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D5.2.8 Analysis of requirements for up/down response

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Introduction

The purpose of this document is to outline the requirements for up/down response, which may be used as a starting point when designing demand response of distribution network loads. The main focus is on the consequences of intermittent renewable power production, which in Nordic conditions mostly means wind power.

The wind power production is highly variable, which raises the question of control power to level the gap between production and demand. So far this power has been produced by hydro power plants, but it is foreseen than when the Nordic power system is more strongly integrated with the other European countries, the relative availability of hydro based control power may become a subject of competition, thus requiring new control capacity being built in Nordic countries.

An alternative to new peak power capacity may be demand response. This paper is an attempt to outline the time and volume requirements for demand response, used in coordination of increased wind capacity in Finland in the foreseen future.

Introducing more renewables

Reducing carbon dioxide and other greenhouse gas emissions requires several actions. The European Union has assessed renewable energy production targets for the EU member countries. Directive 2009/28/EY aims for notable increase in use of renewables. In 2020, the share of renewable energy of the final energy consumption in every member country should exceed 10 percent. The Finnish target has been set to 38 percent, which is an increase of 9.5 percent from the 2005 level. The Finnish government has approximated that the final energy consumption in 2020 would be 327 TWh of which renewables should cover 124 TWh. In practise, this means an increase of 38 TWh to the renewable energy production levels in 2005. http://www.tem.fi/files/26294/HEluonnos_110310_.pdf
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:fi:PDF

In March 2010, the ministerial working group reached common understanding of implementing this new national energy policy that is in line with the EU directive. This advancement of renewable usage would decrease the total carbon dioxide emissions by seven million tonnes. In addition, the reduction in coal-based energy generation would decrease the carbon dioxide emission level by two million tonnes.
http://www.tem.fi/index.phtml?101881_m=98836&s=4265
http://www.tem.fi/files/26643/UE_lo_velvoitepaketti_Kesaranta_200410.pdf

The renewed energy policy includes increasing energy self-sufficiency, implementing the renewable energy obligations (EU), and utilizing nuclear power in an efficient way. These primarily base on sustainability, domestic energy production, as well as enhancement of technology, employment and economic growth. Renewable energy solutions are favoured in order to be implemented in three sectors: electricity production, heating and cooling, as well as traffic. Improvement in energy self-sufficiency will be obvious, as the self-sufficiency increases to nearly 40 percent. At the moment, around 30 percent of the used energy in Finland is home-grown: wood, water, wind, peat, heat pumps etc. In several countries, solar power is awaited to increase its proportion in electricity generation. Table 1 describes the assumed renewable usage in Finland in 2020, as well as the realized production levels from 2005. Wind and solar power are underlined for they represent intermittent energy generation.
http://www.tem.fi/files/26643/UE_lo_velvoitepaketti_Kesaranta_200410.pdf

Table 1: Renewable energy sources in Finland in 2020, the increase from the 2005 http://www.tem.fi/files/26643/UE_lo_velvoitepaketti_Kesaranta_200410.pdf

Renewable energy sources, TWh			**Change**
As primary energy	**2005**	**2020**	
Fuel forms depending on the industrial production			
Waste liquor	37	38	1.1
Wood (waste from industry)	20	19	-1.8
total	**57**	**56**	-0.7
New energy policy			
Hydropower (normalized)	13.6	14	0.6
Wind power	0	6	5.8
Forest converted chips	6	25	18.9
Wood (small-scale)	13	12	-0.5
Heat pumps	2	8	6.1
Traffic biofuels	0	7	6.5
Biogas	0	1	0.7
Pellets	0	2	1.6
Recycled fuels	2	2	0.7
Other renewables (solar power, solar water heating etc.)	0.4	0.4	0.0
total	**37**	**77**	40.0
Renewable energy as primary energy, total	94	134	39.2
Renewable energy in final consumption	87	124	37.5
Final energy consumption	303	327	23.6
Renewables' share of final energy consumption (%)	28.5 %	**38 %**	9.5%

Wind power in Finland

Wind power generation is presumed to notably increase during the next ten years in Finland. Although solar power and solar water heating are not planned to be increased by 2020, it is noteworthy to mention that these intermittent energy generation technologies (underlined in Table 1) – also wind power – relate to the topic of this document because of their intermittent nature.

