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Investigating the Prospect of Rooftop Flapping Wind Turbine in Bangladesh

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Abstract

The objective of this research is mainly focused on environment-friendly and moderately slow flapping wind turbine which can easily operate in or near urban areas or rooftops owing to scale merit with low-frequency turbine noise, installation cost, avian mortality rate and safety consideration etc. We considered lift and drag based slow flapping type wind turbine to operate in the residential arena. In order to study the flapping wind turbine performance, we collect ten years of wind velocity records from the Bangladesh Meteorological Department for two different stations in Bangladesh. The velocity contours and profiles have been the points of observation to find out the suitable turbine shape having the efficiency to initiate the turbine rotation. We made a simple comparative study of the wind velocities profile obtained from the different stations in Bangladesh. A simple numerical study has been conducted and presented by graphical analysis to inspect the wind flow above the constructed structure. Finally, we analyze the wind velocity for the individual months and determine the turbine performance in terms of torque for the average wind velocities of Dhaka and Cox's Bazar stations.

Keywords

Flapping Wind Turbine, Average Wind Velocity, Torque

1. Introduction

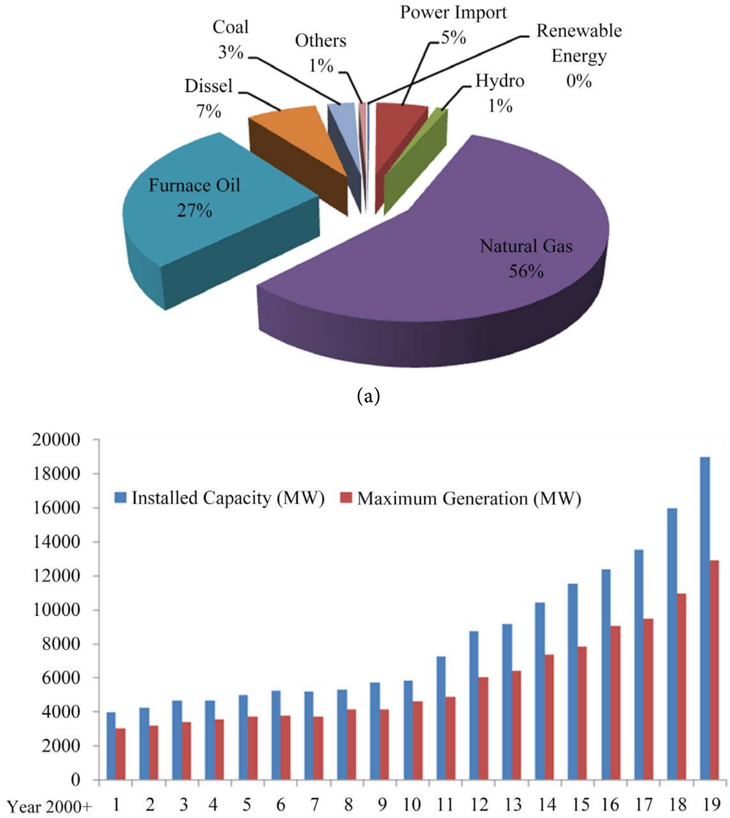
An increasing public awareness of the rising level of greenhouse gas emissions and the need of tackle fuel security with achieve reductions in emissions has resulted in significant efforts to adopt renewable energy technologies [1]. Power is the backbone of development of a country. It is the most important factor for a developing country like Bangladesh. In Bangladesh, demand for power is increasing day by day, but the sources of energy are not increasing in satisfactory level. Fossil fuels are getting diminished day by day [2]. Bangladesh is encountering difficulties in supplying energy to maintain its economic growth. The growth rate of industrialization in Bangladesh may slow down due to shortage of energy supply. Government of Bangladesh is looking for renewable energy sources to meet up the total power demand in this country. Wind can be a solution to this problem. Wind energy has the potential to provide mechanical energy or electricity without generating pollutants [3].

The present study aims to assess wind energy potential in Bangladesh as a sustainable solution to overcome the energy crisis. The integration of wind turbines into the built environment poses challenges due to the low energy yield resulting from low mean wind speeds in urban areas as well as environmental impacts [4] [5] [6]. Due to the availability of wind and the considerable range of power control, wind turbines are now coming up in almost all parts of the world. Wind energy is fast becoming the most preferable alternative to conventional sources of electric power [7]. The practical use of rooftop wind turbine in the city areas is still in progress. Energy from rooftop wind turbine can be an alternative source of carbon-based fuels [8]. Flapping wind turbine is an interesting and relatively new one; our designed flapping wind turbine can work under low wind velocity from any direction and has the advantage of low noise generation without disturbing nature. In our research, we focus on the generation of torque by the rooftop wind turbine under variable wind speeds at different locations in Bangladesh. If the idea of rooftop wind turbine comes to the light, increasing demand for energy could be solved significantly. We considered the "Blade element theory", "Blade element momentum theory", "Betz limit", "Bernoulli's principle", and other some theories related to the wind turbine to calculate the generated energy by the wind turbine in terms of torque. We use MATLAB software to analyze the performance of the blade as well as the turbine.

