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Small Windmill as Alternative Power Source for Bangladesh: a Feasibility Survey under Wind Speed Scenarios

Md. Anwarul Karim*

Abstract – *Wind energy is zero fuel consuming, environmentally friendly and cost effective alternative renewable power source. A survey of wind speed was conducted all over Bangladesh within different seasons in a year. A handmade small windmill was used to investigate the voltage generation, current generation and power generation with respect to the wind speed during March 2018 to September 2018 at Chittagong, Bangladesh. The experimental results from small windmill and the survey reports on wind speed especially in coastal areas of the country suggest that the wind energy can be an alternative power source for Bangladesh.*

Keywords – *energy, power generation, small windmill, survey, wind speed.*

1. INTRODUCTION

It is proven all over the world that the windmill can convert wind into electricity and can be a cheap source of grid quality renewable energy. A 1MW grid quality AC power from wind energy costs about 10 times less than that of 1MW grid quality AC power from PV solar cells. Other renewable energy sources have limited scope and are costly. In the world the total installed capacity of wind energy is more than 1,300,000MW. Germany installed more than 30,000MW capacity of wind power plant. Neighbouring country, India also installed 12,000MW capacity of wind power plant. A wind energy power plant can convert wind into electricity in the range from 27% to 30% [1]. From the conversion rate, the wind energy power plant is technically feasible and commercially viable. But the wind energy is facing two major obstacles: 1) the speed of the wind does not remain constant at all. It fluctuates in every second. 2) it is also not available all hours in a day.

Among all renewable energy sources, wind energy is one of the most cost-effective and environmentally friendly sources [2]. Bangladesh has a coastal line of 724 km along the Bay of Bengal [3]. Due to large coastal belt along with wind speed in some regions, the potential of wind power is enormous here [4]. In Bangladesh, power generation is mostly dependent on natural gas, around 76.74% of electricity is being produced from domestic gas reserves [5] and this percentage of electricity generation uses 37% of total gas consumption [6], while demand for gas consumption is increasing by about 8% per year [5]. We are still far from the expected growth of renewable energy, *i.e.,* target 1000-1200 MW and currently produce about 2 MW [7]. Wind can be a major source of energy for Bangladesh, if accurately examined and utilized. Various studies [8]-[11] have been conducted on wind energy and its usefulness in coastal areas in Bangladesh; and they have discussed about the potential of small size wind turbines.

The current government of Bangladesh has given priority to develop renewable sources and wind energy is one of them. Bangladesh Power Development Board (BPDB) has taken up projects in different areas in the country to setup windmill for electricity generation such as Kutubdia Upazila, Cox's Bazar; Sonagazi, Feni; Sirajganj Sadar Upazila, Sirajgonj; Kalapara Upazila, Patuakhali; Maheshkhali Upazila, Cox's Bazar, Chakaria Upazila, Cox's Bazar *etc*. [12].

Among them, Kutubdia (1MW) and Feni (900Kw) are currently generating electricity from wind and supplying to consumers. The wind battery hydrid power plant which is installed at Kutubdia island is an experimental plant with 1 MW capacity. Bangladesh Power Development Board (BPDB) has installed 50 small wind turbines each having 20 kW capacity. This wind battery hydride power plant is successful in Bangladesh and producing the first grid quality, 11 KV or more. It supplies electricity 3 hours during daytime and 3 to 4 hours during night. This project has been running well for more than two years. The wind battery hybrid power plant is supplying 0.60 to 0.80 MWH electrical energy every day at 11KV. Presently, the Wind Battery Hybrid Power Plant (WBHPP) is supplying over 240 MWh electricity at Kutubdia Upazilla [13]. Kutupdia project during cyclone SIDAR was not damaged.

Moreover, there are agreements with private companies for four locations with potential wind speed in the coastal areas of Bangladesh. These locations are (1) Parky Saikat near Patenga, Chittagong; (2) Mognamaghat, Pekua, Cox's Bazar; (3) Muhuri Dam, Sonagazi, Feni; and (4) Kuakata, Patuakhali. These four sites are representatives of the entire coastal areas of Bangladesh. We have seen that the annual average wind speed in these four sites is more than 6.5 m/s. It is an

*Department of Applied Chemistry and Chemical Engineering, University of Rajshahi, Motihar, Rajshahi 6205, Bangladesh.

[1]Corresponding author;
Tel: + 880721711106, Fax: + 880721750064.
E-mail: makarim72@ru.ac.bd.

internationally accepted thumb rule that a site having annual average wind speed of 6.0 m/s or higher is feasible for harnessing wind electricity with commercial viability [3].

