# ONLINE-MONITORING AND PREDICTION OF WIND POWER IN GERMAN TRANSMISSION SYSTEM OPERATION CENTRES

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**Abstract**

Normally, electrical systems are able to absorb a certain amount of unregulated and fluctuating production from renewable energy sources (RES), especially wind power. The electrical systems must be designed and operated in order to accommodate the changes in the consumption, a trip of a conventional production unit or a fault on a transmission line. For systems with a high penetration of wind power, the most significant difference is that in addition to forecasts of the consumption, predictions are also to be prepared of the unregulated wind power production. Such predictions are necessary both for the Transmission System Operator (TSO) and for the players on the power market that owns significant wind power production sites as well. At the end of 2002, more than 13.500 Wind Turbines (WTs) with an installed capacity of 12.000 MW generated approx. 17.300 GWh and supplied about 3.6 % of the German electricity consumption [1]. Wind-generated power now provides a noticeable percentage of the total electrical power consumed, and also exceeds the base load on the network in some utility areas. This indicates that wind is becoming a significant factor in electricity supply, and in balancing consumer demand with power production. Not least in the grid areas of the German TSO's E.ON Netz and Vattenfall Europe Transmission GmbH more than 100% of the electricity consumption at times has been covered by wind power. A well-established and scientific analysis of the time response of wind power as well as the accurate determination of the current and expected wind power will lead to an improved integration of wind generation into the electrical power system and reduce CO2 emissions sustainable. In frame of governmental and EC funded projects and in co-operation with the German TSO's E.ON Netz, RWE Net and Vattenfall Europe Transmission, ISET developed a new planning tool to support large scale wind power integration into the electrical energy supply system – the Wind Power Management System WPMS. WPMS provides the current level of wind power generation (online-monitoring) as well as the short-term prediction from 1 hour up to 72 hours.

## Problem

In Europe, the Transmission System Operators (TSO's) are responsible for a save grid operation. They have to provide system services like online regulation, planning and estimation of regulation power (load prediction for its grid area in comparison to the sum of the nominated load prediction of the customer-supplying market participants), losses etc. The determination of the amount and the sequence of the wind power feed-in for the following day is the most difficult task of the generation schedule. Apart from power station down-time and stochastic load variations, unexpected variations of wind power are the most frequent cause regulation and compensation power needs. The more accurate the predicted and online monitored wind power production corresponds to the real wind power production, the less regulation power is needed on the present day.

