Experience from wind integration in some high penetration areas

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***Abstract*—The amount of wind power in the world increases fast. The background for this development is improved technology, decreased costs for the units and an increased concern of the environmental problems of competing technologies such as fossil fuels. The amount of wind power is though not spread equally over the world, so in some areas there is a comparatively high concentration. The aim of this paper is to make an overview of some of these areas and shortly describe the consequences of the increase of wind power. The aim is also to try to draw some generic conclusions, in order to get some estimation about what will happen when the amount of wind power increases for other regions where wind power penetration is expected to reach high values in future.**

***Index Terms*— Wind power, integration, power system, power transmission, balancing of wind power.**

I. INTRODUCTION

WINDMILLS have existed for at least three thousand years, mainly for grinding grain or pumping water. The use of windmills to generate electricity is a twentieth-century development and in the early 1970s started the development towards modern wind turbine technology. At the beginning of year 2006, the installed capacity of wind power was about 60 000 MW [1], which corresponds to an energy production of about 120 TWh per year. The increase is related to a fast development of new technology, where new ideas of the electric generation systems have been implemented, the size of the wind power plants has grown, the industry has managed to minimize the environmental, and the cost per produced kWh has decreased significantly. One important driving force for the fast growth is also the increasing concern for the environment. The total electric consumption in the world is currently around 17 500 TWh per year [2], which means that around 0.7% of this electricity comes from wind power.

For the future it is important to get a view on how systems with larger shares of wind power can be operated and designed in order to get an efficient integration without violating the system security. In section 2 below system requirements for the implementation of wind power in an isolated area are treated and in section 3 the method is extended to areas that are interconnected to other areas [3]. An analysis of the different systems is presented is section 4 and section 5 provides a summary and the conclusions.

II. SYSTEM REQUIREMENTS FOR AN ISOLATED REGION WITH A SIGNIFICANT AMOUNT OF WIND POWER

For any power system with or without a large proportion of wind power it is important to operate the system in an efficient way and to have enough margins in order to keep a high reliability. This is a challenging complex task which here will be shortly summarized. We here call the isolated system “region X” and important factors to be considered are:

- Lowest consumption level in X
- Possibilities to control other power sources in X
- Internal grid problems in X

A. Medium penetration of wind power

Fig. 1 shows an example concerning how the consumption and the wind power production could look like in a power system. The data in the figure is from West Denmark in January 2006. In reality Denmark West is highly interconnected to three other countries, but in this section the figure will illustrate the challenge of integrating wind power in an isolated area.

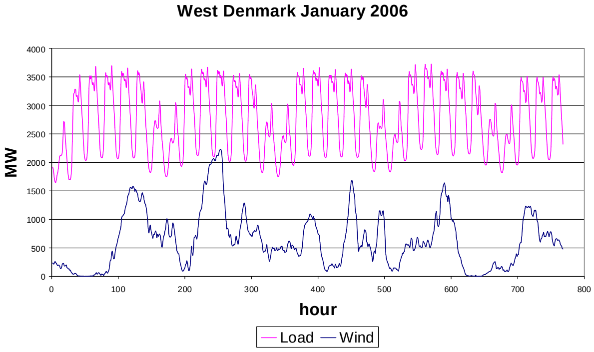

Fig 1. Total consumption and wind power production (20%) for illustration of wind power integration in an isolated power system. (Data source. www.energinet.dk).

In the example in Fig. 1, wind power covers approximately 20% of the consumed energy during the

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period. The problems that occur can be solved in the following way:

a. There must be enough power plants during times with low wind contribution. At around hour 38, the consumption is high and the wind power production is low. During these situations there must be enough power plants, others than the wind power plants, to meet the load. A further analysis is found in, e.g., reference [4].

b. There must be enough power plants with fast control during high wind situations. In a power system, there must be a continuous balance between production and consumption. The only stored energy, rotational energy in all rotating parts of generators and turbines, is just enough for the operation of the power system for some seconds, and therefore there have to be power plants that balance changes in production and/or consumption. At hour 243, the margin between consumption and production is relatively small (32 MW). Also at this situation additional power plants are necessary to keep the needed production-consumption system balance in case the load and/or wind power production changes. In thermal power systems this means that there must be enough capacity in operating thermal plants which must have margins, both to increase and to decrease the production [5]. It is also important to have some power plants that could provide a variable reactive power for voltage control.

