NEWSLETTER

Editorial

This is the second in a series of semi-annual newsletters on the research project WILMAR (Wind Power Integration in Liberalised Electricity Markets), which is supported by the European Commission under the Fifth Framework Programme (Contract No. ENK5-CT-2002-00663). The project was launched in November 2002 with an overall project duration of 36 months. The key task of the project, in which three industrial partners collaborate with several scientific institutions, is to analyse the technical and economical impacts of introducing different shares of wind power in a large electricity system where the dispatch of the power producing units is determined through trade on electricity markets. After providing a brief status of the project, this newsletter contains an analysis of the variability of wind power production in the Nordic countries and the correlations of wind power production with the electricity consumption and the hydropower production. As part of the development of a large stochastic optimisation model of the electricity system in the Nordic countries and Germany, a model that simulates wind speed forecast errors has been constructed, which is also presented in this newsletter. Finally, the newsletter concludes with a short outlook on the project activities in the next half year. People interested in being kept up to date with the progress and results of the Wilmar project should visit the Wilmar homepage (www.wilmar.risoe.dk), where subscription to forthcoming issues of the Wilmar newsletter can be made. People who register to the newsletter will join the Wilmar dissemination group and be informed about the workshops and publications of the project.

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Status of Project

One of the main tasks of Wilmar is to develop a Planning tool that can be used to analyse the consequences of introducing wind power in a large electricity system (see the first Wilmar newsletter available at www.wilmar.risoe.dk for a description of the Planning tool). The development of the Planning tool has shown good progress, and a stochastic optimisation model with hourly resolution that handles stochastic wind power production is nearly finished. This model is being tested on Nordic and German data and the results look promising.

Other models are under development notably a collection of models that enables generation of scenario trees representing the stochastic behaviour of wind power production, and a model optimising the use of water stored in hydro reservoirs.

To analyse the activation of regulating power (secondary reserves), a stepwise power flow model has been developed, which at the moment is being tested on Nordic data.

Figure 1. Fourth Wilmar project meeting at VTT in March 2004.

Extensive data collection has been undertaken to provide input for these models, and two databases holding the data have been designed.

Four reports have been published analysing and discussing different subjects relevant for the design of the Planning tool. Three of them are available at www.wilmar.risoe.dk/Results.htm.

The Variability of Wind Power Production

Hannele Holttinen, VTT Finland

Wind power varies at all time scales. To study the impacts of the variable production, it is important to depict the variations in the right way. Large-scale wind power means production from thousands of wind turbines at hundreds of sites. The smoothing of the variations is important to take into account in order to avoid overestimating the variability of wind power. However, the smoothing effect will not take away all the variations, so it is important not to underestimate it either. It is also interesting to see if there are patterns in the production: diurnal and seasonal variation, or correlation with other variable elements in the electricity production system.

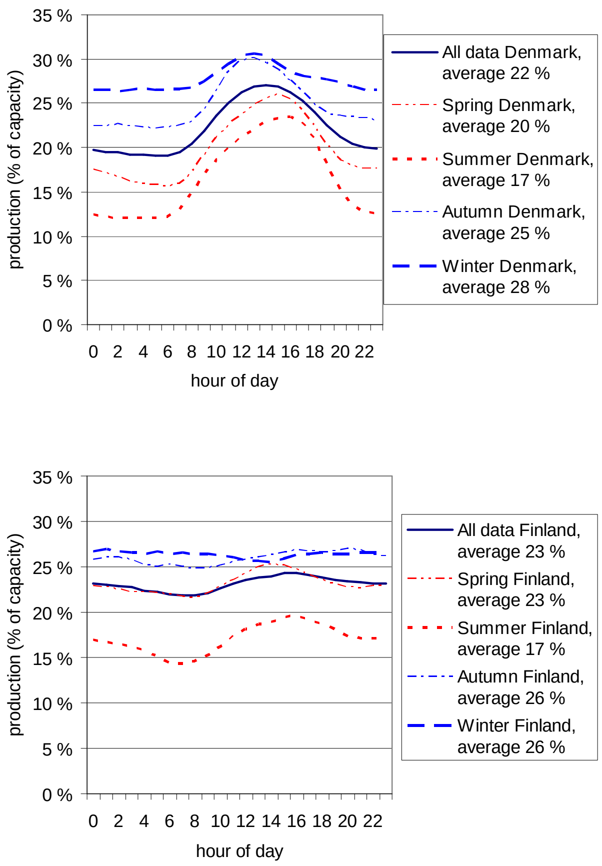

Figure 2. For the Nordic countries, diurnal variation is more pronounced in Summertime and in the South.