2. Overview of Wind Turbine Prospect in Bangladesh

2.1. Power Generation Scenario in Bangladesh

Bangladesh's government has the plan to become a middle-income country by 2021 and a developed country by 2041. Economic growth is the main focus of the government and electricity is one of a key factors. The power sector is heavily dependent on natural gas. This excessive dependence causes several problems. Due to a shortage in supply of natural gas, there is always a significant amount of less power generation than the rated one. The government has planned to produce 19,000 MW within 2021. To fulfill the plan, Bangladesh must look for renewable sources. The contribution of renewable energy is less than 0.5% of the total installed capacity. The wind is the most prospective one among all the renewable sources after hydro due to lower generation cost [9] [10]. The installed capacity by fuel type for FY 2019-20 (February 2020) are shown in the pie chart below. The installed capacities with the maximum generation in MW are shown by the bar graph from FY2000-01 up to FY2019-20 [9] (**Figure 1**).



(b)

Figure 1. (a) installed capacity by fuel type and (b) the installed capacity with the maximum generation in MW.

2.2. Bangladesh Meteorological Department (BMD)

Bangladesh Meteorological Department (BMD) is a government organization under the administrative control of the Ministry of defense, Government of the People's Republic of Bangladesh. The main responsibility is to monitor and issuance of forecasts and warnings of all meteorological extreme events like tropical cyclone, severe thunderstorm/ tornadoes, heavy rainfall, drought, cold and heat wave along with daily routine forecasts of all time scales round the clock [11].

A total of 46 synoptic stations are in operation under Bangladesh Meteorological Department (BMD). All observed and collected data are received on a height of 10meters and gathered at the National Meteorological Communication Centre, Dhaka. Wind velocities data has been stored with a three hours interval in a day. In this paper we worked with the Dhaka and the Cox's Bazar two stations, location shown in the following **Figure 2**.

2.3. Wind Scenario in Bangladesh

According to BMD, the strong south/south-westerly wind coming from the Indian Ocean into Asia in Monsoon. These wind blows over the coastal area of Bangladesh having an average speed of 3 m/s to 6 m/s [11]. Wind speed remains

Figure 2. Dhaka and Cox's Bazar stations location in Bangladesh.

lower between October to February and maximum between June to July. Bangladesh has a lot of hilly region's and isolated island, where the wind average velocities are relatively high. During October to February, wind speed remains relatively lower. The maximum wind speed is gained during June-July. Establishing wind turbine in coastal areas can be a better solution to support the national grid. During the April-May, demand of electricity is on the peak in Bangladesh due to the launching of summer accompanied by heavy demand of water in irrigation purpose. In most of the regions (at least 50%) of Bangladesh suction head is only 6 meter. The required pump is of 12 meter head and 2 cusec capacity, and this demand can easily be met by harnessing the wind potential. At this moment, this demand is mainly fulfilled by diesel. Installation of windmills will not only save the cost of pumping water for irrigation but also increase the power generation from a renewable source [12].

Bangladesh is one of the developing countries of the world, where power demand is increasing intensely day by day. To encounter the present demand, government has established quick rental projects, mainly dependent on diesel and furnace oil. Renewable sources not only give fuel free of cost but also ensure environment friendly emissions. Among all the renewable sources, wind is the most promising one. Although mankind has been using the wind energy since ancient time, its use to produce electricity effectively by means of modern wind turbines is over two decades old [13]. Monthly average wind speed has been studied to estimate the potential period of extracting wind energy. To have the data of average wind speed, previously collected data for successive years has been analyzed.

3. Flapping Type Wind Turbine Working Mechanism

Flapping wind turbine with chebyshev dyad link mechanism was introduced by

M. S. Alam and H. Hirahara. The following content has been briefly discussed in my previous work. A short summary of the turbine working principle and measuring performance described below: Chebyshev-dyad link mechanism has the advantage to transform mechanical forces through the symmetric curve to another symmetric one [14]. In flapping turbine mechanism, a unique eight shape input trajectory of Chebyshev-dyad give us the unique circular output curve in **Figure 4**. In flapping wind turbine, the blade flaps continuously under a unique trajectory, NACA0012 airfoil profile with resulting chord of 200 mm and height of 300 mm give the blades an aspect ratio of 1.5. The wing blade utilizes both lift and drag forces under the variation of attack angle for the turbine motion. Flapping wing makes a distinct aerodynamic flow mechanism by varying position and orientation and due to the periodic movement of the wind turbine even though the flow is uniform the relative velocity of the wing blade and flow direction varies during a cycle. Hence, the lift and drag forces depends on the angle of attack directly with the relative flow velocity and the resultant forces by the wing blade are converted as rotor motion through Chebyshev-dyad link mechanism (**Figure 3** & **Figure 4**).

