UCTE Position Paper

on

Integrating wind power in the European power systems - prerequisites for successful and organic growth

May 2004

1. Executive summary

Wind power is winning recognition as a valuable option for power generation. With a total of more than 20.000 MW of installed wind power capacity, more than the half of the worldwide energy production from wind power is located in Europe (Annex A). The huge success of this renewable and environmentally-friendly energy source and the respective energy output has to be handled by the Continental European transmission system operators (TSO) in their day-to-day operation of the European interconnected system..

UCTE (Union for the Co-ordination of Transmission of Electricity) is the TSO organisation, whose main role is to maintain the security of supply and the quality of the energy delivered. In this context UCTE and its member TSOs share the goal to promote renewable energies and reduce CO_2 emissions according to EU and national targets.

TSOs and their synchronously interconnected power grids provide the reliable infrastructure to wind power generation. The challenges arising out of the integration of wind power were successfully mastered in the past and even in view of the already foreseeable massive increase in wind energy TSOs will remain focussed on their mission to facilitate wind energy.

The extension of wind power requires thorough redesign of the power infrastructure in Europe both on the generation side through additional need for balancing power and on the grid side. The **framework** shall take this into account, in particular by

- committing to binding **wind power extension goals** as indispensable inputs for infrastructural planning and designing activities of TSOs and other market participants (e. g. balancing power providers)
- creating **combined procedures** for wind parks and corresponding grid extension measures.
- ensuring remuneration of **costs for the integration of wind power** into the power systems as well as **providing sufficient financial resources** to the TSO for **funding the investments in grid extension** and for funding the additional operational expenses for balancing power
- Defining grid code requirements to be fulfilled by wind power plants to minimize their impact on the grid. A UCTE working group is preparing a proposal on this subject.

This position paper examines the profile of wind power, its impact on the network, security of supply and the quality of the energy delivered. It further deals with the reasons to establish certain technical requirements for the connection of wind power generation to the network.

2. Goals and framework for wind power

With the Council Decision 2002/358/EC of 25 April 2002 the European Union signed the Kyoto Protocol and agreed on an overall 8% reduction of greenhouse gas emissions compared to 1990 levels by the year 2012. This target has at the same time been fixed for every Member State of the European Union.

In the White Paper "Energy for the Future: Renewable Sources of Energy" the European Commission laid down the target to increase the share of renewable energies from 6% to 12% by 2010. The production of electricity from renewable sources should be increased from 14,3 to 23,5 % by 2010. The White Paper also set a target for the production of electricity from wind power which should be increased to 40.000 MW also by 2010.

The Directive of the European Parliament and Council on the Promotion of Electricity Production from Renewable Energy Sources in the Internal Electricity Market established an increase of electricity production from renewable energy sources (RES) from 14% in 1997 to 22% in 2010.

This Directive is also in line with the EU Strategy on diversification of the energy supply and reducing the dependency on fossil energy imports in the EU area.

UCTE and its member TSOs are committed to proactively support the measures to fulfil this framework. At the same time, it is the responsibility of TSOs to explain the implications for the electricity system.

Among the RES in the sense of the Directive figures also electricity produced from wind power plants which has begun to play an important role in the generation mix of several EU member states. For present and future wind power capacities in selected UCTE-member countries see ANNEX A.

3. Main characteristics of wind power

In some regions in Europe, generation from wind power already plays a significant role in meeting the electricity demand. Nevertheless, great challenges of wind power production are created by the limited predictability and the high fluctuations in production levels as the prime mover of wind turbines, i.e. the wind is hardly controllable and fluctuates randomly.

Location of resources, whether in-shore or off-shore poses additional logistic problems as they are in general located in remote areas far from population centers and transmission network facilities. In the case of off-shore plants the additional cost of constructing offshore and the longer distance to be covered for connecting to the grid must be considered.

Generating systems for wind power also differ from the synchronous generator used in conventional power plants. For major details on the different types of turbines commonly used in a wind energy converter and the impacts of wind power both locally and system-wide please refer to ANNEX B.

