WILMAR Wind Power Integration in Liberalised Electricity Markets

NEWSLETTER

Editorial

This is the third 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 a presentation of two models developed in the project. The Joint Market model is a power market model covering the Nordic countries and Germany and using wind power production as a stochastic input parameter. The Stepwise Power Flow model simulates changes in load and production within an hour with a focus on frequency changes and the activation of regulating power. The design and first results of these models are presented. 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

The development of the Wilmar Planning tool described in the first issue of this newsletter (available from www.wilmar.risoe.dk) is continuing. As shown in figure 1, the Wilmar Planning Tool consists of three sub-models (blue squares), three databases (green cylinders) and one user shell (black square). The user shell controls the selection of input data and the running of the Planning Tool. The design and implementation of the sub-models in the Planning Tool are finished except for the development of the Long-term model. The main effort is now to complete the collection of input data and test and document the developed models.

The design of the Stepwise Power Flow model used to analyse the activation of regulating power (secondary reserves) has been completed. There will be an exchange of results between the Stepwise Power Flow model and the Planning Tool to secure that the results calculated with the Planning Tool (having an hourly time resolution) are credible when issues connected to a finer time resolution, e.g., frequency stability are taken into account.

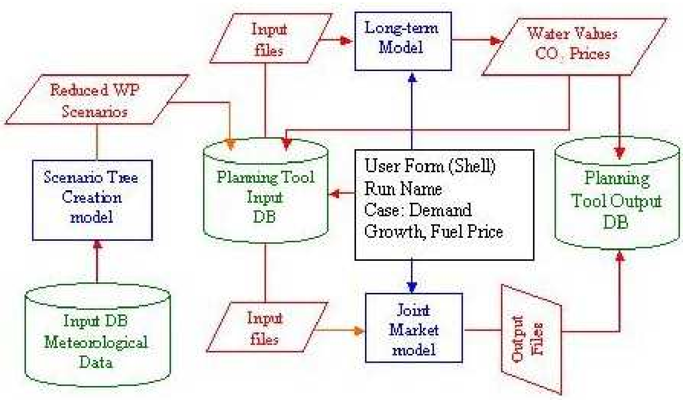

Figure 1: Data flow of the Wilmar Planning Tool.

The data interface between the two models is under development. The first results from the Wilmar project have been presented at conferences. There have been three presentations of Wilmar work at the 2004 European Wind Energy Conference and several presentations at other conferences.

The Joint Market Model

Heike Brand, Rüdiger Barth, IER, University of Stuttgart, Germany

The Joint Market Model analyses power markets based on a description of generation, transmission and demand, combining the technical and economical aspects and it derives electricity market prices from marginal system operation costs. The model optimises the unit commitment and dispatch taking into account the trading activities of the different actors on the different energy markets. Additionally, different restrictions such as transmission constraints or capacity constraints of the power and heat generating units are taken into account.

In order to analyse adequately the market impacts and the integration costs of wind power, it is essential to model explicitly the stochastic behaviour of wind generation. In an ideal, efficient market setting, all power plant operators will take into account the prediction uncertainty when deciding on the unit commitment and dispatch. This will lead to changes in the power plant operation compared to an operation scheduling based on deterministic expectations. Therefore, the proposed market model is defined as a stochastic linear programming model.

In a liberalised market environment, it is possible not only to optimize the unit commitment and dispatch, but to trade electricity at power markets. In this extended model, three electricity markets and one market for heat are included in the planning model:

1. A **day-ahead market** for physical delivery of electricity where the EEX market at Leipzig, Germany, is considered as the starting point.
2. An **intra-day market** for handling deviations between expected production and consumption agreed upon the day-ahead market and the realised values of production and consumption in the actual operation hour. In the model, the demand for regulating power is caused by the forecast errors connected to the wind power production.
3. A day-ahead **market for** automatically activated **reserve power** (frequency activated or load-flow activated). The demand for these ancillary services is determined exogenously to the model. This market will be called the ancillary services market.
4. Due to the interactions of CHP plants with the day-ahead and intra-day market, a **market for district heating and process heat** is included in the model.

