Assessment of wind power potential in a region of Goa, India

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***Abstract*—In this paper, using hourly average wind data recorded for a period of one year is used to estimate wind power potential in a region of Goa, India. The wind power potential is estimated using Weibull probability density function. In this paper, the Weibull parameters namely, shape parameter (k) and scale parameter (c), are estimated by using maximum likelihood method. In this paper, the effect of relative humidity, in addition to that of air temperature and pressure, on air density is considered and wind power density thus calculated is compared with that obtained using constant air density. Results obtained clearly shows that conventional methods overestimate wind power density at a site by a margin of 19.34%.**

***Keywords*—Wind resource assessment, air density, wind power density, Weibull distribution, Maximum likelihood estimation.**

I. Introduction

Among the various alternative sources of energy, wind energy proved to be environment friendly and commercialized source of energy. In India, wind energy utilization has reached the installed capacity of 26,915 MW of electric power generation at the end of march 2016, against the estimated wind power potential of 49,130 MW at 50 m height [1].

Wind resource assessment (WRA) is time-wise extensive and expensive process. The campaign therefore, is supported by Government in several countries. The availability of detailed data at several sites has generated confidence among wind power developers. The basic steps in WRA at a site involve setting up meteorological mast constitutes of anemometer, wind vane and measuring instruments for measuring ambient temperature, pressure and humidity, with programmable data logger facility.

Usually, detailed time-series data on wind speed and direction at 20 m, 50 m or 80 m height above ground and data on ambient air temperature, pressure and humidity at about 3 m above ground at a prospective wind farm site are recorded. The data recorded over a period of minimum one year is considered for characterizing the wind resource at the site.

Prior to undertaking campaign for detailed wind resource assessment, efforts should be made to analyze available wind data for the region. A statistical analysis of data is the basic step for setting up of wind energy project. The wind speed distribution predominantly determines the performance of wind energy systems at a given location and over a period of time. Usually probability distribution of wind energy are Weibull distribution and Rayleigh distribution. The Weibull function is a two parameter function used to estimate the wind speed frequency distribution [2]-[4]. Several methods have been used by researchers to estimate the parameters of Weibull distribution function. In the present study, maximum likelihood (MLE) method is used for determining the Weibull parameters for the estimation of wind power potential [5]-[12].

From the literature, it is noted that most of the researchers assumed air density as constant (1.225 Kg/m^3) while calculating wind power density. But air density at a site depends on the temperature, pressure and relative humidity and therefore it is not constant. In this paper, (in addition to temperature and pressure), the effect of relative humidity on air density is taken into account.

In the present work, wind data recorded for a period of one year at BITS Pilani K.K. Birla Goa Campus, Goa, India (Lat.$15°23'N$, Long. $73°49'E$) is used to analyze wind power potential.

II. Wind Data and Site Description

The hourly measured data on wind speed, direction, temperature, pressure and relative humidity at BITS Pilani, K.K. Birla Goa Campus, Goa, India, during the period from 1 May 2014 to 30 April, 2015 is recorded. The wind speed and direction are measured with the help of standard cup-type anemometer and wind-vane, installed at a height of 20 m above ground level (AGL). Other sensors for measuring air temperature, relative humidity and atmospheric pressure are installed at a height of 3 m AGL.

III. Analysis of Measured Wind Data

The methods of analysis of measured data, for obtaining different statistical parameters characterizing the site, are presented. The characteristics to be determined include average wind speed, air density, wind power density, Weibull parameters, namely shape parameter, k and scale parameter, c and Weibull probability density distribution function (PDF).

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A. Average wind speed (V_m)

In the first step, hourly average wind speed is used to calculate monthly and annual average wind speeds [11],

$$V_m = \frac{1}{N}\sum_{i=1}^{N} V_i \tag{1}$$

Where, V_i is the instantaneous wind speed in m/s, V_m is the average wind speed in m/s, N is the total number of observations.

