INTEGRATING WIND ENERGY INTO PUBLIC POWER SUPPLY SYSTEMS – GERMAN STATE OF THE ART

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ABSTRACT

In Germany, more than 18 GW wind power generating capacity were installed till 2005. The four German transmission system operators (TSO) are obliged to take care of grid operation and safety and to provide balancing power. Knowledge about the instantaneous wind power generation is a prerequisite for any successful integration of wind power into the electricity supply system. Additionally wind power forecasts are essential.

The "Intitut für Solare Energieversorgungstechnik" (ISET) has successfully developed the Wind Power Management System (WPMS), a software tool which supports the German TSO to identify problems of grid operation and to provide balancing power. The system is able to provide the current wind power generation of all wind turbines distributed over the utility supply area by using online power measurements of selected wind farms to calculate the actual generation. Another main functionality of the WPMS is to forecast the expected power feed-in of wind energy. The WPMS includes a number of prediction modules, being optimised for different targets. Each module consists of a set of artificial neural networks (ANN). The inputs of the networks are predicted meteorological parameters like wind speed and direction, air pressure, temperature etc. The result is the wind farm power output for a specific time period up to 72 hours for day ahead- and up to 8 hours for short term forecasts.

Since 2001, the forecast error of the day ahead forecast has approximately halved and is now down to a root mean square error of 6% of the installed capacity for Germany

1 INTRODUCTION

Over the last 15 years wind energy in Germany dramatically increased in capacity and thereby the task of integrating the energy into the electrical power supply system grew rapidly. The “Institut für Solare Energieversorgungstechnik” (ISET) collected valuable experience in supporting the German transmission system operators (TSO) to cope with the resulting problems.

ISET, as an institute affiliated to the University of Kassel, addresses application-oriented research and development in the use of renewable sources of energy and de-central energy supply engineering [1].

This paper points out some solution developed in Germany for the integration of a large amount of wind energy and describes the Wind Power Management System (WPMS) distributed by ISET as a software tool that supports TSO in solving these problems.

The German transmission grid is run by the four TSO E.ON Netz GmbH, Vattenfall Europe Transmission GmbH, RWE Transportnetz Strom GmbH and EnBW Transport-netze AG. These power grids are interconnected and connected to the European neighbours and thereby to the grid of the Union for the Coordination of Transmission of Electricity (UCTE). (See figure 1)

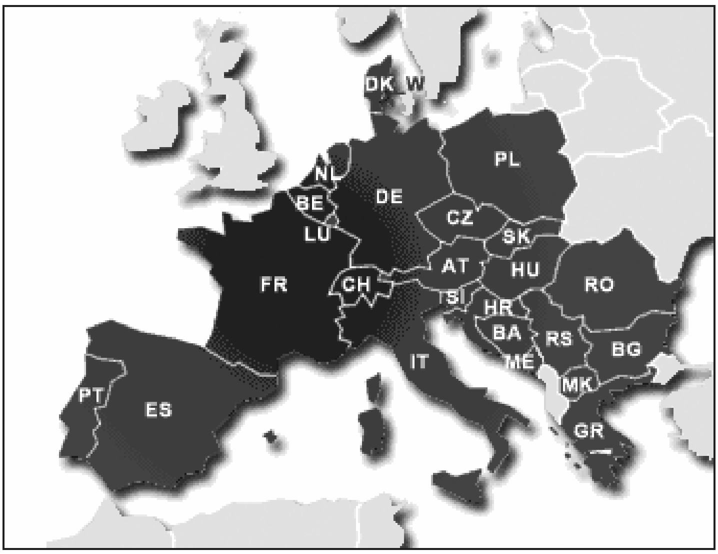

Figure 1: *German power transmission – integrated in UCTE [2]*

In Germany, the TSO are responsible for balancing the power generated by wind tur-bines. The fluctuating wind power fed in the grid is given as a constant power delivery to the distribution grid operators. The difference between the actual wind power feed in and the constant power delivered is balanced in two steps: Firstly, by buying or selling power on the power market day-ahead depending on the day-ahead forecast for wind power feed in, secondly by using reserve power to balance the difference between forecasted and actual generation. Therewith, the accuracy of the wind power forecast has direct influence on the amount of reserve power to be procured. As a new mechanism, intra-day trading is gaining more and more importance. Here, based on an updated short-term forecast, power is bought or sold on the market some hours in advance [3].

