FORECASTING METHODS FOR WIND POWER MANAGEMENT IN LIBERALIZED ELECTRICITY MARKET

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ABSTRACT

Intermittent renewable energy sources are promising to be the future of electricity generation.
In particular wind generation, owing to its stochastic behaviour, has to be carefully managed by the plant's owner, especially if the energy is settled with economic penalties, and by the transmission system operator (TSO) during its despatching service. In order to fulfil this issue both wind and market prices forecasting is needed.
In this paper different methods that involve the connection of statistical and probabilistic approaches are presented. They are applied to a set of historical data for a Sicilian wind farm.
The results confirm that better forecasting performances are reached if a statistical approach is combined with a probabilistic one.

INTRODUCTION

Among renewable power sources wind represents the most attractive one considering the growth rate of world installed capacity during the last ten years (4.8 GW 1995 – 59 GW 2005) [1].
The management of this energy source involves respectively the owner and the TSO. Each of them needs wind forecasting. In some electrical markets where the energy is settled with economic penalties the first one in order to fulfil his trading activities and to minimize imbalances is pushed to manage his plant to respect the energy scheduling. In Italy the market rules suggest the wind power producers to fairly schedule their plants, but don't penalize imbalances [2]. So it could envisage, in the near future, a change in these rules in order to make them uniform with those of other countries where the imbalances are penalizing. Moreover, for the plant's owner, another possibility, that could require a method to improve wind and prices forecasting is to consider the optimal management of a storage unit coupled with the wind farm.
For the activity of the TSO is always necessary to get information about the behaviour of the wind farms in the electrical system with a good level of accuracy using the available production data.
Therefore this paper is focused on the study of different forecasting methods for wind power data and, taking into account the needs of the owner, for energy prices in the electrical market. These data form the input of different useful algorithms for managing a single wind energy conversion systems (Owner) or a group of wind farms (TSO).
The presented methods consider two basic approaches: statistical and probabilistic. To assess their effectiveness a case study has been examined using the historical data of a Sicilian wind farm. First of all, wind and prices data are processed with simple exponential smoothing method (SES). Then, only for wind power production, Markov chains have been employed. Finally a combination between SES and a Markov chain has been proposed in order to improve further the previous performances using the individual methods.
The results confirm that better forecasting performances are reached if a statistical approach is combined with a probabilistic one. This can result useful especially in those case where advanced weather prediction models are not available. The historical data of wind power and of market prices has been gathered for plants placed in Sicily and operating in the Italian Power Exchange (IPEX).

STATISTICAL ANALYSIS

In order to study better the possibility to forecast wind and market prices it is important to analyse the different behaviour of their historical data.
The statistical behaviour of wind and prices data is quite different. This fact is due to the basic cyclic nature of electrical energy price in comparison with wind power data that are determined from a not-linear and low-recurrent phenomena [3]. This difference are shown in Figure 1 e 2 using the Fourier analysis.

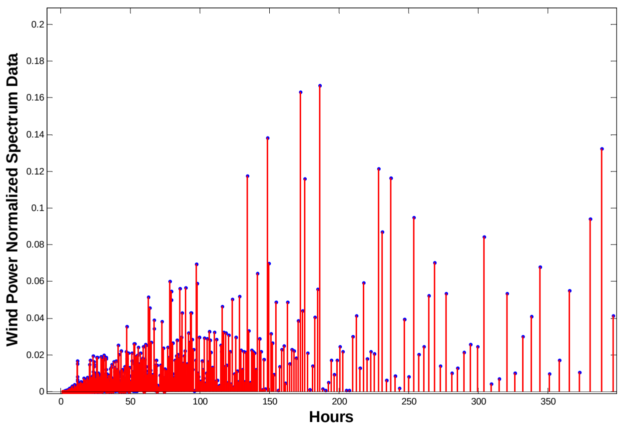

Figure 1. Spectral Analysis of Wind Power Normalized Data (Sicilian Wind Farm)

