New Challenges for the Transmission System Operator

by

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1. Summary

Being the Transmission System Operator in Western Denmark, Eltra faces a great number of new challenges derived from the so far ambitious energy and environmental policy being co-ordinated with the new market concept due to the liberalisation. New paradigms characterise the electricity market for generation and the transmission system since the framework and the conditions have changed dramatically within few years.

Wind power plays an important role together with local CHP plants. We describe the most important topics and their origin and show ways to overcome the obstacles. We also discuss how a transmission system operator can adjust himself to the new conditions.

In Denmark, the ratio of wind power to total generation rose from 2 per cent in 1990 to 13.8 per cent of the energy in 2000. In the western part of Denmark, wind power accounted for more than 80 per cent of the power consumption in low-load hours in 2000. The high amount of wind calls for new ways of securing the supply.

Together with local CHP plants wind power has led to approx. 50 per cent of bound production and to situations with imbalances between production and load. Situations like the ones in California are not likely to occur in the Danish power system.

Denmark's neighbouring countries are experiencing a similar development and are not necessarily prepared to solve problems due to imbalances between load and production for other countries by improving their transmission system.

The bound production calls for development of the transmission capacity. At the same time environmental legislation leads to as much as ten years' work for having new high-voltage transmission lines approved. The development of the market calls for a much faster response. As a result, technology forecasting have increased strongly in importance both with regard to underground cables and technical measures for balancing the system.

The generators supplying the grid and the consumers alike, the latter through the distribution companies, expect a service and a high security of supply at the lowest cost. The location of

production capacity in the distribution networks has led to the need for new energy scenarios to bring security back to normal.

By means of new legislation and other instruments the government tries to set up a framework that matches European regulation, political goals like Kyoto targets, joint implementation, emission quota systems and priorities for renewable technologies. Today's fact is that within a few years Denmark has moved from being one of the countries with the lowest costs for electricity generation to one of the most expensive in Europe. A major job is now to bring the costs down.

2. Introduction

When small-scale generation is integrated into distribution networks several questions and challenges arise. They need new solutions to technical problems, especially as the aim is to maintain the quality of supply in an open market environment.

Eltra is the transmission system operator (TSO) for the Western part of Denmark (covering approx. 60 per cent of Denmark). The formation of Eltra only dates back to January 1998. At that time the new Danish Electricity Supply Act had been passed and opening of the electricity market started. The former company Elsam which was a corporation, was divided into two companies:

- One transmission and overall system operator, a TSO, with the new name Eltra.
- One commercial production company keeping the old name Elsam.

Eltra is a non-profit organisation. One of Eltra's major jobs according to the Electricity Supply Act is to ensure the market function. Another is planning the transmission grid and ensuring the quality of supply. For further information visit www.eltra.dk and choose the English version.

The dispersed generation is mainly private owned. The building of it is entirely determined by subsidy rules and political agreements. Eltra has no influence on the amount or the location and do not know in advance how much will be installed or where it will be installed.

Eltra amba is part of the Nordic market and the spot market trade on Nord Pool (www.nordpool.com). In day-to-day operations Eltra has the job of balancing the power system taking into consideration that:

- The wind power is unpredictably bound to the wind.
- The local CHP plants produce based on the needed district heating.
- Congestion must be managed in a transparent way.
- The security of supply is ensured.
- The market must function well, based on correct pricing.

Non-dispatchable production in Denmark may influence the market in the Nord Pool area by the amount of bound production.

3. Dispersed generation in the Eltra area

Danish energy policies have led to the building of approximately 1,932 MW wind turbines by the end of 2001 and approximately 1,560 MW dispersed CHP production in Western Denmark.

The power system in Western Denmark is a very small system. The key figures for year 2000 are as follows:

Energy consumption:	19,289 GWh (Western Denmark) 32,849 GWh (All Denmark)
Peak load:	**3,650 MW**
Off-peak load:	1,150 MW
Installed capacity in detail:	**6,534 MW**
- Wind power:	1,866 MW
- Local CHP plants:	1,467 MW
- Central power plants:	3,201 MW

In addition to central power plants we see a variety of decentralised production types adjusted to the Western Danish distribution system. Since they are basically privately owned Eltra keeps information about the locating of the installed capacity, the production and fuel in a database. Some examples are:

- wind turbines ranging from 11 kW to 2,000 kW
- gasfired CHP units ranging from 7 kW (in connection with greenhouses) to 98,5 MW
- straw-fired CHP units ranging from 2,2 MW to 18,2 MW
- coal-fired power plant ranging from18 to 44 MW
- waste combustion ranging from 90 MW to 26,200 MW

Some of these units have multi-fuel capabilities.