B. Air density (ρ)

Air density is an important parameter in determination of wind power density. In general, wind resource assessment studies are carried out assuming air density as constant (1.225 Kg/m^3). Using the recorded hourly average values of air temperature (T, in K) and atmospheric pressure (P, in mb), the air density (in Kg/m^3) is determined as [13]:

$$\rho = \frac{p}{RT} \tag{2}$$

Here, ρ is the air density, R is the universal gas constant (287 J/kg K). In this work, instead of assuming air density as constant, it is determined using (3). Thus, the effect of relative humidity (in addition to temperature and pressure) on the air density is taken in o account [14], [15].

$$\rho_H = \frac{p_d M_d + p_v M_v}{RT} \tag{3}$$

where,

$$p_v = \phi . p_{sat} \tag{4}$$

where T is the absolute temperature in $^\circ C$, P is the pressure in Pa, ϕ is the relative humidity (not in terms of %), P_v is the vapor pressure in Pa and P_d is the dry pressure in Pa, ρ_H is the air density with relative humidity into account and The values of M_d and M_v are 0.028964 kg/mol and 0.018016 kg/mol,respectively.

C. Wind power density (WPD_M)

Wind power density (WPD) is a realistic indication of site′s wind power potential. It depends on air density and wind speed and is calculated using following equation [11]:

$$WPD_M = \frac{1}{2}\rho_i {V_i}^3 \tag{5}$$

Here, WPD_M is the measured wind power density in W/m^2.

D. Weibull distribution function

The probability density distribution function (PDF) indicates the time for which the wind speed probably prevails at the location of measurement. The Weibull probability density distribution function (PDF), is a two-parameter function, namely, the shape parameter (k) and scale parameter (c) and is determined as [2]-[4]:

$$f_W(V) = \left(\frac{k}{c}\right)\left(\frac{V}{c}\right)^{k-1} \exp\left(-\frac{V}{c}\right)^{k} \tag{6}$$

here $f_W(V)$ is the probability of wind speed, k is the dimensionless Weibull shape parameter, and c is the Weibull scale parameter in m/s. The scale parameter (c) indicates how 'windy' a location under consideration is, whereas the shape parameter, k, defines the shape of the curve. In this paper, two parameters of Weibull distribution are estimated by using Maximum likelihood method.

E. Maximum likelihood estimation for determination of Weibull parameters

In Maximum likelihood estimation (MLE) a likelihood function based on the available data is developed and the values of the parameters are determined. The parameters can be estimated as follows [9], [10]:

$$k = \left[\frac{\sum_{i=1}^{N} V_i^k \ln V_i}{\sum_{i=1}^{N} V_i^k} - \frac{1}{N}\sum_{i=1}^{N} \ln V_i\right]^{-1} \tag{7}$$

$$c = \left[\frac{1}{N}\sum_{i=1}^{N} V_i^k\right]^{1/k} \tag{8}$$

F. Estimation of wpd (WPD_W)

The wind power density using Weibull parameters at a given site is determined as follows [11]:

$$WPD_W = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) \tag{9}$$

$$\Gamma(y) = \int_0^\infty x^{y-1} e^{-x} dx$$

Here $\Gamma(y)$ refers the gamma function [12].

G. Error in estimation of wpd

The estimated wpd using Eq. (9), at a given site differs from the wind power density obtained by Eq. (5). The error in estimation is calculated as follows [11]:

$$Error\ (\%) = \frac{WPD_W - WPD_M}{WPD_M}.100 \tag{10}$$

Here, WPD_W is wind power density estimated using Weibull parameters.

