Proceedings of 8th International Conference on Mechanical, Industrial and Energy Engineering 2024,
02-04 January 2025, Khulna, BANGLADESH
SciEn Conference Series: Engineering Vol. 3, 2025, pp 176-180 https://doi.org/10.38032/scse.2025.3.43

Study on Development of an Automatic Wind Turbine System

Enamul Hoq[1], *Mohammad Mashud*[2], *Md Mizanur Rahman*[1], *Md. Shariful Islam*[1,2]

[1]Department of Mechatronics Engineering, World University of Bangladesh, Dhaka, Bangladesh
[2]Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh

ABSTRACT
The most swiftly expanding renewable energy source for electricity production is wind power, which is one of the three primary renewable energy sources, along with solar and hydropower. Wind energy is abundant and can supply electricity to a significant portion of the world; however, it is unpredictable and sporadic, which makes it difficult to rely solely on it. Ultimately, the objective of this project is to create and implement an autonomous wind turbine system that can detect wind direction and adjust its orientation accordingly. As a result, we integrate wind from a diverse array of directions, including 0 degrees to 120 degrees, into the traditional sensor-based wind turbine design. By monitoring wind orientation and operating the wind turbine, the wind direction sensor preserves the same efficiency as the direct model's. Our research also indicates that sensor-based wind turbines operate at nearly twice the average efficiency of conventional wind turbines. Regardless of the wind conditions, the objective of this endeavor is to establish the article as a cost-effective alternative power source. Due to improved technologies and reliability, the advantages of the swiftly expanding renewable energy source have a minimal environmental impact.

Keywords: Turbine system, Renewable energy, Kinetic energy, Mechanical, Turbine blade.

Copyright @ All authors
This work is licensed under a Creative Commons Attribution 4.0 International License.

1. Introduction

In recent years, renewable energy sources have garnered significant attention as a result of the current energy crisis and the desire for sustainable energy systems. Wind energy is a primary option because of its robust infrastructure, technology maturity, reliability, and relative cost competitiveness. An environmentally friendly or alternative energy source is deemed to be wind-generated electricity in order to address economic and environmental concerns. Many countries regard wind as a renewable, pure, and limitless energy source that can satisfy their expanding energy needs. Consequently, the global wind power sector has experienced substantial growth in the past two decades, with the total installed capacity of wind power worldwide increasing from 1.29 GW in 1995 to 370 GW by the end of 2015 [Mussilimov, et. al. 2019].

The United States has experienced a substantial decline in the development of wind energy since the late 1980s. Nevertheless, Europe has experienced a significant increase in the adoption of wind energy as a result of a sudden realization and awareness of the urgent need for an environmental response. A variety of studies suggested that the excessive use of fossil fuels could significantly impact the global climate, prompting this realisation. Wind-powered generators of varying sizes are currently available, ranging from small turbines for battery charging to large offshore wind fields that supply electricity to national electric transmission systems. The global recognition of alternative energy sources, such as wind, is increasing; however, a significant number of developing nations have yet to adopt this source of energy [Medojevic, et.al., 2018; Ang et. al., 2017). Wind energy is utilized to power generators that operate a wind turbine, which generates electricity. The kinetic energy of the wind is converted into electrical energy by wind turbines. This procedure employs an exposed rotor. The rotor propels a generator that is typically situated aft of the rotor in order to produce electricity [Anaya-Lara,et. al., 2011].

Long ago, humans introduced sails to wind power. Windmills were in use in Babylon and China as early as 2000 B.C., according to evidence. In the first century AD, the wind wheel was devised by the Heron of Alexandria in Roman Egypt, marking the first known application of a machine's power source. In the subsequent centuries, the utilization of wind power increased; in the 21st century, it became a highly regarded and dependable source of electrical power generation [Solari, 2019]. Vertical and horizontal-axis wind turbines generate electricity by harnessing wind power. The wind turbine's efficacy is contingent upon the direction and velocity of the wind. Modern instruments utilized to quantify wind velocity and direction include anemometers and wind vanes. For the purpose of resource appraisal and power generation system control, these instruments are the primary focus of this investigation. One of the most rapidly expanding sources of energy is wind energy harvesting [Johari, et. al., 2018]

Wind energy is one of the energy sources with the quickest rate of growth worldwide, owing to its numerous benefits. Brings [Leung & Yang, 2012]. The following is a discussion of certain assumptions regarding wind turbine systems.

a) Wind turbine systems are still in competition with conventional power generation sources in terms of cost. The wind turbine system necessitates a greater initial investment than fossil-fueled generation systems [Sims et. al., 2003].