The German Renewable Energies Act (Erneuerbare Energien Gesetz - EEG) grants a fixed feed-in tariff for each kWh produced by Renewable Energy Sources (RES). The aim of this law is to promote the development of RES, which was very successful regarding wind energy. As the feed-in tariff is to be paid by the customer, this would result in an unfair cost distribution. The payment mechanism to avoid these inequities is regulated by the EEG [3] [4].

At the end of 2005, more than 17.000 Wind Turbines (WTs) with an installed capacity of more than 18.000 MW generated approx. 26,5 TWh and supplied about 5,5 % of the German electricity consumption.

Today, the electrical power generated from wind already covers the total load in some grid areas temporarily. This large intermittent generation has growing influence on the electricity market, the required capacity for balancing power and for grid operation and safety.

At the end of December 2005 the total capacity of wind energy added up to over 18 GW. The capacities according to the TSO are shown in table 1.

Table 1: Installed wind power capacities per TSO in MW

E.ON Netz GmbH	7550
Vattenfall Europe Transmission GmbH	7140
RWE Transportnetz Strom GmbH	3310
EnBW Transportnetze AG	275

The wind turbines are not evenly spread over the country. While there are huge amounts of installed capacity in northern Germany, turbines are scarce in southern Germany. The size of the squares in figure 2 represents the amount of installed wind power capacities in the represented areas.

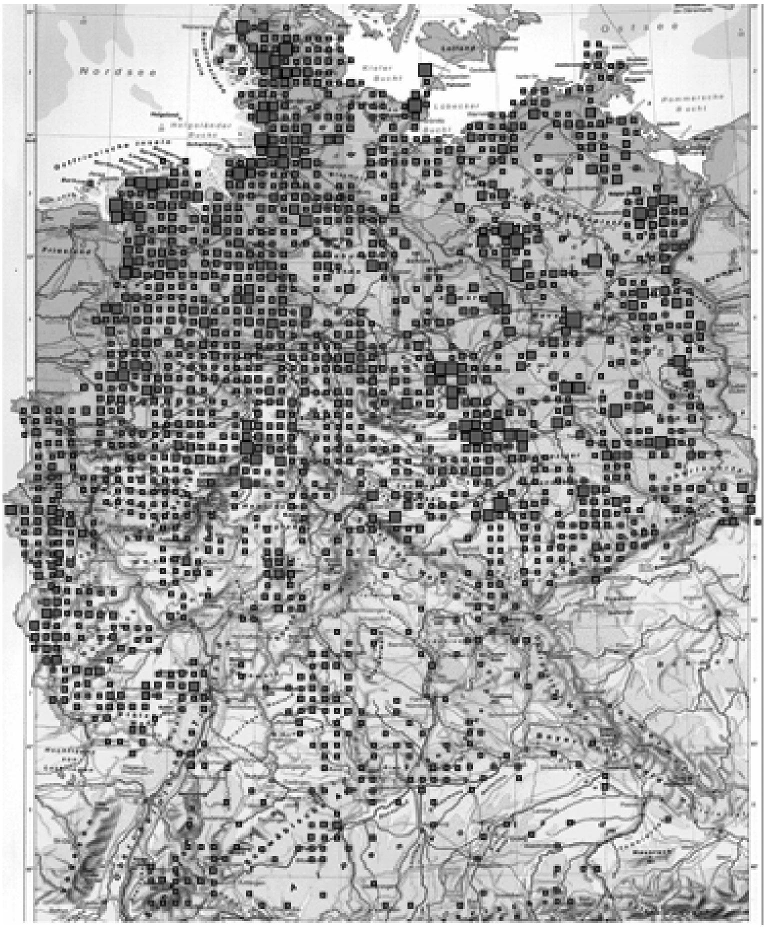

Figure 2: *Distribution of wind energy in Germany*

According to expectations of the German government wind turbines will be erected with a total power of 36 GW on- and offshore in 2015 which would cover around 15% of the German electricity consumption. By integrating this large amount of wind energy it will possible in the year 2015 – depending on the future portfolio of conventional plants - to avoid 20 to 40 Mio t CO_2-emissions.

To cope with the problem of congestions and unexpected power flows it will be necessary to improve 400 kilometres of the present 380 kV grid and to build about 850 kilometres new power lines [5].