In Bangladesh, basically, the power requirement to the tune of 60% is being met through 'Gas' based power plants. There is huge gap between demand and generation of power, which is being covered by coal, diesel, furnace oil and hydro (can be categorized as renewable energy). The contribution of this renewable energy is even less than 2% of total generation. As the demand for power is going up both wind and solar power can be considered as good options. A contract has been awarded to an Indian consortium to set up a 30MW wind power plant in Sonagazi, Dist. Feni. There is a plan to put up three windfarms of 50 MW each, to be installed at Chandpur, Cox's Bazar and Khulan based on 'wind mapping'. In the year 2016 there has been a detailed survey by a consultant from Netherland who declared potential of 16000 MW wind energy for Bangladesh. In the year 2018, USAID reported that Bangladesh is having wind power potential of 34,000 MW at a hub height of 100m based on the simulated study conducted by NREL (National Renewable Energy Laboratory). It is clear from the brief details furnished; there is huge potential of wind energy in Bangladesh.

The country's first ever generation of electricity from wind is at Kutubia Island (20 KW, 50 turbines) with a capacity of 1 MW and another one at Muhuri Dam, Feni having a capacity of 0.9 MW (225 KW, 4Turbines) [14]-[15]. Vesta Company of Denmark is expected to invest 100 MW wind power plant which will be made in Patuakhali. This will be the largest wind power plant of Bangladesh [17]. According to our survey reports of the wind speeds all over the country, it can be assumed that the country has a minimum wind speed to produce wind energy. This is because the effective wind speed of wind turbines usually ranges between 3 and 25 m/s [18].

The aim of the article is to present results from the survey of wind speed and experiment conducted at Chittagong, Bangladesh during March 2018 to September 2018 using handmade small windmill. And the performances of small handmade windmill was measured by generation of power at specific range of heights for wind speed and the rotation of the rotor used in this purpose.

2. METHODOLOGY

Wind Speed Data in Bangladesh

To use wind as an alternative energy source, we need reliable wind data throughout the year. For this reason, different papers are reviewed to summarize the wind speed related information. Table 1 is showing the wind speed in different locations all over the country at 20 m height. Table 2 is summarizes the wind velocity in the whole year (October 2009 to December 2010) at different height at Sandwip. Wind speed in north-eastern part of Bangladesh is above 4.5 m/s while for the other parts of the country wind speed is around 3.5 m/s [19]-[20]. The strong south/south-western monsoon wind come from the Indian Ocean traveling a long distance over the Bay of Bengal, the rough coastal area of Bangladesh. This wind blows over Bangladesh from March to September with a monthly average speed 3 m/s to 9 m/s at different heights. According to studies from Meteorological Department, BCAS, LGED, and BUET [21], these wind speeds are available in Bangladesh mainly during the monsoon. (7 months, March to September). Rest of the months (October to February) wind speed remains either calm or too low. The peak wind speed occurs during the months of June and July [22]. The wind velocity at the coastal area and isolated island is quite higher than the rest of the locations. The Figure 1 is presenting the wind speed at the coastal areas of Bangladesh during March to September 2003 [23]. The wind velocity at the height of 20 m of Sandwip is not sufficient to generate electricity commercially. From the Table 2 the wind velocity at 45m and 60m is sufficient to generate electricity commercially. The average wind velocity at 60m and 45m height are 6.19m/s and 5.65 m/s (calculated) respectively, that are suitable for wind turbine as well as generator. But at winter, the wind velocity goes below the average wind velocity. To fulfil the electrical load demand at Sandwip, high-capacity wind turbine should be used.

Power generation by turbine: Power generated by a wind turbine at particular height, can be calculated by the following equation [24] and a schematic diagram windmill are shown in Figure 2.

$$P = \frac{1}{2}.\rho.a.V^3 C_P \quad (1)$$

Where, ρ= wind power density (w/m^2), a= swept area of blade (m^2), v = velocity of wind (m/sec^2), Cp = rotor efficiency. From that equation we can find out the theoretical wind power density at a certain height. We can also find the range of velocity of wind if we are aware of wind power density of that particular area and vice-versa.

$$C_P = \frac{\left(1+\frac{\vartheta_d}{\vartheta_u}\right)\left(1-\left(\frac{\vartheta_d}{\vartheta_u}\right)^2\right)}{2} \quad (2)$$

