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Assessment of Wind Power Potential at the Chittagong Coastline in Bangladesh

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Abstract

A small wind data logger is used to record the wind speed for one year (2015 to 2016) at the Chittagong coastline in Bangladesh. A multi-storied building's rooftop in Chittagong Export Processing Zone (CEPZ) is selected as a wind data collection site. The recorded data is analyzed using Weibull distribution functions. Three statistical methods are used to find and compare the Weibull parameters. Weibull probability density function and cumulative distribution are used to explain the recorded data. The analysis shows the shape factor of the site is 1.8 and the yearly scale factor is $2.2 ms^{-1}$. The highest values of these parameters are found by calculation in the month of June when the maximum shape factor is 3 and the maximum yearly scale factor is $3.95\ ms^{-1}$. To estimate yearly energy production three different wind turbine models 'Aventa AV-7', 'Enercon E-33' and 'Enercon E-53' are used and the estimation is done using a mathematical approach. The probable wind power production capacity of this site would be around 5457kWh per year and the energy density of this site would be around $11.54\ kWhm^{-2}$. This research work may be helpful for the design and planning of any wind power plant at the Chittagong coastline area in Bangladesh.

Keywords: Weibull, shape factor, scale factor, Wind turbines, Rooftop, Energy Harvesting etc.

I. Introduction

Although the potential of wind energy in the urban areas of Bangladesh are comparatively low[1], wind speed at the roof top of the multistoried buildings in the Chittagong coastline could be a good source of wind power. The site is located at 22°17'16.9" North and 91°46'30.2" East which is situated in Chittagong Export Processing Zone (CEPZ). This site is selected because it is within 2 km radius of the coastline. A wind data logger unit[2] is installed in a multistoried building which is a garment factory. The building is only about 1.5 km distant from the coastline. There is no other taller buildings around 2 km periphery of the said building. So there was no physical obstacle for wind flow. Wind speed data are recorded from July, 2015 to June, 2016. The data are recorded above 30 meter from the ground. Statistical methods are used to predict and characterize the site[3].

Weibull shape and scale parameters are determined using three methods which are given in following section. Energy and power production analysis are done based on these parameters. Also a probable wind power production capacity is calculated to portray the site performance[4].

II. Methodology

For wind data analysis the three parameter Weibull distribution function can be expressed by two parameters[5]. The two parameter Weibull distribution is widely used to analyze wind data characteristics. This distribution is distinct and is actually a generalized gamma distribution. It gives better curve fitting and accuracy for month wise probability density distributions of measured wind speed[6]. The Weibull probability density function is expressed as,

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left(-\left(\frac{v}{c}\right)^{k}\right) \qquad (1)$$

Weibull distribution function is an accepted statistical tool for analyzing the wind speed distribution[6]. Where wind speed is denoted by v. The scale parameter c is the characteristic wind speed of the distribution. The parameter k identifies the shape of a Weibull distribution[5]. Cumulative distribution function of Weibull distribution is an additional part of the probability density function[7] (PDF), and it is stated as,

$$F(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \qquad (2)$$

Weibull shape factor k and scale factor c can be determined using a number of methods[8]. Curve fitting with probability density function, Method of moments (MOM) and Empirical method are used to determine and compare results[6].

III. Determination of Weibull Parameters

In this paper, three methods are used to determine the Weibull parameters to analyze the recorded data. These are discussed in the following sections.

Curve Fitting

Frequency distribution is matched with the probability density function (PDF) from which the parameters are determined and shown in Figure 1. Cumulative distribution function, CDF curve is determined (Fig.2). The Swiss (Switzerland) wind power data analyzing tool[9] has been used to analyze and fit frequency distribution to the corresponding PDF.

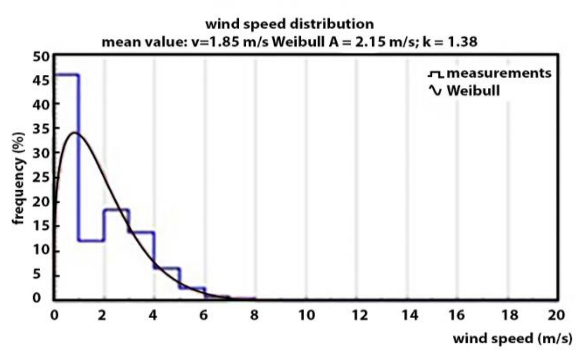

Fig. 1. Frequency distribution and Weibull PDF

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The same procedure is also followed for determining the parameters for each month of the year. Parameters are also calculated using MOM and Empirical method and presented in Table 1. It shows shape and scale parameter of the Weibull distribution of the monthly recorded data. From PDF graph it is evident that the most probable wind speed at 30 meter height for this site is about 1 ms^{-1}.

