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ANALYSIS OF WIND ENERGY RESOURCE AT CHITTAGONG COASTLINE

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Abstract*- This paper presents an assessment of a coast side building rooftop for wind energy harvesting site Data is analyzed using Weibull distribution functions. Three statistical methods are used to find and compare Weibull parameters. Weibull probability density function f(x) and cumulative distribution have been used to explain observed data. Shape factor for this site is found 1.8 and scale factor is 2.2ms^{-1} yearly. The highest values of these parameters occur at June as 3 and 3.95ms^{-1} where mean wind speed is 2.23ms^{-1} and highest speed is 3.7 ms^{-1}. Three small turbines are used to predict yearly energy production with comparison. Possible energy production is about 5457KWh per year with 11.54 KWhm^{-2} of energy density. A data acquisition site was established in Chittagong EPZ and collection was done for one year. Categorized data is analyzed and presented here. The work may help concluding over feasibility of energy harvesting in Chittagong coastline.*

Keywords: Chittagong coastline, Rooftop, Wind energy, Weibull distribution and Wind turbine

1. INTRODUCTION

Solar PV applications has become a popular solution in off grid regions of developing countries. In cities, building's rooftops are being used to install PV based generation units. However, mega Watt scale Solar PV plants are yet to be established [1] in Bangladesh. Although the potential of wind energy over urban areas of Bangladesh is low, wind speed at roof top of high rise buildings might be found considerable for power generation. Coast side areas are considered to be windier than other locations. Analysis is done after the collection of data for one year from the sample site. The site is located at 22°17'16.9" North and 91°46'30.2" East at Chittagong EPZ. The building is adjacent to coastline. Data is recorded with a data logger from 2015 to 2016 to complete a year round. The data logger was installed on the rooftop above 30 meter from ground. Statistical methods are used to predict and characterize the site. Weibull shape and scale parameters are determined using various methods. Energy and power production analysis is done based on these parameters. At the end of this article, an energy production scenario is also drawn using three small wind turbines to conclude the site performance.

2. METHODOLOGY

For wind speed data analysis the three parameter Weibull distribution function can be expressed by two parameters [2]. The two parameter Weibull distribution is widely used for this purpose. 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 [3]. 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 [3]. 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. Cumulative distribution function of Weibull distribution is an additional part of the probability density function (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. Curve fitting with probability density function, Method of moments (MOM) and Empirical method are used here to determine and compare between results [4].

3. DETERMINATION OF WEIBULL PARAMETERS

In this paper, three methods are used to determine the Weibull parameters from the data. These are discussed and commented on following sections.

3.1 Curve Fitting

Frequency distribution is matched with the PDF from where the parameters are determined, shown in figure 1. Figure 2 shows the cumulative distribution function, CDF. The SWISS wind power data analyzing tool [5] has been used to analyze and fit frequency distribution to the corresponding PDF. 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. Table 1 contains shape and scale parameter of the Weibull distribution found from each month data. From PDF graph it is evident that the most probable wind speed at 30 meter height for this site is about 1 m/s. The shape parameter k signifies the stability of the wind speed [6]. It is found 1.8 for yearly values. The characteristics wind speed for this site is 2.2 m/s on that height.

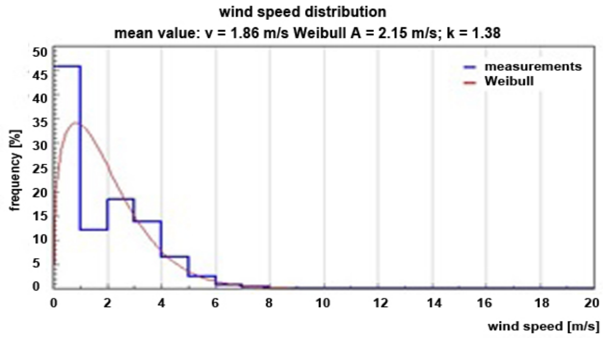

Fig.1: Frequency Distribution and Weibull PDF of measured data

3.2 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 use standard deviation ' σ ', mean wind velocity 'v' and gamma ' Γ ' function. Gamma function given as equation (7) is calculated on (1+1/k). The two moments are given in equations (3) and (4). Equation 4 uses standard deviation also.

$$v = c\Gamma(1+\frac{1}{k}) \qquad (3)$$

$$k = (\frac{0.9874}{\frac{\sigma}{v}})^{1.0983} \qquad (4)$$

3.3 Empirical Method

Similar to that of MOM, Empirical method uses standard deviation and mean wind speed. These are given as 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 found considering all recorded data and the calculated mean is derived from PDF. SWERA data for this location is found measured at 50 meter above the ground and presented in Table 2 along with recorded data. Recorded and SWERA data seem to have differences as those are observed from different heights. There are only one data set is available from NASA for monthly average wind speed for this location. This is a low resolution data measured at 50m above ground [7].