At present, wind power production in Finland remains at a rather low level. Wind power plant capacity is around 200 MW producing approximately 0.3 percent of the country's annual electricity consumption (292 GWh in 2010). Figure 1 presents the growth of wind power usage from the 1992 until the first quarter of the 2011. Currently, the Finnish wind power plants range power-wise from a single 75 kW-unit located in Huittinen to 3.6 MW-units in Tornio, averaging around 1.5 MW. http://www.vtt.fi/files/projects/windenergystatistics/2011_08.pdf / http://www.vtt.fi/proj/windenergystatistics/?lang=fi

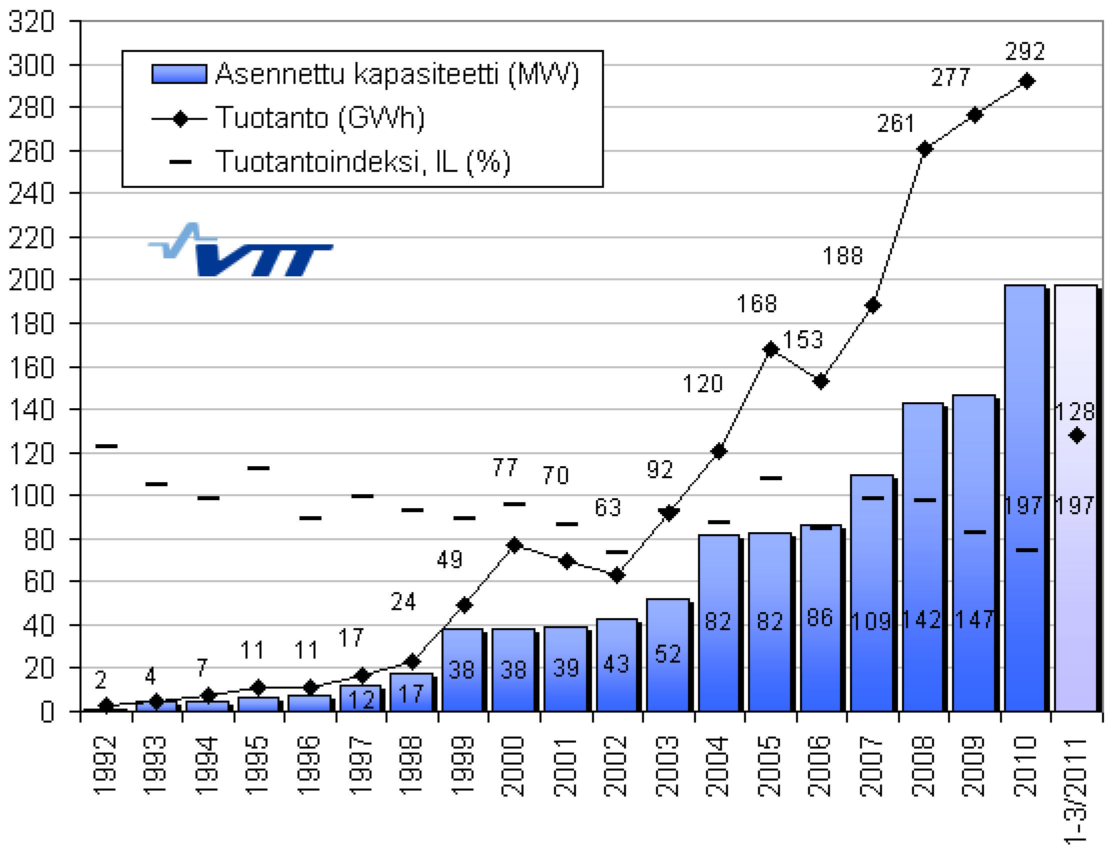


Figure 1: Wind power plant capacity in Finland (http://www.vtt.fi/proj/windenergystatistics/?lang=fi)

