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Alternative Moment Method for wind energy potential and turbine energy output estimation

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ABSTRACT

An accurate analysis of wind characteristics is a critical factor for wind farm energy output estimation. Therefore, it is necessary to develop an effective and efficient method to asses wind energy resource. The main objective of the present paper is to introduce a novel method to estimate Weibull distribution parameters. This method is called Alternative Moment Method (AMM). AMM method is expressed in an analytical form and doesn't need iterative procedure. The efficiency and accuracy of the introduced method is compared with commonly used parameter estimation methods. Result of the graphical comparison showed that AMM method is better than Justus Moment Method (JMM) and Novel Energy Pattern Factor Method (NEPFM). While mean error of AMM was $3.53 \times 10^{-7}\%$, JMM and NEPFM was 0.63% and 0.0031% respectively. AMM method is validated by comparing wind turbine energy output estimation accuracy for 144 cases. AMM mean energy output estimation error for 750 kW and 1600 kW wind turbine was 0.039% and 0.043%, respectively. Moreover, data from 16 weather station distributed around Spain is used to evaluate the power density estimation capability of developed method. Result showed that mean absolute error of AMM and MLH was 3.47% and 10.59%, respectively.

1. Introduction

Energy security problem, increasing energy consumption, depletion of conventional energy sources and the environmental concerns are driving many countries worldwide to utilize renewable energy sources. Among renewable energy sources, wind energy has become a promising renewable energy source due to the mature technology and low energy generation cost. Wind energy is considered as a highly variable in terms of both temporal and geographical aspects for this reason wind characteristics evaluation is a basic task in wind farm project site selection. The variation of wind speed can be represented by statistical distributions to estimate the available wind energy potential. When the probability distribution of wind speed is determined, then its characteristics can be obtained.

Probability distribution models provide the quantitative information about the long term characteristics of wind speed at a measurement site. These models allow us to determine the available wind energy potential and wind turbine energy output. Various models have been used to describe wind speed distribution. Weibull distribution model has been considered as a more representative model to describe wind frequency variations compared to a sample of measured data due to the measurement uncertainty, errors and lack of wind data. Moreover, standards recommend to utilize Weibull distribution to estimate wind energy potential of site [1]. So, Weibull distribution has been used as a default option to estimate electrical energy output of wind turbine or wind farm for numerous commercial wind energy programs such as WAsP and Windrose [2,3]. For these reasons, Weibull distribution has gained a great acceptance to model wind speed distribution. It is significant to emphasize that Weibull distribution is not able to represent for all wind speed distribution encountered in the world such as sites with high percentages of null wind speeds, short time horizons and bimodal shape distributions [4–7].

Parameter estimation of Weibull distribution is a critical topic due to the accuracy of feasibility analysis and maximization of wind farm electrical energy output. Frequency discrepancies may appear between measured wind speed frequency and estimated Weibull distribution frequency. To overcome this problem, several numerical and graphical methods have been developed in the literature to estimate Weibull distribution parameters such as Equivalent Energy Method (EEM), Graphical Method (GM), Justus Moment

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Method (JMM), Maximum Likelihood Method (MLM), Modified Maximum Likelihood Method (MMLH), Moment Method (MM), a Novel Energy Pattern Factor Method (NEPFM)) and Power Density Method (PD) methods. These parameter estimation methods has their own advantages and disadvantages. These parameter estimation methods are compared several times considering various criteria [8–22]. To determine wind energy potential of Bahreyn, Jowder [11] was analysed measured wind data at 10 m, 30 m and 60 m height. Weibull distribution parameters were estimated with GM and JMM methods. Also, wind turbine site matching problem was investigated to select an optimum wind turbine. Rocha et al. [19] attempted to evaluate and compare seven parameter estimation methods for six cases. GM is the best method for three cases, PD method is the best method for two cases, EEM is the best method for one case. The performance of seven parameter estimation method was compared by Azad et al. [20] for six cases. MM method is best method for three case, PD is best method for two cases and MLM is best method for one case. Chang [21] made a comparison between six parameter estimation methods. The result of the paper indicates that six methods are applicable if wind speed fits well with Weibull distribution. Sedghi et al. [22] compared the performance of six methods for eleven sites according to root mean square test and wind energy errors. The result of the paper revealed that JMM and MMLH methods provide more accurate predictions of mean wind speed. Also, it was found that MM and MMLH are the best methods for estimating the electrical energy output of 660 kW wind turbine. Results of the paper summarized in Table 1.

