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Analysis of Air Foils and Design of Blades for a Low-Speed 250W Vertical Axis Wind Turbine Suitable for Coastal Areas of Bangladesh

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***Abstract*—The potential of wind energy in Bangladesh is not so good but has reasonable prospect if modern technology and optimum design of air foils and blades can be used. Coastal regions of Bangladesh including Cox's Bazar, Chittagong, Teknaf, Patenga, Mongla, and Kutubdia, are most suitable points of harnessing wind energy. Although the velocity of wind in these regions is not perfect for harnessing energy from a big sized wind turbine rather it is quite capable to generate electricity from small sized turbine in an efficient way. Vertical axis wind turbine (VAWT) is perfectly appropriate for extracting the maximum power from wind in such low wind speed area. NACA foil is mainly prioritized to build this type of small sized VAWT system because of the low maintained mechanism. The small-sized VAWT system needs more analyzed wind data to work in an optimized condition. The positions and efficiency of the turbine system are highly dependent on the blade lift and drag coefficient because of random wind flow directions. Counting all these points, this paper examines the wind data available in these areas, and describes the design of a vertical axis wind turbine (VAWT) suitable for small sized electricity generation system in an efficient way by optimizing turbine blades and its foil mechanism.**

Keywords—Vertical Axis Wind Turbine; Power Generation; Coastal areas; Blade design; Windpower

I. INTRODUCTION

The electricity generation is increasing rapidly due to it’s high demand [1]. Currently, the energy is produced mostly from fossil fuel as its main sources. The use of these non-renewable fuel sources has genuine harmful effects on surrounds. An abnormal amount of fossil fuel uses can cause several environmental damages like ozone layer exhaustion, acid rain, climate change and so on [2]. It is obvious that fossil fuel is decreasing over the period due to excessive use to generate power. To slow the decreasing rate of fossil fuel and make environment more reclamation, renewable energy is the only alternative solution except nuclear energy which has great negative impact and risk for the livable environment. Currently, many countries adopted renewable energy as their primary electricity generation sources over fossil or nuclear because of less or negligible effect on the environment. Besides the renewable sources are quite available and affordable. There is no cost in raw renewable energy sources.

Also, harnessing wind energy across all over the globe is increasing due to raw energy availability and use of a higher grade of optimized technology. Most of the European countries are adopted this energy expansion over other regions of the globe because of huge availability of wind in these areas.

The situation in Bangladesh is quite different where most of the power generation system is fully depended on conventional fuel sources and alternate energy development is not making that much impact over this. But the development in the solar system is really appreciable in renewable sector although the expansion is not fully satisfactory yet [3]. Currently, different approaches are taking place to improve this solar energy and make it more handy and mainstream. To increase renewable energy generation in this country the only focus on the solar system is not quite enough. Finding the availability of other sources like wind, geothermal, tidal, hydro, biomass, etc. and harnessing energy from these sources are relatively challenging [4]. Few small-sized winds or biomass projects are taking place although most of them are only showcasing the structure and lies on idea of the projects, and many of them are not in working conditions. The main reason behind this kind of wasting technology and resources is the lack of adequate analysis and modification of the technology suitable for Bangladeshi weather and environment. In the context of Bangladesh, the wind has a great prospect. Maybe the available wind energy is not capable to harness a huge amount of electricity but it is quite capable to generate in a micro amount in an efficient way [1, 5, 6]. Currently, the annual average wind velocity in Bangladesh is 2 m/s which is quite low to develop the huge size wind turbines all over the country [5, 6]. But the coastal regions and some hilly areas of Bangladesh has a reasonably good average wind speed to demonstrate the wind energy harnessing in an effective way [1]. The availability of electricity is not regular in these hilly or coastal regions. Hence proper utilization of wind energy can make an off grid or on grid network suitable for home, small business model, several types of commercial enterprises and so on [7]. Proper installation of a bunch of wind turbine can also use for harvesting crops, pumping drinking water which can significantly reduce the use of diesel generator [2]. Still different NGO and government do not show proper interest for harvesting this energy due to the absence of appropriate information about wind velocity, mechanism, weather adjustment, and its future opportunities to expand with latest available technology [1, 5]. Hence the available wind velocity is not adequate for normal or high-speed turbine system, only low-speed turbine system is more efficient over the existing available model.

Counting all these obstacles, the focus of this research work is to examine the actual wind prospect in the coastal region of Bangladesh to determine the available energy and analyze of airfoils to develop a vertical axis wind turbine (VAWT) perfectly suited for low-speed wind to extract the available energy with the maximum efficiency. In low-speed small size power generation, VAWT is much smaller and work efficiently over horizontal axis wind turbine (HAWT). The analysis of air foils of the turbine blade is done using QBlade software which is specially design for existing and new type blade foils analysis made by Hermann Föttinger Institute of TU Berlin.