Figure 2 illustrates the planned wind power projects in Finland (updated 2/2011). Both onshore and offshore plans involve power capacity of around 3000 MW. Some sources suggest that even more capacity has been planned both onshore and offshore – up to 5000 MW and 4800 MW, respectively. By 2020, according to the national renewable policy, wind power production would present power plant capacity of 2500 MW and yearly 6 percent of the electricity consumption (~6 TWh). Assuming all the wind power plant construction plans were implemented and the electricity consumption would be at the assumed 2020-level, wind power would account for over 10 percent of the Finnish electricity consumption. Surpassing of the 10 %-level can be true in the future, perhaps before 2030. http://www.vtt.fi/files/news/2011/Tuulivoima_media-aamiainen_esitys.pdf

On the European level, the European Wind Energy Association, EWEA, has set a target of producing from 14 to 17 percent of the consumed electricity by wind power in 2020. The final figure depends on the then prevailing electricity demand. Currently, wind power provides some five percent of the used electricity in Europe. http://www.ewea.org/fileadmin/swf/factsheet/1_statisticsandtargets.pdf
http://www.ewea.org/fileadmin/ewea_documents/documents/statistics/EWEA_Annual_Statistics_2010.pdf

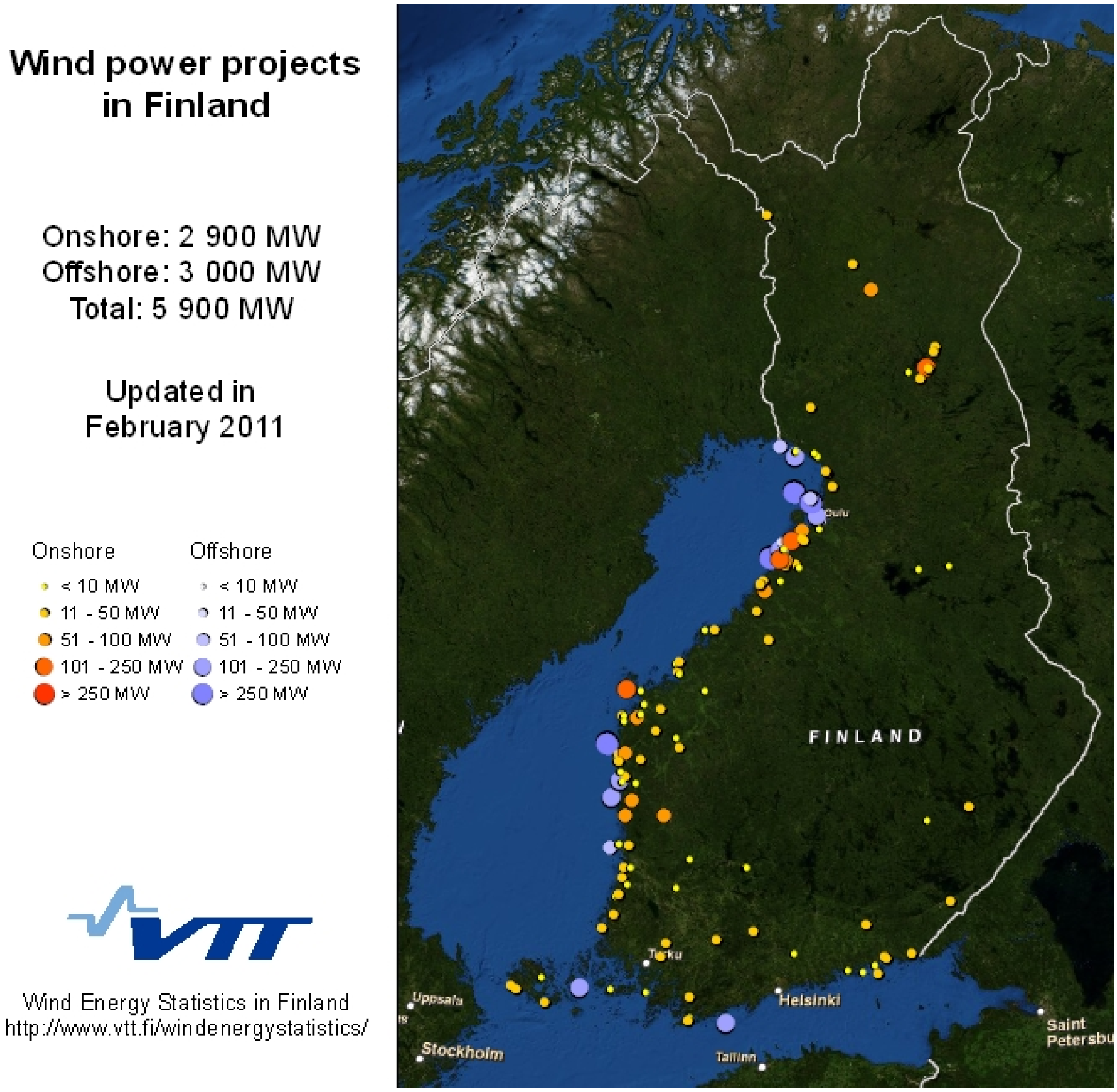


Figure 2: Wind power projects in Finland, 2/2011 http://www.vtt.fi/proj/windenergystatistics/windenergystatistics_projects.jsp

Higher penetration of wind power levels will not come without challenges. The power production by wind and solar power depend highly on the climate and weather conditions – i.e., wind levels, cloudiness. When increasing the penetration of these intermittent energy forms, one must handle the question of grid's power balance management.

Bulk power system and higher penetration of intermittent energy sources

Variability and uncertainty increase as more intermittent energy sources are presented to the national power production. Therefore, system reliability and efficiency must be highly valued when assessing the impacts of broadly used wind and solar power. Implementing intermittent energy production requires attention on several levels. When talking about wind energy, wind power variability and predictability, the technical capabilities of wind turbines, as well as the future plans of implementing wind power must be known in order to support the development and functioning of the power system.