Let λ represent the ratio of wind speed ϑd downstream to wind speed ϑu upstream of the turbine, *i.e.*

$$\lambda = \frac{\vartheta_d}{\vartheta_u} \quad (3)$$

or

$$\lambda = \frac{\text{blade tip speed}}{\text{wind speed}} \quad (4)$$

λ is called the tip speed ratio of the wind turbine. The blade tip speed in meters per second can be calculated from the rotational speed of the turbine and the length of the blades used in the turbine, *i.e.*

$$\text{Blade tip speed}=\frac{\text{angular speed of turbine}(\omega)\text{xR}}{\text{wind speed}} \quad (5)$$

where R is the radius of the turbine and ω is measured in radian per second. Substitution of Equation 3 into Equation 2 leads to

$$C_P = \frac{(1+\lambda)(1-\lambda^2)}{2} \quad (6)$$

Differentiating Cp with respect to λ and equate to zero to find value of λ that makes Cp a maximum, *i.e.* $\frac{dCp}{d\lambda} = \frac{(1+\lambda)(-2\lambda)+(1-\lambda^2).1}{2} = 0$ yielding $\lambda = -1$ or $\lambda = \frac{1}{3}$.

Now $\lambda = \frac{1}{3}$ makes the value of *Cp* a maximum. This maximum value is $\frac{16}{27}$. Thus, the Betz limit says that no wind turbine can convert more than $\frac{16}{27}$ (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor, *i.e. Cpmax* = 0.59. Wind turbines cannot operate at this maximum limit though. The real world is well below the Betz limit with values of 0.35 − 0.45 common even in best designed wind turbines [24].

Wind velocity changes with height; the rate of increase of velocity with height depends upon the roughness of the terrain. The variation of average wind speed can be determined from the following power law expression [6]:

$$\frac{V_Z}{V_{ref}} = \left(\frac{h}{h_{ref}}\right)^{\propto} \quad (7)$$

Where, V_Z and V_{ref} are the average speeds at height of h in meter and at the reference height of h_{ref} = 20 above the ground respectively and α varies from 0.1 to 0.4 depending on the nature of the terrain.

But those turbines are having cut-in velocity more than 4 m/s can generate sufficient energy. On the other hand, small turbine cannot generate sufficient energy.

Nowadays, research and development are going on to improve the technology and design medium or high-capacity turbine with low cut-in speed at 2.5 to 3.5 m/s for feasibility.

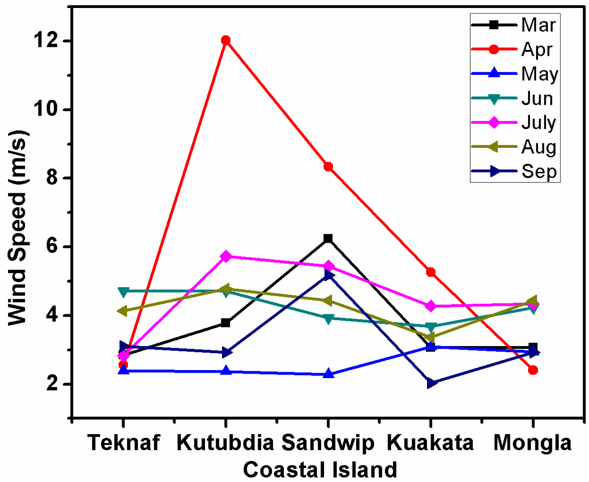

Fig. 1. Average wind speed at coastal Island in Bangladesh during March to September 2003 [23].

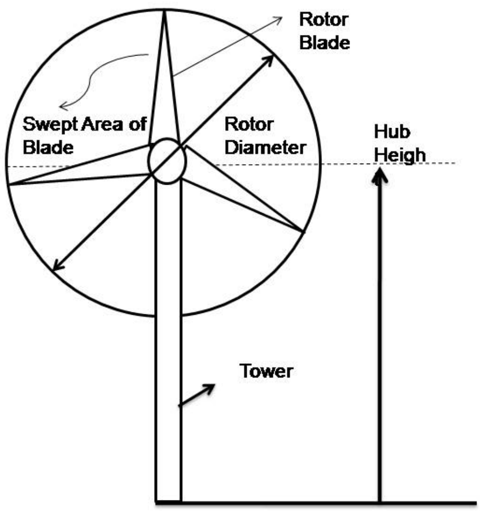

Fig. 2. Schematic diagram of wind mill for calculation.

Table 1. Wind speed data at various locations at 20 m height [23] during October 2009 to September 2010.