According to the geometric relationship in **Figure 4**, the coordinates of point A, B, C and K are expressed relevant to the origin O as follows: Coordinates of point $A(x_1, y_1)$, where: $x_1 = L_1 \cos\theta_1$ and $y_1 = L_1 \sin\theta_1$

Coordinates of point $B(x_2, y_2)$, where: $x_2 = x_1 + L_4 \cos\left\{\theta_2 - \left(\frac{\pi-\psi}{2}\right)\right\}$ and $y_2 = y_1 + L_4 \sin\left\{\theta_2 - \left(\frac{\pi-\psi}{2}\right)\right\}$; Point $C(x_3, y_3) = (L_3, 0)$ is fixed and locus of point $K(x_4, y_4)$, is calculated as $x_4 = x_1 + \sqrt{2(1-\cos\psi)}L_4\cos\theta_2$ and $y_4 = y_1 + \sqrt{2(1-\cos\psi)}L_4\sin\theta_2$. The angle of attack determined by using the following relation with the mounting angle, and wind angle $\alpha = \theta_w - \alpha_0 - \theta_2$.

Torque Calculation

An optimal shape of flapping wind turbine is considered with NACA0012 airfoil section with Wing span (b) = 0.3 m, Chord length (c) = 0.2 m, Deltoid Angle (Ψ) = 70˚, Mounting angle (α_0) = 80˚, Link length (L_1) = 0.5 m, Link lengths (L_2, L_3, L_4) = 0.1 m, Number of node points (n) = 36, Wind incidence angle (θ_w) = 90˚. The torque for a Flapping Type wind turbine is calculated by the following formula:

$$T = (x_1 - x_2)\left\{D + \frac{(y_3 - y_4)\{D(x_1 - x_5) + L(y_1 - y_5)\}}{x_3\cdot y_1 - x_4\cdot y_1 - x_1\cdot y_3 + x_4\cdot y_3 + x_1\cdot y_4 - x_3\cdot y_4}\right\} + (y_1 - y_2)\left\{L - \frac{(x_3 - x_4)\{D(x_1 - x_5) + L(y_1 - y_5)\}}{x_3\cdot y_1 - x_4\cdot y_1 - x_1\cdot y_3 + x_4\cdot y_3 + x_1\cdot y_4 - x_3\cdot y_4}\right\}$$

The relative velocity is calculated with wing velocity as:

$$U = \sqrt{(V_0\cos\theta_w - V_{kx})^2 + (V_0\sin\theta_w - V_{ky})^2}$$

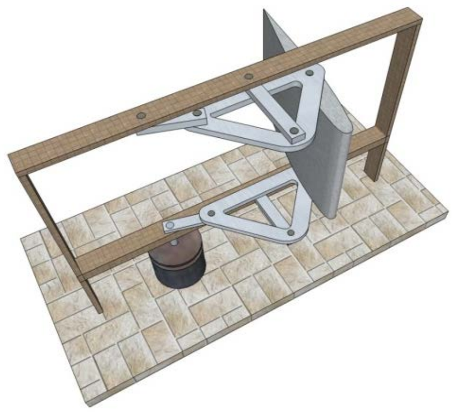


Figure 3. Rooftop flapping type wind turbine prototype.

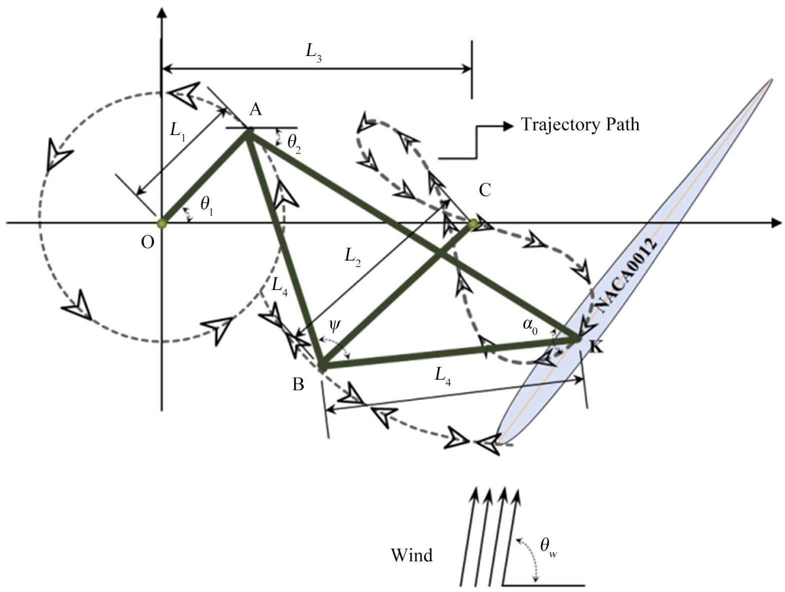


Figure 4. Geometrical representation of the rooftop flapping wind turbine.

where, $V_{Kx} = \frac{x_{K_{i+1}} - x_{K_i}}{dt}$ and $V_{Ky} = \frac{y_{K_{i+1}} - y_{K_i}}{dt}$; and V_0 is the free stream wind velocity.

Lift and Drag force will be obtained from $L = \frac{1}{2} C_L \rho bcU^2$ and $D = \frac{1}{2} C_D \rho bcU^2$.