*Corresponding Author Email Address: shariful.islam@mte.wub.edu.bd

b) The location of wind turbine systems is often remote from communities with a high demand for electricity [Munday et. al., 2011].
c) In order to produce the same quantity of energy as through alternative sources, wind turbine systems necessitate a larger land area. Occasionally, the economic value of the site exceeds that of electricity generation [Conroy & Watson 2008].
d) Wind turbine blades have been known to cause fatalities in birds that have collided with them; consequently, the blades may inflict harm on the animals in the vicinity [Smallwood., 2007]

The electrical interface and wind characteristics of this fastest-growing renewable energy source produce unique effects when connected to a power grid. Wind turbines convert the kinetic energy of the wind into electrical energy [Smith, 1982; Tong 2010]. The US Department of Energy reports that in 1990, wind power installations in California prevented the emission of over 2.5 billion pounds of carbon dioxide and 15 million pounds of other pollutants. 90 million to 175 million trees would be necessary to achieve the same level of air quality [York et. al., 2012].

In comparison to fossil fuel power plants, wind power plants have a less significant environmental impact. The aesthetic impact, the noise of the rotor blades, and the fatalities of bats and birds as a result of collisions with the rotors have all been the subject of concern among the public. Technical innovations or appropriately sized wind farms have resolved or substantially diminished the majority of these concerns. In 2014, over 240,000 commercial-sized wind turbines were operational worldwide, contributing an astounding 4% of the world's electricity [Zhu & Li, 2018]. To demonstrate the alteration of wind components, velocities, and evaporation in Lake Tanganyika, the investigation implemented an extensive network of automated sample stations and meteorological buoys situated at high sampling frequencies. The study employed aerodynamic and energy balance methodologies to ascertain the evaporation rates at the southern and northern ends of the lake. During the day, thermal breezes emanated from the lake, while the land provided nocturnal winds. The arid season was characterised by the most significant onshore-offshore air temperature gradient and the strongest winds during the day [Brown, 2991]. Upon entering the boundary layer, the dune alters the direction of wind flow along its cross-section. Smoke flares illustrate the flow, while anemometers quantify wind velocity. The research proposes a straightforward, phenomenological model of linear dune dynamics. It is predicated on the notion that the dunes' surface erodes as the wind speed increases, while sand accumulates as the wind speed decreases. This investigation exclusively investigates the impact of fluctuating wind speeds on the preservation of linear dunes' form. Other studies have examined secondary wind velocities; however, this study does not [Verburg and Hecky, 2003].

Farms frequently used wind energy by the 1930s, particularly in the United States, where distribution networks were still developing. John Brown & Company constructed the first utility grid-connected wind turbine to function in the UK in the Orkney Islands in 1951. [Stone, 1986]

Bangladesh is located in the region of 88001'-92041' East Longitude and 20034'-26038' North Latitude. The nation has a 724-kilometre-long coastline and a number of tiny islands in the Bay of Bengal, where there is a strong southeasterly trade wind and sea breeze in the summer and a warm northeasterly trade wind and land breeze in the winter [Uddin et. al., 2018]. The government of Bangladesh has realized the importance of renewable energy and published a draft Renewable Energy Policy for socio-economic development and to reduce the dependency on fossil fuels. The renewable energy sources for Bangladesh are mainly biomass, hydro, solar energy, and wind power. Hydropower has minimal potential in Bangladesh since few water resources are available for power generation. The vortex power plant may have limited potential for local electricity needs {Karim et.al., 2019].

The method of determining wind speed in Bangladesh has been significantly less systematic. For the purpose of weather forecasting, the meteorology department has implemented a collection of wind speed data. The information was inadequate to evaluate the potential for wind energy. They released a study in 1982 that included 30 years of meteorological data from a variety of locations throughout the country. The coastline region and the islands in the Bay of Bengal were the only areas that appeared to be encouraging for the potential generation of wind-based electricity. In addition, the investigation reveals that the wind speed at a height of 25 meters surpasses the figures reported in 1982 [Khan et al., 2004].

As a part of the wind turbine project, two places named Kutubdia and Feni in Bangladesh run wind turbines to generate electricity. These plants have a combined generation capacity of about 2 MW. According to a study, Vesta Company, a Danish company, plans to invest in the installation of a 100 MW wind farm for electricity production and generation. This project will be located in the Patuakhali district and will host the largest wind farm in Bangladesh [Hossain & Ahmed, 2013].

