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WIND POWER FORECAST SYSTEM CALIBRATION. CASE STUDY IN ROMANIA

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This paper presents the working principle of numerical weather prediction (NWP) based wind power forecasting systems and points out some of the causes that can lead to low prediction accuracies. The paper also presents the results of the first forecasting system of this kind implemented in Romania.

Keywords: wind power forecasting, NWP, artificial neural networks

1. Introduction

The operation of electrical networks is based on a strict planning of power generation. Conventional power generating units (coal fired, gas fired, nuclear, hydro, gas turbines etc.) are operated at any time in a certain power mode. System faults with corresponding outages of generators are covered by the system spinning reserve. The growing amount of unregulated and fluctuating production from renewable energy sources (RES), especially wind power, creates new conditions in system operation and control. For systems with high penetration of wind power, the most significant difference to operation with conventional power generation is that in addition to forecasts of the consumption, predictions are also to be prepared of the unregulated wind power generation. Such predictions are necessary both for the power producing companies like power authorities and transmission system operators (TSOs) and as well for the players on the electricity market that own significant wind power production sites.

Wind-generated power now provides a noticeable percentage of the total electrical power consumed. For instance, in Germany at the end of 2008, more than 20,000 wind turbines (WTs) generated more than 40,000 GWh with an installed capacity of 23,600 MW. This indicates that wind is becoming a significant factor in electricity supply, and in balancing consumer demand with power generation.

Romania, as one of the countries that ratified the Kyoto Protocol and as a member of the European Union, is trying to reach the goals imposed in the

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Directive of the European Parliament and Council on the promotion of the use of energy from renewable sources for a sustainable development and for environment protection, which states that by 2020 all the country members of the EU have to produce at least 20% of their energy requisite from RES [1]. Of all the green energies, wind power is the one that is being used on large scale to reach the imposed target. The most recent reports released by the Romanian TSO state that the total installed wind power has reached 563 MW (see Table 1) [2] while the forecasts made by the Romanian Wind Energy Association profess that in 2013 that value will be 4013 MW [3].

Table 1

Total installed wind power in the Romanian power system

Name	Peştera	Valea Nucărilor	Fântânele Est and Fântânele Vest	Siliştea	Cernavodă 1	Dorobanţu
Installed power [MW]	90	34	300	25	69	45

This paper presents the first results of Fraunhofer IWES-ISET's Wind Power Management System that was implemented in Romania by Monsson Group and tested on the Topleț and Siliştea 1 wind farms. The paper will also point out some of the weak spots of NWP based wind power prediction systems that have a major impact on their accuracies.

2. The prediction system

The Wind Power Management System (WPMS) is the creation of ISET (Institut für Solare Energieversorgungstechnik), which, from 17 August 2009, has become the Institute for Wind Energy and Energy System Technology (IWES) after it merged with Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V..

In context with governmental and EC funded projects and in co-operation with the German TSOs E.ON Netz, RWE-Transportnetz-Strom, Vattenfall-Europe-Transmission and EnBW Transportnetze AG, ISET e.V. developed a planning tool to support large-scale wind power integration into the electrical energy supply system - the Wind Power Management System (WPMS). Their main advantage was a German federal program that had as purpose the detail monitoring of the evolution of wind power [4] in Germany, program that made possible the creation of large databases that were later used in building the prediction system.

WPMS assess the current level of wind power generation as well as it provides the short term prediction from 1 hour up to 72 hours for wind farms, grid regions and control zones. According to [5], the system first started as an online wind power estimation program that was capable of calculating the generated power of a large area by monitoring only a couple of representative wind farms. For E.ON Netz, WPMS monitored only 25 wind farms with a total installed power of 1 GW and estimated the power production of a control area that had 6 GW of installed power in wind turbines [5].

Later on, a second module – Advanced Wind Power Prediction System (AWPS) – was added to WPMS, making it capable of doing short-term and day-ahead wind power forecasts. Thanks to the online module that was previously described, all the predictions can be made for a single wind turbine, for a wind farm or for a large control zone.