The model is formulated as a general stochastic unit commitment model considering more than one model region. The detailed model equations can be found in Brand et al., 2004.

Inclusion of Uncertainty about Wind Power Production

The inclusion of the uncertainty about the wind power production in the optimisation model is considered by using a scenario tree. The construction of this scenario tree is carried out in two steps described in the following:

1. Modelling the Wind Power Generation Data
The wind power generation model is based on data on wind speed and of historical forecast errors for the forecasted wind speed horizon. Since the errors between the wind speed forecasts and the real wind increase with the length of the forecast period, the so-called “Wind Speed Forecast Error Module” (Figure 2) assumes a multidimensional ARMA time series for this forecast error for each station (Söder 2004). Taking into account the spatial distribution of each station, the “Simulation Module of aggregated Wind Power Prediction scenarios” yields aggregated wind power generation scenarios for each region of the model (Norgard 2004).

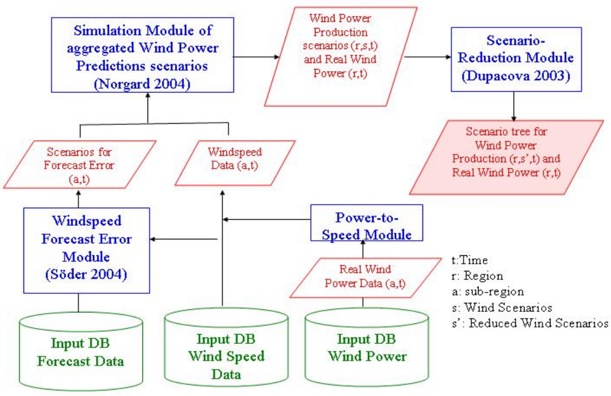

Figure 2: Data flow of the scenario tree creation model.

2. Scenario Reduction
In order to keep computation times small for models representing a national market with a huge number of generating units, the number of scenarios is reduced by the “Scenario Reduction

Module" by applying the approach of Dupacova et al., 2003 (Figure 2).

Rolling Planning

In general, new information arrives on a continuous basis and provides updated information about the status of the energy system (e.g., wind power production, operational status of other production and storage units) as well as information about forecasted and updated day-ahead market and regulating power market prices. Thus, an hourly basis for updating information would be most adequate. However, stochastic optimisation models quickly become intractable, since the total number of scenarios has a double exponential dependency in the sense that a model with *k+1* "information arrival" stages, *m* stochastic parameters, and *n* scenarios for each parameter (at each stage) leads to a scenario tree with a total of $s = n^{mk}$ scenarios. It is, therefore, necessary to simplify the information arrival and decision structure in the stochastic model.

In the current version, a three-stage model is implemented (Figure 3). The model steps forward in time using rolling planning with a 6-hour step. It is discussed to reduce it to 3 hours.

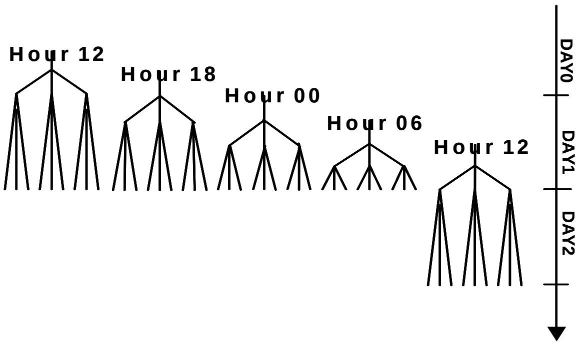

Figure 3: Looping structure.

Application

The model has been applied to several case studies for the German and Nordic electricity system to analyse the market impacts and the varied unit commitment due to a large wind power feed-in.

For the German case study, Germany was divided into three model regions: one for the costal areas in the north-west (model region titled DE_NW) and the north-east (DE_NE), respectively, and a third, larger one for the central and southern part (DE_CS).

