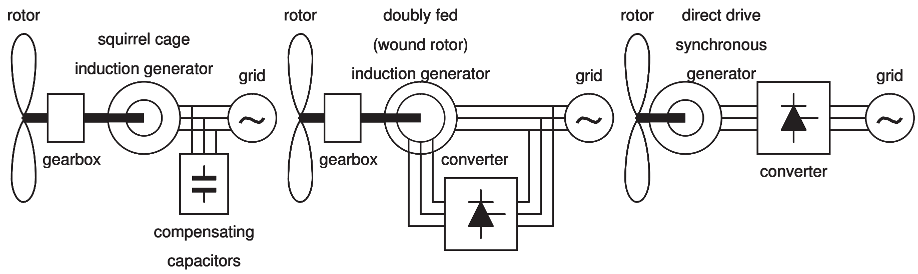

Figure 6: From left to right, commonly applied generating systems in wind turbines: squirrel cage induction generator, double-fed (wound rotor) induction generator, direct-drive synchronous generator

The first variable speed concept is based on the double-fed induction generator. Through the power electronics, a current is injected in the rotor windings of the generator. The stator windings of the generator are directly connected to the grid. The frequency of the current injected into the rotor windings is variable so electrical and mechanical frequencies are decoupled. By doing so, operation with variable speeds is possible. A gearbox adapts the two different speeds of rotor and generator.

A direct drive synchronous generator is used in the second variable speed concept. The additive "direct drive" refers to the fact that these turbines don't have a gearbox. Generator and grid are fully decoupled by power electronics. In this configuration, variable speed operation is also possible. For this concept, some manufacturers use special low revolution generators. Generators with low speeds are recognizable by their relatively large diameters that are positioned close to the turbine rotor.

As can be concluded from this description, there is a fundamental difference between conventional thermal or nuclear power generation on the one hand and wind power on the other, namely: in wind turbines, generating systems different from the synchronous generator used in conventional power plants are used.

Braking system

Wind turbines are equipped with a safety system of a high degree. An aerodynamic braking system is part of this. In case of emergencies, or for parking the turbine for maintenance, a (disk) brake is usually fitted.

Control system

Wind turbines are high-tech machines. After commissioning, a turbine is controlled fully automatically by an internal computer system. Information on the status of the turbine can be retrieved remotely by owner or manufacturer by telecom transmission (e.g. modem).

2.2 Future developments

At the moment, wind turbines with proven technology are available in the range of 1.5 to 3.0 MW. Especially in Western Europe private wind farm developers and utilities focus on wind turbines in the power range of 2.0 to 3.0 MW. All leading manufacturers have one of more wind turbines in the MW+ segment.

In some countries, e.g. Southern Europe, Asia and Latin America, with less developed transport infrastructure or dominated by mountainous areas, wind turbines having more limited dimensions are more appropriate. This is the reason why wind turbines in the power range between 0.8 and 1.3 MW are most in demand worldwide.

Wind turbine prototypes are available in the power range 5 to 6 MW, these turbines are characterized by a shaft height of 120 meter or higher and rotor diameters of more than 110 meter. These wind turbines will become commercially available from 2006. Besides the still high costs of these 5+ MW turbines per installed MW, the main problem is the weight and outer dimensions of the components. Components are of sizes 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. Other manufacturers manage this logistic problem at least partly by building and installing the towers from prefab concrete parts or in-situ concrete tower structure instead of tubular steel segments.

In wind turbine technology, the following developments are under preparation on the drawing boards or are anticipated by experts:

- The market share of variable speed rotor technology, including modern power electronics, will increase further
- Also in the segment of MW+ wind turbines, the gearbox is one of the weakest links, requiring frequent maintenance, and refurbishment or replacement is expensive. A select number of manufacturers offer gearless wind turbines. These wind turbines

are characterized by large, with diameters up to 5 meter, 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. For the coming 5 to 10 years it is anticipated that these different concepts will be developed side by side

- The development of 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 optimization of the control strategy leading to less loaded and so less massive components. Another method is to integrate more functionality in a component or system leading to less or more compact parts.
- Currently offshore wind turbines are equal to or derived from onshore turbines. In the near future the development of offshore wind turbines will deviate from onshore wind turbines. Offshore wind will focus on reliability, remote control and high installed power per wind turbine (up to or more than 10 MW). Onshore wind will concentrate on low and acceptable nuisance (i.e. noise) for the neighborhood, high efficiency, easy and low cost transport to the site, installation by fast and on short notice 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 per location. For commercial use (budget and depreciation over ten years), cost prices vary from 5 c€/kWh on good windy areas up to 8 c€/kWh inland. In comparison: the cost price of electricity generated by fossil fuels is approximately 4 c€/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. This cost calculation is based on the following assumptions:

- A new medium-sized wind turbine of 850 - 2 500 kW capacity
- O&M costs averaging 1.2 c€/kWh over a lifetime of 20 years. The aggregated operational expenses (land rent, taxes, insurance, daily operation, O&M) is approximately 2 c€/kWh.

During the last twenty years, the investment costs per kW installed wind power has dropped. These average costs for a wind turbine project range from € 900 up to € 1 200 per kW installed power. Since the start of the present development in the end of 1970s, generating costs have dropped by about 80%. Expectations tell us that this trend will continue with a reduction of a few percent each year.

