European Network of
Transmission System Operators
for Electricity

# IMPACT OF INCREASED AMOUNTS OF RENEWABLE ENERGY ON NORDIC POWER SYSTEM OPERATION

31.08.2010

# Summary

The Electricity Market Group, which is a working group for the Nordic Council of Ministers responsible to follow up the Ministers' declarations in the area of electricity markets, requested the Nordic Transmission System Operators (TSOs) to present a plan on how to handle increased amounts of renewable energy in operation of the Nordic power system. ENTSO-E Regional group Nordic (RGN) has appointed the Operational Development Group (NOD) for the task. This report is a response to the request.

The Nordic TSOs have chosen to focus on wind power. This is because the volumes from this production technology are expected to grow significantly and that the fluctuations in production will give new challenges for the power system operation.

Approximately 5000 MW of wind power is currently installed in the Nordic Grid. Wind power generation in the Nordic countries is expected to increase in the coming decade due to the European wide climate policy and renewable support systems. There are extensive proposed and planned projects in the Nordic region. The total capacity of all proposed projects widely exceeds the planned targets and forecasts.

The total amount of wind power capacity in the synchronous Nordic power system can be estimated to increase up to about 15-20 GW in 2020. The rapid installed capacities in for example Germany and Spain show that the development may be quick. As a comparison the total installed production capacity of all categories in the Nordic area today is about 100 GW.

Renewable energy is less flexible to the price variations in the energy markets than conventional production and therefore creates an increased need for flexible production and consumption which can react to price variations, i.e. conventional hydro and thermal plants, pump storage power plants, electrolytic hydrogen production, heaters, electric cars and others. There are potentially many flexible regulating resources in the Nordic power system first of all in hydro power. The system can therefore absorb large amounts of renewable energy, if the transmission networks are reinforced to accommodate the need to balance the fluctuating production from renewable energy over large areas.

To prepare for integration of increased volumes of renewable energy, the TSOs will initiate actions related to system operation. The TSOs will:

- Implement actions to mitigate the current weakening trend of the Nordic frequency quality
- Develop harmonized Nordic technical requirements for the installation of renewable production units including requirements for ability to deliver ancillary services
- Contribute to development of more physical flexibility in production and consumption which can react to price variations in the market



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- Contribute to development of more flexible bids in all market segments including the balancing market and delivery of ancillary services
- Develop a suitable and harmonized market design for balancing especially close to the operating hour
- Develop an effective exchange of resources between different synchronous systems
- Develop harmonized Nordic methods to ensure sufficient flexibility to handle the fluctuations in renewable production.
- Contribute to development of improved forecasting procedures and tools for fluctuating production
- Implement requirements for real time measurement of physical production

With these planned actions, the Nordic TSOs are convinced that the Nordic system can be developed to integrate more renewable production without disturbing the system reliability. More in-depth analyses must be performed in the years to come of both technical and economical character related to these issues.



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# Content





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# 1 INTRODUCTION

The Electricity Market Group, which is the working group for the Nordic Council of Ministers and responsible for following through the Ministers' declarations in the area of electricity markets, requested 2.11.2009 the Nordic Transmission System Operators (TSO) to present a plan on how to handle increased amounts of renewable energy in operation of the Nordic power system. ENTSO-E Regional group Nordic (RGN) has appointed the Operational Development Group (NOD) with the task. This report is a response to this request.

The group's members:

| | |
|---|---|
| Gunnar Nilssen | Statnett |
| Jyrki Uusitalo | Fingrid |
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| Per-Ivar Sigelfeldt | Svenska Kraftnät |

Report Secretary:

| | |
|---|---|
| Marit Larssen | Statnett |

The report is based on experiences and expectations from system operation. The group has also checked with results from existing studies, like the European Wind Integration Study (EWIS), and internally initiated studies by the respective TSOs.

We have in this request chosen to concentrate on wind power. This is because the volumes from this production technology are expected to grow significantly and that the fluctuations in production will give new challenges for system operation.

Wind power production has different characteristics from conventional power production. It introduces additional variability and uncertainty into the operation of the power system. In particular is the uncertainty in production level a challenge for system operation.

The present volumes of wind power production installed in the Nordic countries are still limited, with exception of Denmark. But due to the EU climate policy targets and as the rapid development in countries such as Germany and Spain show, this can change during the next ten years. The current and estimated volumes of wind power installed in the Nordic countries are presented in the following section.

Chapter 3 addresses the prerequisites for operating the power system, whereas chapter 4 explains the impact large amounts of wind power will have on the operation of the Nordic power system. Required actions to accommodate large scale integration of wind power are presented in chapter 5.

# 2 WIND GENERATION VOLUMES

About 5000 MW of wind power is currently installed in the Nordic Grid. The details of registered wind power installed and energy delivered in 2009 can be seen in the table 1. The table also contains figures for 2020 as a rouge indication of possible development.

| Country | Installed today, 2009<br>MW/TWh | Estimated/Goal, 2020<br>MW/TWh |
|---|---|---|
| Denmark [i] | 3273/9 | 5635/14 |
| Sweden [ii] | 1448/2,52 | 4550/12,5 |
| Finland [iii] | 147/0,3 | 2500/6 |
| Norway[iv] | 431/1 | 5000? /12? |
| Total | 5300/13 | 17700/44,5 |

TABLE 1 WIND POWER INSTALLED TODAY AND ESTIMATES AND ASSUMPTIONS FOR 2020

Wind power generation in the Nordic countries is expected to increase in the coming decade due to the European wide climate policy and renewable support systems. There are extensive proposed and planned projects in the Nordic region. The total capacity of all proposed projects widely exceeds the planned targets and forecasts.

The target set by the government in Finland is 6 TWh of wind power by 2020.

In Sweden the government has recently updated a target for wind power 12.5 TWh.

For Norway the goal has been 3 TWh of wind power in 2010, which will not be achieved. Currently there are no official estimates, in this paper the estimation for 2020 is set to be in the same level as the Swedish figures partly due to the proposed green certificate market with Sweden.

Denmark’s goal is 20 TWh of wind power by 2025, about 50% of the total demand of electrical energy.

If we sum up the estimates the total amount of wind power capacity in the synchronous Nordic power system can be estimated to increase up to about 15-20 GW in 2020. The rapid installed capacities in for example Germany and Spain show that the development may be quick. As a comparison the total installed production capacity of all production types in the Nordic area is today about 100 GW.

In the northern part of the European continent there are numerous plans for large wind power parks in addition to the ones already build, which will influence the Nordic system operation. This implies that the demand for flexible production resources in the Nordic synchronous area will be enforced.

# 3 PRECONDITIONS FOR SYSTEM OPERATION

Successful wind integration addresses challenges for the electricity markets, the transmission systems as well as for system operation.

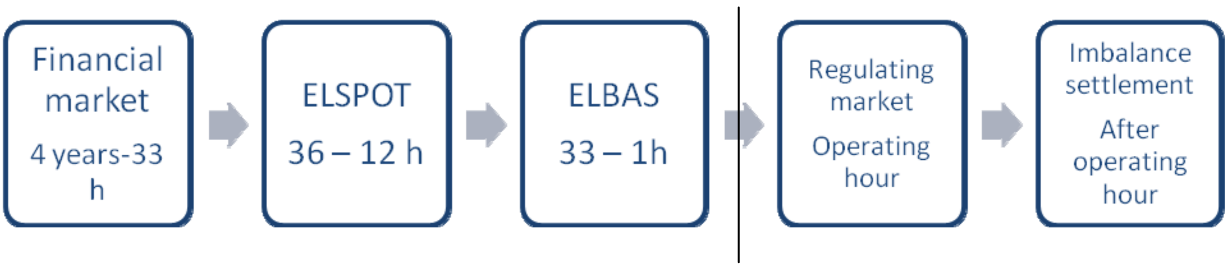
Integrated markets and strong transmission networks ensure the accommodation of varying wind generation. Sufficient flexible production capacity is needed to be able to secure the balance between consumption and production at all times at different load and exchange situations. Operational measures needs to be developed in order to ensure high level system security.