4. Wind power – overall availability of 20%

By nature, wind energy is only available as variable power depending on the weather conditions that may range from calm to stormy conditions. Based on the operational experience gained so far the following can be stated with regard to the power contribution of wind power plants (WPP):

a) An average of 20 per cent of the total wind power installed in a control area was available for electricity generation over the year.

b) For two thirds of the year less than 20 per cent of the installed power was available for electricity generation.

c) For one third of the year, less than 10 per cent of the capacity was available for electricity generation. This was particularly the case in peak consumption periods (annual peak load in winter) or under aggravated generating conditions (e. g. heat wave in the summer 2003).

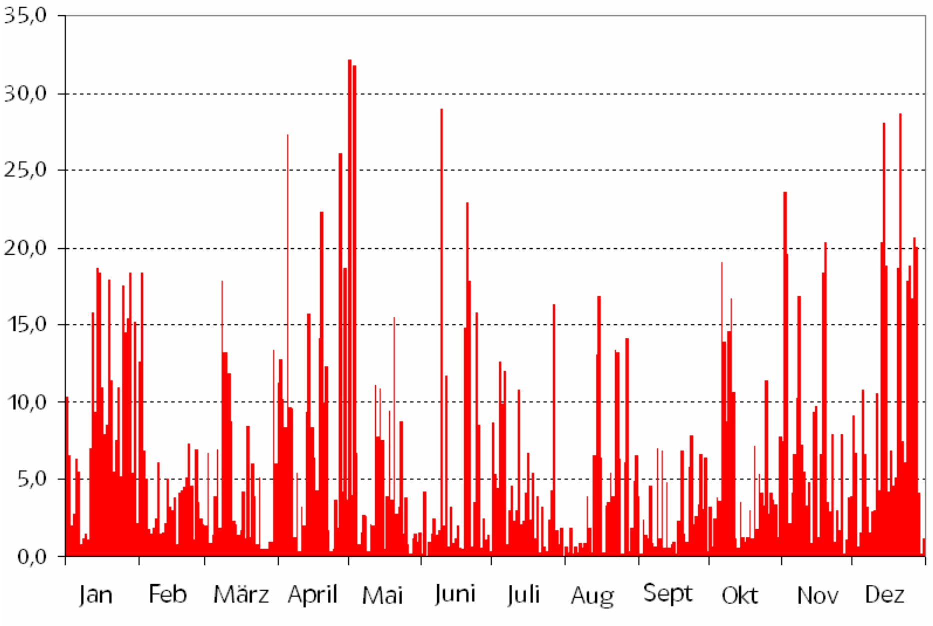

Figure 5.a.- Annual share of daily wind power in respective daily peak demand in E.ON-grid (Germany).

5. Teaming-up for system stability: wind power and conventional back-up capacities

Forecasting the electricity production from wind power is possible only to a limited extent – and the forecasting quality significantly depends on the quality of the weather forecast. Despite the use of advanced tools, the average forecasting error for wind energy supply could only be reduced to some 10-12 per cent of the installed wind capacity. On certain days the forecasting deviations may be as high as 50%.

Maximum expected forecasting deviations increase with the rise in the installed wind capacity. It is not the yearly average but the individual maximum forecast deviation to determine the value of power/energy reserves to be programmed by the transmission system operators in order maintain system stability.

Plant operators could however contribute to more precise forecasts of wind energy production. In view of the growing number of wind power plants and the increasing sizes of these plants the operators of wind power plants should be induced to respect certain obligations, such as informing the transmission system operators about the availability of plants exceeding a certain size. Thus any further wind-related rises in balance power requirement could be avoided.

Back-up capacities from other power plants have to be kept in reserve for cases of total generation outages of WPP (e.g. summer heat waves) as well as for balancing variations in wind energy injections. It will be a big challenge for the future to always guarantee for sufficient amounts of backup and balancing energy to keep up with the massive expansion of wind power. The increasing demand for balancing power may also result in possible price impacts for final customers.

6. Powerful transmission grids for green power

New wind power capacities are mainly installed in peripheral regions with below-average power demand. In particular this will be the case for the upcoming offshore wind parks. Large parts of the energy produced will have to be transported over long distances to the load centers. Consequently, an increase in installed wind power capacities results in further congestion of the existing infrastructure. For example in Germany – where for the time being more than the half the overall European wind power generation is installed - the wind power boom will require grid extensions of approx. 1.400 km of additional high-voltage and extra-high voltage lines plus other technical components (transformer stations, voltage stability systems) over the next ten years.

