SHORT TERM PREDICTIONS FOR THE POWER OUTPUT OF ENSEMBLES OF WIND TURBINES AND PV-GENERATORS

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Abstract - With the increase of penetration of the utility networks by wind- and solar derived electricity both the the power flow in the grids and the conditions on an electricity spot market will be subject to additional stochastic disturbences. Thus for optimal control of the network an the actions on a eclectricity market there will be a need for an accurate short term forecast of the respective power flow.

We present the state of the art of power predictios for wind and solar power plants.with a time horizon of several hours (solar) up to several days (wind). This includes a presentation of the methods for the derivation of power predictions based on meteorological forecasts and the discussion of the quality of the predictions. In view of the application of the forecasts, the focus will be centered only not on the predictions of the output of individual plants but of the combined output of the ensemble of all installations within specified sections of the grid or of all distributed installations operated by one electricity supplier.

1. INTRODUCTION

In several regions (e.g. Danemark, Northern Germany) the penetration of the utility grids by electricity derived from new renewable sources (wind and solar), namely the wind energy, has already reached a remarkable level. In the production mix of the emerging 'green' electricity suppliers the dominance of renewables is the natural case. Thus, the integration of these power flows dominated by the meteorological conditions are subject for the operation of the utility netwoks and the economical actions on a free energy market. For both the day to day operation of the utility power park and the offers to an electricity spot market there is a need for a forecast of the power production of wind and solar generators with time horizons of several hours up to several days. This calls directly for a prediction of the driving meteorological parameters.

In the following, the state of the art of the respective short term predictions will be presented. Besides a short discussion of the basics the accuracy of the predictions will be the special subject.

2. RELEVANCE OF POWER PRODUCTION FORECASTS OF WIND AND SOLAR INSTALLATIONS

First, the relevance of the short term power predictions should be discussed. In the supply grids of the german north sea shore region the installed wind power capacity has reached the order of magnitude of the average load. For the conventional power park, the power production of the wind turbines presents a fluctuating 'negative load' and thus gives rise to an increase of the overall load fluctuations. Taking the temporal evolution of the wind conditions and thus the fluctuations of the effective load as unknown, this leads to consequences for the operation of the conventional park. For time horizons covering hours to several days reserves for a firm power supply must be taken into account, causing an increase of the costs of operation and thus a decreased value of the respective kilowatt hours. With the existens of reliable forecasts of the renewable production this situation is assumed to improve (see. e.g. Watson et al. , 1999).

3. PREDICTIONS OF THE POWER PRODUCTION OF WIND TURBINES

For the forecast of the power production of wind turbines two approaches may be named. On one hand measured time series of the wind speed or the power production of the turbines may be used to set up statistical modells of the respective temporal Evolution. Based on this, the actual data can be used for an extrapolation. An example for this type of approach is e.g. discribed in (Durstewitz et al., 1997). For short time horizons (smaller than a few hours) these methods can lead to reasonable results. However for longer time horizons, the local data do not contain enough information on the temporal evolution of the weather conditions.

This long term and large scale evolution of the weather conditions is subject of the weather prediction modells as operated by the national weather services. For the region of Germany e.g. the german weather service DWD had run the Deutschlandmodell DM and, since december 1999 is running the Local modell LM. These modells give, among others prarmeters forecasts of wind speed and wind direction for a temporal grid of 1 hour and a spatial grid resolution of 14×14 km^2 (DM) and 7x7 km^2 (LM) respectively. Due to this spatial resolution these data can not be used directly for a power prediction of wind turbine installations. It is however possible to set up corrections according the local situation. Respective procedures have been set up in the framework of EC research projects (Landberg, 1997), (Beyer et al. 1999). The accuracy of the outcome in view of the power predictions for time horizons ranging from 6h to 48h will be discussed in the following.

Within the project SHORT-DE (Landberg et al. 2000) the accuracy of the power predictions based on the DWD modells has been tested using measured power data for a set of about 30 turbine instalations in northern Germany. The data mainly stem from the German WMEP data system operated by the ISET (Ensslin et al., 1998). Fig. 1 shows the geografical locations of the turbines in this test set.

