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An investigation of wind power density distribution at location with low and high wind speeds using statistical model

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HIGHLIGHTS

- Wind power density using four statistical models is analyzed.
- Weibull scale c_m and shape k parameters depending on wind speed values are studied.
- Linear regression function between scale parameter c_m and wind speed value was found.
- Wind characteristics extrapolation with the height is applied.
- Wind potential at the locations with low and high wind speeds is modelled.

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ABSTRACT

The study represents wind characteristics and power density in the locations with different wind speed conditions. The wind speed data measured at meteorological stations were used for statistical analysis from two locations with high and low wind speeds in Lithuania. It was found that many of the probability density functions of calculation methods allows you to get a fairly reliable results. However, depending on the geographical situation of the area, the height and other factors affect the wind power density indicates that some of the methods are not acceptable. The Weibull shape k and scale c parameters were calculated by using four methods and after the wind characteristics and power density were estimated. Also, the wind parameters extrapolation with the height was carried out. The mean square error, coefficient of determination, chi-square test and relative error were calculated for validation of goodness fit of Weibull parameters. The empirical model was developed for evaluation of monthly mean wind power density based on the measured wind speeds. The proposed simulation model for assessing the wind energy density could be successfully used for the finding the suitable sites for the development of wind energy in the selected locations.

1. Introduction

It has become necessary to enhance the energy supply from renewables because demand for environmental friendly energy sources is ever increasing. In order to increase the use of renewable energy sources in the energy sector we must have reliable meteorological measurements which will determine the best possible locations for wind turbine placement.

The finest wind energy potential assessment can be given from long-time wind measurement data which are received at the sites where wind turbines are planned to be installed. However, such information cannot evaluate all problems of wind energy distribution drawbacks as different geographical, climatologically and meteorological conditions [1,2]. Furthermore, the wind energy density distribution at the locations during the year, season, month and other time periods must be known. For example, the wind speed volatility is very intensive on the diurnal time. At night times wind speeds are decreasing and with increasing temperature in the course of a day, wind speeds are increasing as well, driven by pressure differences and thermal convection [3]. The following information allows selecting optimal regime for the wind usage and it decreases the expenditure of the wind energy production. Furthermore, it is used in complex statistical measures for predicting the wind energy potential in the collected sites for wind turbines installation [4,5].

In the last few years, researchers in the wind engineering field proposed predictive numerical models to describe wind speed frequency distribution. Numerical model simulation can describe changes induced topography effects, ground cover variation, etc. [6–9]. Wind

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characteristics data from meteorological stations and other wind parameters measurements sites are given and allow to evaluate wind power density variations in different locations [10–13]. The estimation of wind energy potential in different regions by using various probability distribution functions were carried out by researchers in some countries. There are several probability distribution functions (Gumbel, Gamma, Weibull, Rayleigh, Lognormal and others) that can be used in wind power studies [13–17]. Most researches indicated that the Weibull distribution is accurate enough for wind energy estimation in the sites [18–20]. Weibull shape parameter k describes the width of data distribution, while scale parameter c controls the abscissa scale of a plot of data distribution. Coefficient of determination (R^2) and root mean square error (*RMSE*) are often used to test the goodness of fit of these distributions. In general, statistical models are used to establish a relationship between power and other variables. The wind speed data is statistically analysed to find out wind energy characteristics of the selected sites [21,22].

A review of wind energy assessment techniques in different countries disclosed demand of new more precise wind power forecasting methods [23–25]. It is necessary to have accurate analytical models for wind speed and power density estimation in different locations [26]. Moreover, the updated methods and new methodologies for the assessment of long term wind farms' energy production should be proposed [2,10,26].

Al-Abbadi et al. [5] analysed the wind energy resources for five locations with different climatologically and geographical conditions in Saudi Arabia. It was determined that the annual average wind speed distribution and frequency of occurrences were significant factors in assessing the wind power potential at the locations. Akdag and Dinler [22] studied the wind energy potential at some regions in Turkey. A power density method was developed to estimate Weibull distribution parameters for wind energy applications. In literature most frequently used methods are maximum likelihood, WAsP algorithm, moment, graphic and others. Suitability of these methods is judged based on different goodness of fit tests for investigations at different geographical locations. Celik [19] indicates that judgment of suitability of statistical distribution should be carried out based on power density estimation capability. A power density and mean wind speed estimation capabilities must be compared with wind speed measured data at the locations.