http://www.ieawind.org/AnnexXXV/PDF/Final%20Report%20Task%2025%202008/T2493.pdf

Challenges with wind power normally occur in situations with high wind and low load. Operational security and reliability should be kept high by system operators at the same time with maximal wind power production. So far, no major operational problems have been caused as a result of increased wind power production. However, the integration of high wind power capacity requires careful examination and practical actions. The following listing describes some necessary system-level actions for high penetration of wind power:

- **Grid infrastructure:** transmission and distribution upgrades for fluent grid operation
- **Markets**: accommodating uncertainty and wind forecast errors with help of various energy products (e.g., day-ahead, hour-ahead, real-time) and cross-border exchange
- **System tools**: accurate forecasting, real-time generation level metering, efficient assessment of system stability in order to maintain system security by controlling wind power output
- **System flexibility**: reducing the response time of generation plants (thermal, hydro, and variable generation itself), using demand-side response (i.e., electric vehicles, electric space heating), developing energy storages
- **Capabilities, policies etc.**: developing clear grid connection rules (grid codes), handling issues such as transient stability, voltage collapse, as well as reactive power requirements
- **Cooperation of countries in the northern Europe**: jointly planned future offshore wind power generation for more trade capacity http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6049627 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6049630

Estimates of increased power reserve needs

Since the European penetration levels of intermittent energy sources are still not very high, and no major operational problems have occurred during operation caused by intermittent generation, it is still difficult to assess the amount and type of reserve needed in the power grid to level out the uncertainty and instability. Denmark had the largest share of 24 percent of wind power in its electricity mix in the European Union in the end of 2010 (http://www.ewea.org/fileadmin/ewea_documents/documents/statistics/EWEA_Annual_Statistics_2010.pdf).