Locations	Months												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Barisal	2.90	2.57	2.57	3.56	3.23	2.90	2.71	2.64	2.57	2.11	2.07	2.05	2.66
Bogura	1.95	2.20	3.05	4.03	4.15	3.66	3.42	3.05	2.56	2.20	1.83	1.71	2.82
Chittagong	3.64	2.88	4.95	5.01	5.51	6.89	7.09	6.83	4.64	2.82	3.39	2.20	4.65
Comilla	2.26	2.70	2.57	5.45	3.83	3.20	2.88	2.95	1.82	2.38	1.63	1.70	2.78
Cox's Bazar	3.76	3.83	4.51	5.58	3.83	4.14	3.83	3.95	3.20	3.26	2.57	3.26	3.81
Dhaka	3.39	3.26	4.39	5.77	6.33	5.71	6.01	5.89	4.39	3.45	2.64	2.95	4.52
Dinajpur	2.68	2.44	4.88	2.44	2.93	2.68	2.56	2.44	2.44	3.54	2.44	2.44	2.83
Hatiya	3.04	2.64	4.16	3.97	4.82	6.47	5.75	2.64	2.96	2.77	3.06	2.57	3.74
Jessore	2.88	2.95	4.95	8.34	8.34	6.27	6.15	4.95	4.33	3.45	3.32	3.20	4.93
Khepupara	4.20	4.39	3.83	7.09	5.83	4.71	4.14	3.95	3.57	3.70	2.95	2.57	3.74
Khnulna	2.96	1.65	3.04	3.05	4.16	3.89	3.31	2.44	2.51	1.98	3.31	2.38	2.89
Kutubdia	1.77	1.82	2.32	2.70	2.77	3.65	3.61	3.14	2.11	1.45	1.19	1.29	2.32
Mongla	1.07	1.25	1.72	2.51	2.92	2.63	2.48	2.35	1.83	1.27	1.02	1.01	2.20
Rangamati	1.45	1.65	4.42	3.10	2.11	3.32	1.72	2.24	1.45	1.45	1.39	1.59	2.15
Sandip	2.32	3.01	3.20	4.83	2.44	3.83	3.39	2.70	2.32	1.63	1.70	1.70	2.76
Sylhet	2.20	2.93	3.29	3.17	2.44	2.68	2.44	2.07	1.71	1.95	1.89	1.83	2.38
Teknaf	3.70	4.01	4.39	4.01	3.32	3.89	3.83	2.88	2.44	2.20	1.57	1.76	3.17
Patenga	6.22	6.34	7.37	7.92	8.47	8.69	9.20	8.54	7.43	6.93	6.71	5.91	7.48
Sathkhira	4.21	4.40	3.84	7.10	6.11	4.76	4.27	4.03	3.62	3.78	3.54	2.81	4.37
Thakurgaon	4.15	5.06	7.93	8.43	8.66	8.05	7.93	6.59	6.34	5.98	5.25	4.76	6.59

Table 2. Wind velocities at various height at Sandwip during October 2009 to September 2010 [23].

Month ↓	45 m height			60 m height			80 m height		
Terrain →	0.2	0.3	0.4	0.2	0.3	0.4	0.2	0.3	0.4
Jan	4.09	4.45	4.83	4.34	4.86	5.42	4.60	5.32	6.26
Feb	3.11	3.49	3.79	3.41	3.82	4.26	3.63	4.18	4.78
Mar	7.28	7.91	8.59	7.72	8.66	9.65	8.22	9.46	10.84
Apr	9.75	10.59	11.50	10.34	11.59	12.93	11.01	12.67	14.51
May	2.66	2.89	3.14	2.82	3.16	3.53	3.01	3.46	3.96
Jun	4.59	4.99	5.42	4.87	5.46	6.09	5.18	5.97	6.83
July	6.38	6.90	7.50	6.74	7.56	8.43	7.18	8.27	9.46
Aug	5.19	5.63	6.12	5.50	6.17	6.88	5.86	6.75	7.72
Sep	6.06	6.50	7.14	6.42	7.20	8.03	6.84	7.87	9.01
Oct	4.84	5.25	5.71	5.13	5.75	6.41	5.46	6.29	7.20
Nov	4.41	4.78	5.20	4.67	5.24	5.84	4.97	5.73	6.55
Dec	4.13	4.48	4.87	4.37	4.90	5.47	4.60	5.36	6.15
Avg	5.25	5.65	6.14	5.52	6.19	6.91	5.88	6.77	7.77

Working Principle and Preparation of Small Windmill

Wind is actually another form of solar energy. The uneven heating of the atmosphere causes temperature gradient at the surface of the earth, which results in the wind flow. The rotation of earth and irregularities of the earth have vital impacts on wind velocity. A wind turbine converts the kinetic energy of the wind to generate electric or mechanical energy. Wind passes over the blades exerting a turning force.