The shape parameter k signifies the stability of the wind speed[10]. It is found to be 1.8 as yearly average value. The characteristics wind speed for this site is 2.2 m/s.

Method of moment

The method of moments provides similar result as of maximum likelihood method. First two moments of the Weibull density function are used to find the parameters k and c. The formula uses standard deviation σ, mean wind velocity v and gamma Γ function. Gamma function, given as equation 7 which is calculated on (1+1/k). The two moments are given in equations 3 and 4.

$$v = c\Gamma\left(1 + \frac{1}{k}\right) \quad (3)$$

$$k = \left(\frac{0.9874}{\frac{\sigma}{\bar{v}}}\right)^{1.0983} \quad (4)$$

Empirical Method

Similar to that of MOM, Empirical method uses standard deviation and mean wind speed. These are given in equation 5 and 6. Equation 6 uses gamma function given in equation 7. Table 2 shows mean wind speed for each months of the year. Observed data is obtained considering all recorded data and the calculated mean is derived from PDF. Solar and Wind Energy Resource Assessment[11] (SWERA) data for this location was measured at 50 meter above the ground and presented in Table 2 along with recorded data. Recorded data and data retrieved from SWERA have differences as those are observed from different heights. There is only one data set of monthly average wind speed for this location[14] from National Aeronautics and Space Administration[12] (NASA). This is a low resolution data measured at 50m above ground[13].

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \quad (5)$$

$$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \quad (6)$$

$$\Gamma(x) = \int_0^\infty t^{x-1} e^t dt \quad (7)$$

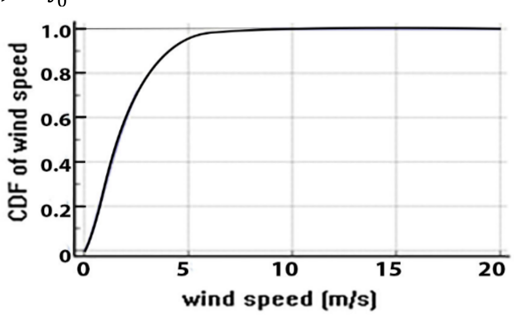

Fig. 2. CDF of measured data

A high resolution data set from WIND RISOE-DTU[14] are given in table 3. This data set considers only wind power density and annual average speed.

Table 1. Weibull Parameters *k* and *c*

Month	Calculated PDF		Method of Moment		Empirical Method	
	k	*c*	*k*	*c*	*k*	*c*
Jan'16	1.28	1.33	0.93	1.06	0.95	1.07
Feb'16	1.01	1.07	1.26	1.61	1.27	1.61
Mar'16	1.06	1.23	1.08	1.44	1.09	1.45
Apr'16	2.93	3.98	3.13	4.14	3.08	4.14
May'16	3	3.95	2.89	3.81	2.84	3.82
Jun'16	2.78	3.56	3	3.92	2.95	3.92
Jul'15	1.43	3.07	1.97	3.84	1.96	3.83
Aug'15	1.88	2.55	1.24	2.25	1.25	2.26
Sep'15	2.01	3.07	1.57	2.84	1.57	2.84
Oct'15	1.01	1.01	0.87	1.21	0.89	1.23
Nov'15	1.07	0.72	1.65	1.34	1.65	1.34
Dec'15	1.48	0.68	0.99	0.5	1.01	0.5
Yearly	1.8	2.2	1.7	2.3	1.7	2.3

The months of April, May and June show the stable trend of wind in this site, where the value of k ranges between 2.78 to 3 and c between 3.56ms^{-1} and 3.98ms^{-1}. Monthly values of k and c found by Method of Moment and Empirical Method have deviation from values found by calculated PDF (Table 1). Deviations are between ±0.1.

IV. Comparison With Other Source of Data

NASA low resolution data at 50 meter height shows the yearly average to be 2.74 and NOAA (National Oceanic and Atmospheric Administration) moderate resolution at 90 meter height is 7.78 whereas measured average is found as 2.23 at 50 meter height. Measured data has difference of 0.51ms^{-1} with provided by NASA data.