2. Methodology

The study converted the meteorological wind speed data to 50 m height in this study and then analyzed it for various durations. Finally, use equation 1 to compute the wind power density [Saxena, & Rao 2016; Jamil et. al., 1995; Changa et.al., 2003; Jowder, 2009; Islam et. al., 2013].

$$WPD = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) \ldots\ldots\ldots\ldots\ldots (1)$$

Where ρ is the air density, Γ is the gamma function, and c is the scale parameter, k is the shape parameter defined by the relation shown in equation 2.

$$\Gamma(x) = \int_0^\infty e^{-t}.t^{x-1}dt \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

This study estimates the wind density at various locations and divides it into several power classes. They are separated into several sizes of generation, such as micro, small, medium, and big scale, based on this power class categorization. After determining the greatest practicable scale of generation in terms of wind power density, we use a wind turbine model to extrapolate probable monthly, annual, and average output power from the wind speed data. Equation 3 computes the monthly, annual, and average plant capacity factor (PCF) from this produced output power.

$$Plant\ Capacity\ Factor = \frac{Average\ Demand}{Plant\ Capacity} \ldots\ldots (3)$$

This study deemed locations with a plant capacity factor (PCF) of more than 20% to be economically feasible. The main focus for this study is to explore experimental methods for developing the automatic wind turbine system that produces electric power. The project's construction involved the development of a wind turbine system, a wind detection system, and a servo mechanism. Finally, assemble all the different systems in one place to develop the complete project. This project has employed an experimental methodology to accomplish our tasks.

The developed wind turbine system consists of a turbine that rotates when the wind flows towards the turbine blade. The DC motor connects to the turbine blade. Therefore, the DC dynamo rotates in accordance with the wind turbine's rotational speed, thereby producing electricity. Therefore, the generated electric voltage comes to the boost converter as an input voltage. Then the boost converter steps up the input voltage and converts it to a usable electric voltage. The output electricity from the boost converter is able to drive a device or charge a battery. The wind direction sensor gives its sensor value to the microcontroller unit, the Arduino UNO. The MCU unit processes the sensor data and sends a command to the servo motor to rotate its shaft. The rotating servo shaft changes the wind turbines' direction according to the wind direction. Figure 2.1 demonstrates the mechanical design of the experimental setup.

The electrical circuit of this wind turbine system divides into two halves. The power-generating part is the first, and the sensor-based servo control system is the second. Figures 2.2 and 2.3, respectively, show the circuit diagram of the wind turbine power generation section and the servo control system.

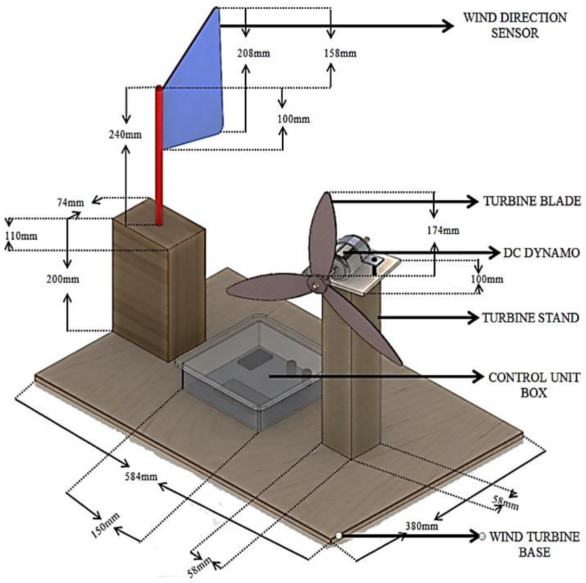

Figure 2.1: Mechanical Design of Automatic Wind Turbine System.

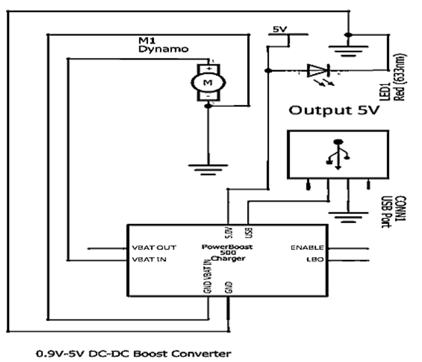

Figure 2.2: Circuit Diagram of Automatic Wind Turbine Power Generation Section.

