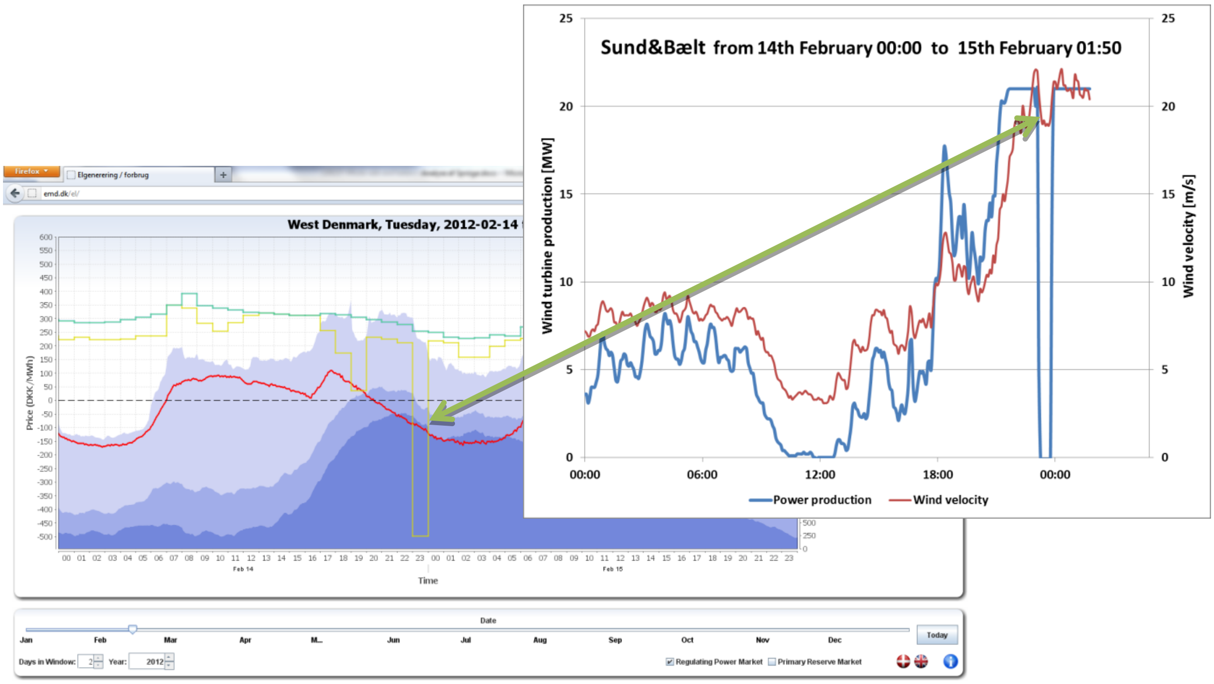
Version 1.0

Proactive participation of wind turbines in the electricity markets



www.emd.dk/el

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1. Introduction

In line with an increasing penetration of wind production (planned in more countries to be up to 50% of yearly electricity demand within a few years), questions about the impacts and costs associated with maintaining a stable grid is receiving growing attention. A detailed analysis of these impacts and costs when operating power systems with large amounts of wind power has been made in the IEA Wind Task 25 [1].

Today the general case in the EU-countries is that wind productions are integrated in the electricity system through the whole sale markets (typically intraday and day ahead spot markets) but are not participating in the balancing markets.

With the quality of day ahead wind production prognosis available today - the day ahead whole sale markets are able to integrate around 3/4 of the wind productions, but the rest are to be integrated and balanced in the intraday whole sale markets and the balancing markets.

In chapter 2 is given an overview of how the whole sale markets and the balancing markets are organized in Europe.

Energinet.dk, the Danish Transmission System Operator, has recently changed its regulation in order to make it manageable for wind turbines themselves to offer activation in the Tertiary reserve market (The Scandinavian Regulating power market). This new regulation is also described in chapter 2.

As an example of increased penetration of wind production - we show online the production of the wind turbines in West Denmark at www.emd.dk/el (see Figure 1).

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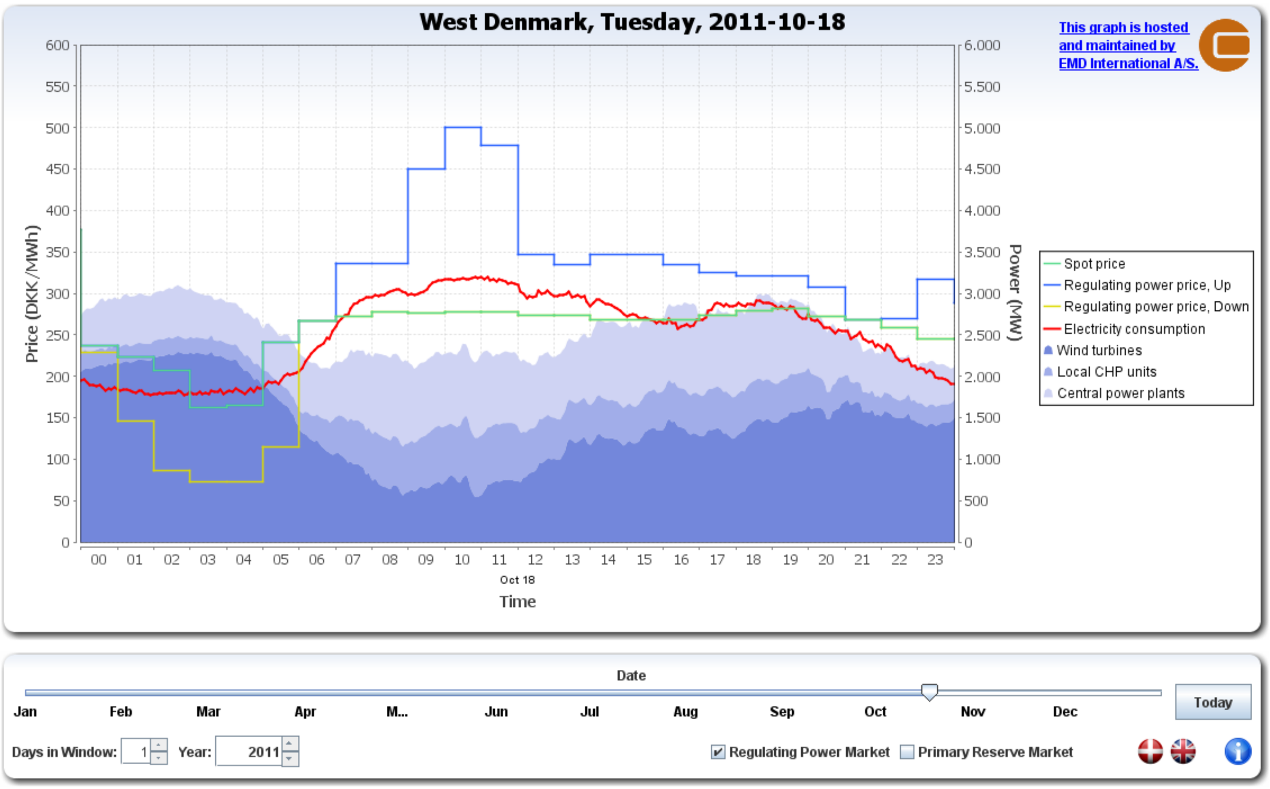

Figure 1: Consumption and production of the wind turbines in West Denmark to be seen at www.emd.dk/el. In addition spot prices and activation prices in the Tertiary reserve market are shown.

In Figure 1 are also shown spot prices and activation prices in the Tertiary reserve market (the Scandinavian Regulating power market). In the figure is shown 18th of October 2011, which illustrates how the balancing of wind productions is made in the Tertiary reserve market.
A weather front passed Denmark that day. But when looking at the activation prices in the Tertiary reserve market, it is obvious that the weather front passed earlier than expected. That is to say, that when the Production Responsible Companies (PRC) for the turbines, sold the wind productions in the spot market the day before, they probably believed that the front would pass around 10 o´clock, but it passed around 3 o´clock. So when coming to the operating hour the Danish Transmission System Operator (TSO) had to buy downward regulation in the Tertiary reserve market around 3 o´clock and to buy upward regulation around 10 o´clock.

In chapter 3 is described the necessary IT-solutions for closing down wind turbines.

In the Scandinavian Regulating power market the gate closure for activation bids is 3/4 of an hour before the operating hour and minimum bid is 10 MW. In chapter 4 is described the short-term forecasting of wind productions, necessary to be able to offer at least 10 MW for downward regulation.

To offer at least 10 MW downward regulation in the Regulating power market it is necessary to establish group of turbines. In chapter 5 is described the considerations that we have been considering about how to establish these group of turbines.

Energinet.dk´s new regulation in order to make it manageable for wind turbines themselves to offer activation in the Regulating power market has been tested on Sund&Bælts 21 MW wind farm (www.sundogbaelt.dk/uk/menu/csr/environment/sprogo-offshore-wind-farm). In more instances in the test period this wind farm has been activated in the Regulating power market (Tertiary reserve market). Results from this test are described in chapter 6, as well as simulated earnings this wind farm could have had in some selected month.

In chapter 7 are collected recommendations to make it manageable for wind turbines themselves to offer activation in the balancing power market, as well as making it manageable for other distributed generators to participate in the balancing of wind productions.
The recommendations are based on the fact that nearly all the balancing of wind productions can be made in the Tertiary reserve market. But to make the Tertiary reserve market the ultimate market for balancing wind productions – it is necessary that the TSOs moves most of the balancing from the more expensive Secondary Reserve market to the cheaper Tertiary reserve market where most plants are able to participate in the balancing.

In the chapter it is argued that a good organization of the Tertiary reserve market comprises:

- Splitting the market into an availability market and an activation market.
- Making the market asymmetric, allowing offering only upward or downward power.
- Organizing the market as a Marginal price market and not as a PayAsBid-market.

2. Overview of whole sale and balancing markets in Europe

In this chapter is given an overview of how the wholesale markets and the balancing markets are organized in Europe.

A major push to harmonize the balancing markets has been made by EU. This push has been especially strongly made by the Agency for the Cooperation of Energy Regulators (ACER), through its Framework Guidelines on Electricity Balancing [2].

The Framework Guidelines on Electricity Balancing (FG) sets out clear and objective principles for the transmission system operators how to develop the network codes for the balancing markets. The FG describes, that the balancing shall be split into three markets:

Frequency containment reserves
Activation of these reserves results in a restored power balance at a frequency deviating from nominal value. This category typically includes operating reserves with the activation time up to 30 seconds. Operating reserves of this category are usually activated automatically and locally.

Frequency restoration reserves
Operating reserves used to restore frequency to the nominal value and power balance to the scheduled value after sudden system imbalance occurrence. This category includes operating reserves with an activation time typically from 5 to 15 minutes (depending on the specific requirements of the synchronous area). Operating reserves of this category are typically activated centrally.

Replacement reserves – operating reserves used to restore the required level of Frequency restoration reserves to be prepared for a further system imbalance. This category includes operating reserves with activation time from 15 minutes up to a couple of hours.