However, some statistical estimations and probabilistic dimensioning methods have been used during the last decade in order to determine the nature of reserves needed in power systems where wind power and other intermittent power sources are largely utilized.

Holttinen (2004, 2005) states that in the Nordic countries most common situation in large-scale wind power generation would involve wind power plant operation within production levels of below 75 percent and above 5 percent of the installed capacity. The hourly changes in wind production would normally stay within ±10 percent in one Nordic country, and in the range of ±5 percent of capacity inside the Nordic area as a whole. http://www.ieawind.org/AnnexXXV/PDF/Final%20Report%20Task%2025%202008/T2493.pdf
http://www.vtt.fi/inf/pdf/publications/2004/P554.pdf

Power systems contain several reserve types functioning on different time scales. Generally, it has been studied that the time scale of seconds to minutes (i.e., primary reserve) is not highly relevant to wind power systems since there is low correlation between separate wind power plants, inertia of the large rotors, variable speed turbines, as well as wind speed variability on different generation zones. These characteristics mitigate the impacts of the variations. Thus, even at a considerable penetration rate, the influence of wind power on the operation of the power system remains low. Contradictory, the time scale from minutes up to an hour and more is more interesting in order to assess the reserve capacity needs. http://www.vtt.fi/inf/pdf/publications/2004/P554.pdf / http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5211199

The need for reserves is assessed through combination of varying electricity consumption and wind power variations. Holttinen (2004) notes that wind power generation does not threaten the grid balance until the electricity mix contains a substantial penetration of wind power. Holttinen has used time scale from 15 minutes to one hour to describe the need for power system reserves (i.e., secondary or tertiary reserve). This time scale is seen relevant in order to handle the unforeseen variation induced from wind power. In the Nordic area, the balancing power market will be influenced by the higher penetration levels of wind power. http://www.ieawind.org/AnnexXXV/PDF/Final%20Report%20Task%2025%202008/T2493.pdf http://www.vtt.fi/inf/pdf/publications/2004/P554.pdf

Table 2 illustrates the reserve needs in the Nordic countries, and separately in Finland. The variations in the Nordic cost figures depend on the smoothing of wind power variability. One option for that could be to build natural gas capacity, which would increase the costs allocated to wind power. The variation in reserve power levels depend on the nature of the wind power production – the more geographically concentrated the production is, the more reserve capacity is needed.
http://www.vtt.fi/inf/pdf/publications/2004/P554.pdf

Table 2: Nordic operating reserve requirements – high wind power penetration http://www.ieawind.org/AnnexXXV/PDF/Final%20Report%20Task%2025%202008/T2493.pdf / http://www.vtt.fi/inf/pdf/publications/2004/P554.pdf

Wind power penetration		**Increased amount of reserves**		
		%	MW	€/MWh
Nordic	5 %	0.8 – 1.2	80 – 100	-
	10 %	1.6 – 2.2	310 – 420	0.5 – 0.7
	20 %	3.1 – 4.2	1 200 – 1 400	1.0 – 1.3
Finland	5 %	2.0	40	
	10 %	3.9	160	-
	20 %	7.2	570	-

NB! The results can be applied only on the operating hour. Prediction errors known 1-2 hours before production are assumed to be levelled out by the balance responsible party and producer.