4. Flapping Wind Turbine Performance for Artificial Wind Velocities

In this section, we calculate the static torque for some fixed velocities using flapping wind turbine. We consider the wind velocities 2 m/s, 3 m/s, 4 m/s, 5 m/s respectively for 36 nodal values for a complete rotation of flapping wind turbine. The resultant torques is presented by the following figure: Figure 5.

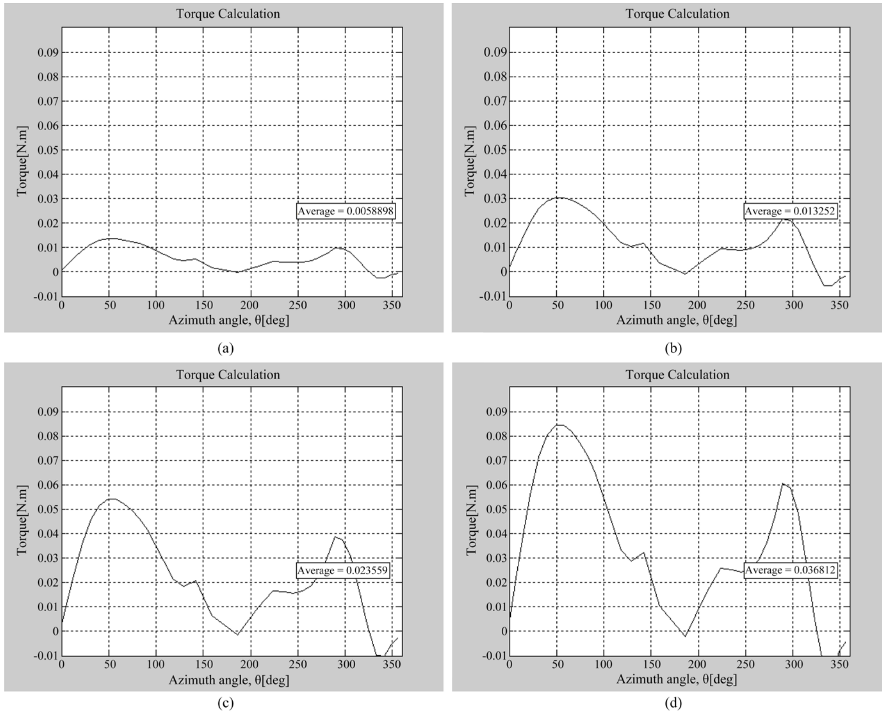


Figure 5. Calculated Torque for the wind velocities 2 m/s, 3 m/s, 4 m/s, 5 m/s respectively for 36 nodal points for a complete rotation of flapping wind turbine.

5. Flapping Wind Turbine Performance for Real Data

5.1. Comparison of Wind Speed for Dhaka and Cox's Bazar Stations

The following figures represent a comparative wind velocity profile for two different stations in Bangladesh namely Dhaka station and Cox's Bazar Station for the year 2018 only and demonstrate the velocity curve for individual months in that year. As we have eight data's in a day with three-hour intervals, we consider the average wind velocity of the particular day to plot the velocity contour. From the figures, we can easily observe that the average velocity profile for Cox's Bazar station is relatively higher than the Dhaka station (**Figure 6**).

5.2. Wind Velocity Profile for Dhaka Station

The following figures represent the average wind velocity contours for the specific months in Dhaka station for the years 2009 to 2018. As we have three hourly wind data in a day, we calculate the average velocities for the distinct months and plot the following curve **Figure 7** for the years 2009 to 2018.

5.3. Wind Velocity Profile for Cox's Bazar Station

The following figures represent the average wind velocity contours for the specific months in Cox's Bazar station for the years 2009 to 2018. As we have three hourly wind data in a day, we calculate the average velocities for the distinct months and plot the following curve **Figure 8** for the years 2009 to 2018.

Figure 6. Average wind speed of Dhaka and cox's bazar station for an individual year 2018.

5.4. Generated Torque by the Flapping Wind Turbine in Dhaka Station

The following figure represents the generated static torque by the flapping wind turbine for one complete rotation under thirty-six nodal points. To calculate the torque we consider the average wind velocities for the last ten years (2009-2018), details in the below **Figure 7**. From the following figures in **Figure 9**, we can easily observe that the average torque and the torque profile for Dhaka station are relatively low from September to February of a year. It is also clear that the produced torque is enough to generate the turbine motion.