The rotating blades turn a shaft inside the nacelle, which goes into a gearbox. The gearbox increases the rotation speed for the generator, which uses a magnetic field to convert the rotational energy into electrical energy. The power output goes to a transformer, which converts the electricity from the generator to the right voltage for the distribution system [25]. In a simplistic view, the working principle of a wind turbine is just opposite to that of a fan as shown in Figure 3.

Wind turbine: Converts wind energy into rotational (mechanical) energy. a) Gear system and coupling: It steps up the speed and transmits it to the generator rotor. b) Generator: Converts rotational energy into electrical energy. c) Controller: Senses wind direction, wind speed, generator output, and temperature and initiate appropriate control signals to take a control action.

Preparation of small wind mill: Rotor is made of plastic with three rotor blades. A 6V D.C. generator is used to convert mechanical energy to electric energy. The based was made by wood frame with PVC pipe for shape and size. The LED light (9 LEDs) was used instead of incandescent light bulbs. Since LED is more efficient and energy saving.

Calculation of the turbine: We used the following data to calculate the power output of the turbine:
Radius of the rotor, r = 0.05 m.
Average rotor efficiency, Cp = 0.35
wind power density in Chittagong using, = 60.33 w/m2
So, power generation in Chittagong according,
P = 8.34 W

But rotor radius of the small wind turbines is between (1-1.5) m range. So, we have calculated wind power in this experiment with rotor size 0.05m (Handmade small windmill in experiment) and 1.5 m (ideal micro wind turbine/small windmill).

The Figure 4 is showing the Kutubdia wind power area and inset handmade small windmill and the Figure 5 are showing the schematic diagram of wind power generation process at Kutubdia. From the concept of kutubdia turbine, a small handmade windmill was made to examine its performances. The small handmade windmill was used to setup experiment with limited range of rotation of the rotor. With this limitation in rotation system, therefore, it is not possible to go through above 60 m height. So, we started from 20m height and we are able to measure 45 m height. It is a trial experiment and that hopes to present a full analysis in future with all suitable parameters.

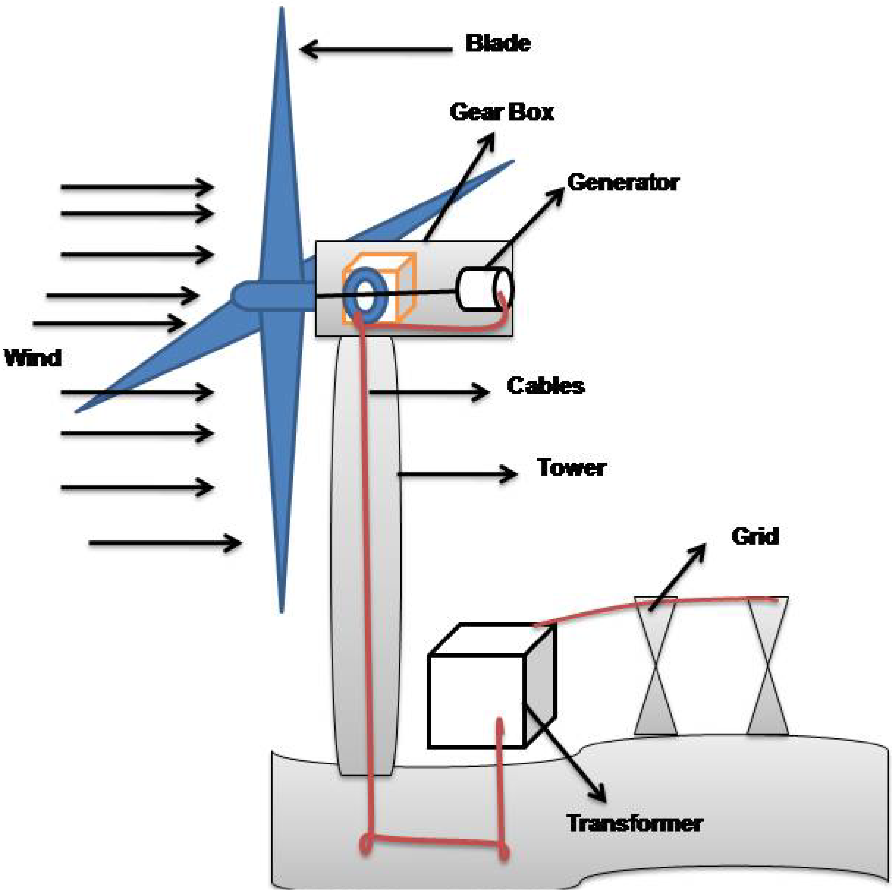

Fig. 3. Overview of working principle for wind turbine.

