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Alessandrini, Stefano ; Sperati, Simone; Pinson, Pierre

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The use of different ensemble forecasting systems for wind power prediction on a real case in the South of Italy

Stefano Alessandrini [1] *
Simone Sperati [1]
Pierre Pinson [2]

[1] Ricerca Sistema Energetico (RSE SpA), Milan, Italy
[2] Technical University of Denmark (DTU), DTU Informatics, Lyngby, Denmark

* stefano.alessandrini@rse-web.it

Abstract

Short-term forecasting applied to wind energy is becoming increasingly important due to the constant growth of this renewable source, whose uncertainty requires a constant effort to meet the needs of the national electrical systems and their operators. Regarding to this, the probabilistic approach applied to wind power forecasting (WPF) is showing an increasingly interest in terms of the possibility to reduce forecast errors, giving also a useful information on the accuracy of a forecast and a reliable estimation of its uncertainty; in fact, the prediction accuracy is not constant and often depends on the location of a certain wind farm, as well as on the atmospheric conditions of the site and the forecast horizon used.

According to previous studies of the same authors, the ECMWF Ensemble Prediction System (EPS) can be used as an indicator of a three-days ahead deterministic WPF accuracy. A statistical calibration performed on the wind speed EPS members allows an improvement from an over-confident situation observable from the rank histograms (in which the measurements fell quite always outside the bounds of the probability distribution) to a consistent ensemble spread. After that it is possible to convert the data to wind energy: the spread calculated on wind power can then be used as an accuracy predictor due to its level of correlation with the deterministic WPF error.

In this presentation we investigate the performances for both wind power and accuracy prediction of the new EPS used at the ECMWF, whose horizontal resolution was increased on January 2010 from 60 km to 32 km, on a complex terrain area already used in previous studies and located in Southern Italy. The work consists in the use of the ECMWF deterministic model in a WPF approach followed by a recursive feed-forward Neural Networks (NN) and finally by the application and verification of the EPS in order to estimate the forecast accuracy. We also preliminary compare these performances with the results obtainable from the application of other ensemble prediction systems with higher resolution.

Analyzing the results it can be seen that EPS calibration is a fundamental requirement in order to extract usable information from data; after an adequate calibration method, the ensemble spread calculated on wind power seems to have enough correlation with the deterministic forecast error in order to be used as a predictor of accuracy, at least until the three days ahead forecast horizon.

Site and wind data description

The case study consists in a wind farm located in a complex-terrain mountain area in northern Sicily. It has 9 equal turbines for a total of 7.65 MW nominal power (NP).

Wind and power data were provided for the period November 2010-October 2011. Wind data has been measured at hub height (50 m a.g.l.) by an anemometer located inside the park. A representative power data series was obtained averaging the values measured by the working turbines for each hour.

Deterministic wind power forecast

A WPF for the forecast horizon 0-72 hours ahead has been performed using the ECMWF deterministic model, whose horizontal resolution was increased in January 2010 from T799 (~25 km) to T1279 (~15 km). In order to correct the intrinsic systematic error of the model, a MOS

technique based on the use of a feed-forward, recursive NN has been applied (Alessandrini et al. 2011, Alessandrini et al. 2009). The NN has been trained on the first 5 months of the dataset, linking the meteorological wind data (i.e. wind speed and wind direction) produced by the model and the time step with the measured power, as shown in Figure 1.
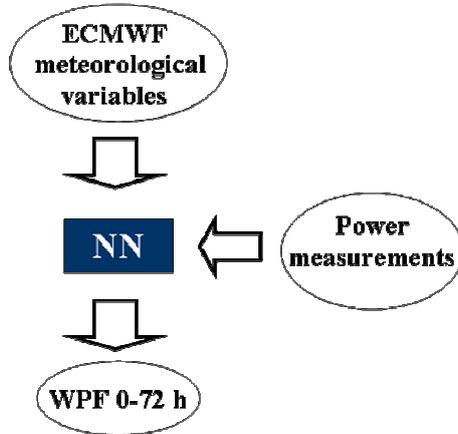

Figure 1 Deterministic WPF system.