The amount of wind power has increased since 1982 in parallel with local CHP plants which have been built since the late 1970's. About 50 per cent of the production is now bound production. The wind power is bound to the wind and the production from the local CHP plants are bound to the demand for district heating.

The many local CHP plants (736 units) are controlled by means of tariffs which intends to place the production at a time interval where the electricity system needs the electricity production. For CHP plants this is partly possible because of their heat storage capacity. These units are basically back pressure units, where a given amount of heat results in a predetermined amount of electricity that cannot be regulated.

3.1 Important elements of the Danish environmental and energy policies

For many years Denmark has had an environmental and energy policy with ambitious goals. This has resulted in large subsidies for construction and the running of small-scale CHP plants and wind turbines. The subsidy has been adjusted regularly, but is now up to DKK/MWh 600 compared to an average market price of approx. DKK/MWh 177 in Western Denmark in 2001.

Energy 21 [ref. 9] published by the Danish government in 1996 sets up overall goals of reducing CO_2-emissions by 20 per cent in 2005 compared to 1988, and as a long term goal to halve CO_2-emissions by 2030 by making one third of the energy use sustainable energy and by making the rest of the energy use more effective.

Accession to the Kyoto protocol defined the goals on an EU level to be an 8 per cent reduction of greenhouse gas emissions from 1990 to 2008-2012. The national Danish goal is under certain conditions a 21 per cent reduction.

The small-scale production has prioritised access to the network so that distribution companies are obliged to connect them. Costs are only paid to the nearest 10 kV connection point even though there is a need for larger reinforcement or for another connection point.

For year 2001 the energy policy has resulted in approximately 50 per cent of the energy production in the Eltra area now being prioritised. This means that the Danish small-scale CHP production and the wind power cannot be regarded as secondary production and it cannot be closed down when needed.

3.2 CHP plants and wind power

The situation in the power system is very different from what was expected in the early 90's. The situation for local CHP plants is that it has developed throughout the 90's to 1,467 MW in 2001. As the amount has been controlled by the need for heat only, we suppose that this kind of production will be stabilised at the reached level (figure 1).

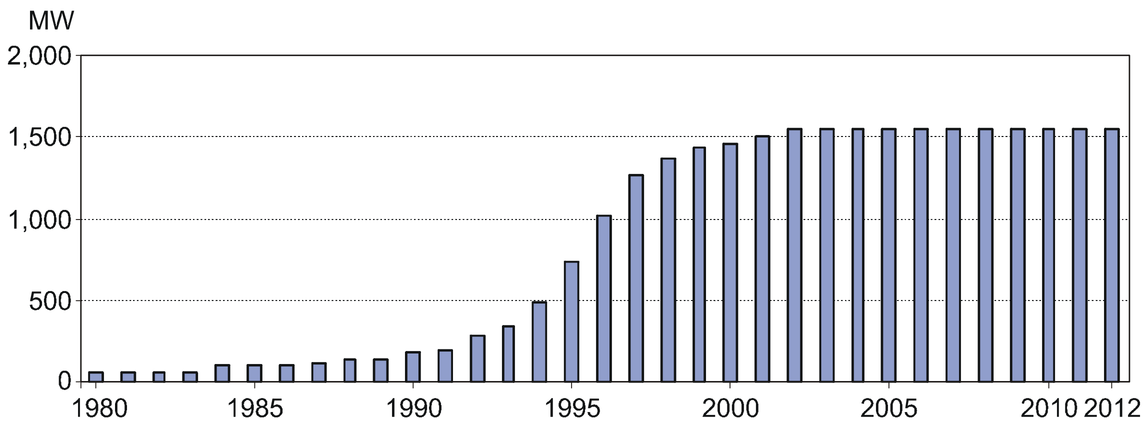

Figure 1: *Development of local CHP units throughout the 90's in the Western Danish power system*

Due to the age of the CHP plants we also expect a considerable number of the units to be replaced within the "Kyoto-period" until year 2012. The economic frames will be important with regard to the amount.

The situation for Danish wind power is more complex [ref. 4]. The development in the early 90's was quite relaxed heading for a total of 1,500 MW for Denmark as a whole in year 2005. From 1995 the increase was larger than expected and the increase in year 2000 was enormous (figure 2). The result was 1,932 MW of onshore wind power in Western Denmark.