c. The system must be robust enough to survive a dimensioning fault. In all power systems there can be faults, and it is not acceptable that a single fault, e.g. a short circuit, causes a total collapse of the system. A short circuit can cause the voltage in the system to vary significantly, and it is important that the rest of the system can manage this in such a way that a single fault does not cause cascading outages of lines and/or production units.

d. There must be enough reserves covering all possible uncertainties of supply and demand (system net imbalances), for example situations with large decrease of total wind power production. This question is about the same as the one under b, but here the question concerns larger capacities that have to be available within some hours. Unlike the conventional plants which can trip off and lose all generation at once, large amounts of wind power spread over a wide area does not drop off simultaneously. Even during a storm front the (distributed) wind power will take 4..6 hours to fall., depending on the size of the area. This implies, e.g., maximum ramp rates of 10 MW/min in Western Denmark (2400 MW wind [6]) and 16 MW/min in North Germany (6000 MW installed). Assume that the total amount of wind power decreases as much as during the period of hour 243...266 (1474 MW) in Fig. 1, and that this occurs at the same time as the load increases as the hour 243...249 (1510 MW). During this situation, there must be enough power plants that can increase the production to compensate both for the load increase and for the wind power decrease. This question is an issue of dimensioning the system and of reliability of forecasts for these situations. More important may be the outage of a power plant with high capacity (the dimensioning fault, c). As for the UCTE-grid it is necessary to consider the outage of the two block units of the power plant with the highest capacity (total 3000 MW) when working on the same bus bar [7].

e. Handling of possible problems in the internal grid. Assume that wind power is located in one part of the region and the main consumption in another part. To be able to use the installed capacity of wind power, there must be enough transmission capacity between the wind power source and the consumption areas.

B. High wind power penetration

Now assume that there is more wind in the system, c.f. Fig. 2.

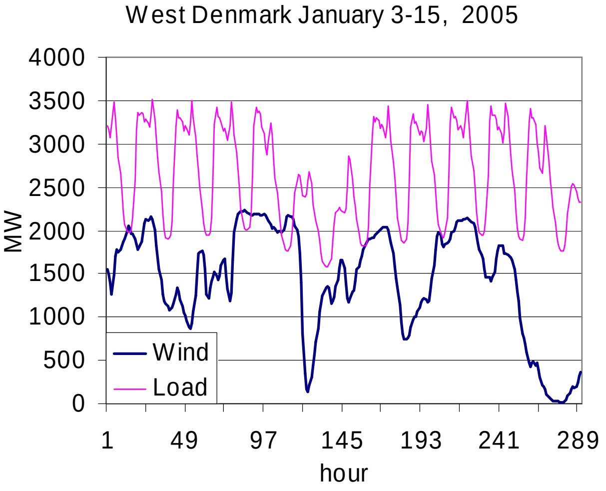

Fig 2. Total consumption and wind power production (54%) for illustration of wind power integration in an isolated power system. The illustrative day of January 8 is here included when a comparatively large part of wind power was shut down because of a storm front. (Data source. www.energinet.dk).

In the example in Fig. 2, wind power covers 54% of the total load during the week. The difference compared to Fig. 1 is that during hour 173, wind power covers the whole load. This leads to a new type of situation that has to be handled.

f. Possibility to down regulate the available wind power during low power consumption. When wind power covers the whole load, there is of course still a possibility that the production in the wind power plants will decrease and/or the consumption will increase. This is a specific situation of type b above. Also in this case there must be power plants available that can increase their production fast. To make this possible, it is often necessary to decrease wind power in these situations in order to keep thermal power plants on a low production level, so they can increase their production if needed. A method for how to perform this is presented in [8].