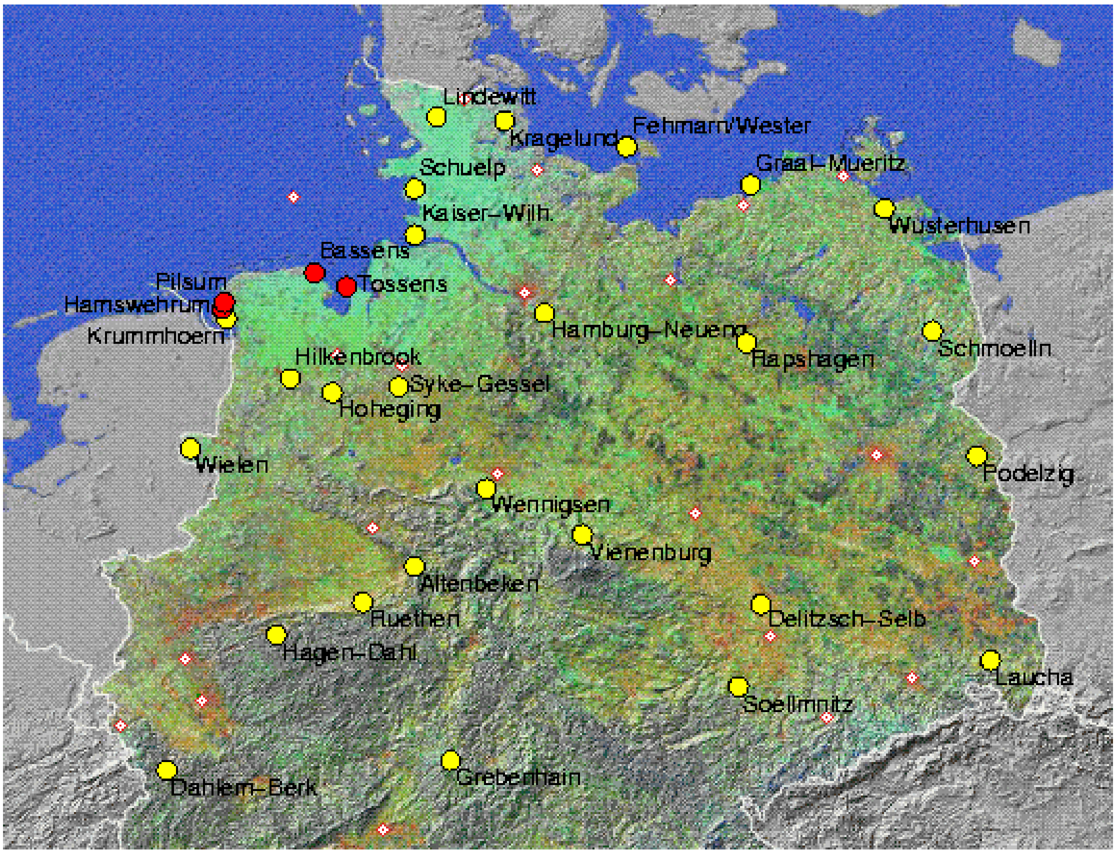

Fig. 1. Geografical situation for the test set used to assess the accuracy of power predictions based on 6h - 48h wind forecasts of the German weather service DWD. For each location actual power output data of wind turbine installations had been available.

The data set covers the years 96-99. The measured data are used for a comparision with the outcome of the prediction runs with the time horizons of 6h to 48h performed each midnight. As an example, figure 2 gives the time evolution of the power output of a turbine over a time span of 12 days. Together with these data, predictions for different time horizons are plotted at the respective hours. Besides the overall good correspondance of the data sets faulty predictions may be identified.

