Selection of an efficient wind turbine generator at Government science college premises Chitradurga, India

G H Smitha patil,1,2 R Megha3, Y T Ravikiran*1,2, M Prashantkumar4
K Udaykumar5 and B G Kumaraswamy6

1Department of PG Studies and Research in Physics, Government Science College, Chitradurga 577 501, Karnataka, India
2Department of Physics, Visvesvaraya Technological University - Research Resource Centre, Belagavi 590 018, Karnataka, India
3 Department of physics, P.E.S College of Enginerring Mandya 571401, Karnataka, India.
4Department of Physics, Government College (Autonomous), Kalaburagi 585105, Karnataka, India
5Department of of Physics, VSK University, Ballari 583102, Karnataka, India.
6Department of Electrical and Electroni , SJMIT Chitradurga 577501, Karnataka, India

Abstract. Wind speed modelling is very crucial in estimating the potential of wind energy for a particular site. In this paper, the wind energy potential at the premises of Government Science College area [Lat. 14°13′ N and Long. 76°27′ E] in Chitradurga town (Karnataka State, India) is statistically analyzed for the year 2019 – 2020. The speed of wind has been assessed at the height of 60 m from the ground level at the site. The seasonal and annual wind speed distributions (WSD) have been modelled using Weibull probability distribution functions (WPDF) i.e., shape parameter, k and scale parameters, c. With the use of them, the wind power density (WPD) has been determined. The WPD estimated from Weibull and normal methods has been found to be comparable. Further, at a height of 60 m above the ground, the capacity factors (CPs) of various marketably useable wind turbine generators have been estimated to achieve the optimal power generation for the chosen site.

Keywords: Mean wind speed, Weibull distribution function, wind power density, capacity factor

1. Introduction

Across the globe, most of the countries have been encouraging the energy harvesting from wind energy resources as it is an affordable, inexhaustible and environmentally friendly alternative energy source [1]. The power output from wind energy sources has recently been observed to be on par with the power generated from conventional power generation methods. The enhancement in the power yield in wind energy can be attributed to the technological advancements that have taken place in recent times. Technology has now made the wind energy easily extractable and economically viable. The optimal installation of a wind energy system at a particular site crucially depends on several factors viz., variation of wind speed distribution, characteristic speeds of turbine and height of the hub. Therefore, it is very essential to employ the best available technologies to estimate these factors at a
given site. In order to meet the required demands, the optimal matching of wind energy to the output energy can be achieved by incorporation of all the crucial factors mentioned above [2].

Many researchers [3-5] have employed simple WSD that are limited to the basis of arithmetic mean of the wind speed (WS). We, in this paper, have used the arithmetic mean of WS data computations for evaluation of the possibility of a given site for the wind power generation. Standard WPDF has been used for modelling WS distribution statistically. Further, the approximation method has been used to compute the Weibull shape parameter, $k$ and scale parameter, $c$ [6]. The annual CP has been estimated on the basis of actual WS measurements and typical speeds of installed wind turbines. In the present work, we have chosen the Government Science College, Chitradurga, a reputed higher education institution in Karnataka state (India) as a site for WS data measurements and also to validate analytical results obtained from the statistical model.

2. Wind Speed Measurements
The reliability of a wind energy system depends on long term measurement of WSs. The literature suggests that the annual mean WSs measured over a year is a good estimate to predict long term wind potentials up to an accuracy of 10 % and a confidence level of 90 % [7]. With this perspective, the WS measurements at a height of 60m above the ground level at the premises of Government Science College, Chitradurga has been carried out using an anemometer with three cone-shaped cups over the period 2019-2020. Using a 10W photovoltaic panel based data acquisition system, the average WSs have been recorded in the interval of 10 min.

3. Wind Data Processing
By processing the acquired data, the average and standard deviations of WSD have been determined [5]. The mean and deviation in WS have been estimated using the relations,

$$\bar{v} = \frac{1}{N} \sum_{i=1}^{N} v_i$$  

$$s = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (v_i - \bar{v})^2}$$  

Where $\bar{v}$ = mean WS in m/s, $s$ = deviation in WS, $v_i$ = specific WS in m/s, $N$ = observed WS values.