New bottlenecks will arise and existing bottle necks will be enhanced. This will result in additional congestion management. A prerequisite for these congestion management measures is the legal and organisational framework that gives the TSO the possibility to intervene in the operation of power stations in case of congestions. Otherwise grid access and grid use has to be restricted in case of limited capacities. Priority has always to be given to all measures that allow the TSO to keep the security and stability levels he is obliged to observe under the EU Directive on the Internal Electricity Market.

Frequently occurring congestions might be preferentially solved by reinforcing the (transmission) grids which brings us back to question of who shall bear the costs for such infrastructural measures. The Regulators and governments should decide whether to socialise all costs or charge them entirely or partly to the ones who cause the costs.

7. "Generation Management" of wind parks as a temporarily solution for congestion

Generally, realisation times for the required infrastructural measures, in particular new power lines, are to a large extent uncertain due to incalculable approval and implementation processes. Without speedier authorization procedures, the discrepancy between the amount of wind power that can be injected and available grid capacities will increase. As a consequence the connection for new wind power plants in regions that are subject to congestion would have to be refused. As a temporary solution until the necessary expansion measures can be realised, "generation management" (temporary injection limits for wind power plants in case of regional congestion) could be explicitly institutionalised with suitable legislation.

In the event of supply restrictions, the grid operator must also make allowance for specific generation plants as well as grid capacities that are essential for maintaining supply reliability (e.g. maintaining the voltage).

8. Wind power and its implications for cross-border electricity transits

The injection of wind power not only affects the individual national systems but also the cross-border electricity transits between neighbouring countries. In the case of Germany, this is true for all transports from Denmark to Germany and from Germany to the Netherlands. If the offshore wind power expansion aimed for by the German Federal government by 2010 is realized and if the wind-related expansion measures in the transmission system already apparent today are not achieved by such date, this will lead to a significant reduction of the capacities available today to European electricity traders.

It can also be foreseen that the necessary provision of a wind-related balancing power range will necessitate intervention in cross-border trading activities: Transmission system operators can be compelled to introduce prophylactic reduction of import / transit capacities in order to balance out major capacity balance deficits arising from forecast deviations for wind power injection by utilising additional power plant capacities from outside their control area. This requires a solid legal basis to prevent disputes between the market players at national and European regulatory level.

Annex A

Wind power capacities in UCTE countries

(Statistical data on wind power installed capacity in UCTE countries in 2003 as at 31st December 2003 and estimation for 2010)

<u>**Annex A**</u>

Present wind power capacities in UCTE countries

All figures of installed capacity as at Dec 31st 2003

<u>Austria</u>:	installed capacity:	415	MW
	estimation for 2010:	1.000	MW
	The majority of the new wind power plants will be installed in North-East of Austria. This will further increase the already existing North-South bottleneck in the Austrian transmission grid.		
<u>Belgium</u>:	installed capacity:	68	MW
	estimation for 2010:	300	MW
<u>Czech Rep:</u>	installed capacity:	11	MW
	estimation for 2010:	600	MW
<u>Denmark</u>:	installed capacity:	3.115	MW
	estimation for 2010:	4.000	MW
<u>France</u>:	installed capacity:	215	MW
	estimation for 2010:	12.000	MW
	Wind farms are currently mainly located in the regions of Languedoc-Roussillon, Brittany and the North Coast (littoral de la Manche).		
<u>Germany</u>:	installed capacity:	14.325	MW
	estimation for 2010:	29.000	MW
	Congestion of present transmission grid in Northern Germany Grid extension measures on the way.		
<u>Greece</u>:	installed capacity:	375	MW
	estimation for 2010:	800	MW
<u>Hungary</u>:	installed capacity:	3	MW
	estimation for 2010:	170	MW
<u>Italy</u>:	installed capacity:	800	MW
	estimation for 2010:	2500-3.000	MW
	Wind power plants are mostly installed in five regions: Abruzzi, Puglia, Campania, Basilicata and Sardegna.		
<u>Luxembourg</u>:	installed capacity:	22	MW
	estimation for 2010:	51	MW
<u>Netherlands</u>:	installed capacity:	895	MW
	estimation for 2010:	1.500	MW
<u>Poland</u>:	installed capacity:	65	MW
	estimation for 2010:	2027	MW