Fig. 4. Kutubdia wind power station (inset handmade wind mill).

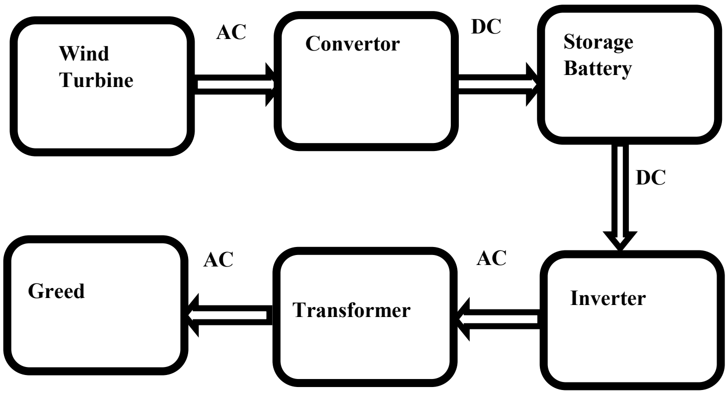

Fig. 5. Schematic diagram of wind electricity at Kutubdia.

3. RESULTS AND DISCUSSION

The handmade small windmill at Chittagong was used from March to September 2018. The experimental results were collected without measuring the wind speed and just measured the rotation of the rotor and calculated voltages, currents and power generation parameters as shown in Figures 6, 7, and 8, respectively. It is well known that the effective wind speed of wind turbines usually ranges between 3 and 25 m/s [14]. Moreover, the amount of wind energy that can be produced using our small windmill with normal wind speed, which is usually we get in our everyday life, was observed.

Our handmade small wind mill was run within the range of rotation 474 to 2739 rpm. The height for small windmill used was in the range of 20-45 m and the results and analysis of the data are presented in Figures 6, 7, 8 and Table 3, respectively.

By using the handmade small windmill, we measured voltage generation with respect to rotation. Figure 6 is presenting rotation versus voltage in operation of small windmill. From the figure it is easy to say that the rotation is directly proportional to the generation of voltage. That means, increasing the rotation will increase the voltage generation. So that, if the wind speed increases, the rotation of small windmill will increase and can get more voltages.

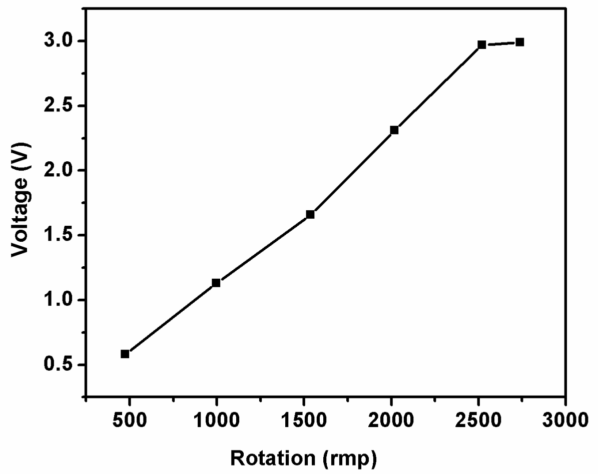

Fig. 6. Rotation versus voltage generation in operation of micro-wind mill.

Figure 7 is showing the current produced by the small wind mill with the rotation range 474 to 2739 rpm. The figure is indicating that increasing the rotation will increase the production of current by the wind mill. The small windmill rotor has limitation in rotation; therefore, it is not able to go furthermore in rotation.

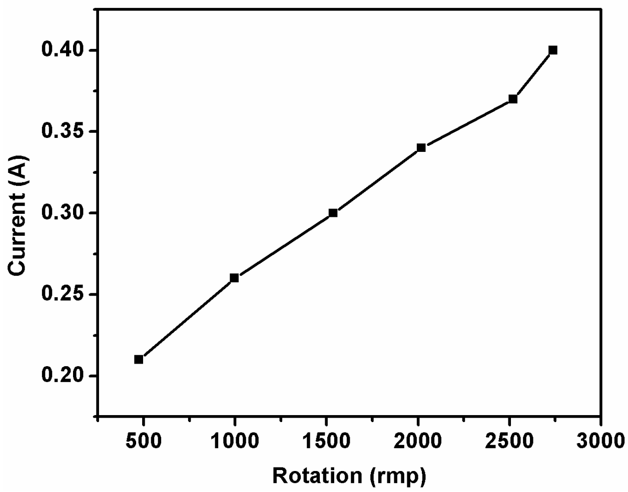

Fig. 7. Rotation versus current generation in operation of micro-wind mill.