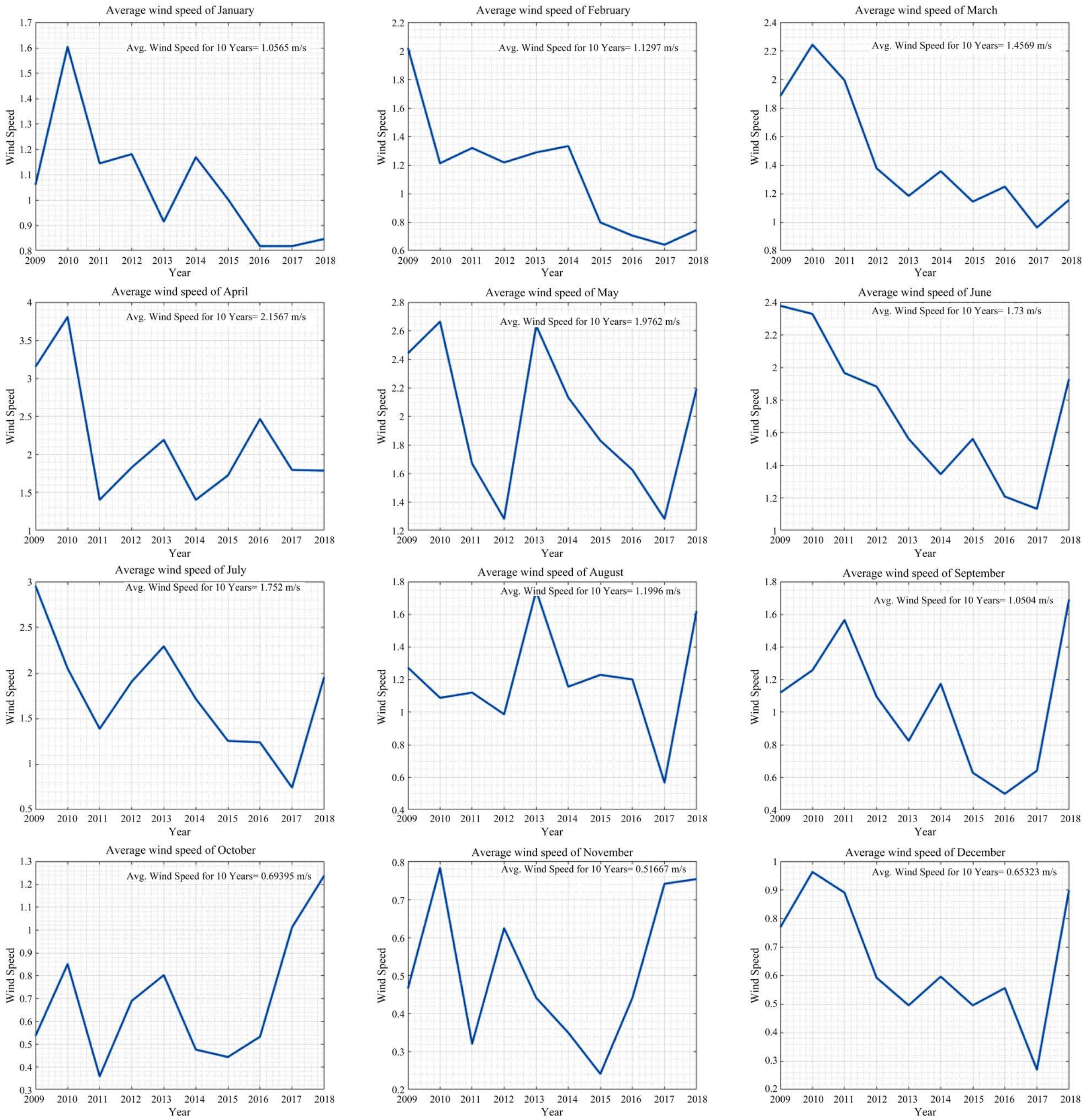


Figure 7. Average wind speed of Dhaka station for 10 years.

5.5. Generated Torque by the Flapping Wind Turbine in Cox's Bazar Station

The following figure represents the generated static torque by the flapping wind turbine for one complete rotation under thirty-six nodal points. To calculate the torque we consider the average wind velocities for the last ten years (2009-2018), details in the below **Figure 8**. From the following figures in **Figure 10**, we can easily observe that the average torque and the torque profile for Cox's Bazar are relatively low from October to December of a year. It is also clear that the produced torque is enough to generate the turbine motion.