Fig 2 also shows some situations when available wind power production is much higher than the load during several hours in the week, e.g. hour 125. In this type of system the system requirements increases:

g. Possibility of continuous control of wind power. The total production in wind power cannot exceed the total load for longer periods. If total wind power exceeds total load, then the consequence will be that the frequency in the system will start to increase. This means that when the frequency increases some wind power plants have be totally shut down, or several wind power plants have to decrease their production by, e.g., pitch control. One alternative is storage, but currently storage of large amounts of energy is comparatively expensive. In the example in Fig. 2, 0.7% of available wind energy has to be spilled. This means that the available wind power will be 0.7% more expensive, compared to the situation if all wind power could be used.

III. SYSTEM REQUIREMENTS FOR A REGION WITH SIGNIFICANT AMOUNTS OF WIND POWER WHERE THE REGION IS INTERCONNECTED WITH OTHER REGIONS

Now assume that the studied region is connected to other regions. In reality this is the way a power system looks like, including the western Danish system, which was used for illustration purposes in Fig. 1 and 2. The European system is, e.g., one system with interconnections between nearly all neighboring countries. It is therefore important to consider that wind power variations in, e.g., northern Germany can be balanced in power plants in northern Germany or in neighboring regions. Because of this there are also some additional items that have to be considered concerning system requirements for an efficient and reliable operation. The main question is then the transmission capability between region X and the other regions and how an efficient treatment of problem a-g is distributed between the different regions. With a transmission capability of P MW between region X and other regions, the challenges are now modified to:

a. There must be enough power plants at low wind. This is valid for region X and could include maximum P MW of imported power, if this is available in neighboring regions.

b. There must be enough power plants with fast control at high wind situations. At high wind situations, there could be export from region X. This then means that the needed fast controllable sources could be outside region X. Sometimes even more than P MW (but < 2P MW) could be used from other regions since export could change to import during fast changes.

c. The system must be robust enough to survive a dimensioning fault. Even internal faults in X should not cause severe problems outside X and vice versa.

d. There must be enough reserves covering all possible uncertainties of supply and demand (system net imbalances), for example situations with large decrease of total wind power production. Like in the previous section, this can be a dimensioning criterion for slower reserves. This type of reserve could be available within the X region or in neighboring regions considering the trading capacities between the regions.

e. Handling of possible problems in the internal grid. Here the interconnections must be considered, since all imbalances in one part of region X can be balanced in another region, which is electrically closer than the other part of region X.

f. Possibility to regulate down available wind power during low power consumption. Here down regulation is only needed if wind power in X is larger than local load plus possible export.

g. Possibility of continuous control of wind power. Continuous control of wind power in X is only needed when required balancing is not available in other power sources within or outside X considering the limited trading capacity.

IV. EXAMPLES OF WIND POWER IN DIFFERENT REGIONS

As shown above, there are several aspects that have to be considered in order to find out the consequences of having a certain amount of wind power in a region. Below some examples concerning experiences of considerable wind power production in a region are shown and commented. These are actual examples, from real power systems.

A. Example Wind power on Gotland

Table I shows the situation in the year 2005 for the Swedish island Gotland, which is connected to mainland Sweden with a HVDC line. Wind power on Gotland covers 19% of the energy consumption on the island. All balancing of net load changes is performed on the mainland. The capacity of the connection to the mainland is 180 MW, i.e., the *maximal share of wind power* is 40% (see definition in eq. 1), i.e., the installed wind power covers at most 40% of possible lowest net consumption, which is lowest local consumption + possible export:

$$Maximal\ \ share\, of\ \ wind\ \ power = \\ \frac{Maximal\ \ wind\ \ power}{Lowest\ \ consumption + possible\ \ exchange} = \frac{90}{45+180} = 40\% \tag{1}$$

This is conservative, as the probability of maximum wind power at the same time as lowest load is very small. This implies that there is a rather large margin up to situations corresponding to problem b in section 3.

TABLE I. DATA FOR GOTLAND

	Min MW	Max MW	GWh/year
Power consumption	45	160	930
Wind power	0	90	180 (19%)
Export capacity	0	180	

It must be noted that sometimes the produced wind power on Gotland exceeds the local load. This implies that in these situations the current in the HVDC line has to go in reverse direction compared to the normal feeding of the island. This made it necessary to introduce some control equipment in order to be able to handle situations when wind power on Gotland is about the same as the load on Gotland. When this happens, the power on the HVDC line is almost zero, which requires special arrangement to be able to change the power flow

direction often.
The experience reported for the issues a)…g) are collected in Table VI.

