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A review of combined approaches for prediction of short-term wind speed and power

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ABSTRACT

With the continuous increase of wind power penetration in power systems, the problems caused by the volatile nature of wind speed and its occurrence in the system operations such as scheduling and dispatching have drawn attention of system operators, utilities and researchers towards the state-of-the-art wind speed and power forecasting methods. These methods have the required capability of reducing the influence of the intermittent wind power on system operations as well as of harvesting the wind energy effectively. In this context, combining different methodologies in order to circumvent the challenging model selection and take advantage of the unique strength of plausible models have recently emerged as a promising research area. Therefore, a comprehensive research about the combined models is called on for how these models are constructed and affect the forecasting performance. Aiming to fill the mentioned research gap, this paper outlines the combined forecasting approaches and presents an up-to date annotated bibliography of the wind forecasting literature. Furthermore, the paper also points out the possible further research directions of combined techniques so as to help the researchers in the field develop more effective wind speed and power forecasting methods.

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1. Introduction

Wind energy is of vital importance among the low-carbon energy technologies, which has the potential to achieve sustainable energy supply and constitutes a keystone component for micro-grids in a way towards the smart grid infrastructure. However, stochastic and intermittent wind power generation poses a number of challenges to the large scale penetration of wind power. These wind-related uncertainties can put the system reliability and power quality at risk with the increasing penetration of wind power and thus, the main grid integration issues such as balance management and reserve capacities can come into question [1–3]. Reducing the need for

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balancing energy and making the power generation scheduling and dispatch decisions can be realized with the help of wind speed and power generation forecasts [4,5]. Furthermore, the forecasts can play a pivotal role in keeping the costs competitive by reducing the need for wind curtailments and thereby, increasing revenue in electricity market operations [5]. However, the random and unstable characteristics of the wind make it considerably difficult to forecast the wind speed and power accurately. Hence, extensive efforts have been devoted for the developments and improvements of wind speed and/or power forecasting approaches by numerous energy- and environment-related research centers and universities.

In the literature, many forecasting approaches have been studied and proposed, each utilizing a different technique and performing well with a different prediction horizon. Recent studies in the area of wind prediction are predominantly focused on the short term wind predictions ranging from minutes to a few days due to the importance of these data on power systems. Especially day-ahead predictions are of significant interest for system operations such as scheduling, unit commitment and load following [6,7]. However, it is generally difficult to accomplish such a long-term prediction and moreover, the approaches designed for long prediction horizons may be deficient for shorter terms in terms of prediction performance. Following many studies in the wind forecasting field, it can be indicated that, to date, the targeted performance levels have not been attained with the individual models due to the fact that these models cannot give satisfactory results for all situations. For instance, the physical models produce coarse predictions for short-term horizons while mostly outperform the other models in medium- and long-term horizons. Also, Artificial Intelligent (AI) based models that rely on a large number of historical data for constructing an input/output mapping function can be less effective than some basic conventional statistical methods for certain application areas in the case of inadequate available information. Therefore, the approaches that incorporate the individually superior features of various forecasting models have emerged, called as hybrid models and combined models, in order to obtain an advanced forecasting method for higher accuracy levels and wider forecast horizons.

After evaluating the findings of the studies on the hybrid models, which will be detailed in Section 2, it can be concluded that these models do not generally contribute to the forecasting performance of the individual models considerably and they can even lead to poor performances under some circumstances [8]. On the other hand, combined forecasting methodologies, which follow a different approach and produce the final forecast generally from the weighting of the single approaches, can be a more viable solution for improving the accuracy of the individual models. To that end, the research effort has been recently oriented towards designing new combined algorithms as well as combination methods, which exploit different single prediction models and enhance the prediction performance while providing a reasonable computation time. However, a study on the classifying and summarizing of the combined methods, which might give an insight about the performance, superiority and application area of various algorithms, has not been presented so far. In view of the above requirement, a comprehensive research has been realized making reference to a large number of studies in combination of wind speed and/or power forecasting field in this paper.

This paper is organized in five sections: Section 2 classifies the forecasting methods and presents the fundamental information about the widely preferred methods with relevant example applications from the literature. Section 3 introduces combined models and classifies all the combined-based forecasting studies present in the literature according to the combination procedure adopted. Section 4 is devoted to a general discussion about the most notable findings and the assessment of the future prospects. Finally, conclusive remarks are provided in the last section.

2. Classification and overview of wind forecasting methods

As indicated above, the underlying idea behind combining models can be described as the utilization of the features of different forecasting methods. In this context, it is reasonable to first briefly mention the most widely used forecasting methods in the literature and their characteristics. To this end, the forecasting methods are classified according to the common terminology criteria for wind forecasting methods and inspected by several studies from the literature.

The majority of the wind forecasting techniques can be clustered into two main groups, namely physical methods and statistical methods. In short, the first group takes into account the physical considerations such as local terrain, wind farm layout and temperature to reach the estimate and utilizes the output from Numerical Weather Prediction (NWP) models which provide weather forecasts by using the mathematical model of the atmosphere. The concept of utilizing the NWP models as an input was taken into account by Landberg and then corrections on the wind speed predictions were applied by making use of various programs such as Wind Atlas Analysis and Application Program (WAsP) and PARK [9]. Furthermore, the NWP model output can be used directly for wind speed predictions, as demonstrated in [10]. Likewise, another NWP model, called as Eta Model, was utilized for wind prediction up to 36 h by Lazic et al. and it was shown that Eta model is quite effective in predicting wind energy [11].

The latter aims at describing the relation between historical time series of wind speed (or power) at the location of interest by generally recursive techniques and it can be stated that short term forecasting models are generally based on statistical approaches due to the fact that NWP models require long operation time and large amount of computational resources. Time-varying Autoregressive (AR) model, a well-known and versatile algorithm, developed by Huang and Chalabi [12] for wind speed forecasts can be given as a typical example in the statistical methods. In addition, an Autoregressive Moving Average (ARMA) model, which has a wide range of applications in the literature and defined as a linear function of last known values and last prediction errors, with pre-processing of data, was proposed for longer prediction horizons by Torres et al. [13]. Moreover, Ergin and Shi employed four competing approaches based on the ARMA method for forecasting of wind speed as well as wind direction and strived to determine the best performing model while making comparisons among them according to the Mean Absolute Error (MAE) criterion [14]. Due to the straightforward implementation and relatively low prediction errors for short-term forecasting, Sfetsos built an Autoregressive Integrated Moving Average (ARIMA) model relying again on the classical Box–Jenkins methodology for hourly prediction of wind time series and compared the results obtained with another forecasting methodology [15]. In a similar manner, Kavasseri and Seetharaman investigated the use of a fractional-ARIMA (f-ARIMA) model in order to improve the forecasting accuracy up to 48 h and showed that the developed model outperforms the persistence model, which is the most frequently used benchmark method in the literature and based on the assumption that wind speeds are highly correlated in short terms, especially for longer prediction horizons [16]. Besides, several time series approaches also have been proven effective in wind forecasting. To name a few here, El-Fouly et al. developed a model predicting a certain time interval based on utilizing wind data from the current year and one and/or two previous years for the same interval [6]. Also, Liu et al. investigated the use of another statistical technique, namely Modified Taylor Kriging (MTK) method, for forecasting with the aim of improving prediction performance and obtained a decrement of error in comparison to the ARIMA models [17].

Apart from the mentioned forecasting techniques, Fuzzy Logic (FL) and machine learning algorithms such as Artificial Neural