International Journal Of Renewable Energy Research, IJRER
A.Roy, Vol.1, No.4, pp.290-297 ,2011

Assessment of Commercial Wind Profiles for Bangladesh in Hotspots Determined by the UNEP

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Received:30.07.2011 Accepted:24.08.2011

Abstract- This paper predicts pragmatic turbine level profiles of wind power, the fastest growing source of renewable energy in the world, for zonal areas in the South Asian country of Bangladesh selected on the basis of global readings provided by the United Nations Environmental Programme (UNEP). Without focusing exclusively on the coastal belt according to tradition, hotspots (regions with high wind potential) uniformly located around the country are taken into consideration. Nine observation stations from three such hotspots in the country are documented with respect to statistics of wind speed, vertical power law coefficients, wind power density distribution at different heights, extraction of energy factor, prominent direction distribution of wind, and approximation of weibull density functions over a ten year period using measured meteorological raw data. Profiles are projected for commercial turbine heights (~40-60m) and the available internationally accepted power classes for wind are identified at the stations to assess the true wind potential of Bangladesh.

Keywords- Regime Prediction, Wind Power Density Distribution (DD), Weibull Distribution.

1. Introduction

With an energy crisis looming in almost every sector of the global industrial production assembly, estimation of feasible wind power resources from available wind data and its promotion as a viable alternative power source are gaining popularity in the research community. Although predictions for natural gas reserve in Bangladesh, a country located in South Asia, have always been optimistic indicating great potential, recent crises in the country's gas sector have worked as a negating factor refuting the previously held assumptions [1]. The country produces three quarters of its electricity using compressed natural methane gas (CNG), but still faces a gaping hole in its supply with the projected deficits reaching up to 814 million cubic feet per day (mmcfd) in a decade's time (around 2019). Even with very low per capita commercial energy consumption rates, the projected energy requirements of the country will depend on the rate of increase in the gross domestic product as a whole, which has shown some signs of promise in recent years [2].

As the conventional power generation and distribution infrastructure in Bangladesh will not be able to expand to support additional demands up to 20,000 megawatts (estimated) according to experts, grid-connected alternative power systems incorporating fuel, solar and wind technology have been tried out in various government and United Nations backed projects [2]. In the opinion of the European Union, wind sector is establishing itself as the alternative choice for power with the highest yearly new installation rate on a global scale. Fig. 1 shows the worldwide cumulative and annual installed wind capacity for the last fifteen years with both rates rising following a fairly consistent rate. The geographical distribution of in the newly launched wind firms (standalone or connected) suggest a relation between the level of economic prosperity and the number of initiated wind projects (see Fig. 2) [3]. So, accurate predictions for wind profile and available wind power in local sites are essential for project planning in the alternative energy sector. Even during this high-time, grid connected turbines currently contribute less than 10% in the spectrum of local alternative power projects in Bangladesh [4].

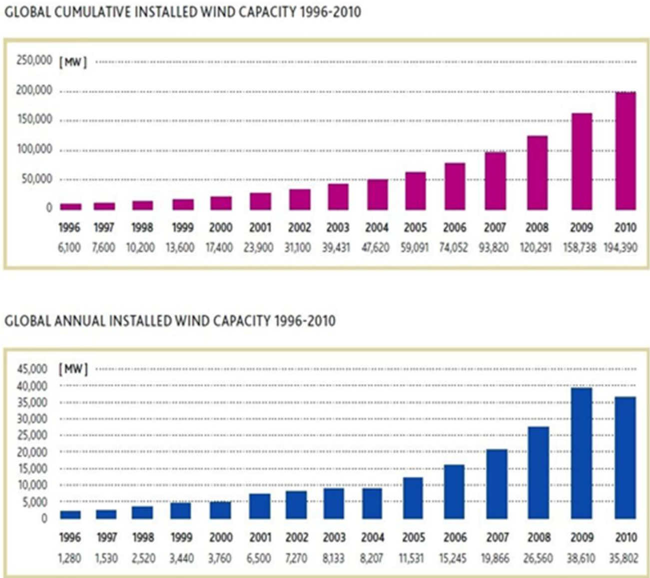
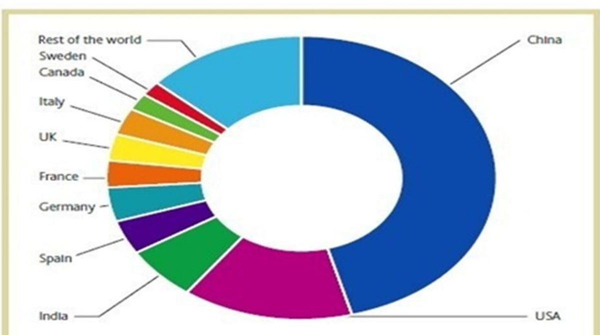


