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Wind Farms and Their Impact on the Environment

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1. Introduction

This chapter summarizes author´s experience with environmental impact assessment in branch of wind farms. The introductory part of chapter describes history and development of wind power utilization world-wide and in the Czech Republic. Next part of chapter deals with technology of wind turbines and their development. The final part of chapter deals with experience with environmental impacts of wind farms and implementation of the environmental impact assessment process (pursuant to the Act No. 100/2001 Coll. on environmental impact assessment, as amended) in the field of wind power in the Czech Republic.

2. History and development of wind power utilization

2.1 Significance of wind energy as a renewable source

A direct impetus for the development of wind energetics in Europe was the energy crisis in 1973 caused by an embargo enforced by OPEC on the oil export into developed countries. Pressured by a sharp increase in the world-wide prices of oil, countries with own limited classical energy sources began to search for a possible utilization of renewable energy sources, including wind, in a wider scale. Denmark was the pioneer in the development of wind energetics in Europe as they started to construct the first wind farms at the end of the 1980s (Štekl et al., 1993).

Wind energetics uses inexhaustible kinetic energy of the wind, totally for free, and thus it is not subject to inflation. In this manner, it reduces the dependence on the import of raw materials for power generation, namely from regions characteristic for their political instability. The principle of inexhaustibility of the wind gains on importance when compared with the brown coal reserves in the Czech Republic (CR). Adhering to the territorial environmental limits set by 1991 government decree, between 2040 and 2050 the extraction of brown coal shall drop below the level of the coal fired power plant needs (Štekl, 2008).

Wind energetics is most environmentally friendly, which is currently extraordinarily important in the climate protection by means of reducing the production of greenhouse gases, particularly carbon dioxide (Cetkovský et al., 2010).

Another argument in favour of wind farms is the fact that the energy return on energy invested is much faster in wind farms than in case of nuclear or coal fired power plants. The

time when a WF generates the same amount energy as expended to construct it ranges from 6 to 12 months at the WF lifespan of 20 years (Mathew, 2006).
Building a WF strains the site in a minimum manner and, roughly, it is a question of one month. Dismantling of the structure takes 2-3 days and the structure hardly leaves any traces in the ground. Wind farms are excellent examples of multifunctional utilization of areas, which means that they permit utilization of agricultural land almost in the original extent both for plant growing as well as for pasturage.
Thanks to reducing specific costs of a generated kWh from wind it may be expected that in the next few years the price of electric power generated from wind and brown coal shall level off (Mathew, 2006).

2.2 Utilization of wind power within the Czech Republic in the past

The first mention of a windmill in Europe comes from 833. Historical sources relate the construction of the first windmill within the territory of the Czech Republic to the year of 1277, namely in the garden of the Strahov Monastery in Prague. The oldest reference from Moravia and Silesia comes from the Opava region and dates back to 1340. Before the 17th century the mentions of windmills are sporadic. In the 18th century the development of wind millery was stimulated by a court decree on the establishment of windmills of 1784, which pursued the objective for each community to have a windmill. As a result, there were thirty windmills registered in Moravia and Silesia. The boom of wind millery in Bohemia is connected with the first half or the first two thirds of the 19th century (Pokorný, 1973). In total, 198 localities with windmills were documented in Bohemia then. In Moravia and Silesia the boom occurred later, namely in the second half or last third of the 19th century and beginning of the 20th century. Within Moravia and Silesia there is a documented existence of 681 windmills (Burian, 1965). In total, within the territory of the CR there was a proven existence of 879 windmills (Cetkovský et al., 2010).

2.3 Development of wind energetics world-wide and in the Czech Republic

Along with cumulative problems in connection with fossil fuel utilization and environmental protection, wind energetics is getting into the forefront of interest and a formerly marginal and low prospective branch is gradually becoming one of the major trends of the world-wide power engineering.
There are registered attempts of wind exploitation for power generation from the very beginning of electroenergetics as such. However, a more systematic development in the sphere of wind energy may be dated approximately into the second half of the 1970s. Oil shocks at that time brought attention to limited classical sources of energy and led to a search for alternatives, wind energy being one of those. As in the nature of new technologies, the beginnings were not easy and for a long time wind energy appeared as interesting but expensive, and not a very utilizable option in a wider scale.
Nevertheless, development continued especially after a strong impulse from California which introduced a temporary generous support for wind energy in the 1980s. From today's point of view of miniature wind farms this era is responsible for the famous arrays in the Californian passes of Tehachapi or Altamont. The technology was in its infancy then and not all the attempts brought success. However, the "Californian boom" contributed to testing various technological concepts and an elimination of diverse development dead ends.
The following years were characteristic for a slow but more organized development under a systematic support, particularly from the part of Denmark and, to a smaller extent, some

other European countries (particularly Denmark much benefited from the support and, as a result, it has currently become a technological leader in the field and wind energetics represents a considerable contribution within the national economy). The basic technological principle of wind farms does not change much nowadays, but it is their reliability, efficiency and last but not least their size that grow gradually. This jointly contributes to lower costs per unit of energy produced and permits a meaningful construction of wind farms also outside prominent localities on the sea coast (Cetkovský et al., 2010).

A country which also takes advantage of the opportunity apart from Denmark is Germany. In connection with introducing favourable and transparent conditions for wind energy purchase and granting permissions for wind farm constructions there was an unprecedented development in the construction of wind farms, which started approximately in the mid 1990s and peaked in the early 21st century. At that time wind energetics turned out to be a considerably inexpensive method how to generate clean energy from home sources and not a mere inconvenient "alternative" technology.

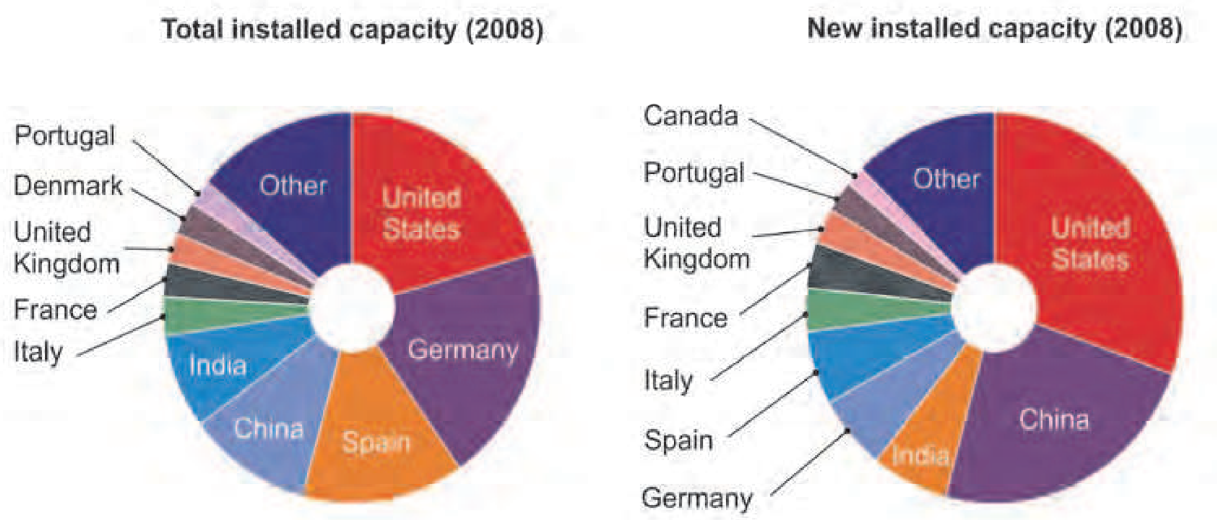


Fig. 1. Participation of the individual countries on the total wind farm output (left) and on the increase in the installed power capacity (right) in 2008 (according to GWEC - Global Wind Energy Council data)

Globally, the present times may be seen as a vast boom in the construction of wind farms. This trend is given by having perfected the technology compared to the past (lower break-down rate and noisiness of the wind farms, higher outputs), a significant drop in their cost and higher interest in the exploitation of wind energy due to high and unstable oil prices as well as growing urgency of environmental issues and forthcoming climatic changes.