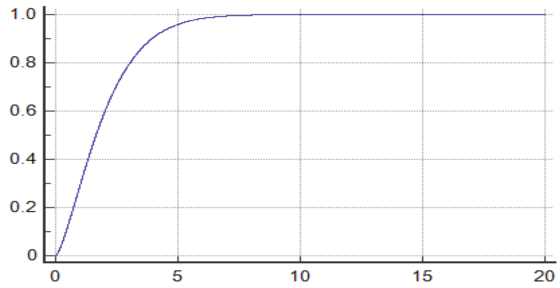

Fig.2: CDF of measured data

$$k = (\frac{\sigma}{v})^{-1.086} \qquad (5)$$

$$c = \frac{v}{\Gamma(1+\frac{1}{k})} \qquad (6)$$

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

Another high resolution data set considers only wind power density and annual average speed. Total 5 results of this set is found for this location which is from WIND RISOE-DTU given at table 4.

Table 1: Weibull parameters k and c

Month	Calculated PDF		Method of Moment		Empirical Method	
January	K	C	K	C	K	C
February	1.28	1.33	0.93	1.06	0.95	1.07
March	1.01	1.07	1.26	1.61	1.27	1.61
April	1.06	1.23	1.08	1.44	1.09	1.45
May	2.93	3.98	3.13	4.14	3.08	4.14
June	3	3.95	2.89	3.81	2.84	3.82
July	2.78	3.56	3	3.92	2.95	3.92
August	1.43	3.07	1.97	3.84	1.96	3.83
September	1.88	2.55	1.24	2.25	1.25	2.26
October	2.01	3.07	1.57	2.84	1.57	2.84
November	1.01	1.01	0.87	1.21	0.89	1.23
December	1.07	0.72	1.65	1.34	1.65	1.34
Yearly	1.48	0.68	0.99	0.5	1.01	0.5
	1.8	2.2	1.7	2.3	1.7	2.3

The month of April, May and June show the stable fashion of wind in this site where the value of k ranges between 2.78 to 3 and C in 3.56ms^{-1} to 3.98ms^{-1}. Method of moment and empirical method data have deviations from calculated values. Deviations are found as ±0.1.

4. COMPARISON WITH OTHER SOURCE OF DATA

NASA low resolution data at 50 meter height shows the yearly average to be 2.74 and NOAA moderate resolution at 90 meter height is 7.78 where measured average is found 2.23 at 50 meter height. Measured data has difference of 0.51ms^{-1} with NASA provided data.

Table 2: Mean wind Speed from different data sources

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

SWERA high resolution data has 5 sets of results for the same site presented in table 3. These data has 1ms^{-1} deviation in between and 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

5. POWER AND ENERGY MEASUREMENTS

Power and energy production potential of a site could be determined in various ways. Energy and power density indicate the availability of producible in every square meter [8]. Most probable wind speed 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. K and C determined in previous section are used here.

5.1 Most probable Wind Speed and Maximum Energy

Most probable wind speed (V_p) and maximum energy carrying wind speed (V_m) is calculated using equation 8 and 9 where Weibull parameters were used. Result is derived for each months and presented in table 4. Again it is evident that on this height three months of a year can be productive for this site.

$$V_p = c(\frac{k-1}{k})^{\frac{1}{k}} \quad (8)$$

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

Table 4: Most probable and most energy carrying wind speed

Months	K	C	Vp	Vm
January	1.28	1.33	0.41	2.77
February	1.01	1.07	0.01	3.15
March	1.06	1.23	0.08	3.34
April	2.93	3.98	3.45	4.75
May	3.00	3.95	3.45	4.68
June	2.78	3.56	3.03	4.33
July	1.43	3.07	1.32	5.66
August	1.88	2.55	1.70	3.75
September	2.01	3.07	2.18	4.33
October	1.01	1.01	0.01	2.98
November	1.07	0.72	0.06	1.93
December	1.48	0.68	0.32	1.21
Yearly	1.80	2.20	1.40	3.33

5.2 Energy and Power Density

Based on Weibull parameters, Power density and Energy density were calculated using equation 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 also. General equation for power density is given in equation 10. Air density ' ρ ' was calculated against the pressure and temperature data of this site and equation 13 was used.