4. Weibull Probability Distribution
The dimensionless quantity, shape parameter $k$ and the scale parameter $c$ (m/s)] satisfactorily explains the experimental WS data. These parameters have been estimated by the approximation method [6]. The probability of WS at any time interval is given by,

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

Where, $k$ is shape parameter and $c$ is the scale parameter and these parameters given by [8],

$$k = \frac{\bar{v}}{\bar{\bar{v}}}^{1.086}$$  

$$c = \frac{\bar{v}}{\Gamma(1 + 1/k)}$$  

Where $\Gamma$ is gamma function.
5. Normal Wind Power Density
The average specific power for a wind stream with velocity \( v \) (m/s) perpendicular to wind turbine is given by [9],

\[
P_{\text{wind}} = \frac{1}{2} r \bar{v}^3
\]

Where \( \rho \) is the standard air density in kg/m\(^3\) (\( \rho = 1.225 \) kg/m\(^3\) dry air at 1 atm and 15\(^0\)C), \( \bar{v} \) is the mean WS in m/s.

6. Weibull Wind Power Density
As per WPD, the anticipated seasonal and annual wind power density is given by,

\[
P_{\text{Weib}} = \frac{1}{2} r c^3 G \left( \frac{\hat{c}}{c} \right)^{3} + \frac{3}{k} \hat{v}^{k}
\]

7. Capacity Factor
The ratio of the average power output to the rated power of the generator is called as the capacity factor which gives the percentile electric power that a turbine can produce at the given site with the available wind [2]. This factor can be estimated by the formula [10],

\[
P_{e,\text{avg}} = P_{\text{rated}} e^{-\left(\frac{v_{n}}{c}\right)^{k}} - e^{-\left(\frac{v_{r}}{c}\right)^{k}} - e^{-\left(\frac{v_{f}}{c}\right)^{k}}
\]

Where \( v_{n} \), \( v_{r} \) and \( v_{f} \) are respectively cut in speeds, rated speeds and furling (cut out) speeds of a wind turbine generator.

8. Results and Discussion
Fig. 1 is a graphic representation of the monthly variation of WS data collected at a height of 60 m above the ground level at the premises of Government Science College, Chitradurga during 2109-2020. It can be noted from Fig.1 that the maximum WS was observed to be high during the monsoon i.e., between the months June and September. The variation in average WS observed from Fig.1 indicates that the WS in this area throughout the year is suitable for tapping wind energy at a height of 60 m above the ground level where the anemometer was installed.

Table 1. Comparison between seasonal and annual power densities calculated from normal and Weibull method.

| Sl. No | Seasons | \( k \) | \( c \) (m/s) | Wind power density (Normal) W/m\(^2\) | Wind power density (Weibull) W/m\(^2\) |
|--------|---------|-------|-------------|----------------|----------------|
| 1      | Summer  | 2.13  | 6.53        | 211.30         | 211.65         |
| 2      | Monsoon | 2.95  | 10.00       | 606.12         | 614.79         |
| 3      | Winter  | 2.64  | 6.53        | 179.90         | 180.76         |
| 4      | Annual  | 2.25  | 7.72        | 337.60         | 333.07         |

Fig. 2 and 3 depict seasonal and annual variation of Probability distribution functions with WS over the year 2019-2020. Using Weibull distribution function and Equation (4) & (5), the \( k \) and \( c \) were calculated and are tabulated in Table 1.
The Annual shape parameter $k$ shows a value of 2.25 which indicates widely dispersed data with uniform distribution across wide range of WS. This implies that the selected area is suitable for wind power generation due to the higher average WS. The smaller $k$ in summer and monsoon seasons point out to the fact that the average WS at this location is sufficiently high enough for the efficient operation of a wind turbine generator. As the average WS are observed to be higher, the $k$ suggests that the chosen site is suitable for wind power generation [10]. The good match of the experimental annual power densities at this site with the corresponding values calculated using Weibull function shows lowest power density in winter and highest power density during monsoon. In this study, the wind turbine generator has been analyzed at the highest capacity factor. The annual capacity factor for various wind turbine generator have been listed in Table 2. The Table 2 shows that turbine 4 (Elecon T600-48) is giving highest capacity factor which is also depicted in Fig. 4. The Seasonal and annual power densities from normal and Weibull techniques are noticeably comparable (Table 1).