The results from analyses for the 3 years of hourly data collected for the WILMAR project show a clear seasonal variation: production in the Winter months is 110-140% of the average and production in Summer months is 60-80% of the average. Average production in the Nordic countries is highest in Norway (31–34% of installed capacity), and about 22–24% of capacity for the other countries during the example years 2000-2002. The wind resource during the period was somewhat less than average. For diurnal variation, the effect of wind picking up in the morning and calming down in the evening can be seen. This is more pronounced for wind power production in Denmark and Sweden, whereas the sites in the northern part of Finland, Sweden and Norway do not experience any detectable diurnal variation (Figure 2).

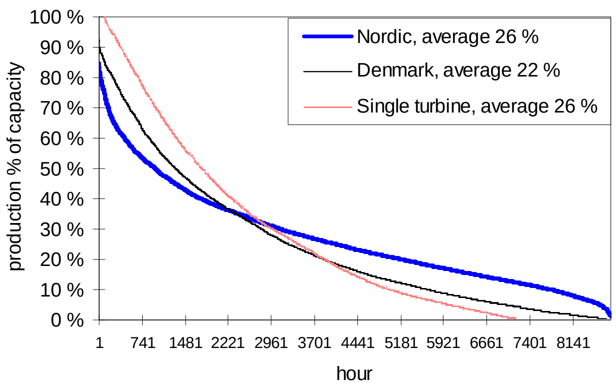

Figure 3. The effect of geographical spreading is to flatten the duration curve of wind power production. Wind energy distributed to all 4 Nordic countries is compared with one of the wind farms and one of the countries (Denmark). Average production for the curves is denoted in the legend text (year 2000 data).

It can be seen that as wind power production derives from geographically distributed wind farms in the Nordic countries, the total production never reaches the total installed capacity. The minimum production is above 0 as it is never totally calm in all of the Nordic area (*Figure 3*). Production above 50% of rated capacity is rare during the Summer and production above 75% is rare during the Winter. The lowest hourly production was 1.2% of capacity. The production was below 5% of capacity for approximately 2% of the time.

Even for large-scale geographically dispersed wind power production, the production range will still be high compared with other production forms. The maximum production will be three or even four times the average production, depending on the area.

The maximum hourly variation – maximum step changes from one hour to the next – is inside ± 30% of capacity for Denmark and ± 20% of capacity for the other Nordic countries, which covers a wider area. The hourly variations in the countries are 91–94% of time between ± 5% of capacity and 99% of time between ± 10% of capacity. For the total Nordic time series, the hourly variations are about 98% of time between ± 5% of capacity (Figure 4).

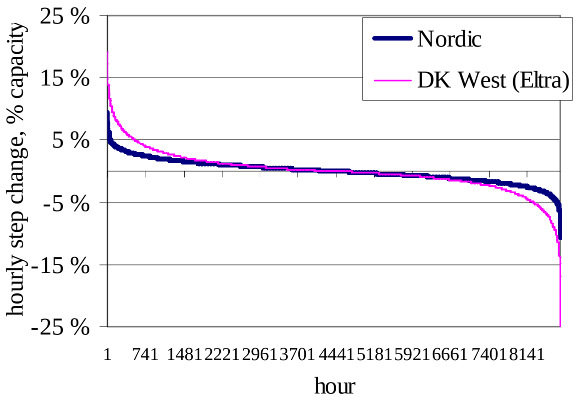

Figure 4. Duration curve for hourly variations of wind power production in the Western Denmark area and in the 4 Nordic countries assuming equal amount of wind power in each country.

The maximum 4-hour-variations are about ± 50% of capacity for one country (for Denmark ± 60% and for Finland ± 40%). For the Nordic area, it is ± 35% of capacity according to the 3-year data set. The maximum 12-hour variation for the Nordic area is ± 50% of capacity (for Denmark ± 80% and for Finland ± 70%).