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

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

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

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

Table 5: Power and Energy density

Month	k	c	P_d (w/m^2)	Hour T	E_d (kWh/m2)
January	1.28	1.33	4.05	744	3.01
February	1.01	1.07	4.34	672	2.91
March	1.06	1.23	5.55	744	4.13
April	2.93	3.98	39.01	720	28.09
May	3.00	3.95	37.75	744	28.08
June	2.78	3.56	28.63	720	20.61
July	1.43	3.07	38.87	744	28.92
August	1.88	2.55	14.47	744	10.77
September	2.01	3.07	23.44	720	16.87
October	1.01	1.01	3.65	744	2.71

November	1.07	0.72	1.08	720	0.78
December	1.48	0.68	0.39	744	0.29
yearly	1.80	2.20	9.81	8760	11.54

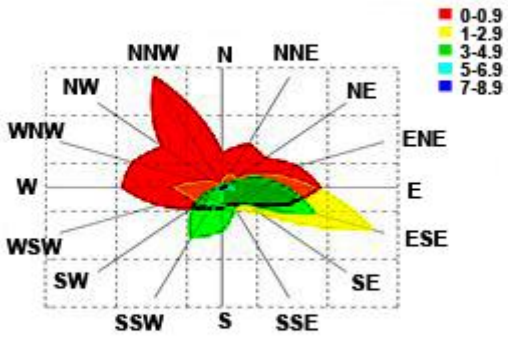

Fig.3: Wind Rose Diagram

Figure 3, wind rose diagram 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. In figure 4 semi diurnal speed 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.

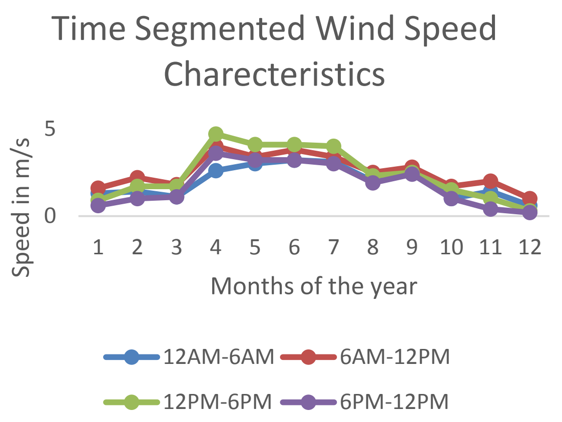

Fig.4: Semi Diurnal speed characteristics

5.3 Output Power and Capacity

Average power output and capacity factor (CF), denote the prospect of a wind power generation site [9]. On the basis of Weibull parameter equation 13 and 14 are used to determine the probable performance of a wind turbine.

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

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

Monthly generation of this site is determined using a small wind turbine. Technical and performance measures of the turbine is given in table 6. Full load hour for this site would be 497 and the total operating hour 5303. It would yield an annual capacity factor of 9.61% in average by producing 5457KWh of energy per year. Figure 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 presented in figure 5. In this simulation and in other calculation air density was assumed to be fixed at 1.225 kgm^{-3}.

Table 6: Turbine Detail

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

In table 7, every month's energy production is predicted along with capacity factor. Capacity factor between Aprils to July is in operational margin. Highest capacity factor would lies between April and May.

