Comparison Of Different Methods for Calculating Wind Energy Potential For Electricity Generation

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ABSTRACT

For the assessment of wind energy potential, we have adopted probability distribution function, namely Weibull & Rayleigh distribution. For the calculation of these two distributions we first calculated standard deviation, gamma function, mean wind speed, most probable wind speed, and maximum energy carrying wind speed. We selected districts of Uttarakhand for the calculation and comparison of Wind Potential using the statistics of 22-year period (January 1983 to December 2004) using the RETscreen climate data base. We found that although Weibull distribution is more accurate as compared to Rayleigh but Rayleigh is more convenient to calculate wind potential and the result of Rayleigh is as satisfactory as the 2 parameters Weibull distribution. Also, Rayleigh Distribution is derived from Weibull Distribution where one of the parameters is taken as constant.

Keywords

Mean wind speed, Rayleigh distribution, Weibull parameters, Wind energy, Wind power density.

Article Received: 10 August 2020, Revised: 25 October 2020, Accepted: 18 November 2020

Introduction

Although fossil fuel has been backbone of all the energy resources, but due to excess use of fossil fuel during past few decades, all the industries have been compelled to find another means of energy production and therefore the role of renewable energy comes into play. At present most of the countries are using fossil fuel to fulfil their energy need and it is causing the various environmental issues. Therefore, the demand to harness renewable energy is increasing day by day [1]. When we talk about renewable energy, wind energy contributes foremost part to it and most importantly it is environment-friendly and sustainable. If we want to minimize the use of fossil fuel wind energy can have a great contribution to achieving this goal. Preferably, only 1% of wind energy can be used to encounter human energy requirements [2]. Therefore, its development has been of primary concern in recent years. Even though we have discussed the importance of wind energy the big question remains which method is more appropriate for the calculation of wind energy potential, this is what we are trying to compare between the two methods Rayleigh Distribution and Weibull Distribution for wind energy potential calculation. To estimate the potential of wind farm, wind power density is found to be an important parameter and if used with the empirical method, it shows better agreement with the measured data of available wind energy per unit area per unit time [3-4]. To calculate the wind energy potential of a given location it is necessary to have wind data of that location. On the basis of these data, we will be able to evaluate the parameters such as frequency, probability density function, variances etc. [5]. Due to the lack of availability of wind data for most of the sites of interest, researchers are obliged to rely on wind speed forecast models [6]. Among the many mathematical models, Weibull Distribution and Rayleigh Distribution calculation value are close to the experimental value with almost the same coefficient of determination value of 0.97 [7]. As we know that wind speed varies with different factors, so we need to gauge these variations and wind speed probability distributions help us to do that [8]. Among various methods existing worldwide, the Weibull distribution function is proved to be a reliable model for wind speed modelling and the method is verified to be a precise approach by various researchers [9-10]. For the assessment of wind energy of any given area, the wind direction has a critical role to play. For the ideal position of the wind farm, directional statistics play a noteworthy reputation [11]. The monthly disparity in wind speed causes a substantial variation in the wind energy potential calculated using Weibull or Rayleigh's estimation. Results of simulation confirm that the parameters of Weibull have direct influence over the wind power available [12]. The probability distribution function of Weibull two-parameters not only satisfies on paper but also in real situation [13]. Research shows that in the Nepal region at a higher altitude, Weibull shows the more promising result as compared to results found by Rayleigh method. [14]. The Weibull and Rayleigh distribution are frequently exercised for the reason that they are easy to design and flexible to apply and compute [15].

Methodology

We selected following districts of Uttarakhand like: Haridwar, Dehra Dun, Chamoli and Gopeshwar, and Pithoragarh, for the calculation of Wind Potential using the statistics of 22-year period (1983 to 2004) from the RETscreen climate database at the height of 10m. Table 1 shows the various geographical and physical properties of selected sites across various Indian states.