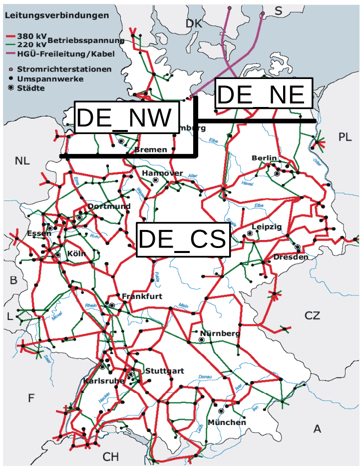

Figure 4: Subdivision of the German electricity system (VDN 2004) into three model regions.

This subdivision reflects the concentration of installed wind power capacities in the coastal areas where the demand is low (especially in DE_NE) in comparison to the central part. Furthermore, the borders of the model regions are reflecting the expected bottlenecks in the German power transmission grid from north to south (Figure 4). The power generating units in Germany are represented by 40 different types of modelled unit groups.

Results

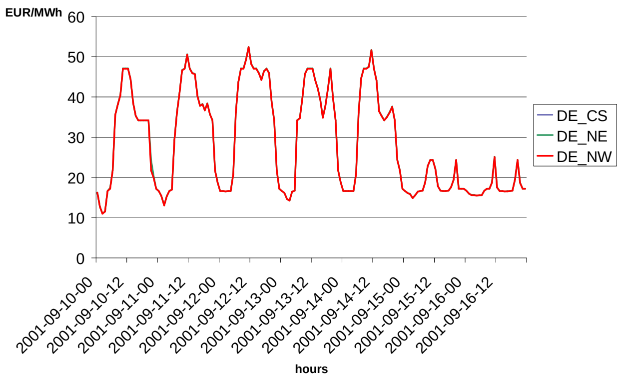

Figure 5: Resulting day-ahead electricity prices for the three German model regions in the considered week for 2001.

For one case study, a week in September 2001 (Monday, 10 September to Sunday, 16 September) was chosen as a basis time frame. This week is characterised by periods with a high and low wind power feed-in in correlation to a relatively low electricity demand. The installed wind power capacity in 2001 was summed up to 4.1 GW in the model region DE_NW, 0.8 GW in DE_NE and 7 GW in DE_CS.

Figure 5 shows the resulting day-ahead electricity prices for the three model regions in this week. The prices in the single model regions show very similar values. This means that no transmission restrictions occur and sufficient electricity can be transmitted between the regions to equal the electricity prices. Arbitrage trade could be possible.

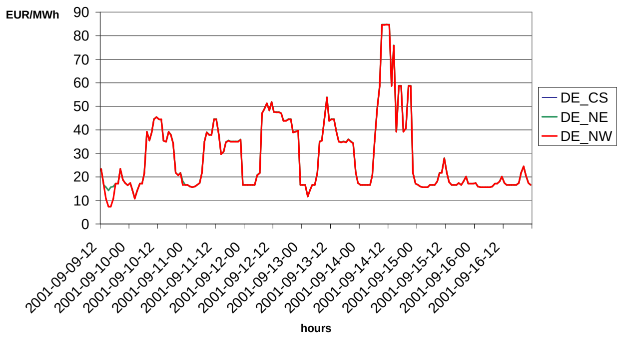

Figure 6: Resulting intraday electricity prices for the three German model regions in the considered week in 2001.

Figure 6 shows the resulting intra-day electricity prices for the three model regions. The prices for the single regions are very similar. For the intra-day prices, we have a daily pattern, but with bigger variations between the different days compared to the pattern in the day-ahead prices. The volatility of these prices depends on the average precisions of the forecasts for wind power energy.

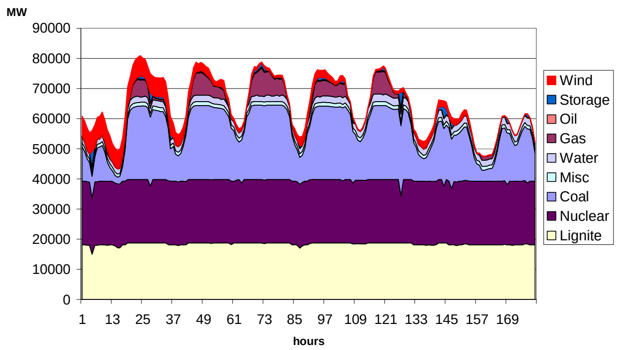

Figure 7: Electricity production differentiated by the use of fuel in Germany in the considered week in 2001.

