Is more than 25 % wind power feasible in a regional electricity market

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Abstract. Since 1999, Denmark west of the Great Belt has been a price area for the Nord Pool power exchange, now covering the four Nordic countries and parts of Germany. In this period the penetration of wind power has increased to 25 % on an annual basis. Thus, wind power has a significant impact not only on the hourly price on the day ahead spot market, but also on the development of the market, in particular the balancing and reserves markets. Since 2005 all thermal generators above 10 MW have been part of these markets (from 2007 above 5 MW). This includes the conventional generators operating large-scale condensing and CHP units and small-scale CHP units, each designed for heat for smaller towns and villages. Market participation for these generators are organised by commercial aggregators (Balance Responsible Parties). Also wind generators are operating on the markets. Of particular interest is their capability to reduce their power supply in case of imbalances, thus providing down-regulation services to the balancing market. Hourly market prices for all markets have been available from the website of Danish TSO since the start of each market. These data include the prices for the two Danish price areas, the neighbouring regions, and the Nord Pool system prices from the electricity spot market, intraday market, balancing market, regional electricity demand, trade with neighbouring regions, and electricity generation by wind, central and decentral generators. The analysis shows that the current market organisation has been able to handle the current amount of wind power at 25 % of the regional consumption. However, much further penetration will require measures in addition to the experience of the market participants and new features within the market. These issues have been analysed in details within the RESPOND.project.

Keywords: Wind power; Nord Pool: Denmark: RESPOND Project.

1 Introduction

Electricity in Denmark is divided into two small markets, each with strong connection to the neighbours, but with no direct connection. Cross-border trade is significant, but varies with the hydro power production in Scandinavia. Since 1999 and 2000 the two parts of Denmark (east and west of the Great Belt) have been price areas of the Norwegian based Nordic Power Exchange, Nord Pool, covering Denmark, Norway, Sweden and Finland and parts of Germany. In the western part the penetration of wind power has increased to 25 % per cent of the consumption on an annual basis. Thus, wind power has a significant impact not only on the hourly price on the day ahead spot market. The impact of the volatily of wind power is reduced by market-driven trade with neighbouring regions. In the eastern part of Denmark wind power covers about 16 % of the consumption.

Another important feature of the Danish electricity market is the penetration of combined heat and power (CHP) for district heating. During the last three decades all new power stations have been CHP units located to supply district heating systems in large, medium and small scales, now covering nearly 50 % of the market for space heating and hot water. Although this feature adds some additional constraints for the operation of the electricity system, it also adds additional generating capacity and enables more flexible

operation of generation units to respond to the variability and unpredictability of intermittent wind power, because heat storages are used to meet the heat demand, and electricity production is scheduled according to electricity system needs.

Response options, barriers and recommendations for large-scale integration of renewable and distributed electricity generation have been analysed in the RESPOND project under Intelligent Energy Europe for the five countries, Denmark, Germany, the Netherlands, Spain and the United Kingdom. As a contribution to the RESPOND project, market results for the price area Western Denmark of Nord Pool were analysed for the day-ahead, intraday and balancing markets for all hours in the years 2006, 2007 and 2008. The wind capacity in the three years was nearly the same, but the amount of wind and hydro power was different, and new features have been added to the market.

2 The Nordic Market

Nord Pool operates a day-ahead spot market with regional hourly prices (Elspot), an intraday market with continuous power trading up to one hour prior to delivery (Elbas), and a financial market for the following days, weeks, months and annual contracts up to five years. The participants in the markets are power producers, distributors, industries and brokers. Nord Pool Spot AS acts as counterpart in all contracts and all trades are physically settled with respective TSOs (www.nordpool.com).