Electrical load is characterised by a daily pattern, higher on weekdays than weekends (Figure 5). In addition to daily cycles, strong temperature dependency can be seen in the Nordic countries. In Denmark, wind strength is taken into account in forecasts for heat demand. For the other Nordic countries, temperature is more dominant. For the Nordic data, there is a slight positive correlation between wind power production and load, which means that the wind power production increased somewhat more often when the load increased and vice versa, than the opposite. However, when looking at the Winter months only, the correlation is near zero. The positive correlation comes from the diurnal pattern of wind power, mostly present during the Summertime. The same can be said about the temperature dependent district heating combined heat and power production: there is no correlation, especially not during the Wintertime.

How do the changes in hydropower and changes in wind power go together? According to yearly data from 1980–2002, the dry years are more likely to be low wind years than high wind years. However, the monthly and weekly distribution over the year is quite beneficial. Hydro inflow has a peak in May/June in the Nordic countries, whereas wind power production is dominant in the Wintertime (October…February).

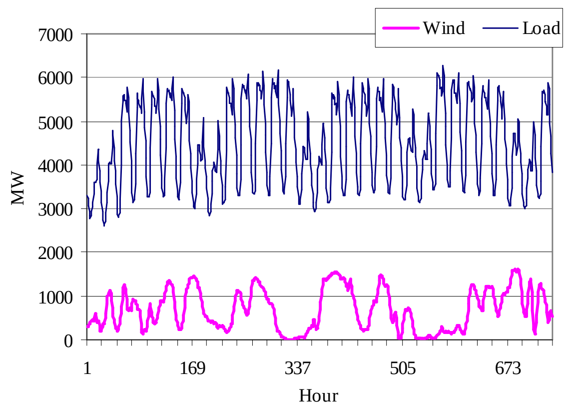

Figure 5. Electricity consumption (load) and wind power production in January 2000, for Denmark (West and East combined, 12% wind power.

References:
Per Nörgård (ed) et al. Fluctuations and predictability of wind and hydropower. WILMAR deliverable D2.1.
Holttinen, H, 2004. Hourly wind power variations in the Nordic countries. Submitted and accepted to Wind Energy.

Simulation of Wind Speed Forecast Errors for Operation Planning of Multi-Area Power Systems

Lennart Söder, KTH, Sweden

One aim of the WILMAR project is to simulate the operation of a power system with a large amount of wind power. The aim of the simulations is to estimate the possibilities of increasing the amount of wind power in the Northern European power system.

This power system consists of several areas (or regions), such as, for example, Jutland or Northern Sweden, which are connected to each other by means of transmission lines with a limited transfer capability. In each of these areas, the amount of wind power can be increased. It can also be assumed that when the amount of wind power in each area increases, then it will be interesting to make wind speed forecasts.

These forecasts are needed in the running of the power system. The reason is that mainly thermal power plants, fuelled with, for example, coal, oil or gas, need some hours to change from the state "not started" to the state "full power production". This means that if good wind speed forecasts are available, then only enough power plants have to be started, so that they can increase their production when the wind power production is increased. The thermal power plants can also be stopped earlier if good forecasts are available. It is here important to note that a wind speed forecast error in one direction (e.g., to high forecast) sometimes is balanced with a forecast error in the other direction (too low forecast) in another region. When this happens, the forecast of total wind power is much better than the forecast of power production in individual wind power plants and groups of plants. But to be able to use the improved forecast, it is necessary to have good transmission capabilities between the regions so that lower wind power in one region can be compensated with high production in other regions.

As stated above, one aim of the WILMAR project is to simulate the operation of a power system with a large amount of wind power. This means that wind speed forecasts in several regions must be considered. One must also consider that the forecast errors in different region are sometimes in the same direction (= high correlation) and sometimes they are in opposite direction (negative correlation). One challenge for the project is that forecasts are only currently available in some of the regions, and only for a limited number of periods, sites and amount of installed wind power. But, since the WILMAR project simulates many regions, and we can also assume that the forecast methods will be improved compared to the situation today, it was decided to develop a method that can *simulate* wind speed forecasts. The simulated forecasts should have the same behaviour as real forecasts, including same forecast error and same correlation between parallel forecasts in different regions.