Frontier & Consentec (2009) describe the need for power reserves influenced by high wind power usage somewhat differently. They present the need for secondary and tertiary reserve to be around 0.25 – 0.3 GW of additional reserve per 1 GW of additional wind power installation. The calculation assumes that secondary and tertiary reserve is used for smoothing the wind power variations. Moreover, it is extrapolated from the German wind energy production figures and takes into account load forecast errors and wind energy forecast errors, as well as plant failures. Therefore, the results of Frontier & Consentec (2009), and Holttinen (2004) are not straight comparable. http://www.energinorge.no/getfile.php/FILER/Om%20Energi%20Norge/IN%20ENGLISH/Frontier%20Blowing%20in%20the%20wind.pdf

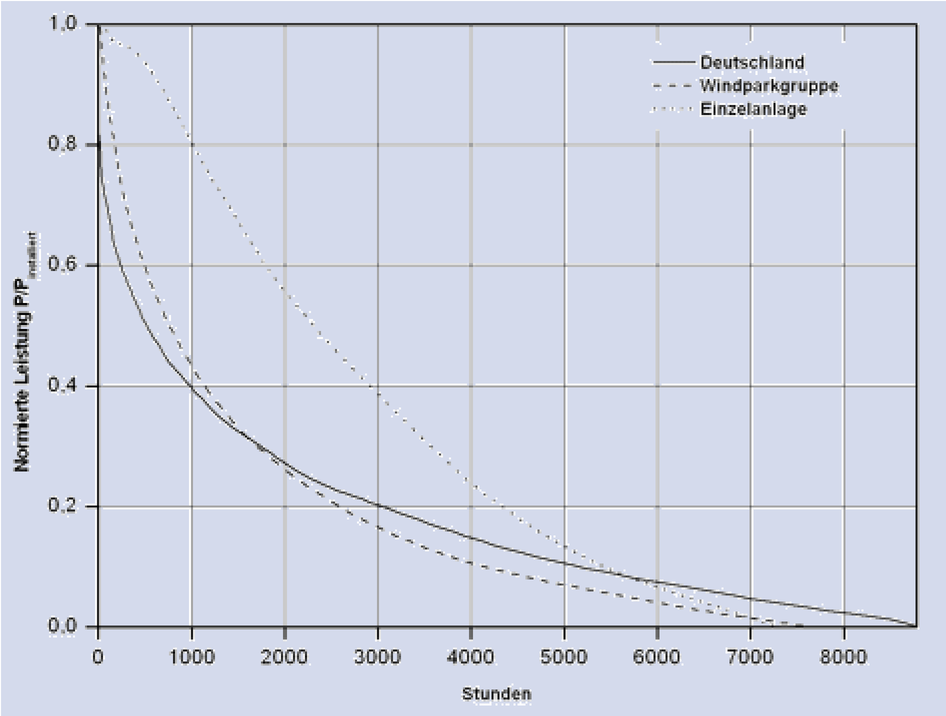


Figure 3: Wind power production versus time of utilisation in Germany. (Country – wind park – single turbine) http://windmonitor.iwes.fraunhofer.de/windwebdad/www_reisi_page_new.show_page?page_nr=155&lang=en (Data source: ISET, IWET - last update: Feb 2006)