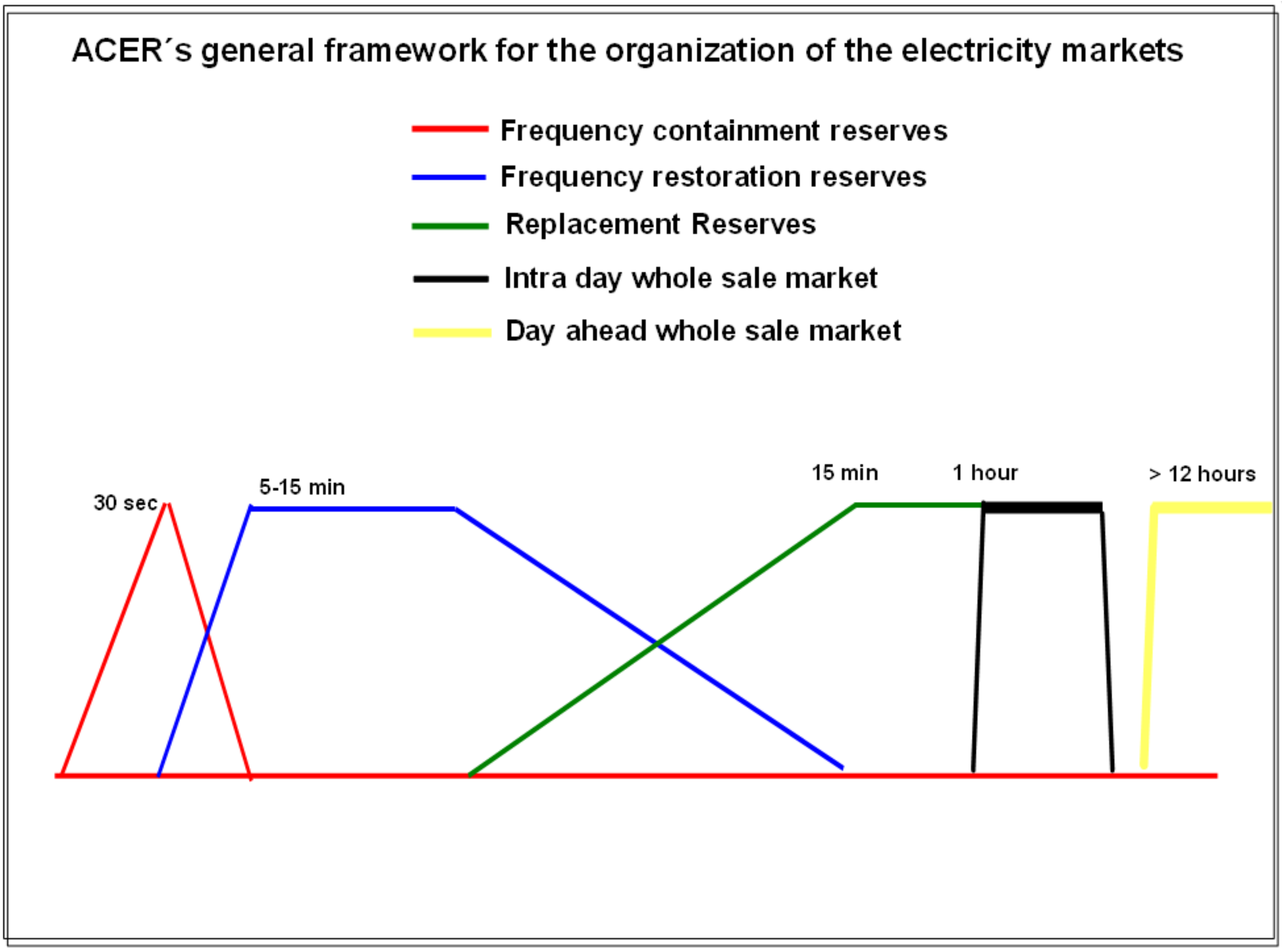

Figure 2: ACER´s general framework for the organization of the electricity markets

Often these three reserves are numbered:
Frequency containment reserves = Primary reserves
Frequency restoration reserves = Secondary reserves
Replacement Reserves = Tertiary reserves

Especially relevant for the participation of wind turbines in the balancing markets is that ACER´s Framework Guidelines emphasizes that the Transmission System Operators (TSOs) shall allow generation units from renewable and intermittent energy sources to become Balance Service Providers (BSP):

"The Electricity Balancing Network Code(s) shall foresee that the terms and conditions for balancing markets allow for load entities (whether through aggregators or not) as well as generation units from renewable and intermittent energy sources to become BSPs. These terms and conditions, including the underlying requirements, shall, in particular, be set in order to facilitate the participation of demand response, renewable and intermittent energy sources in the balancing markets, while respecting the other objectives mentioned in section 2.1 of these Framework Guidelines."

"The Electricity Balancing Network Code(s) shall define common standard balancing energy products with the aim to achieve high liquidity of these products and the objectives mentioned in section 2.1 of these Framework Guidelines. The characteristics of balancing energy products (including technical constraints, speed of activation, duration, minimum bid size, etc.) shall satisfy the needs of the TSOs to balance the system and take into account the technical characteristics of available balancing resources across Europe, in particular from demand and renewable generation units, as well as smaller generation units."

Especially important for wind turbines is that it shall not be necessary to have won availability (be reserves) to be allowed to offer activation in the Tertiary reserve market:

The Electricity Balancing Network Code(s) shall oblige TSOs to allow the participation of non-pre-contracted reserves at least to provide balancing energy that are used as replacement reserves, as well as from manually-activated frequency restoration reserves.

A detailed description of the organizations of these Danish/Scandinavian electricity markets and the markets in France, Germany, Netherlands and Spain are made in the EU-project TradeWind [3].

Also the electricity directive creates the legal framework for organizing the three balancing markets. Amongst others the directive states that these balancing markets shall be organized transparent, cost reflective and nondiscriminatory, so that an important competition in these markets is maintained, to ensure that e.g. the imbalances created by the wind turbines are removed at lowest costs for the wind turbines.

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2.1 Overview of the wholesale and balancing markets in Denmark

In Figure 3 is shown the Danish/Scandinavian balancing markets and whole sale markets.

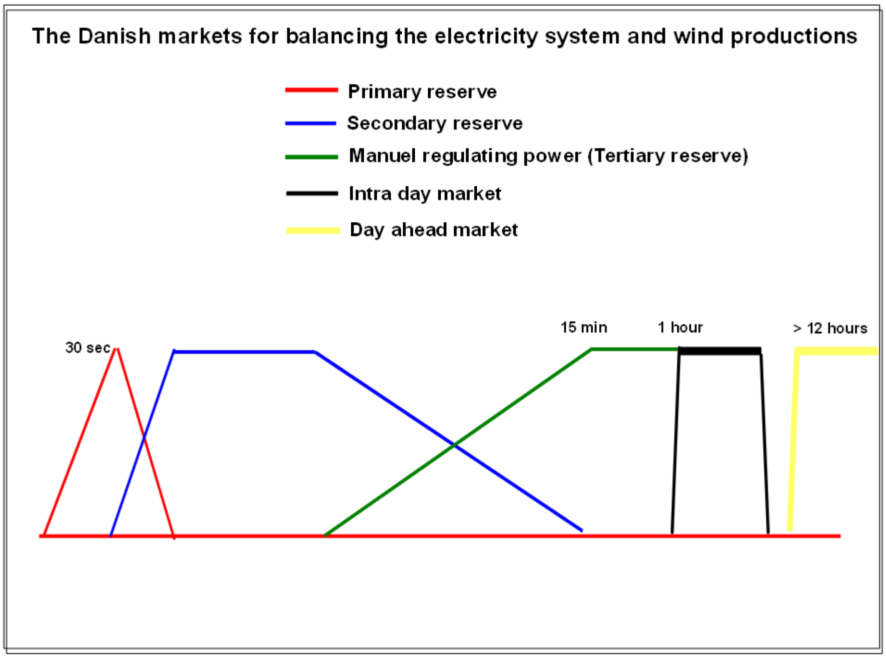

Figure 3: The Danish/Scandinavian balancing and wholesale markets, which for Europe represents a very typical organization of these markets.

The Primary reserve market (frequency regulation) is a very small market, which only task across Europe is to stabilize frequency. It is the Secondary reserve (automatically regulated by the TSO) that will bring the frequency back to 50 Hz. The TSO also uses the Secondary reserve to bring the flows across the interconnectors to other TSO-areas back to schedule. But in fact nearly all imbalances between scheduled wind productions (as traded in the whole sale markets) and the actual wind productions may be balanced in the Tertiary reserve market (in this case the Scandinavian Regulating Power market).

If the Secondary reserve and Tertiary reserve markets are well organized there should be a clear price hierarchy in the activation prices in the two markets, in the sense that it should be cheaper for the TSO to activate Tertiary reserve than to activate Secondary reserve. One reason for this is that a lot more plants are able to participate in the Tertiary reserve market, e.g. a plant with a stopped engine may offer upward regulation in the Tertiary reserve market, because it has 15 minutes to deliver a won activation – enough time to make a cold start on the engine, but a cold engine is not able to start fast enough to deliver Secondary reserve.
In Denmark it is true per definition that it is cheaper for the TSO to activate Tertiary reserve than to activate Secondary reserve – simply because Secondary reserve are paid 100 DKK/MWh-el on

top of the prices in the Tertiary reserve market (in fact Secondary reserve are paid 100 DKK/MWh-el on top of the best prices in the Tertiary reserve market and the spot market).

This price hierarchy is also used by the Danish TSO to emphasize to the PRC the hierarchy in the information that the PRC sends to the TSO. The PRC sends the following two information:

- Hourly energy notification (hourly energy amounts traded in the wholesale market)
- Power schedule at 5-minute intervals (updated as often as necessary)

For the TSO, being responsible for the right frequency and the correct flows across the interconnectors to other TSO-areas, it is more important that the Power schedules are precise than the Hourly energy notifications, in order to use these Power schedules to plan the purchase of Tertiary reserve in the operational hour. That is reflected in how imbalances are punished:

- Imbalances in the hourly energy notification are settled with the activation prices in the Tertiary reserve market.
- Imbalances in the power schedule are settled with the activation prices in the Secondary reserve market.

And since activation in Secondary reserve and Tertiary reserve is organized as Marginal Price markets and since the punishments shall be cost reflective, these activation prices paid to the plants that removes the imbalances are equal to the punishments paid by the energy plants that have caused the imbalance (with only very few exceptions from these general principles).

<u>New regulation in order to facilitate active participation of wind turbines in Tertiary reserve</u>

Energinet.dk, the Danish TSO, has recently changed its regulation in order to make it manageable for wind turbines themselves to participate in the Tertiary reserve market [9].
The PRC for wind turbines used actively in the market now has to send the TSO the following information:

- Hourly energy notification (hourly energy amounts traded)
- Special 5-minute time series showing the number of MWs (**<u>installed capacity</u>**) of the total portfolio of operational wind power plants that have been closed down.

And settlement of imbalances for wind turbines is simplified to:

- Imbalances in the hourly energy notification are settled with the activation prices in the regulating power market.
- Imbalances in the power schedule are **NOT** settled.

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3. Necessary IT-solutions for closing down wind turbines

In Denmark most wind turbines are old wind turbines. They have no load reduction functions or remote control access available and the only possibility to reduce power production from this type of wind turbine is to manual stop the wind turbine.

Modern wind turbines have a different technology and they can receive a max load set point. The wind turbine controller is then controlling the load on the turbine to make sure that the max allowed load of the turbine is not exceeded.

The result of the work in this work project shows that it is technical possible to get remote access to the turbines both old and new type wind turbines, so that the Production Responsible Company (PRC) are able to activate the turbines when winning an activation in the Tertiary reserve market.

3.1 Communication with old type wind turbines

A remote access system must be established to enable start/stop commands to control the turbine operation.

The control system in the wind turbine must be able to receive a start/stop signals.

The most cost effective way to establish communication link to old type wind turbines is through SMS message system. This system is cheap to install, configure and maintain. Both old Bonus/Siemens and old Vestas wind turbines can be upgraded to receive remote stop commands.

3.2 Communication with new type wind turbines

New wind turbines have a SCADA system on top of the park control system and through this system the access for the remote control can be made. The advantage of this system is that there is no need to install anything in the wind turbine. All installation of software is done via the internet. Through this SCADA connection the start/stop signals is transferred to the wind turbine. This communication also allows data to be transferred from the wind turbine to the PBA load management system such as wind speed, actual load and possible load. Modern wind turbines from the middle of the 00´s have incorporated technology that allows to set a max production from the turbines.