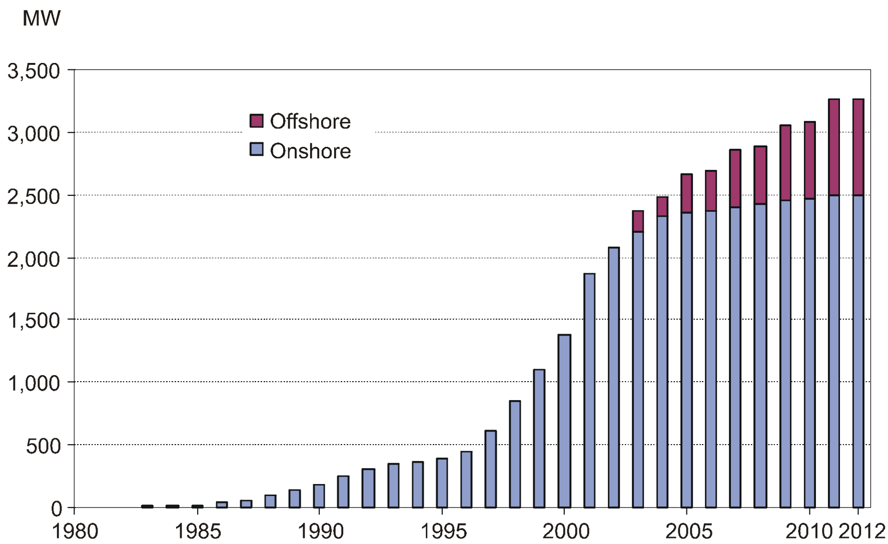

Figure 2: Development of the wind power in the Western Danish Power system

As the development of wind power is basically determined by rules of subsidy it is not possible to forecast a level of stabilisation. Due to the rules now in force we expect onshore wind power to stabilise at 2,500 MW in Western Denmark. But this forecast can turn out to be wrong.

The amount of onshore wind power is determined by a replacement rate decided by the government. The replacement will add approx. 400 MW (see paragraph 7.3).

The amount of offshore wind power shown in figure 2 is decided in a governmental development plan. This plan is now being reviewed by the new Danish government (see paragraph 7.1).

4. Code of practice for the 1990's

Traditionally Eltra has worked out specifications that the production plants should meet. An important framework for the introduction of dispersed generation into the electricity system in the early 90's was the costs of the producers. The connection specifications which had to be set up around 1990 were therefore as minimal as possible for the small units and with the aim to secure them from being damaged during faults in the network. The small units do not need the same requirements as the central units.

The code of practise for the 90's in the Eltra area is divided into different parts:

- Specifications for all power plants larger than 50 MW considered to be traditional CHP plants with demand for frequency control, voltage control and power control, operation at low voltages, transition of house load operation and so on.
- Specifications for plants larger than 2 MW and smaller than 50 MW. In this category the number of plants is approx. 193.
- Specifications for plants smaller than 2 MW. In this category the number of plants is approx. 525.
- Specifications for onshore turbines irrespective of capacity. There are approx. 5,000 turbines connected to the grid (see paragraph 7.2).

5. Transmission and distribution

The transmission grid in the Eltra area covers 712 km of the 400 kV lines and 1,739 km of the 150 kV lines, some of them also combined (figure 3). The interconnection to neighbouring areas has a capacity of about 3,000 MW.

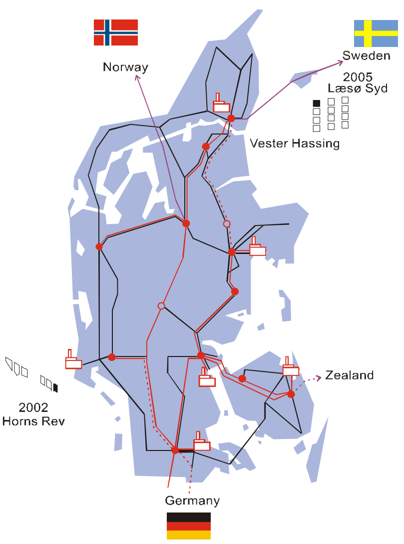

Figure 3: *Structure of the transmission grid in the Eltra area connected to Norway, Sweden and Germany*

The area is interconnected with Norway and Sweden through HVDC links – the first one dating back to 1965. Eltra is also a member of Nordel with the joint rules this involves and with the sharing of operation reserves. The area is connected to the European Continent and the German grid through 400 kV and 220 kV (plus 150 kV and 60 kV) a.c. networks. The Eltra power system forms a link between the Nordel area and of the UCTE area being a member of both organisations.

Balancing a power system like the Danish one can only be done if it is connected to areas with other types of production. This is not a situation that can be accepted without arousing criticism (see paragraph 6).

An overall analysis shows that the amount of production is developing towards lower levels of the grid. At the moment (2001) almost half of the production capacity is now placed in the distribution networks (see figure 4).