II. Wind Prospects in Coastal Region of Bangladesh

Currently the electricity generation in Bangladeshi grid is quite high but most of them are directly or indirectly depend on fossil fuel [2], although most of the coastal areas are not grid connected. The geographical position of Bangladesh is one of the biggest advantages over other small countries because of comparatively large coastal regions. Figure 1 shows the coastal area geographically where the scope between 20°34'- 26°38'N and the longitude between 88°01-92°4E [2]. Strong wind flows are fairly available in the southern part of Bangladesh where 724 km longest coastline is located with 200 km long hilly areas [6]. The average wind velocity in these areas are recorded 5 m/s or greater at a height of 20-30 meter which has decent potential to feed small-sized wind turbine [6, 8, 9]. Although some projects like Kutubdia island and Muhuri dam has been established long ago but all of them are out of order because of lack of proper knowledge about wind prospect and maintenance. Bangladesh government along with several NGOs do some research earlier where it shows clearly that to generate electricity now in a small amount, the desired wind velocity is available from late March till the beginning of October and the maximum peak will be in June-July [1, 6]. Besides coastal areas, many waterfront areas, for instance, Teknaf, Patenga, Cox's Bazar, Chittagong, Hatiya, Mongla, and Kutubdia can also potentially stable to generate wind energy because of availability good wind velocity [10]. The average wind velocity in these areas are recorded to be precise around 3.5 m/s [10, 11].

III. Analysis of Wind Velocity at Coastal Regions

To find out the optimum energy generation in coastal regions of Bangladesh, at first it is needed to analyze the wind velocity, air density on that areas and maximum power calculation for the desired system carefully.

A. *Wind Data Analysis*

It is quite important to measure the minimum, maximum and the average wind velocity on that particular area where the wind turbine system is supposed to be installed. Table I shows the monthly measured average wind velocity of some coastal regions targeted for wind turbine installation. The wind velocity is measured at a height of 20 meters from the ground [11]. The average yearly maximum wind velocity has been recorded 5.52 m/s and the yearly average minimum wind speed is 2.44m/s where May and July can be considered as the most prospective months and November to January can be considered as the least prospective month for wind power extraction. This indicates a good amount of wind energy can be harvested and utilized during the monsoon period in the coastal regions of Bangladesh [7].

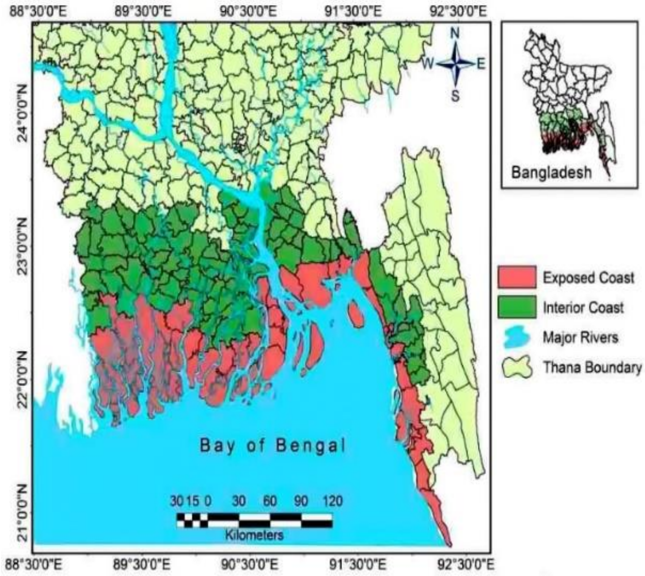

Fig. 1. Wind Prospective Coastal Regions in Bangladesh

B. *Wind Velocity Calculation*

The wind shear exponent can be used to determine the velocity of wind, v at a reference height, h_{ref} and wind velocity at practice height, h [11–14] as equation (1) and plotted in Fig.2.