AWPS is based on artificial neural networks and works by transforming the outputs of the German Weather Service (DWD) NWP, Lokal Modell (LM), into power forecasts. Even though LM has a 7 km horizontal resolution, to improve the results, a mesoscale NWP model is used to convert the outputs of LM to the specific conditions of the wind farms. Furthermore, in order to correct the predictions according to the latest values of generated power measured online, another ANN is used.

The Wind Power Management System has so far been implemented in the German load dispatcher of E.ON-Netz (9,438 MW installed wind power) since July 2001, at RWETransportnetz-Strom (4,265 MW installed wind power) since May 2003 and at Vattenfall-Europe-Transmission (9,966 MW installed wind power) since December 2003. Furthermore the WPMS is used by Verbund, the biggest transmission system operator (TSO) in Austria, since June 2007, by TERNA the only TSO in Italy since 2007, by NREA/Egypt since 2007 and by National Grid the TSO of the United Kingdom since 2008. Soon the system will be adjusted to run at EnBW-Transportnetze-AG, the forth transmission system operator (TSO) in Germany, at Wind Power Energy srl/Romania and at the Jilin/China dispatch center in cooperation with CEPRI/Beijing.

For the German case the system runs two times a day (because of the LM NWP) and offers forecasts for the next 48 hours with a hourly resolution. In these conditions the forecast error for the balancing areas of German TSOs amounts 6-7% of the power output for the day-ahead forecast (14 – 38 hours) and 4-5% for the short-term prediction for 4 hours. Regarding all reference wind farms the average forecast error of the hourly computed short-term prediction (1–8 hours) ranges from 7% to 14% and from 9% to 19% for the day ahead forecast.

3. Factors that influence the accuracy of wind power forecasts

This section presents the details of the case study and some particularities of the NWP based prediction systems in order to point out some of the causes that usually lead to low forecasting accuracies.

All the study case tests were performed on the Topleț and Siliştea 1 wind farms. Some information about their installed power and location is given in Table 2.

Table 2

Characteristics of Topleț and Siliştea wind farms

Name	Installed power [MW]	Location	Owner
Topleț	50.4	Mehedinți county	SC Toplet Energy SRL, SC Smart Team Energy SRL, Euro Wind Energy SRL
Siliştea 1+ Siliştea 2	25	Constanța county	Romconstruct Top

As previously mentioned, the forecasting system employs ANNs, which have to be trained with past measured data. This step is critical in the performance of the system because a poorly trained network will lead to big forecasting errors. This means that during this process the ANN must "learn" from a large number of examples, examples that must be representative for the situations that the network might find during its operation [6]. In the case study presented in this paper, the NWP data available covered the period from 1st of July 2008 – 1st of June 2009, data obtained for the 6:00 hours model's runs. The availability of the on-site meteorological measurements is shown in Fig. 1.

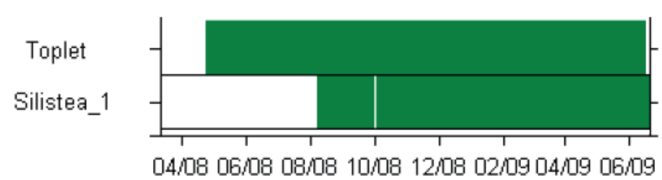


Fig. 1. The availability of the meteorological measurements

The version of WPMS installed in Romania uses data from a NWP model as well as data obtained from measurements. The NWP model runs four times a day from 6 to 6 hours and offers predictions for the next 54 hours. However, due to the complexity of these models, the time required for their run is around 7 hours [7]. This means that the forecasts that are the most reliable, i.e. the ones for the next couple of hours, can never be used, which affects the overall performance of the wind power forecasting system.