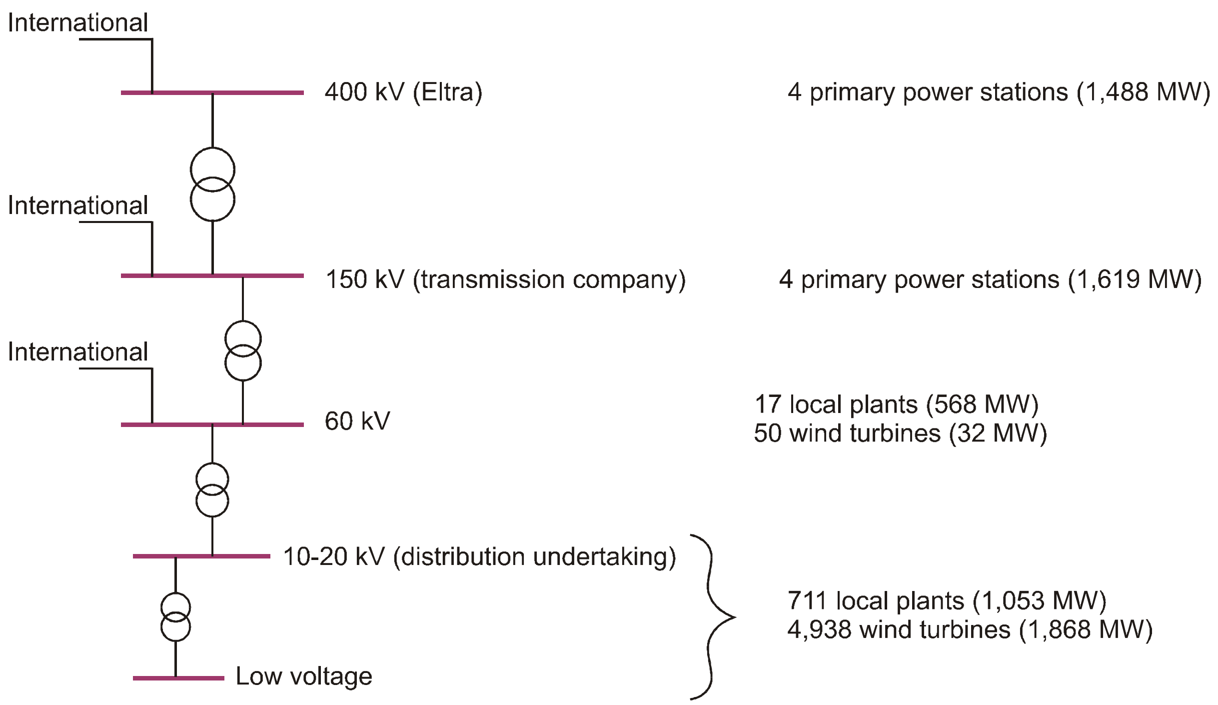

Figure 4: *Division of the production capacity of the actual voltage levels*

This tendency will probably go on. The levels of distribution networks are the low voltage level 240 V, 20 kV, 10 kV level and the 60 kV level.

The dispersed power is unevenly distributed and the production is not always placed near the load centres. A couple of examples on load sum from substations in the transmission system (150 kV) are shown (figure 5). In a typical urban substation (Hasle) there is a flow from high- to low-voltage and that is what the system is dimensioned for. In another substation Bredkaer in a wind power dominated area, we see flows from lower to higher voltages.

The large amount of bound production puts pressure on the transmission capacity internally in the Eltra area and on neighbouring areas.