Fig. 1. Cumulative and annual global installed wind capacity of the last fifteen years [3]

Although initial surveys for the country's wind potential focused exclusively on the country's sea-shore coastal spots in the south-east [5, 6], the United Nations' earth modelling environment programme (UNEP) has identified three potential hotspots (regions with high wind potential) in the Bangladeshi mainland, with land locked mass regions in the north, near-shore inland spots in the southeast along with the potential belt along the sea line and offshore islands [7]. To remove the inadequacies of 10m level anemometers readings [5-6, 8] analysis of wind performance is predicted in this paper at elevations of 50m with respect to statistics of wind speed, vertical power law coefficients, wind power density at different heights, extraction of energy factor, prominent direction distribution of wind, weibull functions and approximation of density functions over a ten year period to predict the true wind potential of Bangladesh.

TOP 10 NEW INSTALLED CAPACITY JAN-DEC 2010



Country	MW	%
China	16,500	46.1
USA	5,115	14.3
India	2,139	6.0
Spain	1,516	4.2
Germany	1,493	4.2
France	1,086	3.0
UK	962	2.7
Italy	948	2.6
Canada	690	1.9
Sweden	603	1.7
Rest of the world	4,750	13.3
Total TOP 10	31,052	86.3
World Total	35,802	100

Fig. 2. Recently installed wind capacity for the year 2010

2. UN Prescribed Wind Map of Bangladesh

Fig. 3 shows an atlas indicating the relative distribution of wind energy on the Bangladeshi mainland, produced following Solar and Wind Energy Resource Assessment Protocols written by the Environment Program of the United Nations (UN) to categorize the landmasses of the country and assess their wind potential [9]. An observation will show that the hotspots (indicated by a rise in the colour index with 1 being the lowest level and 8 being the highest) are not located uniformly

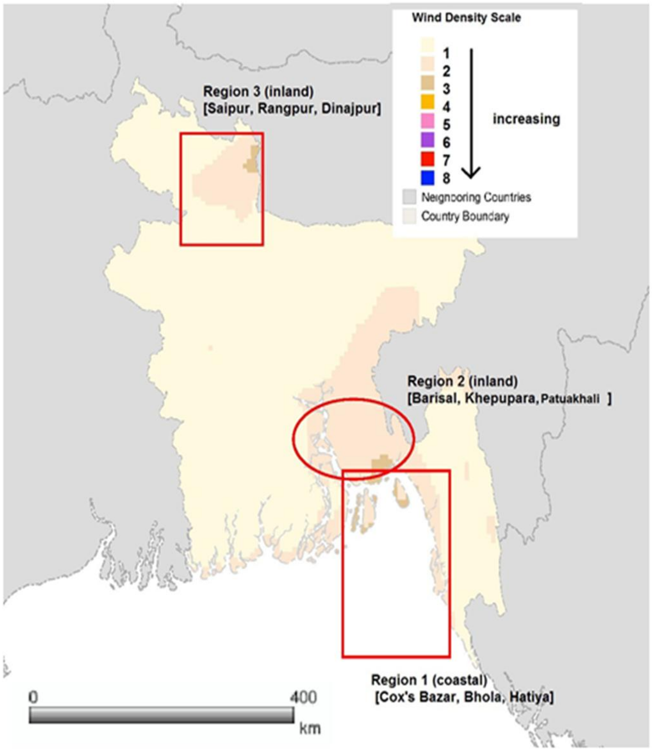


Fig. 3. UNEP prescribed Wind Profile with three Hotspots on the Map of Bangladesh

around the mainland of Bangladesh. They are diversely placed with points located in the north sector in a land locked position (Region 3) and along the south-southeast coastal regions covering offshore, sea-line and deep-inland localities (Regions 1 and 2). Raw data of meteorological information is collected from these hotspots over the concerned interval (1998-2007, ten years) with the help of selected stations owned by the Meteorological Dept of Bangladesh at around the 10m mark. The objective of this paper is to establish a statistical wind regime for selected stations in the mentioned regions at commercial turbine heights.