Figure 8 is showing the production of power generated by a small wind turbine/wind mill. Here, the power is also directly proportional to the rotation of the rotor. The rotor has a limitation in rotation for power generation from small windmill. Therefore, it generated as small amount of power. If the rotation increases the power generation will increase. The Table 3 summarizes the data shown is the above figures.

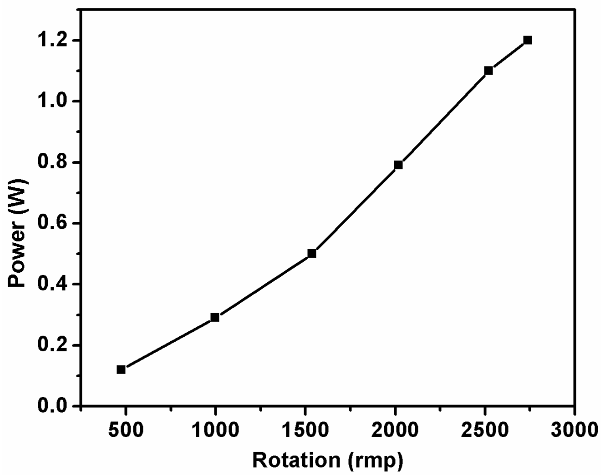

Fig. 8. Rotation versus power generation in operation of micro-wind mill.

Therefore, from the above wind speed survey data (Figure 1, Tables 1 and 2), and small windmill experimental results (showing in Figure 6, 7, 8 and Table 3, respectively), it may be concluded that at 20 m height or above is more suitable for wind energy and and the coastal areas of the country has sufficient wind speed for wind electricity generation [26].

Table 3. Rotation, voltage, current and power data of the small wind turbine operated in this study during March to September 2018.

Rotation (rpm)	Voltage (V)	Current (A)	Power (W)
474	0.58	0.21	0.12
998	1.13	0.26	0.29
1538	1.66	0.30	0.5
2020	2.31	0.34	0.79
2521	2.97	0.37	1.1
2739	2.99	0.40	1.2

4. CONCLUSIONS

The survey reports for wind speed and a handmade small windmill experimental results indicate that coastal zone in Bangladesh is a better wind potential area for wind energy. March-September is the most suitable time to generate more wind energy. Using wind energy, Bangladesh can save natural gas. Cost comparison shows producing electricity by wind is much cheaper than other conventional sources. The experiment with handmade small windmill is feasible, not only in coastal areas but all over Bangladesh. So, the wind energy can be a great alternative energy resource in Bangladesh. The country needs more survey, research, and technical support to improve this sector. Bangladesh is falling far behind in the scientific use of this renewable wind energy due to the lack of technology and research in this field.

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REFERENCES

[1] Kutubi N., 2009. Welcome to Kutubdia - an Island in the Bay of Bengal: Hybrid Power Plant at Kutubdia (Report No. Spot 5). From the world wide web : http://kutubdia.blogspot.com/2009/10/hybrid-power-plant-at-kutubdia.html.

[2] Bhattacharyya S.C., 2015. Mini-grid based electrification in Bangladesh: Technical configuration andbusiness analysis. *Renewable Energy* 75: 745-761.

[3] Rasel M.A.J., Siraj S., and Rahman K.M., 2012. Prospect of renewable energy as the solution of the existing crisis of Bangladesh. *International Journal of Scientific and Engineering Research* 3:1-7.

[4] Baten M.Z., Amin E.M., Sharin A., Islam R., and Chowdhury S.A., 2009. Renewable energy scenario of Bangladesh physical perspective. Proceedings of the *IEEE 1st International Conference on the Developments in Renewable Energy Technology (ICDRET)*. ISBN: 978-1-4244-6012-0, December 19. Dhaka, Bangladesh

[5] Khatun F., 2013. CPD-CMI Research Colloquium, FDI in the Energy and Power Sector in Bangladesh: Revisiting Policies and Contribution. March 11, Dhaka, Bangladesh.

[6] Hossain M.A., Hossain M.Z., Rahman M.A., 2014. Perspective and challenge of tidal power in Bangladesh. *International Journal of Power Engineering* 8(7) :1147-1150.

