International Journal Of Renewable Energy Research, IJRER
A.A.Bhuiyan, A.K.M.S.Islam, A.I.Alam, Vol.1, No.3. pp.83-90, 2011

Application of Wind Resource Assessment (WEA) tool: A case study in Kuakata, Bangladesh

Arafat Ahmed Bhuiyan, A K M Sadrul Islam, Abdullah Ibne Alam

Department of Mechanical and Chemical Engineering, Islamic University of Technology (IUT), Board Bazar, Gazipur-1704, Dhaka, Bangladesh

‡ Arafat Ahmed Bhuiyan, Department of Mechanical and Chemical Engineering, Islamic University of Technology (IUT),

Board Bazar, Gazipur-1704, Dhaka, Bangladesh. Tel: +88029291254-59, Fax: +88029291260,
e-mail: arafat@iut-dhaka.edu , sadrul@iut-dhaka.edu, arafat46@gmail.com

Received : 05.07.2011 Accepted : 06.07.2011

Abstract- Wind data at Kuakata, Bangladesh has been analysed using a web tool named Wind Energy Assessment (WEA) software developed at IUT. The software is available at http://iutoic-dhaka.edu/wea . From March to September the mean wind speed varies between 3 to 5 m/s and the shape factor, k and scale factor, c varies from 1.7 to 2.3 and 4.1 to 5.0 m/s respectively. An assessment has been made of the energy generation by a typical wind turbine of rated capacity of 1 kW. This turbine has been found to produce an energy output per year of 2243 kWh, and the production costs has been found 12.3 ($ 0.175)Taka/kWh. The environment benefits comparing with coal based power plant shows a greater advantage. The amount of harmful emissions saved per year are CO2=1862 Kg, NO2=0.13 Kg, SO2=1.35 Kg, NOx=4.71 Kg.

Keywords- Wind energy, Shape and scale factor, rated power, Weibull and Rayleigh distribution.

1. Introduction

Bangladesh, between 20'34" and 26'39" North Latitude, and between 88'00" and 92'41" East Longitude, is one of the most densely populated countries with 79% of the population living in rural areas. Over 80% of people depend on traditional energy sources for their energy needs. But it is endowed with vast renewable energy resources such as solar, wind and biomass resources. Harnessing these resources appears to be a promising solution for improving the quality of the life of rural villagers, who are unlikely to have access to conventional electricity supply in the foreseeable future. One of the first actions needed when interested in wind energy in a region is to establish an overview of the available wind resource. This overview should make it possible to identify areas of high and low winds. But there is no systematic way to assess the wind potential in the country. Local Government Engineering Department (LGED) and Bangladesh Centre for Advanced Studies (BCAS), two Government Organizations (GO's) in 1996-97 have taken initiatives to assess the wind potential in several coastal regions and the reports indicate that the location of Bangladesh fall in a comparatively low wind regime. Since the study was concentrated in the coastal regions only, the LGED has taken an initiative to measure the wind data throughout the country under "Wind Energy Resource Mapping" program funded by United Nations Development Program (UNDP). The study has been designed in a more comprehensive way aiming at systematic observation on wind regime in initially 20 different suitable locations including Hill Tracts region over a longer period of time. Out of these 20, this study demonstrates the wind energy potential at Kuakata of Bangladesh. Also assessment of the electricity generations at this site and preparation of detail technical and economical analysis will be done.

This assessment will be performed using the online Wind Analysis Tool titled “Wind Energy Assessment Tool (WEA)” at http://iutoic-dhaka.edu/wea which will be helpful for the researcher as well as interested populace to analysis the data of various stations.