On the day-ahead market a 'system price' is calculated covering the whole area of Nord Pool assuming no network constraints. In hours when congestion occurs on interconnections between price areas (Finland, Sweden, Norway (divided in two or more areas), and Denmark (east and west) separate day-ahead market prices are calculated on tha basis of the bids from each price area. It means that congestion is managed by price differences resulting from these implicit auctions (market splitting) on the interconnectors to Norway, Sweden and between Eastern Denmark and Germany (KONTEK). So far, explicit auctions have been used on the interconnector between Western Denmark and Germany. In addition, the hourly prices in each price area are the wholesale prices that apply to generators and consumers in each price area.

On the day-ahead or spot market bids are stated before noon for next day's operation (24 hours). The intraday market, Elbas, makes it possible for actors to trade bilaterally until one hour before delivery in order to minimise their deviations from the production and consumption schedules determined in the day-ahead market. In Denmark this market has so far a fairly small turnover and consequently limited liquidity. Elbas was first introduced in Eastern Denmark from 2004 and Western Denmark from 2007. It was also recently expanded to Germany, and it is planned to start in Norway from autumn 2009.

The balancing markets are operated by the national TSOs. There are auctions for reserves and rules for price settings for up- and down-regulations. These rules differ among the countries.

The Nord Pool day-ahead market dates back to 1971, when it was introduced to trade surplus hydro power among regions in Norway. From 1993 it became a market place open for all generators and consumers of electricity in Norway, and expanded to the other Nordic countries in the following years.

3 Impact of large-scale wind integration

The development of the market in the Nord Pool price area Western Denmark has been driven by electricity import and export and transit between the hydro dominated markets in Norway and Sweden and the termal market in Germany as well as increased amount of wind power and the flexibility capabilities of large- and small-scale CHP.

3.1 Western Denmark 2006-2008

The generation from wind power in the price area Western Denmark covers about 25 % of the electricity consumption on an annual basis. This is currently the largest share of wind power for any price area within an electricity spot market. Detailed market data are available from energinet.dk since 2000. From 2006 all price data are available in EUR/MWh. The maximum hourly demand in all the three years 2006, 2007 and 2008 was about 3.8 GW, and the maximum wind production was about 2.2 GW, see Table 1.