The historical time series were reduced from hourly to three-hourly time steps in order to be aligned with the ECMWF output. After the training, the NN has been applied recursively on the remaining 7 months (test period), at regular intervals. This allowed using test data to update the NN algorithm at every interval, obtaining a final power forecasted series whose performances have been evaluated with statistical indices on the entire test period.
Table 1 reports the indices calculated for the three-days forecast horizons.

Table 1 Deterministic WPF, statistical indices.

	+ 24 h	+ 48 h	+ 72 h
RMSE/NP	14.8 %	15.9 %	17.3 %
MAE/NP	10.4 %	11.4 %	12.6 %
Correlation	0.78	0.75	0.69
BIAS/NP	0.02	0.02	0.03

Figure 2 shows the trend (0-72 hours ahead) of RMSE and MAE, both normalized on nominal power.
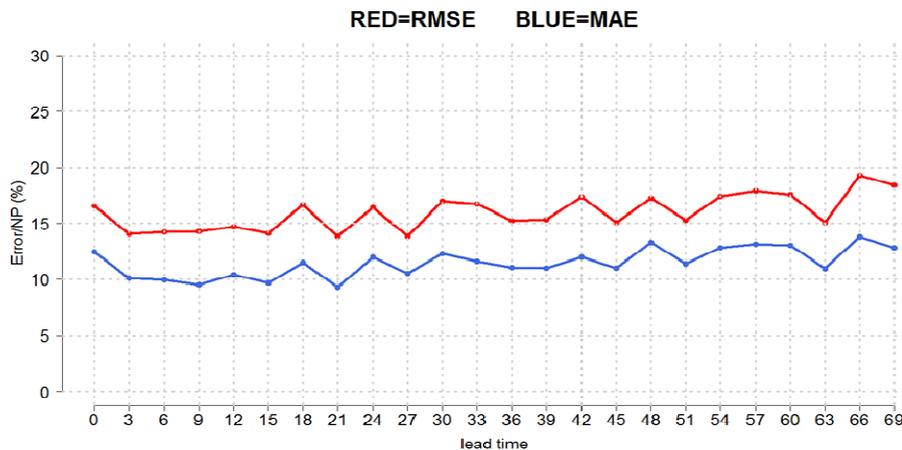

Figure 2 Deterministic WPF, RMSE/NP (%) and MAE/NP (%) on lead time (0-72h)

Ensemble Prediction System

In January 2010 the ECMWF EPS had its horizontal resolution increased from T399/T255 (~60 km) to T639/T319 (~32 km). The Ensemble Prediction System is based on initial conditions perturbation, using a singular vector decomposition technique, and stochastic model perturbations. 50 ensemble members (wind speed and wind direction) are obtained, plus a non-perturbed member (the control run). The 50+1 members are processed by a MOS, using a recursive NN linking the forecasted wind data to the measured wind speed. The MOS-corrected members are then statistically calibrated and finally converted to wind power. The ensemble WPF scheme is shown in Figure 3.
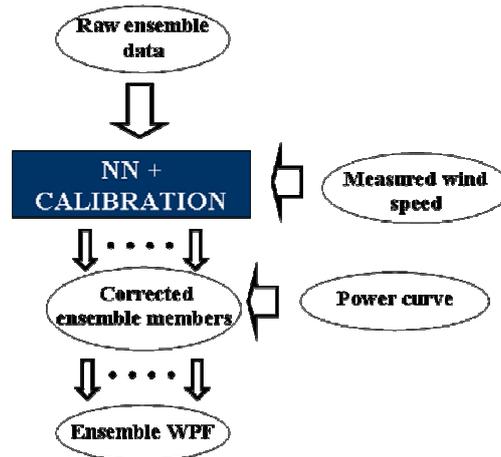

Figure 3 Ensemble MOS + calibration scheme.