Another thing that influences the performance of the forecasting system has to do with the horizontal resolution of the NWP model and the location of the wind speed measurement pole and that of the wind turbines (see Fig. 2). NWP models work by numerically integrating the equations that describe the evolution of the atmosphere and, in order to do that, they divide the atmosphere into a three dimensional grid. The number of these points has to be limited to keep the computation time at a reasonable value. In short, a NWP model is not able to forecast the parameters of interest – the wind speed and its direction – for the exact location of a wind turbine, so these have to be determined by using other methods.

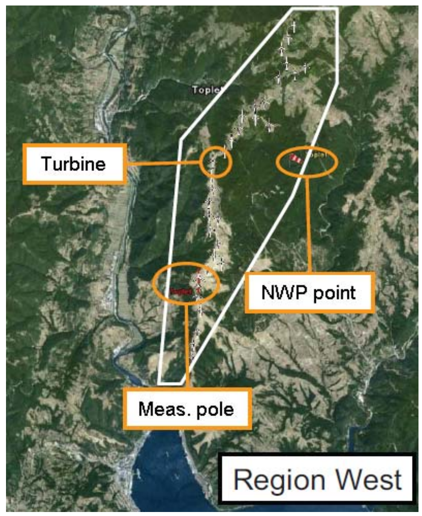


Fig. 2. Location of the wind measuring pole, the NWP grid point and of the turbines for the Topleț wind farm

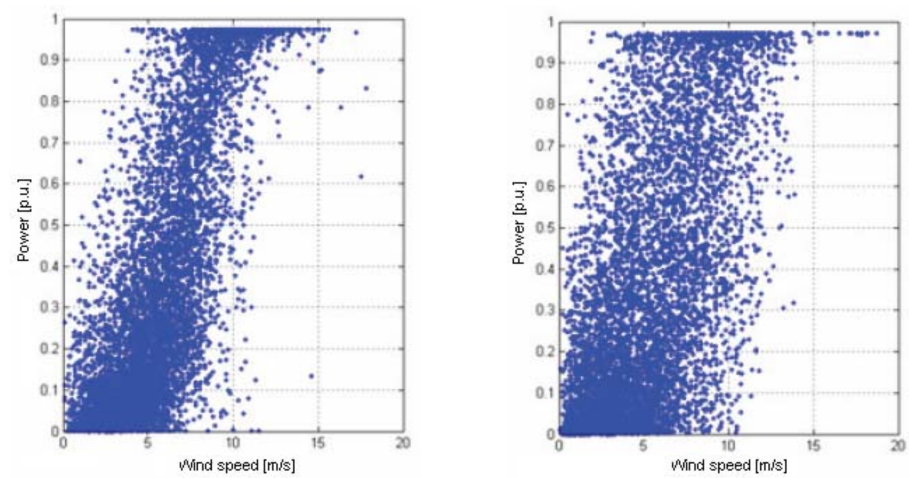
Another particularity of the NWP models is the fact that their output parameters are computed for the upper atmospheric layers and not for heights as those of wind turbines. Hence, the forecasted values of wind speed and direction made by the weather model need to be transformed to the local specific conditions, procedure that can lead to errors.

The last step in the wind power forecasting process is the conversion of wind speed into wind power. This involves finding a model that can describe the connection between the wind speed and the entire power output of a certain wind farm, values that are monitored online. In the specific case of WMPS, this process, as well as the one described beforehand, are done in a single step by artificial neural networks, which are also a source of errors in the forecasting system.

4. Results

Two tests were performed during this case study, one for each wind farm. The system was trained with the available data and its performance was evaluated.

In the first step, the real power curves (see Fig. 3) for the two farms were computed based on the on-site measurements.



a. *b.*

Fig. 3. The power curves for the Siliştea (*a.*) and Topleţ (*b.*) wind farms. The power has been normalized by division to the maximum power of the farm.

Using these curves, all the forecasts made by the NWP model were transformed into wind power forecasts. Comparing these values with the measured ones, the correlation coefficients presented in Fig. 4 were obtained.

