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Wind speed probability distribution estimation and wind energy assessment

Jianzhou Wang [a], Jianming Hu [b,*], Kailiang Ma [c]

[a] School of Statistics, Dongbei University of Finance and Economics, Dalian 116025, China
[b] School of Mathematics and Statistics, Lanzhou University, Lanzhou 730000, China
[c] Petrochina Planning and Engineering Institute, Beijing 100000, China

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ABSTRACT

The statistical characteristics of wind and the selection of suitable wind turbines are essential to effectively evaluate wind energy potential and design wind farms. Using four sites in central China as examples, this research reviews and compares the popular parametric and non-parametric models for wind speed probability distribution and the estimation methods for these models' parameters (the widely used methods and stochastic heuristic optimization algorithm). The simulations reveal that the non-parametric model outperforms all of the selected parametric models in terms of the fitting accuracy and the operational simplicity, and the stochastic heuristic optimization algorithm is superior to the widely used estimation methods. This study also reviews and discusses six power curves proposed by the literature and the power loss caused by the mutual wake effect between turbines in the wind energy potential assessment process. The evaluation results demonstrate that choice of power curves influences the selection of wind turbines and that consideration of the mutual wake effect may help to optimize wind farm design in wind energy assessment.

Contents

* Corresponding author. Tel.: +86 18993173569.
E-mail address: hujm13@lzu.edu.cn (J. Hu).

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1. Introduction

Due to the rapid development of society, economy and industry, China's demand for energy is growing dramatically. Fossil fuels play a critical role in the energy consumption of China. In 2009, the total annual primary energy consumption was equivalent to 2920.28 million tons of standard coal. Coal, petroleum and natural gas constituted 74%, 18.8% and 4.1%, respectively, of the energy consumption [1]. In 2010, the annual energy consumption increased to 3249.39 million tons of standard coal. Fossil fuels (coal, petroleum and natural gas) account for 91.4% of the total annual primary energy consumption [1]. Furthermore, owing to the combustion of these fossil fuels, large quantities of greenhouse gases are being released into the atmosphere, which increases the risks of global climate warming. To alleviate global warming and the pressure on the energy sector, the Chinese government proposed targets in the Twelfth Five-Year Plan as follows: non-fossil energy will account for 11.4% of the primary energy consumption and carbon dioxide emissions will decrease by 17% per unit of GDP [2]. The "medium- and long-term plans of the renewable energy of China" aims to increase renewable energy consumption to 15% by 2020 [3]. These targets encourage new energy project development and the exploration of renewable energy sources.

Wind energy, as one of the cleanest renewable energy resources, has attracted more and more concern and attention in China. Several wind energy projects have been developed for wind power utilization. Additionally, many wind farms are in the design and planning phase. Therefore, it is necessary to develop an effective and efficient method of assessing wind energy resources. An accurate evaluation of wind energy resource potential not only is an important component of wind energy development, but it also provides investors with confidence in financial feasibility and risk mitigation [4].

It is essential to study the statistical characteristics of wind speeds in a wind field because the characteristics of wind speeds are closely related to the assessment of wind energy potential, design of wind farms and power generators, and operation management of wind power conversion systems [5]. Morgan et al. [6] also stated that the probability density function (pdf) of wind speed was critically important in estimating energy production for wind turbine design and site planning. In engineering practice, the pdf of wind speeds is associated with the average wind turbine power $\overline{P_w}$ according to the rule below [7]

$$\overline{P_w} = \int_0^\infty P_w(x) f(x) dx$$

where $f(x)$ is the pdf of wind speed x and $P_w(x)$ is the turbine power curve used to describe the power output from wind speed.

In most studies, Weibull distribution was used to deduce the assessment of wind power density and wind turbine power (for example, see [8–10]). However, this distribution could not represent some wind regimes well. In order to minimize the uncertainty in wind resource assessment, the wind power density and wind turbine power should be derived from the most suitable form of wind speed pdf. The utilization of accurate wind speed pdf will minimize the uncertainty in wind resource estimation and site assessment phase of planning.

The power curve is an important factor in the estimation of energy production for wind turbine design and site planning. Although the uncertainty of $P_w(x)$ is less than the estimation of wind speed pdf $f(x)$, the power curves have an important influence on the accuracy of wind energy assessment. Therefore, it is necessary to analyze the types of power curves. The analysis of different power curves can affect the choice of wind turbines and the result of wind energy planning.

This study takes four wind farms in central China as research objects to review and compare the popular parametric and non-parametric models for wind speed probability distribution and the estimation methods for these models' parameters (the commonly used methods and stochastic heuristic optimization algorithm), and then evaluates the wind energy potential of the selected wind farms. The main objective(s) of the study with respect to those offered by other studies in the same area of research can be summarized as follows:

(1) This paper utilizes examples to illustrate that non-parametric distribution model is an alternative to parametric distributions for wind speed characteristics. Different locations have their own wind speed characteristics, which lead to different wind speed distributions, thereby bringing about difficulty in the choice of parametric distribution. Therefore, for the parametric estimation of wind speed distributions, the selection and performance of the parametric function should be understood and analyzed in terms of the specific statistical characteristics of the wind. Non-parametric distribution models are data-driven and do not make assumptions before describing wind speed characteristics. The simulation for wind speed probability distribution shows that the non-parametric model performs better than the parametric models in terms of the fitting accuracy and the operational simplicity.
(2) Using examples, this paper reviews and compares several parameters estimation methods, with the result that the parameters estimation method influences the accuracy of the parametric distribution model for concrete regions. The stochastic heuristic optimization algorithm is a good alternative to these traditional statistical estimation methods.
(3) Using examples, this paper also compares and discusses the influence of the power curve on wind turbine selection. In evaluating wind energy potential, this study reviews and discusses six power curves proposed by the literature and the power loss caused by wind turbine wakes and the mutual effect between turbines, and proposes the modified indices (the availability factor, the average capacity factor and the modified average capacity factor) for the selection of wind turbines.