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Communication layout old and new type wind turbines

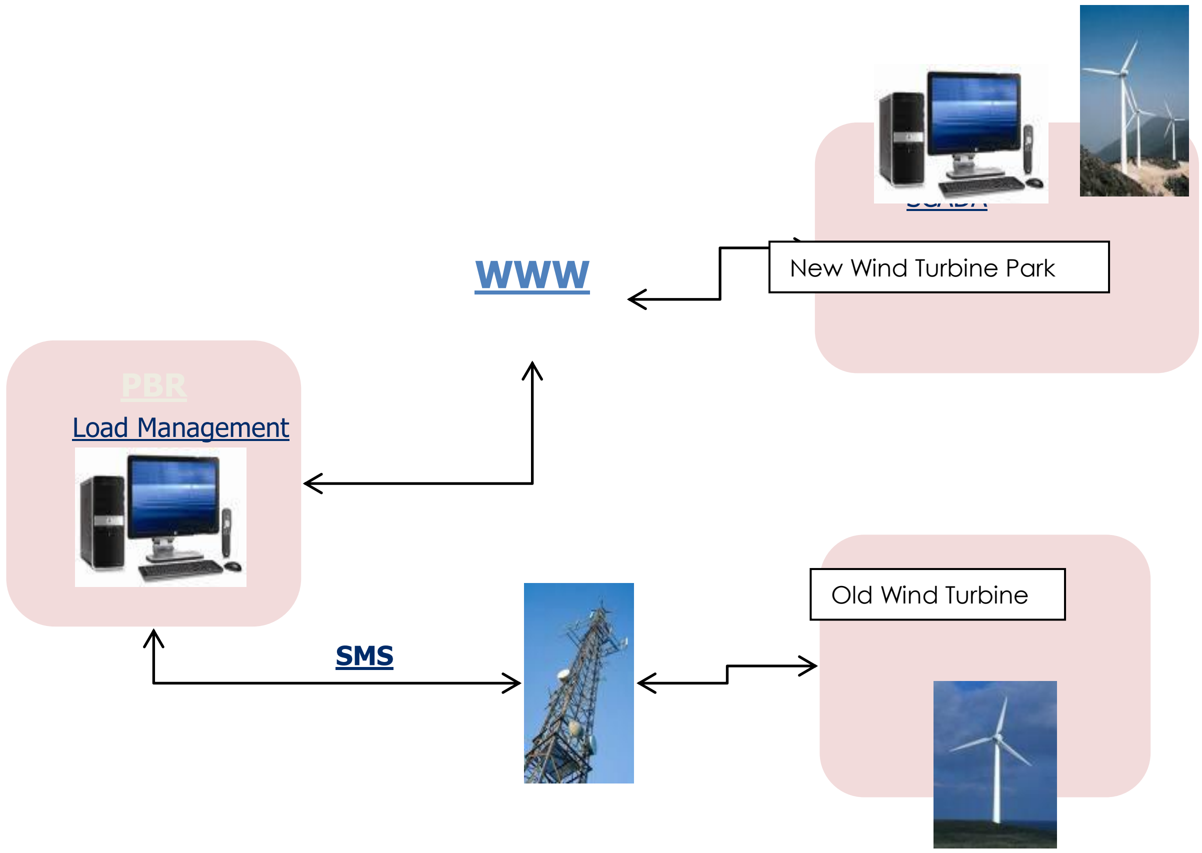

Figure 4: Communication layout old and new type wind turbines

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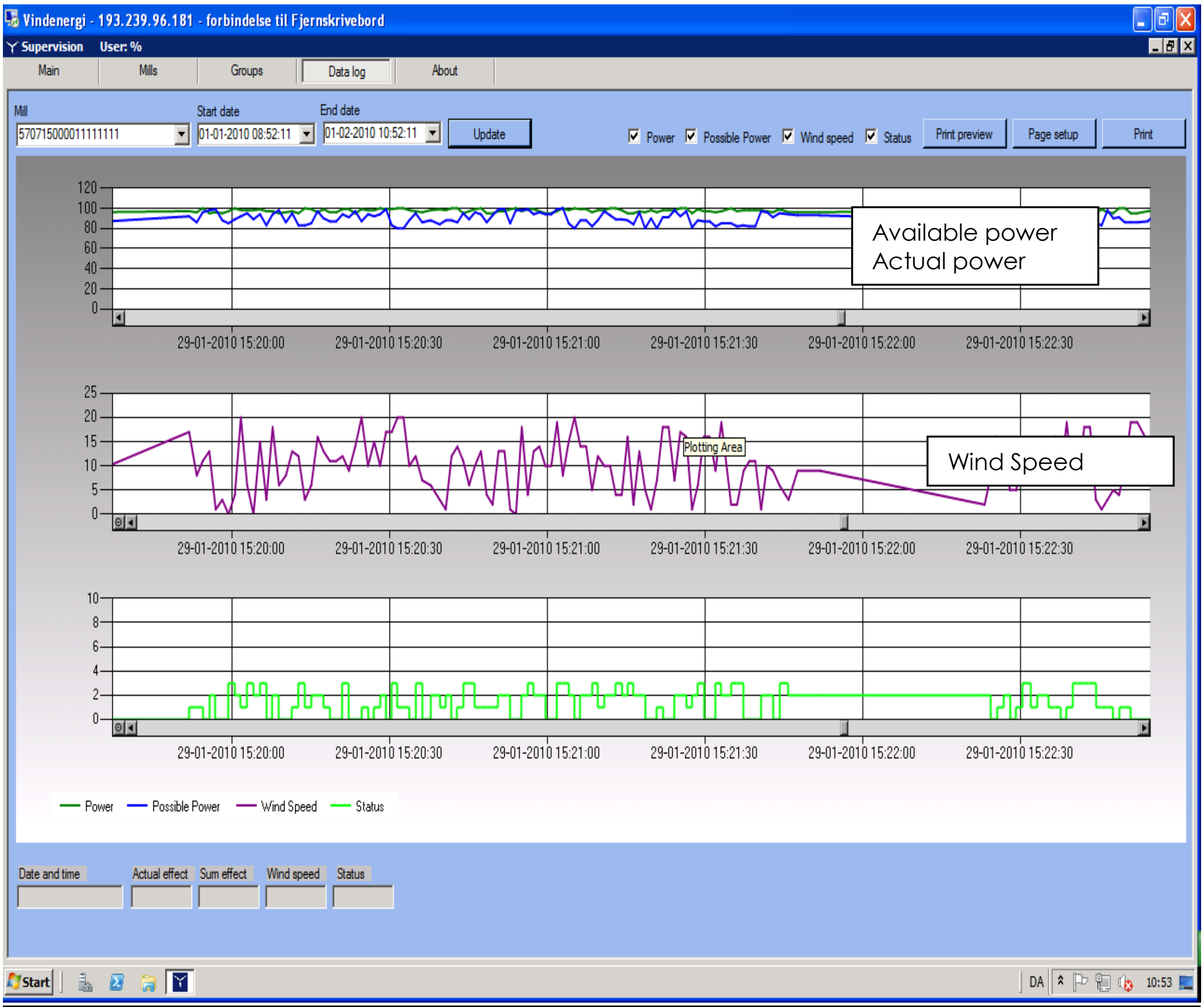

Figure 5: Data logging on new type wind turbines

3.3 PRC load management system

Seen from the Production Responsible Company (PRC) side there is no difference in the handling of the old type of wind turbine and the new type of wind turbines. The PRC just order a load reduction in the operating hours where load reduction is needed.

When entering the operating hours with load reduction a SMS message is send to the old type turbines ordering them to stop. When leaving the operating hours with load reduction a new SMS message is send to the turbines ordering them to run again.

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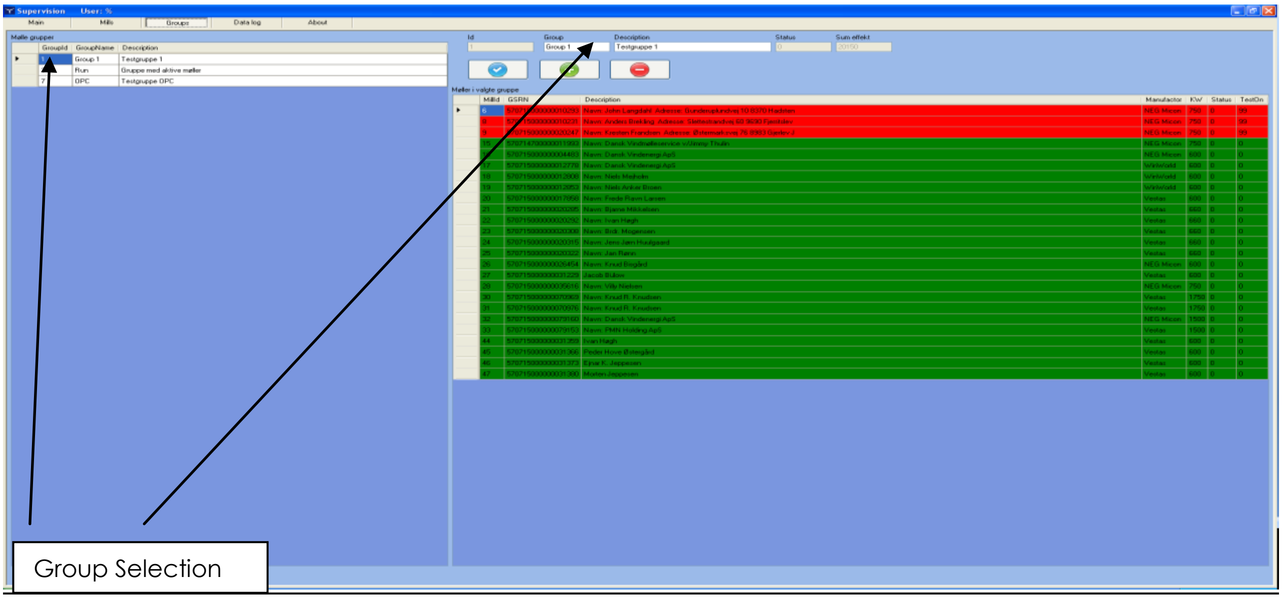
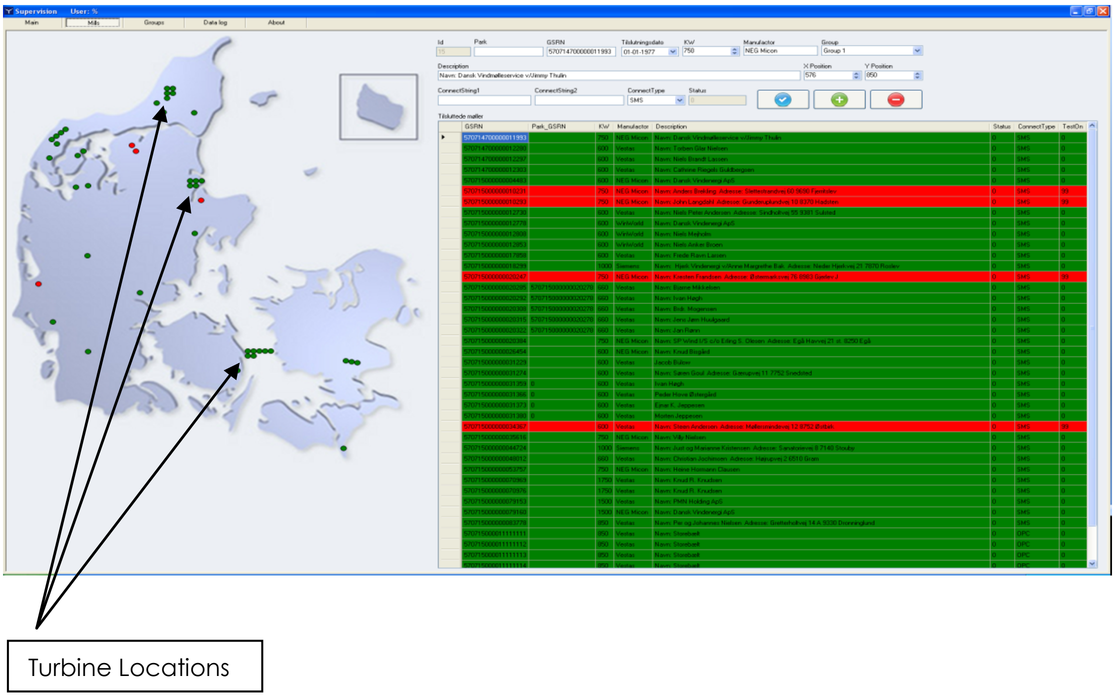
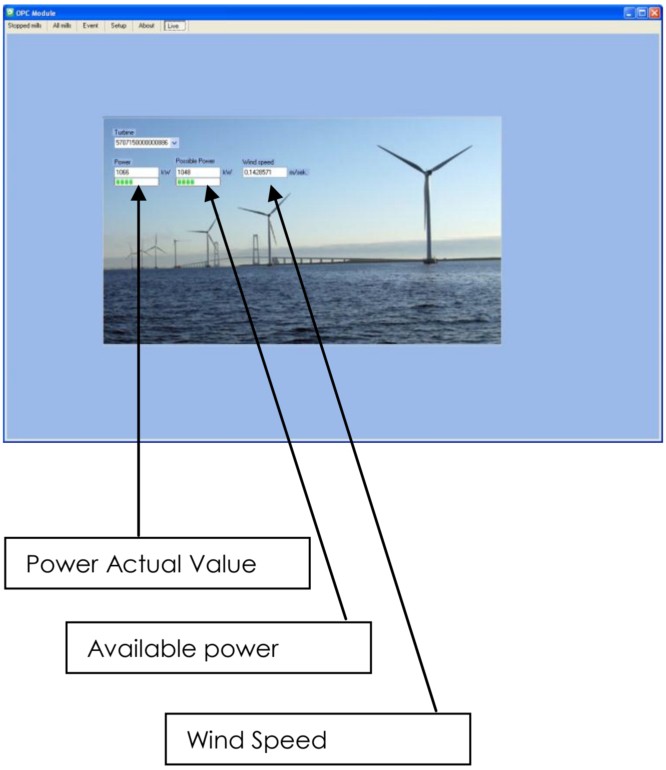
New type of turbines is often arranged in parks and therefore there is only send a max load demand or a stop command to the park controller.