Table 1: Details of selected cities

City	Latitude (ºN)	Longitude (ºE)	Elevation (m)	Air Density (Kg/m^3)
Haridwar (Uttarakhand)	30.00	78.20	428.00	1.07
Dehra Dun (Uttarakhand)	30.30	78.10	1954.00	0.94
Chamoli and Gopeshwar (Uttarakhand)	30.40	79.30	3597.00	0.88
Pithoragarh (Uttarakhand)	29.60	80.20	1667.00	0.95

The statistics associated to wind speed were subjected to two parameters namely scale (C) and shape (K) being the parameters along with other arithmetical and statistical practices. The Weibull distribution is extensively utilized in wind speed data studies. Two-parameter Weibull distribution is generally exercised, compared to three-parameter Weibull distribution as given by below mentioned functions namely equations (1) and (2) respectively [16].

$$f(u) = \left(\frac{K}{C}\right)\left(\frac{u}{C}\right)^{K-1} exp.\left[-\left(\frac{u}{C}\right)^{K}\right] \quad (1)$$

$$F(u) = 1 - exp.\left[-\left(\frac{u}{C}\right)^{K}\right] \quad (2)$$

Where, *f(u)*: probability density function; K: Weibull shape parameter (dimensionless); C: Weibull scale parameter (in m/s) and *F(u)*: cumulative density function.

The mean (u_m) and variances (σ^2) of wind speed data of various cities of Indian states under consideration are calculated from the equations (3) and (4) respectively [17].

$$u_m = \frac{1}{n}\sum_{i=1}^{n} u_i \quad (3)$$

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n} (u_i - u_m)^2 \quad (4)$$

The two parameters of Weibull distribution, C and K are calculated from mean and variances of the wind speed data with the help of equations (5) and (6) respectively [18].

$$K = \left(\frac{\sigma}{u_m}\right)^{-1.086} \qquad (1 \le K \le 10) \quad (5)$$

$$C = \frac{u_m}{\Gamma\left(1+\frac{1}{K}\right)} \quad (6)$$

Where, u_m: mean wind speed (m/s), σ: standard deviation of wind speed data & Γ: gamma function.

For estimating the wind potential of an area, the calculation of the most probable and maximum energy-carrying wind speed is very important. They can be assessed in terms of two Weibull parameters K and C from equation (7) and (8) respectively.

$$u_{mp} = C\left(\frac{K-1}{K}\right)^{\frac{1}{K}} \quad (7)$$

$$u_{Emax.} = C\left(\frac{K+2}{K}\right)^{\frac{1}{K}} \quad (8)$$

Where, u_{mp} is most probable wind speed (m/s) and $u_{Emax.}$ is maximum energy-carrying wind speed (m/s).

The wind power density illustrates the wind power/area and is used in the wind power potential in a particular location. The wind power density is also employable to calculate the attributes of the wind turbines, and for determining the finest wind turbines. The wind power density can be articulated as from equation (9) as:

$$p(u) = \int_0^\infty \frac{1}{2}\rho u^3 f(u)\, du \quad (9)$$

The Rayleigh distribution is also used in wind energy assessment and is expressed by equation (10) and (11) as follows [19-20].

$$f(u) = \left(\frac{u}{c^2}\right) exp.\left[-\left(\frac{u^2}{2c^2}\right)\right] \quad (10)$$

$$p(u) = \int_0^\infty \frac{1}{2}\rho u^3 f(u)\, du = \frac{3}{\pi}\rho C\Gamma\left(1+\frac{1}{K}\right) \qquad (K = 2)$$

(11)

Where *u*: wind speed; C: scale parameter

Result and Discussion

Following table (Table 2) show the monthly & annual mean wind speed figures of 22 years duration (January 1983 to December 2004) from the RETScreen climate record at an elevation of 10m from ground for four districts of Uttarakhand (Haridwar, Dehra Dun, Chamoli and Gopeshwar, and Pithoragarh). The districts are chosen on the basis of population and high energy need. With the use of 2 parameters Weibull and Rayleigh distribution, wind power per unit area for the selected districts of Uttarakhand are computed using mathematical equation (1) to (11). The annual mean wind speed data are 2.90m/s,3.70m/s,4.00m/s and 3.70m/s for Haridwar, Dehra Dun, Chamoli & Gopeshwar, and Pithoragarh. As shown from the table, wind speed varies from 2.60 m/s to 4.30 m/s for the four districts. Also, wind speed values are maximum during April to July throughout the year. The table clearly shows the seasonal variation of wind speed for the four districts. Furthermore, wind speed is not constant throughout the year. The maximum wind speed was observed at Dehra Dun and minimum wind speed was observed at Haridwar. Table 3 shows the result of Weibull statistical analysis of Uttarakhand at 10m. From table 3, it is clearly noticed that the two parameters namely scale (C) and shape (K) for four districts varies from 3.15 to 4.22 and 5.16 to 8.97 respectively. Also, wind speed carrying maximum energy varies from 3.36 to 4.32 m/s for the four districts under consideration. The most important parameter for wind energy assessment known as wind power density varies from 14.90 for Haridwar to 35.90 for Chamoli & Gopeshwar at 10 m elevation from ground as calculated by 2 parameters Weibull distribution. Table 3 shows the values of wind power density calculated using Rayleigh's distribution and comparison with 2 parameters Weibull distribution. Table 3 clearly shows that, wind density calculated using Weibull distribution is closer to actual observation than Rayleigh's distribution.