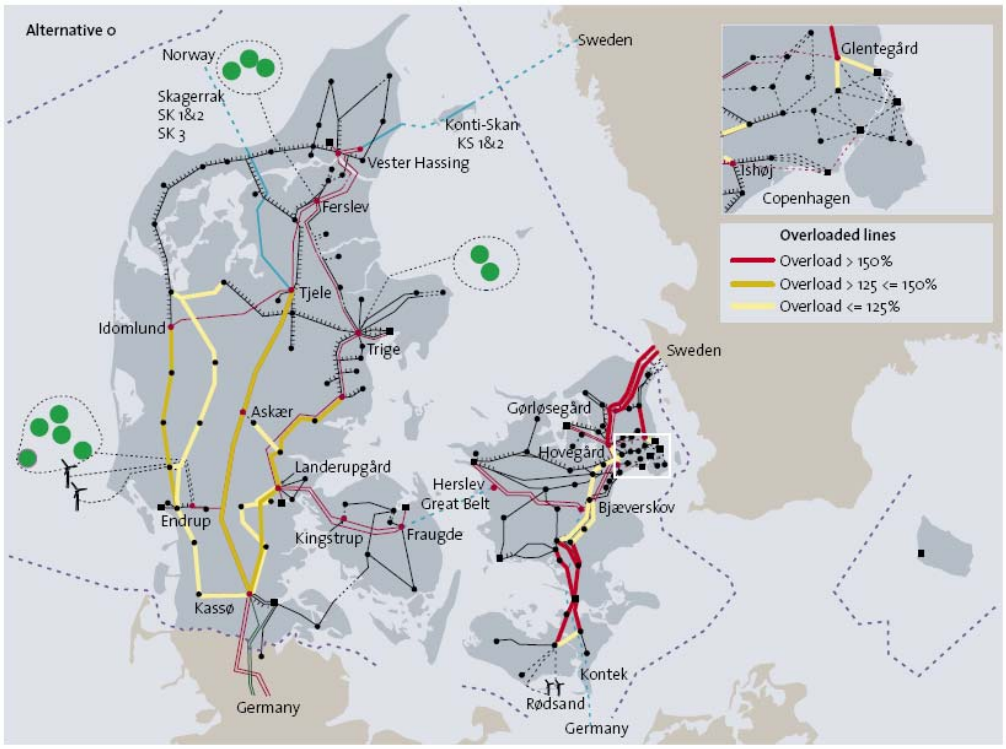

Figure 1. Transmission network in Denmark with future off-shore wind parks.

Source: Energinet.dk (2007), p. 58 (Alternative 0 case)

Table 1. Electricity flows and capacities in Nord Pool price area Western Denmark.

	2006	2007	2008
Consumption, TWh	21.4	21.6	21.6
Wind production, TWh	4.6	5.6	5.2
Net Import, North, TWh	-2.4	3.5	5.6
Net Import, South, TWh	-2.1	-5.2	-6.6
Share of wind	0.216	0.258	0.240
Central thermal capacity, GW	3.40	3.40	
Decentral thermal capacity, GW	1.74	1.74	
Wind power capacity	2.39	2.39	
Max. Load, GW	3.75	3.77	3.75
Min. Load, GW	1.41	1.38	1.30
Max. Wind, GW	2.20	2.21	2.18
Max. import/export capacity, north, GW	1.62	1.67	1.74
Max. import capacity, Germany GW	1.20	1.50	1.70
Max. export capacity, Germany GW	-0.80	-0.95	-0.95

Strong interconnections between Western Denmark and other regions (up to 1.7 GW for import to Northern Germany with very similar conditions for wind power, and 1.7 GW transmission capacity to Norway and Sweden with little wind capacity and large hydro storage capability) will reduce the number of events with consecutive hours with high prices due to lack of generation from wind. Thus, the number of these hours was small in both 2006 and 2007 (see see Table 1). When spot prices were high, forecasts of generation from wind turbines were reasonable, and regulations after market closure were insignificant.

3.2 Analysis of market results

The variations in the hourly area price for Western Denmark is analysed in Table 2 for the three years 2006, 2007 and 2008. The available infrastructure was nearly the same in all the three years, only the transmission capacity between Western Denmark and Germany has been increased. Table 2 shows that the number of hours with extreme area prices, below 5 €/MWh or above 100 €/MWh, is quite small.

Table 2. Prices in Nord Pool price area Western Denmark.

	2006	2007	2008
Nord Pool System price, €/MWh	49.01	29.09	45.74
Area price €/MWh	45.81	34.82	58.33
EEX price, €/MWh	55.04	41.93	69.89
Area price >10 € lower than system price	1799	444	163
Hours below 5 €/MWh	80	185	63
Area price >10 € higher than system price	458	1691	4066
Hours above 100 €/MWh	11	105	293
Hours above 200 €/MWh	0	26	0
Hours above 400 €/MWh	0	5	0
2 or more consecutive hours above 100 €/MWh, events	2	25	34
3 or more consecutive hours above 100 €/MWh, events	1	16	21
6 or more consecutive hours above 100 €/MWh, events	0	2	9
Wind production above 100 % of consumption, hours	27	50	43
Wind production below 10 % of consumption, hours	381	371	352
Above 100 €/MWh and wind production below 10 % of consumption, hours	7	8	12
12 or more consecutive hours with wind production below 10 % of consumption, events	13	9	7
Highest number of consecutive hours with wind production below 10 % of consumption	40	76	25
Above 100 €/MWh and up-regulation more than 20 % higher. hours	1	5	22
Down-regulation negative price, hours	201	137	46
Up-regulation above 100 €/MWh, hours	68	204	585
Up-regulation above 200 €/MWh, hours	1	65	120
Elbas (intraday market): Price quotations, Elbas, hours (from April 2007)	0	1070	1834
Elbas: Difference more than 10 € to area price, hours	0	132	622
Southbound transit, hours	1722	4025	5098
Northbound transit, hours	3324	1091	538
Transit between Sweden and Norway, hours	2130	2678	2634
Export from DK-West to all neighbours, hours	1554	849	342
Import to DK-West from all neighbours, hours	29	116	171