## 3.1 AN EFFECTIVE BALANCING MODEL- BRP AND TSO ROLES

The power system is dependent upon a continuous and momentary balance between production, consumption and exchanges. The Nordic energy market is supposed to secure the balance on an hourly basis. In the Nordic area 70% (2009)[v] of the consumption is traded on the Elspot market 12-36 hours ahead of delivery.

The balance responsible parties (after this called BRPs) in the Nordic power market have according to regulations/rules and agreements to schedule generation and trade themselves into balance in the day-ahead market. The resulting hourly energy notifications (after this called notification plans) are in fact the first level of plans for the physical operation of the power system. After the day-ahead market the BRPs can trade in the intra-day market until 1 hour ahead of delivery (2h in the Norwegian market).

After the intra-day market has closed, the role of balancing is centralised and performed by the TSOs through different tools like primary regulation and the Nordic regulating power market.




Difference between notification plans and realised production during the operation hour creates an imbalance for the BRPs. The imbalances create an economical cost for the BRPs, and this is settled after the operating hour. In this sense wind power producers are as other BRPs economically responsible for their imbalances. Typically accuracy of wind power forecasts improves significantly closer to the operating hour. It is therefore important that late updates of the forecasts are allowed for in balancing actions before real time from BRPs and/or TSOs through trade, changed production/consumption plans or planned activations of reserves to reduce the need for costly real time reserves.

Increased volumes of renewable production may introduce a need to consider changing or moderating the current balancing model.

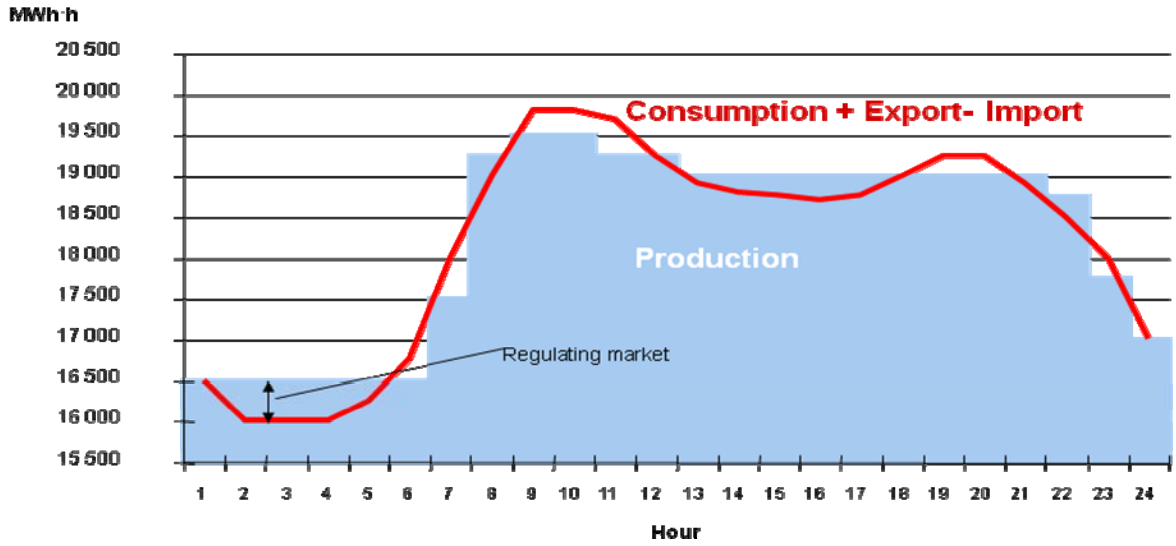



**FIGURE 1 THE BLUE PRODUCTION GRAPH REPRESENTS THE HOURLY NOTIFICATIONS PLAN. THE TSO MUST MAINTAIN THE MOMENTARY BALANCE BETWEEN PRODUCTION, CONSUMPTION AND EXCHANGE IN THE OPERATIONAL HOUR. THE REGULATING MARKET (TERTIARY RESERVE) IS THE TOOL TO ADJUST THE PRODUCTION TO THE ACTUAL CONSUMPTION (NORDIC MODEL).**

In the Nordic synchronous area the essential parameter in controlling the system balance is the system frequency. Normal state operation is expressed through the criteria that the frequency during normal operations has to be kept within the interval of 49, 9 - 50, 1 Hz.

If generation exceeds consumption, frequency rises and, if consumption exceeds generation, frequency falls.

The TSOs utilise the automatic reserves and the regulating power market to adjust the production to the actual consumption in the operational hour. The needed amount of automatic reserves has been defined by the Nordic TSOs, i.e. 600 MW in automatic reserves for normal operation and about 1000 MW to cover the dimensioning fault.



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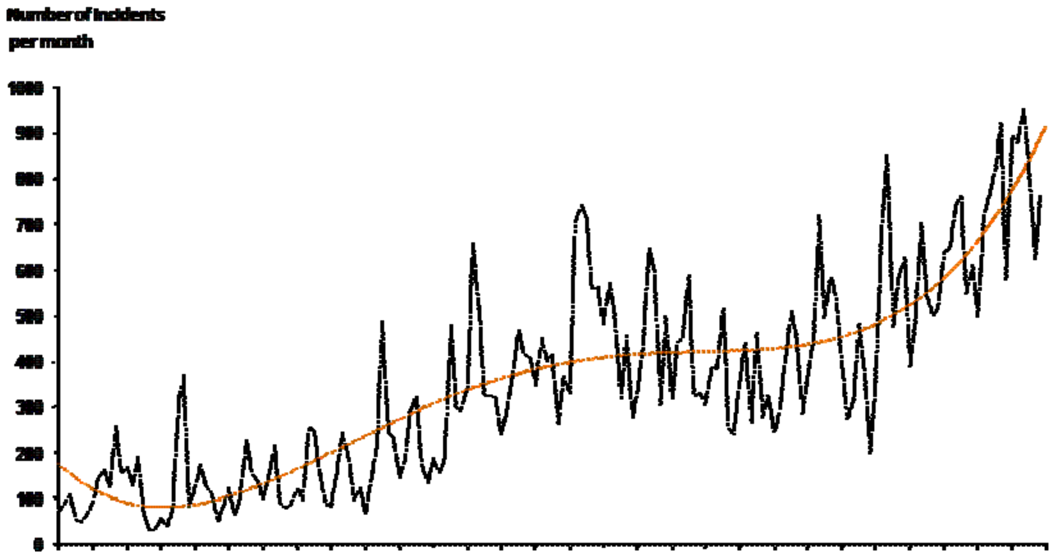


**FIGURE 2 FREQUENCY QUALITY, FROM 1995 TO 2010**

The quality of the frequency of the synchronous Nordic power system has worsened during the last decade. There are many reasons for this. However the weakening trend is a threat for system security and there is ongoing work with several actions by the TSOs to mitigate this trend and improve the frequency quality. This work will also include a review of the requirements and specifications for reserves. The expected development in production and grid structure, with more wind production and stronger interconnections between the European countries, will lead to new similar reviews being necessary in the future.

