Renewable Energy 115 (2018) 1153–1165

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Comparative analysis of Weibull parameters for wind data measured from met-mast and remote sensing techniques

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A R T I C L E I N F O

Article history:
Received 29 July 2016
Received in revised form
11 July 2017
Accepted 7 August 2017
Available online 10 August 2017

Keywords:
Weibull parameters
Wind frequency distribution
Wind speed
Probability distribution function
Statistical analysis

A B S T R A C T

The remote sensing techniques are gaining attention worldwide for the comprehensive assessment of wind resource in flat, complex, and mountainous terrain. This paper presents an attempt to increase the confidence on remote sensing technique to compute Weibull parameters at higher heights for assessment of wind energy resource. The measurement campaign was conducted at Kayathar, Tamil Nadu, India. The 10 min average time series wind speed data for the period of one month (September 2014) were recorded simultaneously at 80 m and 100 m using cup anemometer installed in the proximity of 120 m meteorological mast, Second Wind Triton SODAR (Sound Detection and Ranging) and Continuous-wave wind LIDAR (Light Detection and Ranging). The data obtained from this measurement were analyzed and Weibull parameters were evaluated using nine different methods. The applicability of nine methods for calculation of Weibull parameters is analyzed based on statistical analysis i.e. Root Mean Square Error Test, Coefficient of Determination, Mean Absolute Percentage Error, and Chi-square Test for both measuring techniques. This study also shows the performance of remote sensing technology by comparing with result obtained from met mast. The outcome of this study is expected to encourage the deployment of remote sensing techniques at Indian sites.

1. Introduction

The new and renewable sources of energy, which includes wind, solar, geothermal, biofuels and hydro, are being encouraged in many regions of the world these days to mitigate the challenge of increasing energy demand. Among these sources, wind power has gained a huge attention globally, and in recent past years, it has developed at an unprecedented rate due to its inexhaustible and non-polluting characteristics [1].

The efficient use of wind energy requires exact, accurate and precise wind measurements. The wind resource assessment plays a significant role in successful development of wind power. The detail, accurate and proper wind resource assessment particularly determining wind characteristics i.e. wind speed and wind direction is necessary for proficient planning, implementation of any wind engineering farm project and to encourage the efficacy of wind energy market. Additionally, it will also help in reducing the cost of power generation and most optimum selection of wind energy conversion machines [1,2].

The wind energy sector is moving towards the installation of the wind turbine in hilly, forested and complex mountainous terrain as well as in offshore sites and the modern wind turbine are gaining heights and size generally employs blades with diameters of 60–110 m attached to their hub at heights of 70–100 m. The measurement of the wind at higher heights cannot be represented by met mast techniques which usually employs cup anemometer and wind vanes. Since met mast techniques have a constraint in height due to economic and technical consideration. As the turbine height increases correspondingly met mast instrumentation, erection and maintenance become expensive and cumbersome. The use of remote sensing technique such as SODAR and LIDAR can be used as an alternative technique to measure wind speed and direction due to their ability to correctly measure the wind speed at higher heights and complex terrain [3,4]. The observation from several previous studies shows an excellent agreement and high correlation between the measurement from remote sensing instruments (SODAR & LIDAR) and meteorological mast [3–9]. The measurement result of Smith [6] Pena [7] and S Lang [9] shows an excellent agreement between LIDAR-based measurement and cup anemometer.

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http://dx.doi.org/10.1016/j.renene.2017.08.014
0960-1481/

The Probability density function shows the variation of wind speed over a period of time. Since wind power is cubically dependent on wind speed therefore modelling of wind speed plays a significant role in calculation of wind power and minute error in modelling effects the calculation of wind energy outcome to a large extent. The commonly used distribution for modelling wind speed data is Weibull distribution. The Weibull distribution is a two parameter distribution function (discussed later). In literature, various methods are illustrated to estimates the parameters of Weibull distribution namely graphical method, moment method, least square method, empirical method of Justus and Lysen, power density method, maximum likelihood method, modified maximum likelihood method, and alternative maximum likelihood method [10–16].

This study is focussed on increasing the confidence on the result of Weibull parameters computed for time series wind data measured using remote sensing technique because the literature lacks the study showing the estimation of Weibull parameters for the time series wind data measured by remote sensing technique. However previous studies associated with Weibull parameters estimation in India were based on wind data measured from met mast technique using cup anemometers and wind vanes (Table 1). Therefore, in this study the ground based remote sensing technique i.e. SODAR and LIDAR were used to measure wind data at higher heights because no hypothesis or extrapolation of data in height is required as is generally the case in wind analysis. Firstly, this study shows the performance of nine different methods to determine Weibull distribution parameter i.e. shape parameter k and scale parameter c (m/s) for wind speed data measured from cup anemometer, SODAR and LIDAR at two different heights 80 m and 100 m to identify the most appropriate method for the estimation of Weibull parameters for the selected site. The following methods are selected from literature to compute Weibull distribution parameter i.e. shape factor k and scale factor c (m/s): graphical method, moment method, power density method, empirical method of Justus, empirical method of Lysen, maximum likelihood method, modified maximum likelihood method, least square method and alternative maximum likelihood method. Secondly, the performance of remote sensing technique is examined at higher heights by comparing the result with met mast technique for a selected site to estimate Weibull parameters. Since most analyses are restricted to only a few tenths of meters in height using met mast techniques.