Allouhi et al. [13] evaluated the wind energy potential at six locations in Morocco. They used wind speed measurement data for the statistical analysis. Several methods to estimate the scale and shape parameters of Weibull distribution function were applied. Costa Rocha et al. [18] applied seven numerical methods for determination of Weibull parameters for wind energy generation in the northeast region of Brazil. They detected that the equivalent energy method is an efficient method for determining the Weibull parameters in the coastal area of Brazil. Also, they revealed that numerical methods, which used mathematical iterations in determining Weibull parameters k and c, presented smaller errors in adjusting the Weibull distribution curves. Almi et al. [8] analysed the wind speed characteristics and the wind power potential in Tunisia. Weibul parameters are estimated based on the most frequently used methods in which their accuracy was compared based on different goodness fit tests. It was determined that the Weibull probability function, with the parameters predicted from power density method, is able to estimate frequency distribution more accurately then other methods.

It is necessary to notice that the methodology is absent to assess the distribution of wind energy density in assessing the size of the wind speed in the area. Wind power factor is usually determined by the assessment of Weibull parameters which are calculated based on the measured wind values. Therefore, it is necessary to have the methodology for setting up Weibull parameters for different wind values. Such studies in the literature is not fully developed, although there are different methodologies for the determination of Weibull parameters.

The literature analysis also revealed that Weibull model independently used algorithms for Weibull parameters estimation and gave accurate description of the measured wind data frequencies. However, it must be mentioned Weibull distribution function is unable to represent all wind regimes encountered in nature [19]. One main limitation of the Weibull distribution function is that it does not correctly model a calm wind regime. Investigation of different researchers revealed that information on the wind speed distribution is a fundamental step in the evaluation of wind potential at different locations [15–17]. However, many studies have reported the lack of data is the main problem when it comes to statistical analysis of wind energy [19,23]. Based on the review, it was observed that it is very important to determine which statistical methods adequately describe the wind potential characteristics in location and also to evaluate its statistical parameters.

This study indicates different locations with their own wind speed characteristics which lead to distinctive wind speed distribution. The aim of this work was to find out best suitable methods during different wind conditions and propose a more accurate estimation of the Weibull parameters in order to reduce the uncertainties related to wind energy output prediction from any wind conversion energy systems (WCES).

The structure of the paper is as follows: Section 1 gives the background of information related to the statistical methods used for predicting the wind power density and measures for evaluating wind energy potential in the sites. Section 2 presents the data used for calculation wind characteristics and wind power density distribution. The methods used for predicting Weibull parameters and wind turbine energy output estimating is as well described. In Section 3 statistical analysis of wind power distribution at the locations with low and high wind speeds are analysed and evaluation of the installed wind turbines efficiency are presented. The simulation model is proposed for predicting wind power in the sites for wind turbines installation. Section 4 concludes the paper.

2. Methodology

2.1. Wind speed data

Wind speed is a very volatile process and variation of wind speed over time period is represented by various probability density functions. This requires the existence of time series wind speed data. For the assessment of wind energy resources at different locations, measurement data from meteorological stations were used and different methods for Weibull parameters calculations developed.

The meteorological stations network presented in Fig. 1 very well covers all terrain of Lithuania. Lithuania is situated on the eastern shore of the Baltic Sea and has a border with Latvia on the north, Belarus on the east and south, and Poland and the Kaliningrad region of Russia on the southwest.

Up to 1990, at the Lithuanian Hidrometeorological stations, wind characteristics were measured every three hours; Lithuanian meteorological Service has accumulated measurement data of several decades. In recent years, wind characteristics are measured more accurately using new equipment in these stations. Equipment of wind characteristics measurement in meteorological stations was installed in the sites which has second roughness class. The prevailing wind in the country is in the western and north-western directions. In this study the characteristics of wind measurements were made every one hour, and shall be entered in the database. Measurements are carried out in the period 2014–2015. Fit up to 8760 measurement data was used for calculation of wind characteristics. In this study the annual, seasonal, monthly and diurnal variations of wind characteristics were analysed.

2.2. Theoretical analysis

Wind turbines convert the kinetic energy associated with wind into