While the first surge of wind farm erection concerned a rather narrow number of countries with Denmark and Germany leading the list (including Spain since 2000), since 2005 there has been a massive expansion of wind energetics across the continents. Recently, wind energy has been systematically supported in the USA and China and nowadays also in a number of European countries (e.g. France, Great Britain, Portugal, Italy) as well as in extra-European countries (traditionally India, followed by Canada, Japan, etc.). The United States along with China have become leaders as for the countries with newly installed power capacities, even if much smaller Germany and Spain (behind the USA) still maintain strong positions as for the so far installed power capacity thanks to their head start.

Overall, in 2008 the world-wide installed capacity of wind farms reached the level of 120 GW, out of which 26 GW were gained last year (for a better idea: the total installed capacity of all the power plants in the Czech Republic is about 17.5 GW). The appreciable significance of wind energetics is documented by the fact that within the European Union energy from wind covered 4.2 % of electric energy consumption in 2008 and that year wind farms achieved the highest increase ever in the installed capacity among all the energetic sources.

As for the future development, a decrease in constructions may be expected in the regions where power energetics broke through as first, i.e. particularly in Germany and Spain. The construction of wind farms is slowly facing a shortage of suitable inland localities and power system limits as for the generated power transmission. However, an intense development will continue in other European countries, particularly in the extra-European ones and globally the existing record growth of wind energetics is likely to be beaten. In the near future, we should also live to see a more extensive construction of off-shore wind farms, mainly in the area of the North Sea. It is in case of the "off-shore" wind farms where major technological innovations may be expected and in all probability, for example, floating wind farms to be erected in deep waters or huge off-shore wind farms with an output of over 10 MW may even be anticipated (Cetkovský et al., 2010).

The Czech Republic cannot be included among advanced states as for wind energy exploitation even if the historical development may suggest otherwise. The fact that a lot of attention was paid to wind energetics in the Czech Republic in the past is evidenced by a book by František Kašpar (Kašpar, 1948). The modern development of wind energetics proceeded in two stages in the Czech Republic. The first stage is related to the period of 1990-1995. Then 24 wind turbines were constructed with a total installed nominal output of 8.22 MW. Before 2001 the wind energy purchase prices fluctuated from 0.9 to 1.13 CZK/kWh, which did not make a profit-making operation of WF possible.

The second stage of the development of wind energetics was started by the Energy Regulatory Office price decision for 2002, and gradually also for 2003, which set the minimum purchase price of power generated from wind for the amount of 3 000 CZK/MWh. This price went gradually down to 2 340 CZK/MWh in 2009 and to 2230 CZK/MWh in 2010 and nowadays, but still permits a profit-making construction and operation of wind farm projects.

Since then, the construction of wind farms has been rising slowly. Currently, there are wind farms predominantly in the region of the Ore Mountains (Krušné hory), less in the Drahany Upland (Drahanská vrchovina) or in the Nízký Jeseník Mountains (Czech Republic). The individual wind farms or small wind farms are operated also in other parts of the Czech Republic. The largest wind farm in the CR was erected in 2007 near Měděnec and the water reservoir of Přísečnice in the Ore Mountains. In total, there are nowadays 24 wind turbines of a total output of 49.5 MW, which thus account for more than a third of the overall wind farm output in the CR. The construction of this wind farm resulted in a rather sharp increase in the installed capacity in 2007 (Cetkovský et al., 2010).

In 2008 an increase in the installed capacity was not that significant, namely due to prolonged delivery dates of wind turbines, blocking the capacities to supply the output into the electric network (wind farm projects and projects of other types of renewable energy sources) and growing obstructions from the part of certain state administration authorities.

By the end of 2008 there were 111 wind turbines in operation in the Czech Republic of an overall output of 145 MW. In 2008 wind participated by 0.29 % on the power generation in the CR. The capacity factor (efficiency) of the majority of the wind farms ranges from 20 to 25 %; rarely, however, wind farms in exposed sites achieve much higher values.
The future development of wind energetics in the Czech Republic is unclear. On one hand, there is a favourable purchase price in favour of constructing wind farms and in many localities of the Czech Republic there are quite good wind conditions. On the other hand, the construction is rather slowed down by a complicated and non-transparent permission-granting process and inconsistent public administration's attitude. The most probable scenario for the next few years is a further but slow increase in new wind farms with annual output increases at the level of about 50 MW (in 2010 mere 20 MW – Lapčík, 2010). However, the real development shall predominantly depend on the support from the part of the political representation which is rather unenthusiastic despite the international agreements and national joint responsibility for a dismal development of the earth's climate.
The Czech Republic's wind energy interests are defended by the Czech Wind Energy Association, a voluntary organization of physical and legal entities who are active in the field of wind energy exploitation or are interested in the issue.

3. Technology of wind turbines and their development

A wind turbine is a machine that converts kinetic energy from the wind into electric energy. In dependence on the rotor diameter, defining an area S swept by the rotating blades, the machines are divided into small, medium-sized and large wind turbines (WT).
Among *small wind turbines* (SWT) there are turbines with a nominal output below 60 kW and blade diameter up to 16 m. The most significant category is small SWT with a nominal output below 10 kW, which dominate in producers' catalogues. This group may be divided into two subgroups (Štekl, 2007).
They are micro-sources of a rough output up to 2 or 2.5 kW, the assortment of which is the widest as for the producers. They are small WT with a blade diameter from 0.5 to 3 m, which are solely designed for charging batteries. Such accumulated energy may be used to power communication systems, radio and televisions receivers, fridges and other electrical appliances and light. Small WT have come much useful on sea yachts as energy sources for radio stations, navigation systems, maintaining capacities of starter batteries and lighting. Such devices usually operate with a direct current 12 ÷ 24 V.
The second subgroup of the SWT category are machines with a nominal output from 2.5 to 10 kW. These are turbines with a blade diameter from 3 to 8 m, which similarly to the machines of the previous group operate in the stand-alone regime (are not connected to the grid). Such machines have a usual output voltage of 48 to 220 V and they are offered for the house heating or moderate heating purposes, water heating or to drive engines. A published analysis back in 2002 (Štekl, 2002) proved that power generation by such sources for the needs of houses or small farms, which may be connected to the power grid, is not profitable. From the economic point of view, they are justifiable only in places without a possible connection to the grid and a minimum mean annual wind rate of 4.5 m/s at the altitude of 10 m. Power generation by SWT in order to sell energy to power distributors is not economical due to significantly higher specific costs (by as much as several tens of percents).
Thanks to the growing dimensions of new wind turbine blades, the former category of large WT split into two categories, namely *medium sized wind turbines* with a blade diameter from

16 to 45 m and a nominal output ranging from 60 ÷ 750 kW and *large wind turbines* with a blade diameter from 45 to 128 m and a nominal output of the turbines from 750 to 6 400 kW. The largest WTs with a nominal output over 3 000 kW are mostly facilities designed for offshore operations. Producers sporadically offer WT with a nominal output up to 300 kW or WT with outputs ranging 300 ÷ 750 kW. The widest line of products concerns the output ranges from 1 500 to 3 000 kW. Keeping to this fact, the highest number of WT is in this category (40 %) out of all the constructed WT in Germany before 2005 generating 66 % of the German annual WF energy production. The mean output of all the WF constructed before 2005 in Germany was 1723 kW (Ender, 2006).