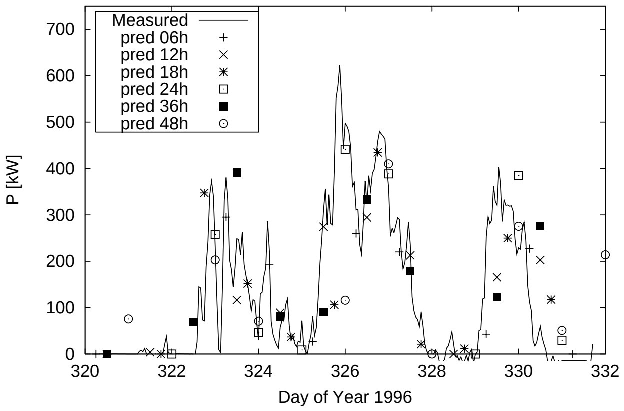

Fig. 2 Time trace of the measured power output of a Wind turbine (600 kW rated) and the power predictions for the respective hours.

As a measure of the quality of the predictions, fig. 3 gives the ensenble average of the annual (year 1996) rms of the prediction error together with the respective values for the location with the best and the worst outcome. For this plot, the errors of the prediction are normalized to the installed capacity at each loaction. The magnitude of the average rms-errors ranges from 10-20% of installed capacity and, as could be expected increases with increasing time horizon.

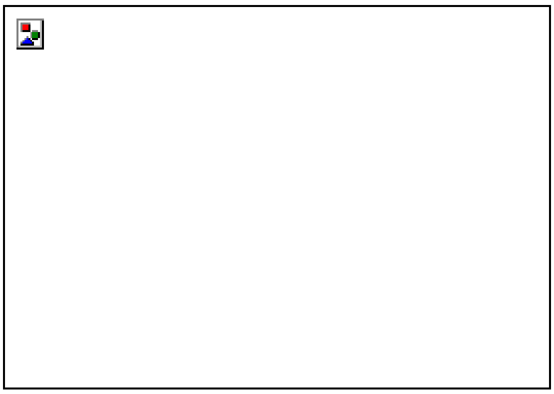

Fig. 3 Average rms error (normalized to the installed capacity) of the predictions with time horizons of 6h to 48h for the whole data set of 1996 (middle curve). The upper and the lower curve give the annual rms avlues for the sites with the best and the worst outcome.

In view of the use of the power predictions as mentioned above, the main figure is not the accuracy of the power prediction of an individual turbine but the errors for the prediction of the ensemble output of all turbines with a certain grid section or the turbines belonging to one operator. For an analysis of the data from this point of view a set of ensemble output data is formed using a scaling of the installed capacity at each location to a common value. This normalized rms errors of the ensemble output may then be compared to the avearge rms error for the single site data. Fig. 4 gives the errors for both ensemble and single site predictions.

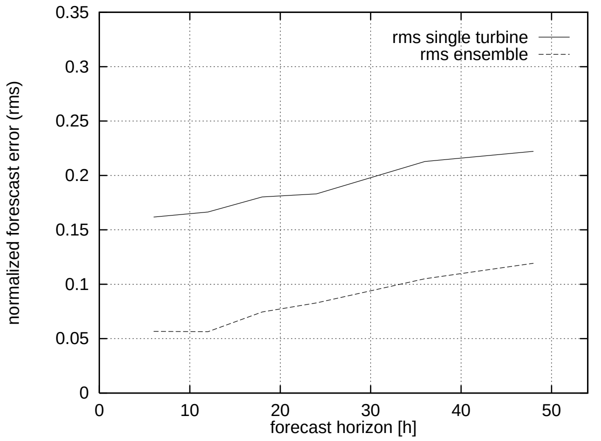

Fig. 4 Normalized rms-errors for the prediction of the output of an ensemble of 30 turbines (lower curve). The upper curve gives the average rms error for the single site of this set.

The normalized forecast errors for the ensemble range from about 5% for a time horizon of 6h to about 15% for a time horizon of 48h and are thus remarkably reduced as compared to the single site data.

For a better understanding of this reduction, the spatial pattern of the prediction errors is analysed. Fig. 5 shows the cross correlation of the normalized prediction errors as a function of the intersite distance.