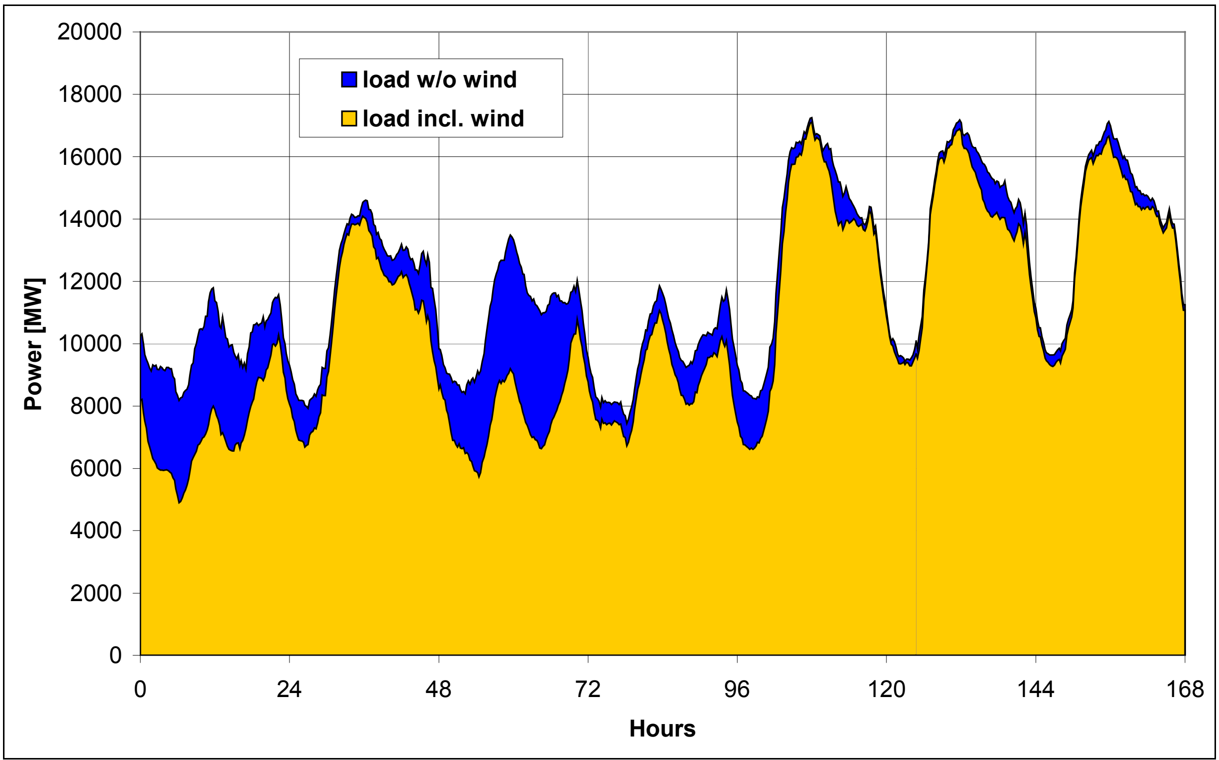


Figure 1: Load profile of E.ON Netz in 05/2003 including wind generation

Figure 1 shows a typical load profile of the E.ON Netz area from 1st – 7th May, 2003. The yellow area shows the power of the conventional power plants while the blue band shows the wind power. Both areas together is the actual customer's demand.

The basis for grid operation and the schedule of conventional power plants is the so-called load schedule, i.e. the amount and temporal course of the power consumption for the near future. This schedule is today determined with modern, computer-aided prediction systems, but also with conventional methods. The power generated from wind and other renewable energy sources is perceived as negative consumption in the system. The measurable amount of load in the system is then the difference between the total consumption and wind power generation. In power plant scheduling, the amount and course of wind power for the following day are the most difficult variables to determine. Beside power plant shutdowns and stochastic load fluctuations, unexpected fluctuations in wind generation are the most frequent cause for the use of regulating and compensating power through system management. The proportion of power from renewable energy sources that power suppliers/traders (so-called balance circles) must accept from electricity transmission companies, according to the Renewable Energy Sources Act (EEG), increases continually and is to be considered correspondingly.

In accordance with the Renewable Energy Act, electricity transmission companies, in whose control areas more renewable energy is fed-in than the corresponding average portion of energy sales to final consumers in German control areas (E.ON Netz GmbH and Vattenfall EuropeTransmission GmbH), can give up this excess to TSOs with lower average quota of renewable energies (horizontal exchange). In this way, the portion of renewable energy accepted in relation to final consumer sales is the same size in every control area after distribution is carried out. The question of how directly this balancing should occur is, however, not regulated in the Renewable Energy Act. The horizontal exchange of available wind energy currently occurs in the framework of daily bands, which are fixed on the previous day on the basis of wind power forecatst by E.ON and Vattenfall Europe Transmission. The usen of a precise and standardised prediction model, also accepted by other TSOs, would reduce mistrust and could serve as a calculation basis for the horizontal exchange of wind power.