3.1 Technical solution of wind turbines

3.1.1 Wind turbine rotors

Apart from the meteorological parameters, the output gained from the flowing air depends on the WT rotor swept area and power ratio value (See the Chapter 3.2). Therefore, rotors are the cardinal components of a WT and they have experienced a surprising development for the past 30 years, as for their size, aerodynamic characteristics and operation regimes. For example, back in 2004 there were 90% of WT with a rotor diameter below 60 m in Germany. A lot produced wind turbines used to be three-bladed, mostly with a "pitch" system rotor regulation and a variable number of revolutions. Growing dimensions of the rotors lay high demands on the construction and used materials in order to ensure reliability of operation. Large blades suffer from considerable loads, e.g. at the moment when a large mass of the blades is halted rearranging the blades into a so-called flag position. Apart from small-scale turbulence, possibly huge vertical wind speed gradients, which may in extreme cases reach up to 10 m/s per 100 m, have a negative impact on the lifespan of the material of large blades (Štekl, 2007).

To prevent an increase in the wind speed, which leads to a rise in output, from causing any damage to the generator, a suitable method must be used how to limit the output supplied by the rotor. There are various methods of the rotor output regulation, which are characteristic for the individual types of WT. In principle, there are three methods of control:

a. regulation when the rotor blades with a constant angle of blades setting cause flow separation, the so-called "stall" regulation,
b. regulation by pitching the rotor blades into larger angles and reducing the lift force and output, the so-called "pitch" regulation,
c. regulation by setting the rotor blades into smaller angles and thus reducing the lift force, increasing the resistance and causing a drop in output, the so-called "active stall" regulation.

The turbines regulated by the "stall" regime are simpler in their construction than the turbines with "pitch" regulation, as they do not have a technical system changing the rotor blades setting. When compared to "pitch" regulated wind turbines, technically the "stall" regulation of output has the advantages below:

- simple construction,
- undemanding maintenance with respect to a lower number of mobile parts,
- high reliability of the output regulation.

What is a disadvantage of the regulation method is the fact that the rotor output falls at high speeds, and thus its efficiency decreases too, which happens in case when the wind energy is at its top. Another drawback of the method is the necessary fine adjusting of the blades frequently after the pilot operation in the given locality. Another *disadvantage* of the rotor is its *inability to start on itself*, which is secured by an *electric motor*. Currently, producers offer the “stall“ regulation regime in WT of a nominal output roughly below 1 000 kW, and exceptionally with larger ones.

The “pitch“ regulation represents an active system which works with an input signal about the generator’s output. Always when the generator’s nominal output is exceeded, the rotor blades change the stagger angle towards the flow, which causes a reduction in the drive and aerodynamic forces as well as it limits the utilization of the turbine output. For all the wind speeds over the “nominal“ speed which is vital to achieve the nominal output, the angle of attack is set so that the turbine provided the required output. Wind turbines with the “pitch“ regulation are more sophisticated than the “stall“ regulation turbines as the rotor blades setting changes continuously. The “pitch“ regulation has the following advantages:

- it permits an active output control within the overall wind speed range,
- when compared to the “stall“ regulation, it provides a higher production of energy under the same conditions,
- a simple start of the turbine’s rotor changing the setting of the angle of attack,
- it does not require any strong brakes for a sudden halt of the rotor,
- it limits the rotor blade load at higher wind speeds over the ”nominal speed“,
- a favourable position of the rotor blades with respect to a low load in case of extreme wind speeds.

The drawback of this type of regulation is a more complicated and significantly more expensive rotor shafts which must carry enormous force exerted on the blades and, at the same time, ensure a possible pitching of the blade around the blade’s linear axis.

In the initial regimes, the regulation “active stall“ is identical to the previous type of regulation, i.e. the “pitch“ one. It differs in the last regime when maintaining the constant output is not achieved by increasing the blade setting angle but decreasing this angle. In such a regime it is the case of separation control on the blades, thus “active stall“. The advantage of this type of regulation, compared to the previous one, is lower sensitivity to the surface pollution on the blade’s leading edges (insects).

3.1.2 Wind turbines with/without a gearbox

Besides the traditional technology with a mechanic gearbox ensuring a transmission of a rotor’s low speed into much faster rotation speed of conventional generators, wind turbines without a gearbox are also produced. So far both types of wind turbines have been successful in the international market. Enercon is one of the leaders in the gearbox-free technology. Both the types have their advantages and disadvantages. A decision whether to make wind turbines with or without a gearbox is often a matter of philosophy from the part of the individual producers, while it is the brand’s tradition, development targets and economic analyses that play an important role too.

The gearbox free solution is based on the exploitation of multi-pole low-speed generators. However, they have rather big dimensions, which may cause problems during transport, especially in the megawatt class. On the other hand, there are a significantly lower number of the machine components. There is no need for a large gearbox, connecting parts, there is a fewer number of rotating elements, simpler nacelle and, after all, the maintenance is easier as well. Both in “stall“ as well as in power controlled “pitch“ regulation and in power controlled system of gondola turning no hydraulic oils are required, which is a great

advantage both for the operation and maintenance. An argument that special generators made only for wind farms in small series are expensive when compared to classical generators is out of place. Along with higher outputs and dimensions of wind turbines, the classical generators and gearboxes are manufactured in small numbers too, which means that a lower price with respect to mass production is not probable.
Traditional constructions of wind turbines are grounded in the use of a drive shaft, bearings, gears and couplings. Technically, all the components are common machinery components that may be supplied by specialized producers. This way it is possible to guarantee a high quality of products at low costs and a possible replacement of a component supplier in order to improve the quality or lower the price. Thanks to the current manufacturing standards of gearboxes, the noise caused by a gearbox does not give cause to construct wind turbines without one. Nowadays, gearboxes are able to last twenty years, while lubricating oil need not be changed that often. The overall machine unit of the gondola is divided into compact components which enable for an easy transport and assembly on site even in the megawatt class.

3.1.3 Wind turbine towers

As clear from company catalogues, the most widespread wind turbine towers are slightly conical steel tubes. Along with a rise in the turbine outputs, towers are becoming higher, as high as 100 to 120 m. Therefore, certain suppliers offer concrete towers for heights over 100 m (e.g. Enercon 4.5 MW near Magdeburg, Germany) and towers in the form of a lattice construction (Štekl, 23007). Lattice towers are perceived adversely due to their "non-aesthetic" appearance and many environmentalists have stigmatized them for damaging the face of the landscape. Other oppose the criticism and say that when compared with the tube towers, the lattice towers have the following advantages in the landscape:

- transparentness, which means that the lattice towers better blend in the landscape, particularly looking from a greater distance,
- minute reflexion of incident light,
- suitable planting into a specific face of the landscape, e.g. forest landscape,
- incorporation into the landscape with already erected structures of such a character (e.g. line masts).