4. Short-term forecasting of wind productions

In the Scandinavian Regulating power market the gate closure for activation bids is 3/4 of an hour before the operating hour and the minimum bid is 10 MW. In this chapter is described the short-term forecasting of wind productions, necessary to be able to offer at least 10 MW for downward regulation.

Forecast models operates on different distinct time horizons, from the ultra-short scale (a number of seconds) to the long term range (a week or more). These very different time scales inherently deals with features such as instantaneous turbine control, power trading, maintenance planning and load balancing. Not all models work equally well in all time scale. Landberg [4] states that a persistence model for turbine yield will typically outmatch meteorological model in ranges below 4 hours. In this paper, our focus will be on the forecasts on the short term range (1-2 hours) and the medium term range (from 1 day to a week). A potential setup of such a system is outlined in Figure 6.

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4.1 Deterministic Weather Forecasts

Much of the uncertainty related to wind power forecasting still comes from the numerical weather prediction (NWP) systems used as input to the wind power forecasts. While this is an area that has received much attention during the last decades, Giebel [5] states that still 80% of the uncertainty related to wind power forecasts arises from the weather forecast model. Weather forecasts comes with different scales, ranging from the large global scale models operated by ECMWF, NOAA and NCEP (shown with **red** color on Figure 6) to regional and local models operated by the national meteorological offices or independent commercial operators (these models are shown with **blue** color on Figure 6. With the availability of open-source NWP models (such as the Global Forecasting Model, GFS), then some traders may even choose to run their own in-house model, however data from the national/regional model are often purchased from a number of providers in order to mitigate the risk of failure of mission critical data delivery from one single provider. Very many different models exist today; Giebel [6] reports more than 50 models at either research or commercial levels.

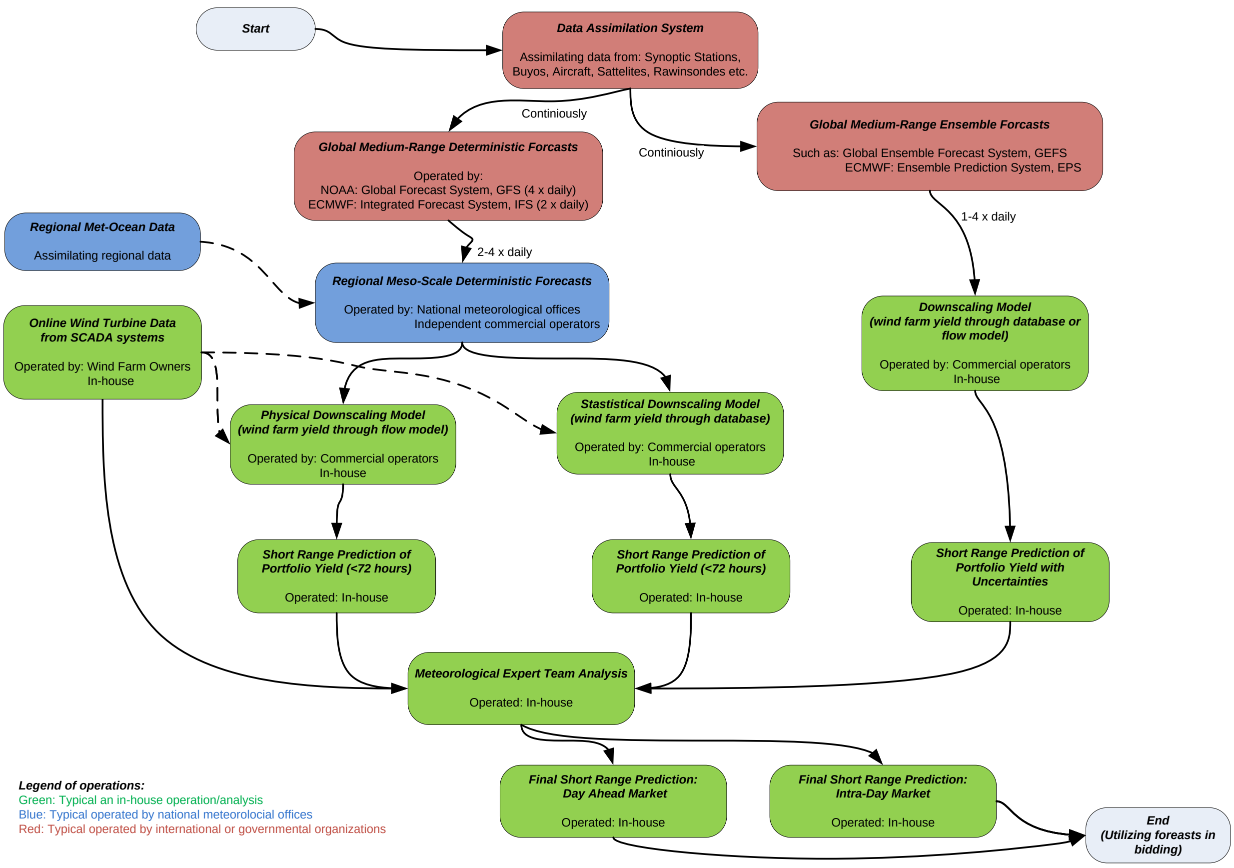

Figure 6: Schematic Diagram of a Setup of an In-House Wind Power Prediction System with the Associated Data Flow.

4.2 Ensemble Weather Forecasts

Ensemble forecasts are used in weather forecasting by running the same deterministic model a number of times with a slightly different starting state. In the phase of initialisation the starting state is determined and this process will according to the method used result in a starting point. By changing the method and parameterisation in the initialisation process slightly the starting state will change. On each starting point a normal model run is carried out and the result from the run will change. By analysing the differences in the result it is possible to obtain a feeling for the uncertainties of the runs. If the spread between each individual ensemble run is large or the difference between the extreme ensemble runs are very significant it is possible to get an idea of the magnitude of uncertainly in the specific meteorological situation.

4.3 Forecasts of Wind Power / Downscaling

Models to produce high resolution wind data to be used in single wind farms of for wind turbines spread over an area are built by using the global models from ECMWF, NOAA and NCEP and others as border. The derived data is thus used to convert detailed information of wind speed into a measure of electrical power units.
The methods used are different and ranges from detailed CFD models taking each individual turbine into consideration to more holistic models using behavior of wind turbines in an area in determining the power production by applying advanced adaptive statistical modeling to the process.

The data from the numerical weather forecasts are processed in the downscaling models so that NWP data is converted into on-site wind farm yields. More methods exists in doing such downscaling, the first is a physical approach where the coarse NWP data is used as input into a micro scale model, a CFD-model or a high-resolution Meso-Scale model. This is done in order to obtain local wind speeds. After that model is run, then the local wind speeds obtained are converted into power yield using a site specific wind farm power curve, such as obtained with the WindPRO / PARK module [6]. Another approach is to use a statistical approach, so that a number of input variables – like NWP output or online data – are statistically related to processed measurements of wind farm yield. Also combine methods, like the Zephyr model and the MORE-CARE model may be used, see Kariniotakis et al [7]. Downscaling modeling is shown with **green** color in Figure 6, indicating that this is typically done as an in-house analysis.

4.4 Dealing with the Uncertainties and the Forecast Errors

When invoking a complex real-time modeling framework for short-term forecasting, then uncertainties and errors within the analysis need to be considered and potentially also mitigated. One

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major source of error is the NWP models. Some uncertainty associated to the NWP modeling can be removed by running or analyzing output from models driven by different global models generally as well as to use a model with ensemble forecasts. Such analysis improves insight in the variation by different NWPs, see the Figure 8, but such scatter requires in-house meteorological knowledge to handle.

Errors with the NWP are grouped in either scale errors (models does not predict the right level) or phase errors (models predict ramp-events erroneous times). Typically such events are dealt with by trading also on the intra-day market.

To some degree, errors in the NWP mitigated by including more spatially distributed wind farms into the portfolio. According to Perkes [8], the mean absolute error (MAE) was 5% lower for a portfolio of 3 UK wind farms when comparing against the individual ones (wind farms have a separation of some hundreds of kilometres). Such effect is due to synoptic weather conditions affecting the sites at different times, reduced local effects from the terrain as well as reduced local errors.

4.5 Including Direct On-Line Measurements

In order to be able to trade in the Tertiary reserve market and thus reducing imbalances in the Tertiary reserve market it is crucial to be able to determine the quantities of imbalance in each trading hour. An essential tool is to be able to online monitor the production from the affected turbines. By online monitoring the production it is possible to merge information from online production with information from NWP and thus get a more exact estimate of the imbalance in the short time frame, which eventually enables trading in the short term market.
A combination of information from online measurements, NWP information and information from local high resolution meteorological model will improve the possibilities further

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4.6 An Example

As an example, the cost associated with an 134 MW imbalance on in the hour 20:00 to 21:00 on May 1st 2010 was 134 x 859 = 115.000 DKK.

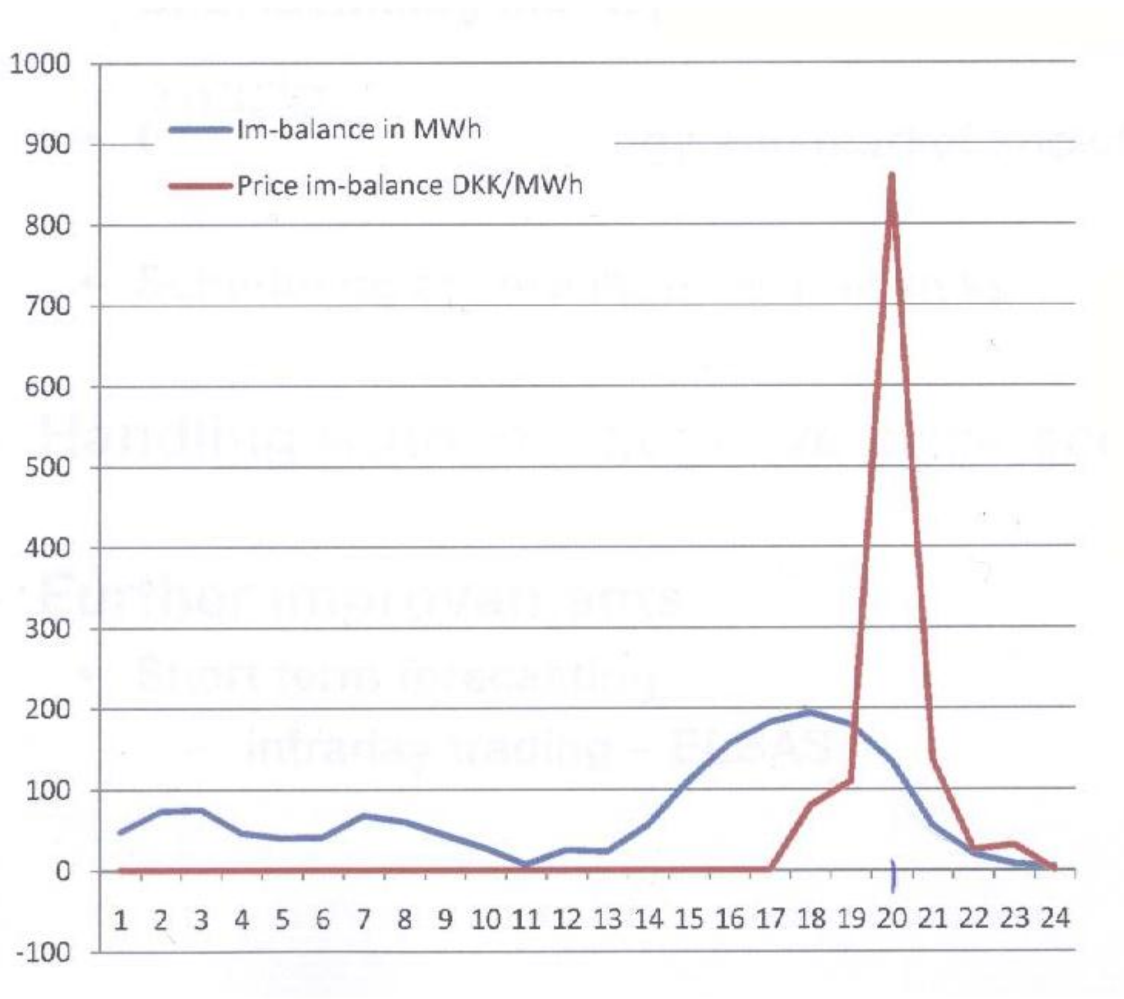

Figure 7: Imbalance on May 1st 2010.