The other principal cost element in generating electricity from wind power is operation and maintenance (O&M). Obviously, there are no fuel costs. O&M costs include regular maintenance, repairs, insurance, spare parts and administration. Because not many machines are more than 20 years old, data is not always available, or comparable. For a new machine, O&M costs might have an average share over the lifetime of the turbine of about 20-25% of the total amortized 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 therefore reduced downtime. The trend towards larger wind turbines also reduces O&M costs per kWh produced.

Except for investment and O&M costs, costs for the following items also have to be taken into account:

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

Benefits of wind power

The owner of a wind turbine sells his generated electricity to a utility company. The value of wind power, as seen by the utility, is to be determined by the costs as caused by the replacement of coal or gas. The average price of this grey power has gone up to approximately 2 to 3 c€/kWh. If the owner were only to be compensated for this part, a wind turbine could not be utilized sufficiently when the present costs are taken into account.

Utility companies also pay for a guaranteed supply of power. "Back up" power is not needed if the power supplied as 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 be competitive with conventional existing power plants at this moment? In this comparison, wind power does not have an advantage because of existing plants that are partly written off. Decisive is, how electricity made by wind will act in ten years in relation to electricity produced by then newly built conventional plants that are powered by fossil fuels; of which all the exhausted gasses need to be cleaned and probably all emitted CO_2 has to be stored. Because sources of fuels are running out, there's 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 dropping.

If wind power works out in a positive way for the next ten years, it has a good chance of becoming a serious competitor to conventional energy sources.

Taxes and incentives

In most European countries, wind power has at this moment no chance of surviving without an incentive contribution from EU governments.

A substantial reason for providing an incentive is that wind power, as (almost) clean energy source has almost no external costs. These costs have been recently determined as part of a study made by the EU. 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 SO_2. This gas 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. The EU could introduce an ecotax for this damage. As a consequence of this, the energy per kWh would be 2 up to 7 c€more expensive.

The other way around is to encourage clean energy sources by incentives, so social and environmental costs are avoided. These subsidiaries 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 c€/kWh depending whether it is located on land or in the sea.

Policy and regulation

Relevant regulations, EU policies and directives concerning wind power

There are major disadvantages in being dependent on oil imports and fluctuating oil prices. Sources of fossil fuels are running out. The environment is also becoming a major issue in terms of CO_2 emissions or how to store nuclear waste.

In the background, many industrialized countries are exerting a major effort 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 in the year 2050. The ambitions to apply wind power are high. Some countries within the European Union have set individual targets to have (for example) 9% of all electricity be generated by renewable power by the year 2010. Half of this percentage might be wind.

These ambitions are very modest compared with the targets that have been set by the European Union. Most countries of the EU now already have a higher share of renewable power generation by the availability of hydropower and a higher use of biomass and wind power. In the former EU (15 countries) and by the year 2010, 22% of all generated electricity must be produced by renewable energy sources. The Union is constantly encouraging all former and new European members to achieve this goal. (Concerning the subject of "Policy and incentives", refer to Section 8.4.1 of this application note).

Local effects of wind power:

When wind power is used, this can cause local inconvenience. Detailed planning can limit the impact of wind power consequences to an acceptable level.

Birds

Birds can run into the rotor blades of a turbine or get caught by the turbulence behind the rotor. Inquiry has shown that the risks for collisions are relatively small. The estimated number of "collision-victims", at an installed power of 1000 MW is approximately 21,000. On an annual basis this seems to be a high number, but this is a small amount when compared to the number of birds that get killed by traffic (2 million) or that die because of power lines (1 million).

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 breeding and foraging areas of the birds have to be considered well.

Fish

Wind turbine (farms) at sea also have positive effects. Over-fishing is a well-known problem; the stocks of many species of fish are threatened. The sailing of ships and therefore fishing is prohibited in and around wind farms. Sea biologists expect that these areas will develop into a breeding ground of several species of fish, and overall this will have a positive effect on fish stocks. Recent research near wind farms confirms this effect.

Noise

Wind turbines produce noise. The rotor makes a zooming sound and the generator and gearbox can also be heard. Carefully designed rotor blades, a limited revolution speed, and effective sound insulation of the gearbox and generator limit the noise emission. By maintaining a sufficient distance from residential or other sound-sensitive areas, noise pollution can also be avoided.

Shadow

Sunshine creates moving shadows when the rotor of a turbine rotates. In winter, when the sun is low, the shadow can be annoying when it falls into a window. Giving wind turbines an appropriate orientation towards houses is sufficient to prevent this problem. If on a yearly basis a small number of hours give inconvenience, the turbine can be stopped at these moments without any particular 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, by arranging them in lines along a dike or waterway. In doing so, the lines of the landscape are taken into account. Research has shown that positioning wind turbines in clusters is more accepted when it is clear to neighboring people that in this situation a great yield can be generated. Whether the lining-up of several turbines is liked or not is and always will be a matter of taste. More important is the relationship between the altitude of the shaft and the diameter of the rotor. Another significant item is the size of the rotor. Rotors that have larger diameters rotate slower and because of this they are quieter.

Summary

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

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.

Not only environmental issues make wind turbines more often seen on the horizon. The continuously lowering of the investment and maintenance costs of wind turbines make this technology interesting for investors and wind farm developers.

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