Online Monitoring and Prediction of Wind Power: Portuguese Transmission System Operator's Methodology

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Abstract

This paper presents the wind power prediction software system utilized by the Portuguese TSO, REN[1], since 2005. The system is being developed by IST[2] and REN. Both the numerical weather prediction model and the adopted downscaling procedure introduction precede the description of the power conversion method. Furthermore, the main results of the performance evaluation report from 2005 second semester are presented, as well as ongoing developments.

Keywords: wind power prediction tool, transmission system integration, performance evaluation.

1. Introduction

According to REN, during last year the country's peak load was about 8000 MW and it will increase to 9000 MW until 2009. Nowadays telemeasured wind parks installed capacity represents 5% of the total consumption and will then represent more than 20%. This growth of installed wind power capacity brings new integration challenges, namely because of wind power's stochastic in-feed characteristic (see Figure 1).

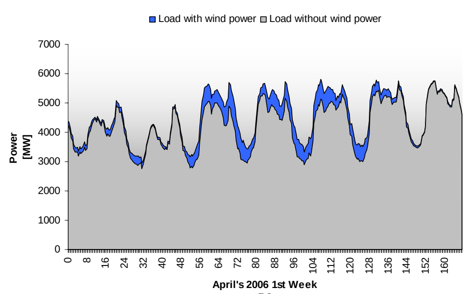

Figure 1: Load profile of REN

TSOs, understanding the physical reality of their network, have to ensure the security of the electric transmission system as well as its quality of service. They have to provide several system services and, in particular, online regulation power. Apart from power station down-time, unforeseen load and wind power variations are the most frequent

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causes for regulation and compensation power needs. The more accurate the predicted wind power production, the less regulation power is needed.

These considerations show that an accurate prediction of wind power with a suitable time horizon (of 24 to 48 hours) is necessary for TSOs to efficiently integrate this power source into the existing electrical system. REN, in cooperation with IST, is developing its own prediction system which is already being utilized for operational purposes, namely load forecast.

This paper provides an overview of the two sub-models that compose the main system – the wind and the power prediction models –, establishing whenever possible the link between the existing field conditions and the corresponding adopted model approach.
In order to test the behaviour of the developed tool, data from last semester of 2005 were analyzed, being the main results presented.

2. Wind Prediction Model

The prediction of the wind field is based on the well known numerical weather prediction model MM5, developed initially at the Pennsylvania State University [3] with later contributions of a large number of Institutions and individuals. The last updated version is MM5_V3_7.3.1 (2005). The model uses the Navier Stokes Equations for a compressible fluid and the energy and water conservations equations on a grid following the terrain height using a pressure scaled vertical coordinate system (sigma coordinate). Being a local area model (LAM) the initial and boundary conditions are given by the GFS model (Global Forecast System) of the NWS (U.S.A) (United States National Weather Service) and uses a nested grid system for downscaling. In the operational numerical implementation currently in use at IST (http://meteo.ist.utl.pt) 3 nested domains with grid sizes of 81x81, 27x27 and 9x9 km are used, with two way interaction (see Figure 2).

The model is used operationally since 2001, and since 2005 the wind prediction at the hub height is used by REN. A summary report of the general behaviour of the model in this application is available in [4].

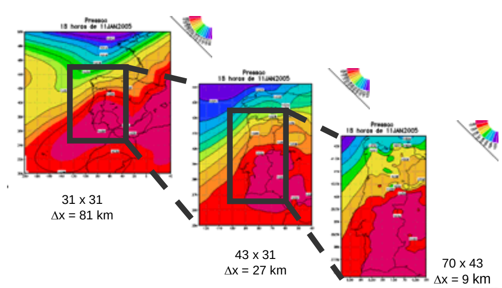

Figure 2: IST-MM5 nested domains (http://meteo.ist.utl.pt)

3. Power Prediction Model

The power prediction model can be described as follows (see Figure 3).

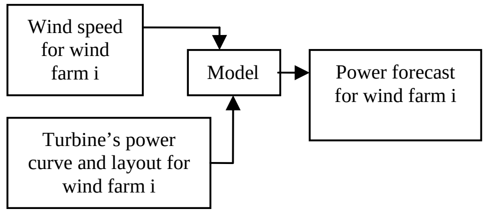

Figure 3: Power prediction model

For each telemeasured wind farm, the wind prediction model yields a wind speed for the given turbine hub height. This wind speed is then converted to power by means of the corresponding manufacturer's power curve polynomial approximation. This leads to hourly based individual forecasts for every wind farm considering a time horizon of 72 hours, refreshed every 6 hours. The final step of the model is the sum of the individual power predictions in order to obtain the national forecast which is available at REN's homepage[3].