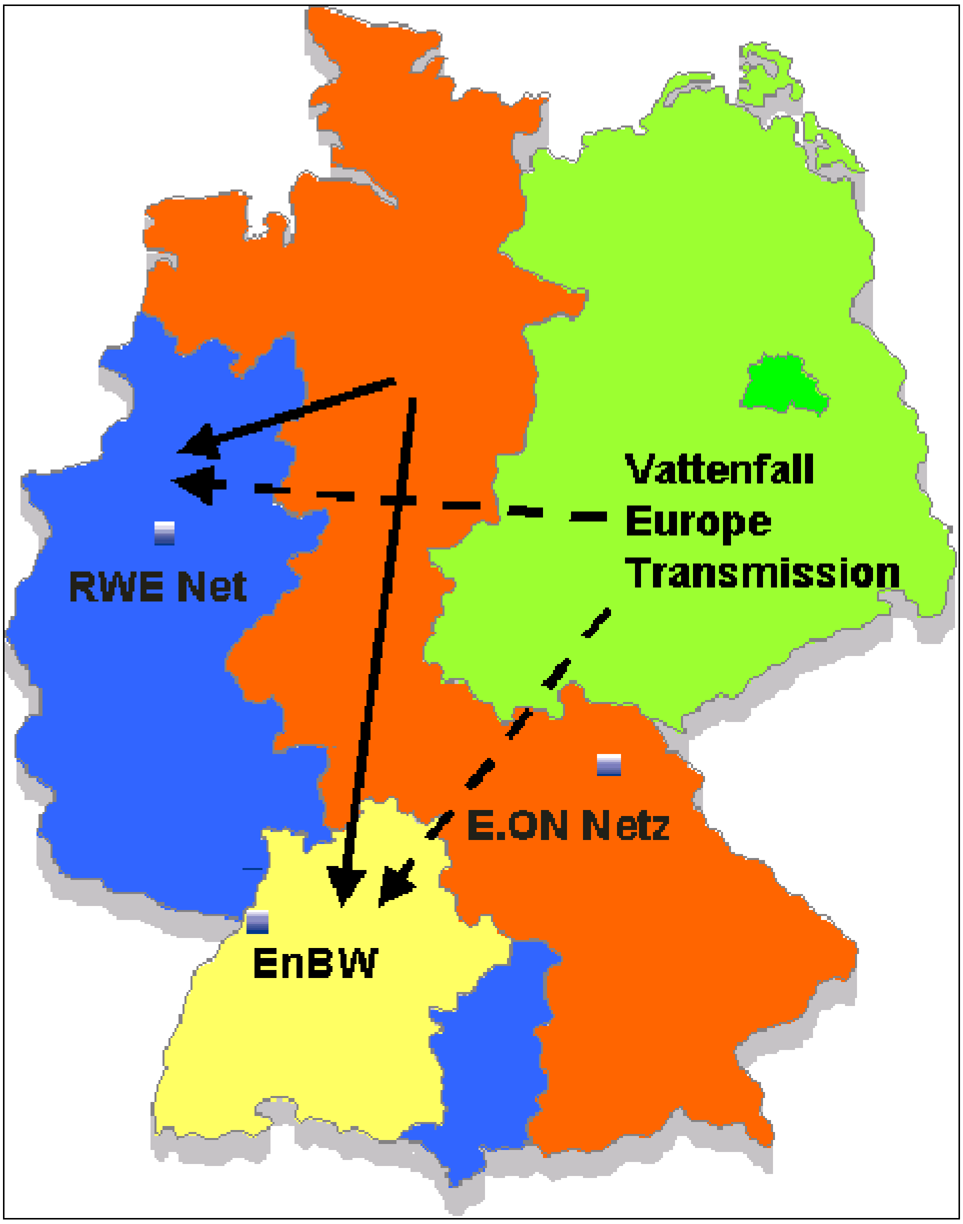


Figure 2: Horizontal exchange of energy from renewable sources

Further development, modification and adapting of existing prediction models is necessary for the operational control of large on and offshore wind farms. Besides prediction of the temporal course of the total power of all wind turbines for the following days, short-term highly resolved predictions (from 15 minutes up to 24 hours) for individual wind farms, and wind farm clusters, are the basis for secure grid and system control. The operational control of large on and offshore wind farms places new increased demands on wind power prediction.

**Online-Monitoring of Wind power Generation**

The most precise procedure for obtaining basis data for generation schedule and grid balance can be considered to be the online acquisition of the power output of all WT's operated in a supply area. However, due the very widespread installed WT's in Germany it is hardly realistic to equip all WT's with monitoring systems. Online monitoring requires an evaluation model which allows the observed time series of power output of representative wind farms to be extrapolated to the total feed-in from WT's of a larger net region or control area. In co-operation with E.ON Netz, the TSO with the worldwide largest wind capacity (5.5 GW as of 4/2003), ISET has successfully developed an online monitoring system, which is able to provide the current wind power generation of about 5 GW from all plants distributed over the utility supply area [2]. This model transforms the observed power output from 50 representative wind farms with a concerning capacity of 1953 MW into the total wind power input into the grid. The determination of the wind farms and the development of the transformation algorithms are based on the long-term experience of the "250 MW Wind" program and its extensive stock of measurement data and evaluations [3].