The production from the same wind turbine capacity was 20 % higher in 2007 than in 2006 and in-between in 2008. 2006 was a dry year in Norway and Sweden, leading to import from Denmark, while 2007 and 2008 have been more wet years with export to Denmark and further to Germany. However, the much higher prices in 2008 are reflecting the much higher EUA (CO_2 allowances) prices in 2008 than the almost zero price level for 2007.

Figure 2 shows the number of hours with differences between the area price for Western Denmark and the Nord Pool system price. In all years the number of hours with extreme price below 5 €/MWh or above 100€/MWh were negligible, except for hours above 100 €/MWh in 2008. In the dry year 2006 the average area price in Western Denmark was 3 € lower than the system price, and there were far more hours with area prices more than 10 €/MWh lower than the system price than there were hours with prices above. In the following two wet years 2007 and 2008 the numbers of hours with prices more than 10 €/MWh above the system price were much higher.

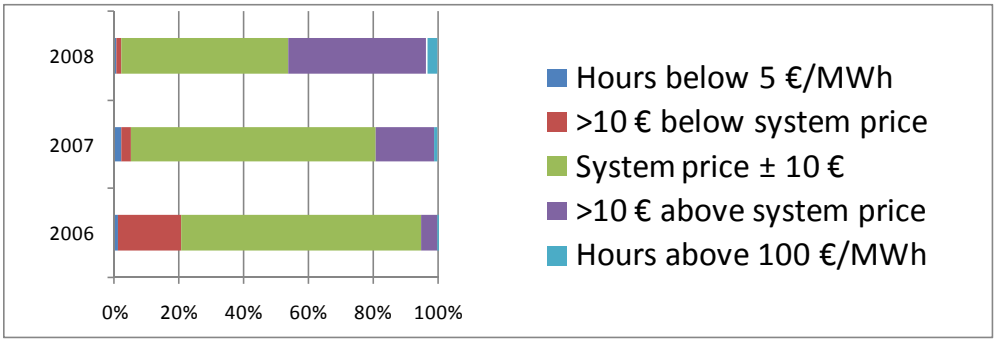

Figure 2. Western Denmark. Differences between area prices and Nord Pool system price, 2006-2008.

3.3 Identification of consecutive extreme hours

Figure 3 shows the number of "extreme" hours in 2007. However, the criteria for extreme hours were selected quite modest. These are hours above 100 €/MWh divided into single hours and consecutive hours, and up-regulation above 100 €/MWh. On the other hand wind production above the consumption within the price area. The latter situation will lead to low or zero prices, if the demand for export is too low.