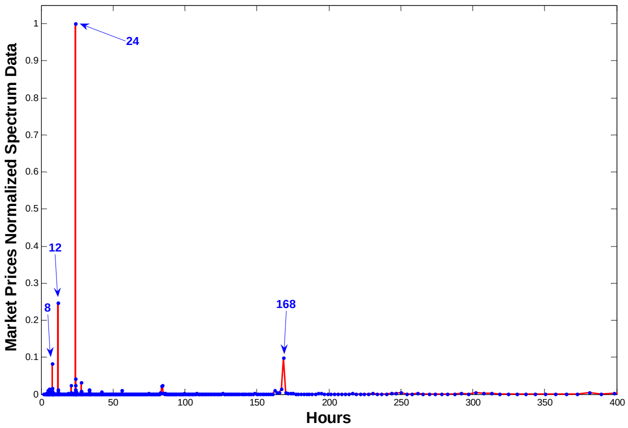

Figure 2. Spectral Analysis of Normalized IPEX Market Price (Sicilian Zone)

It can easily be seen in the first figure an uniform distribution of the wind power spectral density in contrast with the same distribution for prices, where the main periodical components (8h – 12h – 24h – 168h) that influence the phenomenon can be easily identified.
This fact, especially for the wind, pushes towards methods that could compensate for this lack of predictability.
It has been shown in [4] that an approach using the SES method improves the correlation from hour to hour of wind forecasts with respect to a method that simply generates a swing around the actual measurement with a normal distribution [5]. Moreover in another publication using Markov Probabilities for a wind farm power production can reduce the energy imbalances especially where advanced weather prediction models are not available[6]. Therefore it is possible to obtain an overall improvement from using the previous method together.

FORECASTING METHODS

As previously indicated the proposed forecasting methods are: SES, Markov and a possible their combination. After each application they are checked using the cross-correlation and root mean square error (RMSE)

Performance Indexes

In order to assess the effectiveness of the proposed methods their performances are measured using two different indexes.

Cross-Correlation

The cross-correlation is used to measure a statistical connection between two data series. The level of correlation is measured by the Bravais-Pearson correlation coefficient (r)
and it is computed between two time series: the forecasted power output $P_{wf}(t)$ and the actual measured power output $P_{wr}(t)$, considering their average values P_{mwf} and P_{mwr}:

$$r = \frac{\sum_{t=1}^{T}\left[\left(P_{wr}(t)-P_{mwr}\right)\cdot\left(P_{wf}(t)-P_{mwf}\right)\right]}{\sqrt{\sum_{t=!}^{T}\left(P_{wr}(i)-P_{mwr}\right)^2}\sqrt{\sum_{t=1}^{T}\left(P_{wf}(t)-P_{mwf}\right)^2}}$$

The same formula can be employed with the market prices, simply substituting the actual and forecasted powers with the corresponding prices.

RMSE

The root mean square error between the forecasted power output [7] and the actual measured power output, relative to the wind turbine's rated power P_n is expressed by the following equation:

$$RMSE = \frac{1}{P_n}\sqrt{\frac{1}{T}\sum_{t=1}^{T}\left[P_{wr}(t)-P_{wf}(t)\right]^2}$$

Likewise the cross-correlation, the previous formula can be employed with the market prices, substituting also the average price to the rated power.

SES

This method is based on the following recursive relation between the previous forecast of the period just ended $P_{wf}(t)$ with the corresponding actual measure $P_{wr}(t)$ and the forecast of the next period $P_{wf}(t+1)$.

$$P_{wf}(t+1)=\alpha P_{wr}(t)+[1-\alpha]P_{wf}(t)$$

where α ($0<\alpha<1$) is the smoothing constant**.** The choice of α depends on the process detected. Especially with the wind phenomena it is important to have a forecasting able to react quickly to sudden changes of the power output, so it has been chosen 0.3. The same value is assumed for the market prices forecasting.
The first iteration is led using, as initial forecast, the average of some preceding periods of the starting one [8].

