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Analysis and application of forecasting models in wind power integration: A review of multi-step-ahead wind speed forecasting models

Jianzhou Wang [a], Yiliao Song [a,b,*], Feng Liu [a,b], Ru Hou [b]

[a] School of Statistics, Dongbei University of Finance and Economics, Dalian 116025, China
[b] School of Mathematics and Statistics, Lanzhou University, Lanzhou 730000, China

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ABSTRACT

Wind energy, which is clean, inexhaustible and free, has been used to mitigate the crisis of conventional resource depletion. However, wind power is difficult to implement on a large scale because the volatility of wind hinders the prediction of steady and accurate wind power or speed values, especially for multi-step-ahead and long horizon cases. Multi-step-ahead prediction of wind speed is challenging and can be realized by the Weather Research and Forecasting Model (WRF). However, a large error in wind speed will occur due to inaccurate predictions at the beginning of the synoptic process in WRF. Multi-step wind speed predictions using statistical and machine learning methods have rarely been studied because greater numbers of forecasting steps correspond to lower accuracy.

In this study, a detailed review of wind speed forecasting is presented, including the application of wind energy, time horizons for wind speed prediction and wind speed forecasting methods. This paper presents eight strategies for realizing multi-step wind speed forecasting with machine-learning methods and compares 48 different hybrid models based on these eight strategies.

The results show good consistency among the different wind farms, with COMB-DIRMO models generally having a higher prediction accuracy than the other strategies. Thus, this paper introduced three methods of combining these COMB-DIRMO models, an analysis of their performance improvements over the original models and a comparison among them. Valid experimental simulations demonstrate that ALL-DDVC, one combination of the COMB-DIRMO models, is a practical, effective and robust model for multi-step-ahead wind speed forecasting.

Contents

Abbreviations: MSE, mean square error; AE, absolute error; CS, cuckoo search; BP, back propagation; COMB, combination model; WCOMB, weighted combination model; ARMSE, adjusted root mean square error; DIRMO, combination of dirrect and MIMO strategies; PRESS, predicted residual sum of squares; MAPE, mean absolute percentage error; MIMO, multi-input and multi-output strategy; DirRec, Combination of recursive and direct strategy; ALL-DDC, Adjusted Lazy Learning with denoising and the DIRMO strategy improved by cuckoo search; ALL-DDVC, Adjusted Lazy Learning with denoising and the DIRMO strategy improved by validation cuckoo search; REC, recursive strategy; DIR, direct strategy; Q1–4, Quarter 1–4; WINNER, WINNER-take-all model; VC, validation cuckoo search

* Corresponding author at: School of Statistics, Dongbei University of Finance and Economics, Dalian 116025, China.
E-mail address: songyl13@lzu.edu.cn (Y. Song).

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1. Introduction

Concerns regarding conventional resource depletion have forced entrepreneurs to explore alternatives that may serve as important solutions to the overwhelming global energy crisis and reduce environmental pollution. Among various renewable resources, such as tidal, solar, and geothermal energy, wind energy is clean, inexhaustible, inexpensive, and indispensable [1–3]. However, the use of wind power still faces several challenges, including its unsteady provision of electricity to the power system and its temporal and spatial variability [4–8]. The scheduling and formulation of power generation decisions and the unbalanced energy crisis could be mitigated by reliable wind speed prediction [9,10]. Furthermore, the accuracy of wind speed forecasting is a critical factor in maintaining competitive generation costs and in augmenting income in the operation of the electricity market because prediction provides a solid basis for profit [11,12]. However, although established geographical theories exist regarding wind and airflow, the random and unsteady characteristics of wind make it difficult to accurately forecast quantitatively. Hence, extensive efforts have focused on the development and improvement of wind speed and power forecasting approaches using numerous energy- and environment-related studies [12].

Wind speed forecasting can be divided by time horizon [13], including very short-term (a few seconds to 30 min ahead), short-term (30 min to 6 h ahead), medium-term (6 h to 1 day ahead) and long-term (more than 1 day) forecasts. The purpose of wind speed forecast differs from time scale that long-term forecasting mainly inform location selection, windmill planning and the determination of the optimal turbine size for a specified location [14] while when minutes, hours or days of data are involved, a precise prediction is required to frequently adjust wind speed estimations to minimize scheduling system errors, which affect market-related ancillary service costs and grid reliability [15,16]. Generally, the academic research of wind speed forecast approaches considers the robustness and generality other than accuracy. However, once the wind speed forecast is involved into industry, accuracy is one of the most important criteria because precise wind forecasts could assist the grid operator and power producer schedule the spinning reserve capacity, manage the grid operations in advance and hence increase the economic profits. In practice, majorities of the models are data-driven. Moghram and Rahman conclude that there is no one best approach, model performance under specific conditions should be analyzed and understood and incremental improvements made based on knowledge gained [17].

For short-term and long-term periods, multi-step prediction is important because wind speed forecasting is a critical and indispensable component in wind power estimations. Additionally, multi-step-ahead forecasting that uses wind energy information for the more distant future allows entrepreneurs to make flexible commercial plans. In some fields, multi-step-ahead forecasting is called long-term forecasting [18]. However, to distinguish it from wind speed forecasting for more than 1 day, multi-step forecasting will not be used for long-term forecasting in this study. Multi-step forecasting surpasses single-step forecasting in two aspects:

1. It requires less real-time data to process. For example, with a single-step day forecasting method, the prediction of the following Friday must be computed using the real value of Thursday for the following week. With a multi-step forecasting method, this prediction can be known on Friday if the step is set at seven;
2. Multi-step forecasting has more knowledge about the future. With multi-step-ahead forecasting, the estimation after a week or more can be determined through historical daily values, thus allowing projects to be developed in advance. In this paper, we focus on the multi-step-ahead forecasting of ten-minute intervals of wind speed for four wind farms.

Generally, there are five strategies for multi-step forecast including Recursive strategy (also called Iterated strategy), Direct strategy, DirRec strategy, MIMO strategy and DIRMO strategy. Chevillon conclude that the direct can improve the forecast accuracy of Iterated strategy by an investigation of the South