3. Methodology and Results of Commercial Wind Regime Assessment

3.1. Average Statistics of Wind Distribution

The estimation of average wind speeds calculated for each month of the observed ten year period helps to identify seasonal variation of the wind potential and the time period when the output of the wind farm will be maximized at elevations greater than 30m. The local mean wind speeds can also be the basis of a fair estimation of projected annual energy production for a standalone wind farm. Fig. 4 shows the average statistics in terms of predicted monthly wind velocity at a height of 50m for six weather stations (Cox's Bazar, Bhola, Patuakhali, Barisal, Dinajpur, Saidpur) from the three discussed regions during the period of 1998-2007. The results project that, similar patterns of

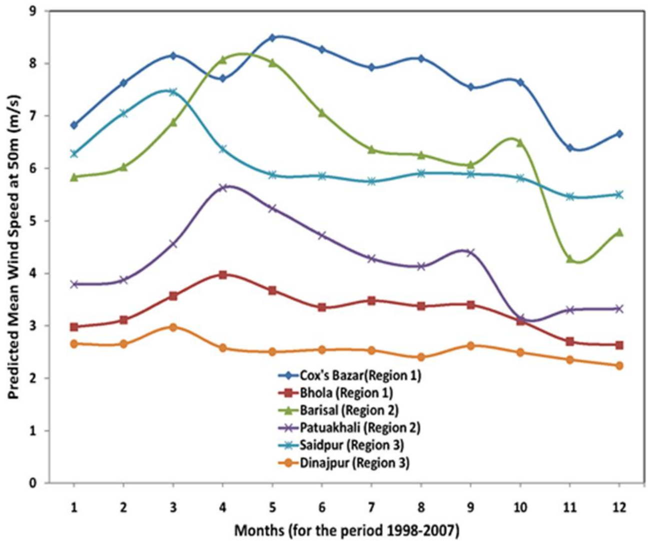


Fig. 4. Average monthly wind profiles at 50m from the three regions

consistent high winds within the interval of March to July for Cox's Bazar. For Region 2 (Patuakhali, Barisal), the wind curves have two peaks, a maximum peak around April (5.5-8.5 m/s) and a shorter peak around September-October (4.5-7 m/s). Region 3 shows lower speeds peaking around the months of February to April at the start of the year with Dinajpur occupying the bottom spot showing a relatively flat profile.

3.2. Vertical Wind Speed Factor for Speed Prediction

The measured data accumulated from BMD (National Met. Department) owned substations are obtained at a ground-level height averaging around 10-15m in tower altitude. However, projected wind speeds at a higher altitude of 50-70m become necessary for new installation of wind and hybrid generators as raw data are not directly available in the absence of *sub-100m* weather stations. An efficient way of predicting the wind speed at 50m and 70m will be using the power law equation of the wind profile [8]. In this method, the value of the power law coefficient (γ) is used to extrapolate wind speeds at hub-heights for the practical wind turbines. For neutral stability conditions, we propose γ to be approximated by the $1/7^{th}$ power law. The value of this coefficient is assumed to be constant during evaluation of wind resources, because differences of velocity between two altitude levels in the *10-70m* domain are limited within a threshold level which does not introduce significant deviations in the predictions. The factor is also verified by equation (1) when measured data are available for two different altitudes (*10-100m*) in the same location. Here,

$$\gamma = \frac{\log(Vp / Vg)}{\log(H_2 / H_1)},$$

(1)where Vp and Vg are the predicted (or collected) and measured wind speeds at heights H_2 and H_1, respectively. Factor γ can be empirically derived which also supports the choice of the one-seventh law [10]. With this assumption, if the hub height of a wind turbine is h_{new}, then the extrapolated wind speed $V_{turbine}$ measured on the basis of known data V_{mes} at height h_{mes} will be given by

$$V_{turbine} = V_{mes} * (\frac{H_{new}}{H_{mes}})^{\gamma}. \qquad (2)$$

Following the mentioned criteria, measured and predicted wind profiles for the three hotspots at different hub heights of ~10m and 50m for a ten year period are derived using the power law profile [11] and shown in Table I as a chart.