Markov Chains

The discrete Markov process is useful for describing stochastic processes that can reside in two or more states [6].
Using this approach it is possible to divide the wind power output in discrete bands or states ($P_1, P_2, \ldots, P_N$) and, on the basis of the historical data, to determine the so-called transition matrix that contains the conditional probabilities (π_{ij}) between the different possible states (N) from a period to the next one.

This relation for each transition can be expressed by:

$$\pi_{ij}=\Pi\{P_w(t+1)=j|P_w(t)=i\}$$
$$i,j=P_1,P_2,\ldots,P_N$$

For each day the conditional probability referred to the first iteration of Markov chains has been initialised considering the last available measure immediately before the gate closure.
This method, however, requires a lot of historical data and the matrix can be different due to the effect of seasons. In any case it could be applied to any form of forecasting as a way of describing the forecasting uncertainty.

SES/Markov Method

The previous methods can be applied together to the wind forecasting in order to improve statistical performance indexes.
Starting from the historical data of wind energy the SES method has been employed to forecast a certain number of hours after the market gate closure and the remaining hours without forecast have been filled using the Markov approach.
For each day the conditional probability referred to the first iteration of Markov chains has been initialised considering the last available SES forecast.

APPLICATIONS AND RESULTS

The explained methods have been applied to some Sicilian wind farms and the results have been compared using the cross-correlation and the RMSE.
The time resolution *(t)* that has been taken into account is one hour both for the wind power and for the market prices, while the chosen time window *(T)* is one year.
All the simulations have been performed with the aid of Matlab® software.

SES Application

The SES method has been employed considering the Italian electrical market with a gate closure fixed at 9 a.m. of the previuos day.

Wind Power

The SES method used for wind power has been applied to a wind farm located in Sicily.
A comparison between real and forecasted data is reported in figure 3.

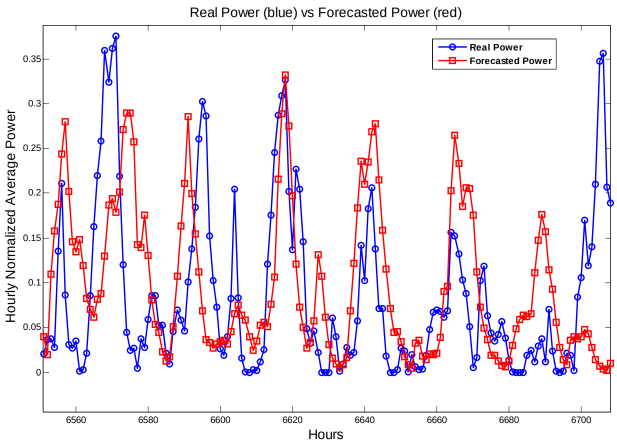

Figure 3. Real vs Forecasted normalized wind power data (one week)

The performance indexes are equal to 0.27 and 0.3 respectively for the cross-correlation and for RMSE.

Market Price

The SES method used for market prices has been applied to the Sicilian Zone in the IPEX.
A comparison between real and forecasted data is reported in figure 4.

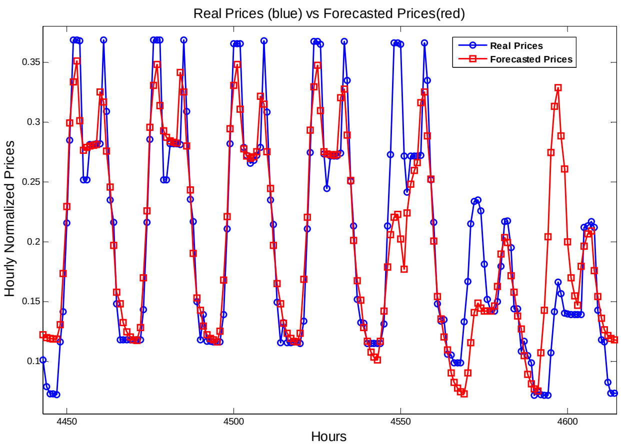

Figure 4. Real vs Forecasted normalized market prices data (one week)

The performance indexes are equal to 0.82 and 0.1 respectively for the cross-correlation and for RMSE.
It is important to notice the good performance of the SES method for the market prices that is due to its statistical behaviour examined before.