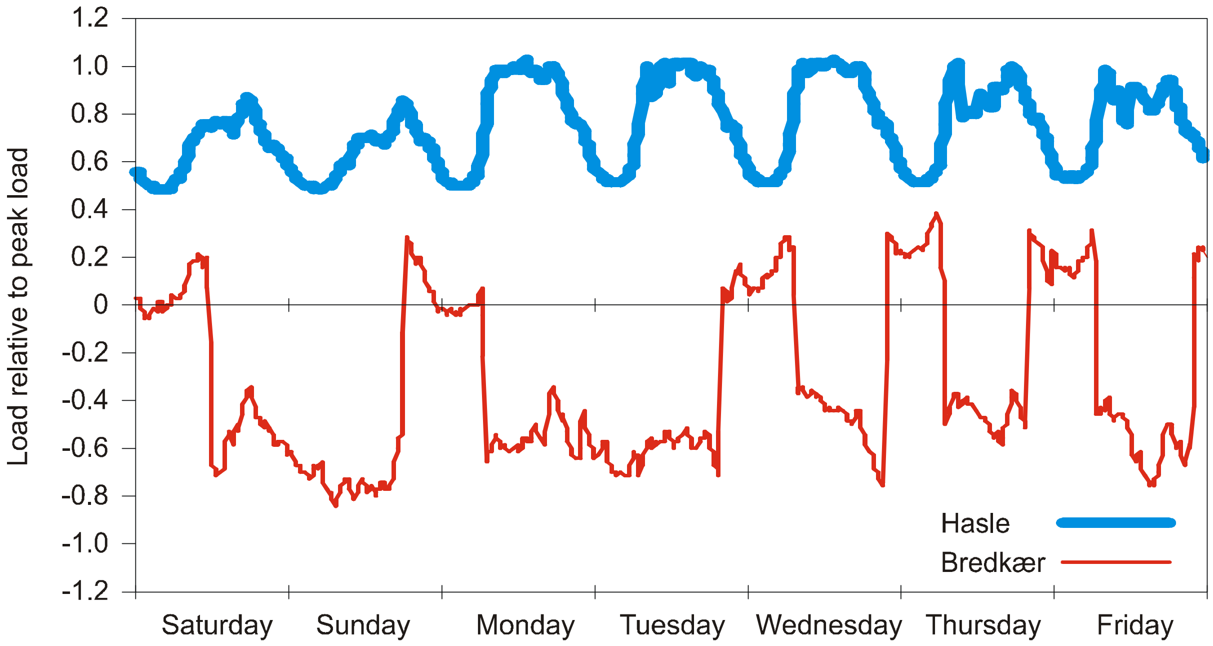

Figure 5: *Flow in the 150/60 kV substations Hasle and Bredkaer*

The flow towards transmission level causes problems with regard to regulating tap changes of the transformers and with regard to the voltage profiles in the distribution networks having lower voltages at the points of transformation than the points of infeed of the wind power. Distribution companies therefore often connect the wind power at separate outlets where consumption is not connected. This leads to more networks than needed for consumption only.

6. The imbalanced power system

Due to the large amount of non-dispatchable power production in the distribution networks the Eltra power system can be an unbalanced power system since the production does not follow the load.

There are situations with lack of production, for instance, by high load and no wind. On the other hand, situations often occur with excess production: by off-peak load and windy conditions and the CHP producing bound to be heat demand. These situations often occur during weekends and holidays. Then the system has created an overflow.

6.1 Balancing of the power system

Balancing the system and operating it requires detailed planning the day before the spot market closes and also following hours until the moment of operation – the period when imbalances are handled in the regulating market. Even though you expect a balanced system many things can turn out differently. The imbalance is often in the order of 800-1,000 MW.

The wind plays a special role in the power balance. Therefore it is important to have good wind forecasts. Figure 6 shows an example from operation situations a) where the wind is rising later than forecasted giving a shortage of 800 MW b) where the wind is rising earlier than forecasted giving a surplus, c) where the wind is rising as forecasted.

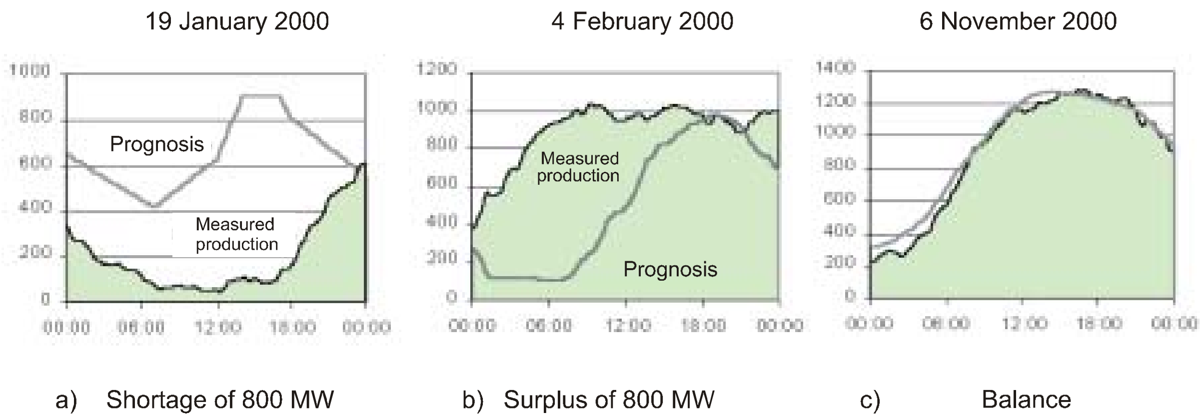

Figure 6: *Examples of wind power rising later or earlier than forecasted*

6.2 Power overflow

The excess production from the bound production can be exported if capacity is available on the interconnections to Norway, Sweden and possibly Germany. If the oversupply is becoming larger than the capacity it will be a critical power overflow. During a critical overflow there is a risk of disturbances and a break-down in the system.