4. Global Performance Evaluation

This section presents the main results from [2]. The analyzed data are from the last semester of 2005 and the statistical methodology follows the approach proposed by [1]. Let ε be the error, understood as the difference between predicted and measured values.

$$\varepsilon = x_p - x_m \tag{1}$$

The root mean square error (*rmse*) is defined by

$$rmse = \sqrt{\overline{\varepsilon^2}} \tag{2}$$

which can be expressed as

$$\begin{aligned} rmse^2 &= bias^2 + sde^2 = \\ &= bias^2 + sdbias^2 + disp^2 \end{aligned} \tag{3}$$

where

$$bias = \overline{\varepsilon} \tag{4}$$

$$sde = \sigma(\varepsilon) \tag{5}$$

$$sdbias = \sigma(x_p) - \sigma(x_m) \tag{6}$$

$$disp = \sqrt{2\sigma(x_p)\sigma(x_m)(1-r)} \tag{7}$$

with r being the cross-correlation coefficient between the two time series and σ the standard deviation.

As it can be seen from Equation (3) three different terms contribute to the *rmse:*

- bias: accounts for the difference between the mean values of prediction and measurement;
- sdbias: evaluates errors due to wrongly predicted variability;

[3] http://www.ren.pt/sections/exploracao/dpe/default.asp

- disp: involves the cross-correlation coefficient weighted with the standard deviations of both time series.

The terms bias and sdbias constitute an indicator for amplitude errors whilst disp accounts for the contribution of phase errors to the rmse.

All the presented values were normalized with its corresponding monthly mean measurements thus enabling the joint identification of both local and global characteristics.

One must underline that REN is presently receiving wind speed real time measures from only one park and so the wind speed measurements are obtained by converting measured wind power into wind speed through the inverse function of the respective power curve. This process introduces errors thus being more correct to adopt the expression "forecast deviation" instead of "forecast error" throughout this study.

Figures 4, 5, 6 and 7 show respectively the normalized values of rmse, bias, sdbias and disp for the wind prediction for all the available months and wind farms.

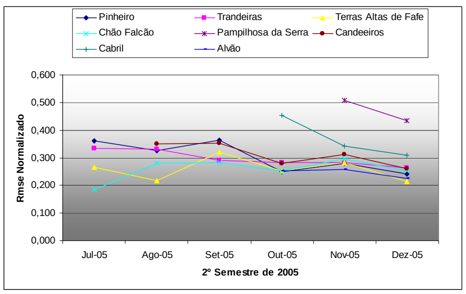

Figure 4: Wind speed normalized rmse

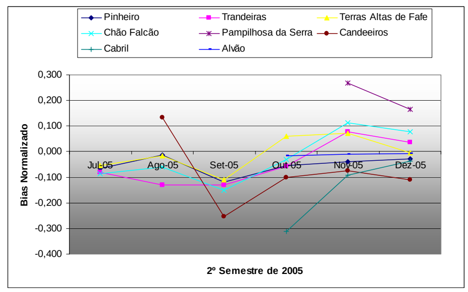

Figure 5: Wind speed normalized bias

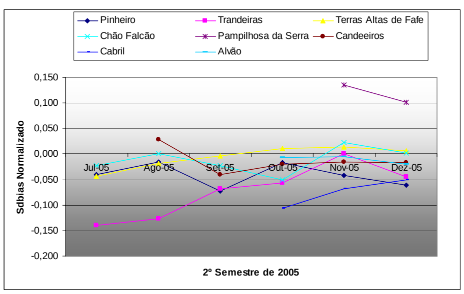

Figure 6: Wind speed normalized sdbias

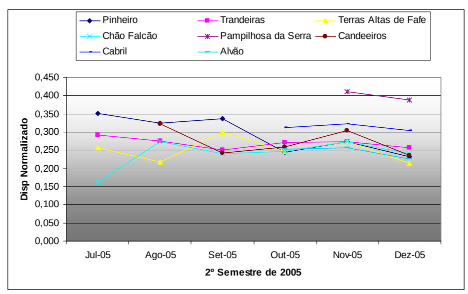

Figure 7: Wind speed normalized disp

During October the wind prediction system was modified in order to take into account the various turbines' hub height and so one can observe an overall improvement during the last three evaluated months.

It can be seen that the normalized rmse value is between 20% and 50% presenting a similar temporal evolution for the majority of the parks. As a general rule the phase error is much more significant than the amplitude one and the nature of the last changes from an underestimation to an overestimation of the wind speed. While amplitude deviations are mainly influenced by on-site conditions and thus can be calibrated by linear correction procedures, phase deviations reflect the time accuracy of the prediction model and constitute the challenge for further improvements.