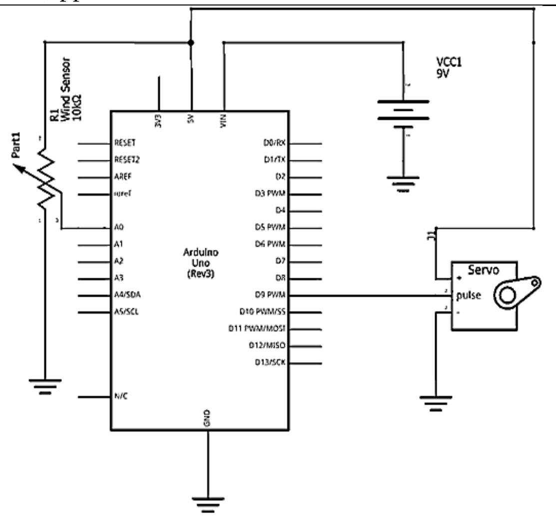

Figure 2.3: Circuit Diagram of Wind Turbine Sensor Based Servo Control Section

3. Result

Figure 3.1 below shows the experimental setup of the automatic wind turbine system, which includes all functional components.

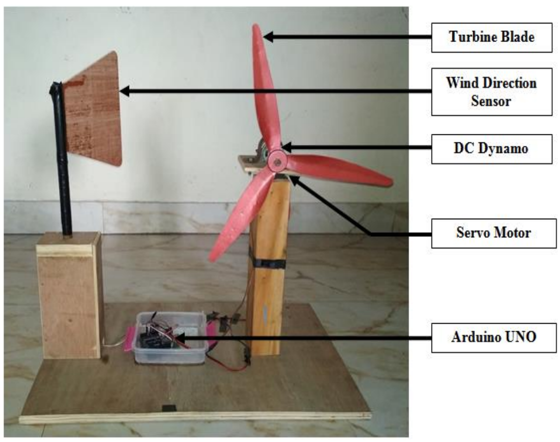

Figure 3.1: Hardware Setup.

The automatic wind turbine setup allows for various observations at different wind speeds. The table (TABLE I) below shows these observations, which include voltage, current, and power.

Table I. Obtained Voltage, Current, and Power for Different Wind Speeds.

Wind Speed (m/s)	Voltage (V)	Current (A)	Power (W)
2.5	0	0	0.0
2.569	5	0.9	4.5
2.639	5	1.1	5.5
2.708	5	1.3	6.5
2.778	5	1.5	7.5

Additionally, the study estimated relative observations using the conventional wind turbine. The results indicated that the model wind turbine power increases with wind speed if the direction of wind is parallel to wind turbine axis. The table below (TABLE II) illustrates these observations at various angles and wind speeds.

Table II. Automatic Wind Turbine vs. Conventional Wind Turbine.

Criterion		Automatic Wind Turbine			Conventional Wind Turbine		
Angle	Wind Speed (m/s)	Voltage (V)	Current (A)	Power (W)	Voltage (V)	Current (A)	Power (W)
0^0	**2.778**	**5**	**0.9**	**4.5**	**5**	**0.9**	**4.5**
30º	**2.778**	**5**	**0.9**	**4.5**	**5**	**0.8**	**4.0**
60º	**2.778**	**5**	**0.9**	**4.5**	**4.1**	**0.56**	**2.296**
90º	**2.778**	**5**	**0.9**	**4.5**	**3.5**	**0.42**	**1.47**
120º	**2.778**	**5**	**0.9**	**4.5**	**1.1**	**0.12**	**0.132**
Average	**2.778**	**5**	**0.9**	**4.5**	**3.74**	**0.56**	**2.47**

Power increase = Automatic wind power – Convectional wind power = 4.5-3.8 = 0.76 Watt

Percentages of power increases

$$= \frac{0.76 \times 100}{3.74} = \frac{0.76 \times 100}{3.74} = \frac{0.76 \times 100}{3.74} = \frac{0.76 \times 100}{3.74} = 19.79\%$$

Wang et al. (2018) proposed a self-powered wind sensor system that is capable of simultaneously detecting wind speed and direction. This system is based on a wind vane triboelectric nanogenerator and an anemometer triboelectric nanogenerator. The researchers discovered that this system has significant potential for use in wireless environmental monitoring applications.

