Application of wind power prediction tools for power system operations

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Application of Wind Power Prediction Tools for Power System Operations

Kurt Rohrig[1], Bernhard Lange[2]

Abstract: The wide use of wind energy in Germany results in a lot of new power system operation problems corresponding especially to the stochastic character of the wind speed and to the not controllable production of energy. The significant amount of installed wind power in the German power system (currently more than 17 GW) make the traditional scheduling of the power generation for the next day very unsure. Consequently the costs of the power system operation are high because of a large scale provision of spinning reserve power coming from the traditional power plants. The decisive rule in the decreasing of these costs plays the exactness of the wind energy transformation modelling process which starts with the forecast of wind speed. In Germany since more than ten years the knowledge how to solve this problem is available. Based on more than 100 representative wind farm power measurements all over Germany very exact models for the determination of the current and expected wind power are developed. The models are in operation at the control stations of the Transmission System Operators.

Index terms -- Distributed generation, renewable energy, system services, forecasting, wind farm operation, design, optimisation, modelling

I. INTRODUCTION

By the end of October 2005, more than 16,900 Wind Turbines (WTs) with an installed capacity of 17,500 MW generated approx. 21.5 TWh and supplied about 4.5% of the German electricity consumption [1], [2]. Today, the electrical power generated from wind already covers the total grid load in some grid areas temporarily. According to Federal German Government planning, in the medium-term (2015) wind turbines will be erected with a total power of 36 GW on- and offshore which would cover around 15% of the German electricity consumption [3]. This large intermittent generation has growing influence on the security of grids, the operation of other power plants and on the economics of the complete German supply system. In frame of governmental funded projects, an in co-operation with the German Transmission System Operators (TSOs) E.ON Netz (ENE), Vattenfall Europe Transmission (VE-T) and RWE Transportnetz Strom (RWE), solutions for an optimized integration of the large amount of wind power into the electrical supply system have been investigatet.

One task of the TSO is the permanent grid balancing within it's control area. The grid load and the feed-in from conventional power plants is available in form of power exchange balance group schedules and is calculated with adequate accuracy. The need for balancing power arises; therefore, from the difference in the predicted feed-in from WTs and the actual feed-in values. Therewith, the accuracy of the wind power prediction has direct influence on the amount of control power to be procured.

II. PREDICTION METHODS

The model for the determination of the instantaneous wind generation (online-model OM) delivers time series of the aggregated wind power for grid areas, control zones as well as for the whole German grid by using online measurements of representative wind farms.

The prediction model delivers the temporal course of the expected wind power for the control area for up to 96 hours in advance. To achieve this, the exact co-ordinates of the representative wind farms or wind farm groups in Germany were determined For these locations numerical weather predictions are used to deliver meteorological parameters in one hour intervals for a forecast period of up to three days. The corresponding predicted

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wind farm power is calculated using artificial neural networks (ANN).

Intermediate wind generation calculation

The determination of the intermediate wind generation is calculated by transformation of online measured wind farm power values of the representative wind farms [4]. The transformation algorithm is based on the sub-division of the related control zone (or sub-grid area) into small sections analogue to the finite element method. For each section the associated rated power, roughnes parameters and control types of the WTs are determined and converted into parameters. The current wind power feed-in is determined by the summation of the wind power feed-in of all sections.

$$P_{sum} = \sum_i P_i \quad (1)$$

where P_i is the current wind power feed-in of section *i*. The wind power feed-in of each section is then calculated by a differently weighted summation of measured wind power signals of the representative sites.

$$P_i = k_i \sum_j s_j * A_{ij} * P_j \quad (2)$$

with

P*j*: standardized measured wind power of site j

S*j*: status of measurement (0 := wrong; 1 := o.k.).

A*ij*: weight factor.