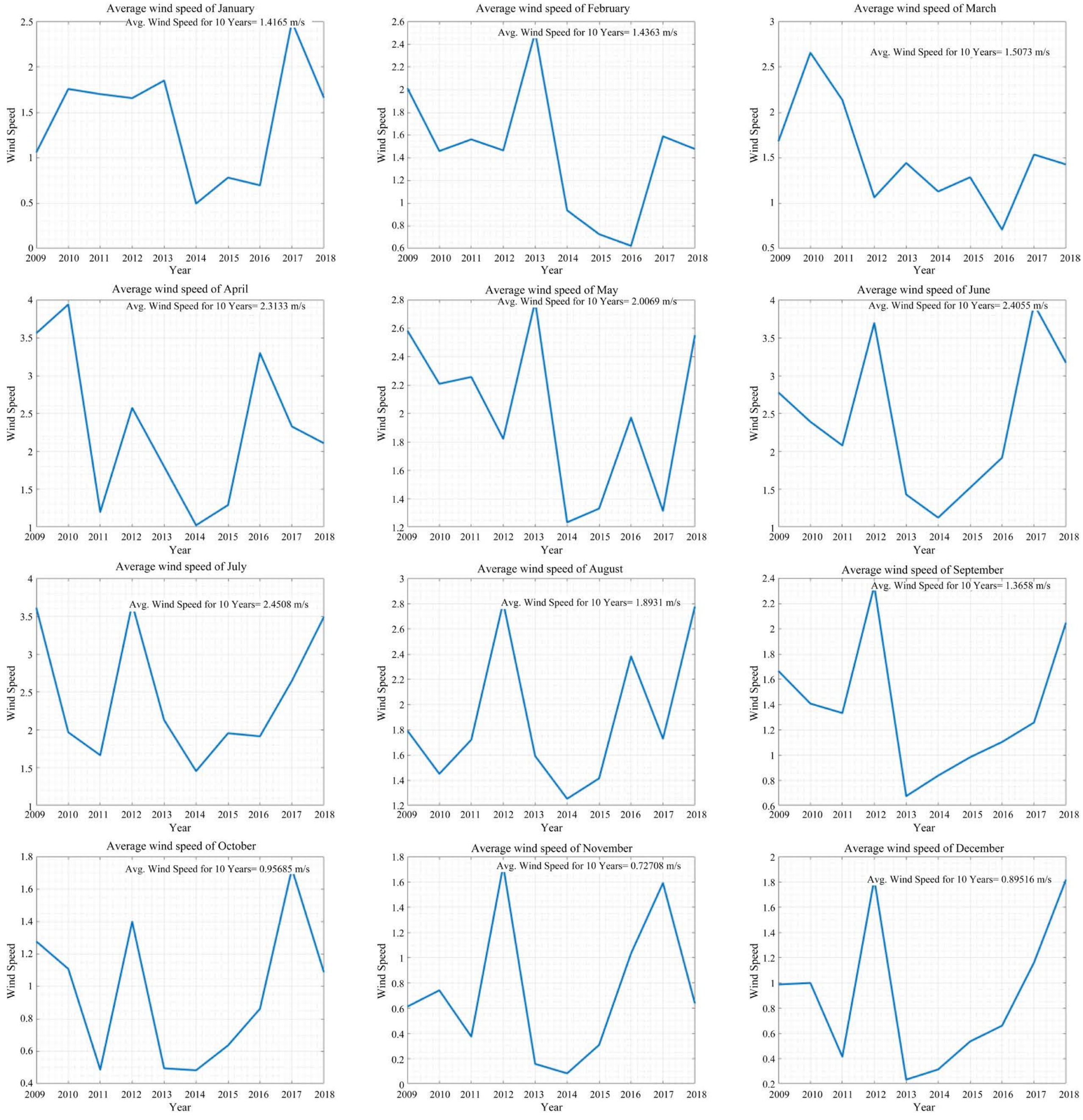


Figure 8. Average Wind Speed of Cox's Bazar Station for 10 years.