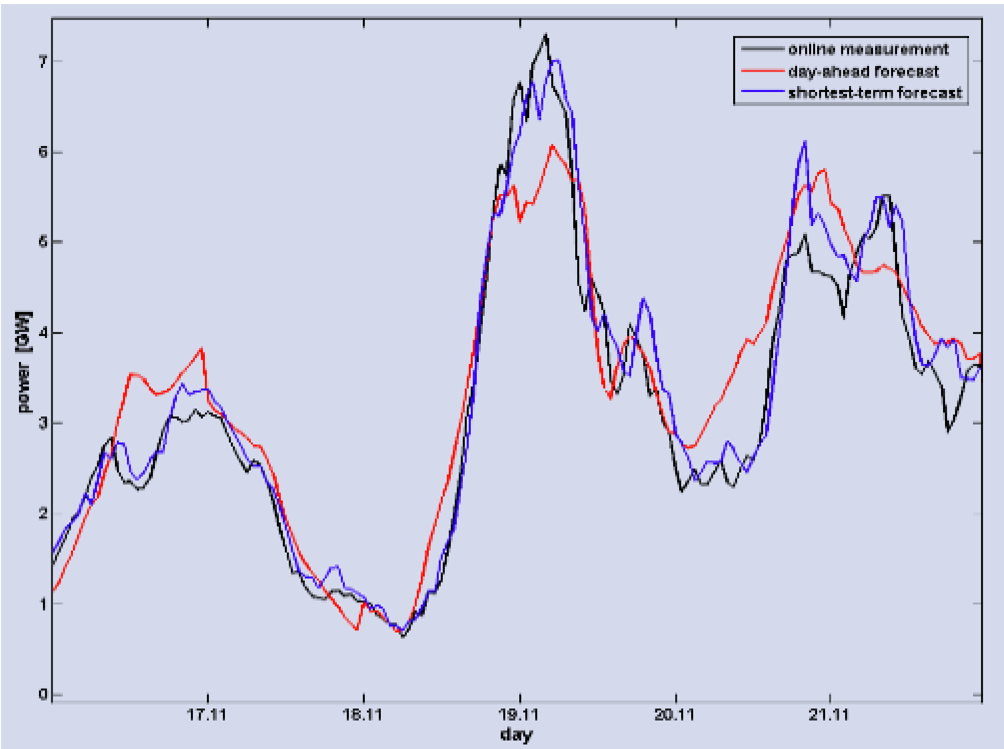


Figure 4: Feed-in of wind-generated electricity, Germany http://windmonitor.iwes.fraunhofer.de/windwebdad/www_reisi_page_new.show_page?page_nr=154&lang=en (Data source: ISET, IWET - last update: Sep 2009)