2 INTEGRATION OF WIND POWER WITH THE WPMS

The increasing feed-in of fluctuating wind power causes considerable costs for its balancing by the TSO. As the production of wind power is not evenly distributed over the control areas either, the costs are higher for those TSO with a higher wind energy share.

This is the reason, why the amendment to the EEG provides the so-called immediate horizontal exchange of wind power.

This obligates the TSO to control the balancing error caused by the total wind power in Germany according to its market share and no longer according to the production of wind power in its control area. To put this into practice it is necessary for the TSO to exchange information about the currently produced wind power and also predictions of the expected wind power [6].

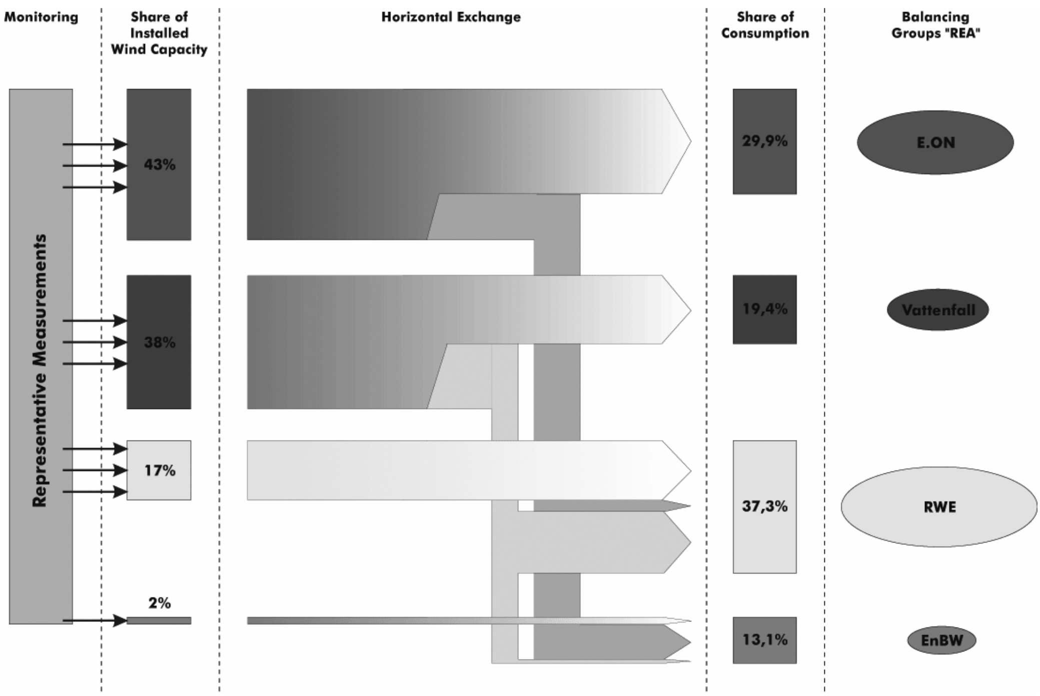

Figure 3: *Horizontal Exchange of wind power [6]*

As to see in figure 3 the installed capacity of wind power in the area of E.ON Netz GmbH adds up to 43 percent of Germany. Though consumption of electricity in this control area is 29.9 percent of Germany's total E.ON has to balance this amount.

An additional effect of this exchange mechanism is, that the total amount of balancing power decreases since deviations between predicted and actual wind power feed in in the different control zones partly balance each other.

To provide reserve power and assure grid safety are responsibilities of the TSO. For this an online monitoring system of the actual feed in as well as a certain wind power forecast system is indispensable. Three of the four major TSO in Germany are using ISET's Wind Power Management System (WPMS) as a software tool for this. At the fourth TSO it is currently implemented.

The WPMS consists of three parts. The online monitoring calculates the total generated wind power output based on power measurements of representative wind farms. The day-ahead forecast module produces 12 hourly mid- term wind power prediction values based on numerical weather prediction (NWP) data. The short-term forecast generates shorter range predictions (15 minutes up to 8 hour) based on NWP and online wind power measurements in order to produce more accurate prediction results according to the day ahead forecast. The TSO are communicating the current wind power feed-in every 15 minutes and a 72 hour prediction of wind power twice a day, both calculated by the WPMS.