Several assessments have been given for different location for the potentiality of wind by different researchers. A. S. Ahmed Satha, R. Hanitsch [1-2] evaluated the wind energy potential of Mediterranean Sea in Egypt and analyzed the potential of electricity generation on the east coast of Red Sea in Egypt. Wind characteristics have been analyzed on long-term measured data of monthly mean wind speed. Ten coastal meteorological stations along the Mediterranean Sea in Egypt and seven meteorological stations along the east coast of Red Sea in Egypt have been used for statistical analysis to determine the wind characteristics. The methodical analysis for the corrected monthly wind power density at a height of 10 m above ground level, over roughness class 0 (water), for each station was done. It was found that three stations of Mediterranean Sea in Egypt show annual mean wind speed greater than 5.0 m/s. The methodical analysis for all stations was done for the corrected monthly and annual mean wind power at a height of 10 m, over roughness class 0 (water). The recommended correlation equation was also stated for Mediterranean Sea zone in Egypt and for Red Sea zone in Egypt. Also the wind power densities for heights of 10-50 m were calculated for all stations of Mediterranean Sea in Egypt and the corrected annual wind power density at the heights 50-70 m was obtained for all stations of Red Sea in Egypt. In order to identify the Weibull parameters for all stations two different methods were applied. They have also perform economic analysis with capacity factor and cost analysis of electricity generation from two turbines machines having capacity of 1000 and 600 kW. M. Arif Hossain et al [3] assessed the wind resource of four meteorological stations of Barishal division close to the Bay of Bengal. From the available observed raw wind data long term averages on monthly and annual basis have been obtained, from which probability distribution of wind speed, velocity duration curves and distribution of power in the wind are plotted. Using the probability distribution of wind speed, the Weibull scale and shape parameters are calculated. The annual Weibull parameters (k and c respectively) for all the stations of Barishal divisions are, Barishal 1.048 and 1.566, Bhola 2.198 and 1.407, Khepupara 1.947 and 2.660, Patuakhali 2.283 and 2.100.

2. Methodology

As mentioned earlier that the present study aims to assess the wind potential in Bangladesh using the built up software on Wind Resource Analysis titled “Wind Energy Assessment Tool (WEA)” is based on the following methodology.

For estimating the wind energy potential of a site, the wind data collection from the location should be properly analyzed and interpreted. For a better understanding of wind variability, the data are often grouped and presented in the form of frequency distribution. For wind power calculations, averaging the velocity using basic equation is often misleading. For wind energy calculations, the velocity should be weighted for its power content while computing the average [5]. If the velocity is presented in the form of frequency distribution, the average velocity, V_m and standard deviation, σ_v are given by,

$$V_m = \left(\frac{\frac{1}{n}\sum_{i=1}^{n} f_i V_i}{\sum_{i=1}^{n} f_i} \right)^{\frac{1}{3}} \qquad (1)$$

$$\sigma_v = \sqrt{\frac{\sum_{i=1}^{n} f_i (V_i - V_m)^2}{\sum_{i=1}^{n} f_i}} \qquad (2)$$

Here, Vm = Average velocity, fi = Frequency, V = mid value of the corresponding interval and n = Number of wind data.

Several methods can be used to assess the wind for a particular site [4-15]. Justus CG and Mikhail Amir [4], Lysen H [6], Darwish ASK and Sayigh AAM [7], Nafaoui et al [8], Jamil M et al [9], Khogali A et al [10] and Vogiatzis N et al [11], have shown four different methods for the estimation of k and c parameters. Weibull distribution is a good match with the measured data. The idea is that only annual or monthly average wind speeds are sufficient to predict the complete frequency distribution of the year or the month. In Weibull distribution, the variations in wind velocity are characterized by the two functions: (i) The probability density function f(V) and (ii) The cumulative distribution function F(V) as given in the following equations [5].

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} e^{-\left(\frac{V}{c}\right)^{k}} \quad (3)$$

$$F(V) = \int_0^\infty f(V)\,dV = 1 - e^{-\left(\frac{V}{c}\right)^{k}} \quad (4)$$

Here, k is the Weibull shape factor and c is scale factor.

Average wind velocity and the standard deviation of wind of a regime, following the Weibull distribution are given by the following equation (6).

$$V_m = c\Gamma\left(1 + \frac{1}{k}\right) \quad (5)$$

$$\sigma_V = c\left[\Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right)\right]^{\frac{1}{2}} \quad (6)$$

Graphical method (GM) is another way to determine the k and c from Weibull distribution [5]. We transform the cumulative distribution function in to a linear form, adopting logarithmic scales .Taking the logarithm twice, we get,

$$\ln\{-\ln[1 - F(V)]\} = k\ln(V_i) - k\ln c \quad (7)$$

Plotting the above relationship with ln(Vi) along the X and ln{-ln[1-F(V)]} along Y, if we generate the regression equation, we can find out the values of k and c.