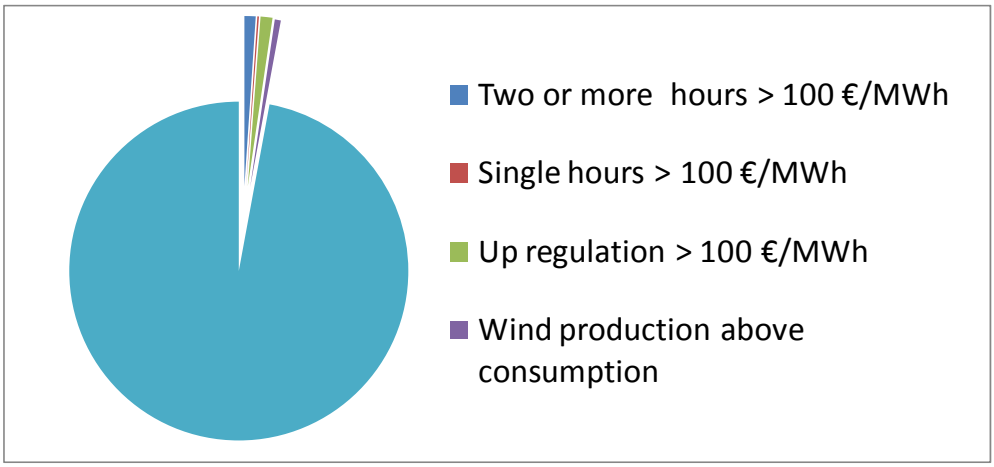

Figure 3. Western Denmark. Extreme hours 2007.

Currently, low supply from wind is not critical for Western Denmark, but problems may occur in the future, if the existing thermal capacity will be reduced. Limited supply from wind (here defined as 10 % of the consumption – or less than half of the annual average) is found in about 4 % of all hours. However, most of those hours are consecutive, so short-term storages will be of little help. Longer periods (e.g. 12

hours or more) with little or now wind will occur roughly once a month. The longest period with low wind that was found during the three years was 76 hours in November 2007.

3.4 Wind production during storm

When the wind is too strong, electricity generation from wind turbines will be cut off for security reasons. This could be the most serious impact of intermittency. However, these events are quite seldom.

During the worst storm in recent years (Saturday 8 January 2005) some 2000 MW wind turbines in Western Denmark stopped due to wind speeds more than 25 m/s of mean wind. The TSO had to buy large amounts of regulation power. During the night the area spot and regulation prices had been zero, but prices were not abnormal during the outage of the wind capacity. Thus, the combined spot and balancing market was able to handle this particular event. However, by chance this was a Saturday with lower demand than weekdays.

The previous storm was 3 December 1999. At this time there was much less wind power in Denmark.