Markov Application

For the reason explained in the previous paragraph, the Markov method has been applied only for wind power considering the same wind farm located in Sicily and operating in the IPEX with a gate closure fixed at 9 a.m. of the previous day.
A comparison between real and forecasted data is reported

in figure 5.

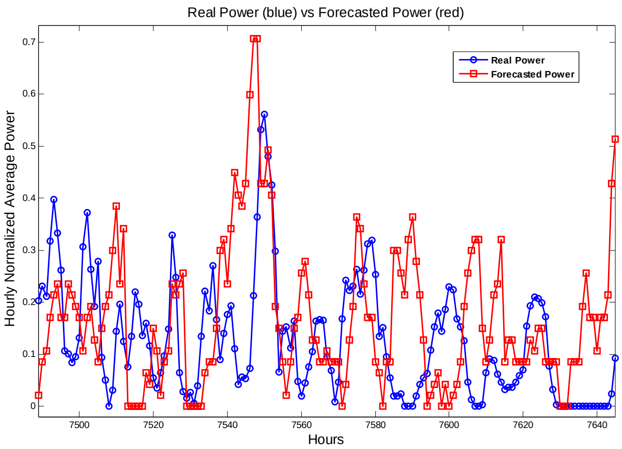

Figure 5. Real vs Forecasted normalized wind power data (one week)

The performance indexes are equal to 0.08 and 0.32 respectively for the cross-correlation and for RMSE. These results are less interesting than those obtained with the SES method.

SES/Markov Application

In order to improve Markov performances the SES/Markov method has been applied considering the same input data. A comparison between real and forecasted data is reported in figure 6.

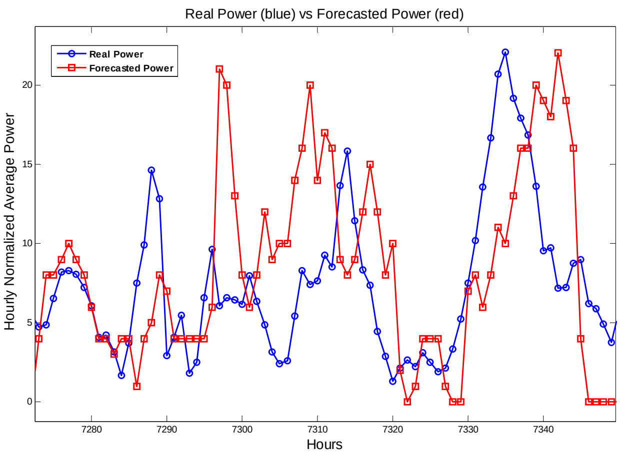

Figure 6. Real vs Forecasted normalized wind power data (one week)

The performance indexes are equal to 0.2 and 0.29 respectively for the cross-correlation and for RMSE. These results show an improvement in the cross-correlation using the proposed method instead of Markov. However the best level has been reached with the SES method. While in the RMSE the SES/Markov method has been obtained the best performance with respect to the others

CONCLUSION

In this paper different forecasting methods have been described. In particular a combination of the SES and Markov chains has been proposed in order to improve the energy management both for the wind farm's owner and for the TSO.

After having applied the previous methods to a case study of a wind farm located in Sicily the results have been reported calculating cross-correlation and RMSE indexes.

For the market prices, owing to their statistical characteristics, the SES method has shown good performances and it is sufficient to the aim.

For the wind power the results suggest that the proposed method is better than the simple Markov considering the cross correlation while it is the best in the RMSE.

Therefore, where the weather forecasts are not available, combining statistical and probabilistic approaches in the suggested way is good choice both for the wind farm's owner and for the TSO.

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