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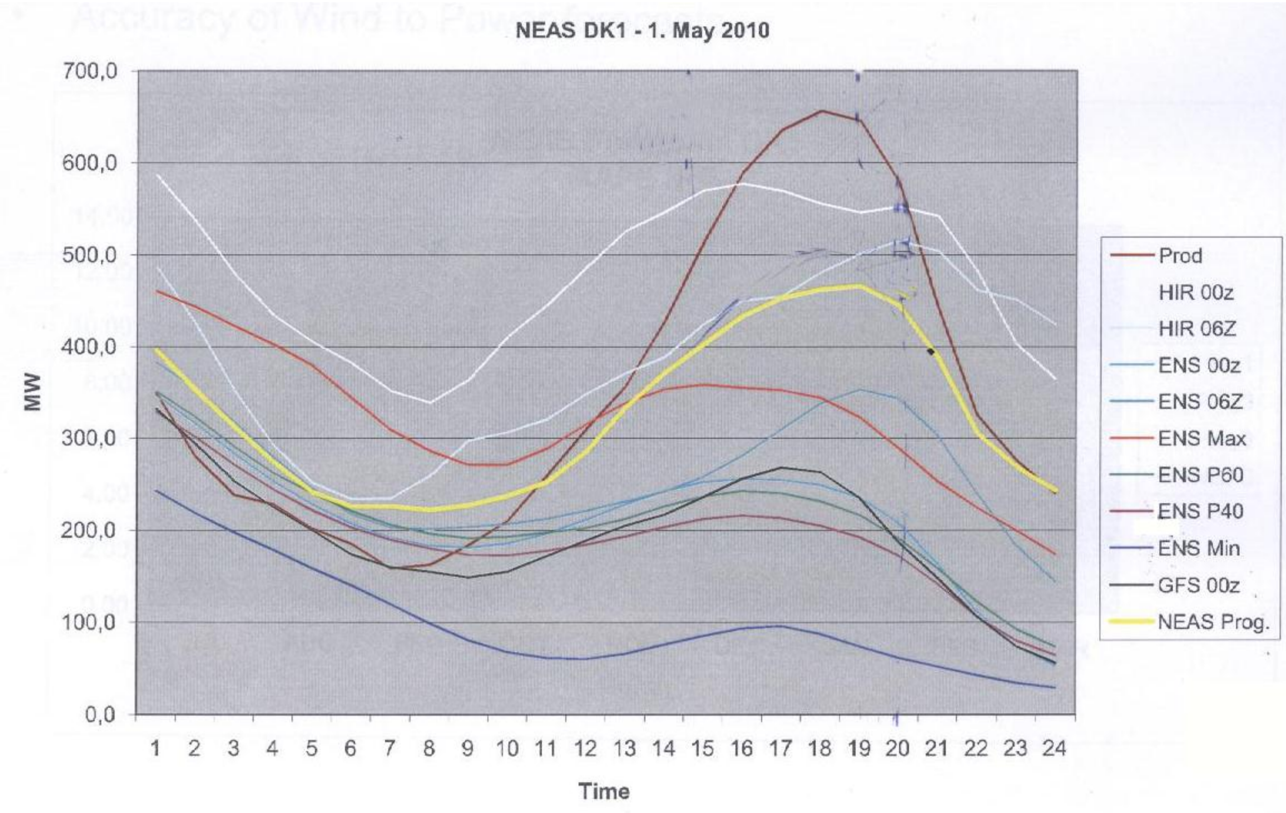

Figure 8: Different Forecasts for May 1st 2010.

5. Establishing groups of turbines

In the Scandinavian Regulating power market the gate closure for activation bids is 45 minutes before the operating hour and the minimum bid is 10 MW. The PRC shall be able to downward regulate the offered amount of MW-wind production in the full operating hour.

To be able to offer at least 10 MW downward regulation in the Regulating power market it is necessary to establish a group of turbines producing at least 10 MW in the operating hour. In this chapter are described core considerations to be taken into account when establishing these groups of turbines and recommendations are given.

A PRC are able to make an activation bid of 10 MW, when the production prognosis for all the PRC´s turbines shows, that in the coming operating hour these turbines will produce at least 10 MW in each quarter of an hour of the operating hour.

When coming to the operating hour where activation has been won, the PRC shall downward regulate a certain number of the turbines with a production equal to the won regulation.

BUT it is to be remembered that even if you are offering e.g. 10 MW in an operating hour, the Regulating power market is a 15-minutes market and it is likely that the 10 MW will be activated only in a part of the operating hour – that is to say that the financial settlement may include less than 10 MWh for this operating hour.

AND it is to be remembered that when making an offer of 10 MW you also need to decide about the bidding price and that you probably cannot use the same bidding price for all turbines, due to that the costs of downward regulating the turbines will differ.

Taking into account that the financial settlement for each turbine being activated in the Regulating power market shall be easy to handle – it is found that a good practice is to work with fixed groups of turbines – each group being bigger than 10 MW.

To make it even more easily handling the financial settlements for each turbine it has been preferred that if more turbines are owned by the same owner – they are to be found in the same fixed group.

The owner of a turbine is to decide in which group the turbine are to be placed. This choice will primarily depend on which bidding price is allocated to a certain group. The owners will receive a careful advice about which group to choose.

In a situation, where a turbine gets a premium of 250 DKK/MWh-el on top of the spot price in a certain amount of full load hours and a downward regulation is won, the turbine will not be paid this premium in that hour. But the premium is not lost. The payment of the premium will just be delayed to the end of the premium period some years later. So in this case depending on how close the turbine are to the end of its premium period the owner of the turbine has to estimate, what the cost is of delaying the premium. This cost becomes the highest bidding price for this turbine – if e.g. the cost of delaying the premium is estimated to 100 DKK/MWh-el, the highest bidding price for this turbine for a downward regulation is -100 DKK/MWh-el (the bidding price for a downward regulation is the highest price that the operator is willing to pay to the TSO for being downward regulated – when the bidding price is negative the operator wants money for being downward regulated).

Consideration about price formation has to be taken into account when choosing the right group for a turbine. It is assumed a certain group(s) of turbines soon will be the ones that determine the bottom prices for downward regulation. If offering a downward regulation to the marginal cost for the turbine of being downward regulated – the risk is that the turbine owner will earn nothing - because the marginal price for being downward regulated in a certain hour - paid to everyone - will be determined by this group of turbines. That calls for that the bidding price for a downward regulation shall be lowered with a desired profit margin.

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Another considerations is that a turbine being downward regulated face a small risk that it will not start again after having been downward regulated and that a service contract e.g. are to paid for per MWh-el, etc.

When it comes to a recommendable geographical distribution of the turbines in a certain group, it may be an advantage that the turbines in the group (the sum of installed capacities being bigger than 10 MW and less than 25 MW) have a considerable geographical distribution. That will expectedly improve the quality of the hour ahead wind production prognosis of the group. This improvement is well documented when day ahead wind production prognosis are considered (see page 26 in [1]), but is expected to be less when the hour ahead wind production prognosis of the group is considered. An argument against a big geographical distribution is that it e.g. is easier to make one wind farm being one group – that is to say that you only need to send one activation signal to the wind farm, when winning a downward regulation for this group.

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6. Life test of wind turbines offering downward regulation

Energinet.dk´s new regulation that makes it manageable for wind turbines themselves to offer activation in the Regulating power market has been tested on Sund&Bælt´s seven 3 MW turbines, in total 21 MW installed capacity (www.sundogbaelt.dk/uk/menu/csr/environment/sprogo-offshore-wind-farm). Examples of the results from this test are described in this chapter, as well as simulated earnings this wind farm could have had in some selected month.

Nordjysk Elhandel is the PRC in the test and Inopower has implemented the communication between the PRC and the turbines and implemented the control of the turbines. Besides that, Nordjysk Elhandel has made the short term production prognosis – needed to offer precise downward regulation activation bids of the turbines.

Figure 9: Sund&Bælt´s seven 3 MW turbines.

As one example of a won activation, look at hour 24 the 14th of February 2012 (see Figure 10). In that hour the activation price in the Regulating power market (the Tertiary reserve market) was negative (showing that the TSO badly needed downward regulation, but it seems that few were interested in doing so – since the activation price became negative (see Figure 10)).

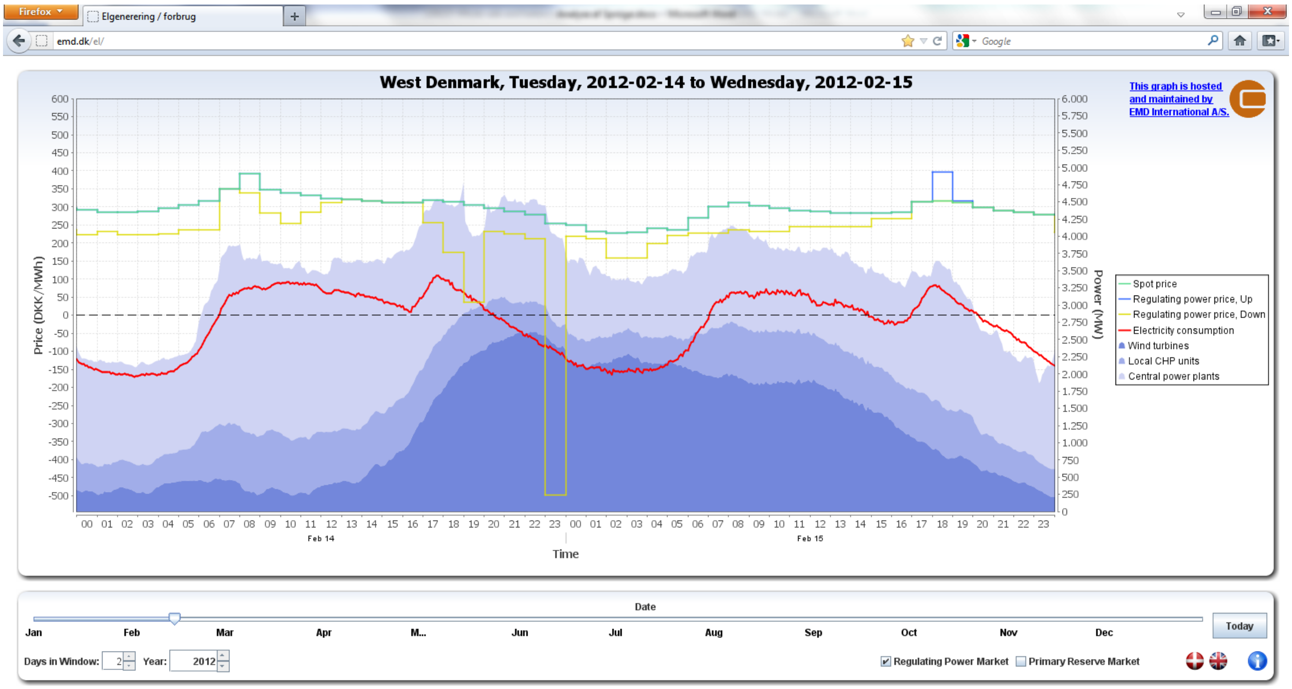

Figure 10: We show prices in the Regulating power market (the Tertiary reserve market) at www.emd.dk/el. In hour 24 in 14. February 2012 the activation price in the Regulating power market was negative (yellow prices).

The activation bid of Sund&Bælt´s turbines was set to -100 DKK/MWh-el. The reason for this bidding price is that the turbines get a premium of 250 DKK/MWh-el on top of the spot price in a certain amounts of full load hours. So when downward regulating - they will not be paid this premium in that hour. But the premium is not lost. The payment of the premium will just be delayed to the end of the premium period. So the -100 DKK/MWh-el represents the lost value of the premium, because it is paid later. When the turbines are at the end of the premium period this activation bid could be raised to 0 DKK/MWh-el.
Since activation in the Regulating power market is organized as a Marginal price market, you can offer the activation at this marginal cost.