The Weibull factors k and c can also be estimated from the mean and standard deviation of wind data by the following equation (6).

$$\left(\frac{\sigma_V}{V_m}\right)^2 = \frac{\Gamma\left(1+\frac{2}{k}\right)}{\Gamma^2\left(1+\frac{1}{k}\right)} - 1 \quad (8)$$

Once σ_m and V_m are calculated for a given data set, then k can be determined by solving the above expression numerically [5]. Once k is determined, c is given by,

$$c = \frac{V_m}{\Gamma\left(1+\frac{1}{k}\right)} \quad (9)$$

For the precise calculation of k and c, adequate wind data, collected over shorter time intervals is essential. In many cases, such information may not be readily available. Under such situations, a special case of the Weibull model can be derived, approximating k as 2 [5]. This is known as the Rayleigh distribution, taking k=2, we have,

$$V_m = c\Gamma\left(\frac{3}{2}\right), c = \frac{2V_m}{\sqrt{\pi}} \quad (10)$$

Wind energy density and the energy available in the regime over a period are usually taken as the yardsticks for evaluating the energy potential. The interested factors are the wind energy density (E_D), most frequent wind velocity (V_{Fmax}) and the velocity contributing the maximum energy (V_{Emax}). Peak of the probability density curve represents V_{Fmax}. For a unit area of the rotor, power available (PV) in the wind stream of velocity V is given by the following equation (6).

$$P_V = \frac{1}{2}\rho_a V^3 \quad (11)$$

Where ρ_a= Density of wind.

The fraction of time for which this velocity V prevails in the regime is given by f(V). The energy per unit time contributed by V is PV f(V). Thus the total energy, contributed by all possible velocities in the wind regimes, available for unit rotor area and time may be expressed as [5]

$$E_D = \frac{\rho_a c^3}{2}\frac{3}{k}\Gamma\left(\frac{3}{k}\right) \quad (12)$$

Once E_D is known, energy available over a period (E_T) can be calculated as [5]

$$E_T = E_D T = \frac{\rho_a c^3 T}{2}\frac{3}{k}\Gamma\left(\frac{3}{k}\right) \quad (13)$$

Where T is the time period. The most frequent wind velocity and the velocity contributing maximum energy to the regime are given by [5]

$$V_{Fmax} = c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \quad (14)$$

$$V_{Emax} = \frac{c(k+2)^{\frac{1}{k}}}{k^{\frac{1}{k}}} \quad (15)$$

Considering Rayleigh distribution, wind energy density and energy available for the unit area of the rotor can be expressed as [5]

$$E_D = \frac{3}{\pi}\rho_a {V_m}^3 \quad (16)$$

$$E_I = E_D T = \frac{3}{\pi}\rho_a {V_m}^3 \quad (17)$$

The most frequent wind speed and the velocity contributing maximum energy are defined as [5]

$$V_{Fmax} = \sqrt{\frac{2}{\pi}} V_m \tag{18}$$

$$V_{Emax} = 2\sqrt{\frac{2}{\pi}} V_m \tag{19}$$

The factors influencing the energy produced by a Wind Energy Conversion System (WECS) at a given location over a period are: (i) the power response of the turbine to different wind velocities (ii) the strength of the prevailing wind regime and (iii) the distribution of wind velocity within the regime.

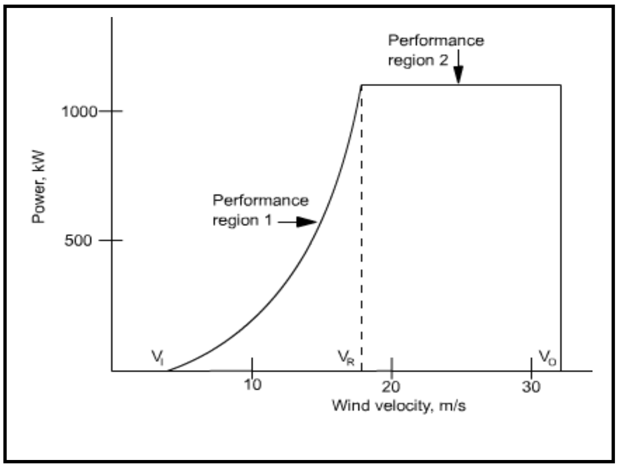

Fig. 1. Ideal power curve of a pitch controlled wind turbine [5]