Another advantage of the lattice towers when compared to the tube ones is a lower consumption of steel, which means that at identical costs the produced lattice tower is 20 % higher than the tube one. For instance, the company of Nordex offers a steel tower of 100 m at 319 t and a lattice tower of 105 m at 185 t. The company of Fuhrländer even offers a lattice tower which is 160 m high (weight of 350 t). The assembly of a lattice tower and the transport of its components is simpler, which constitutes a great plus in the construction of wind farms in the mountainous conditions. Having finished the lattice tower by zinc coating a 40-year lifespan is guaranteed, which means no painting the steel tube towers is required.

3.1.4 Wind turbine Vestas V90 – 2.0 MW

Another example is a wind turbine by Vestas Wind Systems A/S, type Vestas V90 – 2.0 MW, which is a characteristic representative of the wind turbine group with a gearbox (from the rotor the mechanical energy is carried by the main shaft via a gear unit onto the generator). Such wind turbines are produced in a mass scale and at present are erected both in the EU countries as well as outside the EU (in the USA, Mexico, Australia, etc.). It must be pointed out that as for the basic parameters, wind turbines with a gearbox from other producers do not much differ from the Vestas machines, which still belong to the most experienced producers in the field.

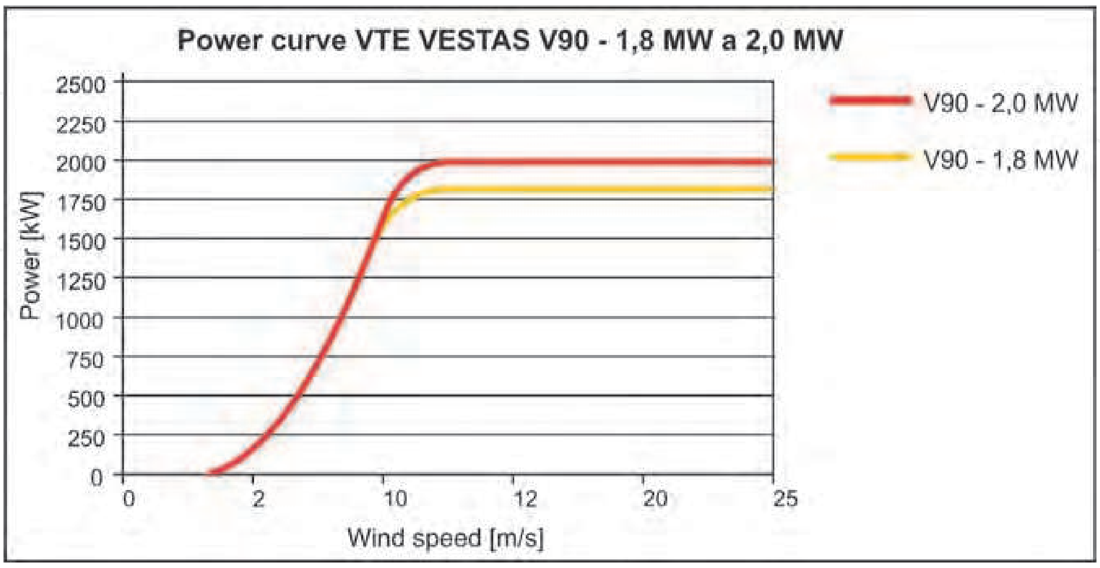


Fig. 2. Wind turbine power curve (Vestas V90)

A Vestas V90-2.0 MW wind turbine has a 45 m long rotor blade (rotor diameter is 90 m – See Figures 3 and 4). It is a slow-circulating machine with revolutions from 9 ÷ 14.9 rev/min. The cut-in wind speed is 2.5 m/s, the wind nominal speed is 13 m/s (See Fig. 2), and the cut-out (maximum) wind speed is 21 m/s. Exceeding this speed the machine automatically brakes and shuts down.

The wind turbine is regulated by pitching the blades (“pitch“ regulation) by means of an OptiTip® device by Vestas with an active steering the rotor up the wind. By means of OptiTip® the rotor blade setting angles are under permanent control and thus the blade setting angle is always adjusted to the prevailing wind conditions. In this manner, power generation is optimized and noise is minimized.

The rotor blades (Fig. 4, Lapčík, 2009) are made from epoxy resin reinforced by glass fibre (laminate). Each rotor blade is made up from two halves glued together by a carrier profile. Special steel anchoring fills join the rotor blades to a rotor blade bearing. If required, a technology with heated rotor blades may be supplied.

The main machine room and rotor shaft segments are in Figure 6. From the rotor the mechanical energy is carried by the main shaft via a gear unit onto the generator. The gearbox is combined with a planet gear and spur bearing. The output transfer from the gearbox onto the generator is carried out by means of a composite coupling that does not require any maintenance. The generator is special as it is quadripolar, asynchronous and with an advanced rotor.

Braking the wind turbine is conducted via arranging the rotor blades into a so-called flag position. The parking disk brake is situated on the high-speed power shaft.

All the wind turbine functions are controlled by control units based on a microprocessor base. This operation control system is placed in the nacelle. Changes in the rotor blade setting angle are activated via a torque arm by a hydraulic system which allows the rotor blades rotate axially by 95°.