### 3.1.1 THE BALANCING MODEL IN WEST-DENMARK

In the Danish area operational planning and expectations to the system imbalance ahead in time, ensures that more than 80 % of the system imbalance is handled with manual reserves. This minimizes the need for automatic "high quality" reserves. This also ensures that as much of the automatic reserves as possible are available for the unexpected events as power plant failure etc.

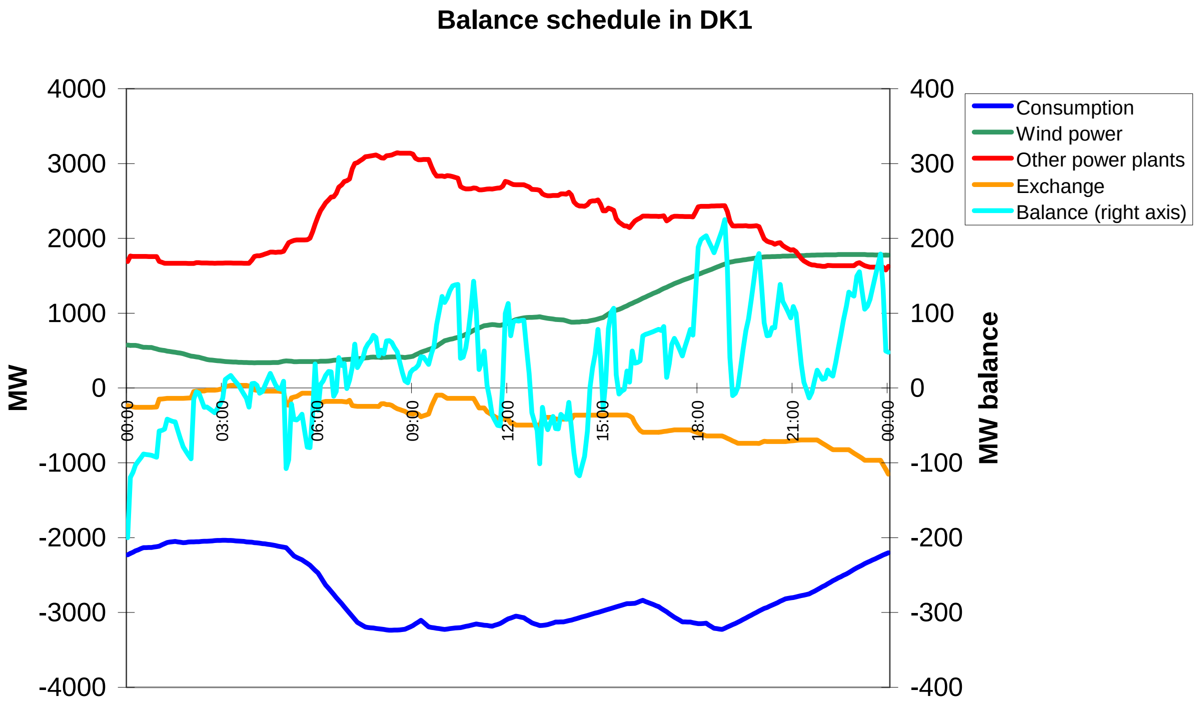


**FIGURE 3 WITH OPERATIONAL SCHEDULES FROM THE PBR'S (RED GRAPH), WIND POWER FORECAST (GREEN GRAPH), CONSUMPTION FORECAST (BLUE GRAPH) AND INTERCONNECTOR EXCHANGE SCHEDULES (YELLOW) THE TOTAL EXPECTED IMBALANCE CAN BE CALCULATED. THIS INFORMATION IS USED TO ACTIVATE REGULATION IN THE TERTIARY MARKET. THIS METHOD ENSURES THAT MORE THAN 80 % OF THE TOTAL SYSTEM IMBALANCE CAN BE HANDLED WITH MANUALLY RESERVES AND SAVE THE AMOUNT OF NEEDED AUTOMATIC RESERVES. (DANISH MODEL)**

## 3.2 STRONG TRANSMISSION NETWORKS

Wind variations can be exploited over larger areas. Thus the transmission networks have to be strong with a capacity that accommodates the need to balance the fluctuating production from wind power. As long as grid capacity is available, the required flexible regulation capacity may be shared between countries.

Currently, a large part of the incidents with frequency exceeding agreed limits in the Nordic system are linked to highly congested corridors. In the Nordic grid there is continuously occasions where the grid is fully loaded in several corridors at the same time.

This reduces the effect of offsetting the regional imbalances through cross-border flows.

A significant strengthening of the transmission networks is a necessity to be able to implement large volumes of wind power.

Similarly the local/regional networks need to have sufficient transmission capacity to accommodate the fluctuating production from the renewable energy. The local/regional networks must also have the adequate amount of system stabilizing components to support the voltage and system stability when increased amounts of renewable energy production are installed.



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The TSOs continuously makes plans for how to strengthen important corridors in the network, such plans can be found in ENTSO-E's pilot Ten-Year Network Development Plan (TYNDP) ENTSO-E amongst other.[vi]

## 3.3 SUFFICIENT PRODUCTION CAPACITY

Wind power production introduces additional variability and uncertainty into the operation of the power system. To meet this challenge sufficient flexible production capacity will be needed at all time frames, day-ahead, intra-day and in the balancing market to offset the variation in the renewable energy production level.

Renewable and other types of fluctuating power production are not or are at least less flexible to variations in the prices in the energy markets than conventional production and this creates a need for flexible production capacity which can react to price variations, e.g. conventional hydro, thermal and pump storage power plants. Changed procedures and equipment to create more flexibility in fluctuating power production is also a prerequisite to be able to handle all balancing situations.

The market design must support the construction of new and consolidation of existing flexible production capacity and load, which can balance the fluctuating power production when the weather conditions changes.

## 3.4 INTEGRATED AND FUNCTIONING CROSS-BORDER MARKETS

Standardized market arrangements are important for a well-functioning market. The national markets need to be integrated so that cross-border trade of the renewable and fluctuating energy is possible in the day-ahead and the intra-day markets

That implies the need for harmonized framework, rules and gate closure times which will help ensure that the TSOs have appropriate means to maintain system security and the BRPs can trade efficiently in the Nordic and the European markets.

It is expected that especially the intra-day market will "grow" due to the fluctuations introduced by renewable energy, and consequently production plans from renewable and conventional units will change a lot close to operating hour. This is a challenge for the system operation as handling of congestions and frequency to some extent must be planned and actions taken before real time (operational planning). There must be sufficient time available between gate closure for the energy market and operating hour for considerations and procedures for both BRPs and TSOs.



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# 4 IMPACT OF LARGE SCALE WIND POWER ON POWER SYSTEM OPERATION

The main challenges for the TSOs concerning system operation with a significant contribution from wind generation are:

- Balancing production and consumption in the presence of wind variability
- Managing of different technical features of wind generation –e.g. amount of rotating mass, voltage support and short circuit capacity.

These challenges were also found in the comprehensive European Wind Integration Study (EWIS)[vii].

As the amount of wind generation increases, the challenges related to the variability and uncertainty of wind are expected to become more significant. Improvements in forecasting and the extended use of flexible generation units and load are the principal mitigations that are currently perceived to address these challenges.