Let E_{IR} and E_{RO} be the energy developed by the system at its performance regions 1 and 2 respectively referring to fig. 1. Then E_{IR} and E_{RO} can be computed by adding the energy corresponding to all possible wind velocities between V_1 and V_2. Thus,

$$E_{IR} = T\int_{V_I}^{V_R} P_V f(V)dV \tag{20}$$

$$E_{RO} = T\int_{V_R}^{V_O} P_V f(V)dV \tag{21}$$

The total energy generated by the wind turbine, over a given period of time, is the sum of energy derived from the performance region 1 and 2. Thus

$$E_T = E_{IR} + E_{RO} \tag{22}$$

Capacity factor is one of the important indices for assessing the field performance of a wind turbine. The capacity factor (C_F) of WECS at a given site is defined as the ratio of the energy actually produced by the system to the energy that could have been produced by it, if the machine would have operated at its rated power throughout the time period [5]. Thus,

$$C_F = \frac{E_T}{TP_R} \tag{23}$$

There are three different ways in which the cost of a wind energy system is commonly expressed. They are (1) cost per rated power of the turbine (2) cost per unit rotor size and (3) cost per kWh of electricity generated are given in the following equations [5].

$$C_{PR} = \frac{C_T}{P_R} \tag{24}$$

$$C_A = \frac{C_T}{A_T} \tag{25}$$

$$C_E = \frac{C_E}{E_I} = \frac{C_A}{8760\, C_F P_R} \tag{26}$$

C_T is the cost of the turbine, A_T is the rotor area, C_A is the cost unit size of the turbine, E_I is the kWh generated, C_F is the capacity factor. Annual cost of operation of a project would essentially have two components fixed costs and variable costs [5]. Thus,

$$C_A = F_C + V_C \tag{27}$$

3. Results and Discussions

In this study the wind data has been used in Kuakata which is in the southern part of Bangladesh, one of the windiest areas. LGED has wind monitoring station in Kuakata, Patuakhali, which locates 21°54.76’ north 90°08.24’ east. The sample data was taken for the year of 2006 at 20 m, 30 m heights.

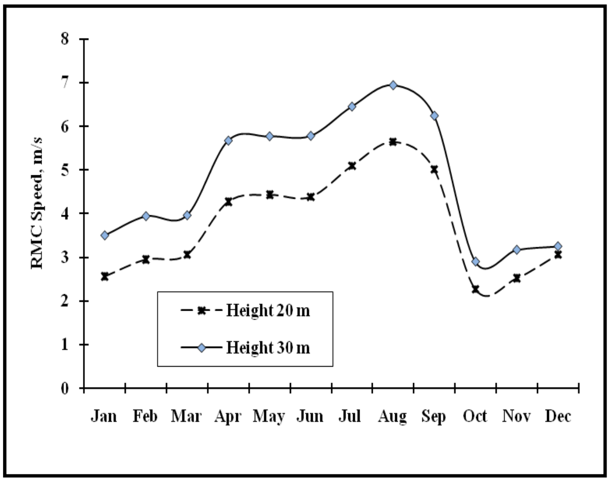

Fig. 2. Monthly RMC Speed at various heights

The RMC speed of wind for two different heights is graphically shown in Fig. 2. It shows that at different heights, the respective lowest winds occur through post monsoon (from November -February) period. From the starting of pre-monsoon (March-May) the speed starts to climb up, and attain their maximum by August and nearly remains constant through the months, and then it gradually decreases till to October. The maximum monthly wind speed is in the month of August of about 5.64 and 6.94 m/s for the height of 20 and 30 m respectively. Minimum speeds are 2.27 and 2.9 m/s in the month of October. The site is assumed to be windy as the average speed is 3.77 and 4.79m/s throughout the year.

One year data with an interval of ten minutes of the mentioned stations have been analyzed on both monthly and yearly basis. Following parameters have been generated for monthly data analysis: Mean velocity (V_m) (m/s), Root Mean Square (RMS) (m/s), Root Mean Cube (RMC) (m/s),Shape parameter, k (dimensionless), Scale parameter, c (m/s), Most frequent wind velocity, V_{Fmax} (m/s), Velocity contributing maximum energy, V_{Emax} (m/s), Energy density, E_D (kW/m^2). Monthly data analysis using Weibull and Rayleigh based approach is given in table 1 and 2 for the height of 20m and 30m respectively.