H. Performance Analysis

The accuracy of the results obtained can be determined by correlation coefficient, (R^2) which is a measure of difference between the observed probability of a wind speed and estimated value obtained using parameters of Weibull distribution. The correlation coefficient is determined as follows [16]:

$$R^2 = \frac{\sum_{i=1}^{N}(y_i - z_i)^2 - \sum_{i=1}^{N}(x_i - y_i)^2}{\sum_{i=1}^{N}(y_i - z_i)^2} \tag{11}$$

where y_i is the measured value, x_i is the estimated value, z_i is the mean value. The unity value of R^2 indicates complete agreement between measured data and the estimated data.

IV. RESULTS AND DISCUSSIONS

In the present work, using the detailed time-series data recorded over a period of one year (from 1 May 2014 to 30 April 2014) is used to analyze the wind power potential. The measured data is processed using Windographer software [11], [17]. The data measured on wind speed is represented as graphical time-series data and measured wind direction data is represented as wind-rose diagram for the site. Fig. 1 shows month-wise daily variation of average wind speed measured at 20 m (AGL). It is observed from the site measurement, the daily average wind speed varies from a minimum of 1.25 m/s on 11 November 2014 to a maximum of 6.8 m/s on 22 July, in the year.

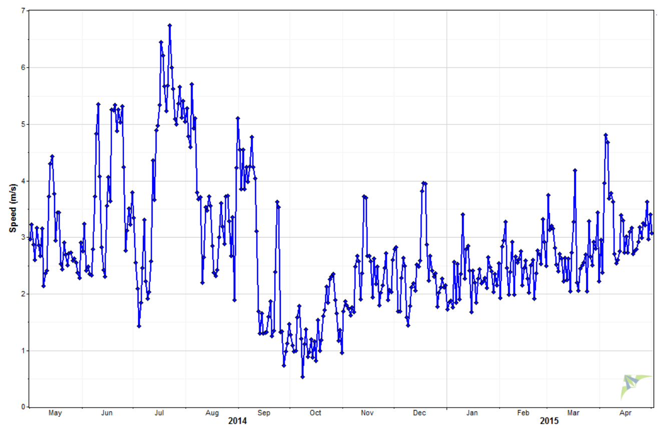

Fig. 1. Month-wise daily values of average wind speed at the site.

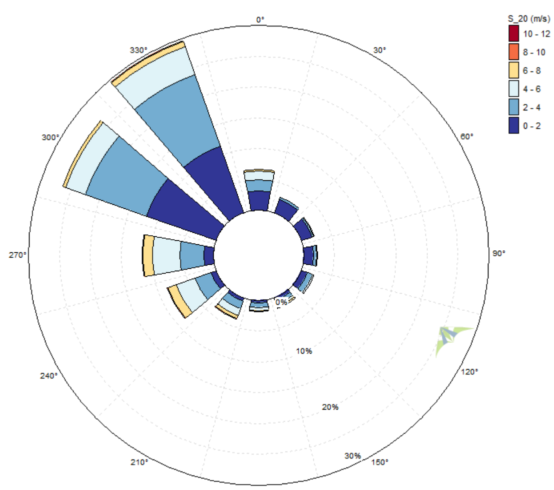

Fig. 2. Wind rose diagram.

Fig. 2 shows a wind rose diagram that represents distribution of recorded wind direction corresponding to measured wind speed in that direction, during the year. From Fig. 2, it can be concluded that the site of measurement predominantly receives maximum winds from west for most part of the year.

The statistical parameters are obtained using MATLAB, for each month and the year of measurement. It is observed from Table I, monthly average wind speed varies between minimum of 2.23 m/s occurs in November and maximum of 4.12 m/s occurs in July, in the year. Also it is seen from the table, the wind power is calculated with constant air density (WPD_C), and Wind power density with variation of air density (WPD_H), are reported to be 31.19 W/m^2 and 25.15 W/m^2, respectively for the year of measurement. It is observed that there is a difference of -19.34 % of wind power density when variation of air density is taken into account.