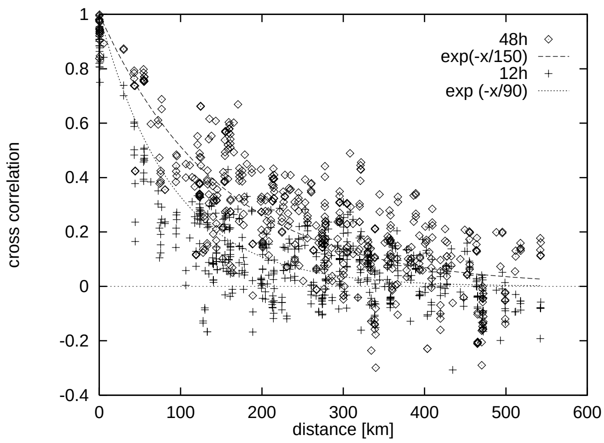

Fig. 5 Cross correlation of forescast errors as function of the intersite distance. The data for the 12h (crosses) and the 48h (diamonds) are analysed. The curves give exponential fits to these sets.

The field of errors for the 48h prediction horizon in general shows a higher correlation than 6h data set. For both the 6h and a 48h predictions the crosscorrelation shows a decrease with distance.

With these correlation chracteristics it is to be expected that the errors for the prediction of the ensemble power will drecrease with the number of locations involved and with the average intersite distance in this set. Using the present data set, subgroups located in circles with a radius of 140km are inspected (fig.6). Table 1 gives the normalized prediction error for the turbines of these groups relative to the single site prediction errors. For comparision the respective value to be expected for the case of uncorrelated errors is given. This shows, that the correlation of the errors which is present in the data set has a non neglectable influence on the outcome.

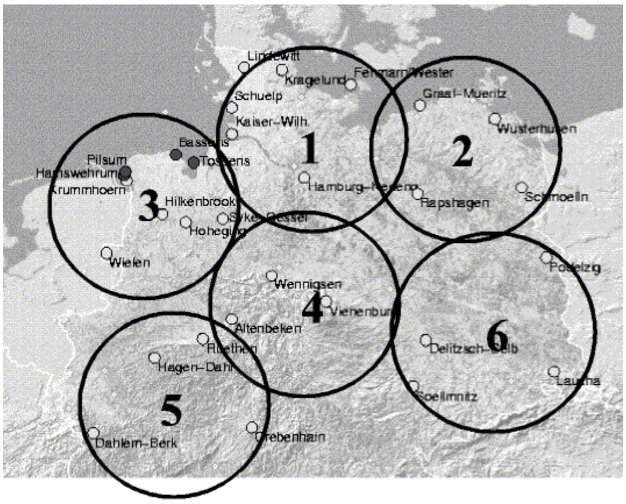

Fig. 6 Subsets of turbine groups forming circles with aradius of 140 km.

Prediction time Regionsize	1/√N	6h	12h	24h	48h
140 km	0.71	0.81	0.95	0.82	0.82

Table 1. Ratio of the rms error for the different subregions and the rms error for single sites. N is the number of sites within the subregion.

Using a simple model of an exponential decay of the correaltion with distance, the errors to be expected for other ensembles of sites may be evaluated. As an example the normalized prediction errors for an ensembles of installations positioned at the gridpoints of a 225km x 150km mesh with a spacing of 15 km (this configuartion may be seen a a very simplified representation of the situation at the eastern north sea shore in the Germany is calculated. The uncertainty of the power prediction for this ensemble may be set to about 9 % (12h) and 16% (48h) of the installed capacity.

4 PREDICTIONS OF THE POWER OUTPUT OF PV-GENERATORS

For the power output of PV-systems we will discuss predictions for a time horizon of one hour. As for the wind power predictions, forecasts may be based on local measurements (see e.g. Gruffke et al., 1998) or large scale information, in this case given by meteorological satellites.