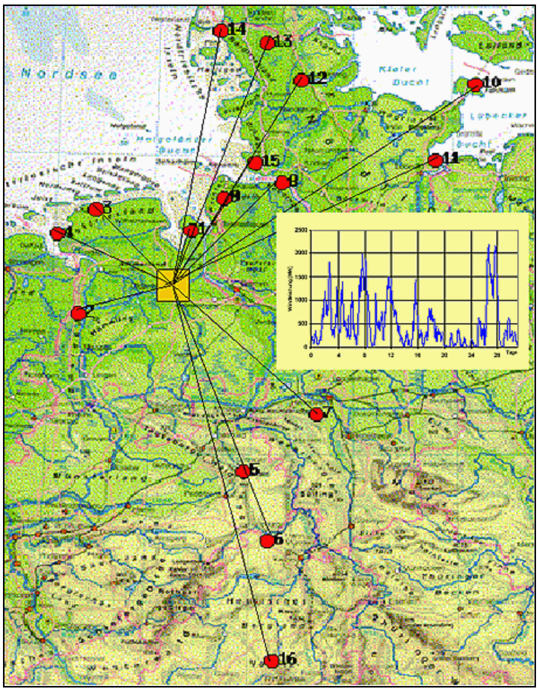

Fig. 1. Schematic view of transformation algorithm

This algorithm allows the calculation of sum curves for the intermediate wind generation as well as for predicted wind power. Furthermore, the wind generation time series for arbitrary future scenarios can be calculated. For instance, ten years of wind generation have been calculated for different future scenarios and denaotes the fundamental groundwork of the dena grid study [3].

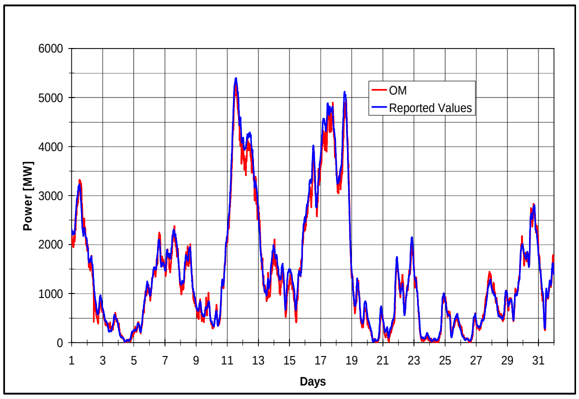

Fig. 2. Wind generation in the control zone of VE-T – calculated by OM and reported values.

The figure shows the wind generation in the control zone of VE-T in March 2005, calculated by the online model (OM) in comparison to reported values. The deviation (RMSE) between the curves is 2.3% of the installed capacity.

Day ahead wind power prediction

The artificial neural network consists of nonlinear functions g which are combined by a series of linear filters with weights [5]. In this study we use a neural network with one hidden layer, so that we have a network with two weight matrices A and a:

$$\hat{P}(t) = g\left[\sum_{j=1}^{m} A_{ij}\, g\left(\sum_{i=1}^{m} a_{jk} x_k\right)\right] \quad (3)$$

where x_k are the k input values and $\hat{P}(t)$ denotes the output value, i.e. the predicted power at the time t. We train the ANN by gradient descent with the back propagation algorithm. It minimizes the least square error E between the measured power P_n and the predicted power $\hat{P}_n$ at time step n over a training data set with N data points:

$$E = \sum_{n=1}^{N} \left(\frac{P_n - \hat{P}_n}{P_{rated}}\right)^2 \quad (4)$$

where P_{rated} is the rated power of the wind farm. For the training of the ANN historical NWP data and historical measured power data for the same discrete time steps is used. As input data for the time step n we use the NWP data for the location of the wind farm, namely 3 values of wind speed

$ws(n-1)$, $ws(n)$, $ws(n+1)$, 3 values of the wind direction $wd(n-1)$, $wd(n)$, $wd(n+1)$ and 2 values related to the time, i.e. the sine and cosine of the time with a period of one year. The ANN provides then the power value for the time step n. For the training of the ANN we take one half of the whole data set and the other half is used for the test of the model. The prediction errors are related to this test part of the data.