Portugal:	installed capacity:	299	MW
	estimation for 2010:	3000	MW
Romania:	installed capacity:	1	MW
	estimation for 2010:	120	MW
Slovakia:	installed capacity:	3	MW
	estimation for 2010:	20	MW
Spain:	installed capacity:	5.086	MW
	estimation for 2010:	13.000	MW
	The wind power plants are installed all around the country.		
Switzerland:	installed capacity:	5	MW
	estimation for 2010:	15	MW

Source: UCTE /EWEA

Annex B: [2]

Main characteristics of wind power

Wind power has several characteristics different from other classical sources of power:

- Location of resources:

  In-shore: in general the wind resources are located in remote areas far of population concentrations, so far of transmission network facilities, then new transmission network extensions are needed to integrate the wind power in the generation mix.

  Off-shore: of shore resources are located in shallow waters up to thirty metres deep. In densely populated countries, such as many countries in Northwest Europe, construction of offshore wind farms is considered a promising option. The advantages of offshore wind power are reduced visibility and noise problems and steadier winds with higher average speeds, resulting in a higher energy yield. The disadvantage is the cost increase when compared to onshore turbines, caused by the additional cost of constructing offshore and the longer distance that must be covered for connecting to the grid and the consequently reinforcements in the present grid

- Wind generating systems

  Generating systems different from the synchronous generator used in conventional power plants are applied.

  There are three different types of turbines that are commonly used in a wind energy converter:

  Constant speed turbine with:

  - Squirrel cage induction generator

  Variable speed turbines with:

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

  Squirrel cage induction generator

  A squirrel cage induction generator is an asynchronous machine, composed by a squirrel cage rotor and a stator with three distributed windings which are directly coupled to the grid. The wind turbine rotor is coupled to the generator through a gearbox. Substantially this is a constant speed wind turbine because the power converted from the wind is limited by designing the turbine rotor in such a way that its efficiency decreases in high wind speed.

  This kind of generators always consumes reactive power hence capacitors are necessary close to generators to avoid a voltage decrease because these generators cannot control and regulate the voltage level.

  Double fed (wound rotor) induction generator

  A double fed induction generator has a wound rotor that is connected to the grid through a back-to-back voltage source converter which controls the excitation system in order to decouple the mechanical and electrical rotor frequency and to match the grid and rotor

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[2] Provided by the UCTE-Network „Windpower“

frequency. The wind turbine rotor is coupled to the generator through a gearbox in the same way of the constant speed generator.

Direct drive synchronous generator

The most important characteristic of this wind generator is that it is completely decoupled from the grid by a power electronics converter connected to the stator winding. The converter is composed by a voltage source converter on the grid side and a diode rectifier (or a voltage source converter) on the generator side. The direct drive generator is excited by an excitation winding or permanent magnets.

- Windily dependence:

  The prime mover of wind turbines (i.e., the wind) is hardly controllable and fluctuates randomly. There are to be considerer two factors:

  - Wind generation prediction for load coverage
  - Imbalances produced by turbulence and high wind speed

  To be able to predict the wind generation accurately is of course the most important objective of a wind generation forecast. Different weather conditions are associated with different uncertainties. This information could influence the day-ahead needed regulating capacity in the system. It could also have influence on the trading strategy.

  The best way to estimate the uncertainty of a forecast is to base the evaluation on several forecasts. This rules out the most common of today's meteorological forecasting methods, the deterministic forecast.

  Power fluctuations are induced by turbulence, which is a stochastic quantity that evens out when many turbines are considered. An exception, however, is formed by storm-induced outages that occur when the wind speed exceeds the cut-out value. These are not induced by stochastic turbulence but by storm fronts and can therefore affect a large number of turbines simultaneously

  If for instance, a wind front builds up earlier than expected, then online measurements (including neighbouring areas outside of the TSO responsibility) could warn the forecasting system and the operator before the deviation suddenly shows up.