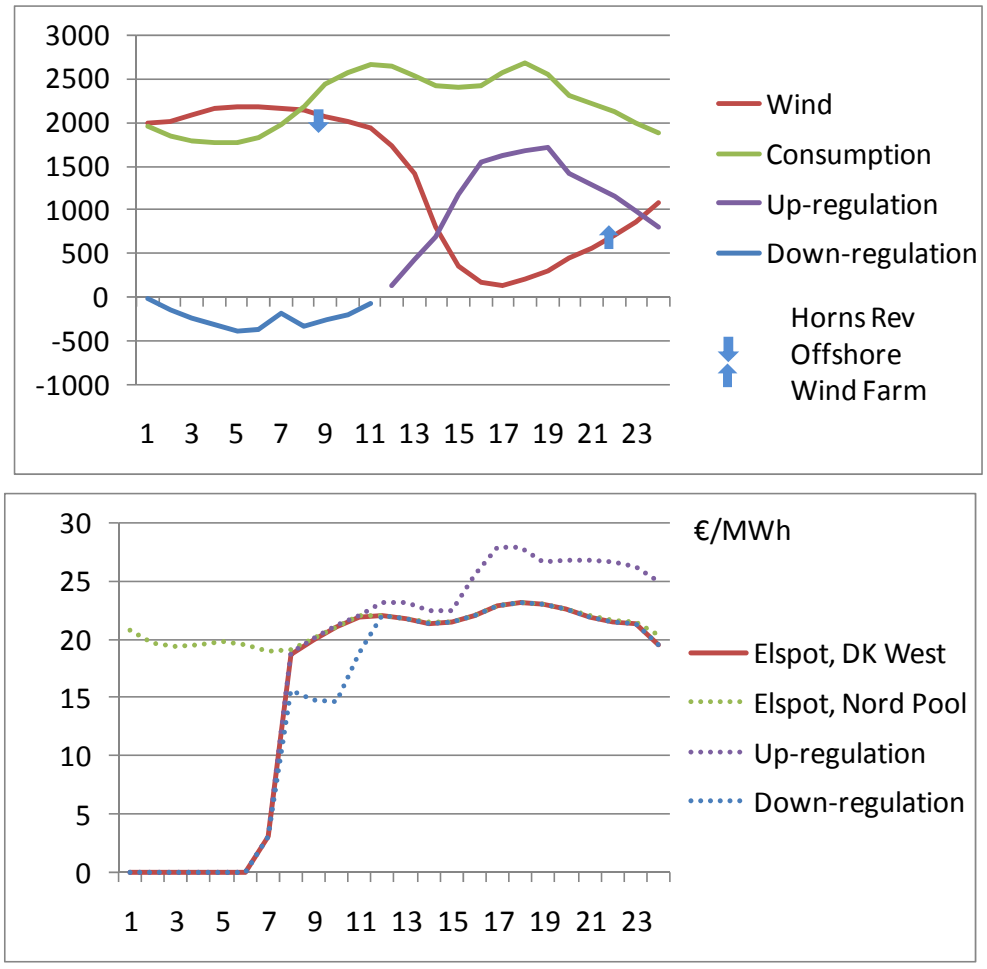

Figure 4. Western Denmark Electricity generation and market prices during storm 8 January 2005.

3.5 Market development until 2007

A major effort in the development of the market was taken already in 2004-05 by the TSOs in cooperation with a group of traders (commercial aggregators also acting as balance responsible parties), each with several small and medium scale CHP units in their 'stables', were introduced to the market, instead of receiving a three-level time-of-day tariff. These units – with capacities up to 100 MW – operate on-off with heat storages for the heat supply in more than 100 towns and villages as well as industries. In total small

and medium scale CHP covers 18 % of the thermal capacity and 20 % of the total generation in 2007, a little more than wind generation.

It means that decentral CHP above 10 MW must take part in the market from 2005 (above 5 MW from 2007). In addition, daily auctions for reserves from April 2007, and at the same time the intraday market Elbas was introduced introduced in Western Denmark.

This effort may be seen as an early full-scale example of 'virtual power plants', including the software needed for operation of the various markets.

3.6 Intraday market

The intraday market, Elbas, with continuous trade until closure time one hour before delivery, mainly works as a mechanism for fine-tuning of the day-ahead prices. In 2008 there were price quotations for Western Denmark in about 20 % of the time. This type of market was originally introduced in Finland in 1996 (EL-EX) and shortly after merged with Nord Pool with trade also in Sweden and later Eastern Denmark and parts of Germany. Thus, from its origin this market was designed to meet the requirements of large-electricity consuming industries, rather than the challenges of wind energy.

The intraday market may be an important tool for generators to reduce their production forecast errors, and thus reduce their exposure to imbalance costs. This is possible even when the intraday market may have a low liquidity. However, the practical experience with the intraday market is still limited in regions with a large share of wind power.

3.7 The balancing market

The regulating power market is run by the Nordic TSOs based on bids from the Nordic area. In general parties are penalised if they cannot fulfil their bids to the day-ahead market. It depends though on the need for balancing. If the system in a specific situation requires upward balancing and a producer is below his expected production, he will be penalised by the cost of balancing up. However, the power producer will not be penalised if he is above his expected production. In this case the spot price for the surplus production will be paid. This mechanism is applied vice-versa for balancing down (NordPool, 2007).

The key principle for this market (partly including West Denmark[1]) is that the balance responsible parties submit bids for upward or downward regulation to the local system operator stating the offered quantity energy payment. The system operators send the regulating power bids to a 'coordinator' (Statnett in Norway), who compiles a joint list of all regulating power bids in the Nordic countries, sorted by price. If regulation in the joint Nordic synchronic system is required, the most advantageous regulating power bids on the joint list are activated taking grid congestions into consideration.

Table 2 also shows that there are a number of hours with negative down-regulation prices, although the number of hours has been significantly reduced from 2006 to 2008. These negative prices are due to high start and stop costs of decentralized CHP generation in Denmark. Also down regulation by using electricity in electric boilers in district heating systems may lead to negative prices.