Table 2. Mean wind Speed from different data sources

Months	Observed Mean (July'15-Jun'16) (30m)	Calculated Mean (30m)	NASA (50m) Low R	NOAA (90m) Mid R
Jan	1.1	1.12	2.48	-
Feb	1.5	1.16	2.73	-
Mar	1.4	1.17	2.9	-
Apr	3.7	3.14	3.07	-
May	3.4	3.17	3.04	-
Jun	3.5	3.15	3.42	-
Jul	3.4	3.05	3.25	-
Aug	2.1	2.13	2.93	-
Sep	2.6	2.15	2.44	-
Oct	1.3	1.24	2.04	-
Nov	1.2	0.69	2.24	-
Dec	1.5	0.58	2.33	-
Yearly	2.23	1.89	2.74	7.78

The high resolution data has 5 sets of results for this site as presented in Table 3. These data has 1m/s deviation from the measured data.

Table 3. Available Data from SWERA WIND RISOE-DTU

Wind Risoe-DTU High Resolution (W/m sq. at 50m ASL)		
Available Data	**AVG. ANN. Wind Power Density(w/m2)**	**AVG. ANN. Wind Speed**
Result 1	69.784	3.453
Result 2	120.188	4.098
Result 3	69.36	3.336
Result 4	176.564	4.792
Result 5	220.936	5.149

V. Power and Energy Measurement

Power and energy production potential of a site can be determined in various ways. Energy and power density indicate the availability of producible power in every square meter[15]. Most probable wind speed (MPWS) is also a key point to summarize a site character. Statistical method is used to measure all these values. Generalized equations are modified as functions of Weibull parameters. Weibull Parameters, k and c determined in section III are used here to find MPWS and maximum energy carrying wind speed.

MPWS

MPWS (v_p) and maximum energy carrying wind speed (v_m) is calculated using equation 8 and 9. Result is derived for each month and presented in Table 4. Again it is evident that at this height three months of a year could be productive for this site.

$$v_p = c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \quad (8)$$

$$v_m = c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \quad (9)$$

Table 4. Most probable and most energy carrying wind speed (July, 2015-June, 2016)

Months	*k*	*c*	*Vp*	*Vm*
Jan’16	1.28	1.33	0.41	2.77
Feb’16	1.01	1.07	0.01	3.15
Mar’16	1.06	1.23	0.08	3.34
Apr’16	2.93	3.98	3.45	4.75
May’16	3.00	3.95	3.45	4.68
Jun’16	2.78	3.56	3.03	4.33
Jul’15	1.43	3.07	1.32	5.66
Aug’15	1.88	2.55	1.70	3.75
Sep’15	2.01	3.07	2.18	4.33
Oct’15	1.01	1.01	0.01	2.98
Nov’15	1.07	0.72	0.06	1.93
Dec’15	1.48	0.68	0.32	1.21
Yearly	1.80	2.20	1.40	3.33

Energy and Power Density

Based on Weibull parameters, Power density and Energy density were calculated using equations 11 and 12. Table 5 contains month wise k, c, power (P_d) and energy density (E_d) for a given period of time is presented. General equation for power density is given in equation 10. Air density‘ ρ ’ was calculated against the pressure and temperature data of this site using equation 13.

$$p_d = \frac{p(V)}{A} = \frac{1}{2}\rho v^3 \quad (10)$$

$$p_d = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) \quad (11)$$

$$E_d = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) T \quad (12)$$

$$\rho = 1000\left(\frac{287.05P}{t+273.15}\right) \quad (13)$$

Table 5. Power and Energy density (July, 2015-June, 2016)

Months	*k*	*c*	P_d	Hour	E_d
Jan’16	1.28	1.33	4.05	744	3.01
Feb’16	1.01	1.07	4.34	672	2.91
Mar’16	1.06	1.23	5.55	744	4.13
Apr’16	2.93	3.98	39.01	720	28.09
May’16	3.00	3.95	37.75	744	28.08
Jun’16	2.78	3.56	28.63	720	20.61
Jul’15	1.43	3.07	38.87	744	28.92
Aug’15	1.88	2.55	14.47	744	10.77
Sep’15	2.01	3.07	23.44	720	16.87
Oct’15	1.01	1.01	3.65	744	2.71
Nov’15	1.07	0.72	1.08	720	0.78
Dec’15	1.48	0.68	0.39	744	0.29
yearly	1.80	2.20	9.81	8760	11.54

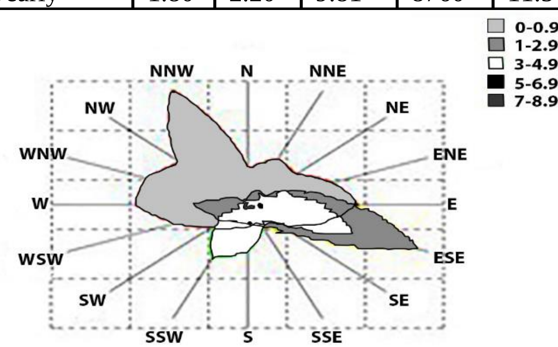

Fig. 3. Wind Rose

Wind rose diagram (Fig. 3) for this site indicates that low speed wind is flowing from the northern direction of the site and higher speeds are occurring from the southern part.