The electricity production differentiated by the use of fuel in Germany is shown in Figure 7. The sum of the generated electricity is equal to the total electricity demand. Power plants with low variable costs (e.g., nuclear and lignite power plants) run mostly with their maximal capacities whereas the output of power plants using more expensive fuels (e.g., coal and gas) is varied. Wind shows a large share of generated power at the beginning of the week with a maximum of 13.5 % of the total load.

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Stepwise Power Flow

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The joint market model in the WILMAR project gives results with respect to production, load and balancing power from hour-to-hour. However, the market model does not take into consideration physical constraints that might appear in the power system grid as the load and production change from minute-to-minute between the simulated hours. Thus, there might be situations simulated by the joint market model, which could cause the power system to be stressed, or, in worse case, cause blackouts or disconnection of load/generation in parts of the system.

Stepwise Power Flow (SPF) is a method that takes into consideration the physical constraints in the grid, and simulates change in load and production within an hour. The stationary state of the grid is simulated with a traditional load flow every 5 minutes as the production, load, and topology in the system changes. The production is changed after a chosen schedule. Typically, the production is ramped in the middle of the simulated hour, but sources such as wind power may change its production every 5 minutes. The load changes linearly through the hour. This is illustrated in Figure 1.

As the SPF is simulated the user obtains the following results:

- System frequency;
- Active power generation and consumption;
- Spinning reserves and system frequency bias (MW/Hz);
- Critical line flows.

These are measures on how close the system is of being in a critical situation. For instance, if the frequency falls from its nominal value of 50 Hz towards 49.9 Hz a loss of a generator will be critical. In real life, a drop in frequency towards 49.9 Hz causes the system operator to trade on balancing power market. This way, the frequency normally rises again towards or above 50 Hz. The SPF takes into consideration the balancing power market, and activates balancing power if the frequency is falling below a limit. A SPF simulation could reveal if the balancing power on the market for a certain hour is sufficient to handle the change in load and production within the simulated hour.

The model has been used to simulate frequency changes in the Nordic grid. In Figure 2, the result from such a simulation on a full-scale model of the Nordic system is shown. In the WILMAR project, it has so far been demonstrated how the model can be used to reveal how large-scale integration of wind power in the Nordic system may influence the system frequency. In Figure 3, a result from a simulation on the 23rd generator model of the Nordic system used in the WILMAR project is shown. In this case, the load was low and there was a high scheduled generation of wind power. During the first 30 minutes of the hour, the real wind production becomes lesser and lesser than scheduled. Thus, the trend is a decrease in frequency. Eventually, there is no balancing power left and the frequency falls below 49.9 Hz.

In the context of the WILMAR project, there are no plans to change the SPF routine further. The WILMAR project has already caused the inclusion of HVDC-links, and wind power based on measurements to the SPF routine. The SPF routine will be used in the WILMAR project to simulate selected cases from the joint market model simulations.

Project Outlook

The forthcoming 6 months of the project period will be used to finalise the Planning Tool with a focus on the experiences gained from the end-user testing of the tool. The focus will be on testing and documenting the sub-models in the Planning Tool, and finalise the data collection. Next, the Planning Tool and the Stepwise Power Flow model will be used to analyse the integration costs of wind power and the performance of integration measures.