In order to analyze the energy generated by the wind turbine, 1 kW turbine with following specification is considered: Rated Power, P_R= 1 kW, Cut-in Velocity, V_I¬= 2 (m/s), Rated Velocity, V_R= 9 (m/s), Cut-out Velocity, V_O= 13 (m/s), Ideal velocity power proportionality, n = 2. The power curve of the sample turbine is shown in fig. 3. Yearly data analysis and energy generation output with above mentioned sample wind turbine using the developed software is given in table 3. Following parameters have been generated for annual data analysis and energy generation: Mean velocity, V_m (m/s), Root Mean Square, RMS (m/s), Root Mean Cube, RMC (m/s), Shape parameter, k (dimensionless), Scale parameter, c (m/s), Most frequent wind velocity, V_{Fmax} (m/s), Velocity contributing maximum energy, V_{Emax} (m/s), Energy density, E_D (kW/m^2), Total energy output, E_T (kWh), Capacity factor, C_F.

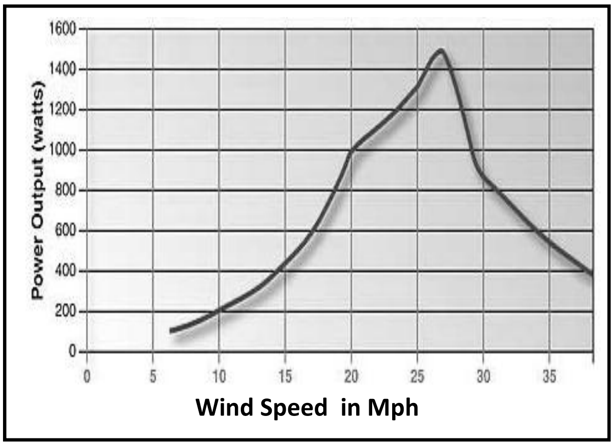

Fig. 3. Power Curve of 1kW sample wind turbine [16].

Let us assume the 1 kilo-watt turbine considering the following specifications: Price of the turbine is, 2027 USD approximately, Initial installation cost is, 608 USD Approximately (30 % of turbine cost), Annual operation and maintenance cost, 70 USD approximately (3.5 % of turbine cost), Rate of interest is, 5%, 10%, 15%, Life period of turbine is, 25 years (assume). As seen from the yearly data analysis that mean speed is 4.18 m/s at 30m height and CF=0.23. Based on the above statistics, the cost of wind energy has been calculated for 30 m height and is given in table 4.

As per estimates of the IEA, 23683 Mt of CO_2 has been released to the atmosphere by the power sector during 2001 [17]. Emission of CO_2 due to power generation has registered an increase of 65 percent in during the past three decades. Wind energy does not pollute the air or water with harmful gases and materials not generate hazardous waste. Being a non depletable source, extracting energy from wind does not pose the threat of over exploiting the limited natural resources. Hence wind is considered as one of the cleanest sources of energy available today. So based on the statistics, the amount of harmful emission saved per year by extracting energy from wind at Kuakata is shown in table 5. Environmental benefits can also be compared with fuel emission based power plant after some modification of the coding in the development of the software.

Table 1- Monthly data analysis at 20 m height

Month	*Rayleigh Based Approach*				*Weibull Based Approach*									
					Graphical Method					*Standard Deviation*				
	V_m	V_{Fmax}	V_{Emax}	E_D	k	c	V_{Fmax}	V_{Emax}	E_D	k	c	V_{Fmax}	V_{Emax}	E_D
Jan	2.15	1.71	3.42	0.01	1.51	2.56	1.26	4.47	0.02	3.06	2.98	2.62	3.51	0.02
Feb	2.62	2.09	4.18	0.02	2.46	2.9	2.34	3.69	0.02	3.45	3.47	3.14	3.96	0.02
Mar	2.65	2.11	4.23	0.02	2.19	2.94	2.23	3.95	0.02	3.15	3.6	3.19	4.2	0.03
Apr	3.83	3.06	6.12	0.07	2.59	4.02	3.33	5.02	0.04	3.5	4.95	4.5	5.63	0.07
May	3.79	3.02	6.05	0.06	1.92	4.33	2.95	6.29	0.07	3.01	5.13	4.49	6.08	0.08
Jun	3.82	3.04	6.09	0.07	2.28	4.1	3.19	5.4	0.05	3.14	5.08	4.5	5.94	0.08
Jul	4.44	3.54	7.08	0.1	2.21	4.76	3.62	6.37	0.08	3.16	5.89	5.22	6.88	0.12
Aug	4.75	3.79	7.58	0.13	1.93	4.99	3.42	7.21	0.11	2.8	6.49	5.55	7.87	0.17
Sep	3.81	3.04	6.08	0.06	1.7	4.62	2.75	7.29	0.1	2.51	5.73	4.68	7.25	0.13
Oct	1.75	1.4	2.8	0.01	1.25	1.97	0.55	4.23	0.01	2.72	2.56	2.17	3.14	0.01
Nov	2	1.59	3.19	0.01	1.33	2.52	0.88	5.02	0.03	3.15	2.86	2.53	3.34	0.01
Dec	2.04	1.63	3.26	0.01	1.16	2.46	0.44	5.84	0.03	2.68	3.32	2.79	4.08	0.02