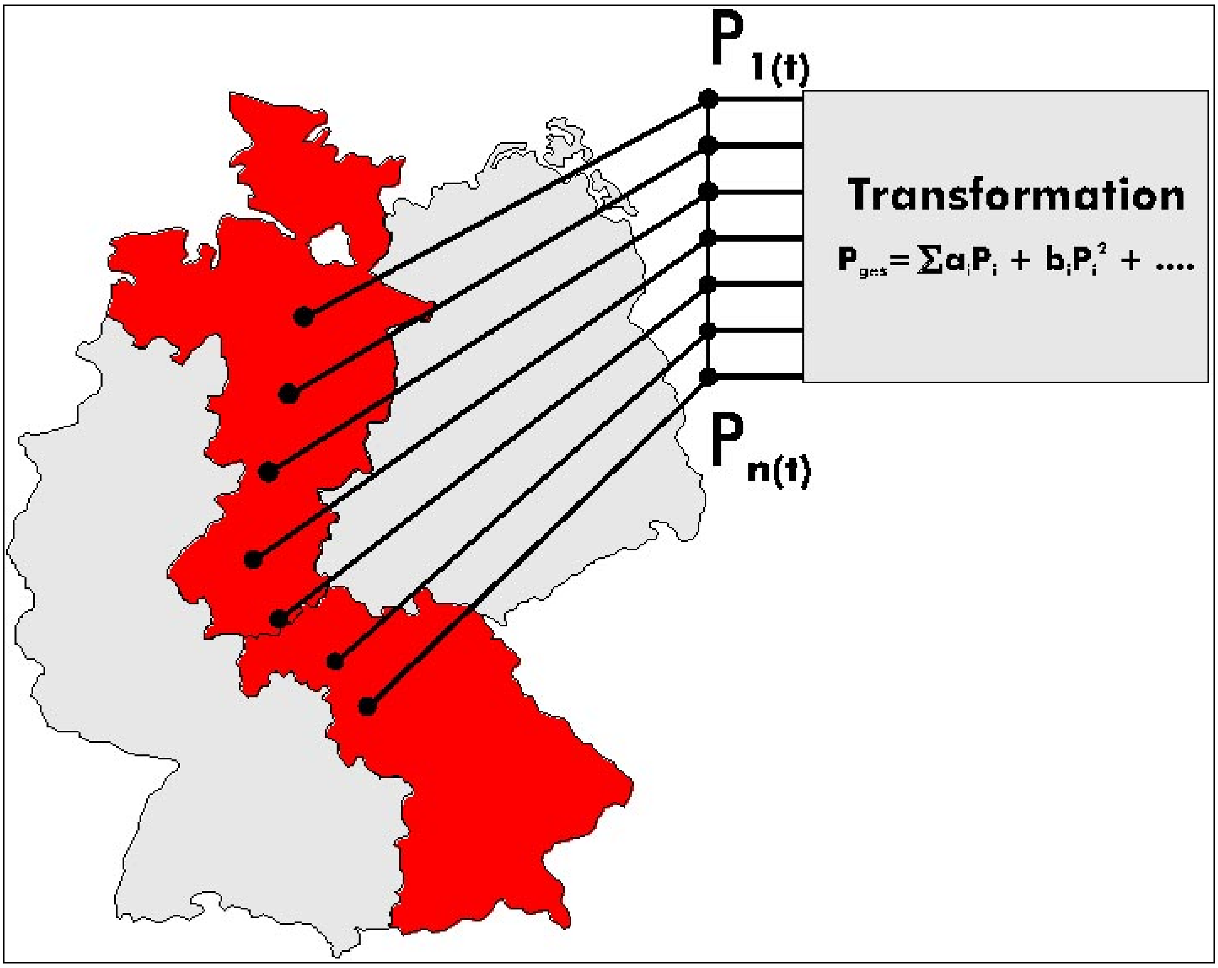


Figure 3: Online Acquisition and Projection

The current wind power production is calculated by extensive equation systems and parameters, which consider various conditions, such as the spatial distribution of WT's or environmental influences. The observed time series from the selected wind farms are thereby transmitted online to the control center.

This model has been successfully utilised since mid 1999 in the load dispatcher of E.ON Netz GmbH for the online recording of current wind feed-in. Since January 2003, the online model has also been operated by the load dispatcher of the RWE Net and is now being adapted for Vattenfall Europe Transmission GmbH. The model is a basic part of ISET's Wind Power Management System (WPMS) which consists of three levels. The 2nd and 3rd levels are based on ISET's wind power prediction tool.

### Short-term prediction

Supported by the Federal Ministry for Economics and Technology, and in co-operation with E.ON Netz, Lahmeyer International (LI) and the Fördergesellschaft Windenergie (FGW), a numerical model for wind power prediction has been developed by ISET [4]. This model is based on three essential foundations:

- predictions of wind speed and direction from the Deutschen Wetterdienstes (DWD) for selected representative locations,
- determination of the corresponding wind power, with the help of Artificial Neural Networks (ANN),
- extrapolation of the wind power on the total feed-in in the control area with the transformation model (online model).