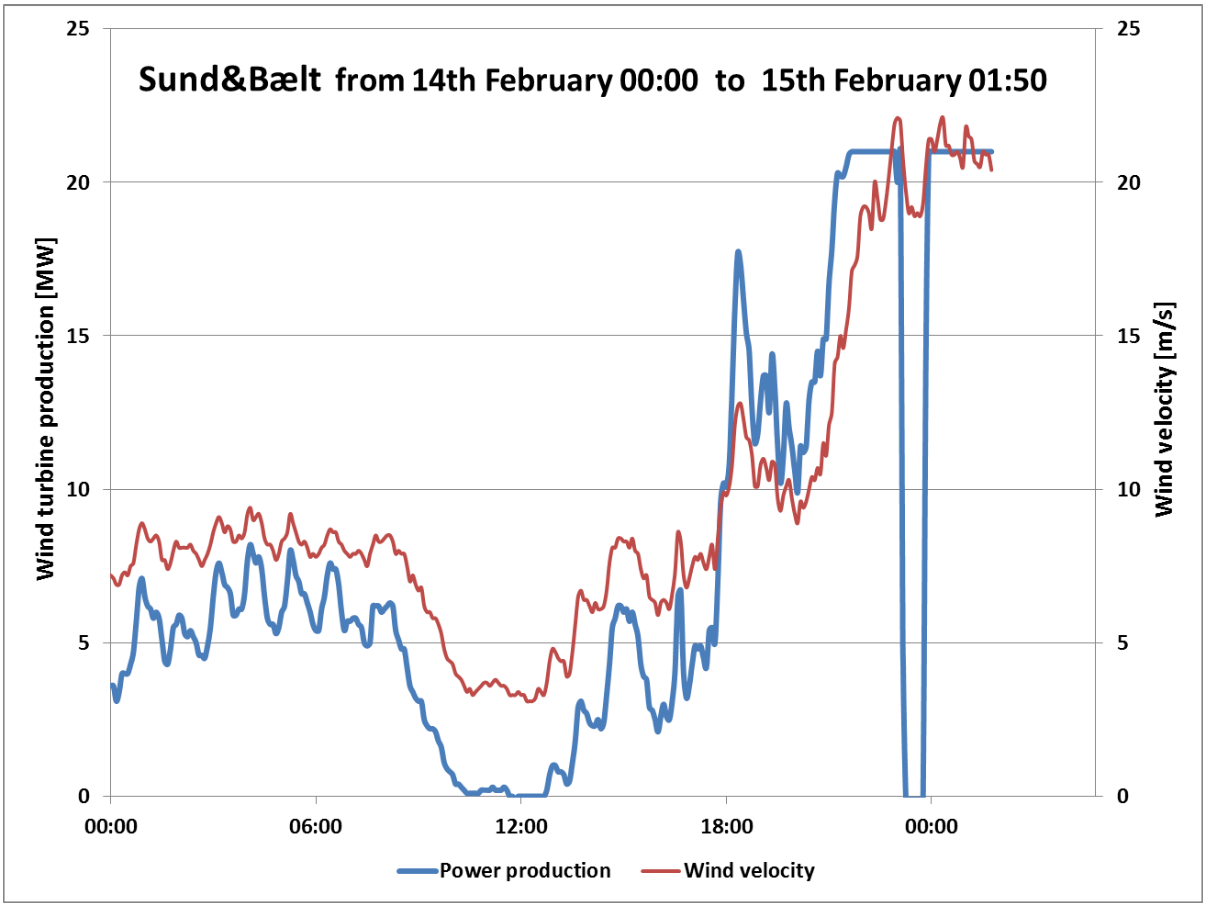

Figure 11: Sund&Bælt´s turbines won downward regulation in hour 24 the 14th of February 2012

The increase in earning in hour 24 the 14th of February 2012, when being downward regulated is calculated to 173 % (see Figure 12).

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Profit calculation of won downward regulation in hour 24 of 14 February 2012						
Production in that hour if not being downward regulated		21,0	MWh-el			
Production in that hour when being downward regulated		6,7	MWh-el			
Sold at spot market in that hour		17,8	MWh-el			
Spot market price in that hour		252,70	DKK/MWh-el			
Downward regulation price in that hour		-497,97	DKK/MWh-el			
Cashflow in that hour in case of not offering downward regulation						
Sold at spot market	17,8	MWh-el á	253	DKK/MWh-el	4.498	DKK
Surplus (imbalance), (21 - 17,8 MWh)	3,2	MWh-el á	-498	DKK/MWh-el	-1.594	DKK
Total payment for hour 24					**2.905**	**DKK**
Cashflow in that hour in case of offering downward regulation						
Sold at spot market	17,8	MWh-el á	253	DKK/MWh-el	4.498	DKK
Settlement (Regulating power), (17,8 - 6,7 MWh)	-11,1	MWh-el á	-498	DKK/MWh-el	5.527	DKK
Net present value of delayed 250 DKK/MWh	21,0	MWh-el á	-100	DKK/MWh-el	-2.100	DKK
Total payment for hour 24					**7.926**	**DKK**
Increase in profit in that hour in case of offering downward regulation					**5.021**	**DKK**
					173%	

Figure 12: Increase in earning in hour 24 the 14th of February 2012, when being downward regulated, was 173%.

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Another example of a won activation, look at 25th and 26th December 2011, where the .

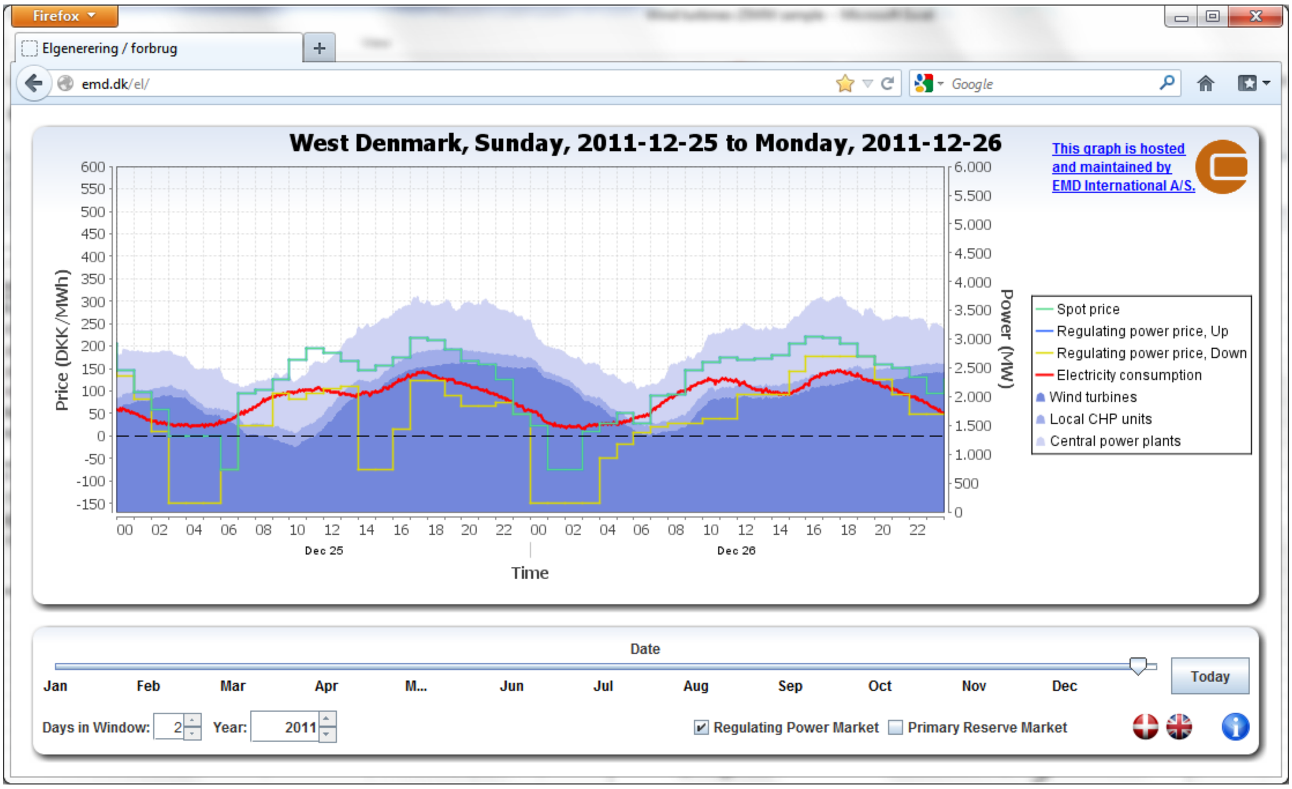

Figure 13: 25th and 26th December 2011the activation price in the Regulating power market was negative in more hours (yellow prices).

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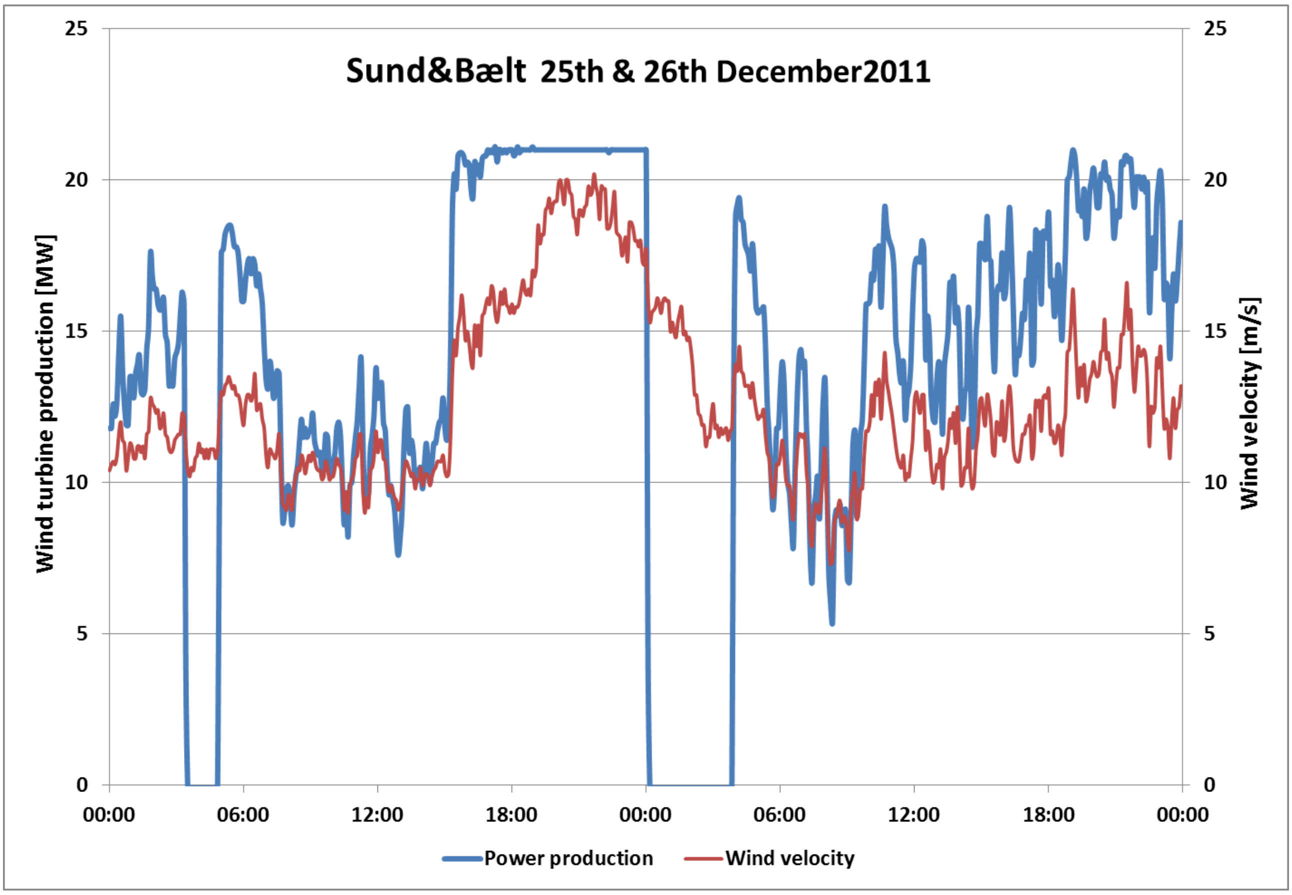

Figure 14: Sund&Bælt´s turbines won downward regulation 25th and 26th December 2011.