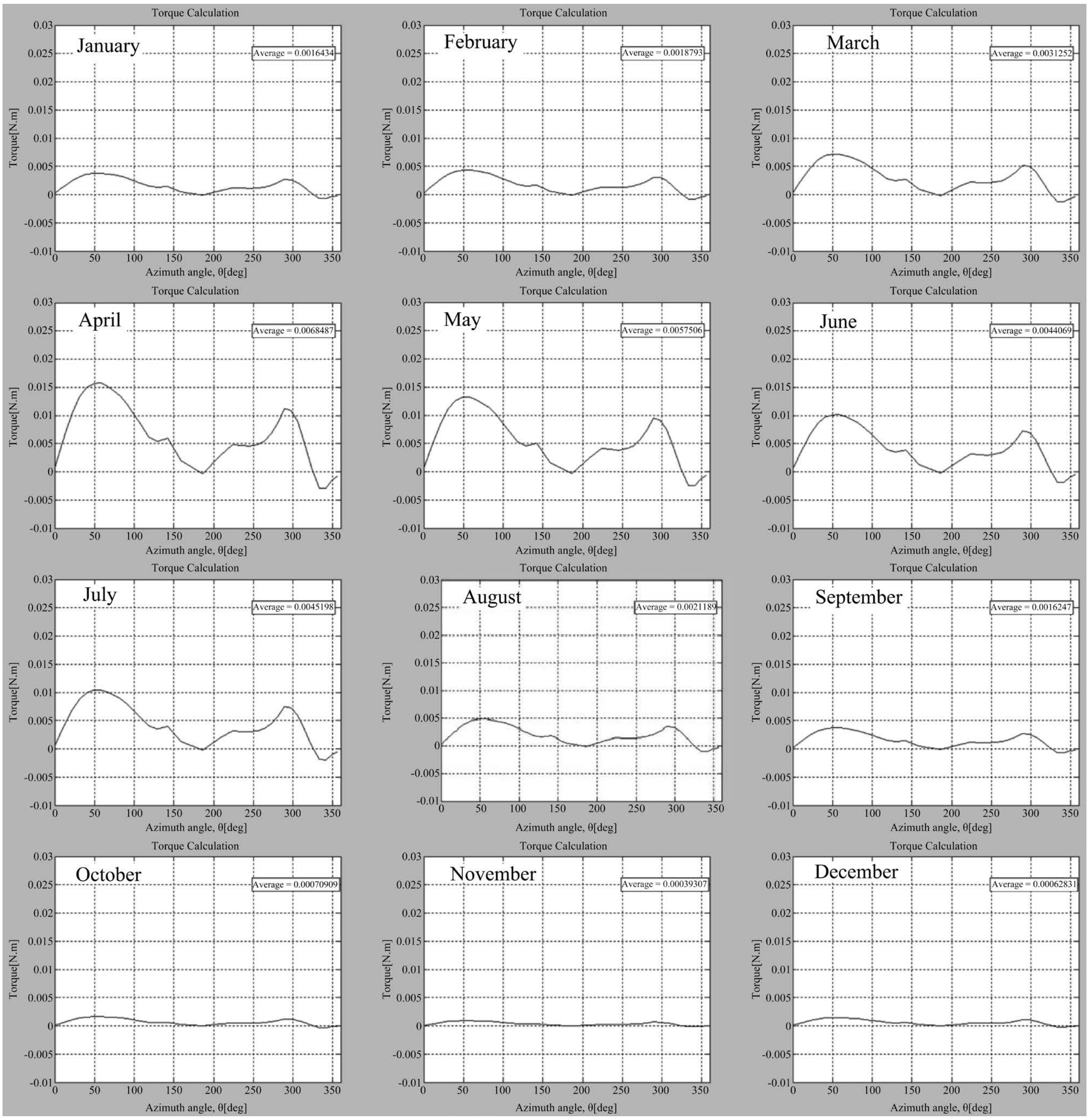


Figure 9. Calculated torque for one single rotation of the flapping wind turbine based on the Average Wind Velocity of Dhaka Station.