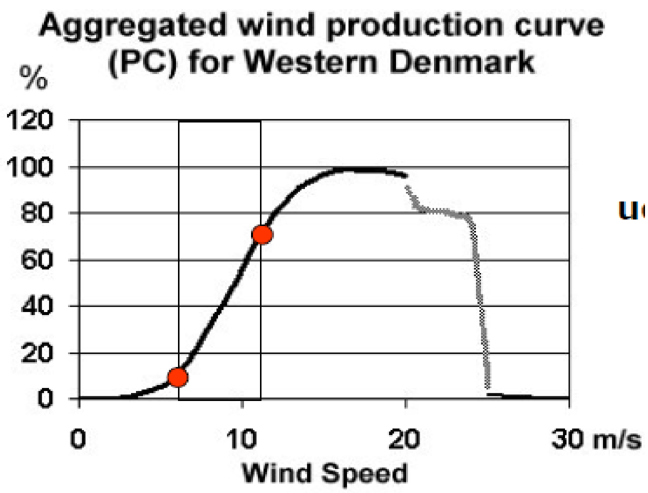


FIGURE 4 AGGREGATED WIND TURBINE PRODUCTION CURVE FOR WESTERN DENMARK

Today Denmark has the highest wind penetration in the world. If the wind forecast ranges from gentle breeze to fresh breeze the power output can vary between 200 to 1600 MW in western Denmark. Depending on where the production level is on the turbine production curve, a deviation in the wind forecast of ±1 m/s can result in ± 320 MW. Hence the production level of wind power varies largely and introduces more uncertainty into the operation of the power system. The wind power production at periods with high wind power production should be easy to forecast, but if the wind speed goes over a certain limit (25m/s) the wind power turbines start to shut down as a safety measure. This means that regional wise the balance can be changed from full production to full stop within a relative short time frame (4 - 6 h). Forecasting the difference in production from one hour to another, as well as during the operation hour, is an important focus point when it comes to integrating large amounts of wind power into the power system.



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When considering wind power variations in the Nordic area, we are most likely considering a geographical spread of the wind turbines. The geographical spread will in fact help mitigate the variations of wind power as the weather front will not pass the wind parks at the same time. Looking at one wind park, the second to second variation will be smoothened out, since a wind gust do not pass the turbines standing 100 meters apart at the same time. Analogous for a larger area with distributed wind farms the minute wise variations will be smoothed out. In the scale of 200×200km$^2$ the second and minute variations will not be significant[viii].

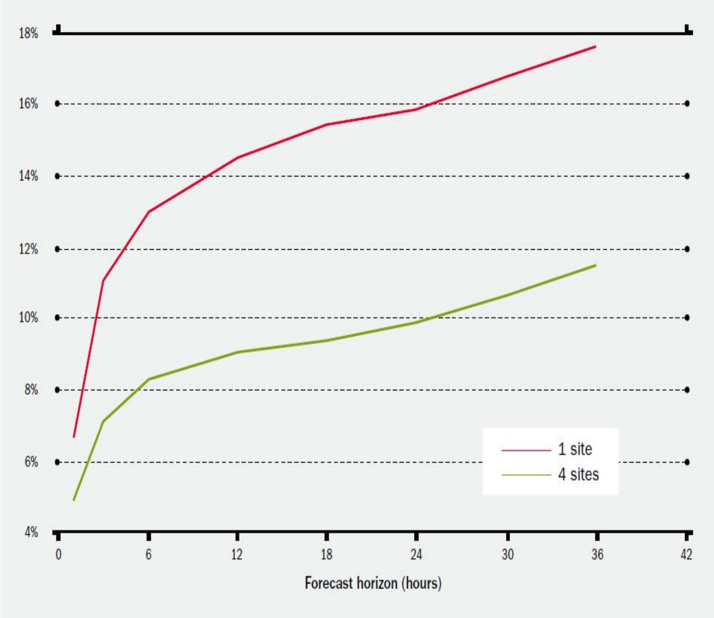


**FIGURE 5 MEAN ABSOLUTE ERROR AS % OF CAPACITY- YEAR 2004 FINLAND**

Figure 5 above illustrates this by showing prediction errors (mean absolute) for a single site and for the aggregated output of four sites (with a maximum distance of 380 km), for a range of forecast horizons. Thus fluctuations in wind power production due to meteorological variations are smoothed out over larger areas and allows for a higher predictability.

The TSOs are working on a correlation analysis for wind production in all the Nordic countries to investigate the smoothing effects of the existing wind power production.

## 4.1 INCREASED NEED FOR BALANCING – FORECAST ERROR

The forecasts are more accurate closer to the operation hour, like the research from Denmark shows; the forecast error in percent decreases closer to the operational hour, from 5,2 day-ahead to 3,0 one hour ahead of the operating hour. This means that the resulting regulation needs are smaller when the BRP’s can trade in the intra-day market to reduce their imbalances, as they can update their forecasts, and have a more accurate plan than they had before delivering their bids0 day-ahead.



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| NRMSE [%] DK1 | Load forecast error | Wind power forecast error |
|---|---|---|
| day-ahead | 2,5 | 5,2 |
| 4h ahead | 1,5 | 3,6 |
| 2h ahead | 1,5 | 3,3 |
| 1h ahead | 1,5 | 3,0 |

TABLE 2 LEVEL OF ACCURACY OF WIND POWER PREDICTIONS WILL INCREASE WHEN PREDICTING FOR LARGER AREAS AND FOR SHORTER TIME SCALES. EXAMPLE FROM DENMARK WEST (NRMSE = NORMALIZED ROOT MEAN SQUARE ERROR, % OF INSTALLED WIND CAPACITY). NOTE THAT THE ERROR IS CALCULATED ON BASIS OF SETTLEMENT MEASUREMENTS THAT THE FORECAST SYSTEM DID NOT HAVE THIS ACCURATE INFORMATION ABOUT THE ACTUAL PRODUCTION AT THE TIME THAT THE FORECASTS WERE CALCULATED. THE ERROR ON THE ONLINE ESTIMATION OF THE WIND PRODUCTION THEREBY INFLUENCES THE RESULT THAT YOU SEE IN TABLE 2, FIGURE 5 AND FIGURE 6. SOURCE: ENERGINET.DK