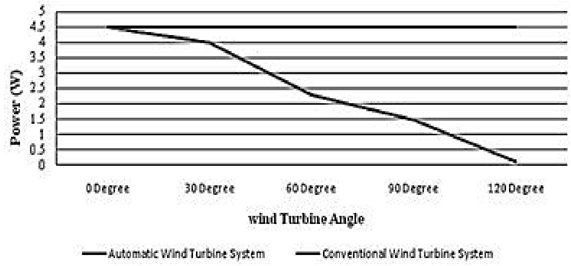

Figure 3.3: Relative analysis of Automatic & Conventional Wind Turbine System

Indirectly influencing the quality of measurements and the safe operation of wind turbines are the inherent issues or environmental influence of wind speed sensors, according to Wagner et. al., (2008). This could result in catastrophic malfunctions or a decrease in performance. By surmounting the constraints of inaccuracy and partially missing measurements in physical sensors, a digital twin-driven sensing methodology can significantly enhance the wind turbine's performance [Wagner, et. al., 2008)].

Research also demonstrated that the power output of wind turbines can be improved through the implementation of a meticulous control method design, thereby significantly reducing mechanical stress and actuation utilization, which are critical components of the system's objectives. In addition, the controller's robustness can be enhanced by the addition of additional sensors, which help it accomplish its objective more efficiently. Consequently, these controllers can be applied to commercial turbines to a limited extent [Elkodama et. al., 2023].

4. Conclusion

Nowadays, technological advancement depends mostly on the availability of energy sources. Due to the insufficiency of conventional energy sources, researchers are working on renewable energy sources. Wind energy could be a suitable Wind energy is one of the most readily available renewable energy sources for rural areas. Despite some installation constraints, the fuel-free, clean energy generation capacity and technological advancements emphasize the utilization of wind energy to meet the increasing energy demands. The developed project proposes the use of an automatic wind tracking turbine to generate electricity. This design focuses on maximizing power generation from the wind when the wind direction changes relative to the wind turbine. Moreover, a wind direction tracking sensor tracks the wind direction and moves the wind turbine, thereby increasing the wind turbine efficiency. Therefore, the design illustrates a model for an optimum automatic wind turbine system.

References

[1] Mussilimov, K., Ibraev, A., & Wójcik, W. (2019). Development of wind energy complex automation system. Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska, 9(2), 36-40. DOI: 10.5604/01.3001.0013.2545

[2] Medojevic, M., Villar, P. D., Cosic, I., Rikalovic, A., Sremcev, N., & Lazarevic, M. (2018). Energy Management In Industry 4.0 Ecosystem: A Review On Possibilities And Concerns. Annals of Daaam & Proceedings, 29. DOI: 10.2507/29th.daaam.proceedings.097

[3] Ang, J. H., Goh, C., Saldivar, A. A. F., & Li, Y. (2017). Energy-efficient through-life smart design, manufacturing and operation of ships in an industry 4.0 environment. Energies, 10(5), 610.

[4] Anaya-Lara, O., Jenkins, N., Ekanayake, J. B., Cartwright, P., & Hughes, M. (2011). Wind energy generation: modelling and control. John Wiley & Sons.

[5] Solari, G. (2019). Wind science and engineering: Origins, developments, fundamentals and advancements. Springer. doi.org/10.1007/978-3-030-18815-3

[6] Johari, M. K., Jalil, M., & Shariff, M. F. M. (2018). Comparison of horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). International Journal of Engineering and Technology, 7(4.13), 74-80.

[7] Leung, D. Y., & Yang, Y. (2012). Wind energy development and its environmental impact: A review. Renewable and sustainable energy reviews, 16(1), 1031-1039. doi:10.1016/j.rser.2011.09.024

[8] Sims, R. E., Rogner, H. H., & Gregory, K. (2003). Carbon emission and mitigation cost comparisons between fossil fuel, nuclear and renewable energy resources for electricity generation. Energy policy, 31(13), 1315-1326. https://doi.org/10.1016/S0301-4215(02)00192-1

[9] Munday, M., Bristow, G., & Cowell, R. (2011). Wind farms in rural areas: How far do community benefits from wind farms represent a local economic development opportunity?. Journal of Rural Studies, 27(1), 1-12. https://doi.org/10.1016/j.jrurstud.2010.08.003

[10] Conroy, J. F., & Watson, R. (2008). Frequency response capability of full converter wind turbine generators in comparison to conventional generation. IEEE transactions on power systems, 23(2), 649-656. https://doi.org/10.1109/TPWRS.2008.920197

[11] Smallwood, K. S. (2007). Estimating wind turbine-caused bird mortality. The Journal of Wildlife Management, 71(8), 2781-2791. https://doi.org/10.2193/2007-006

[12] O.J. Smith, "Wind Turbine System," U.S. Patent No. 4,330,714. Washington, DC, 1982

[13] W. Tong, (2010) "Fundamentals of wind Energy." WIT Transactions on State of the Art in Science and Engineering, Vol. 44, 2010

[14] R.M. York, R. T. Simmons, & C. Steed, (2012) "The Political, Legal, and Administrative Pitfalls Facing Green Energy Production." Green Vs Green, 1st Edition, New York, 14 November 2012

[15] L. R. Brown, "State of the World 1991: World Watch Institute report on progress towards a sustainable society," WW Norton & Company, 2001.