3.8 Issues for intermittent generation

Wind power is the main source of intermittent generation. Large amount of wind power will have a significant influence on the prices on the day-ahead market, because it is possible to predict the volume of wind power within the time-frame 12-36 hours with relatively good accuracy. However, uncertainties remain until real time delivery. On the other hand large modern wind turbines can exhibit some very short-term regulation capability.

1 "Energinet.dk West will exchange supportive power with the synchronous system after contacting Statnett." Nordic Grid Code 2007, p. 75.

Regulation capability of wind power

Wind power will be able to respond to system requirement in the short-term – in particular for a few seconds or within an hour. The main barrier is several hours with little or no wind. The only means to meet this situation is reduced demand or other generators. Most of these situations will be addressed within the day-ahead spot market. A reduction in wind power production also makes it possible to use the wind turbines for providing both upward and downward regulation.

Energinet.dk will also explore the possibility of furnishing reactive reserves independently of the central production facilities in the future.

A situation with too much wind that stops a large number of wind turbines cannot be predicted very well with much certainty, but – as mentioned above – these situations are rare. Also, it is very unlikely that all turbines within one region stop at the same time. There will be time to activate other generators, and the TSO may increase the capacity for reserve capacity in daily auctions.

The traditional support scheme in the form of feed-in tariffs does not give wind generators an incentive to meet system needs. Thus, the key recommendation from the RESPOND project for support is to replace feed-in tariffs with premiums for distributed and renewable generators, and also to encourage these generators to take part in the whole range of spot and balancing markets (adapt regulation to that aim if necessary). The market premium that is required in addition to the market prices differs between countries and may be as low as € 13 per MWh for wind generators as in Denmark. This is a relatively small amount compared to the annual average electricity price around € 50 per MWh or few hours with extreme values above € 100 per MWh.

Response by peak load units

Installation of peak-load units, e.g. gas turbines to respond to the variability and unpredictability of intermittent generation should be recommended only when the response from hydro power, CHP systems or larger gas-fuelled units operating at intermediate load is insufficient.

Existing contingency units (e.g. hospitals) have been encouraged to participate in system security after a black-out in 2003. They may be used for the reserve and balancing market.

Use of heat distribution infrastructure and heat storages

Support schemes for micro CHP units mainly for individual homes are considered in the RESPOND project. There is a significant potential for micro-CHP in the UK and the Netherlands, which may replace gas-fired heat-only boilers. In Denmark the market for micro-CHP is much smaller, because of the large share of district heating. A large number of natural gas boilers that were installed in the 1980s and 1990s will be mature for replacement during the next decade. It is recommended that units designed for on-off operation with heat storage should be encouraged as standard for mass production (e.g. 3 kW electric), rather than very small units (e.g. 1 kW) for continuous operation, following the current heat requirement.

However, micro CHP is recommended only for the very small-scale heat distribution systems. Larger heat distribution systems or district heating systems offer a range of options for flexibility that is needed by the electricity system, e.g. electric boilers for down-regulation, or electric heat pumps for heat base load, which may be cut off, when up-regulation of electricity is needed.

In Denmark the district heating markets covers nearly 50 % of the market for space heating. With better insulation the heat demand from existing heat consumers will decrease, but new consumers can be added to existing network, and grids are being expanded to cover new developments of built-up areas and urban renewal – for example abandoned industrial sites or harbour areas in major cities. Transferring areas currently zoned for natural gas to district heating is also being considered in several studies, taking into account that the current zoning regulation dates back to the early 1980s.

3.9 Further market development

In the short term negative prices on the spot market are considered as the most important additional measure to address the challenge of the large amount of intermittent generation. Negative prices have already been introduced on the German EEX spot market, and from October 2009 a negative price floor at -200 €/MWh will be introduced by Nord Pool, which will be significant mainly for Denmark.