However, the TSO are all using the ISET-tool for online monitoring in different ways. This usages range from the simple implementation of the algorithm in the control centre software at E.ON to a complete solution for information management at RWE.

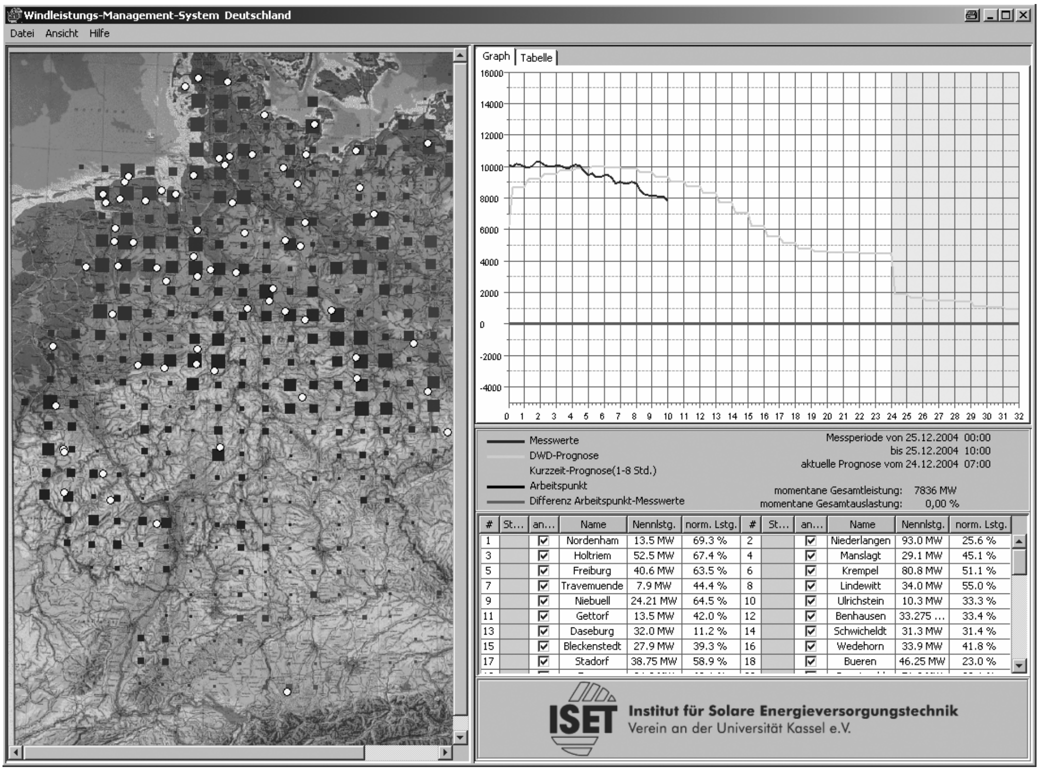

Figure 4: *WPMS – Graphical user interface*

Figure 4 shows the graphical user interface of the WPMS, displaying the actual wind power feed in of Germany.

2.1 Online calculation

For identifying the actual feed in of wind power into the electrical power supply system it is not possible to measure all turbines. Thus the WPMS calculates the actual feed in value by using an upscaling algorithm. This algorithm extrapolates the geographical position and installed capacity of only a few measurements to the unmeasured wind farms. As to see in figure 5 the output of a wind farm approximates the output of closer measured farm like number 13. Nevertheless farther reference wind farms like number 1 and 9 have certain influence on the output.