Stronger wind flow from east-south-east and south-south-west corner of the location. Semi diurnal speed (Fig. 4) is shown for typical days over the year. The midday to late afternoon exhibits most windy nature for this site for three to four months.

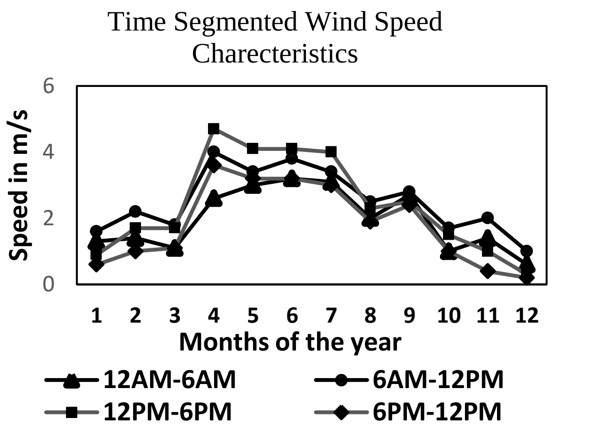

Fig. 4. Semi diurnal speed characteristics

Table 6. Turbine Detail

Turbine Model	Aventa AV-7	Enercon E-33	Enercon E-53
Rated Output	6.5kW	335kW	810 kW
Rotor Diameter	12.9 m	33.4 m	53 m
Cut In Speed	2 ms^{-1}	3 ms^{-1}	2 ms^{-1}
Cut Off Speed	15 ms^{-1}	26 ms^{-1}	26 ms^{-1}
Energy Output	5457 kWh/year	25392 kWh/year	74429 kWh/year
Capacity factor	9.61%	0.90%	1.0%
Full Load Hour	497 h/year	77 h/year	92 h/year
Operating Hours	5303 h/year	2'488 h/year	5'303 h/year

Output Power and Capacity

Average power output and capacity factor (CF), denote the prospect of a wind power generation site[16]. On the basis of Weibull parameter equation 13 and 14 are used to determine the probable performance of a wind turbine.

$$P_{e,avg} = P_{rated}\left(\frac{e^{-\left(\frac{v_c}{c}\right)^k} - e^{-\left(\frac{v_{rated}}{c}\right)^k}}{\left(\frac{v_{rated}}{c}\right)^k - \left(\frac{v_c}{c}\right)^k} - e^{-\left(\frac{v_c}{c}\right)^k}\right) \quad (14)$$

$$c_f = \frac{P_{e,avg}}{P_{rated}} \quad (15)$$

Monthly generation of this site is calculated for three different wind turbine models. Technical specifications of these turbines are given in Table 6. Full load hour of this site would be 497 and the total operating hour would be 5303. It would yield an annual capacity factor of 9.61% in average by producing 5457kWh of energy per year. Fig.5 shows the output power curve of this turbine in different speed according to the Weibull parameters. Power production distribution and wind speed distribution are also shown (Fig. 5). In this simulation, air density was assumed to be fixed at 1.225 kgm^{-3}.

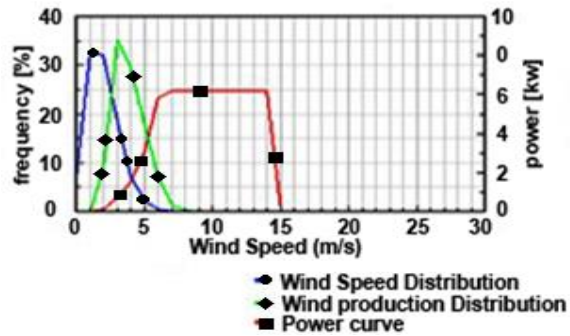

Fig. 5. Power Curve

In Table 7, every month's energy production is predicted along with capacity factor. Capacity factor between the months of April to July is in operational margin. Highest capacity factor is found in between April and May (2015-2016).