3.3. Density Distribution of Wind Power

The density distribution (DD) in W/m^2 is often employed to get an approximate measure of extractable wind power that could be supplied from grid-connected turbines at possible wind sites. Under conditions of atmospheric stability, if there is not a perceptible change of average density of air in the surroundings of the turbine, then mean density distribution (in W/m^2) has the expression

$$DD = \frac{1}{2}\rho U^3, \tag{3}$$

where ρ is averaged over reading of the ambient air density and U^3 is the long term (ten year: accounting for the yearly months) average reading of the third degree exponents of mean monthly wind speeds. Statistically speaking, if the frequency of occurrence of particular wind speeds is accessible and taken into account then this curve can provide the extracted shape factor which could

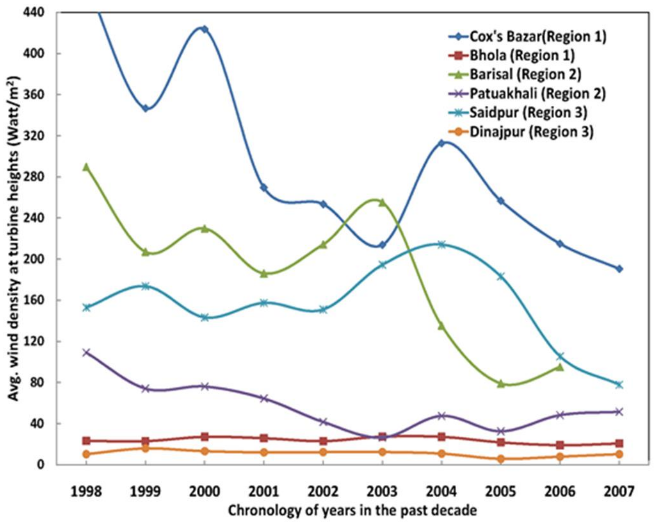


Fig. 5. Average wind density distribution at turbine heights for six stations

be incorporated to get a more accurate estimate [12] of elevated wind density distributions like

$$DD = \frac{1}{2}K\rho V^3, \tag{4}$$

with K being the extracted shape factor and V being the averaged over wind speed during the period of observation. Following the chronology of ten years ('98-'07), average density distribution of six stations are made available in Fig. 5 indicating inconsistency in the distribution patterns. Stations at Bhola and Dinajpur records readings below 40 W/m^2 but at the same time produce a relatively flat curve. Saidpur, Cox Bazar and Barisal have the highest average values in this distribution.

3.4. Wind Regime by Power Class and Weibull Distribution

The wind potential of an area is globally classified by the wind power classes which depend on the ambient wind density distribution and the height of the turbine axle. Fig. 6 records Wind Power Classes (at 50m) available in Bangladesh over the last ten years following international standards, showing a highest obtainable class of four on a scale of seven.

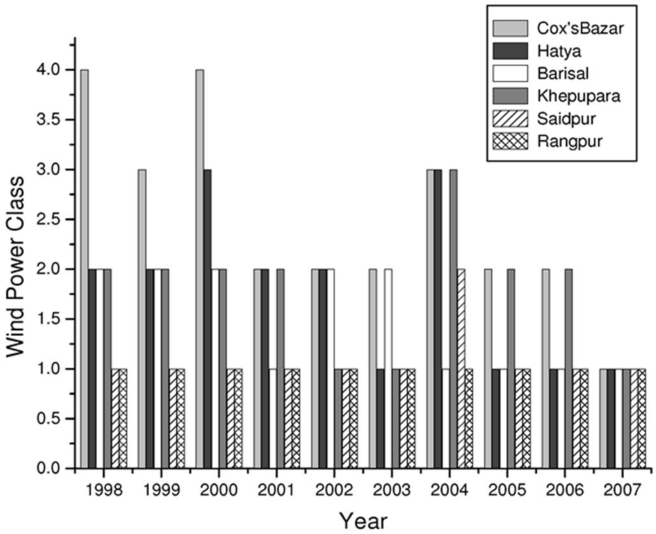


Fig. 6. Available wind power classes (at 50m)