POWER SYSTEM Impacts

The wind power characteristics are reflected in a different interaction with the power system:

Local impacts of wind power are impacts that occur in the (electrical) vicinity of a wind turbine or wind farm and can be attributed to a specific turbine or farm. Local impacts occur at each turbine or farm and are largely independent of the overall wind power penetration level in the system as a whole.

System-wide impacts, on the other hand, are impacts that affect the behaviour of the system as a whole. They are an inherent consequence from the application of wind power but cannot be attributed to individual turbines or farms

Local impacts:

Wind power locally has an impact on the following aspects of power system:

- branch flows and node voltages

- protection schemes, fault currents, and switchgear ratings
- Power Quality:
    - harmonic distortion
    - flicker.

The first two topics must always be investigated when connecting new generation capacity. This applies independently of the prime mover of the generator and the grid coupling, and these issues are therefore not specific for wind power. The third topic, harmonic distortion, is particularly of interest when generators that are grid coupled through a power electronic converter are used. For wind power, it does therefore mainly apply to variable-speed turbines. Further, it applies to other converter connected generation, such as photovoltaics and small-scale CHP (combined heat and power) systems that are often based on high-speed synchronous generators interfaced with power electronics. The last topic, flicker, is specific for wind power.

The way in which wind turbines locally affect the node voltages depends on whether constant-speed or variable-speed turbines are used. The squirrel-cage induction generator in constant-speed turbines has a fixed relation between rotor speed, active power, reactive power, and terminal voltage. Therefore, it cannot affect node voltages by adapting the reactive power exchange with the grid. To this end, additional equipment for generating controllable amounts of reactive power would be necessary. On the other hand, variable-speed turbines have, at least theoretically, the capability of varying reactive power to affect their terminal voltage. Whether this is indeed possible in practice depends, however, on the rating and the controllers of the power electronic converter.

The contribution of wind turbines to the fault current also differs between the three main wind turbine types. Constant-speed turbines are based on a directly grid-coupled squirrel-cage induction generator. They therefore contribute to the fault current and rely on conventional protection schemes (overcurrent, overspeed, over- and undervoltage). Turbines based on the doubly fed induction generator also contribute to the fault current. However, the control system of the power electronics converter that controls the rotor current measures various quantities, such as the grid voltage and the rotor current, at a very high sampling rate (several kHz). A fault is therefore observed very quickly. Due to the sensitivity of power electronics to overcurrents, this wind turbine type is currently quickly disconnected when a fault is detected. Wind turbines with a direct-drive generator hardly contribute to the fault current because the power electronics converter through which the generator is connected to the grid is not capable of supplying a fault current. Normally, these are also quickly disconnected in case of a fault.

The third topic, power quality is divided in to subtopics:

Harmonic distortion is mainly an issue in the case of variable-speed turbines because these contain power electronics, an important source of harmonics. However, in the case of modern power electronics converters with their high switching frequencies and advanced control algorithms and filtering techniques, harmonic distortion should not be a principal problem. Well-designed, directly grid-coupled synchronous and asynchronous generators hardly emit harmonics. Harmonic distortion is therefore not an issue for constant-speed wind turbines based on directly grid-coupled asynchronous generators.

Flicker is a specific property of wind turbines. Wind is a quite rapidly fluctuating prime mover. In constant-speed turbines, prime mover fluctuations are directly translated into output power fluctuations because there is no buffer between mechanical input and electrical output. Depending on the strength of the grid connection, the resulting power fluctuations can result in grid voltage fluctuations, which can cause unwanted and annoying fluctuations in bulb brightness. This problem is referred to as *flicker*. In general, no flicker problems occur with variable-speed turbines, because in these turbines wind speed fluctuations are not directly translated to output power fluctuations. The rotor inertia acts as an energy buffer.

System-wide impacts

Apart from the local impacts, wind power also has a number of system-wide impacts because it affects:

- power system dynamics and stability
- reactive power and voltage control
- frequency control and load following/dispatch of conventional units.