$$v = v_0 \left(\frac{h}{h_{ref}}\right)^{\alpha} \qquad (1)$$

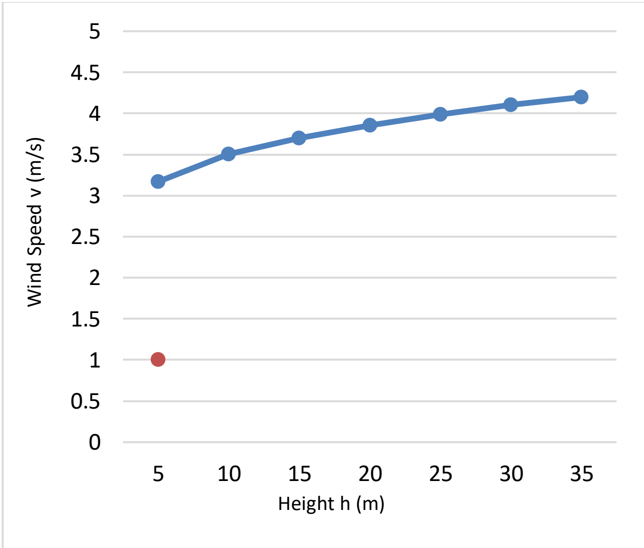

Fig. 2. Height from ground vs. wind speed

C. *The Density of the Air Factor*

The density of the air, ρ is the mass per unit volume of Earth's atmosphere. Power extraction from a wind's kinetic energy significantly depends on various factors such as air moisture and air density. Here the density of the air has been considered since it has a great impacts during power extraction. Within a settled atmospheric pressure, a list of the density of the air at various temperature is given in Table II [15]. In this research work ρ =1.16 kg/m^3 is considered as the average coastal temperature is 30°C in Bangladesh.

Table I. Wind Speed (m/s) at a height of 20m in Various Coastal Areas of Bangladesh

Locations	Monthly wind velocity (m/s)												Yearly Maximum	Yearly Minimum	Yearly Average
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
Chittagong	3.65	2.87	4.94	5.02	5.52	6.88	7.08	6.85	4.63	2.81	3.38	2.21	7.08	2.21	4.66
Cox's Bazar	3.76	3.86	4.53	5.56	3.84	4.13	3.84	3.96	3.21	3.27	2.58	3.27	5.61	2.58	3.82
Teknaf	3.71	4.01	4.39	4.02	3.33	3.88	3.85	2.71	2.43	2.21	1.58	1.77	4.38	1.58	3.16
Hatiya	3.05	2.64	4.18	3.98	4.83	6.48	5.76	2.63	2.97	2.78	3.07	2.58	5.76	2.58	3.73
Patenga	6.23	6.34	7.37	7.91	8.48	8.68	9.19	8.55	7.49	6.94	6.72	5.92	9.21	5.92	7.47
Kutubdia	1.78	1.82	2.34	2.74	2.78	3.66	3.62	3.15	2.12	1.46	1.18	1.28	3.66	1.18	2.32
Mongla	1.06	1.25	1.76	2.52	2.93	2.64	2.47	2.36	1.84	1.26	1.03	1.02	2.93	1.02	1.85

D. Calculation of Maximum Available Power

The kinetic energy available in the wind cannot be converted more than 59% into the mechanical energy as stated in Betz law where practically the power extraction is usually calculated less than 45% [11]. By considering VAWT's rotor blades swept area, $A = rl$, the velocity of air = v, length of the VAWT blade = l of the density of the air = ρ and the theoretical Betz limit C_p=0.59, the output power, P (maximum) availability can be calculated by,

$$P_{available\ (max)} = \frac{1}{2}\rho A v^3 C_P \qquad (2)$$

By considering the average wind velocity from the height 5m to 15m, v= 3.437 ms^{-1} as calculated in section III.B, length of the blade, l= 10m, the radius of a swept area by blades, r = 3m, the total swept area can be calculated, $\mathrm{A} = 30\mathrm{m}^2$, air density, ρ = 1.16 kg/m^3 as measured in Table II, Betz coefficient, C_p = 0.59 (theoretical) and considering Betz coefficient, C_p = 0.35 (practical), the maximum output power availability for the proposed low-speed vertical axis wind turbine (VAWT) can be found using the equation (2) as

$$\begin{aligned} P_{available\ (Max)} &= \frac{1}{2}\rho A v^3 C_P \\ &= \frac{1}{2} \times 1.165 \times 30 \times 3.437^3 \times 0.59 \\ &\approx 480W\ (theoretical) \end{aligned}$$

$$\begin{aligned} P_{available\ (Max)} &= \frac{1}{2}\rho A v^3 C_P \\ &= \frac{1}{2} \times 1.165 \times 30 \times 3.437^3 \times 0.35 \\ &\approx 270W\ (practical) \end{aligned}$$

Table II. Air density vs. Temperature

Temperature, T (°C)	Air Density, ρ (Kg/m^3)
35	1.143
30	1.165
25	1.184
20	1.204
15	1.226
10	1.247
5	1.269
0	1.292