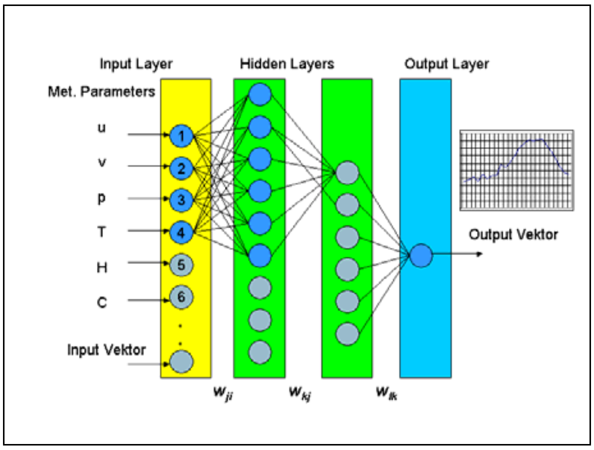

Fig. 3. ANN layout of prediction module

The ANNs are trained with predicted meteorological parameters and contemporaneous measured power data from the past, in order to learn physical coherence of wind speed (and additional meteorological parameters) 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 depends on a multitude of local influences and is therefore very complex, i.e. physically difficult to describe. The advantage of artificial neural networks over other calculation procedures is the “learning” of connections and “conjecturing” of results, also in the case of incomplete or contradictory input data. Furthermore, the ANN can easily use additional meteorological data like air pressure or temperature to improve the accuracy of the forecasts. The deviation (Normalized Root Mean Square Error NRMSE) between the (day ahead) predicted and actual occurring power for the control areas of ENE, VE-T and RWE currently is about 6,5 % of the installed capacity. The prediction error for the total German grid amounts to 5,7%.

Short-term wind power prediction

In addition to the forecast of the total output of the WTs for the next days (up to 72 hours), short-term high-resolution forecasts of intermittent generation in separate network regions or for wind farms and their clustering are the basis for a secure power system management. Apart from the meteorological values such as wind speed, air pressure, temperature etc., online power measurements of representative sites are an important input for the short time forecasts (15-minutes to 8 hours).

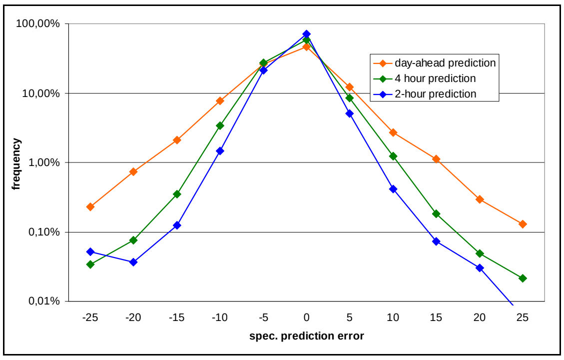

Fig. 4. frequency distribution of prediction error

The figure shows the frequency distribution of the prediction errors of the day ahead prediction in comparison to the 4-hour and 2-hour short-term forecast. For the day ahead forecast, the prediction error (P*meas* – P*pred*) of -10% was recognized in 7.7% of the total period (8760 hours), the 4-hour prediction counts this deviation in 3.6% of the duration and the 2-hour forecast in only 1.5% of the year. In addition to the expected value of power, the forecasting system also provides a tolerance band (i.e. a reliability measure), which is determined from the experiences (prediction errors) of the past and from the data of the meteorological services.

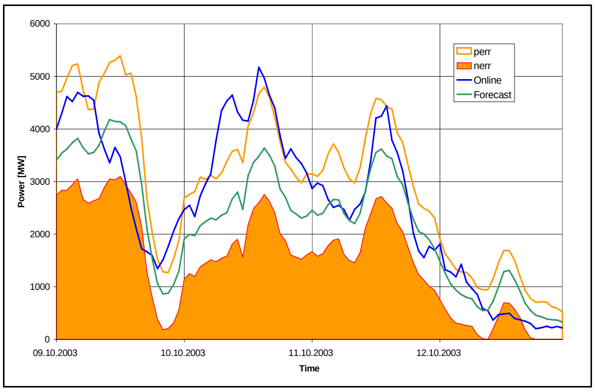

Fig. 5. Measured and predicted wind generation with associated tolerance area

III.EMPLOYMENT OF PREDICTION TOOLS

In Germany, the integration of renewable energy sources in the energy supply system is regulated by law. The total amount of renewable energy and the achieved proceeds are equally distributed to all end customers of energy.

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 (ENE, VE-T), 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 was not regulated in the Renewable Energy Act since 2004. The horizontal exchange of available wind energy currently occured in the framework of daily bands, which are fixed on the previous day on the basis of wind power forecatst by ENE and VE-T. In summer 2004, the Renewable Energy Act was modified. One modification committed the TSOs to equalize the amount of the wind caused regulation power immediately. Based on the Wind Power Management System (WPMS), a hard- and software solution, verified by the combination of online-determination and day ahead forecast of wind power, the wind caused regulation power is exchanged and distributed equally between the TSOs every 15 minutes.