[7] Shaik M.A., Chowdhury K.M.A., Sen S., and Islam M.M., 2017. Potentiality of wind power generation along the Bangladesh Coast. In *Proceeding of the 1st International Conference on Mechanical Engineering and Applied Science (ICMEAS)*, February 22-23, 2017, Dhaka, Bangladesh. *AIP Conference Proceeding* 1919(1): 020035-1 – 020035-10. https://doi.org/10.1063/1.5018553.

[8] Mukut M.I., Islam Md.Q., Alam M.M., 2007. The wind energy scenarioin coastal region of bangladesh. *Proceedings of the International Conference on Mechanical Engineering (ICME2007),* December 20-31. Dhaka, Bangladesh.

[9] Alam M.M. and J.D. Burton, 1998. The coupling of wind turbine to centrifugal pumps. *Journal of Wind Engineering* 22: 223-234.

[10] Suresh R. and D.S. Block, 1998. Field testing of geared type deep well wind pumps in India. *Journal of Wind Engineering* 22: 17-129.

[11] Amin M.T., 2015. Prospects of wind energy in Bangladesh. I*nternational Journal of Advanced Renewable Energy Research* 2(8): 213-218.

[12] Sustainable and Renewable Energy Development Authority (SREDA): National Database on Renewable Energy /Wind Projects. January 06, 2021 from the world wide web: https://ndre.sreda.gov.bd/index.php?id=1&i=11.

[13] Ullah M.H., Hoque T., and Hasib M.M**.,** 2012. Current status of renewable energy sector in Bangladesh and a proposed grid connected hybrid renewable energy system. *International Journal of Advanced Renewable Energy Research* 1: 618-627.

[14] Farha N., Nur-Us-Safa M., Rahamatullah B.D., Ali M.S., 2012. Prospects of wind energy in the coastal region of Bangladesh. *International Journal of Scientific and Engineering Research* 3(8):1-5.

[15] Wyatt A. 1986. Electric Power: Challenges and Choices. Canada: Book Press, Toronto, p-63.

[16] Saifullah A.Z.A, Karim M.A., Karim M.R. 2016. Wind Energy Potential in Bangladesh. *American Journal of Engineering Research (AJER)* 5(7): 85-94.

[17] Li G. and J. Zhi 2016. Chapter 2: Analysis of Wind Power Characteristics. In Ed. Wang N., Kang C. and Ren D. In *Large Scale Wind Power Grid Integration*. Academic Press Elsevier Inc., p-28. https://doi.org/2013-0-18686-2.

[18] Li G., and Zhi J. 2016. Chapter 2: Analysis of Wind Power Characteristics. In Ed. Wang N., Kang C. and Ren D. In *Large Scale Wind Power Grid Integration*. Academic Press Elsevier Inc., p-19-51. https://doi.org/2013-0-18686-2.

[19] Khan M.J., Iqbal M.T., Mahboob S., 2005. A wind map of Bangladesh. *Renewable Energy* 29(5):643-660.

[20] Ramachandra T.V. and B.V. Shruti, 2005. Wind energy potential mappings in Karnataka, India, using GIS. *Energy Conversion and Management* 46: 1561-1578.

[21] Mukut A.N.M.M.I, Islam M.Q., and Alam M.M. 2008. Analysis of wind characteristics in coastal areas of Bangladesh. *Journal of Mechanical Engineering* 39(1): 45-49.

[22] Ahmmed S., Islam M. Q., 2004. Wind Power for Rural Areas of Bangladesh. *3rd International Conference on Electrical and Computer Engineering (ICECE)*, December 28-30, Dhaka, Bangladesh.

[23] Mirza R., Hossain M., and Hossain A., 2010. Design of an often cost affective wind power system for a remote Bangladesh locality. *Thesis.* BRAC University, Bangladesh. Retrieved from the World Wide Web: http://dspace.bracu.ac.bd/xmlui/handle/10361/847.

[24] Manyonge A.W., Ochieng R.M., Onyango F.N., and Shichikha J.M., 2012. Mathematical modelling of wind turbine in a wind energy conversion system: Power coefficient analysis. *Applied Mathematics Sciences* 6(91): 4527-4536.

[25] Miah M., 2015. Denmark will invest in wind power plant. Energy Bangla. Retrieved from the World Wide Web: http://energybangla.com/denmark-will-invest-in-wind-power-plant/.

[26] Khadem S.K. and M. Hussain, 2006. A pre-feasibility study of wind resources in Kutubdia Island, Bangladesh. *Renewable Energy* 31: 2329–2341.