IV. DESIGN OF BLADES FOR A 250W VAWT

A. Calculation of Blade Radius

In consideration of the average wind velocity as calculated in section III.B (from height 5m to 15m), v = 3.437 ms^{-1}, desired output power, $P_{desired\ (Max)}$= 250W, density of air at 30°C temperature, ρ = 1.165 kg/m^3 (as measured in Table II), and considering the Betz coefficient, C_p ≈0.35 (practical), the blade radius, r can be determined using eq.(1) as

$$\begin{aligned} r &= \sqrt{\frac{2P_{available\ (max)}}{\rho v^3 C_P \pi}} \\ &= \sqrt{\frac{2 \times 250}{1.165 \times (3.437)^3 \times 0.35 \times 3.1416}} \\ &\approx 3.0\mathrm{m} \end{aligned}$$

B. Selection of Air Foil

There are lots of NACA airfoil models available right now. For low-speed small size VAWT system, numerous studies suggested that NACA 0021 is one of the lightest weights, robust, efficient and shapeable air foil. As the blade length covers 2/3rd of the entire pole which is 15m in length and the velocity of wind is under 5 ms^{-1}, weight is the primary reason to select NACA 0021 airfoil as for the research. Another important goal is to reduce the cost as the NACA 0021 air foil is one of the low costs and commercially available airfoils which is suitable for small size low-speed blade. With a wide operational range, this airfoil performs at its best with an optimum efficiency [15, 16]. Selection of the air foil in the Qblade simulation software with 21% thickness and 100 measurement points are shown in Fig. 3. The operational points and air foil pressure point analysis of the blade (NACA 0021) are shown in Fig. 4 where the angle of incidence α = 18 (as simulated).

Although blades of VAWT generally operates in high inflow angle range, due to the limitation of the simulation software used in this study, the airfoil's inflow angle range is limited to take from -25° to +25° as shown in Figs. 5-8 where the curve shows the coefficient of lift vs. coefficient of drag behavior, lift coefficient vs. pitching moment coefficient analysis and incidence angle vs. pitching moment coefficient