Table 2. Monthly data analysis at 30 m height

Month	*Rayleigh Based Approach*				*Weibull Based Approach*									
					Graphical Method					*Standard Deviation*				
	V_m	V_{Fmax}	V_{Emax}	E_D	k	c	V_{Fmax}	V_{Emax}	E_D	k	c	V_{Fmax}	V_{Emax}	E_D
Jan	3.11	2.48	4.96	0.04	2.19	3.32	2.51	4.47	0.03	3.36	4.1	3.69	4.71	0.04
Feb	3.57	2.85	5.7	0.05	2.52	3.98	3.26	5.03	0.04	3.76	4.59	4.23	5.15	0.06
Mar	3.54	2.83	5.66	0.05	2.46	4.02	3.25	5.12	0.04	3.55	4.61	4.2	5.23	0.06
Apr	5.07	4.05	8.09	0.15	2.49	5.51	4.48	6.98	0.11	3.47	6.54	5.93	7.45	0.16
May	4.97	3.96	7.93	0.14	2.16	5.32	3.99	7.2	0.11	3.03	6.65	5.83	7.86	0.18
Jun	5.07	4.05	8.1	0.15	2.46	5.51	4.46	7.02	0.11	3.22	6.66	5.93	7.73	0.18
Jul	5.74	4.58	9.15	0.22	2.36	6.2	4.91	8.06	0.17	3.4	7.42	6.69	8.5	0.24
Aug	5.97	4.76	9.53	0.25	2.11	6.29	4.64	8.63	0.19	2.97	7.97	6.94	9.48	0.31
Sep	4.93	3.94	7.87	0.14	1.95	5.95	4.12	8.53	0.18	2.62	7.16	5.97	8.89	0.24
Oct	2.56	2.04	4.09	0.02	2.31	2.72	2.13	3.56	0.01	3.34	3.42	3.07	3.93	0.02
Nov	2.79	2.23	4.46	0.03	1.74	3.49	2.13	5.43	0.04	3.58	3.7	3.37	4.18	0.03
Dec	2.82	2.25	4.5	0.03	1.7	3.13	1.86	4.95	0.03	3.15	3.79	3.36	4.43	0.03

Table 3(a) - Annual Energy Generation at different heights by Weibull based approach

			Height 20m	*Height 30m*
Weibull Approach	Graphical Method	k	1.60	1.87
		c (m/s)	3.74	4.90
		V_{Fmax}	2.02	3.25
		V_{Emax}	6.22	7.23
		E_D	0.06	0.10
		E_T (kWh)	1376	2243
		C_F	0.16	0.26
	Standard Deviation	k	2.51	2.68
		c (m/s)	4.68	5.97
		V_{Fmax}	3.82	5.02
		V_{Emax}	5.91	7.35
		E_D	0.07	0.14
		E_T (kWh)	1877	3170
		C_F	0.21	0.36

Table 3(b)- Annual Energy Generation at different heights by Rayleigh based approach

		Height 20m	*Height 30m*
Rayleigh Approach	RMS (m/s)	3.62	4.70
	RMC (m/s)	4.08	5.19
	V_m (m/s)	3.14	4.18
	V_{Fmax} (m/s)	2.50	3.34
	V_{Emax} (m/s)	5.01	6.67
	E_D (kW/m^2)	0.04	0.09
	E_T (kWh)	1036	2045
	C_F	0.12	0.23