Calibration is a necessary procedure to obtain a set of probabilistic forecasts whose statistical properties are similar to those possessed by the observations. Its purpose is a probabilistic extension of the ensemble spread, in order to obtain a probability distribution with a standard deviation equal to the measurements variability interval; this allows to consider the possible evolutions of the states of the atmosphere. After calibration the ensemble set acquires certain properties (e.g. accuracy, consistency), assessable with different indices or diagrams.

Ensemble Calibration and verification

Wind speed forecasted and measured data are initially transformed using a logit function in order to better approximate a Gaussian distribution.
For the training period and for each lead time, the ratio between RMSE, calculated between ensemble median and measured wind speed, and the mean of the standard deviation calculated on the ensemble members, constitutes a variance deficit coefficient. This allows determining the value at which the ensemble spread should increase in order to assume a variance value similar to that of measured data. For each lead time, each coefficient is applied on the test period to correct the ensemble median and the variance of the transformed members, which are then transformed back with inverse-logit function.
Figure 4 shows the rank histogram calculated for the ensemble members, after MOS and after calibration respectively, for the first forecast horizon (+24 h).
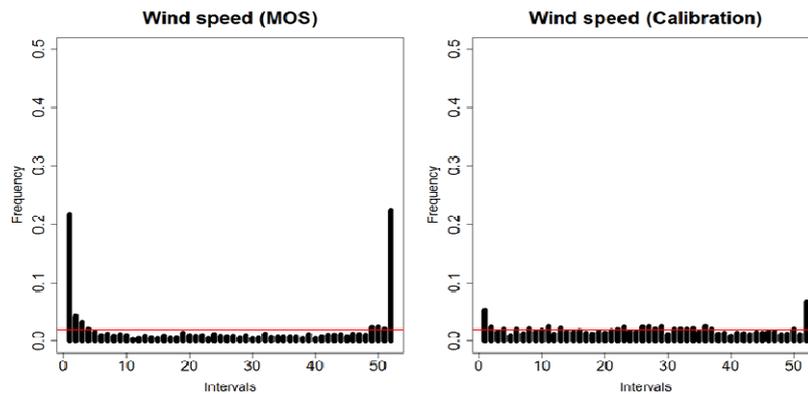
Figure 4 Rank histogram, +24 h forecast.

Looking at the diagrams, there is an improvement from an over-confident situation (even after MOS) to a more consistent ensemble spread, in which the observations are quite uniformly distributed among the ensemble members. The two extreme intervals, however, are still a bit more populated than the rest of them.

Figure 5 shows the trend of the ensemble spread, expressed as mean value for each lead time.
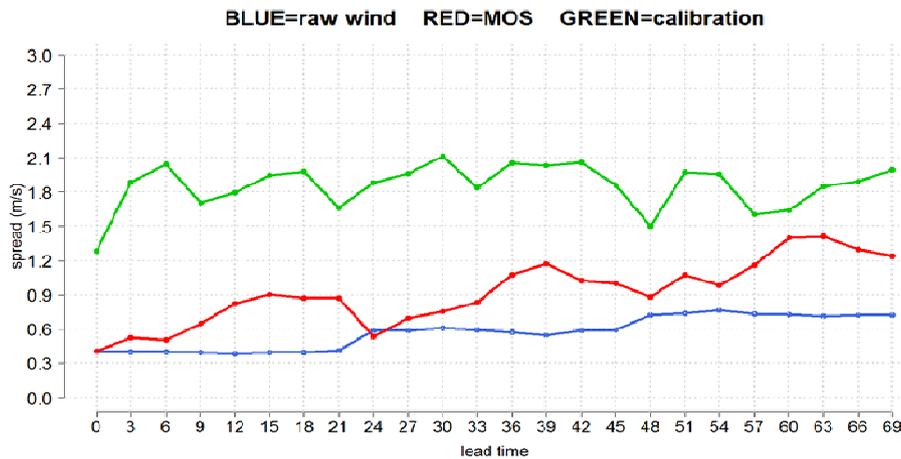

Figure 5 Ensemble spread, trend 0-72 h.