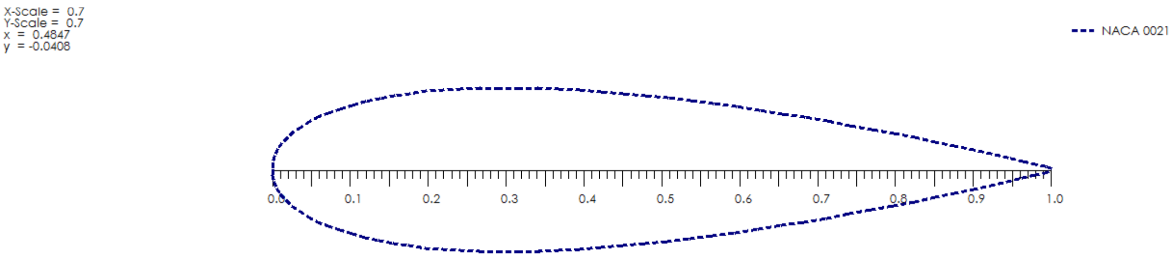

Fig. 3. NACA 0021 Airfoil Selection

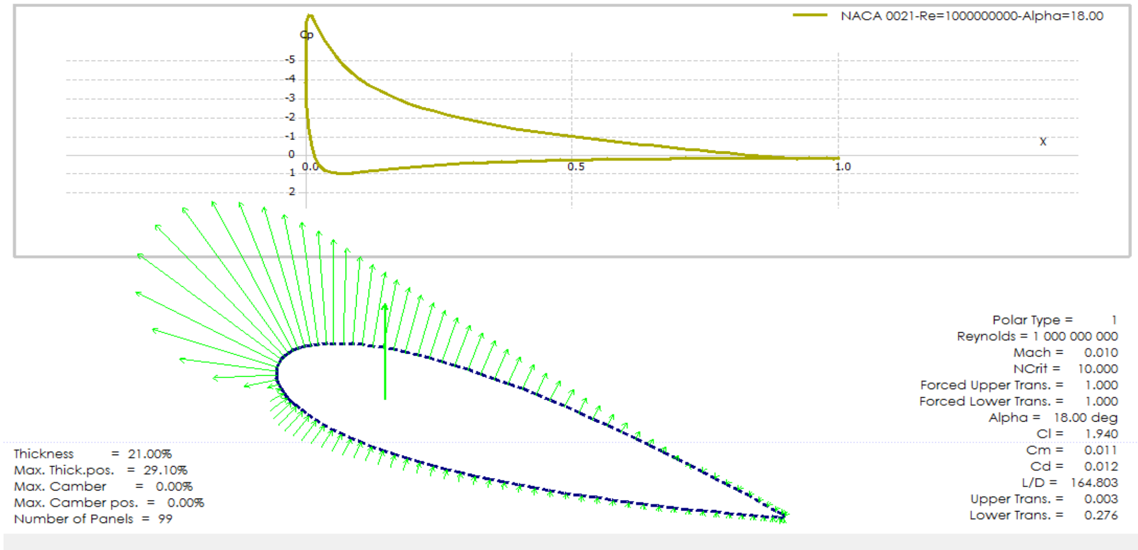

Fig. 4. NACA 0021 operation point and pressure analysis

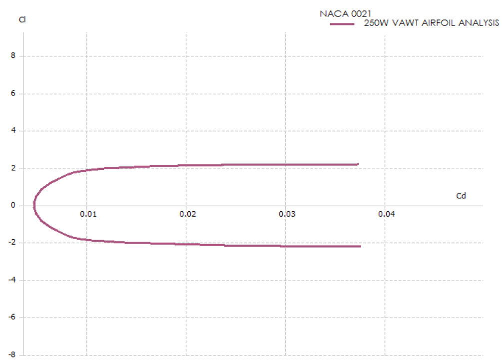

Fig 5. NACA 0021 Lift coefficient, C_l vs. drag coefficient, C_d (inflow angle --25° to +25°)

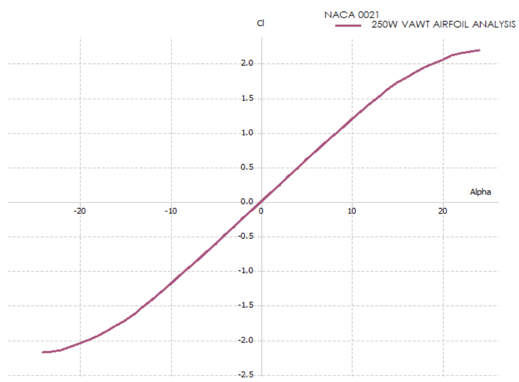

Fig. 6. NACA 0021 Lift coefficient, C_l vs. Pitching moment coefficient, α (inflow angle -25° to +25°)

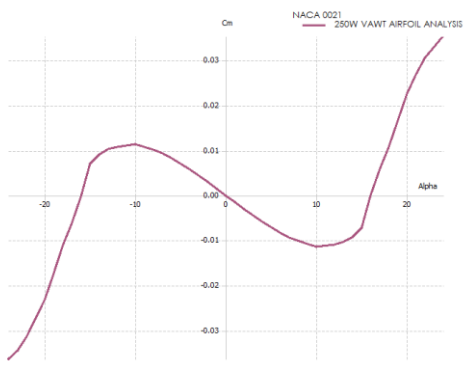

Fig. 7. NACA 0021 Incidence angle, α vs. Pitching moment coefficient, C_m (inflow angle -25° to +25°)

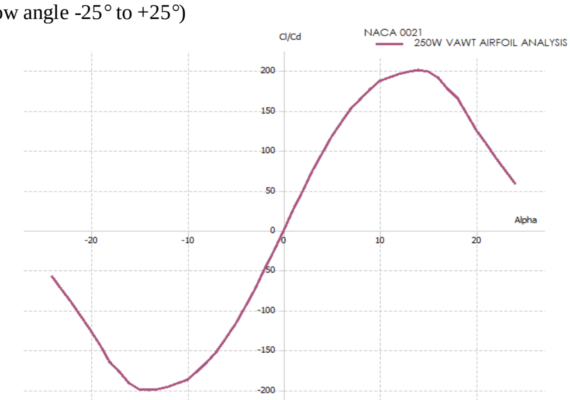

Fig. 8. NACA 0021 Glide ratio C_l / C_d vs. Incidence angle, α (inflow angle -25° to +25°)