The Weibull parameters along with variation of wind power density are listed in Table II. From the table, it is noted that the for the year of measurement, the wind power density estimated using Weibull parameters for constant air density and varying air density are found to be 30.79 W/m^2 and 24.83 W/m^2, respectively. Thus, it is observed that there is a difference of -1.29 % while estimating wind power density using maximum likelihood method.

TABLE I. MONTH-WISE VARIATION OF AIR DENSITY AND WPD AT THE SITE.

Month, Year	V_m	Air density (ρ)		WPD_M	
	(m/s)	ρ_C (kg/m^3)	ρ_H (kg/m^3)	WPD_C (W/m^2)	WPD_H (W/m^2)
May-14	2.92	1.225	1.113	29.37	26.70
Jun-14	3.74	1.225	1.114	50.77	46.18
Jul-14	4.12	1.225	1.116	72.09	65.69
Aug-14	3.60	1.225	1.102	45.87	41.27
Sep-14	3.05	1.225	1.103	29.76	26.79
Oct-14	2.25	1.225	0.952	11.35	08.82
Nov-14	2.23	1.225	0.894	12.66	09.24
Dec-14	2.40	1.225	0.892	15.92	11.60
Jan-15	2.27	1.225	0.897	13.28	09.72
Feb-15	2.55	1.225	0.893	22.17	16.16
Mar-15	2.73	1.225	0.886	26.66	19.28
Apr-15	3.30	1.225	0.885	43.89	31.71
Annual	2.93	1.225	0.988	31.19	25.15

TABLE II. MONTH-WISE VARIATION OF WEIBULL PARAMETERS AT THE SITE.

Month, Year	k	c	WPD_W		Error	R^2
		(m/s)	WPD_C W/m^2	WPD_H W/m^2	(%)	
May-14	2.01	3.31	29.30	26.62	-0.28	0.79
Jun-14	2.47	4.22	51.13	46.51	0.72	0.81
Jul-14	2.21	4.65	74.36	67.76	3.15	0.60
Aug-14	2.37	4.05	46.50	41.84	1.38	0.80
Sep-14	2.30	3.46	29.58	26.63	-0.61	0.77
Oct-14	2.46	2.54	11.13	08.65	-1.96	0.90
Nov-14	2.14	2.53	12.25	08.94	-3.24	0.89
Dec-14	2.12	2.72	15.45	11.25	-2.96	0.85
Jan-15	2.13	2.57	12.95	09.48	-2.5	0.84
Feb-15	1.80	2.88	21.84	15.92	-1.48	0.78
Mar-15	1.85	3.09	26.25	18.98	-1.55	0.78
Apr-15	1.91	3.72	44.01	31.86	0.47	0.83
Annual	1.93	3.32	30.79	24.83	-1.29	0.84

The annual estimated values of Weibull parameters (k and c) obtained are used to plot the Weibull PDF are compared with the actual PDF and is shown in Fig. 3. The correlation coefficient R^2, is determined to estimate the accuracy of prediction of probability of wind speed using Eq. (11). For the site, while using MLE method the value of R^2 is found to be 0.84. The annual values of k and c are further used to estimate the capacity factor of the site.

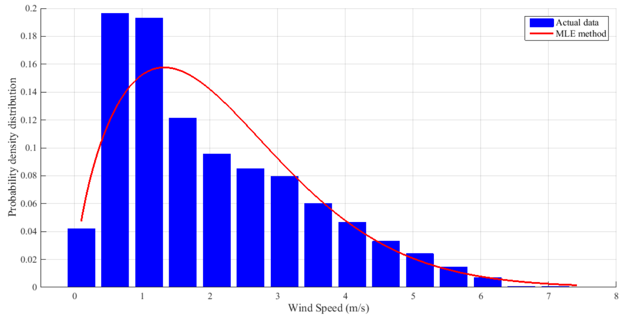

Fig. 3. Annual probability distribution function

V. CONCLUSIONS

In the present work, detailed time-series wind data measured over one year period at a region in Goa, India is analyzed for estimation of wind power potential.