The rest of this paper is organized as follows: the next section gives a detailed study of literature; Section 3 shows measurement site, instrumentation detail and data collection. Section 4 presents different methods to compute Weibull parameters; Section 5 discusses the result and discussion in detail; Section 6 summarizes the conclusions derived from this study.

2. Literature review

In recent past years, a lot of studies have been conducted to estimate wind energy potential in different regions by using different probability distribution functions, and the results have shown that the Weibull and Rayleigh distributions can illustrate wind speed probability distribution accurately and assertive [10–16].

Justus and Mikhail [10] suggested the method of moment similarly Deaves and Lines [11] proposed graphical method as an alternative with high-quality reliability to estimate Weibull parameters. J.V. Seguro & Lambert [12] analyzed three methods namely maximum likelihood method, modified maximum likelihood method and graphical method for the calculation of Weibull parameters. Akpinar and S. Akpinar [13] used Weibull density function to estimate the potential of wind energy in Maden-Elazig, Turkey, consisting of hourly wind speed data of five years (1998–2003). They also compared the obtained result with Rayleigh method and indicated that the Weibull model is assertive and most accurate.

Akdag and Dinler [14] proposed a new method called power density method as a suitable standard option to calculate the shape (k) and scale (c) parameters of the Weibull distribution and carried comparison with graphical, maximum likelihood and moment method followed by the statistical analysis: RMSE, power error and analysis of various. In 2011 Chang [15] performed a comparative study of six numerical methods namely energy pattern factor method, empirical method, moment method, maximum likelihood method, modified maximum likelihood method and graphical method to calculate the parameter of the Weibull curve using wind speed data later on Rocha et al. [16] compared a seven numerical method adding energy equivalent method in the study done by Chang.

Talha Arslan et al. [17] presented L-moment method for the evaluation of wind speed parameter and compared this method to the Moment method and Maximum likelihood method using Monte Carlo simulation for the estimation of the scale (c) and shape (k) parameters for a Weibull distribution. Shahnawaz Farhan Khahro et al. [18] analyzed and compared five different numerical methods to calculate Weibull shape and scale parameter for the available time series wind data at Babaurband Sindh in southern region of Pakistan.

B.R. Karthikeya et al. [19] used two measurements system, mobile Light Detection and Ranging (LiDAR) profiler and a roof top wind mast to investigate Weibull distribution, roughness length, wind roses across various sites in Singapore to understand the wind characteristics for the economic feasibility of roof top wind turbines. Tatiane C. Carneiro et al. [20] used Particle Swarm Optimization (PSO) method to determine the Weibull parameters for the wind resources of different sites in Brazilian Northeast Region (BRNER) at 80 m height. Additionally compared the PSO performance with moment method, energy equivalent method, empirical method, maximum likelihood method, energy pattern factor method. The result shows that PSO has a better performance with an error close to zero and higher correlation coefficient for the estimation of Weibull parameters. Fatma Gul Akgul et al. [21] employed an alternative method to model the wind speed called inverse Weibull method to obtain the best fitting distribution for the two different stations of Turkey, namely Sakarya and Bursa. Firstly, the author obtained the parameters of inverse Weibull using modified maximum likelihood method and secondly compared the efficacy with maximum likelihood method and least square method through Monte-Carlo simulation. The correctness of these distributions is compared with coefficient of determination (R^2) and root mean square error (RMSE) and also indicated that least square method is less assertive among other methods. Jong Kuk Lee et al. [22] investigated the Weibull parameters k and c using a double logarithmic transformation for the calculation of directional wind characteristics in Barakah nuclear power plant area approximately 250 km west of Abu Dhabi, UAE. A new energy pattern factor method developed by Seyit Ahmet Akdag [23] indicates a reasonable accuracy and simpler calculation method to determine Weibull parameters compared to Maximum Likelihood Method, Graphical Method, Power Density Method, Moment Method, Alternative Maximum Likelihood Method, Modified Maximum Likelihood Method, Justus Moment Method and WAsP Method. The various measurement campaigns carried out at Indian sites by different researchers (Basamatary et al., KS Murthy et al., K. Sukkiramathi et al., Bharat Kumar saxena et al., Arnab Sarkar et al.) [24–28] used meteorological mast to estimate Weibull parameters