The impact on the dynamics and stability of a power system is mainly caused by the fact that, in wind turbines, generating systems are applied that are not based on a conventional synchronous generator. The specific characteristics of these generating systems are reflected in their response to changes in terminal voltage and frequency, which therefore differs from that of a grid-coupled synchronous generator. It is possible to comment on the impact of the three main wind turbine types on power system dynamics and stability in a qualitative sense by analysing their properties. Squirrel-cage induction generators used in constant-speed turbines can lead to voltage and rotor-speed instability. During a fault, they accelerate due to the unbalance between mechanical power extracted from the wind and electrical power supplied to the grid. When the voltage restores, they consume much reactive power, impeding voltage restoration. When the voltage does not return quickly enough, the wind turbines continue to accelerate and to consume large amounts of reactive power. This eventually leads to voltage and rotor-speed instability. Opposite to what applies to synchronous generators, whose exciters increase reactive power output at low voltage and thus accelerate volt-age restoration after a fault, squirrel-cage induction generators hence tend to slow down voltage restoration.

With variable-speed turbines, the sensitivity of the power electronics to overcurrents caused by voltage drops can have problematic consequences for the stability of the power system.

When the penetration level of variable-speed turbines in the system is high and they disconnect at relatively small voltage drops (figure 4.a), as is the case nowadays, a voltage drop in a wide geographic area could lead to a large generation deficit. Such a voltage drop could, for instance, be caused by a fault in the transmission grid. To prevent this, some grid companies and transmission system operators facing a high contribution of wind power in their control area are currently proposing more demanding connection requirements. They prescribe that wind turbines must be able to withstand voltage drops of certain magnitudes and durations, in order to prevent the disconnection of a large amount of wind power at a fault. In order to meet these requirements, manufacturers of variable-speed wind turbines are implementing solutions to reduce the sensitivity of variable-speed wind turbines to grid voltage drops.

Figure 4.a.- Recorded wind power and wind power outages induced by well cleared short-circuits in the Transmission Network (Spain).

The impact of wind power on reactive power generation and voltage control originates first from the fact that not all wind turbines are capable of varying their reactive power out-put, as stated above when discussing the local impacts of wind power. However, this is only one aspect of the impact of wind power on voltage control in a power system. Apart from this, there are two other issues that determine the impact of wind power on reactive power generation and voltage control. First, wind power cannot be very flexibly located when compared to conventional generation. As mentioned above, wind power affects the scenery and can hence only be constructed at locations at which this is not considered a major problem. Further, it must be erected at locations with a good wind resource. The locations that meet these two conditions are not necessarily locations that are favourable from the perspective of grid voltage control. When choosing a location for a conventional power plant, the voltage control aspect is often easier to consider because of the better location flexibility of a conventional plant. Second, wind turbines are relatively weakly coupled to the system because their output voltage is rather low and because they are often erected at distant locations. This further reduces their contribution toward voltage control. When the output of conventional synchronous generators is replaced by wind turbines at remote locations on a large scale, the voltage control aspect must therefore be taken into account explicitly.

The impact of wind power on frequency control and load following is caused by the fact that the prime mover of wind power is uncontrollable. Therefore, wind power hardly ever contributes to primary frequency regulation. Further, the variability of the wind on the longer term (15 minutes to hours) tends to complicate the load following with the conventional units that remain in the system, as the demand curve to be matched by these units (which equals the system load minus the wind power generation) is far less smooth than would be the case without wind power. This heavily affects the dispatch of the conventional generators.

Note that the aggregated short-term (<1 min) output power fluctuations of a large number of wind turbines are very much smoothed and are generally not considered problematic.

These fluctuations are induced by turbulence, which is a stochastic quantity that evens out when many turbines are considered. An exception, however, is formed by storm-induced outages that occur when the wind speed exceeds the cut-out value. These are not induced by stochastic turbulence but by storm fronts and can therefore affect a large number of turbines simultaneously.

The impact of wind power on frequency control and load following becomes more severe the higher the wind power penetration level is. The higher the wind power penetration level, the larger the impact of wind power on the demand curve faced by the remaining conventional units, resulting in and fewer remaining units. Thus, the requirements on the ramping capabilities of these units must be stricter in order to match the remaining demand curve and to keep the fluctuations of the system's frequency, caused by unbalances between generation and load, within acceptable limits. It is, however, impossible to quantify the wind power penetration level at which system-wide effects start to occur because of the differences in, for example, conventional generation portfolio, wind speed regime, and geographical spread of the turbines, demand curve, and network topology between various power systems.