B. *Example: Wind power in West Denmark*

TABLE II shows the situation in the year 2005 for West Denmark. The two parts of Denmark are not connected. Denmark West is synchronously connected to the European continent, the UCTE system, while Denmark East is synchronously connected to the North European system, the Nordel system. Denmark West has several connections with neighboring countries with a total capacity of about 2830 MW (Norway 1000 MW, Sweden 630 MW, Germany 1200 MW), Denmark East has connections with a total capacity of about 2300 MW (Sweden 1700 MW, Germany 600 MW).

Wind power in East Denmark covers 12% of the energy consumption and in West Denmark 24% of the energy consumption.

In West Denmark the installed wind power covers at most 58% of possible lowest net consumption, which is lowest local consumption + possible export:

$$\text{Maximal share of wind power} = \frac{\text{Maximal wind power}}{\text{Lowest consumption} + \text{possible exchange}} = \frac{2380}{1266+2830} = 58\% \quad (2)$$

Since Denmark East and West are not connected wind power has to be balanced separately in both areas. The maximal share of wind power is 58% in Denmark West and 23% in East.

For West Denmark, there is data available for the occurrence of maximal wind power during low consumption times. First of all, wind power distributed over larger area with thousands of turbines will never reach full output. In Denmark, which is a country with a smaller expansion, the maximum power recorded on-land has been 2230 MW compared to 2380 MW installed on-land capacity, that is about 94 % of installed on-land capacity. Further, the minimum load in wintertime, when this maximum wind power could be reached, is about 100 MW higher than in summertime. Correcting for these in formula (2) would give 57 % for the maximal share of on-land wind power. Additionally a 160 MW offshore wind farm is installed, which is not considered in this investigation.

TABLE II. DATA FOR WEST DENMARK.

	Min MW	Max MW	TWh/year
Power consumption	1266	3697	21.1
Wind power, on-land	0	2380	5.0 (24%)
Export capacity	0	2830	

This implies that theoretically there is room for more wind power in Denmark West, but here also the significant heat bound power production has to be taken into account, although this production is low in summer, where the lowest power consumption is. The lowest production left for wind, might be in a winter hour with large heat bound power production. The lowest consumption after removing of decentralized production was 764 MW in 2005; this gives 66% as maximal share of wind power. If the heat bound power production from centralized production is also taken into account the share is even larger, sometimes above 100%. Before the decentralized production came to working according to market signals 1st of January 2005, it was more necessary to cut down the wind production than after that date, because occasionally production could exceed consumption simultaneously to a limitation export possibility to Germany due to large wind power production in the North of Germany. Curtailing wind power has not happened so often since then.

The experience reported for the issues a)…g) are collected in Table VII.

C. *Example Wind power in Schleswig-Holstein*

At the end of 2005, wind farms with a total installed capacity of around 7,564 MW were connected in the E.ON Netz control area, accounting for 41% of total installed wind power capacity in Germany. More than one fourth of installed capacity is located in the northern part of the control zone of E.ON Netz in Schleswig-Holstein.

E.ON Netz is responsible for a secure and reliable operation of the transmission system. To guarantee the security of supply and therefore a balance between generation and consumption of electrical energy control power is required by the transmission operator at all times. A certain amount of this control power is dedicated to balance deviations of the actual wind power in-feed from its day-ahead prognosis. Therefore E.ON Netz has to tender and purchase adequate control power both for in-hour variations and on basis of the day-ahead wind power prognosis.

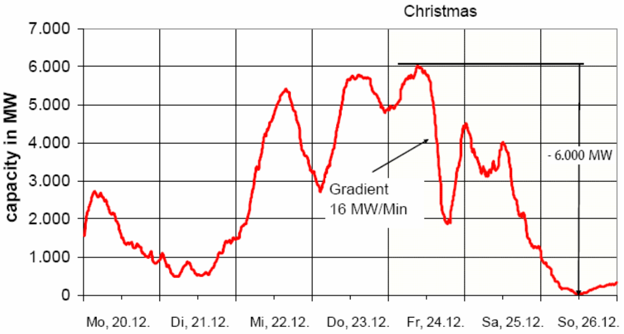

Fig 3. Wind power production in E.ON Netz area over one week December, 2004 [9].