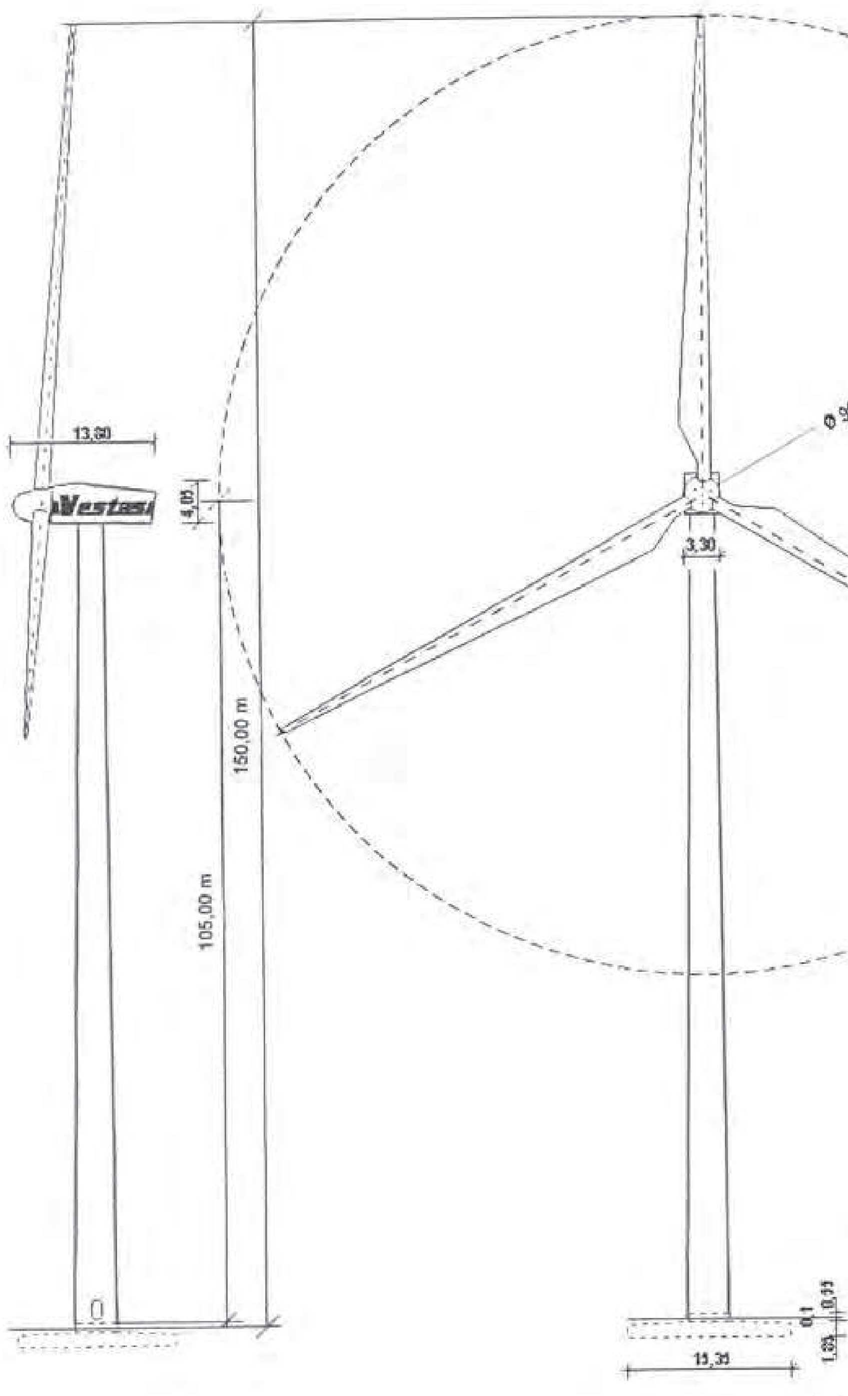


Fig. 3. Wind turbine of Vestas company – an overall view

Four power driven gearboxes are responsible for positioning the nacelle up the wind turning the pinions that reach into the dents of a yaw bearing placed on the top of the tower. The bearing system of positioning up the wind is a sliding bearing system with a built-in friction and self-locking function.

The nacelle cover (Fig. 6) made of plastic reinforced by glass fibre protects all the components inside the nacelle from rain, snow, dust, solar radiation, etc. The gondola is accessible through a central aperture from the tower. Inside the nacelle there is a jib crane for maintenance.

Fig. 4. View of a rotor blades, nacelle and upper section of the Vestas wind turbine tower

There has been a significant development in the wind turbine towers, which have grown from the original 20 m to 100 or 120 m, or higher in extreme cases. The most widespread are poles in the form of slightly conical steel tubes. Currently, at the heights over 100 m the poles are usually made of concrete or combine steel and concrete. A possible option are lattice construction poles which are advantageous both as for their price and construction. However, they are refused by a group of "environmentalists" who feel that the towers damage the face of the landscape.

A conical steel tubular tower (Vestas) is either 105 metres or 80 metres high (Fig. 3 and 4). The diameter of the ground flange is 4.15 m (Fig. 5), the top flange diameter is 2.3 m. It is supplied with a finish in a green-grey colour. The tower is anchored into the foundation in the form of a ferroconcrete plate of about 16 metre diameter, height of 1.9 m (on a footing bottom in the depth of 3 m). The foundation is placed below the ground surface and topped with a one-metre-thick layer of ground.

The total weight of the technological part of the wind turbine (without the foundation) is 331 tons (gondola 68 t, rotor 38 t, tower 225 t).

The wind turbine is constructed for the temperatures ranging from -20 °C to +55 °C. Special measures must be taken beyond the afore mentioned temperature range.

Beside the wind turbine there is a container concrete transformer station (in the majority of cases there is one transformer station for three machines). The transformer is oil, two-winding in a container version. The transfer is from 690 V to 34 kV and the nominal output is 1.6 MVA. Nowadays most of producers place the transformer station directly inside the wind turbine tower.

Fig. 5. View of the anchorage of the wind turbine pole into the anchor plate (Lapčík, 2008)

3.2 Calculation of wind turbine output

The term of wind power density P is understood as the capacity which could be obtained at hundred-percent exploitation of the kinetic energy of the wind flowing by an area per unit perpendicularly to the flow direction. It may be determined according to the relation

$$P = \frac{u^3}{2}.\rho \qquad [W/m^2] \tag{1}$$

The wind power density passing through the plane S [m²] perpendicular to the flow direction is expressed as below

$$P_S = \frac{u^3}{2}.\rho.S \qquad [W] \tag{2}$$

The power of a wind turbine removed from the blowing air through the turbine rotor P_s is expressed by the relation below

$$P_S = \frac{u^3}{2}.\rho.S.c_p \qquad [W] \tag{3}$$

where
u …. wind speed (m/s),
ρ …. specific weight of the air (kg/m^3),
S …. rotor swept area (m^2),
c_p … power coefficient (-) which is dependent on the extent to which the rotor decreases the speed of the flowing air; the power coefficient has a theoretical maximum c_{pmax} = 0.593, really is value to 0,5.

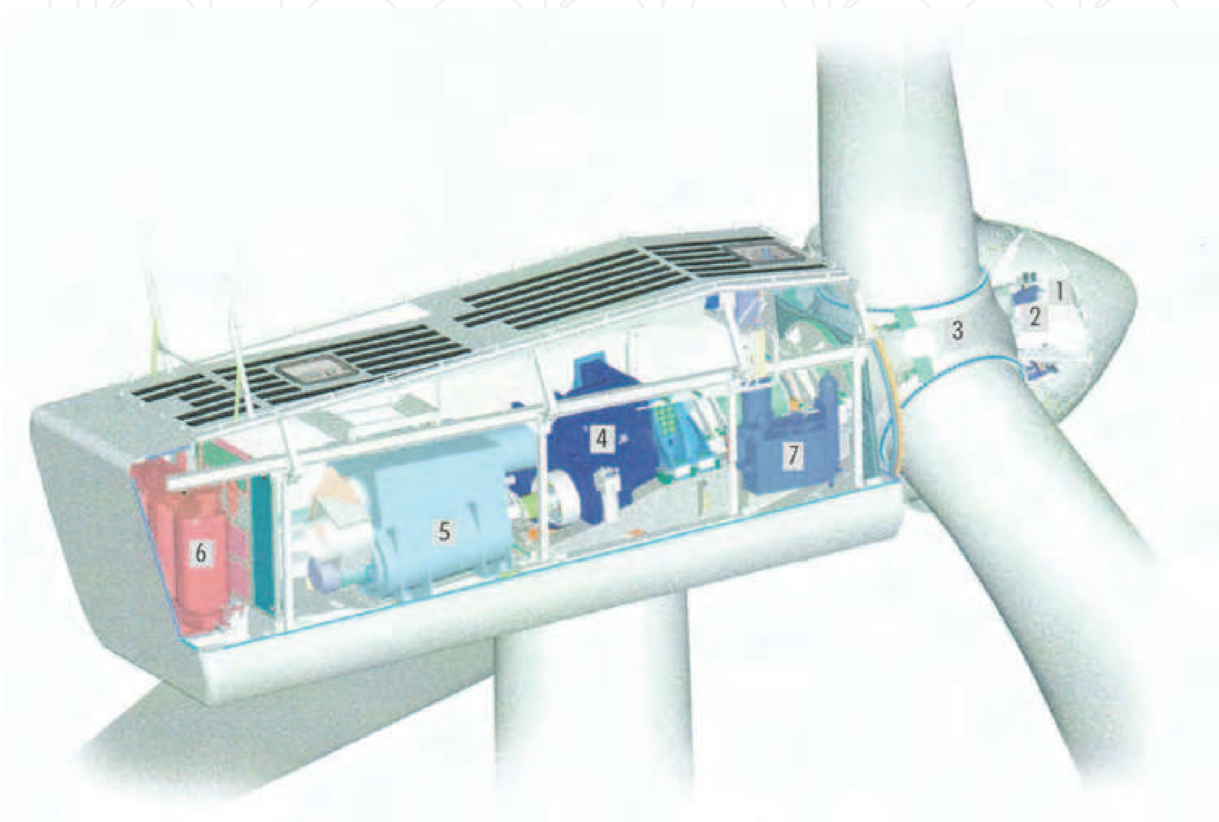


Fig. 6. View of the wind turbine nacelle: 1 – hub controller, 2 – "pitch" control cylinders, 3 – blade hub, 4 – gearbox, 5 – generator, 6 – high voltage transformer, 7 – hydraulic unit (Vestas, 2009)