Wind Speeds Forecast Error Simulation

The first step was to find a model that can simulate realistic wind speed forecasts. The way this is done is to *simulate realistic forecast errors*. These are then added to available wind speed measurements and in this way realistic wind speed forecasts are obtained. The first step is to assume that the accuracy of the wind forecasts is available. The straight line in Figure 6 shows one example of how this can be described:

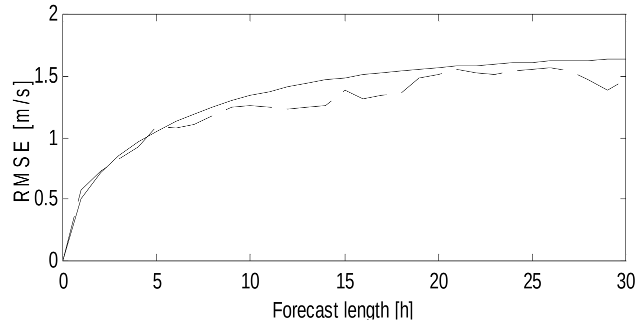

Figure 6. Forecast error standard deviation (data, straight line), 50 series (dashed line).

The method developed is based on the so-called ARMA series. The method will use an ARMA (1,1) approach, i.e., Auto Regressive Moving Average series. This series is defined as

$$\begin{aligned} X(0) &= 0 \\ Z(0) &= 0 \\ X(k) &= \alpha X(k-1) + Z(k) + \beta Z(k-1) \end{aligned} \qquad (1)$$

where X(k) = wind speed forecast error in k-hour forecast, and Z(k) = random Gaussian variable with standard deviation σ_Z.

When the errors are known (as straight line in Figure 6), it is possible to identify the three parameters in eq. 1. For the available data in Figure 1, the parameters can be estimated to α=0.97, β=-0.38 and σ_Z=1.31. Figure 6 shows the obtained standard deviation (= forecast error) for 50 time ARMA time series with data as above. In Figure 7, four simulated outcomes of the time series are shown.

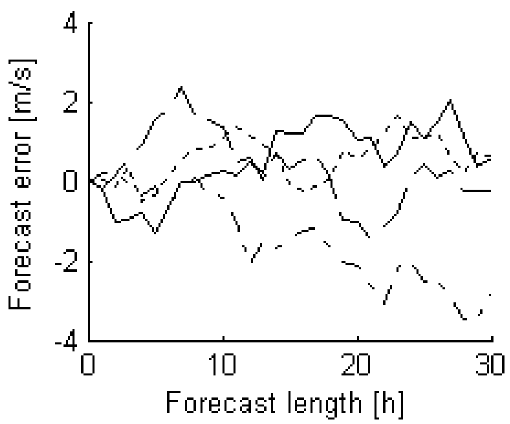

Figure 7. Four examples of ARMA (1,1)-outcomes of wind speed forecast errors.

Since realistic forecasts are needed for several regions, it is necessary to develop ARMA-series that are dependent in order to simulate that wind speed forecasts that are made in neighbouring regions have probably rather often forecast errors that are close to each other since they are affected by the same, un-forecasted, weather situation. For a N-region system, eq. 1 can be expanded to

$$\begin{aligned}
&[X(0)]=[0]\\
&[Z(0)]=[0]\\
&[X(k)]=[\alpha]\cdot[X(k-1)]+[Z(k)]+[\beta]\cdot[Z(k-1)]\\
&[Z(k)]=[C]\cdot[Z_0(k)]\\
&[W(k)]=[W_f(k)]+[X(k)]
\end{aligned} \qquad (2)$$

where $[X(k)]=$ *N*-vector with forecast errors for hour *k* for the *N* regions.

$[Z(k)]=$ *N*-vector with correlated noises for hour *k* for the *N* regions.

$[\alpha]=N\times N$ diagonal matrix with the ARMA α parameters for the *N* regions.

$[\beta]=N\times N$ diagonal matrix with the ARMA β parameters for the *N* regions.

$[C]=N\times N$ matrix with connection parameters for the different Z_0-noises.

$[Z_0(k)]=$ *N*-vector with independent noises for hour *k* for the *N* regions.

$[W(k)]=$ *N*-vector with simulated wind speeds for hour *k* for the *N* regions.

From estimations of correlation between forecast errors in different regions, it is possible to estimate all parameters in eq. 2 so that it can be used in order to simulate the required forecasts.

Project Outlook

The different sub-models in the Planning tool will be finalised during the next half-year of the project and tested by using data for the German and Nordic electricity systems. A power producer and a transmission system operator will participate in the testing of the Planning tool to ensure that the tool becomes as relevant for these users as possible.

The results of the first analysis using the Planning tool will appear and be presented at conferences (we hope to obtain a presentation at the 2004 European Wind Energy Conference).

The development of the models to analyse system stability and activation of secondary reserves will continue, and results regarding these issues will also be presented at conferences.

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