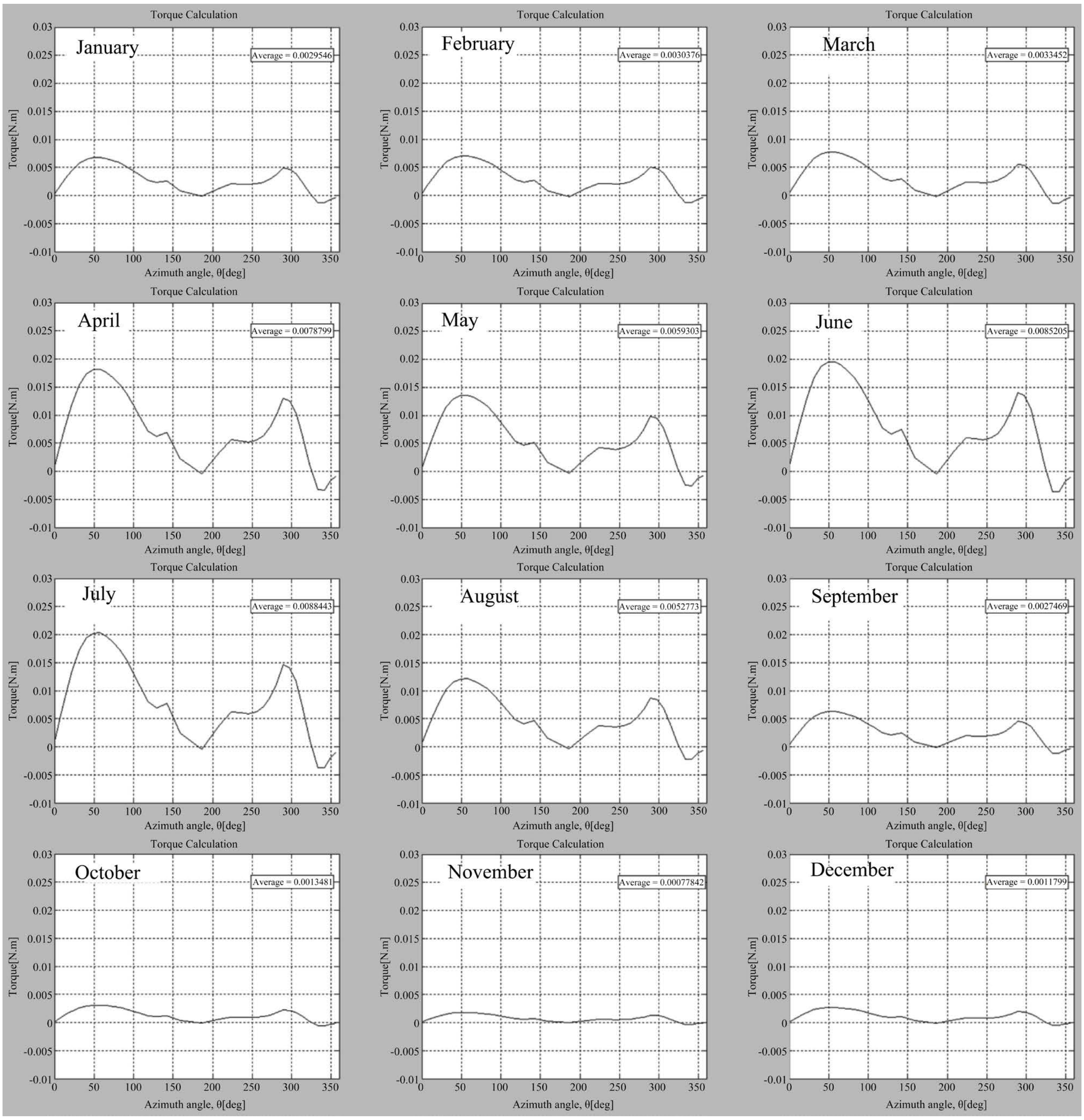


Figure 10. Calculated torque for one single rotation of the flapping wind turbine based on the Average Wind Velocity of Cox's Bazar Station.

6. Conclusions

This paper mainly focused on the performance of rooftop flapping wind turbine which can easily operate in the residential area drive at a slow speed. As flapping wind turbine has the advantage on noise, pollution and aviation mortality rate, it has the potential to install in residential areas like Dhaka and Cox's Bazar cities. In our analysis, we found that the wind velocities are not the same in all the months of the year in Bangladesh. Wind velocities are high in the months of April, May, June and July and low in the months of September, October, November and December. Wind velocities remain medium in the months of January, February and March. Therefore, we investigate the average wind velocities of Dhaka and Cox's Bazar stations for the previous ten years for each month and find a suitable range of wind velocities, which is our research interest to operate wind turbine with slow flapping motion.

Observing the average wind velocities of Dhaka and Cox's Bazar stations, it has been found that wind velocities of these two stations are not high enough to produce plenty torque as well as sufficient electric power. But due to the scale merit of flapping wind turbine, we can easily rearrange the flapping turbine configuration with the velocities available at Dhaka and Cox's Bazar so that this turbine can extract energy from the wind. More investigation will give a better upshot in this field to obtain better performance from flapping wind turbine installed in residential areas.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Tabrizia, A.B., Whalea, J., Lyons, T. and Urmee, T. (2014) Performance and Safety of Rooftop Wind Turbines: Use of CFD to Gain Insight into Inflow Conditions. *Renewable Energy*, **67**, 242-251. https://doi.org/10.1016/j.renene.2013.11.033

[2] Islam, S. and Khan, M.Z.R. (2016) A Review of Energy Sector of Bangladesh. 1*st International Conference on Energy and Power*, *ICEP*2016, Melbourne, 14-16 December 2016, 611-618.

[3] Historical Development of the Windmill. (1990) NASA Contractor Report 4337. DOE/NASA/52661.

[4] Tummala, A., Velamati, R.K., Sinha, D.K., Indraja, V. and Krishna, V.H. (2016) A Review on Small Scale Wind Turbines. *Renewable & Sustainable Energy Reviews*, **56**, 1351-1371. https://doi.org/10.1016/j.rser.2015.12.027

[5] Barrios, L. and Rodriguez, A. (2004) Behavioural and Environmental Correlates of Soaring-Bird Mortality at On-Shore Wind Turbines. *Journal of Applied Ecology*,

41, 72-81. https://doi.org/10.1111/j.1365-2664.2004.00876.x

[6] Bakker, R.H., Pedersen, E., van den Berg, G.P., Stewart, R.E., Lok, W. and Bouma, J. (2012) Impact of Wind Turbine Sound on Annoyance, Self-Reported Sleep Disturbance and Psychological Distress. *Science of the Total Environment*, **425**, 42-51. https://doi.org/10.1016/j.scitotenv.2012.03.005

[7] Saad, M., *et al*. (2014) Comparison of Horizontal Axis Wind Turbines and Vertical Axis Wind Turbines. *IOSR Journal of Engineering* (*IOSRJEN*), **4**, 27-30. https://doi.org/10.9790/3021-04822730

[8] Nakvee, S. and Rahman, I. (2018) Numerical Analysis of Wind Flow over Various Shaped Rooftop of Buildings for Renewable Energy Application in Bangladesh. 2*nd International Conference on Innovation in Science, Engineering and Technology* (*ICISET*), Chittagong, 27-28 October 2018.

[9] Bangladesh Power Sector Review for 2020: Saleh Ebn Sharif, August 2020.

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

[11] Khatun, M.A., Rashid, M.B. and Hygen, H.O. (2016) Climate of Bangladesh. Bangladesh Meteorological Department Technical Report, 1-158.

[12] Amin, M.T. (2015) Prospects of Wind Energy in Bangladesh. *International Journal of Advanced Renewable Energy Research*, **2**, 213-218.

[13] Boyle, G. (1601) Renewable Energy Power for a Sustainable Future. Third Edition, Oxford University Press, Oxford.

[14] Dijksman, E.A. (1981) Watt-1 Linkages with Shunted Chebyshev-Dyads, Producing Symmetrical 6-Bar Curves. *Mechanism and Machine Theory*, **16**, 153-165. https://doi.org/10.1016/0094-114X(81)90061-6