As mentioned in the previous section, the shape fctor (*k, no unit*) is utilized fro predicting density distribution (*DD*), and it also can be incorporated in the Weibull distribution [13] to derive the scale parameter (*c, unit m/s*) which would provide a long-term estimate of the average wind velocity in the site. Statistical derivation of the shape factor is possible from a curve plotting the ratio of standard deviation of wind samples (σ) and weighted mean wind speed ($\bar{v}$) [14]. To find the shape of the probability histogram curve the factors c and k are defined as

$$c = \bar{v}/\Gamma(1+\frac{1}{k}), \text{ and} \tag{5}$$

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086}, (1 \le k \le 10) \qquad (6)$$

following the definition of the first order Bessel function used in the definition of the scale factor [15]. This Bessell relation has linear and exponential components both depending on the scale factor derived empirically or from the ratio curve:

$$\Gamma\left(1+\frac{1}{k}\right) = 0.825 + 0.0135k + \exp[-(2+3(k-1))].$$
(7)

The ratio curve discussed with relation to the weibull parameters is documented in Fig. 7 for a limited range when the shape factor lies in the domain *1<k<4* and the ratio has less than the unit value. The factor of energy pattern (EPF) is a second way [14] of relating the measured or predicted wind speed statistics to the shape (k) and scale (*c*) factors. If the derived EPF is plotted against the k parameter, then the curve traces a similar pattern in Fig. 7 like the $\sigma / \bar{v}$ locus presented in the same frame.

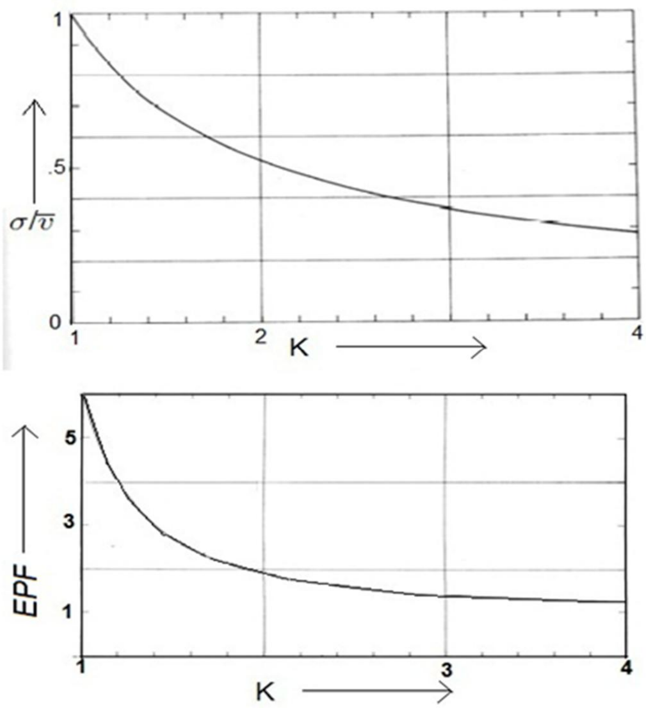


Fig. 7. The dependence of the ratio curve and energy pattern (Ke) on the histogram shape factor

Here, EPF is derived from the average monthly wind data for a particular year with the definition

$$EPF = \frac{\frac{1}{Y}\sum_{j=1}^{Y}(U_j)^3}{\left(\frac{1}{Y}\sum_{j=1}^{Y}U_j\right)^3}. \qquad (8)$$

In this equation, the total number of samples for a yearly set is usually twelve (*Y=12*) with *Uj* representing the estimated profile at 50m for the individual months. So, the *k* factor extracted using the previous method can be verified against the *EPF vs k* curve. The extracted density distribution at turbine elevations along with the scale factors, wieighted averages and enrgy pattern factors are tabulated in table II at three sample stations in Hatya, Barisal and Rangpur.