The results of the papers showed that in some cases parameter estimation methods can provide dramatically different results for the distribution parameters. From the Table 1 and literature it is found that performance of distribution parameter estimation methods may depend on various factors such as sample size, measured data format, data recording interval, shape of data distribution, selected goodness of fit test, and statistical judgment criteria. So, it can be concluded that there is not a single, universally accepted, best method to estimate Weibull distribution parameters. In this context, fitting methods must be analysed separately due to the error related to their use.

It is widely accepted that parameter estimation methods have vital effects on the success of Weibull distribution. However, there is not a single, universally accepted, best method to estimate Weibull distribution parameters. Thus, literature shows us that this topic is still open to exploration. In this paper to achieve this goal, alternative Weibull distribution parameter estimation method is developed.

The main objective of the present paper is to introduce a robust, efficient and practical method to estimate parameters. This novel method is called as Alternative Moment Method (AMM). AMM method is expressed in an analytical form and does not need iterative procedure. To evaluate the introduced estimation method data from several weather stations distributed around Spain and generated data sets were used. The accuracy of the AMM method is verified using different data sets. Introduced method is compared with commonly used parameter estimation methods. The remaining of the paper is organized as follows, commonly used JMM, MLM and NEPFM methods of Weibull distribution was briefly described in Section 2. AMM method was introduced in Section 3. Then, in Section 4, in order to verify the suitability of AMM method, energy output error analysis was carried out for two wind turbine and 144 cases. Also, in Section 4, to prove the accuracy of AMM method, power density obtained by this method are compared with the results of previous papers for 16 stations. The conclusion is presented in Section 5.

Table 1
Rank of parameter estimation methods in Iran.

	1th	2nd	3rd	4th	5th	6th
GM		1		1	5	4
PD	3	1			2	5
MLM	3	2	1	3		2
MM	2	2	3	1	3	
MMLM	3	3	1	3	1	
JMM		2	6	3		

2. Methodology

Due to the wind turbine power output estimation uncertainties and accuracy of energy output estimation, selection of the appropriate parameter estimation method to model wind speed data is pivotal in wind energy applications. Weibull distribution is the most widely used distribution to analyse wind characteristics of the measurement site. Therefore, a reasonably accurate knowledge of the Weibull distribution parameter at any wind energy site is critical to select optimum wind turbine and minimize energy generation cost. In literature, different methods have been developed to determine parameter of Weibull distribution. In this section of the paper, a review of Weibull distribution and distribution parameter estimation methods are briefly given.

2.1. A review of existing methods to estimate Weibull distribution parameters

Weibull distribution can encompass characteristics of various distributions and it can be used in many different fields due to its greater flexibility and simplicity. Therefore, Weibull distribution has gained considerable attention. Probability density function and the cumulative distribution function of Weibull distribution are given by the following equations (1) and (2), respectively

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{\left(-\frac{v}{c}\right)^{k}}, \quad v; c; k > 0 \tag{1}$$

$$F(v) = 1 - e^{\left(-\frac{v}{c}\right)^{k}}, \quad v; c; k > 0 \tag{2}$$

Where $f(v)$ is the Weibull probability density function, $F(v)$ is cumulative Weibull distribution function, k is the dimensionless shape parameter and c (in same unit of v) is the scale parameter of Weibull distribution. For wind speed data, Weibull distribution shape parameter is generally greater than 1.

In this subsection of the paper a review of three parameter estimation methods are briefly given.

2.1.1. Maximum Likelihood Method (MLM)

According to the MLM method Weibull distribution parameters are estimated with equations (3) and (4).

$$k = \left(\frac{\sum_{i=1}^{n} v_i^k \ln v_i}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} \ln v_i}{n}\right)^{-1} \tag{3}$$

$$c = \left(\frac{\sum_{i=1}^{n} v_i^k}{n}\right)^{\frac{1}{k}} \tag{4}$$

Where v_i wind data and n is the number of nonzero data. One of the most important problem of MLM method is computational requirements.