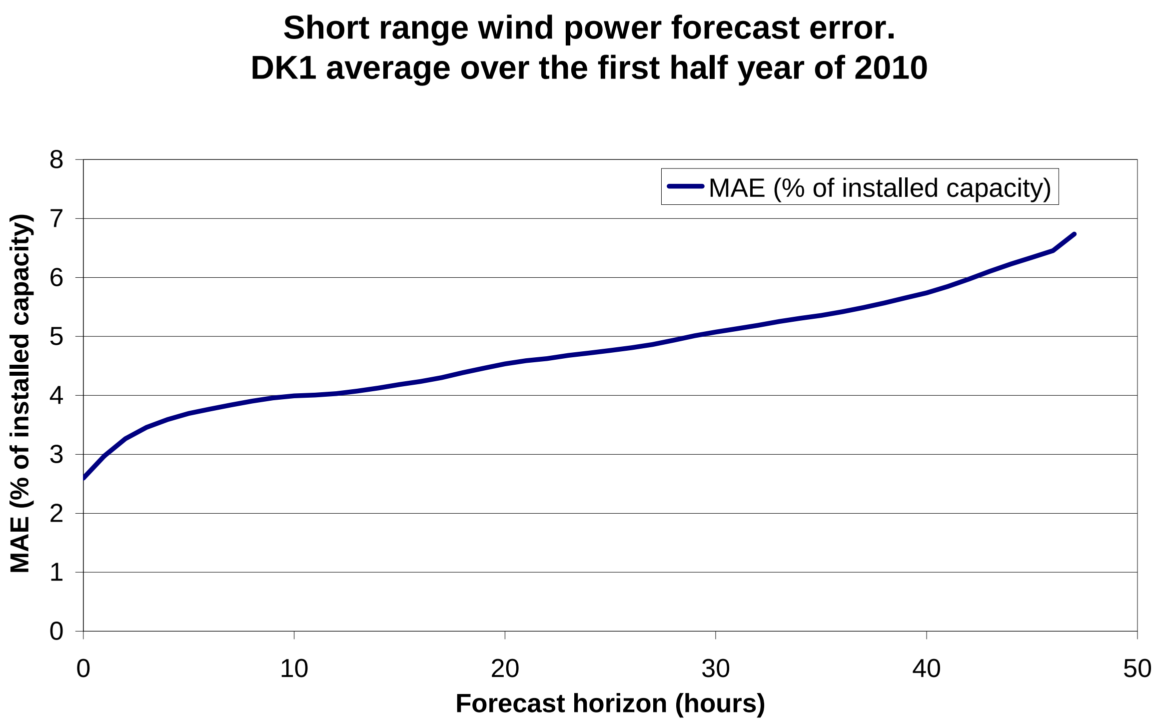


FIGURE 6 MEAN ABSOLUTE ERROR AS % OF CAPACITY- YEAR 2010 DENMARK WEST (DK1) OF THE SHORT RANGE FORECAST. THE GRAPH SHOWS THE AVERAGE ERROR AS FUNCTION OF FORECAST HORIZON WHEN LOOKING AT ALL CALCULATED FORECASTS AT ANY GIVEN TIME. NOTE THAT THE FORECAST ERROR IS CALCULATED ON BASIS OF SETTLEMENT DATA NOT KNOWN IN REAL TIME. SO THE MEAN ABSOLUTE ERROR IN THE OPERATIONAL HOUR (0 HOUR HORIZON) IS NOT ZERO. SOURCE: ENERGINET.DK

Today's forecasts can predict the trends rather well, but the exact time of the front is often more difficult to predict.

Variations in the production from wind power plants and other fluctuating production introduces more uncertainty into the planned balance of the power system. Denmark has experienced different examples where wind power forecasts in West-Denmark compared to real output range from almost 0 % to in worst case 50 % of installed capacity when evaluating the day-ahead forecast.

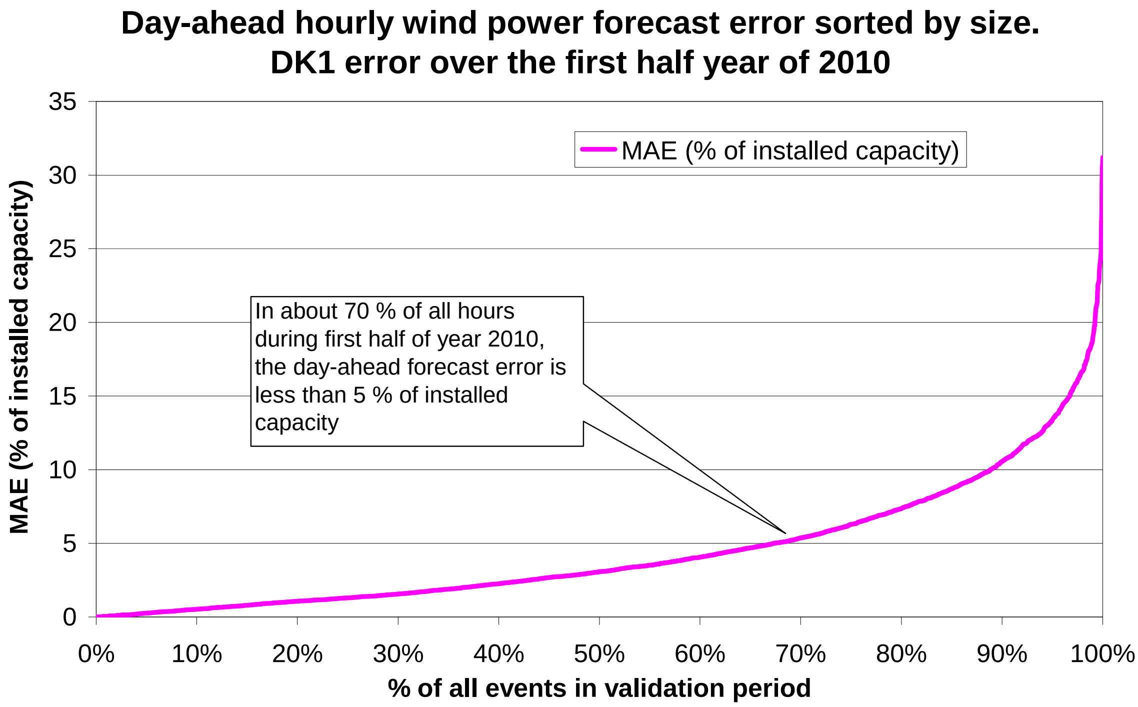


**FIGURE 7 MEAN ABSOLUTE ERROR AS % OF CAPACITY- YEAR 2010 DENMARK WEST (DK1) OF THE DAY AHEAD FORECAST CALCULATED IN THE MORNING AT 8 O'CLOCK. ERRORS ARE SORTED BY SIZE. THE BIG ERRORS ARE RARE BUT DO OCCUR. IN ABOUT 70 % OF ALL FORECAST HOURS THE DAY-AHEAD ERROR IS LESS THAN 5 % OF INSTALLED CAPACITY**