The overflow as a phenomenon is already observed in daily operations and the amount is expected to increase. For year 2005 it is expected to be approximately 2,900 MW calculated as the difference between the bound production and the low load.

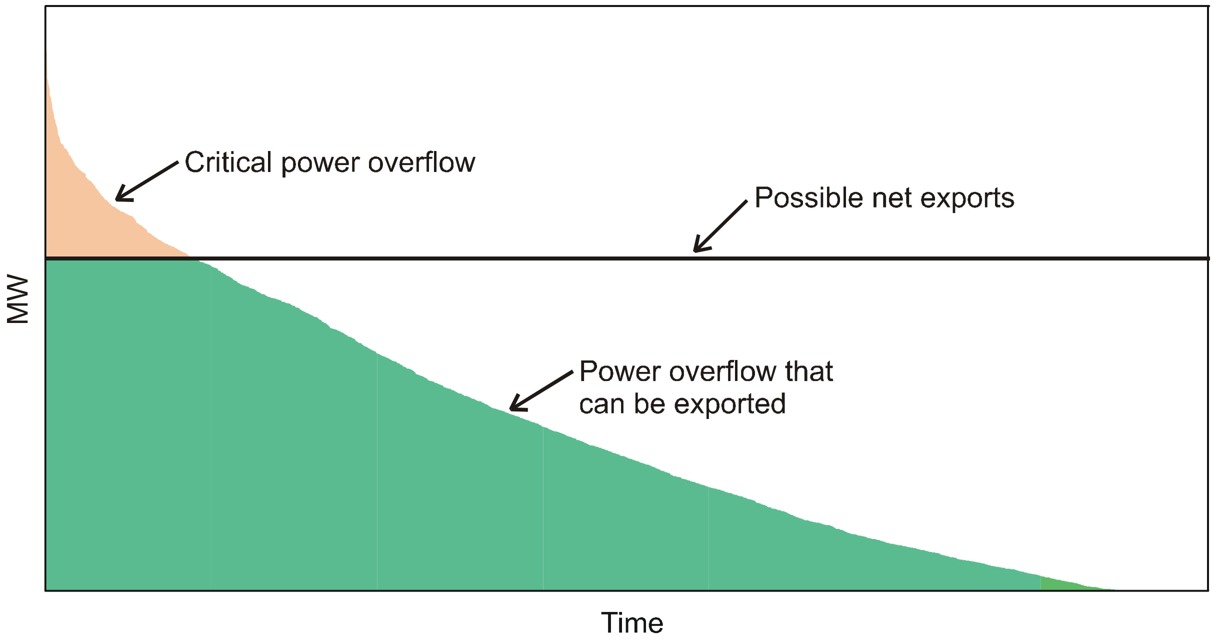

Figure 7: *Power overflow divided into export overflow and critical overflow*

To give an example of overflow, April 12, 2001 led to a critical situation because the weather forecast suddenly changed. It was forecasted that the wind should drop and the decentralised CHP plant and CHP plants take over the electricity production. With the changed weather forecast the prospect was suddenly a surplus of 800 MW. The interconnection to Norway and Sweden was (except for 100 MW) completely utilised for exports. E.ON in Germany could not take over the excess production because of their own wind power.

For such abnormal situations an emergency instruction is available in the control centre. The operation plan was then decided to regulate down 350 MW of CHP plants, to stop two local plants of 100 MW, to overload the cables to Norway and Sweden by 70 MW. The remaining 180 MW could not be handled and a critical situation could be foreseen. Fortunately, the wind forecast suddenly reversed to the original and an expected critical excess situation was reversed into a deficit situation of 300 MW.

On New Year's Day we faced a similar overflow situation with low load cold weather and high wind power. Here we were actually forced to close down wind turbines to balance the system and avoid critical overflow.

6.3 Measures to balance the system

As the overflow situation can become critical within the next few years we have to find ways of balancing the system by means of internal Danish meassures. An analysis made in co-operation with the Danish Energy Agency [ref. 8] states that the following devices are of interest:

- closing down wind turbines
- closing down local CHP plants
- introducing flexible loads
- installing heat pumps

At the moment Eltra is analysing the possibility of dispatching the local CHP's. The use of these measures will need changes in the taxation system.