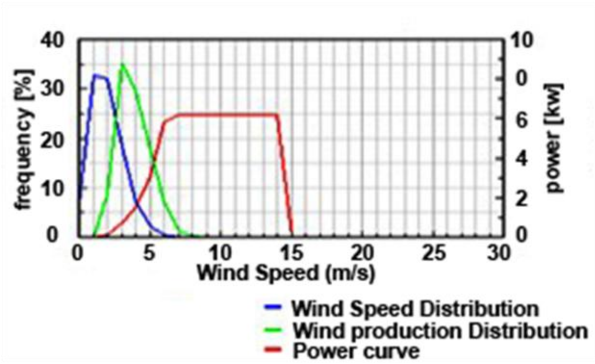

Fig.5: Power Curve

Table 7: Month wise generation profile

Month	K	C	KWh Per month	Capacity Factor
January	1.28	1.33	104.13	2.20%
February	1.01	1.07	99.80	2.30%
March	1.06	1.23	142.77	3%
April	2.93	3.98	1119.62	23.90%
May	3	3.95	1124.32	23.20%
June	2.78	3.56	824.05	17.60%
July	1.43	3.07	870.55	18.00%
August	1.88	2.55	400.44	8.60%

September	2.01	3.07	650.30	13.90%
October	1.01	1.01	96.06	2.00%
November	1.07	0.72	21.62	0.50%
December	1.48	0.68	3.40	0.10%
Average	1.8	2.2		
Total			5457KWh per year	9.61% yearly

6. CONCLUSION

The prospect of wind energy in Bangladesh is yet to be studied more to explore it properly. It is very necessary to carry out data collection activities throughout the country. Coast lines are naturally remains open from sea sides. Installing small wind turbines may be initiated to study for real time generation. This paper conducts Analysis on some specific aspects of wind energy research on acquired data. Analysis shows the possible energy generation by different schemes. All calculated results shows the possible generation only on per meter square area on 30 meter above the ground. Multiple installations on higher heights would increase the generation capacity. If we consider to install a handful numbers of wind turbines, coastal areas would be a good choice to examine the real time generation at first.

7. ACKOWLEDGEMENT

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8. REFERENCES

[1] Md. H. Ullah, T. Hoque, and Md. M. Hasib, "Current Status of Renewable Energy Sector in Bangladesh and a Proposed Grid Connected Hybrid Renewable Energy System", *International Journal of Advanced Renewable Energy Research*, Vol. 1, Issue. 11, pp. 618-627, 2012.

[2] S.A. Akdag, H.S. Bagiorgas, and G. Mihalakakou, "Use of two component Weibull mixtures in the analysis of wind speed in the Eastern Mediterranean" *Applied Energy*, vol. 87, pp. 2566-73, 2010.

[3] E.G. Justus, W.R. Hargraves, A. Mikhail, and D.Graber, "Methods for estimating wind speed frequency distributions", *Journal of Applied Meteorology and Climatology*, vol. 17, pp. 350-53, 1978.

[4] C.G. Justus, W.R. Hargraves, A. Mikhail and D. Grabber, "Methods for Estimating Wind Speed Frequency Distributions", *Journal of Applied Leteorology*, Vol. 17, pp. 350 – 353, 1978.

[5] http://wind-data.ch/index.php. (19th January, 2017)

[6] K. Conradsen, L.B. Nielsen, L.P. Prahm, "Review of Weibull statistics for estimation of wind speed distributions", *Journal of Climate and Applied Meteorology*, Vol. 23, issue. 8, pp. 1173-1183, 1984.

[7] https://maps.nrel.gov/swera/#/?aL=0&bL=groad&cE=0&lR=0&mC=40.21244%2C-91.625976&zL=4. (22th April, 2017)

[8] M. Jamil, S. Parsa, and M. Majidi, "Wind Power Statistics and an Evaluation of Wind Energy Density," Renewable Energy, Vol. 6, pp. 623-628 1995.

[9] T. J. Chang, Y. T. Wu, H. Y. Hsu, C. R. Chu, and C. M. Liao, "Assessment of Wind Characteristics and Wind Turbine Characteristics in Taiwan," *Renewable Energy*, Vol. 28, pp. 851-871, 2003.

9. NOMENCLATURE

Symbol	Meaning	Unit
T	Temperature	(K)
P	Pressure	(Pa)
A	sweep area of blade	(m^2)
CF	capacity factor	Unit less
P_d	Power density	(Wm^{-2})
E_d	Energy density	($kWhm^{-2}$)
f ( )	Weibull pdf	
F( )	cumulative Weibull function	
Γ( )	Gamma function	
K	Weibull shape factor	Unit less
C	Weibull scale factor	(ms^{-1})
v_p	most probable wind speed	(ms^{-1})
v_m	wind speed carrying maximum energy,	(ms^{-1})
v	wind speed,	(ms^{-1})
T	time period	hr
σ	Standard deviation	Unit less
ρ	air density,	(Kgm^{-3})