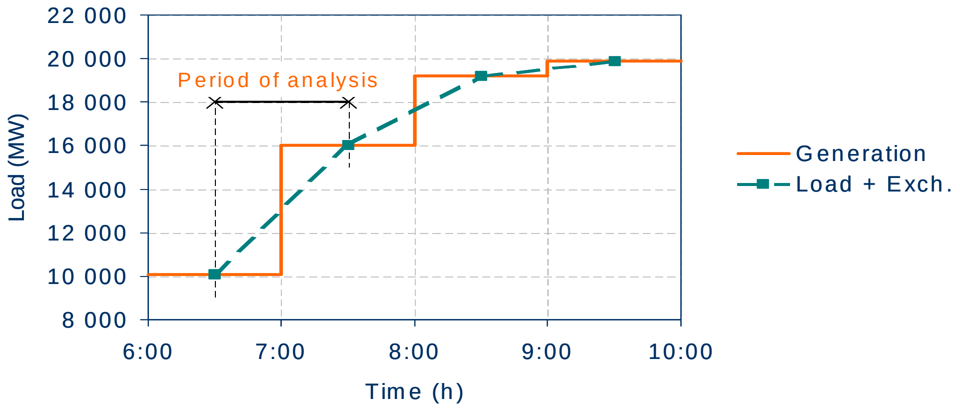

Figure 1: Period of analysis for Stepwise Power Flow simulation

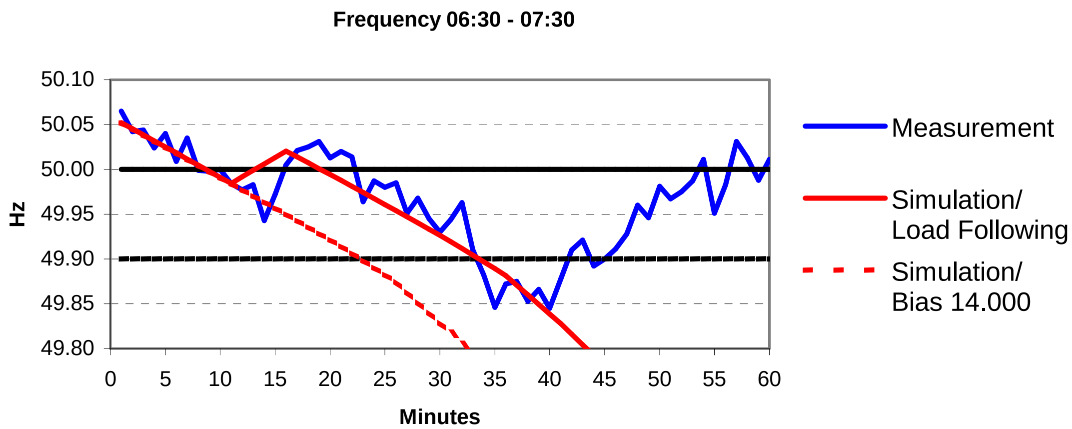

Figure 2: Measured system frequency in the Nordic system 6:30-7:30, 13 October 2003

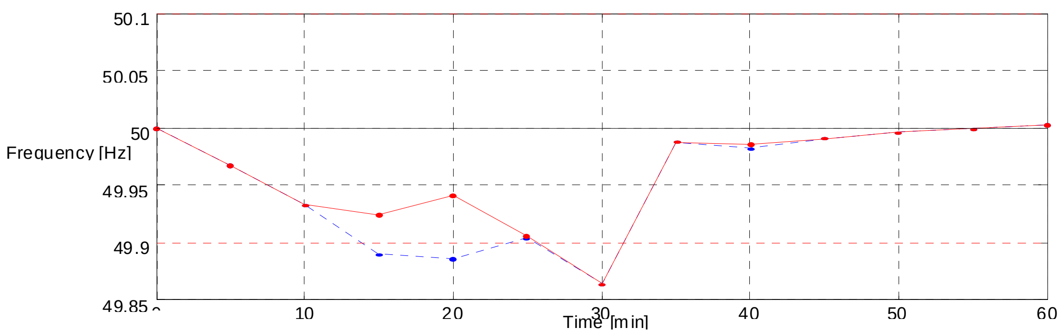

Figure 3: Simulated frequency as a consequence of less than scheduled wind power production. As all the Balancing power is used, the frequency drops below the critical 49.9 Hz limit.

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