Looking at the previous graph there is a significant spread increase after calibration; after MOS, the spread increases slightly and is still partly overlying that of raw data. It is notable that, after calibration, the spread doesn't follow an increasing trend anymore, but generally oscillates in a range between ~1.5 m/s and ~2 m/s instead. As already said, the variance deficit coefficient is calculated and applied for each time interval from 0 to 72 hours ahead; consequently, there are intervals with a greater variance deficit and others with a lower one.

The calibrated members are converted to wind power using theoretical power curve provided by the turbine manufacturer (Vestas V52 - 850 kW), obtaining 50+1 WPF series.

WPF accuracy estimation

Referring to previous studies (Alessandrini et al., 2011, Von Bremen, 2007), we tested the possibility of using the ensemble spread as a forecast accuracy indicator. In the approach, we studied the relationship between the RMSE/NP of a deterministic forecast, performed using the scheme showed in Figure 1, and the spread measured as standard deviation of the ensemble members obtained after wind power conversion. Both the power spread and the deterministic error are calculated on a daily basis as average value for each time rate. The study involves the

use of a contingency diagram for each forecast horizon, in which to compare the spread and the RMSE, both normalized on NP.

According to the statistical median of the two indices, the diagram is divided into four quadrants in which to observe the dispersive behaviour of data. Figure 6 shows the diagrams for the three-days forecast horizon.
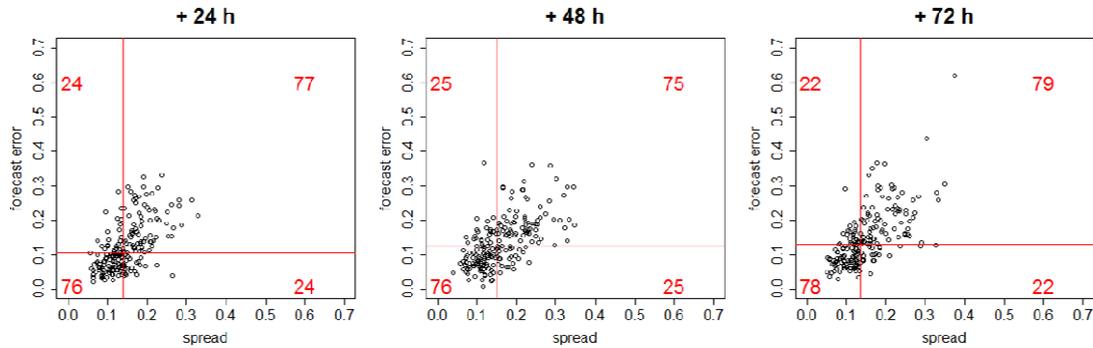

Figure 6 Contingency diagrams, daily RMSE vs daily ensemble power spread; EPS data.

The diagonal entries are more populated than the off-diagonal cases, meaning a good level of correlation. Each quadrant reports the number of points in it. The lower left quadrant indicates that a low ensemble spread corresponds to a lower forecast error, while the top right corner indicates that an increase in the spread is reflected in an increase in the forecast uncertainty.

Other ensemble systems and conclusions

A preliminary comparison with EPS was conducted using data of the COSMO-LEPS ensemble model, which consists in 16 members and has a horizontal resolution of about 10 km, using the same calibration procedure previously described.

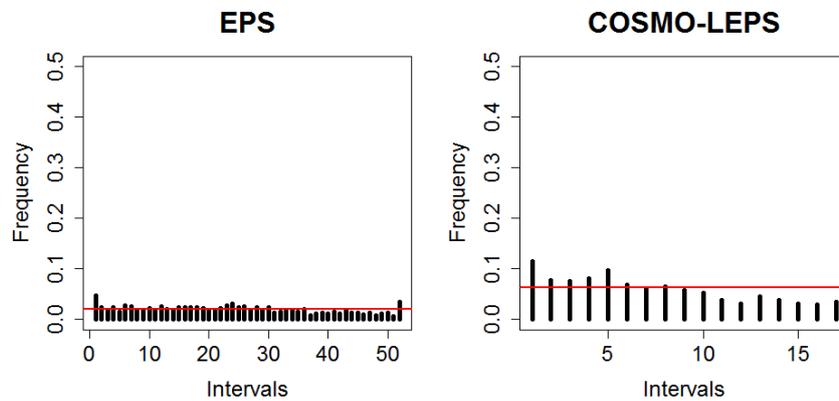Figure 7 shows the rank histogram calculated on wind power for each ensemble system.