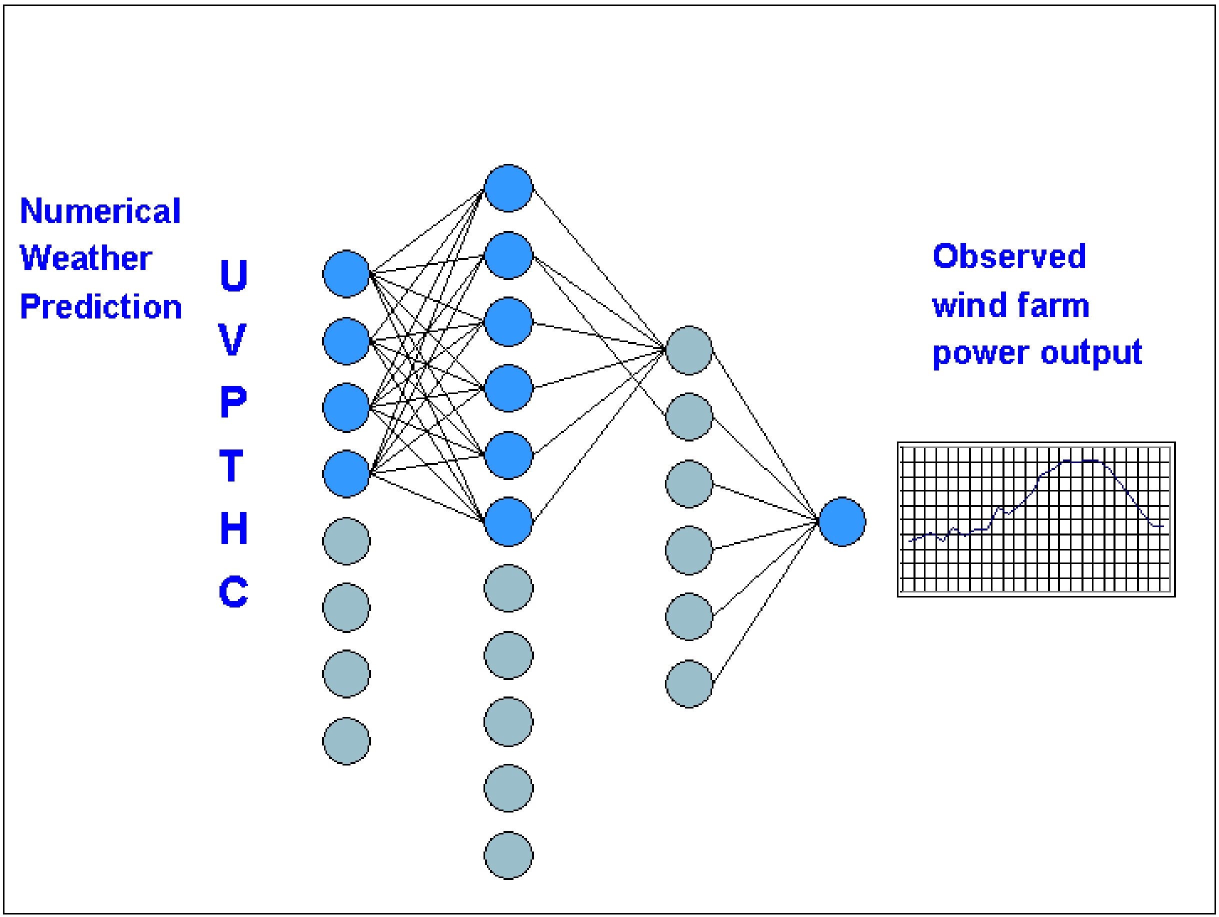


Figure 4: ANN layout and inputs

The prediction model delivers the temporal course of wind power to be expected for the E.ON control area for up to 72 hours in advance. To achieve this, representative wind farms, or wind farm groups, were determined and equipped with measurement technology. For these representative locations, the DWD provides routine time series of predicted meteorological parameters in 1-hour intervals for a forecast period of up to 72 hours and a spatial dispersion of 7 km. The high-resouted forecasts are achieved by the non-hydrostatic grid point model (local model LM). The horizontal resolution amounts to 7 km by 35 vertical model layers and approx. 106,000 grid points per layer. The first model output is available at 7.00 am (MET), and includes 72 intervals per location from 12.00 midnight of the current day. The second output is provided at 7.00 pm (MET) and includes the time period from 12.00 noon of the current day up to 72 hours. The corresponding power of the wind farm is calculated with the help of Artificial Neural Networks. The ANNs are trained with predicted meteorological parameters and measured power data from the past, in order to learn the relation between wind speed and wind farm power output. This method is superior to other procedures, which calculate the relation between wind speed and power by the use of power curves of individual plants, as the actual relation between wind speed (and other meteorological parameters) and wind farm power output is dependent on a multitude of local influences and is therefore very complex, i.e. physically difficult to describe. A further advantage of artificial neural networks over other calculation procedures is the “learning” of relations and “conjecturing” of results, also in the case of incomplete or contradictory entry data [5].