The total wind power normalized deviation’s evolution is presented in Figure 8.

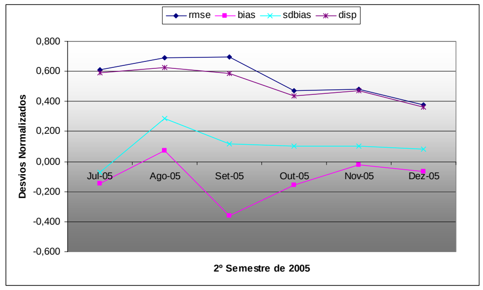

Figure 8: Wind power normalized deviations

It can be seen a global tendency for the error to diminish and as occurred for the wind speed prediction the total error is almost coincident with the phase error.

Table I presents the rmse values for power prediction and the mean rmse values for wind prediction as well as the respective ratio.

Table I: Ratio between wind and power rmse

	$rmse_p$	$\overline{rmse_w}$	$rmse_p / \overline{rmse_w}$
Jul	0.610	0.285	2.1
Aug	0.692	0.300	2.3
Sep	0.697	0.322	2.2
Oct	0.471	0.289	1.6
Nov	0.480	0.320	1.5
Dec	0.377	0.275	1.4

It can be seen that passing from wind speed prediction to wind power prediction introduces a deviation multiplicative factor comprised between 1.4 and 2.3. This factor can be regarded as the effective non-linearity factor that describes the scaling of variations in the wind speed due to the variable slope of the power curve.

5. Ongoing Development

Although this is the present prediction model one can foresee some modifications that are expected to improve the so far obtained results, namely:

- the substitution of the manufacturer’s power curve by the estimated power curve, for each wind quadrant, enabling the consideration of not only the wind speed but also the wind direction and the wake effect. Figures 9 to 12 show the significant difference between the manufacturer’s power curve and the real wind farm curve, for a wind farm in a complex terrain with northwest predominant winds.
- the integration of persistence approach that has proven very useful on the short time scales;
- the adoption of Model Output Statistics (MOS) techniques, namely with ensemble forecast;
- the automatic consideration of related transmission lines’ planned outages.

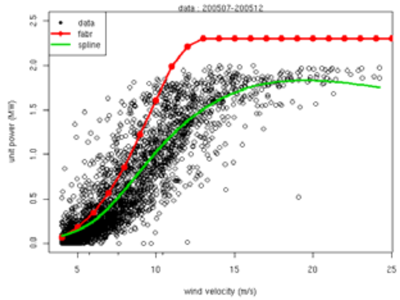

Figure 9 – Power curves for a wind farm: red – manufacturer's curve; green – approximated spline to the measured wind speed and output unit power (black dots)

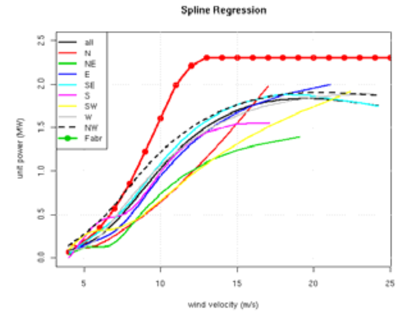

Figure 10 – Wind farm estimated power curves by wind quadrant

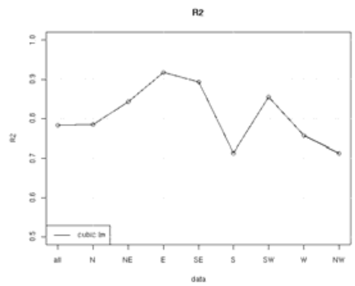

Figure 11 – Squared correlation coefficient of the approximated cubic splines in Figure 10

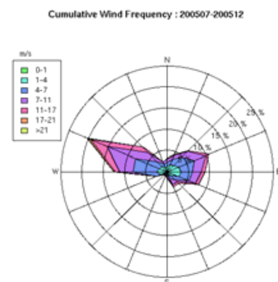

Figure 12 – Wind rose for this wind farm

6. Conclusions

Even with its present limitations, due mainly to the scarcity of wind speed measurements (this situation is expected to improve in 2006), the prediction model in its present stage of development has already shown its usefulness in operational use. There are, however, several improvements which will be introduced when more reliable data become available (wind, land cover, etc), such as tuning spatial resolution and terrain details of the meteorological model. The analysis of a complete year, covering the winter-spring and spring-summer transitions must also be performed in order to proper evaluate the model.

References

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