Figure 7 Rank histogram, +24 h forecast, EPS (left), COSMO-LEPS (right).

The rank histogram for EPS shows a quite uniform distribution similar to that obtainable on wind speed after calibration. The COSMO-LEPS diagram shows a slightly biased situation, the first half of the intervals are in fact a bit more populated than the second half of them.

The WPF accuracy estimation has been conducted for COSMO-LEPS data too, using the same contingency diagrams approach used for EPS.

Figure 8 shows the contingency diagrams calculated on the COSMO-LEPS application, for the three days period.

Table 2 reports the diagonal ratio (i.e. the ratio between number of points falling in a quadrant on the diagonal and sum of the points falling in two adjacent quadrants) and the Pearson correlation index between daily RMSE and daily power spread.
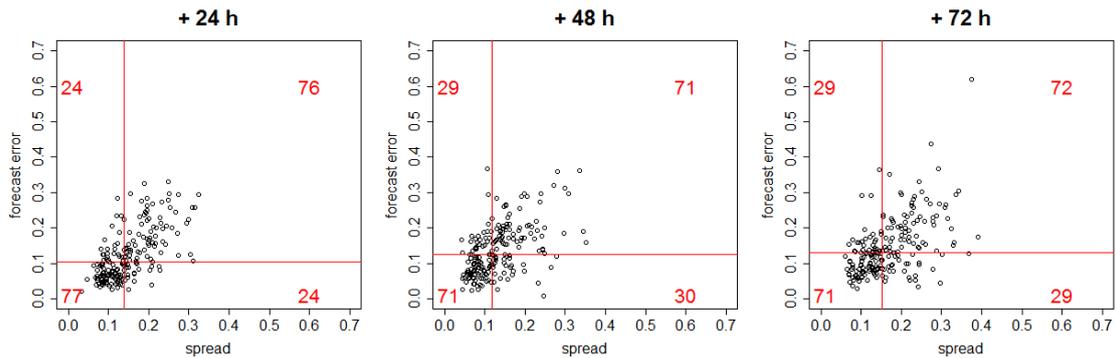
Figure 8 Contingency diagrams, daily RMSE vs daily EPS power spread; COSMO-LEPS data.

Table 2 Spread/error correlation.

		Diagonal ratio	Correlation
EPS	*+ 24 h*	0.76	0.59
	+ 48 h	0.75	0.61
	+ 72 h	0.78	0.66
COSMO-LEPS	*+ 24 h*	0.76	0.65
	+ 48 h	0.70	0.53
	+ 72 h	0.71	0.53

In both cases the diagonal ratio is greater than 70%. The correlation coefficient actually indicates the relationship between ensemble spread and deterministic error. EPS also shows slightly increasing indices at the increase of the forecast horizon.

Table 3 shows the Continuous Ranked Probability Score (CRPS) calculated on raw, MOS, calibrated wind data and power data for both the ensemble systems.

Table 3 CRPS on raw, MOS, calibrated wind and power.

		+ 24 h	+ 48 h	+ 72 h
EPS	*raw speed (m/s)*	3.66	3.53	3.49
	MOS speed (m/s)	1.22	1.30	1.24
	calib. speed (m/s)	1.11	1.19	1.20
	power (kWh)	67.13	68.76	72.34
COSMO-LEPS	*raw speed (m/s)*	2.70	2.50	2.50
	MOS speed (m/s)	1.21	1.21	1.31
	calib. speed (m/s)	1.13	1.17	1.28
	power (kWh)	73.71	72.35	80.70

COSMO-LEPS shows better CRPS on raw data than EPS, however the calibration process seems to be more effective on EPS allowing to obtain better results on corrected wind members and wind power.

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