6.1 Simulated profit for wind turbines offering downward regulation

Based on the historic spot prices and the historic activation prices in the Regulating power market (Tertiary reserve market), it has been simulated for 9 month in 2010 what a 21 MW-plant could have earned by offering activation in the Regulating power market. In Figure 15 is shown the result of this simulation. It shows that the earning would have gone up with around 8 percent, but that production in these 9 month would have been reduced with around 5% if offering activation in the Regulating power market.

This is certainly a rough calculation – which do not relate very much to an expected future reality. If enough turbines offers activation, they will soon become the plants determining the activation prices in the Regulating power market in the hours with very negative activation prices – to say that they will earn nothing if offering downward regulation at a bidding price equal to their cost of being activated and only a few of them will be downward regulated. But still all the turbines will benefit of these proactive turbines offering activation, because all the turbines will avoid high imbalance costs.

Rough simulation of the value of Proactive participation of a 21 MW windfarm in the first 9 month of 2010 in Westdenmark		
(all amounts in €)	**Proactive**	**Reference**
Sold electricity in the spot market	1.270.825	1.270.825
Surplus (imbalance)	188.052	147.224
Shortfall (imbalance)	-158.963	-158.999
Activation income in the Regulating power market	88.745	
Value of delayed 250 DKK/MWh-premium (100 DKK/MWh)	-23.057	
Income total	**1.365.602**	**1.259.050**
Profit of proactive participation	**106.552**	
	8,5%	
Produced in the first 9 month of 2010	32.788	MWh
Sold in spot the first 9 month of 2010	30.100	MWh
Downward regulated when being proactive	1.718	MWh
Average error in prognosis (relative to full load)	6,2%	

Figure 15: Simulated profit for wind turbines being activated in the Tertiary reserve market

7. Conclusion and recommendations

Today the general case in the EU-countries is that wind productions are integrated in the electricity system through the wholesale markets (typically intraday and day ahead spot markets) but are not participating in the balancing markets.

Energinet.dk, the Danish Transmission System Operator, has recently changed its regulation in order to make it manageable for wind turbines themselves to offer activation in the Tertiary reserve market (The Scandinavian Regulating power market).
Energinet.dk´s new regulation in order to make it manageable for wind turbines themselves to offer activation in the Regulating power market has in this project been tested on a 21 MW wind farm. In more hours in the test period this wind farm has been activated for downward regulation in the Regulating power market, and it has been shown that this proactive participation of wind turbines in a balancing market increases the profit of the turbines.

Proactive participation of wind turbines in the wholesale markets are in fact also a possibility. E.g. in the Scandinavian day ahead spot market, NordPool, it is allowed to offer sale to negative prices, and we have seen an example of that turbines was closed down due to sufficiently negative prices in the day ahead spot market.

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In general the benefits for the wind turbine owners in trading on the wholesale markets have been analyzed in a number of studies. Perkes et al [8] reported that the financial benefit (increase in value for wind energy) for a UK wind farm was £8 per MWh, while in Spain it was €10 per MWh. Another UK study by Barthelmie et al [10] showed indications of an increase in price aound £5 per MWh, which was about 14% of the electricity price in 2003.

Nearly all the balancing of wind productions can be made in the Tertiary reserve market. But to make the Tertiary reserve market the ultimate market for balancing wind productions – it is necessary that the TSOs moves most of the balancing from the more expensive Secondary Reserve market to the cheaper Tertiary reserve market - where most plants are able to participate in the balancing – the rationale is that the balancing should never be made on a higher level than needed – in the sense that the Secondary Reserve market is a higher level than the Tertiary reserve market.

When splitting the market into an availability market and an activation market, gate closure for the activation bids should be moved close to the operating hour.

A good organization of the Tertiary reserve market comprises:
- Splitting the market into an availability market and an activation market.
- Making the market asymmetric, allowing offering only upward or downward power.
- Organizing the market as a Marginal price market and not as a PayAsBid-market.

When comparing the Danish and German Secondary Reserve and Tertiary Reserve markets against the proposals in this chapter, it is to be noticed that the German Tertiary Reserve market is not split into an availability market and an activation market, and it is organized as a PayAsBid-market and not as a Marginal price market.

Rough comparison of balancing markets in Germany and Denmark

	Positive Secondary Reserves (Sekundärregelung)	**Positive Tertiary Reserves (Minutenreserve)**
Germany	**3000 MW**	**3000 MW**
West Denmark	**100 MW**	**500 MW**

As mentioned nearly all the balancing of wind productions can be made in the Tertiary reserve market, but from the table above, comparing the ratio´s between the sizes of the Secondary and Tertiary reserve markets, it seems as if most of the balancing of wind productions in Germany is made in the Secondary Reserve market.

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The above mentioned organization of the Tertiary reserve market allow the wind turbines themselves to participate in the balancing of the wind productions.
BUT perhaps even more important it would also allow thousands of distributed plants to participate in the balancing. This has been dealt with in the EU-projects, MASSIG [11] and DESIRE [12] and been analyzed in more papers [13..21]. These distributed plants needs in the future to be designed so that they have a high flexibility in integrating fluctuating productions, amongst others also equipped with energy storages and units that can convert electricity to other energy types, e.g. heat, renewable energy gases or transport fuels. Skagen CHP-plant in Denmark is a good example of how flexible distributed plants shall be designed in the future. This plant has an electrical capacity of 14 MW, have installed an electrical boiler of 11 MW and a big thermal store. The operation of Skagen CHP-plant is shown online at www.emd.dk/desire/Skagen.

Figure 16: Skagen CHP-plant in Denmark.

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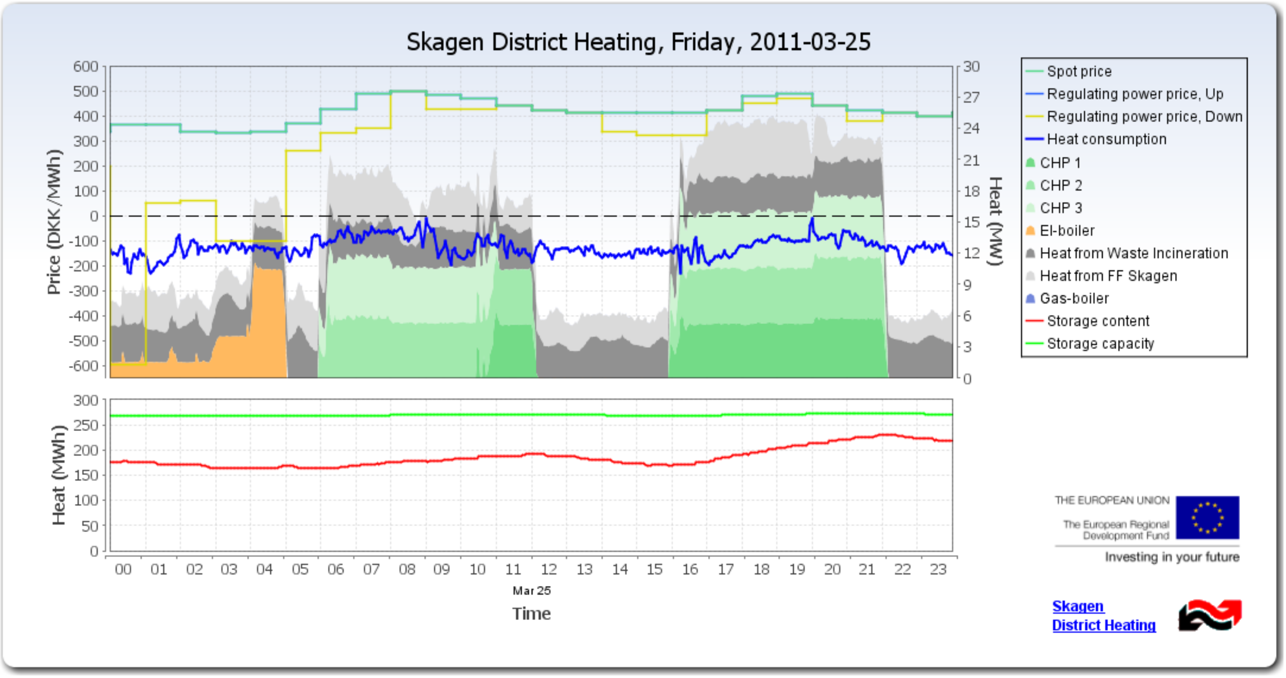

Figure 17: The online operation of Skagen CHP-plant shown at www.emd.dk/desire/Skagen.

An interesting example of Skagen CHP-plant's regulating potential occurred on the 25th of March 2011, as displayed in Figure 17. In the first four hours of the day, Skagen won negative Primary reserve with the 10 MW electrical boiler. Hence, it operated below full capacity. A little before 3 o´clock, Skagen won a downward regulation in the Tertiary reserve market, so the electric boiler increased its output to approximately 4 MW. At the same time, Skagen still performed the frequency regulation which it had won in the Primary reserve market. After 4 o´clock, Skagen had not won anymore Primary reserve and so the electric boiler was offered at full capacity (i.e. 10 MW) for downward regulation in the Tertiary reserve market, winning activation for a full hour. From 16 - 20 o´clock, only part of the CHP units were sold in the spot market which made it possible to offer both positive Primary reserve and negative Primary reserve during these 4 hours.

The conclusion of this project is that allowing wind turbines themselves to offer activation in the Tertiary reserve market will imply that all the turbines will benefit of these proactive turbines offering activation, because all the turbines will avoid high imbalance costs. And the implication of allowing wind turbines themselves to offer activation in the Tertiary reserve market will be that there will be a better balance between the needed investments in the turbines and the needed investments in the electrical grid.

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List of Symbols

ACER	Agency for the Cooperation of Energy Regulators
PRC	Production Responsible Company
TSO	Transmission System Operator

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Appendix 1: Wholesale and balancing markets in UK

The electricity market in UK is divided into:
- The power exchanges and bilateral trading (whole sale markets)
- The balancing mechanism market
- The balancing services (Ancillary Services). E.g. the Short Term Operating Reserves market (STOR-market)

The wholesale markets in UK

The UK whole sale electricity markets is based mainly on bilateral contracts between generators and suppliers of electricity. In 2008 only app. 3% of the electricity was handled by the power exchanges. The generators are dominated by six big companies and besides these companies; there is a number of independent power producers.

The bilateral contracts and the trade at the power exchanges aggregates into the individual generators and suppliers production and consumption plans, which are handed into the System Operator (National Grid) in the following sequence:
- Initial Physical Notification (IPN) which is released at 11.00 a.m. for the day ahead
- Final Physical Notification (FPN) which is released at gate closure one hour before the start of the settlement period. Each settlement period is a ½ hour, which means that a standard day has 48 settlement periods.

The power exchange N2EX

www.n2ex.com

The power exchange N2EX consists of three markets:
- Day Ahead Auction Market
- Spot Market
- Prompt Market

Only the first two are relevant in this context and described in this section.

N2EX Day Ahead Auction Market

The N2EX Day Ahead Auction Market is a day-ahead auction where producers and consumers make anonymous bids without access to any information about the bids of other players in the auction. The bids are made for each hour of the next delivery day. Bids are accepted all day until gate closure occurs at 09:30. Following gate closure the bid information (supply and demand prices and volumes) are utilized to determine an equilibrium market price for each hour of the next delivery day. In between 09:45 and 10:00 the prices are published for bidding participants to view. There are three types of bids that can be made by participants - they include single bid, block bids and flexible hourly bids.

Single bids are a group of price/volume pairs per hour that state the desired sale or purchase volume at different price levels. A minimum and maximum price is selected so that all bids have the same price range. Within this acceptable price range each generator/consumer will submit their desired volumes and prices taking into account their consumption needs and/or cost of generation, delivery obligations and also bilateral contracts (Over The Counter). The acceptable price range is £ 0 to £ 2000 per MWh.

Block bids cover multiple consecutive hours of the day. They also stipulate a single price and volume rather than a group of price/volume pairs. This single price and volume make it an "all or nothing" bid, meaning that if the bid is not accepted, then the player will not buy or sell any power. A sale offer will be accepted if the price is lower than the average price. A purchase bid will be accepted if the bid price is above the average price.

Flexible hourly sale offers and purchase bids consist of a single price and volume, however the hour of the day is not pre-determined. As a result, the offer will be accepted in the hour with the highest price, pending that the highest price is above the bid price.

A marginal pricing formation is utilized in the N2EX Day Ahead Auction Market. As a result, the calculated equilibrium price applies to all trades conducted during a specific hour.

N2EX Spot Market (Intraday)
The intraday market, also termed the spot market consists of half hourly bids that are traded during the day of delivery or day-ahead once the Day Ahead Auction Market has been closed. Table 1 summarizes the different products offered in the spot and prompt markets.