To compute the correlation coefficient, the following formula was used:

$$r(P_M, P_P) = \left[\overline{\left(P_M - \overline{P_M}\right)\left(P_P - \overline{P_P}\right)}\right] \Big/ \sigma(P_M)\sigma(P_P), \qquad (1)$$

where P_M and P_P are the measured and predicted power time series, σ is the standard deviation, and the “ ¯ ” denotes the mean value.

It can be observed that for the Topleţ wind farm the correlation coefficient has a lower value. The most probable cause for this is the influence of the terrain, because this wind farm is located in a mountain region, whereas Siliştea wind farm is on a flat terrain.

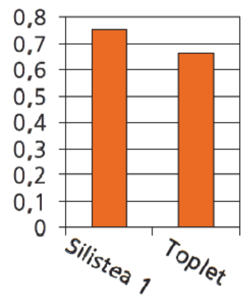


Fig. 4. The forecasted and measured wind power correlation coefficient

The version of WPMS installed in Romanian is designed to work with eight NWP prediction models, denoted with STF on Fig. 5, and with one that aggregates all of them, denoted with the DAF acronym. For each of these models the normalized root mean square prediction error (nRMSE) was calculated for the largest forecasting horizon. The results are presented in Fig. 5,*a*. Fig. 5,*b* presents the correlation coefficient between the predicted and real measured wind power at the two analyzed wind farms.

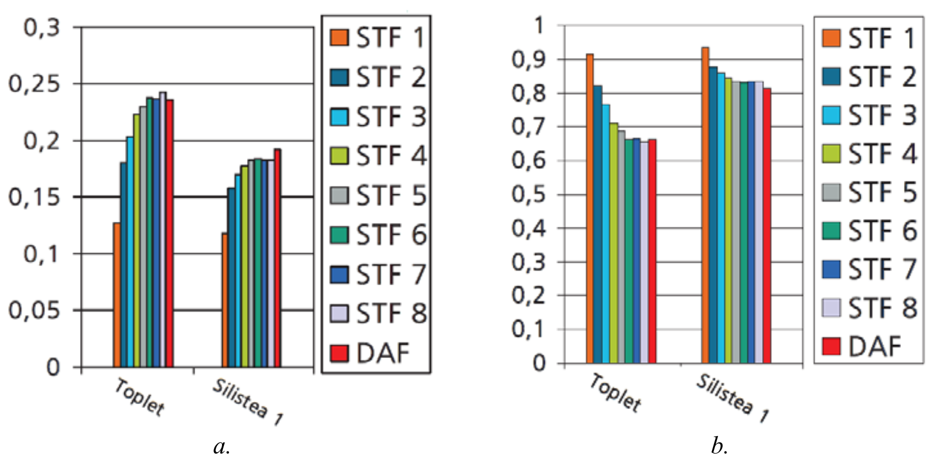


Fig. 5. The nRMSE (*a.*) and the correlation coefficient (*b.*) for each of the prediction models used by WPMS

It can be observed that the forecasting errors have smaller values for the Siliştea wind farm. Taking into account the fact that the data availability was worse for this farm than for the Topleţ one, which means that the ANN was not fully trained (normally the system needs at least one year of data for training in order to offer good forecasting results), the only conclusion that can be drawn from here is that the conditions of the site have the greatest impact on the performance of the forecasting system.

5. Conclusions

This paper presented the working principle and main disadvantages of NWP wind power forecasting systems. Based on the results of the first system of this type implemented in Romania it can be concluded that the disadvantages of usual NWP systems can be overcome by using an ANN to represent the connection between the outputs of the meteorological model and the generated wind power. Thanks to the capability of self-adaptation of ANNs, the measured and forecasted wind speeds can be corrected in time if the initial NWP weather forecast is properly chosen and the input data is good.

The case study shows that depending on orography and topography, the power forecast can be different. Topleț site is on the mountains and Siliştea wind farms is in Dobrogea flat terrain, which is the main reason why the obtained results are better for the latter wind farm. To sum up, the bigger the wind farm and the flatter the terrain is, the better the correlation coefficient and forecast will be.

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