3.5. *Directional Distribution in Terms of Frequency*

Estimation of commercial wind profiles also depends on the directional distribution of wind gusts which is prominently available in the

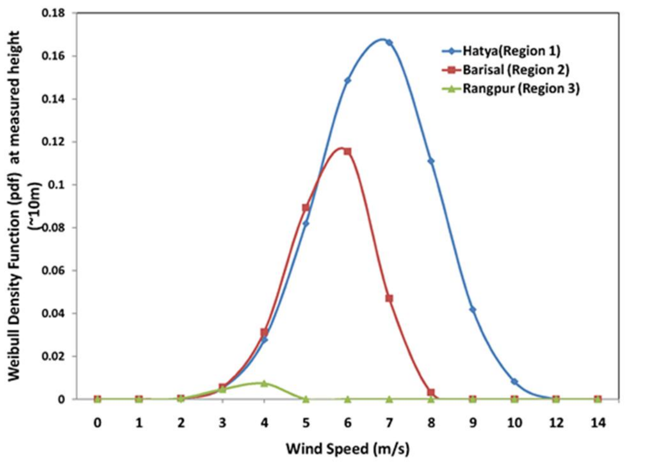


Fig. 8. Weibull functions for three stations at weather tower heights

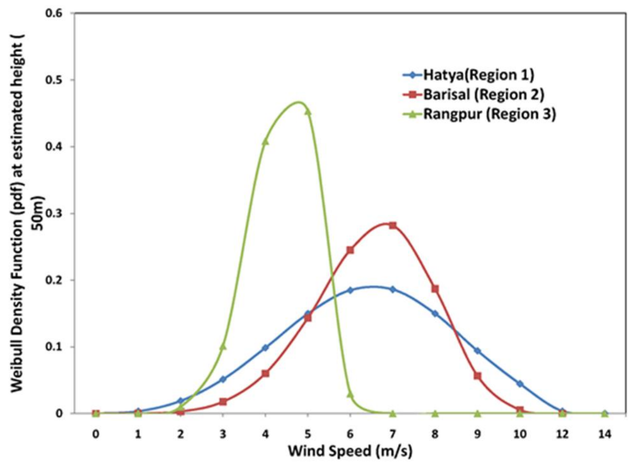


Fig. 9. Elevated weibull functions for 50m turbine level

weather station in question. As shown by table III, which is derived from data obtained for six weather points in the three hotspots in 2007; for Hatya and Coz's Bazar in Region 1 and Barisal and Patuakhali in Region 2, the predominant direction is south occypying 60% of the spectrum for Barisal and Cox's Bazar and 42% of the coverage for Hatya. For these two near-shore and inland regions around 20% of the direction spectrum is covered by north, north-east and north-west directions during the winter months. The land-locked third inland hotspot represented by Rangpur and Sydpur experience 58% and 41% of their flows from the east and the north-east vectors, respectively. The mean standings for the entire country puts the southern direction strictly in the top position with a 40.3% coverage during a typical year.

3.6. PDFs for Range of Predicted Wind Speed

Probability distribution function (PDF) can help to characterize the domain or range of speeds which are particularly likely to occur in a concerned station under observation. This information helps to determine the size and capacity of installed wind turbines. Out of the two distribution functions which are employed in this case [16], the weibull function (f) is defined for a specific wind velocity (v) to define the range of variability of wind speed in a particular location

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right](k > 0, v > 0, c > 1). \quad (9)$$

Here *k* and *c* are the statistical factors defined in the previous section. The *CDF* (cumulative distribution function) for the wind speed *v* is derived by integrating the weibull function to find the relative probability of finding a particular window in the speed range for a specific region on the basis of previously observed data. The integration results in the expression

$$F(v) = \int_0^v f(v)dv = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right]. \quad (10)$$

The weibull function (from eq. (9)) for the three stations (Hatya, Barisal, Rangpur) calculated using the anemometer wind velocity (a littile over 10m) and the estimated profile (at 50m) are shown in Fig. 8 and 9, respectively. The *PDF* for Rangpur is almost grounded at 10m but at the turbine height it has the highest percentage probability albeit with a narrower range of speeds. At the commercial turbine height, region 1 (Hatya) has the widest range of available wind speeds peaking at 7m/s whereas regions 2 (Barisal) and 3 (Rangpur) have higher probabilities of getting peak wind speeds of 7 and 4.9 m/s, respectively.