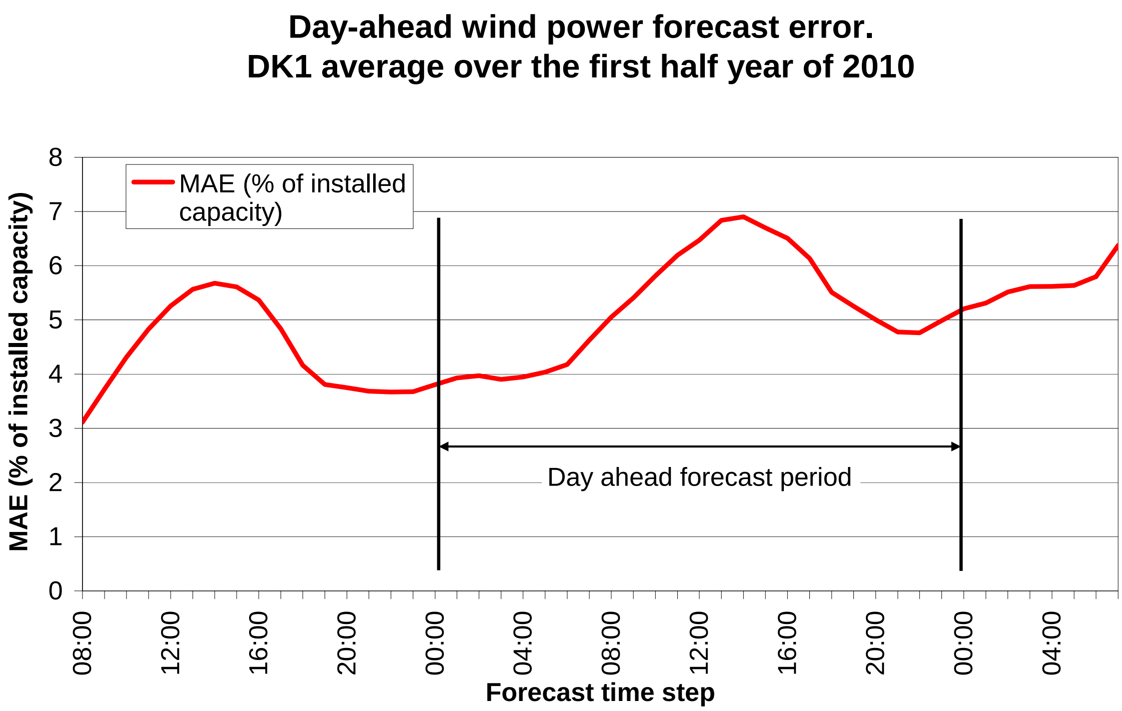


**FIGURE 8 MEAN ABSOLUTE ERROR AS % OF CAPACITY- YEAR 2010 DENMARK WEST (DK1) OF THE DAY AHEAD FORECAST CALCULATED IN THE MORNING AT 8 O'CLOCK. THE GRAPH CLEARLY SHOWS THAT THE FORECAST ERROR FOLLOWS THE DIURNAL CYCLE OF THE DAY. AS THE WIND TENDS TO RISE IN THE MORNING THE AVERAGE ERROR IS BIGGER DURING THE MIDDLE OF THE DAY. SOURCE: ENERGINET.DK**

The accuracy of the meteorological forecast is the main source to the wind power production forecast error and the source to improving the forecast lays in the effort to improve the meteorological forecasts. Over the recent years many such projects has be done in different consortiums.

Improvement in meteorological forecasts and the models to convert m/s into MW productions has over the last ten years lead to a reduction in the day-ahead wind power forecast from 8,5 % to 5 %  (NRMSE = normalized root mean square error, % of installed wind capacity).

However the need for ever more accurate short range forecasts (0 to 6 hours) to improve the efficiency of balancing the system on basis of expected wind power production, will need a closer corporation in the region to gather and share online meteorological information's which gives the possibility to re-run meteorological forecast models more often than every 6 hours as it is today.

## 4.2 INCREASED NEED FOR BALANCING - OPERATIONAL HOUR

In the operational hours the TSOs must balance the system for each hour and within the hours. They ensure real-time matching of production and consumption and will adjust the balance in the operation hour with planned actions to adjust the balance main part of the regulations to reduce what must be handled by real time activations. The costly automatic reserves should in principle not be used to handle predictable imbalances, but must be ready to handle unforeseen events as failures on power plants and interconnectors.

Experiences from Denmark show that variation of wind power generation level during operating hour is mostly limited to 25% onshore and 50 % offshore of installed wind capacity.

## 4.3 INCREASED CONGESTION MANAGEMENT ACTIVITIES

Efficient utilization of the transmission grid implies that the grid is operated frequently close to the security limits. Larger amounts of fluctuating wind power production will lead to increased variation in physical power flow in the transmission corridors in the operational phase. Due to the variation in physical flow congestion management measures have to be used more frequently to keep the power flow within security limits in the congested transmission corridors.

With sufficient network capacity the imbalances in wind power and other power production, consumption and external exchange will be smoothed out. The resources to balance the system can also be chosen from a larger area.



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## 4.4 IMPACT OF WIND POWER UNITS STALLING IN STORM

Most wind power turbines stall at about 25 m/s. Due to the smoothing effect a storm front will come over hours so it will be possible to handle the shutdown of wind power production via the regulating power market, like in the example shown in figure 9 from the hurricane “Gudrun”. Consideration is needed when a large amount of wind power is installed in small geographical areas.

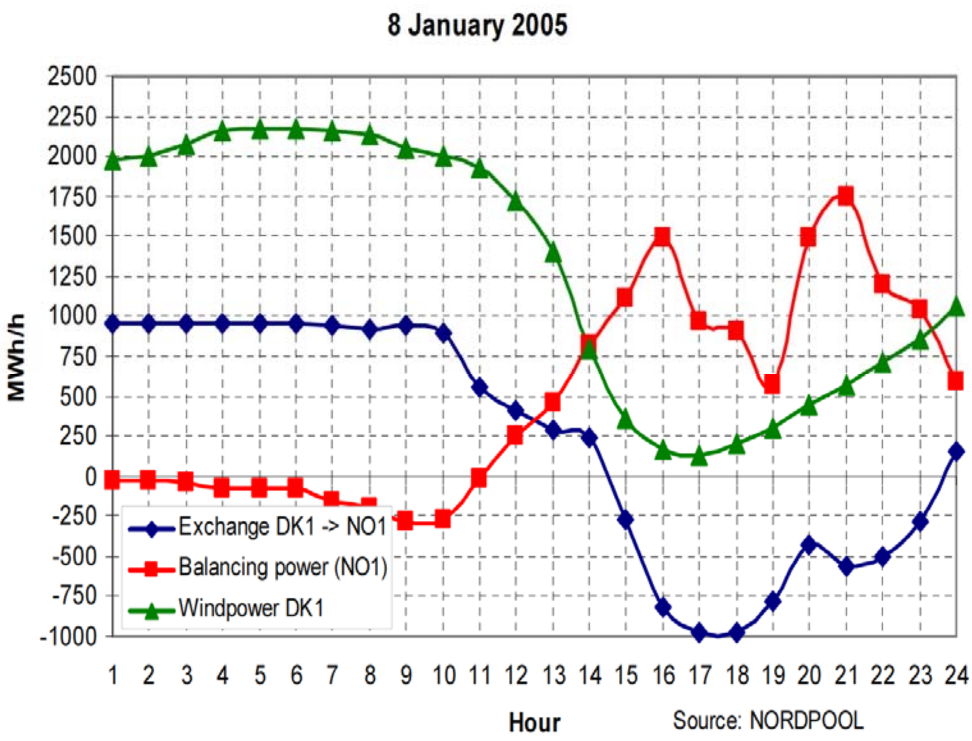


**FIGURE 9 THE GREEN GRAPH IS THE WIND POWER PRODUCTION, THE BLUE GRAPH IS THE EXCHANGE ON SKAGERAK AND THE RED GRAPH IS THE BALANCING POWER ACTIVATED IN SOUTHERN NORWAY.**

In January 2005 the hurricane Gudrun crossed over southern Scandinavia initially giving high wind power production in Western Denmark. At some point in time the wind turbines started to cut-out due to excessive wind speeds and the wind power production was reduced from 2200 MW to 100 MW. Despite the fact that this was an extreme event, it did not cause all the wind power production to stall at the same time. It actually took ten hours to go from maximum wind production (2200 MW) to minimum production (100 MW), the steepest drop was about 600 MW in one hour. The situation was handled in the national control centres by compensating the loss of generation through the regulating power market and changing the flow on the HVDC link between Norway and Denmark from full export to full import. The example shows that the Nordic power system is able to handle large amounts of wind power through the existing marked based mechanisms when the resources are available[ix].



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### 4.4.1 Utilization of flexibility in different areas

In the case shown in figure 10, the expected high wind power production in the day-ahead horizon resulted in export from DK1 to NO1 as a result of the bidding in the spot market. In this case the consequence was a surplus of available production capacity in the NO1 area, which could be utilized when the wind power did not "deliver". This example shows the utilization of flexibility in the production in different areas in practice.

Opposite, if there had been no wind power production predicted day-ahead of January 8, then conventional production would have covered the demand in the day-ahead market. These units could be activated as down regulation bids if wind power production had been under predicted in the day-ahead forecast.