Type	Length
Half Hour	½ Hrs
1 Hour	1 Hrs
2 Hour Blocks	2 Hrs
4 Hour Blocks	4 Hrs
Day block 3+4	8 Hrs
Day overnight	8 Hrs
Day Peak	12 Hrs
Day Off-Peak	12 Hrs
Day Extended Peak	16 Hrs
Day Base	24 Hrs
Weekend 5	8 Hrs
Weekend 6	8 Hrs
Weekend 3+4	16 Hrs
Weekend Overnight	16 Hrs
Weekend Peak	24 Hrs
Weekend Off-Peak	24 Hrs
Weekend Extended Peak	32 Hrs
Weekend Base	48 Hrs

Unique Spot market products

Products transferred from the Prompt market

Table 1 Products offered in Spot and Prompt Market

These products are available for trade in the spot market continuously 24 hours a day, 7 days a week. Trade may occur from up to 48 hours before delivery to 15 minutes prior to gate closure. Gate closure occurs 75 minutes prior to the time of delivery. Contracts will cease to be available for trading according to the following:

- Half Hour contracts: 15 minutes ahead of Gate Closure
- 1 Hour contracts: 16 minutes ahead of Gate Closure
- 2 Hour Blocks: 17 minutes ahead of Gate Closure

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- 4 Hour Blocks: 19 minutes ahead of Gate Closure
- Listed Block combinations: 19 minutes ahead of Gate Closure

Products that are not unique to the spot market are originally offered in the prompt market. Prompt market products are then moved to the spot market two business days prior to delivery when the prompt market closes at 19:00. Table 2 illustrates the timing on which prompt market contracts are “roll over” into the spot market.

Roll-over schedule from the Prompt market to the Spot market	
Trading Day	**EFA Day for Delivery corresponding to**
Monday	Thursday
Tuesday	Friday
Wednesday	Saturday
Thursday	Sunday
Friday	Monday, Tuesday, Wednesday
Saturday	(no roll-over)
Sunday	(no roll-over)

Table 2 Roll-over schedule from Prompt to Spot Market

Pay-as-bid price formation is utilized in the spot market where offers to purchase and sell power are matched continuously throughout the trading period. This continuous trade matching means that an incoming offer is immediately matched to an existing order with the best price. The best price is defined as the highest price for sale offers and the lowest price for purchase bids. If two existing offers have the best price, the one that was entered first will be selected. It should be noted that if an incoming offer has a better price than the best price offer, the best price offer will be selected to match and the original order price will prevail. (e.g. a sale offer price is higher than the existing best purchase price, the sale offer will be matched with the best possible purchase price and the price bid by the existing offer will prevail. i.e. the best possible purchase price).

The power exchange APX

www.apxendex.com

The power exchange APX consists of three markets:

- APX UK Power Auction
- Spot Market
- Prompt Market

The first two are described in this section. The Prompt Market is described in section “**Error! Reference source not found.**. **Error! Reference source not found.**”.

APX UK Power Auction

The APX auction is a day-ahead auction where producers and consumers make anonymous bids without access to any information about the bids of other players in the auction. The bids are made for each hour of the day, and from this information (supply and demand) they are able to determine a market price for each hour of the following day. Each player is allowed to make multiple bids for each hour thus defining their own demand/supply curve, and thus effectively ensur-

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ing that an economically attractive offer is accepted or considered "in merit". A pay-as-bid system exists in this market where the generators and consumers of electricity pay/receive the amount stipulated in the bid regardless of the average price.

Using the calculated market prices for the next day, APX Power UK publishes three indices that can be used by the players as a reference for the spot price of electricity. The indices are:

- Base Load (23:00 – 23:00 GMT)
- Peak Load (07:00 – 19:00 GMT)
- Off-Peak Load (23:00 – 07:00 and 19:00 – 23:00 GMT)

The indices can be viewed at: http://www.apxendex.com/?id=49. The peak load index is the highest, off-peak is the lowest and base load is simply an average of the two.

The time line associated with this auction is as follows:

- Offers/bids are accepted until 10:30 GMT the day before delivery.
- Bids are matched with offers directly following closing of the market.
- Results are released to players by 10:45 GMT.
- Contract notifications are submitted to Elexon by 11:00 GMT.
- Results are published on website following notification of Elexon.
- Financial settlement of auction is completed once weekly.

APX Spot Market

The spot market enables trading of electricity 24 hours a day, 7 days a week. The market is utilized for the purposes of both electricity trade and balancing. Physical electricity products are sold in half hour increments or standardized blocks made up of multiple half hour increments. The products offered in the spot market are summarized in Table 3. A pay-as-bid system is utilized to determine the price/compensation paid of each trade as each individual sale bid is matched with an individual purchase bid.

Contract	Period Covered	Hrs	Opens for Trading
4 Hrs block	6 blocks/day, block 1 begins 23:00; block 6 ends 23:00	4	Rolling 7 days
2 Hrs block	12 blocks/day, block 1A begins 23:00; block 6B ends 23:00	2	49 1/2 Hrs prior to start of delivery
1 Hr block	Day Ahead Auction, 24Hrs/day, begins 23:00; ends 23:00	1	Hourly auction opens for order entry at 00:00, 14 days prior to delivery; matching takes place at 10:30 daily
Half hour block	48 periods/day, 1/2 Hr 1 begins 00:00; 1/2 Hr 48 to end 00:00	0.5	49 1/2 Hrs prior to start of delivery

Table 3 APX Spot Market Products

Payments for deviations from the Final Physical Notification

Deviations from the Final Physical Notification (FPN) are settled for each settlement period using the periods System Sell Price (SSP) and System Buy Price (SBP).

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- Generators which over-generate in a settlement period are paid the SSP for the additional amount.
- Generators that under-generate has to pay the SBP for the missing amount.

The SSP and SBP are the weighted average price of the balancing mechanism offers and bids.

The SSP and SBP can be found at www.elexonportal.co.uk/category/view/175 (Login is required, however registration is free)

An example of one week's SSP and SBP can be seen in Figure 18, where a week in February 2012 is shown.

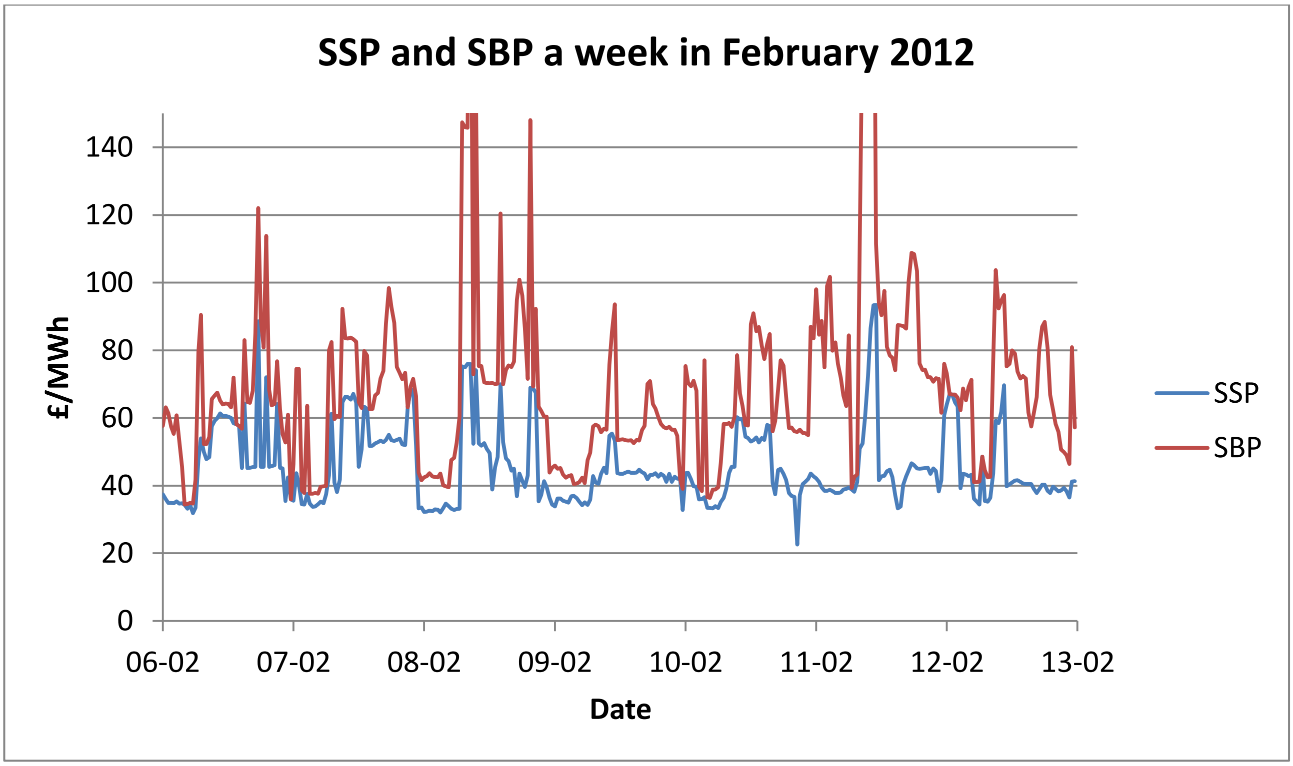

Figure 18 System Sell Price (SSP) and System Buy Price (SBP) from the 6th – 12th of February 2012

Balancing markets in UK

Balancing mechanism in UK

The balancing mechanism (BM) is a balancing market that works from gate closure (one hour before settlement period) until the real time in order to real time balance supply and demand. Participation in the BM is done by submitting bids and offers to the National Grid Company up until gate closure at which time they become frozen and must be available to the National Grid Company should they require them. The participants are compensated on a pay-as-bid basis, where National Grid accepts the cheapest bids and offers required to perform their balancing obligations.

With the FPN's gate closure one hour before the start of the settlement period, the UK balancing mechanism gate closure is equal to the power exchanges gate closure. Along with the FPN the generators and suppliers can submit notices defining the price for deviating from their FPN. The deviations are described by:

- The settlement period it refers to
- An offer (£/MWh) to increase production/reduce demand or
- A bid (£/MWh) to reduce production/increase demand
- The minimum offer/bid has to be at least 1 MWh

During each settlement period the System Operator chooses the bundle of balancing actions that minimises the price impact for the power system.

After the settlement period has been run, the system operator calculates the imbalances and the responding prices in order to bill the generators/suppliers that deviated from their FPN's and pay the generators/suppliers that delivered the balancing services during the settlement periods in order to keep the system in balance.

For each half hour trading period the System Sell Price or the System Buy Price will be associated with Balancing Mechanism Bids and Offers. In this case the price will be known as the Main Price. The other price will be derived from short term energy trades (no more than 3 business days prior to gate closure) and is known as the Reverse Price. To calculate the Reverse Price a Market Index Price is found, which reflects the price of the wholesale electricity in the short-term market. The Market Index Price can be found here www.elexonportal.co.uk/article/view/188 (Login is required, however registration is free)

All types of generators can participate in offering/bidding for deviations from the FPN. There is potential for distributed generators to take part in both the bilateral/power exchanges and bid into the balancing mechanism.

Short-Term Operating Reserve market (STOR-market)

Besides the intra-day market in UK, the National Grid is procuring short term operating reserves via tenders. On this market the participants have to declare available services up to a week before actual delivery. The minimum capacity to be bid into the market is 3 MW with an availability time of max 240 minutes and a minimum duration of 2 hours. The STOR services are considered committed or flexible. Committed services are where the provider agrees to offer the service in all available windows and the TSO agrees to buy all available service provided. In contrast, flexible STOR services do not have to be provided in all windows and the TSO is not obligated to buy all available service provided.

STOR services are procured via a competitive tender process that occurs three times annually. National grid has different requirements for STOR depending on the time of the year (i.e. seasonally, monthly, weekly and daily). As a result the National Grid breaks the year into six seasons that generators and loads may tender for. Tenders are either accepted or rejected by National Grid depending on the requirement and cost of service. Accepted tenders become contractually binding agreements.

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Payment for STOR services provided are availability payments (£/MW/hour) and utilization payments (£/MWh).

Daily historical data for the STOR prices and volumes can be found here
www.nationalgrid.com/uk/Electricity/Balancing/services/STOR/storcv and here
www.bmreports.com
Yearly reports can be found here www.nationalgrid.com/uk/Electricity/Balancing/services/STOR/

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