The dependence of power in the wind on the air density in the real atmosphere is expressed by a function of the altitude and further on, it is a function of an aperiodic alternation of warm and cold air masses (Štekl, 2007). Roughly, if we take as a basis a wind turbine output at the sea level, the output will be lower by 5 % at the altitude of 500 m, at the altitude of 800 m by 7 % and at the altitude of 1200 m by 11 %.
The output produced by a wind turbine is indicated by a power curve (See Fig. 2 above), which is a basic indication of each wind turbine type.
It is apparent from the relations above that the wind turbine output depends on wind speed in an extraordinarily sensitive manner. It is clear that evaluating the wind potential, errors in wind speed determination may thus project into the result in a negative way.
Pursuant to the law, the power grid operator is obligated to take electric power generated by a wind turbine at a rate set by the Energy Regulatory Office price decision. According to this price decision for wind farms put in operation after 1st January 2010, the purchase price of

power supplied to the network is 2.23 CZK/kWh and for wind farms put in operation after 1st January 2009 it was 2.34 CZK/kWh. In 2008 it was 2.55 CZK/kWh, in 2007 2.62 CZK/kWh and in 2006 it was 2.67 CZK/kWh.

In 2008 the new wind turbines in Germany belonged to Enercon 52 %, Vestas 32 %, REpower 6 %, Fuhrlander 5 %, Nordex 2 % and other companies are represented by three percents (Ender, 2009).

The technology of wind turbines has experienced an extraordinary progress since 1980, a beginning of the modern wind energetics in Europe. The development has been manifested by:

- increasing the WT output per unit due to a growth in rotor diameter,
- increasing the WT tower height and reducing the adverse influence of the earth surface roughness,
- higher quality WT demonstrated by lower break-down rates, noisiness and demands of operation,
- lower specific costs of the generated power.

4. Environmental impacts of wind farms

Assessing the environmental impacts of wind energetics projects the following factors must be taken mainly into consideration (Lapčík, 2008, 2009):

1. noise,
2. impacts on the face of the landscape,
3. impacts on the migration routes and bird nesting, impacts on the fauna, flora and ecosystems,
4. stroboscopic effect,
5. impacts on the soil, surface water and ground water,
6. other impacts.

4.1 Noise

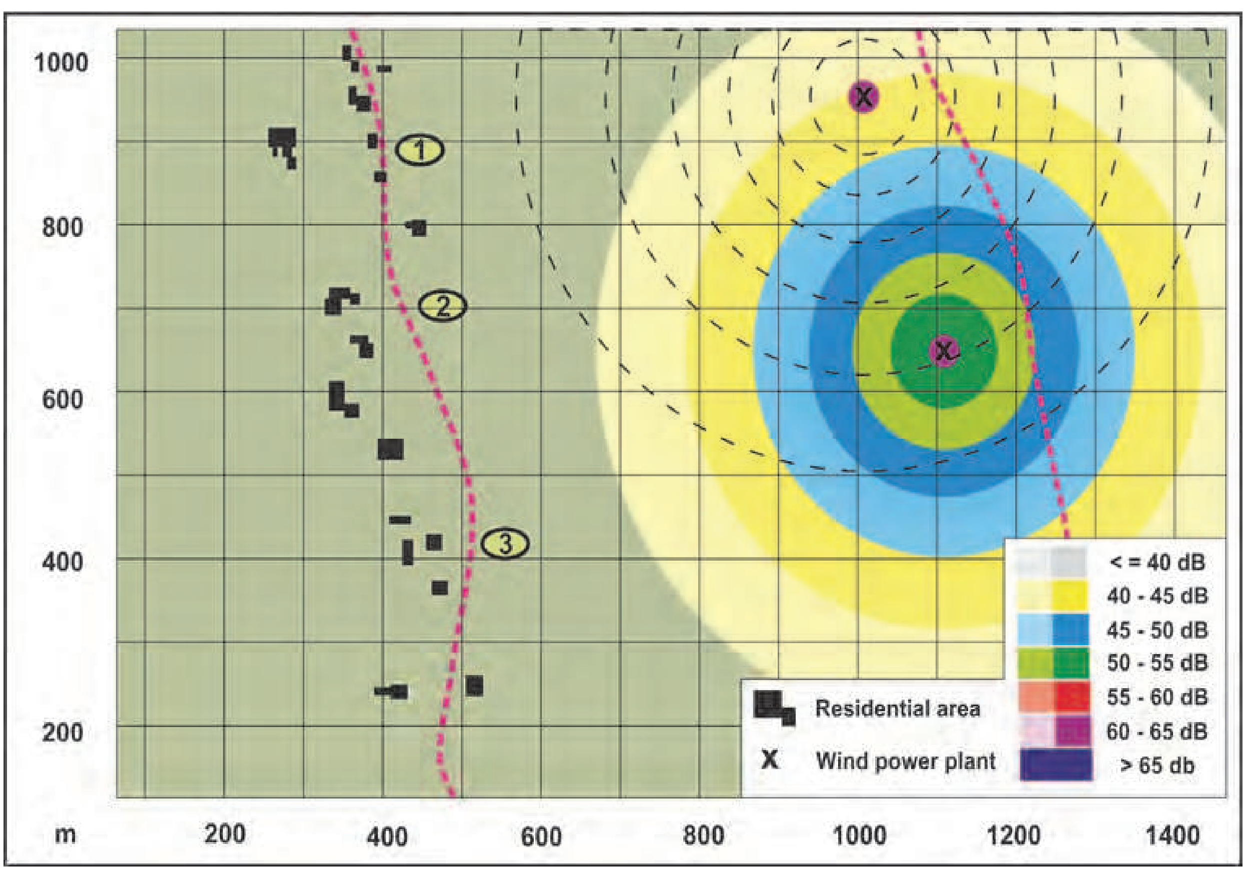
Operating a wind farm two types of noise arise. It is a **mechanical noise**, the source of which is a **machine room** (a generator including a ventilator, gearbox, rotation mechanisms or a brake). The amount of noise emitted into the environment depends on the construction quality of the individual components (e.g. gearwheels) of the overall machine as well as on the placement and enclosure of the overall machinery. All the stated parameters of the currently lot produced wind turbines are optimized. Except for small deviations when turning the gondola, the noise is stable.