The METEOSAT satellite offers half-hourly images with a spatial resolution of about 10*10 km^2. taken in the visible wavelength band. From these images the cloud cover and - using a radiation transfer modelling - the radiation at ground level may be derived. Taking consecutive images, the temporal evolution of the cloud situation may be analysed as given in fig. 7. Based on this, the cloud situation presented by the actual images may be extrapolated to future time steps. A respective procedure is described by (Hammer et al. 1999). For an assesment of the prediction quality it has been tested with images for an area covering about 1000x1000 km^2. For comparision, the errors of the predicted cloud cover (measured by a cloud index ranging from 0 to 1) are compared to those of a persistence forecast (i.e. prediction = present situation). The persistence forecast shows an average error of 26% compared to the error of the prediction based on the cloud evolution analysis of 18% (fig.8).

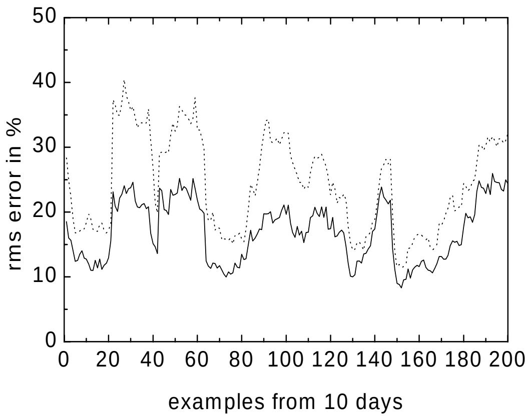

Fig. 8. Daily rms-errors of the cloud field predictions as derived with a persistence forecast (dotted curve) and with the use of the cloud field evolution detectet. Given are the results for 10 days of data.

Changing from cloud cover predictions to predictions of the irradiance has to involve the systematic variations superimposed by the changing position of the sun and thus the radiation intensity. This, on one hand leads to a reduction of the absolute errors for the morning and the evening hours and may be taken into account easily. In addition, as for the prediction of the power output of wind turbines the average radiation effective for an ensemble of PV-systems should be investigated. The effects of both the change from cloud cover data to irradiance data and the reduction of relative errors for the prediction of the average effective radiation of ensembles of various sizes is given in fig. 9. Here calcuations are performed for systemes consisting of up to 1100 systems distributed evenly within an aera of 750 km x 1200 km.