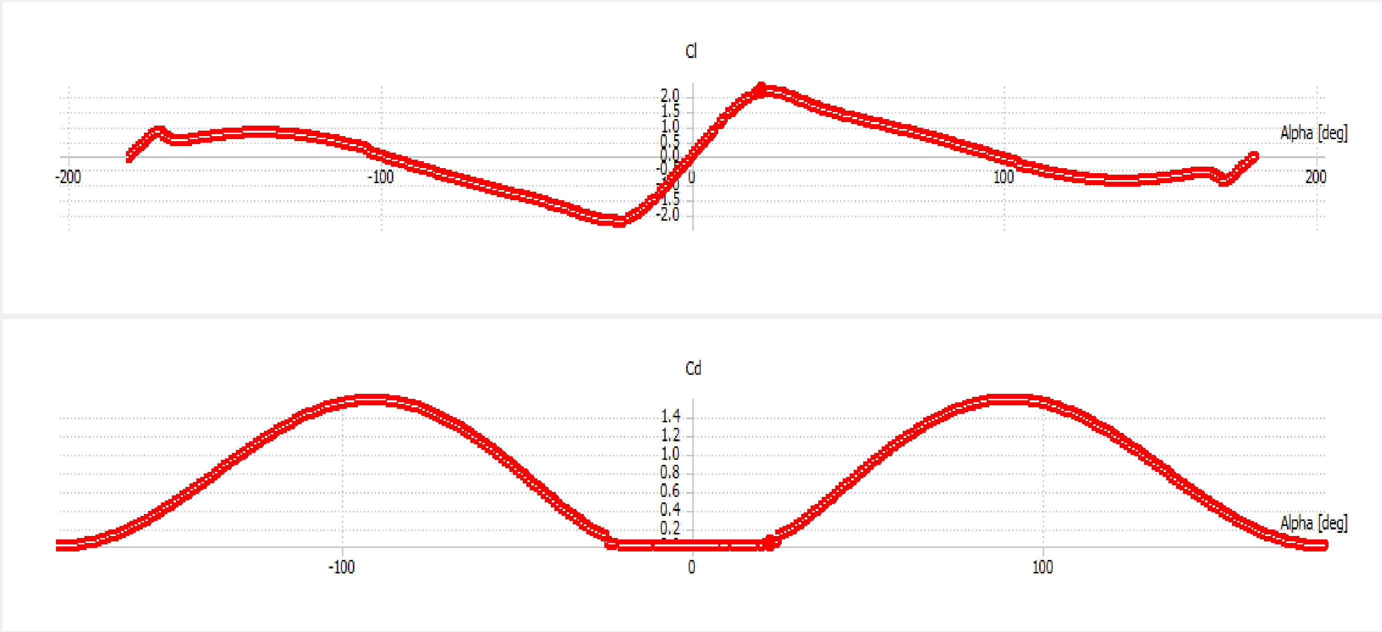

Fig. 9. 360 Polar extrapolations of NACA 0021 airfoil responses

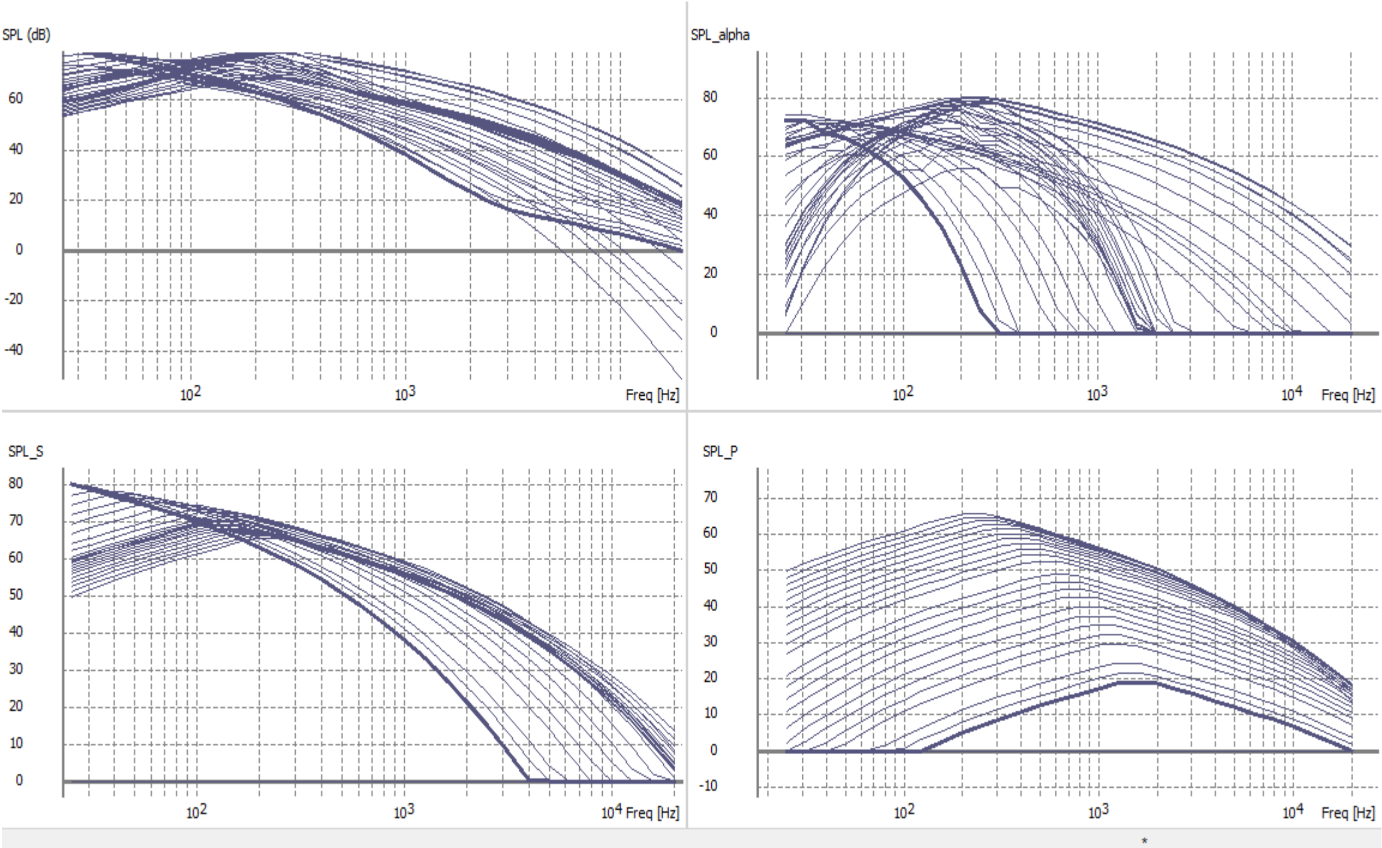

Fig. 10. Noise simulation of NACA 0021 at all operational points

with Glide ratio vs. Incidence angle, respectively. To minimize the limitation, an extrapolation of 360° of the inflow angle has been executed within the Qblade in order to converge in practice and to achieve an error-free analysis as shown in Fig.9, where angle of incidence = α , coefficient of lift = C_l, lift = L, coefficient of drag = C_d , drag = D and pitching moment coefficient = C_m.

A simulation of possible noise and interferences at different operational points are made within the Qblade as shown in Fig.10. For the purpose of this research, NACA 0021 Airfoil analysis was made to understand the blade element momentum theory. To find out the response of the selected airfoil drag, lift, the angle of incidence, glide ratio and other coefficients were analyzed. The 250W low-speed VAWT's designed blades with single blade view and rotor view using NACA 0021 air foils at different points of the blades are shown in Figs. 11 and 12, respectively, which will be used to install the wind power system in the proposed location.