7. Wind power

During the 90's the development of technical properties regarding wind turbines has been significant so instead of building small turbines (55-600kW) they started building larger turbines (1.5-2 MW) and expect to build even bigger ones in the near future.

With the present national goals, everything seems to indicate that in 2020 Nordel will comprise at least 10,000 MW of wind turbines. So, in the light of this, scenario 1 is absolutely not an extreme scenario. Scenario 2, however, assumes that the wind power expansion is speeded up compared to present goals.

Year 2020	**Consumption**				**Wind power**		**Local/ in-dustrial CHP**
	Winter		**Summer**		**MW**		
	Max. MW	**Min. MW**	**Max. MW**	**Min. MW**	**Scenario 1**	**Scenario 2**	**MW**
Norway	26,000	22,700	17,100	13,800	1,000	4,000	250
Finland	16,500	10,600	10,900	7,400	500	2,000	3,200
Sweden	32,000	23,000	15,000	9,800	4,000	8,000	3,000 [1]
Denmark	7,500	3,000	6,000	2,500	5,400	7,000	2,550
Total	82,000	59,300	49,000	33,500	10,900	21,000	9,000

Figure 8: *Potentials for wind power have been examined for 2 scenarios in the Nordel-area*

In Nordel a special report has, therefore, been prepared on the non-dispatchable production [ref. 3] which can be expected in the system in different scenarios and the requirements for regulating capacity.

7.1 Large wind farms

The Western Danish power system could face a large amount of offshore wind power in selected areas. For offshore wind power we have reached a decision that This power should not be connected to the distribution networks up till 60 kV even though it might be possible. This decision is based on experience with too much onshore wind in too small networks. There are two major reasons for that statement:

- the offshore potential in the Western part of Denmark is enormous. The government's action plan quotes 4-5,000 MW.
- when connecting to the transmission grid from the start we are able to set out more detailed rules and make offshore wind farms function as if they were power plants.

Eltra has developed a set of regulations regarding connections of large wind farms [ref. 5]. The conditions are determined for wind farms connected to the transmission network, but they apply to both onshore as well as offshore farms. The document is available in English on

[1] Only part of this power is non-dispatchable, as some local CHP units in Sweden can produce heat independently of the electricity production.

www.Eltra.dk. We have observed that the turbines on the market can actually meet more severe demands than we have made.

The energy efficiency is expected to be much better offshore than for the farms onshore. Measurements indicate that the same amount of energy can be produced by half the amount of turbines offshore than onshore. We expect a utilisation time of more than 4,000 h at sea.

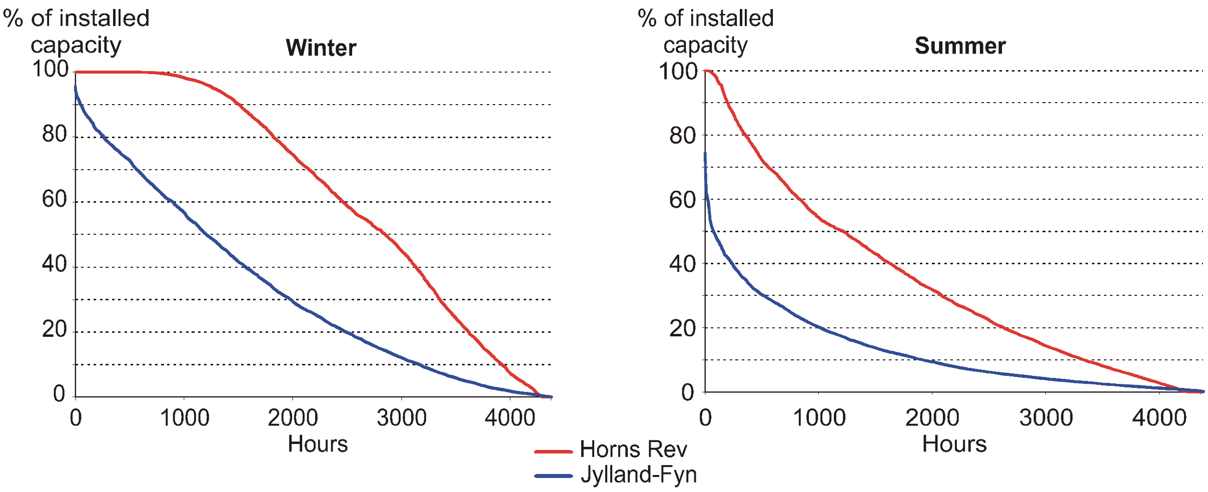

Figure 9: *The production during the winter and summer*

We have forecast an urgent need for regulation basically per minute (power gradients) and an example is given in "Towards a Wind Energy Power Plant [ref. 2].