Certain noise impacts result from the blades passing the wind turbine tower. In the past, pole vibrations appeared in some wind turbines, which has been overcome by modern technologies (Štekl, 2007). Next, it is an **aerodynamic noise** that arises due to the interaction of flowing air and the rotor airfoil and whirl winds relaxing behind the blade edges. Its frequency spectrum is very balanced and falls with a rise in frequency. Aerodynamic noise is reduced by the state-of-the-art constructions of rotor blades or rotor types when at the expense of a slight fall in the generator's output the noise levels are reduced.

The noise spreads from the point source in dependence on the direction and speed of air flows, in dependence on the intensity of vertical mixing of air (below the temperature inversion the transfer of noise is prevented in the vertical direction), on the shape of the earth surface and on the existence of obstacles to the noise spread. The noise spreading from the point source subdues along with the distance. A simplified version deals with a drop in the acoustic pressure along with a distance logarithm as a wind speed function. Mostly, this simplified version of the calculation (i.e. without the influence of the wind rose, relief shape, temperature layers, etc.) is used in model calculations to define an noise field in the surroundings of a wind farm.

The intensity of the perception caused by noise is greatly influenced by the proportion between its intensity and the intensity of other noises labelled as the **background noise**. It is known that a noise caused by a viscous and turbulent friction of air and the earth surface reaches high values, especially in the mountain conditions. For instance, during a windstorm human speech becomes difficult to understand under such conditions. In the test polygon in Dlouhá Louka in the Ore Mountains measurements were conducted that showed that at wind speed up to 5 m/s the background noise level was within the limits 30 ÷ 40 dB, but at the wind speed about 6 m/s the background noise was from 33 to 47 dB. At the wind speed over 8 m/s the noise exceeded the value of 45 dB (Štekl, 2007).

Government Decree 148/2006 Coll. on health protection against negative impacts of noise and vibrations sets the top admissible level of acoustic pressure outdoors at 50 dB during the day (06 ÷ 22 hours) and at 40 dB at night. However, this decree does not consider the circumstances when the background noise exceeds the noise produced by a wind farm.



Note: Wind turbine No. 1 (in the top) is shut down at night time. Check point of noise – points No. 1, 2 and 3.

Fig. 7. Equivalent levels of noise – night operation of wind farm.

The own assessment of acoustic situations is carried out by means of a noise study which assesses the noise near the nearest built-up area. It happens that the admissible equivalent noise level is not observed in the loudest night hour in the outside protected area. In such cases, the wind farm regime is required to be limited via reducing the output, which thus results in lowering the acoustic output (e.g. from 109.4 dB to 102.0 dB). In some cases it is though necessary to switch off several machines at night – See Fig. 7 (Lapčík, 2006, 2007, 2009). For example, in Germany it is recommended to construct wind farms more than 300 m from a single residence and more than 500 m from an end of a settlement. Nevertheless, the experience of the monograph author is that the minimum distance of wind farms from any housing development should be 575 to 600 metres.

Traffic noise arising in the time of construction and operation of a wind farm is time limited and usually negligible. In the time of construction it is important to ensure disposal of the spoil in the volume of about 770 m^3, delivery of concrete in the volume of about 490 m^3 per one machine and delivery of the own technological facility (Lapčík, 2006, 2007, 2010). In the time of operation, there are only one or two vans per week.

The impact of traffic noise and its changes in connection with construction and later operation of wind farms mostly shows in the day in the surroundings of the access road to the site. As the points for calculations, for which the calculation of noise from stationary sources is carried out, are often far away from the road, it is important to describe changes in the noise situation in a noise study changing the equivalent noise levels in a standardized distance from roads (e.g. 7.5 m from the axis of the closest lane).

4.2 Impacts on the face of the landscape

A term of the face of the landscape has been introduced by Act 114/1992 Coll. on the conservation of nature and landscape. Therein, the face of the landscape is defined (§ 12) as a natural, cultural and historic characteristics of a particular site or region. The face of the landscape is protected against activities degrading its aesthetic and natural value. Interference with the face of the landscape, particularly as for locating and approving structures, may occur only with regard to keeping significant landscape elements, especially protected areas, cultural dominant features of the landscape, harmonic criteria and relations in the landscape.

Talking of the impacts on the face of the landscape, in case of complying with measures connected with the interests of health protection against unfavourable impacts of noise and the interests of the nature conservation, the impact on the face of the landscape may be defined as a dominant aspect in connection with the assessed type of project.

There is no doubt that the erection of wind farms embodies a highly visible interference with the face of the landscape. As for the protection of the face of the landscape it is vital to find out if the planned structure does not interfere with any natural park. Stipulated by law, a natural park represents one of the most sensitive areas in the protection of the face of the landscape and a construction of a wind farm should not be implemented there. Natural parks are landscapes with concentrated significant aesthetic and natural values for the conservation of which they have been established (in accordance with § 12 art. 3 of Act 114/1992 Coll. on the conservation of nature and landscape, as amended). It is solely the protection of the face of the landscape which makes the core of their protection.

Visualization of wind farms is usually processed by means of computer animation and making use of photographs of the existing landscape in order to assess the impacts on the face of the landscape – See Figure 8 (Lapčík, 2009).

Fig. 8. A view of photo-visualized wind farm

The site of the face of the landscape affected by the assessed wind farm plans (i.e. an area from where wind farms can be potentially seen) is usually a vast territory. The site of the face of the landscape, i.e. an area which may be visually influenced by the assessed structure, is considered in terms of distance views as far as 2 to 5 km in case of a strong visibility range and as far as 10 km in case of a clear visibility range – by course of a Methodical Direction 8/2005 (Methodical Direction of the Ministry of the Environment No.8, June 2005). Areas which are shaded by forming the georelief are excluded from the ranges.

There is a frequent question whether it would be possible to generate an identical volume of electric power by wind farms even at possible lowering of their towers and reducing the rotor diameters as in this manner the face of the landscape would be less altered. The calculations may be carried out on the grounds of known relations for the calculation of wind (P_S) power (See Chapter 3.2 above).

The calculation results though imply that shortening the wind turbine pole height from 100 metres to 70 metres (at wind speeds c = 8.5 m/s and c = 6.5 m/s) and using a rotor of 90-metre diameter, the electric power fell from 100 % (pole height of 100 m) to 45 % (pole height of 70 m). Using a rotor of 50-metre diameter (instead of 90 m) the electric power would drop to 31 % (pole height of 100 m) or to 14 % (pole height of 70 m) – (Lapčík, 2006, 2007, 2008).

It is thus clear that lowering the pole height or reducing the wind turbine rotor diameter there would be a considerable loss in the gained electric power and practically an analogous facility with all its negative environmental impacts would have to be constructed (noise, land required for the machine’s foundations, access roads, energy infrastructure, etc.) as if implementing a wind turbine of 100-metre-high pole and 90-metre rotor diameter. At the same time, the impact on the face of the landscape in smaller machines would be identical. The facilities would only appear to be located further away from the observer than in case of higher facilities (higher pole and wider rotor diameter).

4.3 Impacts on the migration routes and bird nesting, impacts on the fauna, flora and ecosystems

The literature does not report any significant negative impacts of wind farms on birds. The results of a wind farm impact research on the avifauna in the Netherlands (Winkelman, 1992) imply that no verifiable impacts on nesting birds or birds perching for food into the vicinity of wind farms have been registered. A long-term observation of 87,000 birds in the vicinity of wind farms show that the majority of birds completely avoided the wind farms (97 %) and only a fraction chose to fly through a rotor. This usually results in a clash with a blade. Despite being hit by the blade there is no inevitable rule of a serious injury or death of the bird. The existence of a pressure field in front of the rotating blade forms a barrier which often repels the birds.