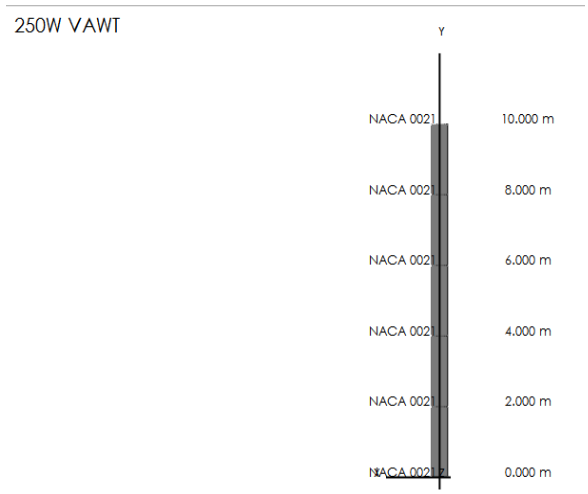

Fig. 11. Design of the Blade

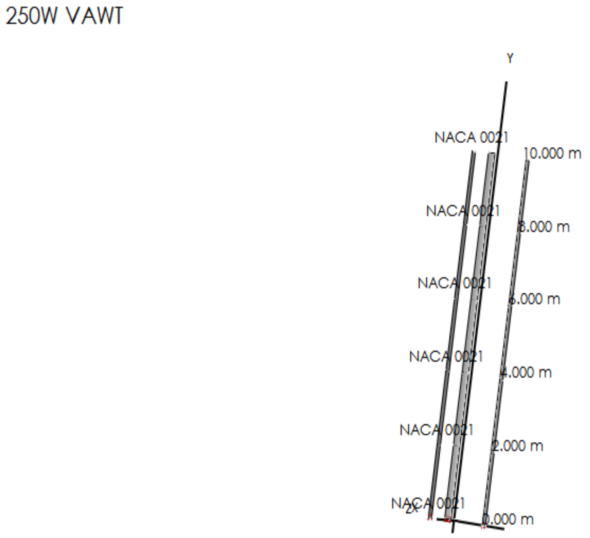

Fig. 12. 3-Blades rotor view

V. CONCLUSION

In this research work, the theoretical and statistical analysis have been studied for a small-sized low-speed vertical axis wind turbine perfectly suitable for the areas where wind velocity is quite low like coastal region of Bangladesh using NACA 0021 airfoil. The pole heights of the VAWT is keeping optimum to build at a low cost and can extract the efficient energy from available wind. In a small scale, the vertical axis turbine makes smaller in diameter and protect all the system quite well than horizontal axis turbine. That's why the VAWT is used here for low wind flow rate. Single airfoil can make this blade more robust and maintenance free. This type of small system is good for power solution for thousands of people living in these areas which can significantly reduce the pressure on fossil fuel and can have some contribution to growing electricity demand.