Table 2. Mean wind speed at 10 m in different cities of Uttrakhand

Month	Mean wind speed at 10 m in different cities (m/sec)			
	Haridwar	Dehra Dun	Chamoli & Gopeshwar	Pithoragarh
January	2.60	3.60	4.00	3.60
February	2.80	3.70	4.00	3.60
March	2.90	3.70	3.90	3.70
April	3.20	3.80	3.90	3.80
May	3.60	4.20	4.30	4.10
June	3.70	4.30	4.20	4.00
July	3.40	3.80	4.00	3.80
August	3.10	3.50	3.90	3.70
September	2.90	3.50	4.00	3.60
October	2.40	3.50	4.10	3.70
November	2.20	3.50	4.00	3.60
December	2.40	3.60	4.10	3.60

The comparison between Weibull and Rayleigh wind power density is also shown graphically in figure 2 to better understand the differences.

Table 3. Result of Weibull statistical analysis of Uttarakhand at 10m

City	Haridwar	Dehra Dun	Chamoli & Gopeshwar	Pithoragarh
u_m	2.90	3.70	4.00	3.70
σ	0.64	0.50	0.53	0.52
u_{max}	3.70	4.30	4.30	4.10
K	5.16	8.74	8.97	8.38
C	3.15	3.91	4.22	3.92
u_{mp}	3.02	3.86	4.17	3.86
u_{Emax}	3.36	4.00	4.32	4.02
P(u)	14.90	28.53	35.90	28.68

Table 4. Comparison of wind power density of four districts of Uttarakhand

City	Wind power density (W/m^2)		
	Weibull	Rayleigh	Actual Observation
Haridwar	14.90	2.85	16.30
Dehra Dun	25.06	3.11	27.10
Chamoli & Gopeshwar	29.52	3.14	33.45
Pithoragarh	25.46	3.15	27.75

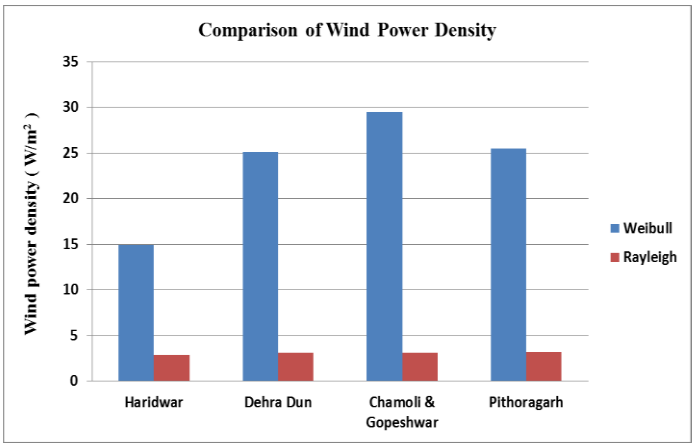

Figure 1: Comparison between Weibull and Rayleigh Wind Power Density

Conclusion

After the thorough investigation of results, it can be concluded that the four Uttarakhand districts considered in this study namely Haridwar, Dehra Dun, Chamoli & Gopeshwar, and Pithoragarh are not appropriate for large-scale electricity generation from wind power at a height of 10 m above the ground. We found that although wind energy potential assessment based on Weibull distribution is more accurate as compared to Rayleigh but Rayleigh is more convenient to calculate wind potential and hence employed frequently. Also, Rayleigh distribution is derived from Weibull Distribution where one of the parameters is taken as constant. As shown in table 4, the values of wind power density calculated through Weibull distribution is closer to actual calculated values than Rayleigh distribution. The comparison between Weibull and Rayleigh wind power density is also shown graphically in figure 2. The summary of result obtained from Weibull statistical analysis is shown in table 3 for decision making and understanding the wind energy potential at selected cities.