1) The annual values of k and c, determined using maximum likelihood are found to be 1.93 and 3.32 m/s, respectively.
2) The annual values of R^2 and % error in wind power density are 0.84 and -1.29 %, respectively, while using maximum likelihood method.
3) It is seen that the wpd estimated by assuming air density to remain constant is 19.34 % overestimated above wind power density estimated by considering air density to be function of temperature, pressure and humidity.
4) Since, the wind power density is less than 100 W/m^2 at 20 m height, it is concluded that the site is suitable for small scale wind power generation.

REFERENCES

[1] National Institute of Wind Energy, http://niwe.res.in/.

[2] J. F.Manwell, Wind Energy Explained Theory, Design and Application, John Wiley & sons, 2002.

[3] S.N.Bhadra, D.Kastha and S.Banerjee, Wind Electrical Systems, Oxford University Press, 2005.

[4] S. Mathew, Wind Energy: Fundamentals, Resource Analysis and Economics, Springer-Verlag Berlin Heidelberg, 2006.

[5] S.Rehman, A. Alam, J.P.Meyer and L.M.Al-Hadhrami, Wind Speed Characteristics and Resource Assessment using Weibull Parameters, International Journal of Green Energy, Vol. 9,No.3, pp.800-814, 2012.

[6] S. A.Ahmed, Comparative study of four methods for estimating Weibull parameters for Halabja, Iraq, International Journal of Physical Sciences, Vol. 8, No. 5, pp. 186-192, 2013.

[7] A. Genc, M. Erisoglu, A. Pekgor, G. Oturanc, A. Hepbasli and K. Ulgen, Estimation of Wind power potential using Weibull Distribution, Energy Sources, Vol. 27, No.9, pp. 809-822, 2005.

[8] H.S.Bagiorgas, G.Mihalakakou and D.Matthopoulos, A Statistical Analysis of Wind Speed Distributions in the area of Western Greece, International Journal of Green Energy, Vol.5, No.1, pp. 120-137, 2008.

[9] J.A.Carta, P.Ramrez and S.Velazquez, A review of wind speed probability distributions used in wind energy analysis case studies in the Canary Islands, Renewable and Sustainable Energy Reviews, Vol.13, No.5, pp. 933-955, 2009.

[10] T. P. Chang, Performance comparison of six numerical methods in estimating Weibull parameters for wind energy application, Applied Energy, Vol. 88, No.1, pp. 272-282, 2011.

[11] H. S.Bagiorgas, M. Giouli, S. Rehman and L. M. Al-Hadhrami, Weibull Parameters Estimation using Four Different Methods and Most Energy-Carrying Wind Speed Analysis, International Journal of Green Energy, Vol. 8, No. 5, pp. 529-554 , 2011.

[12] P. A. C. Rocha, R. C. de Sousa, C. F. de Andrade and M. E. V. da Silva, Comparison of seven numerical methods for determining weibull parameters for wind energy generation in the northeast region of Brazil, Applied Energy, Vol. 89, No. 1, pp. 395-400, 2012.

[13] A. Keyhani, M. Ghasemi-Varnamkhasti and M. Khanali, R. Abbaszadeh, An assessment of wind energy potential as a power generation source in the capital of Iran, Tehran, Energy, Vol.35 pp. 188201,2010.

[14] A. Picard, R. S. Davis, M. Glaser and K. Fujii, Revised formula for the density of moist air, Metrologia, Vol. 45, pp. 149-155, 2008.

[15] R.Shelquist, Equations air density and density altitude, 2009. URL http://wahiduddin.net/

[16] D.A.Fadare, A Statistical Analysis of Wind energy potential in Ibadan, Nigeria, based on Weibull Distribution Function, The Pacific Journal of Science and Technology, Vol. 9, No.1, pp. 110-119, 2008.

[17] Windographer Software for data analysis https://www.windographer.com.