In the E.ON Netz grid wind power in-feed decreases of 16 MW/minute have happened. Within a few hours the feed-in capacity can experience large changes frequently. Fig 3. reproduces the course of wind power feed-in during the Christmas week from 20 to 26 December 2004. Whilst wind power feed-in at 9.15am on Christmas Eve reached its maximum for the year at 6,024MW, it fell to below 2,000MW within only 10 hours, a difference of over 4,000MW. This corresponds to the capacity of 8 x 500MW coal fired power plant blocks. On Boxing Day, wind power feed-in in the E.ON grid fell to below 40MW. Handling such significant differences in feed-in levels poses a major challenge to grid operators, especially as the forecasting of these changes is not always correct.

The example of Schleswig-Holstein shows surplus wind power on windy days. Whereas total electricity consumption (grid load) is between ca. 750 MW (low load) and ca. 2000 MW (high load), wind farms with a total production capacity of over 2200 MW are installed in the area (TABLE III).

Consequently, even at periods of high consumption, around four times as much electricity is generated by wind power on windy days than is used by customers This surplus wind power has to be transported to consumers over long distances. The size and operation of the grids must be altered to cope with this requirement, with the primary objective of avoiding overloading lines and the resulting losses of supply.

TABLE III. DATA FOR SCHLESWIG-HOLSTEIN.

	Min MW	Max MW	TWh/year
Power consumption	750	2000	12.6
Wind power	0	2275	4.2 (33%)
Export capacity	0	4400	

In Germany the Renewable Energy Sources Act of 21 July 2004 stipulates among others the priority connection of installations for the generation of electricity from renewable energies to the general electricity supply grids and the priority purchase and transmission of this electricity. Therefore a continuous control of wind power is not possible. However, the large rapid expansion of the installation of wind farms in Schleswig-Holstein means that on windy days, the grid capacities are entirely exhausted. Although E.ON Netz instituted grid expansion measures at an early stage, it must be assumed that it will take several years before the planned power lines are built. In order to be in a position to connect further renewable energy generators before the grid expansion is completed, E.ON Netz has developed the so-called generation management as a transitional solution. Generation management involves the intermittent reduction of the power fed in by the renewable energy generators, in order to protect grid equipment such as overhead lines or transformers from feed-in-related overloads, thereby avoiding supply failures. In mid 2003, E.ON Netz implemented generation management in all ten regions in Schleswig-Holstein and in the first half of 2005 in the first regions within Lower Saxony.

The experience reported for the issues a)…g) are collected in TABLE X.

D. Example Wind power in Ireland

TABLE IV shows the situation in 2006 for the whole island of Ireland. This system is a separate synchronous system and the only interconnection to other systems is a 500 MW HVDC cable between Northern Ireland and Scotland. The system is operated in two regions, Northern Ireland(NI) and Republic of Ireland (ROI). ROI has approximately 500MW of wind power currently installed (8% of capacity), while NI has approximately 100MW(approx 5% of capacity). There is one 600MW AC interconnection between the two regions, so they can be treated as a single synchronous system.

The island of Ireland has one of the best wind resources in Europe. While the current penetration of wind power is small compared to other systems, there are plans to install up to 1500MW of wind by 2012. This will help meet the RES-E target of 13.2% energy from renewable sources, and would correspond to approx 75% of minimum demand. Due to the relatively weak interconnection to other systems, this could cause problems for system operators. There are plans to install a 500MW DC interconnector to Britain, from the east coast of ROI. However, the amount of reserves available from the 2 interconnectors will still be low, and the managing of wind power will mainly have to be done internally. Most of the wind farms currently operating in Ireland are in the North-West and South-West. As these are away from the major centres of population, the transmission grid is weak in these areas, and there could be issues regarding transmission of power from wind farms to population centres.