4. Present and Future Prospects of Wind Energy in the Three Hotspots

The physical implementation of wind energy systems in Bangladesh has been initiated mainly by Bangladesh Power Development Board (BPDB) with four units of grid connected wind energy turbine systems, each having a rating of 225kW located in remote regions. BPDB has also installed 50 stand-alone wind turbines, each having a capacity of 20kW, on the island of Kutubdia (Region 1) in 2008. The Local Government Engineering Department has also implemented a 10kW hybrid power system using wind energy at Saint Martin's island and a 400W emergency system at a cyclone shelter in Patuakhali (Region 2) [4, 17]. The analysis and the figures of the previous section suggest that among the regions with wind potential in Bangladesh the near-shore zone in the southeast (Barisal) are suitable for medium scale wind farms and the coastal belt and the offshore islands are suitable for larger projects (Cox Bazar, Hatya) [9]. It would suggest that, establishment of more meteorological stations are necessary for the north zone and the concerned authorities can look for increasing on their efforts with medium scale wind projects in regions one and two in the south and the southeast. Already istalled turbines in Bangladesh account for 5.2% of the total generations in the renewable sector. The power generation record in Bangladesh stands at 4936MW, achieved on 18 July 2011, still falling short of the daily peak demand of around 5100MW [18]. In the present situation, BPDB has planned to expand wind power (100-200MW off-shore) systems in coastal areas of Anoara, Chittagong (Region 1) [11].

Table 1. Measured and predicted mean monthly wind speeds for the Hotspots

Month	Mesured Speed at 10m (Region1, Hatya)	Predicted Speed at 50m (Region1, Hatya)	Mesured Speed at 10m (Region2, Barisal)	Predicted Speed at 50m (Region2, Barisal)	Mesured Speed at 10m (Region3, Rangpur)	Predicted Speed at 50m (Region3, Rangpur)
January	3.41	4.29	4.63	5.83	2.83	3.56
February	4.34	5.46	4.79	6.03	3.23	4.07
March	5.20	6.55	5.47	6.88	3.70	4.66
April	5.89	7.42	6.41	8.07	4.32	5.44
May	6.13	7.71	6.37	8.01	3.38	4.25
June	6.11	7.69	5.61	7.06	3.27	4.12
July	5.98	7.53	5.06	6.36	3.42	4.31
August	5.19	6.53	4.97	6.25	3.23	4.07
September	4.88	6.15	4.82	6.07	3.60	4.53
October	5.46	6.88	5.16	6.49	3.70	4.66
November	3.75	4.73	3.40	4.28	3.19	4.02

Table 2. Ten-year turbine-level estimation of scale factors (C in m/s), EPF factors and Density Distribution (DD)

Place	Hatya(Region 1)				Barisal (Region 2)				Rangpur (Region 3)			
Year	Scale (m/s)	Vmean(m/s)	DD (W/m2)	EPF Factor	Scale (m/s)	Vmean(m/s)	DD (W/m2)	EPF Factor	Scale (m/s)	Vmean(m/s)	DD (W/m2)	EPF Factor
1998	7.65	6.67	234.22	1.29	8.26	7.61	289.47	1.08	4.10	3.86	36.94	1.05
1999	7.51	6.50	242.86	1.44	7.48	6.69	207.06	1.13	4.37	4.03	42.84	1.07
2000	8.55	7.44	324.97	1.29	7.70	6.98	229.68	1.11	5.13	4.77	70.60	1.06
2001	7.46	6.51	214.21	1.27	7.17	6.54	186.10	1.09	4.53	4.05	46.74	1.15
2002	8.29	7.22	298.10	1.30	7.53	6.61	214.17	1.21	4.56	4.20	48.60	1.08
2003	6.31	5.69	125.00	1.11	7.86	6.83	255.01	1.31	4.37	4.21	47.13	1.04
2004	8.44	7.36	318.14	1.30	6.47	5.86	135.33	1.10	4.98	4.51	62.20	1.11
2005	6.16	5.39	116.56	1.22	5.41	4.79	78.92	1.17	4.99	4.61	64.02	1.07
2006	5.66	4.87	106.46	1.51	5.74	5.19	94.94	1.11	5.27	4.64	75.21	1.24
2007	5.62	4.91	90.11	1.24	-	-	-	1.14	4.68	4.19	51.35	1.15

Table 3. Yearly Frequency Distribution (Percentage) of Wind Directions

Direction	Cox's Bazar	Hatya	Barisal	Khepupara	Saidpur	Rangpur
S	58.33	41.67	58.33	75	0	8.33
SW	0	0	0	0	0	0
W	0	0	8.33	0	25	8.33
NW	0	16.67	8.33	0	0	0
N	25	16.67	16.67	25	0	0
NE	16.67	8.33	0	0	16.67	41.67
E	0	0	8.33	0	58.33	25