## 4.5 Weakened frequency response of the system

High wind production will sometimes lead to low production in conventional units. Dependent on the technology used for the wind turbines, this can lead to less kinetic energy in the power system. The amount of kinetic energy in the power system will decide the initial gradient of the frequency drop, for that reason the lack of kinetic energy (mechanical energy) is especially critical in the first few seconds of a disturbance. This will not be an issue when the production levels in general are high, because there will be enough production from conventional units which can contribute to the frequency response. In low load situations however many of the generators in conventional units will run at minimum levels or stop and it might be necessary to take specific actions to ensure minimum levels of kinetic energy in the power system and sufficient frequency response.



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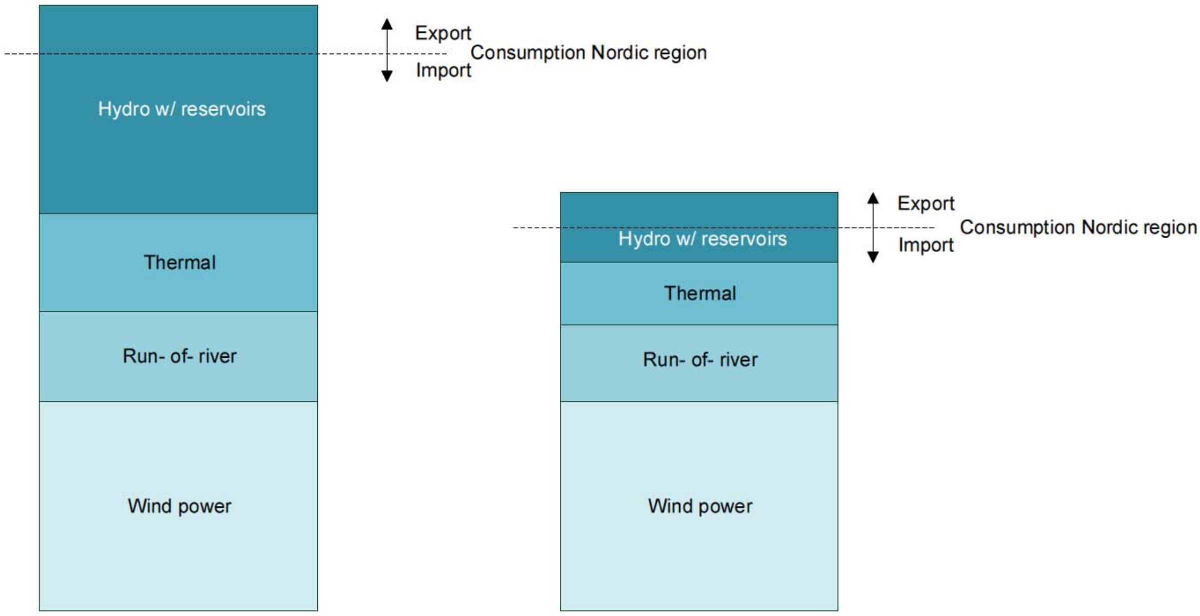


FIGURE 10 DIFFERENT CONSUMPTION LEVELS RESULT IN PRODUCTION MIXES WHERE FLUCTUATING POWER PRODUCTION MAY REPRESENT A SIGNIFICANTLY LARGER SHARE OF THE TOTAL PRODUCTION IN LOW LOAD THAN IN HIGH LOAD.

## 4.6 LESS SHORT CIRCUIT CAPACITY, LESS VOLTAGE SUPPORT

Voltage control, i.e. reactive power compensation, voltage stability, transient and dynamic stability are some of the different aspects where wind power causes an impact or contribute to the grid.

Short circuit capacity above a certain level is needed to maintain a secure system operation. In general wind power production contributes significantly less than thermal/hydro power in this aspect due to the use of induction generators or converters between the generators and the network.

Due to disturbances in the grid reactive power shortage at the wind power plant may occur. If the power system cannot supply reactive power, a voltage instability or collapse may occur.

In the early phase of wind power integration, the protection systems of wind power turbines were designed to disconnect and stop the units whenever a grid fault was detected. Nowadays system requirements imply that wind turbines must be able to “ride through” temporary faults, and contribute to the provision of important ancillary services, such as short circuit capacity. Thus the majority of wind power parks being installed today make use of technologies that enable reactive power control, i.e. voltage support and ability to ride through faults [xi].

The rotating production plays an important role in maintaining the power systems need for stability, flexibility and balancing. In periods with low consumption, wind power may as mentioned be a larger share of the production mix, thus the wind power plants need to deliver ancillary services.

# 5 REQUIRED ACTIONS

In order to operate the power system with the increased uncertainty introduced by the variations of wind power certain actions are required. Most of the suggested actions are a part of "The NORDEL package"[x] and are planned to mitigate the trend of increasing frequency deviations in the current system, thus those actions are needed anyway independent of increased wind power production. The actions range from those which are under implementation and those which need to be studied further.

Stronger grid connections and development of mechanisms for exchange of energy and ancillary services will lead to continental wind power production influencing the Nordic system operation more than today. This will increase the need for some of the mentioned actions. On the other hand stronger grid connections increase the possibility to utilize levelling of wind power production in the different market horizons to mutual benefit for both the continent and the Nordic region.

Improvements in forecasting and the extended use of flexible generation units and load are the principal actions that are perceived to address the challenges introduced by the wind power production. Along with system requirements which ensure wind turbines that are able to "ride through" temporary faults, and contribute to the provision of important ancillary services.

## 5.1 PLANNING PHASE

Ahead of the operational hour the TSOs prepare for the planned production levels of wind power together with plans for conventional production, load and exchange and from that the possible regulation needs to maintain the system balance.

### 5.1.1 NOTIFICATION PLANS

In order to get better control of the production changes during operating hour, notification plans on a quarterly resolution shall be introduced. This is also relevant for wind production. The level of reporting shall be typically objects in the same location of the grid and wind power generation shall be reported separately from the BRPs other generation.

Plans with even one or five minutes resolution is also under consideration to get better control with the physical changes especially in mornings and afternoons.

In DK1 5 minute planning has been used during the last 6 years. This scheme will also be introduced in DK2 during the next 6 months.



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#### 5.1.1.1 SUFFICIENT TIME FOR PLANNING –GATE CLOSURE

In order to do the centralized planning, the TSOs need sufficient time after gate closure to receive the production plans and make actions before real-time operation.

The Nordic TSO's have already decided to harmonize the gate closure times for production plans and bids in the regulating power market. Binding production plans and bids in the regulating power market shall be submitted to the TSO's 45 minutes before the beginning of the operating hour at the latest. The closing time for the Elbas market is currently one hour before the beginning of operating hour. The consequence of this is very little time for the BRPs and TSOs for rescheduling and planning of balancing actions.

**More renewable production will on one hand imply a need for closing of the energy market close to the operating hour to reduce imbalances for BRPs but on the other hand a need for the TSOs to have more time for planning of balancing actions including congestion management. Currently the Nordic TSOs have different opinions about gate closure times and how more wind power will affect the time needed for rescheduling and planning of balancing actions. Some reason for this is probably differences in external conditions like national system structure and procedures and current Nordic responsibilities for balancing. A harmonized solution is preferable.**

### 5.1.2 FORECASTS OF WIND POWER PRODUCTION

The BRPs and the TSOs (dependant on national responsibilities) prepare forecasts for the wind power production firstly for the day ahead, and then update them closer to the operation hour. The forecast error of wind power production will decrease based on higher accuracy in prediction closer to the operation hour.