[16] Zhu, C., & Li, Y. (2018). Reliability analysis of wind turbines. Stability control and reliable performance of wind turbines, 169-186. DOI: 10.5772/intechopen.74859

[17] P. Verburg and R. E. Hecky, (2003) "Wind Patterns, Evaporation, and Related Physical Variables in Lake Tanganyika, East Africa," Journal of Great Lakes Research, Volume 29, Supplement 2, Pages 48-61 https://doi.org/10.1016/S0380-1330(03)70538-3

[18] L. Stone, (1986) "Geomorphological significance of wind flow patterns over a Namib linear dune," Aeolian Geomorphology, pp. 97-112, 1986.

[19] Uddin, M. M., Faysal, A., Raihan, M. R., & Jahangir, K. M. (2018). Present energy scenario, necessity and future prospect of renewable energy in Bangladesh. Am J Eng Res, 7, 45-51.

[20] Karim, M. E., Karim, R., Islam, M. T., Muhammad-Sukki, F., Bani, N. A., & Muhtazaruddin, M. N. (2019). Renewable energy for sustainable growth and development: An evaluation of law and policy of Bangladesh. Sustainability, 11(20), 5774. https://doi.org/10.3390/su11205774

[21] Khan, M. J., Iqbal, M. T., & Mahboob, S. (2004). A wind map of Bangladesh. Renewable energy, 29(5), 643-660. https://doi.org/10.1016/j.renene.2003.10.002.

[22] Hossain, M. A., & Ahmed, M. R. (2013). Present energy scenario and potentiality of wind energy in Bangladesh. World Academy of Science, Engineering and Technology, 7(11), 1001-1005.

[23] B. K. Saxena, K. V. S. Rao (2016), "Estimation of wind power density at a wind firm site located in the Western Rajsthan region of India," Procedia Technology Volume 24, pp. 492-498, 2016.

[24] M. Jamil, S. Parsa, M. Majidi. (1995), "Wind power statistics and an evaluation of wind energy density." Renewable Energy Volume 6, Issues 5–6, pp. 623-628, July–September 1995.

[25] T. J. Changa, Y. T. Wua, H. Y. Hsua, C. R. Chub, and C. M. Liaoa, (2003) "Assessment of wind characteristics and wind turbine characteristics in Taiwan," Renewable Energy Volume 28, Issue 6, pp. 851-871, May 2003.

[26] F. A.L. Jowder, (2009) "Wind power analysis and site matching of wind turbine generators in the Kingdom of Bahrain," Applied Energy Volume 86, Issue 4, pp. 538-545, April 2009.

[27] M. S. Islam, A. Islam, M. M. Hasan, A. H. Khan (2013) "A. H. Khan Feasibility Study of Wind Power Generation in Bangladesh: A Statistical Study in the Perspective of Wind Power Density and Plant Capacity Factor," International Journal Of Renewable Energy Research, Volume 3, Issue 3, pp. 476–487, 2013.

[28] Elkodama, A., Ismaiel, A., Abdellatif, A., Shaaban, S., Yoshida, S., & Rushdi, M. A. (2023). Control methods for horizontal axis wind turbines (HAWT): State-of-the-art review. Energies, 16(17), 6394. https://doi.org/10.3390/en16176394

[29] Wang, J., Ding, W., Pan, L., Wu, C., Yu, H., Yang, L., ... & Wang, Z. L. (2018). Self-powered wind sensor system for detecting wind speed and direction based on a triboelectric nanogenerator. ACS nano, 12(4), 3954-3963. https://doi.org/10.1021/acsnano.8b01532

[30] Wagner, R., Antoniou, I., Pedersen, S. M., Courtney, M. S., & Jørgensen, H. E. (2009). The influence of the wind speed profile on wind turbine performance measurements. Wind Energy: An International Journal for Progress and Applications in Wind Power Conversion Technology, 12(4), 348-362. https://doi.org/10.1002/we.297

NOMENCLATURE

ρ : Air density, kg/m-3

Γ: Gamma function

c : Scale parameter

k: Shape parameter