Negative prices will be an incentive for flexible generators to reduce their production – or consumers to use more – in few critical hours. Modern wind turbines are able to regulate their production more easily than most thermal generators.

Western Denmark was 'born' as a price area within Nord Pool. However, in addition to other measures, Energinet.dk in considering dividing Western Denmark into two price areas (Energinet.dk, 2007).

More transmission capacity is under construction or planned. This includes 600 MW or larger links between Western and Eastern Denmark, and links to Norway and the Netherlands.

Other measures considered in the System Plan 2007 by the TSO are demand response by all types of consumers, electrical vehicles with charge and discharge of batteries according to system needs, and active network management by the DSOs.

Price areas and locational transmission tariffs

An important recommendation from the RESPOND project has been locational transmission tariffs or zonal or nodal pricing. The aim is to give incentives to renewable and distributed generators to meet system needs in their location and operation. However, the possible variation of transmission tariffs that seldom exceed 10 €/MWh is small compared to the dramatic variations that is experienced on the spot and balancing markets. Even the differences of the annual averages among the price areas are much larger than possible variations in transmission tariffs.

4 Perspective for other regions

In all countries there is a day-ahead market. These markets have been developed significantly in recent years. Cross-border market coupling was established early in the Nordic region and recently between the Netherlands, Belgium and France, leading to more efficient price setting and trade within a region. In most regions of Europe, existing price areas follow national boundaries.

This is not efficient in large countries with a large penetration of wind power and bottlenecks in the transmission system. Splitting national markets into price areas that reflect these constraints have been practiced in the Nordic region for more than a decade. This leads to prices that reflect the expected amount of supply of wind power in each area, among other variables influencing the energy dispatch. To get the right price signals for generators and consumers, it is becoming increasingly important that the geographical price areas for the day-ahead market reflect the pattern of wind variations and transmission constraints.

Market splitting into price areas will also lead to more transparency concerning the need for new transmission capacity. Large and frequent price differences between neighbouring price areas clearly indicate the need for new transmission lines.

The Netherlands is similar to Western Denmark in area, climate, international connections, wind power and CHP, but the electricity system is six times larger. This indicates that this type of market splitting is very unlikely to be used within the Netherlands. In the UK the situation is quite different. There is already an imbalance between the location of generating capacity in the north and population centres in the south. So a large amount of wind power mainly in the north will add to the imbalance.

Some regions in Germany and Spain may have larger penetration of wind than Western Denmark, but these regions are not identified as price areas in the electricity markets.

5 Conclusion

The current market organisation was able to handle the current amount of wind power at 25 % of the regional consumption in Western Denmark. The most important features to handle the variability and unpredictability of wind power have been the international transmission lines and the large amount of CHP systems with heat storages within the region. However, much further penetration of wind power will also require additional measures, in particular demand response and use of new technologies, e.g. electricity storages.

The analysis shows that there have been relative few hours with extreme prices or consecutive hours with no wind or maximum wind. Even during the worst storm in ten years, when most of the wind capacity was cut off due to high wind speed, prices on the balancing market were not abnormal.

The current liberalised electricity market has created an institutional structure of the electricity supply with an open and much more dynamic development than in the previous organisation of the power industry. The spot and balancing markets are changed and adapted continuously in many countries to meet the new needs of the electricity system with increasing and large shares of intermittent type of renewable generation and distributed technologies. Generally, most of the measures proposed in the RESPOND project to accommodate more intermittent generation can be summarised and categorised as measures or regulation for:

- Increasing the flexibility of conventional generation, i.e. hydro power with reservoirs and gas fuelled plants.
- Constructing more transmission capacity.
- Enhance response capabilities by peak load units and heat distribution systems supplied by CHP.
- Establish commercial aggregators to develop ‘virtual power plants’.
- Establish geographical price areas for spot and balancing markets to provide price signals for demand response and network congestion management.
- Regulation for proper pricing for incentivising demand response and Active Network Management by DSOs.

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