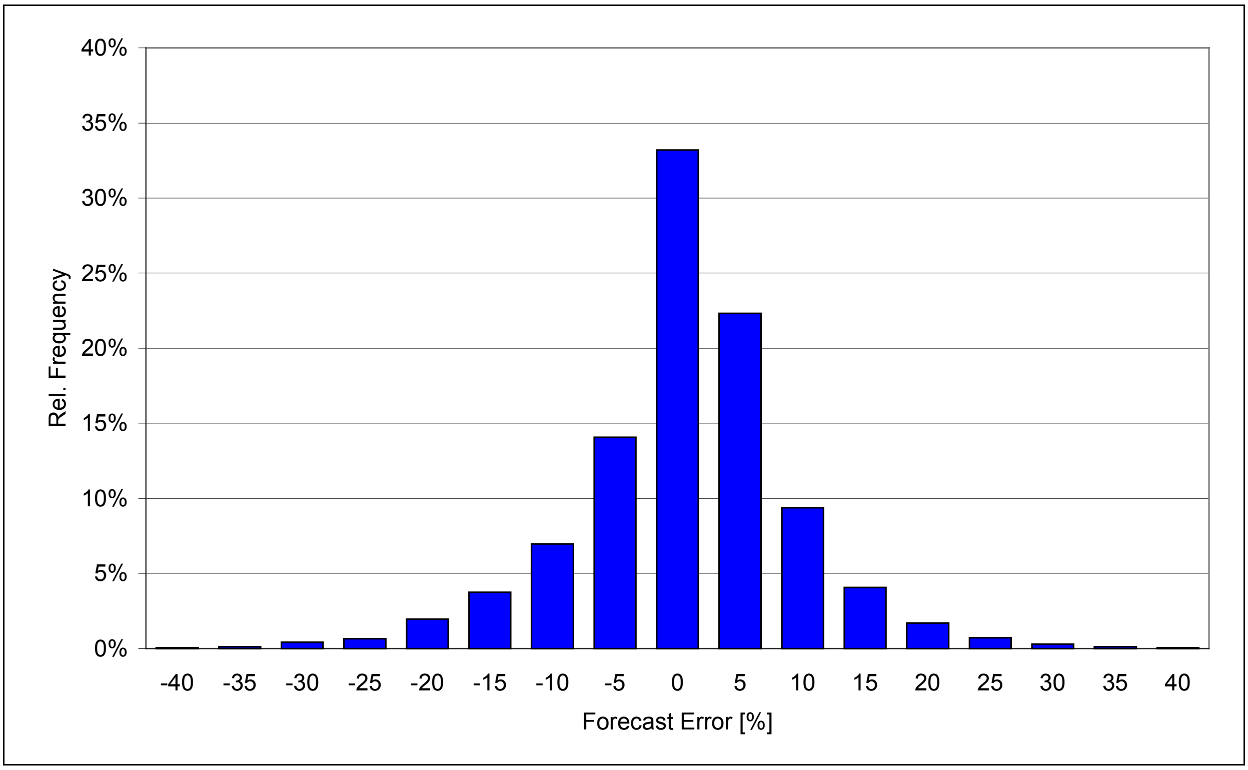


Figure 5: Frequency distribution of the forecast error

Figure 5 shows the frequency distribution of the forecast error ($P_{predicted} - P_{measured}$) for a period of 680 days. 86 % of the forecast error are in the range of +/- 10 % of the installed capacity.

The ability of ANNs to enable short-term predictions of the power of WTs was investigated in the past by several institutes [6], [7]. This ability is used to evaluate deviations between the current values and the prediction of the wind farm power and to adjust the predictions for the next 1 to 8 hours to the current situation. The shorter the prediction horizon, and the smaller the spatial spreading of the intermittent generator, the greater is the dependence of the feed-in on local influences. From there, the forecast error also decreases with the reduction in the spatial spreading of the prediction area. Furthermore, current changes in the weather conditions cannot be taken into account by models that are based purely on numerical weather forecasts.

As the local weather conditions in the near past (and present) are indirectly recorded over the measured power output of the wind farm, the predictions can be significantly improved for short time horizons through the inclusion of this information. Compared to the results from [6], [7] the short-term prediction is not exclusively based on information from the present and near past, but on the comparison of predicted and measured power data. For this, the output of the ANN module, which calculates the wind farm power from meteorological parameters (WPMS2), is used together with measured power data from the near past as input for a further ANN module. Through the comparison of time series from (meteorological) forecasts and measured power data from the near past, especially deviations of the temporal course can be recognised and corrected.