References

[1] Feretic, D., Tomsic, Z. and Cavlina, N., Feasibility Analysis of Wind-Energy Utilization in Croatia. Energy, 24, 239-246. (1999)

[2] Adami, L., Castagna, G., Magaril, E., Giurea, R., Ferronato, N., Ruggieri, G., Torretta, V., Rada, E.C., Criticalities and potentialities of local renewable sources of energy, WIT Transactions on Ecology and the Environment, 222, 103-115, (2019)

[3] Hansen, U.E., Nygaard, I., Morris, M., Robbins, G., The effects of local content requirements in auction schemes for renewable energy in developing countries:

A literature review, Renewable and Sustainable Energy Reviews, 127, (2020)

[4] Lehmann, P., Söderholm, P., Can Technology-Specific Deployment Policies Be Cost-Effective? The Case of Renewable Energy Support Schemes, Environmental and Resource Economics, 71(2), 475-505, (2018)

[5] Samuel Perkin, Deon Garrett, and Pall Jensson, “Optimal wind turbine selection methodology: A case-study for Búrfell, Iceland”. Renewable Energy, 75, 165-172. (2015)

[6] Mathew, S., Pandey, K.P. and Kumar, A.V. Analysis of Wind Regimes for Energy Estimation. Renewable Energy, 25, 381-399. (2002)

[7] Malinowski, M., Milczarek, A., Kot, R., Goryca, Z., Szuster, J.T.,.Optimized Energy-Conversion Systems for Small Wind Turbines: Renewable energy sources in modern distributed power generation systems, IEEE Power Electronics Magazine, 2(3), 16-30, (2015)

[8] Ionescu, R.D., Ragazzi, M., Battisti, L., Rada, E.C., Ionescu, G., Potential of electricity generation from renewable energy sources in standard domestic houses, WIT Transactions on Ecology and the Environment, 176, 245-253, (2013)

[9] Sulaiman, M.Y., Akaak, A.M., Abd. Wahab, M., Zakaria, A., Sulaiman, Z.A. and Suradi, J. Wind Characteristic of Oman. Energy, 27, 35-46. (2002)

[10] Singh, R., and Prakash, O. Wind energy potential evaluation for power generation in selected districts of Jharkhand, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, Vol. 40, Iss. 6, 673-679. (2018). DOI: 10.1080/15567036.2018.1454548.

[11] Oztopal, A. Sahin, A.D. Akgun, N. and Sen, Z. On the Regional Wind Energy Potential of Turkey. Energy, 25,189-200. (2000).

[12] Albadi, M.H., El-Saadany, E.F. and Albadi, H.A. Wind to Power a New City in Oman. Energy, 34, 1579-1586. (2009).

[13] Singh, R., and Prakash, O. Assessment of wind energy potential in four cities of Gujrat, India, U.P.B. Sci. Bull., Series D, Vol. 81, Iss. 1, 207-2016. (2019).

[14] Ajayi, O.O., Fagbenle, R.O. and Katende, J. Assessment of Wind Power Potential and Wind Electricity Generation Using WECS of Two Sites in South West, Nigeria. International Journal of Energy Science, 1, 78-92. (2011).

[15] Ilinca, A., McCarthy, E., Chaumel, J.-L. and Retiveau, J.-LWind Potential Assessment of Quebec Province. Renewable Energy, 28, 1881-1897. (2003)

[16] B.R. Karthikeya, Prabal S. Negi, N. Srikanth Wind resource assessment for urban renewable energy application in Singapore Renewable Energy, 87, Part 1, 403-414. (March 2016)

[17] Ahmed, S.A. Wind Energy as a Potential Generation Source at Ras Benas, Egypt. Renewable and Sustainable Energy Reviews, 14, 2167-2177. (2010)

[18] Seguro JV, Lambert TW. Modern estimation of the parameters of the Weibull wind speed distribution for wind energy analysis. J Wind Eng Ind Aerodyn, 85, 75–84. (2000)

[19] Pashardes S, Christofides C. Statistical analysis of wind speed and direction in Cyprus. Sol Energy, 55(5), 405–14. (1995)

[20] Argungu, G.M., Bala, E.J., Momoh, M., Musa, M., Dabai, K.A., Zangina, U. and Maiyama, B.A. Statistical Analysis of Wind Energy Resource Potentials for Power Generation in Jos, Nigeria, Based on Weibull Distribution Function. The International Journal of Engineering and Science (IJES), 2, 22-31. (2013)