Data are found in TABLE IV and the experience reported for the issues a)…g) are collected in Table IX

$$\text{Maximal share of wind power} = \frac{\text{Maximal wind power}}{\text{Lowest consumption} + \text{possible exchange}} = \frac{596}{1930+500} = 25\%$$

TABLE IV. DATA FOR IRELAND.

	Min MW	Max MW	TWh/year
Power consumption	1930	6344	33.66
Wind power	0	596	1.373 (4 %)
Export capacity	0	500	

E. Example Wind power in New Mexico

Public Service Company of New Mexico (PNM) is a retail energy provider for most of New Mexico, and transmission service provider in the Southwest . PNM also operates a control area (balancing authority) with a peak demand of about 2,350 MW (summer). A single 204 MW wind power plant (about 8.7% of its peak load) was installed in its control area in 2003. This large wind power plant is connected to a long, radial EHV line (345 kV). During time of minimum control area load (about 1,150 MW), the wind power can represent 17.7% of on-line load. PNM normally uses internal resources to supply most of the load in its control area. Several large power plants are jointly owned, and a portion of the output is scheduled to neighboring control areas. PNM transmission system is capable of exporting up to 1,200 MW of power. However, the present system configuration and generation resources are such that available transmission capability between PNM and its neighboring system is very limited. Most of the transmission capacity is under contract and not available for other purposes on a firm basis.

Infrequent but rapid ramping of wind power is concern to PNM system operators. Under certain conditions, the wind power plant can ramp from 0 to full output (204 MW) or vice versa within 30 minutes. However, so far PNM has been able to maintain acceptable control area performance with this level of wind penetration. TABLE V shows the situation in 2005.

The physical system is capable of transferring large amount of power in and out of the control areas (total transfer capability), but contractual agreements and economic dispatching practices often lower the capability (available transfer capability). PNM control area can absorb all the wind power even during system minimum load periods. Exporting capability does not play a significant role in managing wind power. The experience reported for the issues a)…g) are collected in Table VIII

$$\textit{Maximal share of wind power} = \frac{\textit{Maximal wind power}}{\textit{Lowest consumption} + \textit{possible exchange}} = \frac{204}{1150+1200} = 9\%$$

TABLE V. DATA FOR NEW MEXICO.

	Min MW	Max MW	TWh/year
Power consumption	1150	2350	14.092
Wind power	0	204	0.513 (3.6 %)
Export capacity	0	1200	

V. CONCLUSION

This paper reports on the experience of regions where wind power produces up to 35 % of yearly gross demand. The regions are part of larger power systems, however, some impacts due to large wind power production can be seen.

In all the regions, the “maximal wind power” is considerably less than minimum load plus export possibility. In Gotland island all issues of reliability are solved outside the region with the flexible HVDC connection to mainland. In Denmark and Germany, most issues due to variability of wind are solved outside region. On Ireland most issues are solved on the island since the connection to other systems is comparatively small. Also in New Mexico most integration issues are considered inside the region.

From the experience reported, it seems that when making sure that the following aspects are covered, the wind power can be managed as a combined inside/outside region solution:

- the interconnectors can react fast enough
- most of the wind farms do not trip off due to grid faults and thus cause a dimensioning fault
- it is possible to curtail the wind power production in critical (rare) occasions

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REFERENCES

[1] *Wind Power Monthly*, Volume 22, no 4, April 2006
[2] BP Statistical Review of World Energy June 2005,
[3] Söder L. *On limits for wind power generation*, Int. J. Global Energy Issues, Vol. 21, No. 3, 2004
[4] Söder. L. *Wind Power Systems*, Encyclopedia of Physical Science and Technology, Third Edition, Academic Press, 2002
[5] Doherty R., O’Malley M. *Quantifying Reserve Demands due to Increasing Wind Power Penetration*, IEEE Bologna Power Tech Conference, June 2002
[6] Eriksen, P.B., Ackermann, T., Abildgaard, H., Smith, P., Winter, W., Garcia, J.R. System Operation With High Wind Penetration. IEEE power & energy magazine, Dec 2005.
[7] UCTE Operation Handbook, available on www.ucte.org
[8] Christiansen P., Jesper R. Kristoffersen J. R., *The Wind Farm Main Controller and the Remote Control System of the Horns Rev Offshore Wind Farm*. Proceedings of Fourth International Workshop on Large-scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms, 20-21 October 2003 in Billund, Denmark.
[9] E.ON Netz Wind report 2005, available on www.eon-netz.com
[10] DENA Grid Study: Planning of the Grid Integration of Wind Energy in Germany Onshore and Offshore up to the Year 2020, Deutsche Energie-Agentur GmbH, 2005.