7.2 The farm at Horns Rev

The first offshore wind farm built according to Eltra specifications will be in operation this summer [ref. 1]. Therefore, we have no operational experience yet. The farm at **Horns Rev** will consist of 80 turbines of 1.5 MW each, totally 160 MW. The wind farm is situated 54 km from the transmission network (figure 5).

Figure 10: *The situation of Horns Rev in the North Sea*

The offshore wind energy power plant at Horns Rev is a demonstration project and one of the purposes is to test different techniques and to adjust the demands on the turbines. The instruction to the Danish electricity companies is to build five farms of 750 MW in total in selected areas. The intention of the new government is that new capacity will be implemented on more commercial terms.

For the next sections the technical rules of connection will also be developed.

The wind energy power plant at Horns Rev disconnects in case of grid faults, but the turbines reconnect only seconds after the fault disappears. The disconnection and the fast reconnection are a compromise between the technical possibilities of the turbines and Eltra's wish that the turbines should remain connected in case of grid faults.

Some of the wind energy power plant's control functions are controlled centrally for the entire plant, whereas others are managed individually by the turbine in question. The production of the wind farm is controlled centrally and this regards the entire wind energy power plant according to the following requirements for the control functions:

- **Production limitation,** where it is possible to set how much the wind energy power plant can produce as a maximum
- **Reserve** where it is possible to operate the wind energy plant with a certain reserve capacity in relation to the possible output
- **Balance control** where the production can be adjusted downwards or upwards in steps
- **Grid protection interventions** where the output can be adjusted downwards in the case of critical situations in the grid
- **Gradient limitations** where it is possible to set how fast the output can be adjusted upwards and downwards

The reactive power can be controlled centrally or for each turbine according to the principle agreed on relative to limits for intake and consumption.

Each turbine handles its own frequency control. In addition, the reactive power can be controlled locally so that the wind energy power plant's total consumption/intake of reactive power is kept within ±16 MVAr at the 34 kV side of the wind farm transformer if the central control is not connected. Disconnection of the turbines in case of grid faults or too strong winds is also controlled individually.

7.3 Onshore wind turbines

In Denmark we have a set of recommendations which describe the technical demands to grid connected wind turbines. These specifications ensure that there is no unacceptable disturbance in the distribution grid caused by wind turbines [ref. 7]. For instance there are requirements for continuous production, compensation by capacities, flicker and the protection system for the wind turbine.

As guidance to the distribution company there are recommendations of how to solve problems with regard to design of the grid, rising voltage, apparent power and transformer sizes.

Until now there are approx. 5,000 wind turbines connected to the distribution networks respecting these specifications.

8. Conclusions

In Western Denmark the large amount of dispersed generation causes a temporarily reduced quality of supply. The aim is to bring the quality back to normal.

In the early 90's there were only marginal costs for implementing wind power and local CHP plants. At the same time there was a postponement of the need for transmission network due to savings in losses and the placement of production in the same networks as the load. So, the dispersed generation showed benefits.

But as the amount was growing this is no longer the case. The expenses are now growing dramatically because the low-voltage distribution network and the 10 kV networks are "filled" with dispersed generation and the need for reinforcement is moving to the 60 kV grid with higher costs.

Wind power is often built in areas with very low load and in weak networks. In many situations the reinforcements are made by networks collecting power and which are of no value for the distribution of energy to consumers. In the period from 1992 to 2001 the extra investments made represent more than DKK 630 mio. (DKK 400 mio. due to wind power).

Wind power and local CHP plants are bound production which have led to overflow situations and the need for internal Danish measures to avoid critical situations and disturbances.

From a TSO's point of view it is crucial that the earlier passive production units be transformed into active elements so they can deliver the needed ancillary services.

An obvious price for the Danish policy has been a very complex power system to operate. Balancing a power system like the Danish one can only be done if it is connected to areas with other types of production. This is not a situation that can be accepted in the long run. Eltra is therefore working on methods in order to run local CHP plants on market terms. Eltra therefore assesses that Californian situations will not occur in Western Denmark.

Wind power and local CHP plants have displaced central units which are being decommissioned as there are no longer any commercial basis for them. It means that the regulating units disappear in areas where the need for regulating capacity is growing. The regulating must then be effected by the local CHP plants and the wind power.

It also means that the level power and short-circuit power is reduced. The result is a) increased risk limitations on the use of HVDC links especially to Sweden, b) increased risk of harmonics, c) increased risk of voltage steps when connecting and disconnecting lines and d) a risk that faults can be seen at a longer distance.

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