5. Conclusion

A estimated projection of Bangladesh's potential for wind energy is presented in this paper to identify diverse locations to support the country's feeble power sector. The points of observation are selected employing a survey by the Environment Programme of the United Nations (UNEP). A number of weather stations from three different hotspots are covered to extract projections in terms of average statistics for wind speed distribution, vertical wind speed factors, frequency and density distribution, probability functions and energy factors. The findings identify the coastal belt of the country with the highest potential at turbine level with fourth level wind classes and the necessity of installing more observation spots in the inland areas to enable an accurate assessment of integrating small to medium range turbines (driven by 5-10 m/s gusts at 50m) to boost the power production for the country.

Acknowledgements

The author will like to thank the authority of BUET, Bangladesh and Bangladesh

Meteorological Department (BMD) for supplying weather data used during this work.

References

[1] S. Khan, “The search for alternatives," in Star Weekend Magazine, vol. 8, Apr. 2009.

[2] USAID Bangladesh, ``Facts about Energy'', Report on energy situation of Bangladesh, Available at: http://www.usaid.gov/bd/programs/energy.html.

[3] Danish Wind Industry Associations, Statistics on global trends of wind power, Available at: http://www.windpower.org/en/knowledge/statistics/the_global_market.html.

[4] Renewable Energy Research Center (RERC), University of Dhaka, Solar and Wind Energy Resource Assessment (SWERA) - Bangladesh project, Feb. 2007.

[5] S. Dey, ``Wind regime and wind power in the southern coastal islands of Bangladesh," Proc. International Conf. on Energy and Environment, pp. 83-87, Aug. 2006.

[6] M. Islam, Q. Islam and M. Alam, ``Analysis of wind characteristics in Coastal Areas of Bangladesh," IEB J. of Mechanical Engineering, vol. 39, pp. 45-49, Jun. 2008.

[7] UNEP Solar and Wind Energy Resource Assessment (SWERA) Project database, Available at: http://swera.unep.net/index.php?id=7.

[8] N. Diwakar, et al., ``Prediction of wind power potential by wind speed probability distribution in a hilly terrain near Bhopal, Madhya Pradesh'', Int. J. of Emerging Tech., vol. 1, pp. 80-86, 2010.

[9] A. Roy, ”Estimation of Wind Resources at Commercial Altitudes for United Nation Surveyed Inland And Coastal Regions of Bangladesh”, accepted in 9th International Conf. on Mechanical Engineering (ICME), Dec. 2011.

[10] Touma, J.S., ``Dependence of the wind profile power law on stability for various locations'', J. of Air Pollution Control Association, Vol. 27, pp. 863-866, 1977.

[11] A. Roy, ”Prediction of Wind Class and Weibull Regime at Turbine Elevation in Regional Gale Centers of Bangladesh”, under review in International Journal of Engineering and Applied Sciences, 2011.

[12] T. Hughes, ``Oklahoma Windpower Tutorial Series," Environmental Verification and Analysis Center, University of Oklahoma, Nov. 2000.

[13] L. Lin and Y. Hongxing, "Wind Data Analysis and a Case Study of Wind Power Generation in Hong Kong", Wind Engineering, Vol 25, No. 2, 2001, pp 116-123.

[14] Lysen, E., ``Introduction to Wind Energy'', 2nd Edition, Consultancy Services Wind Energy Developing Countries, 1982.

[15] S. Biswas, B. N. Sraedhar, Y. P. Singh, ``A Simplified Statistical Technique for Wind Turbine Energy Output Estimation'', Wind Engineering, Vol 19, No. 3, pp 147-155.

[16] C. Palese, L. Lassig, G. Cogliati and A. Bastanski, “Wind Regime and Wind Power in North Patagonia,Argentina”, Wind Engineering, Vol 24, No. 5, 2000, pp 361-377.

[17] Official Website of Renewable Energy and Environmental Information Network (REEIN). [online]. Available: http://www.reein.org/.

[18] Official Website of Bangladesh Power Development Board (BPDB). [online]. Available: http://www.bpdb.gov.bd/bpdb/index.php?option=com_content&view=article&id=26&Itemid=24.