Table 4 - Cost of wind energy

Station Name	V_m (m/s)	C_F	*Cost of wind energy (Taka/kWh)*		
			5%	10%	15%
Kuakata	4.18	0.23	12.3($ 0.175)	11.11($	10.44($

Table 5 - Environmental benefits comparing with Coal based Power Plant

Station Name	V_m (m/s)	E_T (kWh)	Amount of harmful emission saved per year (kg)				
			CO_2	NO_2	SO_2	NO_x	Particula
Kuakata	4.18	2243	1862	0.13	1.35	4.71	0.22

Conclusion

A web tool titled "Wind Energy Assessment Tool" developed at IUT has been used to prepare a technical assessment of the energy generation for a sample wind turbine of 1 kW at Kuakata. From March to September the mean wind speed varies between 3 to 5 m/s and the k and c varies from 1.7-2.3 and 4.1-5.0 m/s respectively. It was also found that energy output per year of 2243 kWh and the production costs was found 12.3 (USD 0.175) Taka/kWh for interest rate of 5%.

Acknowledgements

The authors are greatly thankful to the authority of Islamic University of Technology (IUT) for hosting this free website.

References

[1] A. S. Ahmed Satha, R. Hanitsch. "Evaluation of wind energy potential and electricity generation on the coast of Mediterranean Sea in Egypt." Renewable Energy 2006; 31(8):1183-23.

[2] A. S. Ahmed Satha, R. Hanitsch. "The potential of electricity generation on the east cost of Red Sea in Egypt." Renewable Energy 2006;31(10):1597-4.

[3] M. Arif Hossain, M Zakir Hossain, A.K.M. Sadrul Islam, "Wind Resource Assessment of Bangladesh: Bay Belt Meteorological Stations of Barishal Division." BSME-ASME Internal Conference on Thermal Engineering 31 December 2001 – 2 January 2002, Dhaka, Bangladesh, PP 571-576.

[4] Justus CG, Mikhail Amir. "Height variation of wind speed and wind distributions statistics." Geophysical Research Letters 1976;3(5):261-4.

[5] Sathyajith Mathew, "Wind Energy, Fundamentals, Resource Analysis and Economics", ISBN-10, 3-540-30905-5, Springer Berlin Heidelberg, New York.

[6] Lysen H. "Introduction to wind energy." Consultancy Services, Wind Energy, Developing Countries (CWD), 82-1, May, 2nd Edition, The Netherlands; 1983. p. 36-47.

[7] Darwish ASK, Sayigh AAM. "Wind energy potential in Iraq." Solar & Wind Technology 1988;5(3):215-22.

[8] Nfaoui H, Bahraui J, Darwish ASK, Sayigh AAM. "Wind energy potential in Morocco"Renewable Energy 1991;1(1):1-8.

[9] Jamil M, Parsa S, Majidi M. "Wind power statistics and evaluation of wind energy density." Renewable Energy 1995;6(5):623-8.

[10] Khogali A, Albar OF, Yousif B. "Wind and solar energy potential in Makkah (Saudi Arabia) – Comparison with Red Sea costal sites." Renewable Energy 1991;1(3):435-40.

[11] Vogiatzis N, Kotti K, Spanomitsios S, Stoukides M. "Analysis of wind potential and characteristics in North Aegean, Greece." Renewable Energy 2004; 29:1193-208.

[12] Justus CG, Hargraves WR, Mikhail A, Graber D "Methods of estimating wind speed frequency distribution." J Applied Meteorology 1978; 17:350-353

[13] Boweden GJ, Barker PR, Shestopal VO, Twidell JW "The weibull distribution function and wind statistics." Wind Engineering 1983; 7:85-98.

[14] Chang TJ, Wu YT, Hsu HY, Chu CR, Liao CM "Assessment of wind characteristics and wind turbine characteristics in Taiwan." Renewable Energy 2003; 28:851-871.

[15] Corotis RB, Sigl AB, Klein J "Probability models for wind energy magnitude and persistence." Solar Energy 1978; 20:483-493.

[16] http://windenergy7.com/forums/

[17] IEA (2003) Emissions. Key world energy statistics. International Energy Agency pp 44-46.