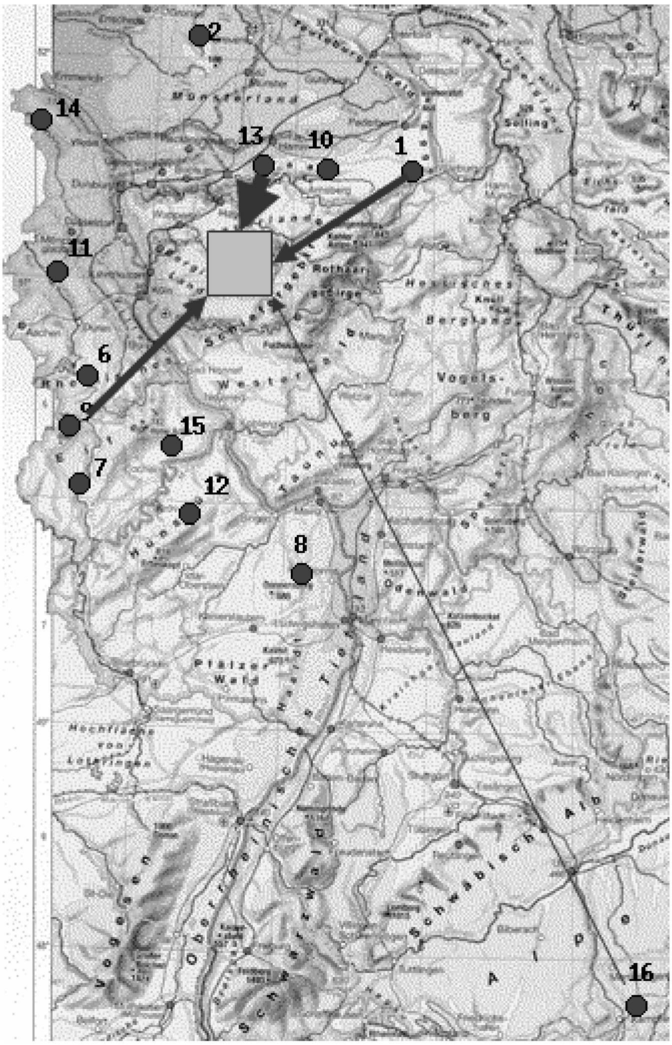

Figure 5: *WPMS – Algorithm to upscale the power feed in from reference measurements [7]*

2.2 Day ahead forecasts

In order to find a relationship between input data and wind farm power output, ISET's prediction system is based on Artificial Neural Networks (ANN). The main advantage of ANN is the "learning" from experience even if their inputs are contradictory or incomplete. The performance is good if there is enough data available. Various ANN modules (more than 200) are trained to learn the relationship between variations in the meteorological data and the wind power output using past wind and power data. By comparing the results with measured power data, the optimal configuration of ANN modules is determined [8].

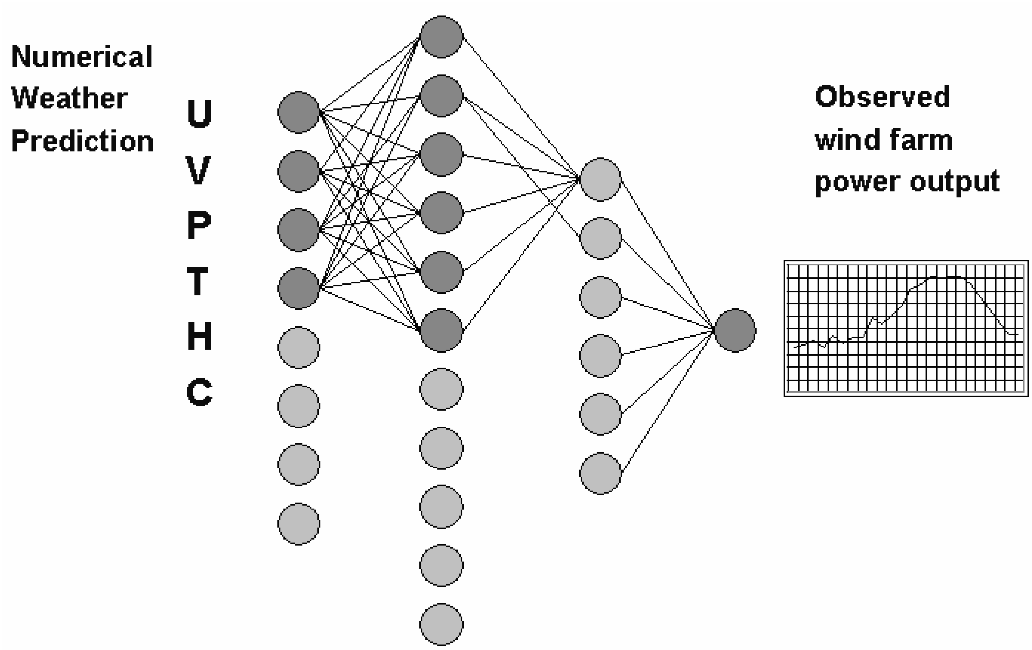

Figure 6: *The sketch of an artificial neural network (ANN)[7]*

For the purpose of learning the relationship between meteorological data and wind farm power output, the ANN needs to be trained with numerical weather forecasts and measured power values from the past. The minimum of data is about 6 months in 1 hour time resolution. It is also possible to use shorter intervals like 15 minutes depending on the application. After this initial training phase, the model can be implemented and operated. During operation, the ANN are trained again in regular intervals with the increased amount of data available. In figure 6 you see the principal layout of an ANN. This network is trained be feeding weather data like wind speed (U, V), pressure (P), temperature (T), humidity (H) and cloud coverage (C).