Table 7. Month wise Power generation profile (July, 2015-June, 2016)

Month	*K*	*C*	KWh Per month	Capacity Factor
Jan'16	1.28	1.33	104.13	2.20%
Feb'16	1.01	1.07	99.80	2.30%
Mar'16	1.06	1.23	142.77	3%
Apr'16	2.93	3.98	1119.62	23.90%
May'16	3	3.95	1124.32	23.20%
Jun'16	2.78	3.56	824.05	17.60%
Jul'15	1.43	3.07	870.55	18.00%
Aug'15	1.88	2.55	400.44	8.60%
Sep'15	2.01	3.07	650.30	13.90%
Oct'15	1.01	1.01	96.06	2.00%
Nov'15	1.07	0.72	21.62	0.50%
Dec'15	1.48	0.68	3.40	0.10%
Average	1.8	2.2		
Total			5457kWh per year	9.61% yearly

VI. Conclusion

The wind energy potential are yet to be explored in Bangladesh. It is necessary to carry out resource assessment activities throughout the country. Usually the Coastline remains open from sea sides thus it gets more wind energy than the urban areas. Installing small wind turbines may be helpful to study the real time wind power generation in the coastal areas. The analysis shows the Shape factor of the site is 1.8 and the yearly scale factor is 2.2ms^{-1}. The highest values of these parameters are recorded in the month of June when the maximum shape factor is 3 and the maximum yearly scale factor is 3.95 ms^{-1}. The probable wind power production capacity of this site would be around 5457kWh per year and the energy density of this site would be around 11.54 kWhm^{-2}. The yearly capacity factor is found 9.61% which is low but still could return economic benefit. Usually the rooftops of garment factories remain unused. Turbines can be installed directly on the rooftop using small stands and thus can save the construction cost of big tower for each turbine. Multiple installations of such small turbines on same rooftop could increase the overall power generation capacity and could become economically viable.

VII. Acknowledgement

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References

1. Islam M. R., M. N. Rahman, M. A. Mannan, 2016. Study of Wind Power in different parts of Bangladesh, *International Research Journal of Engineering and Technology*, **3, (9)**, 1290-1299
2. Power Predictor Technical Specification Version 1.1
3. Akpinar, E. K. and S. Akpinar, 2004. Statistical analysis of wind energy potential on the basis of the Weibull and Rayleigh distributions for Agin-Elazig, Turkey. *Journal of Power and Energy*, **218**, 557-565.
4. Rocha, P. A. C. R., Sousa R. C. D., Andrade C. F.D, and Silva M. E. V. D, 2012. Comparison of seven numerical methods for determining Weibull parameters for wind energy generation in the northeast region of Brazil, *Applied Energy*, **89**, 395–400.
5. Akdag S.A., H.S.Bagiorgas, and G. Mihalakakou, 2010. Use of two component Weibull mixtures in the analysis of wind speed in the Eastern Mediterranean, *Applied Energy*, **87**, 2566-73.
6. Justus E.G., W.R. Hargraves, A.Mikhail, and GraberD., 1978. Methods for estimating wind speed frequency distributions, *Journal of Applied Meteorology and Climatology*, **17**, 350-53.
7. Celik A.N., 2004. A statistical analysis of wind power density based on the Weibull and Rayleigh models at the southern region of Turkey. *Renewable Energy*, **29**, 593-604.
8. Deaves D.M., I.G. Lines, 1997. On the fitting of low mean wind speed data to the Weibull distribution. *Journal of Wind Engineering and Industrial Aerodynamics*, **66, 3,** 169-178.
9. General wind energy information, Federal Office of Energy, The website for wind energy data of Switzerland, http://wind-data.ch/index.php.
10. Conradsen K., L.B. Nielsen, L.P. Prahm,1984.Review of Weibull statistics for estimation of wind speed distributions, *Journal of Climate and Applied Meteorology*, **23, (8),** 1173-1183.
11. Open Energy Information (Open EI), National Renewable Energy Laboratory and the U.S. Department of Energy, https://openei.org
12. NASA Surface meteorology and Solar Energy: GlobalDataSets,https://eosweb.larc.nasa.gov/cgi-bin/sse/global.cgi
13. Open Energy Information (Open EI), National Renewable Energy Laboratory and the U.S. Department of Energy, https://maps.nrel.gov/swera/#/?aL=0&bL=groad&cE=0&lR=0&mC=40.21244%2C-91. 625976&zL=4.
14. Global Wind Atlas (GWA2.0), Technical University of Denmark (DTU Wind Energy) and the World Bank Group (consisting of The World Bank and the International Finance Corporation, or IFC). https://globalwindatlas.info.
15. Jamil M., S. Parsa, and M. Majidi,1995. Wind Power Statistics and an Evaluation of Wind Energy Density, *Renewable Energy*, **6**, 623-628.
16. Chang T. J., Y. T. Wu, H. Y. Hsu, C. R. Chu, and C. M. Liao,2003. Assessment of Wind Characteristics and Wind Turbine Characteristics in Taiwan, *Renewable Energy*, **28**, 851-871.