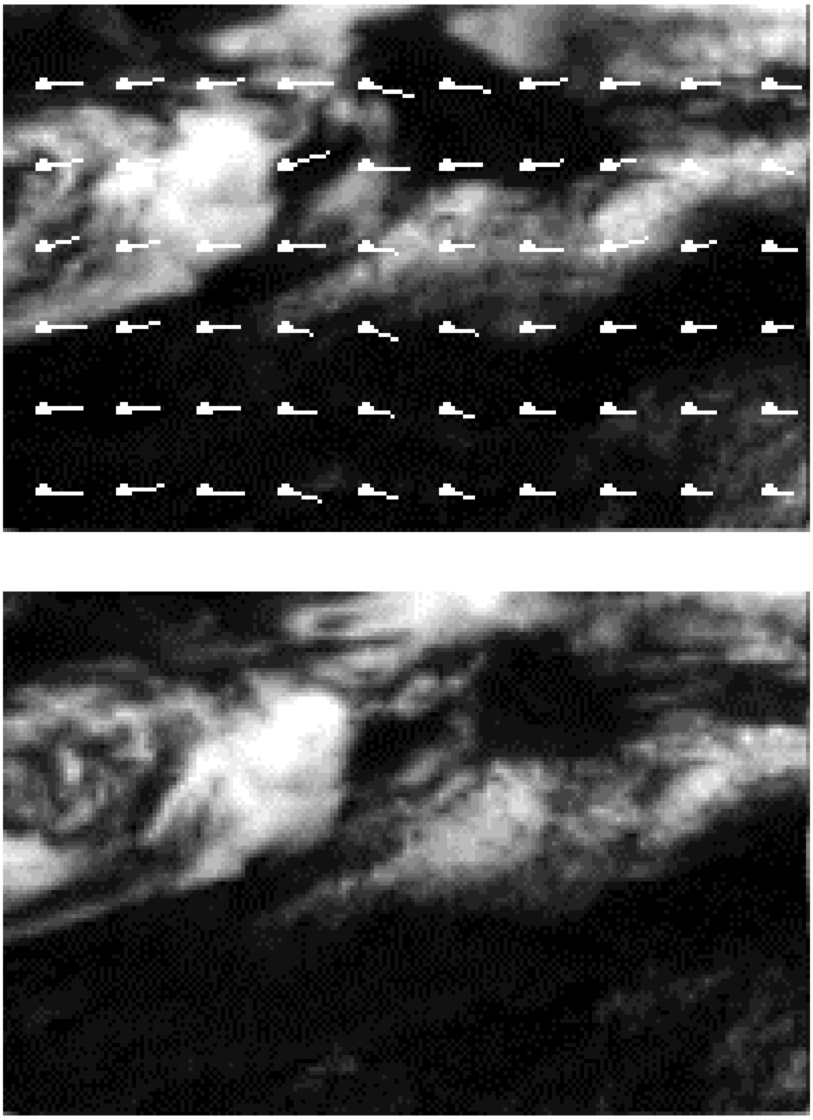

Fig. 7. To consecutive images of the cloud situation together with a field of cloud movement vectors derived from this set.

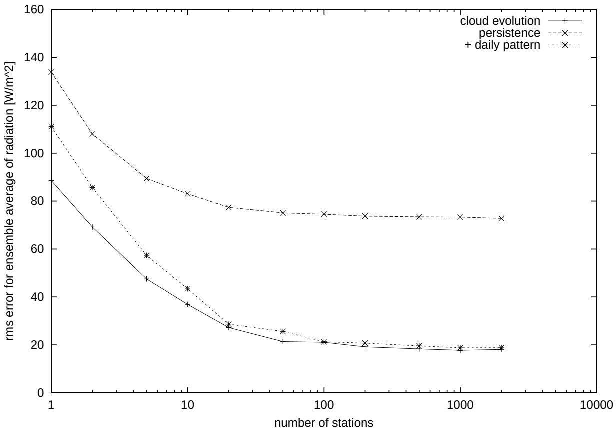

Fig.9 Errors for the + 1h prediction of the average radiation effective for ensembles of PV-systems ditsributed evenly within an aerea of 750km x 1200 km. The use of a persistence forecast assuming constant irradiance values, a forecast with additional respect to the trend due to the sun position and a full cloud evolution procedure are compared.

Looking at the persistence forecast which in this case assumes constant irradinaces, it may be remarked that the change from single site to ensemble predictions leads finally to a reduction of the forecast errors by a factor of 0.6. Adding the knowwegde of the change of the sun position causes a decrease of the error for a single site prediction by 0.8. For the ensemble of 1100 systems only a fraction of about 0.2 of the single ite error. Using the forecasts of the cloud evolution gives, for the single site a reduction 0.85 as compared to the cloud persistence+dayly trend data. For larger ensembles this advatage is diminished. This is due to the fact, that the average cloud situation for a region has only a small variability during the time horizon in discussion. Accordingly, the hourly variations of the putput of PV-ensembles is limited (see e.g. (Beyer et al., 1991) and (Beyer et al., 1992).

4. OUTLOOK

For time horizons expanded to several hours and days the stocastic of the small scale cloud evolution prohibits a reasonable prediction for a single site with a high temporal resolution (i.e. 'instantaneous' or hourly mean values). However for the case of ensemble data for a region or single site data concering temporal averages (e.g. daily data) reliable predictions may be expected. As for the case of wind predictions, for this task the outcome of the numerical weather modells may be used. The modells give information on the cloud situation and atmospheric turbidity for longer time time horizons from which the again the solar radiation at ground level may be derived. This use of the numerical modells however is up to now not established and call for intensified efforts.

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