As mentioned above, the ANN based prediction model has mainly two kinds of input data, numerical weather prediction values received from German Weather Service (DWD) or other MET offices and measured power data. The accuracy of the prediction model mainly depends on the reliability and accuracy of NWP data.

2.3 Short term forecasts

Besides the prediction of the entire power output of the WT for the next days (up to 72 hours), short-term high-resolution forecasts of the wind power generation is essential to get more accurate power predictions. Online measured wind power data is used as additional input for the ANN based prediction model, in order to optimize a short-term prediction from 15 minutes to 8 hours. Furthermore, current changes in the weather conditions cannot be taken into account by models that are based purely on numerical weather forecasts. This model is based on the prediction of meteorological parameters such as wind speed and direction under determination of corresponding measured power values.

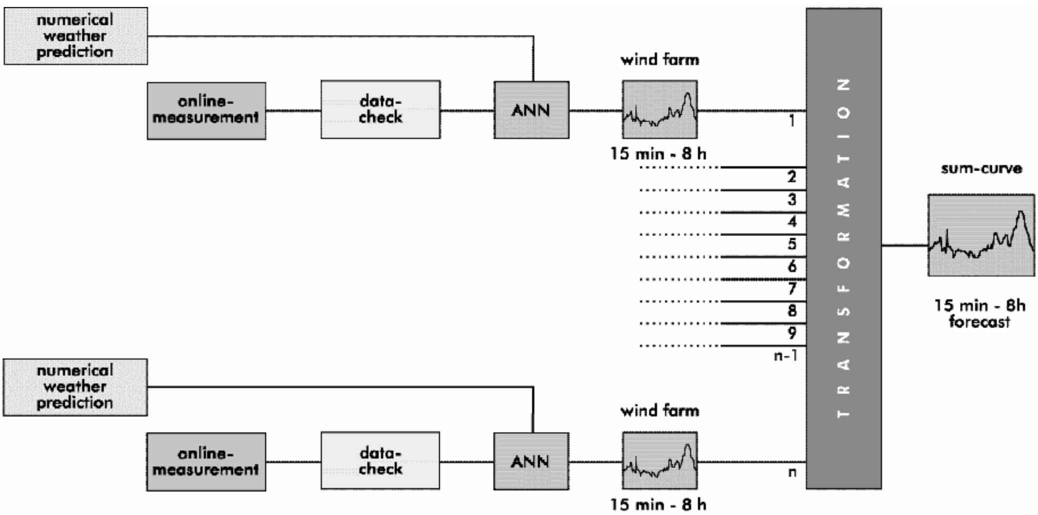

Figure 7: *Schematic structure of the model for short-term wind power forecasting [8]*

As the local weather conditions of the near past (and present) are indirectly recorded over the measured power of the wind farm, the forecast can be significantly improved for short time horizons through the inclusion of this information. Highly resolved and precise wind farm predictions, for the next 15 minutes up to 4 hours, are especially important for the operational control strategies. (See figure 7)

Through the comparison of time series from (meteorological) forecasts and measured power data from the near past, deviations of the temporal development can be recognised and corrected [8].

2.4 Forecast errors

Because the power forecasts base on numerical weather prediction which are an element of uncertainty, there is always a difference between forecasted and real power output.