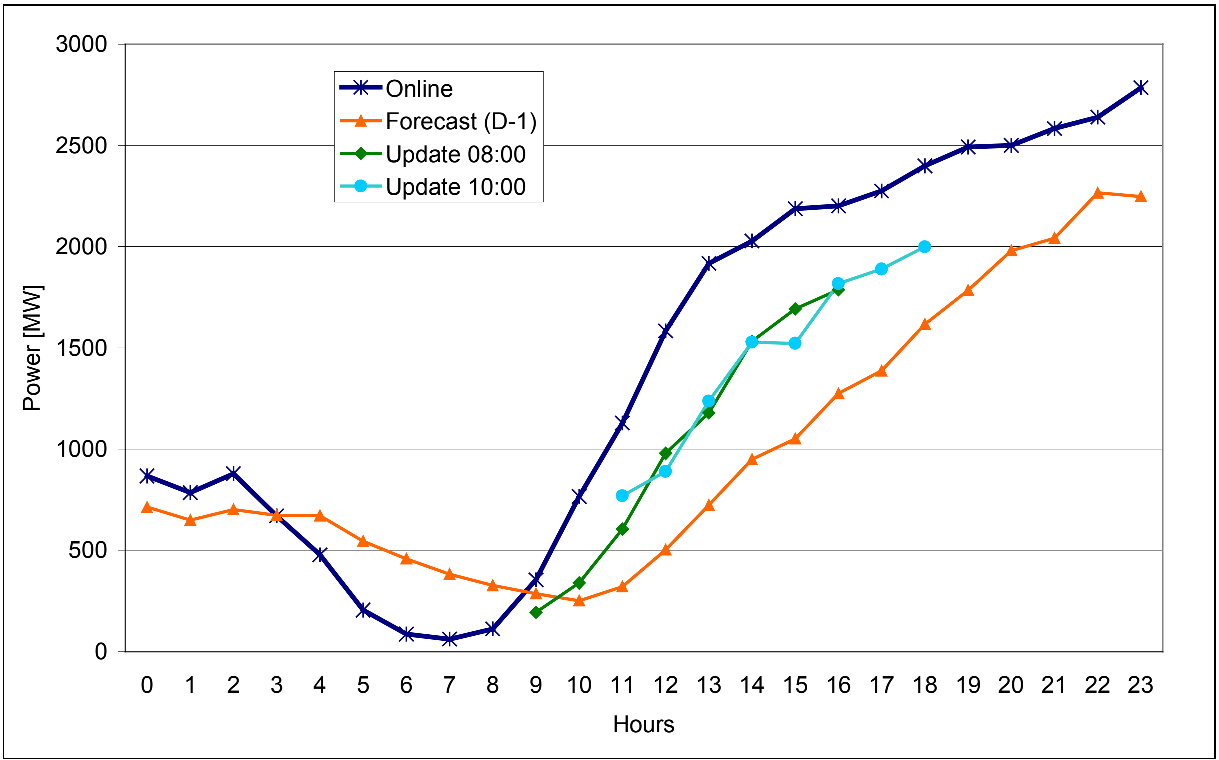


Figure 6: Real and predicted course of wind generation

The Figure shows the real and the predicted course of the wind generation. The deviation of the day ahead forecast is corrected by the short-term forecasts of the 3rd level of the WPMS. The Table shows the accuracy of the 1 – 8 hour forecasts for a coastal wind farm in comparison to an inland wind farm and the E.ON Netz control area. A great advantage of this method is that the expected wind generation can be newly calculated at any time, i.e. calibrated with current measurement data. The predicted wind farm power output from representative sites, calculated from the predicted meteorological parameters of the DWD and with ANN, are then transformed to the total feed-in of the control area or sub-regions.

| | coast | | inland | | control zone | |
|---|---|---|---|---|---|---|
| hours | RMSE | correlation | RMSE | correlation | RMSE | correlation |
| 1 | 5,5% | 0,956 | 7,3% | 0,939 | 3,2% | 0,981 |
| 2 | 7,4% | 0,930 | 10,2% | 0,892 | 5,4% | 0,972 |
| 3 | 8,0% | 0,919 | 13,4% | 0,815 | 6,3% | 0,961 |
| 4 | 8,6% | 0,909 | 14,3% | 0,785 | 6,9% | 0,951 |
| 5 | 8,9% | 0,903 | 14,9% | 0,764 | 7,4% | 0,945 |
| 6 | 9,1% | 0,900 | 15,4% | 0,750 | 7,6% | 0,940 |
| 7 | 9,1% | 0,898 | 15,8% | 0,741 | 7,8% | 0,937 |
| 8 | 9,1% | 0,897 | 15,8% | 0,735 | 7,9% | 0,935 |

Table: accuracy of short-term forecasts computed by WMPS 3

The WPMS has been implemented in the load dispatcher of E.ON Netz since July 2001 and is used for establishing the load schedule and for power plant scheduling. The model has its particular advantages in precision, short computing time and low operating costs, as only a low number of forecast and measurement locations are necessary through the use of the already implemented transformation model. The forecast error of the model amounts to 8.8% of the installed capacity for the day-ahead forecast and 6% for the short-term prediction from 1 to 8 hours.