References

[1] A. N. M. Mominul Islam Mukut, Md. Quamrul Islam, Muhammad Mahbubul Alam, "Analysis of Wind Characteristics in Coastal Areas of Bangladesh", Journal of Mechanical Engineering, The Institution of Engineers, Bangladesh, Vol. ME39, No. 1, June 2008.

[2] M. Murshed, Y. Arafat, M. A. Razzak, "Analysis of Air Foils and Design of Blades for a Low-Speed 250W Horizontal Axis Wind Turbine Suitable for Coastal Areas of Bangladesh," 4th International Conference on the Developments in Renewable Energy Technology (ICDRET), 07-09 January, 2016, Dhaka, Bangladesh, pp.1-6.

[3] Y. Arafat, M. Murshed, M. M. Hasan, M. A. Razzak, "Design Aspects and Performance Analysis of Inner and Outer Rotor Permanent Magnet Alternator for Direct Driven Low-Speed Wind Turbine," 2nd IEEE International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB), 27-28 February, 2016, Chennai, Tamil Nadu, India, pp.1-6.

[4] "Installed capacity report- BPDB", Bangladesh power development board, Available at http://www.bpdb.gov.bd/bpdb/index.php?option=com_content&view=article&id=5&Itemid=6 [May 21, 2015]

[5] Anwar Hossain, "Wind Energy in Bangladesh", Sustainable Development Networking Programme. Available at: http://www.sdnbd.org/wind.htm [June 19, 2015]

[6] M. J. Khan, M. T. Iqbal, S. Mahboob, "A wind map of Bangladesh", Renewable Energy (2004), Volume: 29, Issue: 5, Publisher: Elsevier, pp. 643-660.

[7] M. Murshed, Y. Arafat, M. A. Razzak, "Design of blades for a low-speed 400W wind turbine suitable for coastal area of Bangladesh" 3rd International Conference on Green Energy and Technology (ICGET), 11-12 September, 2015, Dhaka, Bangladesh, pp.1-6.

[8] T. V. Ramachandra, B. V. Shruti, "Wind energy potential mappings in Karnataka, India, using GIS", Energy Conversion and Management 46 (2005) pp.1561-1578.

[9] "Record Year for Wind Energy: Global Wind Power Market increased by 43% in 2005", Global Wind Energy Council Press Release, Brussels, 17th February 2006.

[10] "Final Report of Solar and Wind Energy Resource Assessment (SWERA)- Bangladesh", Renewable Energy Research Centre (RERC), University of Dhaka, Bangladesh, Available at http://xa.yimg.com/kq/groups/14503985/2014718169/name/ SWERA _Bangladesh_FullReport.pdf[July 18, 2015]

[11] Sultan Ahmmed and Quamrul Islam, "Wind power for rural areas of Bangladesh", 3rd international Conference on Electrical and Computer Engineering (ICECE), 28-30 December, 2004, Dhaka, Bangladesh.

[12] M. L. Kubik, P. J. Coker, C. Hunt, "Using meteorological wind data to estimate turbine generation output: a sensitivity analysis", World Renewable energy congress 2011, 8-13 May 2011, Linkoping, Sweden.

[13] H. Panofsky and J. Dutton, "Atmospheric Turbulence: models and methods for engineering applications", Pennsylvania State University: John Wiley and Sons, 1984.

[14] Wikipedia: web-based encyclopedia project supported by the Wikimedia Foundation, "Density of air" available at http://en.wikipedia.org/wiki/Density_of_air [June 11, 2015]

[15] John McCusker, "Design and Optimization of a Small Wind Turbine", An Engineering Project Submitted to the Graduate Faculty of Rensselaer Polytechnic Institute Available at: http://www.ewp.rpi.edu/hartford/ ~ernesto/SPR/McCosker-FinalReport.pdf [June 23, 2015]

[16] M. H. Mohamed, A. M. Ali, A. A. Hafiz, "CFD analysis for H-rotor Darrieus turbine as a low-speed wind energy converter", International Journal of Engineering Science and Technology, 18 (2015) pp.1-13.