![Fig. 1 Variation of average wind speed with month](image1)

Fig. 1 Variation of average wind speed with month

![Fig. 2 Seasonal variations of Probability distribution functions with wind speed.](image2)

Fig. 2 Seasonal variations of Probability distribution functions with wind speed.
Fig. 3 Annual variation of Probability distribution functions with wind speed.

Fig. 4. Annual variation of CP at elevation of 60 m for various wind turbines listed in Table 2
Table 2. Wind turbine data at 60 m height.

| Sl. No | Turbine name and model | Rated power [KW] | Cut-in speed vc [m/s] | Rated speed vr [m/s] | Cut-out speed vf [m/s] | Capacity factor CF |
|--------|------------------------|------------------|-----------------------|----------------------|-----------------------|-------------------|
| 1      | BHEL NORDEX            | 600              | 4.0                   | 13                   | 25                    | 0.25              |
| 2      | ELECON: TURBO WIND     | 600              | 3.5                   | 12.5                 | 25                    | 0.29              |
| 3      | TACKE                  | 600              | 3                     | 13                   | 20                    | 0.27              |
| 4      | ELECON T600-48         | 600              | 3                     | 12.5                 | 25                    | 0.30              |
| 5      | VESTAS V44             | 600              | 4                     | 16                   | 20                    | 0.16              |

9. Conclusion
The WS and wind power density measurements have performed at the premises of Government Science College, Chitradurga for the year 2020-2021. Using the Weibull Distribution function, the measured data has been analyzed. The seasonal and annual WSD modeled using WDF. Using Weibull parameters, the WPD of the site has been determined. The WPD estimated from Weibull and normal methods has been found to be comparable. Also, the annual variations of CPs for optimum selection of wind turbine generators have been studied. Further, by approximating the capacity factors of different industrial wind turbine generators, the site matching has been done.

Acknowledgement
The authors acknowledge the support from Research Resource Centre, VTU, Belagavi.

References
[1] Yi Li, Xuan Huang, Kong Fah Tee, Qiusheng Li, Xiao-Peng Wu. 2020, Sustainable Energy Technologies and Assessments 39 100711.
[2] Tai-Her Yeh and Li Wang, 2008, IEEE Trans Energy Convers, 23, 2, 592-602
[3] Gholamreza Janbaz Ghabadi, Bahram Gholizadeh and Bagher Soltani. 2011, International Journal of physical Sciences, 19, 6, 4621-4628.
[4] Kumaraswamy B. G., Keshavan B. K. and Ravikiran Y. T., July 2011, 978-1-4577-1002-5/11, IEEE PES General Meetin..
[5] Seyit A. Akdag and Ali Dedinler, April. 2009, Energy conversion and Management, 50, 1761-1766.,
[6] Vladislavas Katinas, Giedrius Gecevicius, Mantas Marciukaitis,. 2018, Applied Energy, 218, 442-451.
[7] Renewable Energy World. ‘Wind Energy - A True Option for Developing Countries’. November 1998, James and James (Science Publishers) Ltd, United Kingdom, 1, 3, 62.
[8] Gungor A., Gokcek M., Ucar H., Arabaci E., Akyuz A. 2020, International Journal of Environmental Science and Technology, 17 1011-1020.
[9] Fawzi A.L. Jowder, 2009, Applied Energy, 86, 538-545.
[10] Faleh H. Mahmood, Ali K. Resen, Ahmed B. Khamees. 2020, Iraq. Energy Reports, 6 79-87.