The TSOs collect the forecasts for wind power production and consumption and the plans for the BRPs physical production in other production units and compare with the scheduled exchange with the neighbouring areas. Hereby the national balances are known the day ahead and updated closer to the operation hour. The national information is collected in a Nordic Information System (NOIS) which presents Nordic prognoses for quarterly system balance.

The TSOs use the forecasted system balance to activate balancing resources before real time to reduce the amount of automatic and manual reserves needed in real time.

To improve short range wind power forecasting, information of the current weather in the neighbouring areas are of great importance, therefore a common Nordic effort to gather and share online meteorological information should be developed.

**The quality of the prognoses which is basis for the forecasted system balance must be improved in the future. More fluctuating production will increase the imbalances for the BRPs and the need for balancing actions before real time.**



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### 5.1.3 Quarterly Settlement

Today the Nordic market is hourly based. This is the case for Elspot, Elbas and bilateral trade. Consequently the settlement is also hourly based. In addition some TSO's have introduced operating plans on quarterly basis (Norway and Sweden), ancillary services on quarterly basis (Norway, Sweden and Finland) and even quarterly settlement against operating plans in addition to ordinary hourly settlement (Western Denmark).

In the long run economic incentives probably will have to be introduced for the BRP's on quarterly basis, and quarterly settlement overall may be the result.

Introduction of quarterly resolution for all plans, generation, load, market and possibly also for settlement will increase the complexity in the system but potentially reduce the regulation needs which has to be regulated by the TSOs. Renewable production will increase the need for these actions.

## 5.2 Operational Phase

A set of tools shall offset the system balance which remains during the operating hour even if good operating plans are prepared and followed. Currently the TSOs monitors and maintains the balance by automatic primary control, activating bids in the Nordic regulating market, and if necessary curtailing renewable energy production.

To be updated on the system state, there is also a need for real time measurements of wind power.

Experienced from countries with high amount of wind power also show increased volumes of manual regulations i.e. use of tertiary reserves which means there is a need for further development of the regulating power market, for instance will electronic activation of regulation bids be needed to ensure quick and efficient balancing actions.

### 5.2.1 More resources for balancing

Experiences show that the imbalances caused by fluctuations in wind production are mainly an hourly and quarterly challenge for system operation. This means that the imbalances will have to be handled by tertiary reserves mainly. Primary and secondary reserves will also of course contribute to continuously maintaining a balanced system, but it is mainly other reasons creating a need and the dimensioning criteria for these reserves.

As more renewable production is integrated in the power system, there is an increased risk for larger imbalances. The TSOs must be sure that these imbalances can be handled and have different options for how to do this.



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Experiences from the Nordic system operation shows strained availability of resources in the balancing market in some peak and low load situations. Some potential means to achieve sufficient resources for balancing for the TSOs are:

- The TSOs can secure regulating capacity in the balancing market by organizing national or regional capacity markets. These markets can be voluntary or mandatory.
- The TSOs can instruct producers and consumers not participating in the balancing market to change production and consumption when needed
- The TSOs can define requirements for availability to change production/consumption level when needed
- The TSOs can reserve capacity in cables and lines for exchange of reserves with other areas if it can be shown to be socio-economically more beneficial than allocating capacity to the market, considering the environmental aspect and where the cost of reservation is reflected in the cost of wind power generation
- The TSOs can exploit not used capacity or short term overload capacity in cables and lines for exchange of regulating capacity with other areas

Currently the Nordic TSOs have different philosophy/mandate how to deal with those situations. There is a strong need for harmonization in this area involving both TSOs and authorities.

To be updated on the system state, there is also a need for real time measurements of wind power. This must be formulated as requirements before installation.

**Methods to dimension the need for tertiary reserves to handle fluctuations in renewable production will have to be developed. Experiences from other countries will be valuable input for this.**

### 5.2.2 Development of the Regulating Power Market

When operating plans on quarterly resolution are introduced and possibly also quarterly settlement, the regulating power market will naturally develop into a market also on a quarterly resolution. The rules for and implications of this must be studied further. This may unify the presently separate markets for quarterly regulations and regulating power on an hourly basis into one market on a quarterly basis.

New products like bids with other activation times than 15 minutes and block bids may also improve the possibilities to handle imbalances and constraints in the system. These products need to be studied further.

### 5.2.3 TECHNICAL REQUIREMENTS FOR INSTALLATION OF RENEWABLE PRODUCTION

To secure a high reliability of supply in the Nordic power system, wind power has to be met with technical requirements.

In periods with low consumption wind power may be a larger share of the production mix. The production online must at all times maintain the power systems need for stability, flexibility and adjustment/regulation. So it is a general principle that it is an advantage for the power system that all production units, to a large extent have the same electrical abilities. This ensures predictable and reliable operation of the power system independent of the production mix. Hence the wind power plants need to deliver ancillary services.

Grid codes determine what is required of power plants when connecting to the network. Grid code requirements have to define minimum requirements so that wind generation can efficiently produce ancillary services.

Grid code requirements for wind power plants in several countries include a requirement for fault ride through capabilities in the event of system faults. The fault clearing times as well as the voltage dip requirements and the requirements for providing voltage support during the fault, vary in the Nordic codes. The grid code can also include a requirement for reactive power control. Additional requirements that are being met when requested include voltage control, active power and frequency control (for example ramp rate control, see figure 11)[xi]. The ability to adjust the production of renewable energy should be seen as a part of the regulating possibilities.

One example of requirements imposed on wind power plants connected to the grid at the transmission system level, is the Danish technical requirement (Energinet.dk, 2004) specified by Energinet.dk, and implemented e.g. at the Horns Rev offshore wind power plant. The technical requirements specify six types of active power regulation available to the TSO:

- absolute limit of the output of the wind power plant to a specific value set by the operator,
- balance regulation where the wind power plant is ordered to reduce the output with a certain amount,
- delta control where the output of the wind power plant is reduced with a delta amount so this amount can be used as spinning reserve,
- rate limitation where the output of the wind power plant is not allowed to increase more than a specified amount per minute,
- droop control and
- system protection by output reduction.

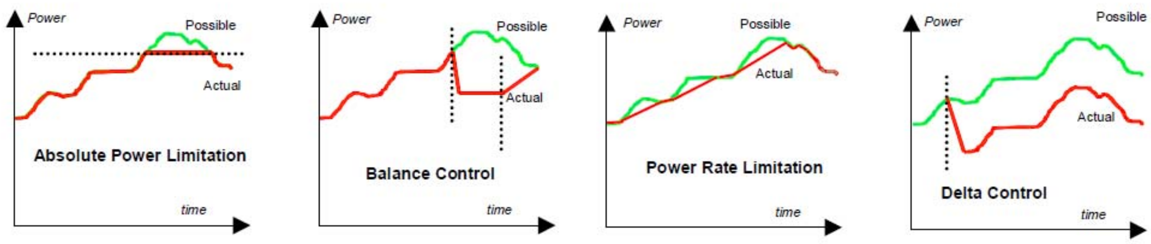


**FIGURE 11 OUTLINE OF THE ACTIVE POWER CONTROL FUNCTIONS. THE PLOTS SHOW THE POSSIBLE POWER AND THE ACTUAL ACHIEVED POWER WITH THE DIFFERENT CONTROL FUNCTIONS ACTIVE.**

ENTSO-E is preparing European wide grid connection rules. These rules have to be supplemented with common Nordic rules to accommodate the special features like size or production structure of the Nordic synchronous area.

**Nordic technical requirements for installation of renewable production must be developed to be able to realize the planned production volumes.**

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