TABLE VI EXPERIENCE FROM GOTLAND. WIND ENERGY COVERS 19 % OF GROSS DEMAND AND THE MAXIMAL SHARE OF WIND POWER IS 40 %.

Problem		**Gotland**	**Solution region?**
a	Enough power plants at low wind	Import capacity from mainland enough. Local gas turbines for emergency situations.	Solved mainly outside region.
b	Enough power plants with fast control during high wind	The HVDC to mainland is easy to control, also around 0 MW (control enhanced to enable this), and from mainland side point of view wind power on Gotland is comparatively small	Solved outside region.
c	The system must survive a dimensioning fault.	Wind power would be part of dimensioning problem in cases of transmission faults. The HVDC link and mainland production can act as reserve.	Solved outside region.

d	Enough reserves at large decrease of total wind power	The HVDC to mainland is easy to control, and all balancing is therefore performed on the mainland. From mainland point of view, wind power production on Gotland is comparatively small.	Solved outside region
e	Handling of problem in internal grid	Reactive power support from synchronous compensator and a local HVDC-VSC (Voltage Source Converter). Not a limiting factor, except for c.	Voltage problem only within each region because of HVDC.
f	Possibility to down regulate wind power	Used frequently up to 2003 when the possibility to controllability around 0 MW on the HVDC was installed.	Currently only at rare grid problems.
g	Possibility of continuous control of wind power	Not implemented, since there are local gas turbines and a 35 MW diesel plant that are started at an outage of the HVDC link	Only of interest at isolated operation (very rare).

TABLE VII EXPERIENCE FOR WEST DENMARK. WIND ENERGY COVERS 24 % OF THE YEARLY ELECTRICITY CONSUMPTION AND THE MAXIMAL SHARE OF WIND POWER IS 58 %.

Problem		**Denmark West**	**Solution region?**
a	Enough power plants at low wind	Power production capacity enough	Solved inside region
b	Enough power plants with fast control during high wind	Regulating power (10 minutes) is traded at the Nordic TSO`s regulating power market (NOIS) and can be supplied from all Nordpool members, within the limit of the DC connections to Sweden and Norway. From the importer’s point of view wind power in West Denmark is comparatively small	Solved in the Nordpool region (inside and outside region)
c	The system must survive a dimensioning fault.	Dimensioning fault is large conventional power plant or transmission line.	Solved inside and outside region
d	Enough reserves at large decrease of total wind power	Regulating power (10 minutes) is traded at the Nordic TSO`s regulation power market (NOIS) and can be supplied from all Nordpool members. The HVDC to Sweden and Norway is easy to control, and from the Nordic Power System`s point of view the necessary positive regulation power for West Danish wind power is comparatively small, but its availability is varying.	Solved inside and outside region
e	Handling of problem in internal grid	Reactive power support from synchronous compensator. Not a limiting factor, except for c.	Voltage problem is solved locally.
f	Possibility to down regulate wind power	Has been used, but very seldom	Currently only at rare grid problems.
g	Possibility of continuous control of wind power	Regulation capacities used as needed for one large wind farm. It’s also possible to cut off wind farms. Of interest only at isolated operation	Only at large offshore wind farm.

TABLE VIII EXPERIENCE FOR NEW MEXICO. WIND ENERGY COVERS 3.6 % OF THE YEARLY ELECTRICITY CONSUMPTION AND THE MAXIMAL SHARE OF WIND POWER IS 9 %.