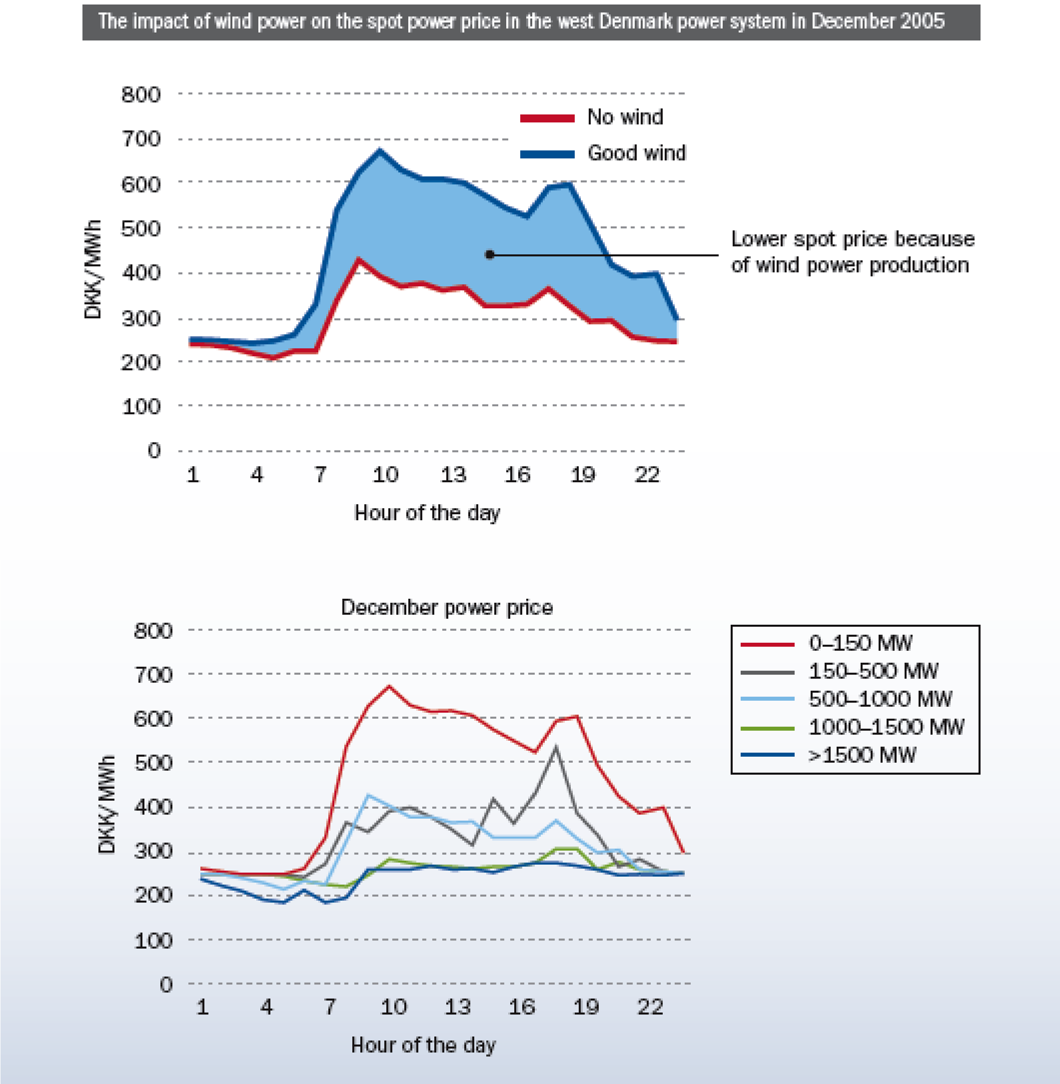
Measured data of wind power production utilization times in Germany is given in Figure 3 for the whole country, a wind power park and a single wind turbine. At the country level, the average production is about 15% of the installed capacity. An example of the production variation in three subsequent days is given in Figure 4. For instance from 18.11. to 19.11. the variation of production was from rough 1 GW to over 7 GW. Day ahead forecast seems to give an error of about 1 GW at maximum (~14%), the shortest term forecast being only slightly more accurate.

The capacity utilization of wind power in Finland

According to VTT, the production of wind power in Finland is higher in winter than in summer due to the better wind conditions in winter. As an example: 8/2011 the production compared to installed capacity was in average about 14%, whereas in 2/2011 it was 22%. (http://www.vtt.fi/proj/windenergystatistics/?lang=fi)**:**

Spot power price and wind production

One way to assess the impact of wind power production variation on power system control needs is to observe the variation of power price in electricity exchange. An example from west Denmark is given in Figure 5. We notice that the amount of wind production strongly dominates the power price on the December 2005 day observed. The duration of the higher price period is 10-12 hours.



Source: Risoe DTU

Figure5: Wind power - spot market price http://www.ewea.org/fileadmin/swf/factsheet/2_electricitymarkets.pdf

Summary

The estimates for the needs of additional reserves due to increased wind power production vary largely depending on the size of power system and according to the assumptions made. In Germany it has been estimated that the amount of new reserves should be 25-30% of the new wind power production capacity, whereas in Finland VTT has suggested much lower figures, 2-8 % for operating hour reserve needs. These figures may be compared to the forecasting accuracy, which in Germany case varies in the range of 10-14%.

These figures should be compared to the wind power target values for 2020, i.e. 2500 MW. Need for the new controlled capacity, which could possibly be produced partly by demand response, is hence at least 50 MW, and in the maximum 750 MW, the most likely figure being somewhere between 250 and 350 MW.

Another issue is the day level control of loads in order to level the balance of production and demand. As example from Germany shows, the variation of wind production between subsequent days may easily be over 80% of the installed capacity. In west Denmark there are days that the wind power clearly dominates the hourly power price in the spot market. To cope with these variations, the timely shift of demand should be in the order on 10-12 hours.