## Outlook

In the framework of an further project funded by the Federal Ministry for Economics and Technology, and in co-operation with E.ON Netz, Vattenfall Europe Transmission, DWD and AKTIF Technology, besides the qualitative improvement, especially for the use in complex terrain, the expansion of the model to further supply areas or control areas will be realised. The extended model provides wind power predictions for the control areas of E.ON Netz GmbH and Vattenfall Europe Transmission GmbH, as well as for the complete German grid. The core of the model is the transformation model, which enables the transmission of wind power forecasts of a reference measurement network to chosen grid areas in Germany. The reference measurement grid was extended from 16 to 50 locations in the new project. A further aim of the project is the improvement of local forecasts, in order to avoid the overloading of transmission lines and to support new control strategies for offshore wind farms. The transformation model enables the transmission of the reference forecasts to every chosen sub-area in Germany. From there, the model can be employed, with precise forecasts for areas with weak grids and high wind power, in order to detect early and avoid possible bottle-necks and overloads of grids. An online version of the forecast model will provide the results on the Internet. The forecasts will be offered for the German interconnected network as well as for wind farm operators or regional energy suppliers. Apart from this, WPMS is currently adapted for the operation at RWE Net and for the support of a wind farm owner in UK. The prediction model (WPMS2) provides wind power forecasts for wind farms operated by National Wind Power, a large owner and operator of wind farms, and part of a major electricity company within the UK [8].

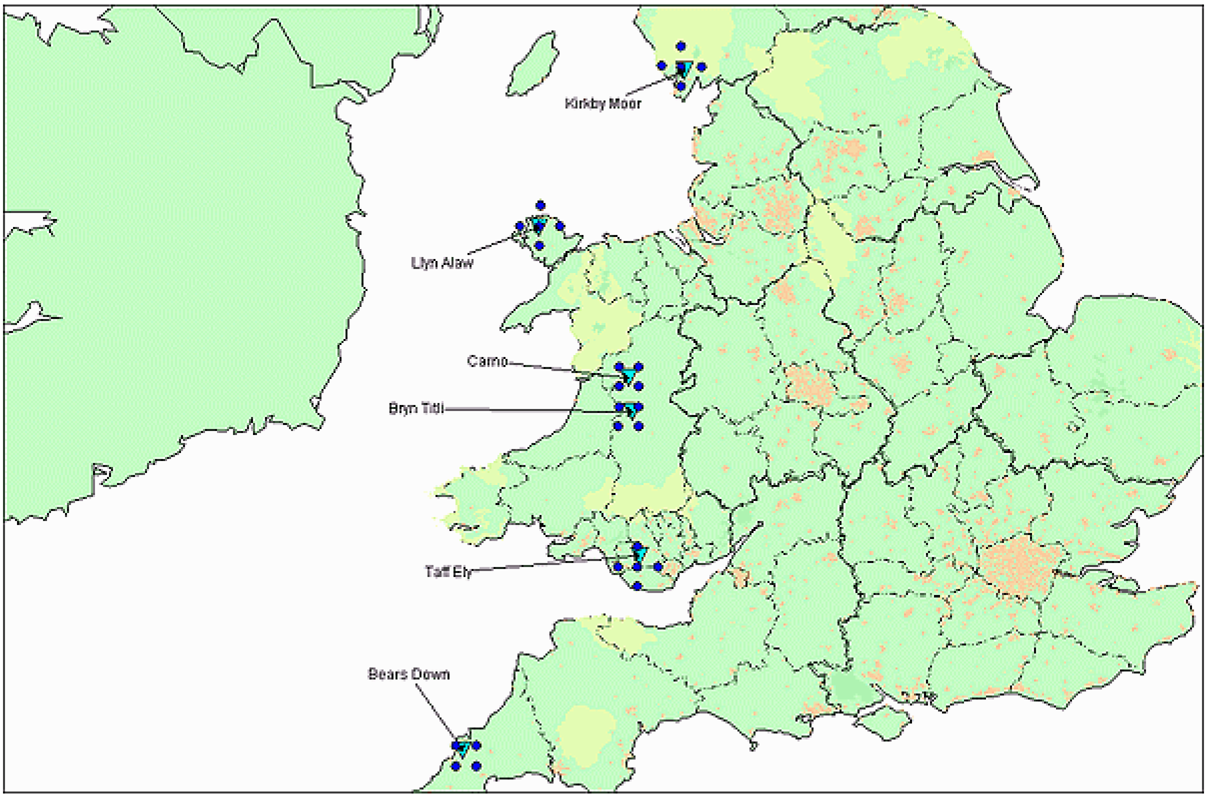


Figure 7: Wind farm locations of National Wind Power

The Met Office provided the required meteorological forecasts and ISET designed the layout and adapted the ANN modules and transformation models for the calculation of the wind power forecasts. Thus, in 2003, all German TSO's with high wind power penetration will use this model which predicts more than 95 % of wind power in Germany.

With the model for online monitoring of the wind power feed-in and the prediction model, a systematic solution for the integration of wind energy has been developed by ISET, which is now operated, or is being implemented, by electricity transmission companies with high penetration of wind energy. In conclusion, it can be established that a precise model for wind power prediction, which can be adapted to arbitrary locations, in combination with the model for online monitoring, significantly reduces obstacles for the acceptance of wind energy use from the perspective of energy suppliers and grid operators and, therewith, further consolidates the position of renewable energies in the electrical energy supply.

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