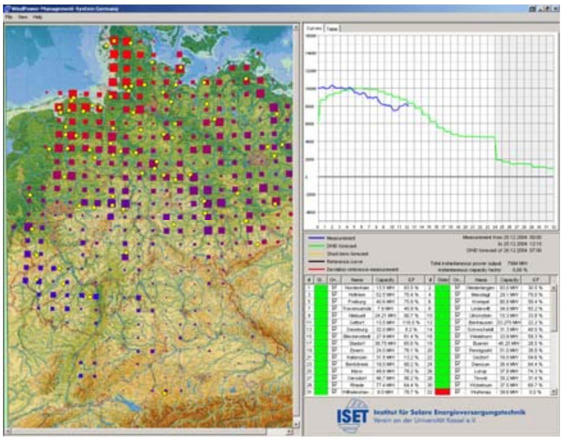

Fig. 6. GUI of Wind Power Management System

IV. ACTIVE CONTRIBUTION TO SYSTEM RELIABILITY

Since 100% accuracy of wind power forecasting is not realisable, the difference between the forecasted and actual supply must be minimised by means of control strategies of Wind farm Cluster Management (WCM) to ensure generation schedule. Power output in this case will be controlled in accordance to the schedule determined by short-term forecasting. This strategy has a large impact on wind farm operation and requires matching of announced and actual generation on a minute-to-minute basis [5], [6]. The schedule execution should be realised within a certain (determined by forecast error) tolerance band. Time-variable set-points should be constantly generated and refreshed for an optimum interaction of wind parks with WCM. A continually updated short-term forecasting for wind farms and cluster regions is assumed for this kind of operation management based on the following control strategies:

- limitation of power output;
- energy control;
- capacity control;
- minimisation of ramp rates.

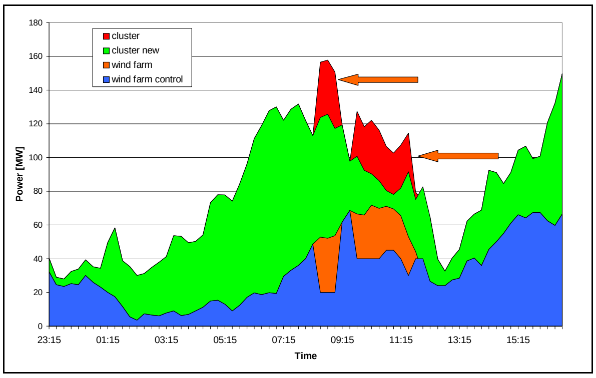

Fig. 7. Profile based operation

Non-controllable wind farms can be supported by controllable ones of that cluster. So, the strategy allows hybrid clusters to meet their requirements.

V. CONCLUSIONS

The energy sector is under strong pressure to integrate renewable energy sources (RES), particular wind power to meet the requirements of the Kyoto Protocol. The relatively low level of predictability of wind power is one of the main barriers to increase the share of these energy source. In Germany, research institutes like ISET developed reliable and precise algorithms to increase the predictability of wind power. The tools are in operation at all four TSOs to prevent imbalances caused by fluctuating wind generation. Furthermore, the software is used to organize the immediate equalization of reserve power between the control zones. These approaches can be very helpful for other countries to increase the share of RES. The prediction tools are also basic elements for advanced wind farm control strategies to integrate the expected wind power in GW range for the future scenarios.

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VII. BIOGRAPHIES

Dr. Kurt Rohrig is head of ISET’s Program Area Information and Energy Economy. Dr. Rohrig worked with ISET since 1991 and has been the scientist-in-charge for projects handling the online monitoring and prediction of wind power for large supply areas – operated in co-operation with large power transmission utilities. The computer models and approaches, developed in frame of his work are in operation at all German transmission system operators with high wind power penetration. Furthermore, Dr. Rohrig is head of the thematic network “Energy and Communication” which consists of 12 partners of industry, universities and research institutes.

Dr. Bernhard Lange is head of Information and Prediction Systems of the Program Area Information and Energy Economy at ISET. He is a physicist with MSc from the University of Oldenburg. After graduating he worked in Denmark with Risø National Laboratory and Wind World A/S. 1998 to 2002 he prepared his PhD about offshore wind power meteorology at Risø National Laboratory and University of Oldenburg. His main research interests for the last 10 years are wind power meteorology and wind farm modelling.