Since the WPMS is in operation, several improvements of the forecast methods have been developed. As a result the root mean square error (RMSE) in % of installed capacity of the day ahead forecast for a TSO control zone decreased from 10 down to 6 percent. (See figure 8)

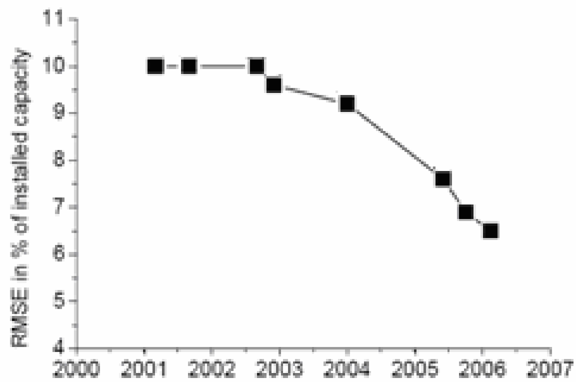

Figure 8: *Development of the forecasting error of the operational day-ahead forecast for a control zone; shown is the root mean square error of the forecasted time series compared to the online monitoring [8]*

As to see in figure 9, the RMSE values from short-term prediction (2 and 4-hour ahead forecasts) of wind generation are dramatically lower than the day ahead prediction value. Here the yearly average RMSE of the German forecast can be seen. Due to smoothing effects, forecast accuracy is higher than for a regional or an individual wind farm forecasting [9].

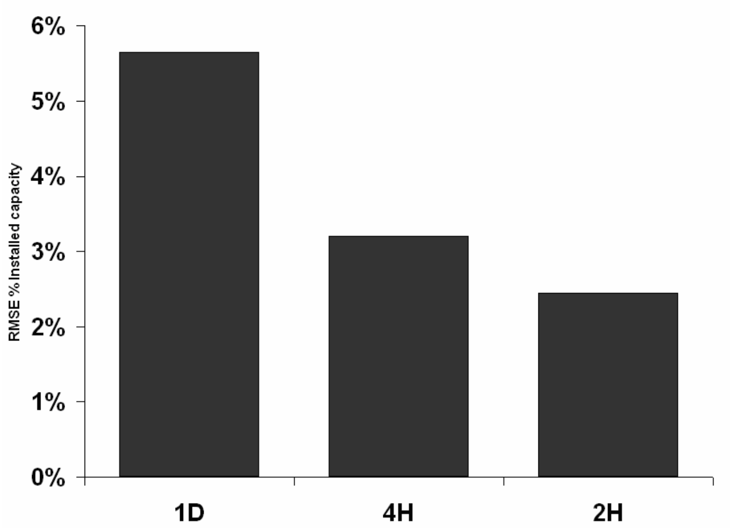

Figure 9: *Comparison of the wind power accuracy for day ahead, 4 and 2 hours ahead wind power prediction models [8]*

3 CONCLUSION

Wind energy in Germany increased dramatically over the last 15 years. The installed wind power capacity has approximately doubled between 2000 and 2005. In the end of 2005 more than 18 GW wind power generating capacity were installed.

The German Renewable Energies Act grants a fixed feed-in tariff for each kWh produced by Renewable Energy Sources. This energy has to be integrated into the electrical power supply system by the four German transmission system operators (TSO). They have to take care for grid operation and safety and to provide balancing power. Today, the electrical power generated from wind already covers the total load in some grid areas temporarily. The amount of regulating power that is needed to balance forecast errors in the wind power production depends on wind power capacity and forecast accuracy.

Because wind turbines are not evenly spread over the country – most of installed capacity is located in northern Germany - the production of wind power is not evenly distributed over the TSO control areas. The so-called immediate horizontal exchange of wind power regulates the control of balancing error caused by the total wind power in Germany according to the TSO's market share and not to their production of wind power in the control areas. To compensate this imbalance, German TSO are obliged to exchange the current wind power feed-in every 15 minutes.

For the integration of wind power generation in Germany, the TSO use ISET's Wind Power Management System (WPMS) which includes an online-monitoring of the wind generation currently produced and forecasting systems for day-ahead and short-term forecasting. It also builds the basis for the horizontal exchange mechanism of wind power between the TSO.

The forecasting accuracy of the system has been improved continuously and very significantly during its operational use since 2001. Due to improvements of the forecasting system, the forecast error which has to be balanced by the TSO has nearly halved. Thus, the total balancing power needed for the integration of wind power production into the existing power supply system did not increase since 2000. On the contrary, since the operational use of the WPMS at the German TSO first started between 2001 and 2003, the actual amount of balancing power has decreased.

Supporting TSO by integrating the wind power feed in into the electrical power supply system remains a great challenge. Over the last years ISET collected valuable experiences in calculating the actual power feed in by wind turbines and in power forecasting. The Wind Power Management System will be improved continuously to face this challenge.

4 REFERENCES

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