Experience from the observation of bird behaviour close to wind farms has also been gained in the Czech Republic. For example, in the Ore Mountains in the surroundings of the municipality of Dlouhá Louka a detailed research in nesting bird associations in three most significant biotopes (in the forest, on the meadow and cottage settlement) was carried out in 1993 and 1994, i.e. prior to and after the construction of a wind farm. The results presented in the study document that the operation of the wind farm does not affect nesting of bird associations in a significant manner.

Based on surveys, possible risks connected with wind farm operation (particularly collisions of birds and bats with the facility) are greater than those related to an operation of other similar structures (high towers, high voltage wires, roads, etc.). Moreover, it may be said that in the majority of cases applying suitable technical solutions there is no reason to expect distinct degradation of the conditions of the site suggested for the construction of wind farms from the environmental point of view.

Nevertheless, it is convenient for wind farms to be located outside important birds' migration routes and breeding places. This may be checked preparing a study which assesses impacts of planned wind farms on birds and other vertebrates.

The wind farm structures are mostly situated outside the component parts of the ecological stability zoning system, outside areas of higher degrees of ecological stability, or outside localities with near nature ecosystems. Also, a possible impact on especially protected areas and biotopes of specially protected animal species is negligible. In order to exclude unfavourable impacts on the flora and fauna it is advisable to process a biological (floristic and faunistic) assessment of the localities in question.

4.4 Stroboscopic effect

Stroboscopic effect is a phenomenon when rotating objects lit by a periodically variable light do not seem to be moving. In case of wind farm operation it is a rather a possible effect of gleams and shading by a mobile shade under the sunlight. The gleams of light from the rotor blades may be eliminated by a matte finish of the rotor blades (e.g. in grey colour).

If a rotor of commonly applied wind turbines rotates within the range of 8 to 17 revolutions per minute, the frequency of gleams is at the level of 0.4 Hz to 0.9 Hz. Safely outside the frequency from 5 to 30 Hz, it is however on a level which could cause the so-called photosensitive epilepsy in sensitive people found near wind farms.

Shading by a mobile shade may be observed in wind farms at optimal light conditions within 250 to 300 metres from the wind farm. It is practically negligible at further distance. With regard to the fact that the majority of assessed wind turbines are usually located in the distance of 500 metres from any residence, this phenomenon appears as minor.

4.5 Impacts on the soil, surface water and ground water

One wind turbine is expected to take up an agricultural land from 0.10 to 0.13 ha, where the own built-up area for the machine is about 200 m^2 (Lapčík, 2006, 2007, 2010). Mostly, it is land with predominantly substandard production capacities and limited protection. Having terminated the wind turbine operation, the land is expected to be reclaimed for possible agricultural use. The stabilized access roads can be used as access roads for pieces of land from the adjacent roads.

The operation of wind turbines does not produce any technological water or sewage. The rainwater from the stabilized access road areas is mostly drained gravitationally into the surroundings and the ditches.

The impact on the surface and ground water is not expected implementing such projects, but it is important to adhere to all the relevant safety measures. The wind turbine facilities do not influence surface water or the quality, water level or flow directions of the ground water, both during construction and own operation. However, during construction of service roads and the wind turbine facilities it is important to take such measures to prevent changes or worsening of water discharge, the occurrence of the manifestations of erosion or to limit the pollution and soil drag into influent stream beds to minimum in course of construction.

4.6 Other impacts

Within the winter operation there may be a situation when *ice* or *ice fragments* fall off the blades. New wind turbines are expected to be equipped with signalling which recognizes ice in time or the wind turbine is shut down. Also, technical equipment is expected which is able to prevent the formation of ice in an effective manner (the rotor blades are produced from such materials that prevent clinging of the ice onto the blades).

A minimum measure in this respect is an installation of panels warning about a possible risk of injury due to falling ice off the rotor blades in a sufficient distance from wind farms (about 250 m).

5. Conclusion

In the Czech Republic a big number of wind turbines and wind farms are being prepared to be constructed. Nevertheless, the implementation of the approved structures is progressing rather slowly. The total installed capacity of wind farms in the Czech Republic had been 50 MW by the end of 2006 (Koč, 2007). By the end of December in 2009 the Czech wind farms had a total installed capacity of 192,9 MW, by the end of November in 2009 then a total installed capacity of 212,6 MW.

Wind farms of a total installed capacity higher than 500 kW_e or with tower height exceeding 35 meters are classified according to the Appendix 1 to Act 100/2001 Coll., as amended, into the category II (projects requiring rogatory proceedings), article 3.2 (the project is administered by Regional Offices). This implies that the majority of the designed wind farms in the Czech Republic nowadays must undergo rogatory proceedings.

As a rule, a number of studies make parts of the notification processed according to Appendix 3 to the Act. For example, they are a noise study, assessment of impacts on the face of the landscape, assessment of wind turbine impact on birds and other vertebrates, or the project's impact assessment on Europe's outstanding localities and birds' territories according to §45i of Act 114/1992 Coll. on the conservation of nature and landscape, as amended. Certain notifications also contain health risk assessments, which are required by the law processing the documentation according to Appendix 4 to Act 100/2001 Coll. on environmental impact assessment, as amended.

Nevertheless, despite the complications (the notification actually takes the form of documentation) in the majority of cases the process of impact assessment for wind farms is not currently discontinued within the rogatory proceedings (in the so-called shortened proceedings), but it must be continued in the full extent (documentation compilation, opinion elaboration, public hearing), often with repeated supplements to the documentation before the opinion is elaborated.

This is caused by the negative attitude of the regional offices as well as of the public to wind energetics, who mostly hold a negative attitude to this renewable source of energy. Nevertheless, it must be said that the public comments are frequently presented in a very general manner and still certain types of criticisms reappear even if those have already been discussed and disproved.

With regard to the above mentioned public and regional offices' attitudes to wind farms, the environmental impact assessment process for the facilities is protracted and complicated (in the majority of cases the full assessment process must be taken into account).

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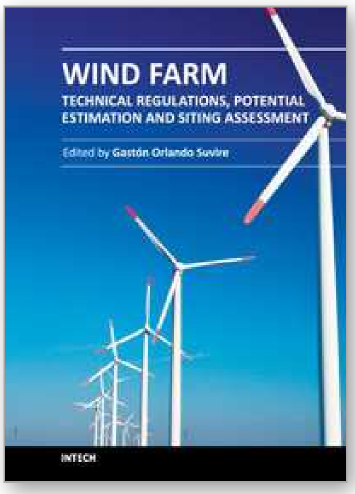

Wind Farm - Technical Regulations, Potential Estimation and Siting Assessment
Edited by Dr. GastÃ³n Orlando Suvire

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The evolution of wind power generation is being produced with a very high growth rate at world level (around 30%). This growth, together with the foreseeable installation of many wind farms in a near future, forces the utilities to evaluate diverse aspects of the integration of wind power generation in the power systems. This book addresses a wide variety of issues regarding the integration of wind farms in power systems. It contains 10 chapters divided into three parts. The first part outlines aspects related to technical regulations and costs of wind farms. In the second part, the potential estimation and the impact on the environment of wind energy project are presented. Finally, the third part covers issues of the siting assessment of wind farms.

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