Problem		**PNM**	**Solution region?**
a	Enough power plants at low wind	There is enough capacity to meet the peak demand without wind power	Solved inside the control area
b	Enough power plants with fast control during high wind	At current wind power penetration level, PNM is able to maintain acceptable control area performance (CPS1 and CPS2) with existing regulation capability	Solved inside the control area
c	The system must survive a dimensioning fault	PNM system meets all NERC reliability criteria regarding contingency and loss of load. The wind power plant complies with PNM fault tolerance criteria. However the wind plant may not remain in service after a fault internal to the plant.	Solved inside the control area
d	Enough reserves at large decrease of total wind power	Rapid decrease of wind power can cause large change of ACE. As a result, average ACE could be outside the NERC specified limit for several 10-minute periods. The situation is corrected with internal resources.	Solved inside the control area
e	Handling of problem in internal grid	Large swings (rapid ramping) of wind power sometimes may require higher-cost gas units to provide regulation services.	Solved inside the control area
f	Possibility to down regulate wind power	There is no provision to curtail output of wind plant except during system emergency. So far wind power has not been curtailed.	Solved inside the control area
g	Possibility of continuous control of wind power	Not implemented	

TABLE IX EXPERIENCE FROM THE ISLAND OF IRELAND. WIND ENERGY COVERS 4 % OF THE YEARLY ELECTRICITY CONSUMPTION AND THE MAXIMAL SHARE OF WIND POWER IS 25 %.

Problem		Ireland	Solution Region?
a	Enough Power Plants At Low Wind	Power production capacity enough	Inside region
b	Enough Power Plants With Fast Control During High Wind	Enough power plants are installed in the region. Only very small amounts of additional fast reserve are required for large wind penetration	Solved inside Region
c	The System Must Survive A Dimensioning Fault	Dimensioning fault is large conventional power plant or transmission line	Solved inside region
d	Enough Reserves at large decrease of total wind power	Enough Power Plants are installed in the region – reserves dominated by largest infeed (500MW). Interconnector also contributes to reserve	Solved inside and outside region
e	Handling of problem in internal grid	Adequate transmission capacity between generation and consumption areas	Solved inside region
f	Possibility to down regulate wind power	Possibility to use, not used often due to relatively low share of generation	
g	Possibility of continuous control of wind power	Not implemented	

TABLE X EXPERIENCE FROM SCHLESWIG-HOLSTEIN. WIND ENERGY COVERS 33 % OF THE YEARLY ELECTRICITY CONSUMPTION AND THE MAXIMAL SHARE OF WIND POWER IS 18 %.

Problem		Schleswig-Holstein	Solution region?
a	Enough power plants at low wind	In principle enough power plants are available in that region.	Solved inside region
b	Enough power plants with fast control during high wind	In principle enough power plants are available in that region (Since TSOs are not dealing with unit commitment as far as no congestion limits are exceeded and since the region is part of the interconnected power system of the UCTE power plants will be operated according to availability and costs.).	Solved inside and outside region
c	The system must survive a dimensioning fault.	Faults in the extra-high voltage grid can result in a sudden failing of a huge number of wind power plants in the affected region: up to 3,000 MW can fail, thereby putting the grid stability at risk [10]. In general outages of more than 3,000 MW are defined as endangered in the UCTE synchronously interconnected system. For further expansion of wind power, grid connection regulations are continuously improved by E.ON Netz to take care of grid stability and supply reliability.	Has to be solved inside region in future (grid codes with Fault-Ride-Through to avoid wind power becoming dimensioning fault)
d	Enough reserves at large decrease of total wind power	E.ON Netz has to tender and purchase adequate control power as well on basis of the day-ahead wind power prognosis.	Solved inside and outside region
e	Handling of problem in internal grid	Voltage regulation has to solved locally, as long as there are enough power plants online this is not a limiting factor (see answer to problem b). New wind farms have to contribute to the reactive power supply and voltage regulation. Depending on their size new wind farms have to keep either a certain power factor or have to feed in a certain amount of reactive power, which is given by the control centre, or have to participate in voltage regulation.	Voltage problem is solved locally. New wind farms are contributing.
f	Possibility to down regulate wind power	In mid 2003, E.ON Netz implemented generation management in ten regions of Schleswig-Holstein	Has been used since 2003
g	Possibility of continuous control of wind power	A continuous control of wind power is not possible due to the feed-in law (Renewable Energy Sources Act, 21.7.2004)	