



Performance of the Pumpkin Wind Turbine

Toto Rusianto^{1*}, Saiful Huda¹, Angge Dhevi Warisaura², and Andrean Emaputra³

¹Department of Mechanical Engineering, Institut Sains dan Teknologi AKPRIND
Yogyakarta 55222, Indonesia

²Department of Environmental Engineering, Institut Sains dan Teknologi AKPRIND
Yogyakarta 55222, Indonesia

³Department of Industrial Engineering, Institut Sains dan Teknologi AKPRIND
Yogyakarta 55222, Indonesia

Corresponding Author's email: toto@akprind.ac.id

Abstract. This paper reports existing studies on the influence of the number of blades on vertical axis wind turbine (VAWT) performance. Wind turbine blade is an important element in the conversion of wind energy to electrical energy, because of their ability to convert wind kinetic energy, even at low wind speeds. Therefore, the choice of airfoil-shaped wind turbine blades is very suitable for application in areas with low wind speeds. The VAWT blade installed resembles a pumpkin when it spins, so is called a pumpkin wind turbine. The blades were installed on VAWT with various 2, 3, 4, and 5 blades, while the performance of the wind turbine was determined with various wind speeds, respectively. The successful manufacture of blades can be an advantageous solution for vertical wind turbines. The turbine with three blades has the largest tip speed ratio (TSR) of 4.08. The test results of this pumpkin wind turbine show the maximum efficiency power expressed in C_p of 0.49 with the number of three blades. For application, a vertical pumpkin wind turbine with a stand-alone has been installed for lighting in Mount Ireng in Pengkok Village Patuk Gunung Kidul Special Region of Yogyakarta.

Keywords: Wind turbine, pumpkin, ireng, energy, blade.

1 INTRODUCTION

A wind turbine is a machine that converts the wind kinetic energy into mechanical energy in the form of shaft rotation. The wind turbine shaft is coupled with the generator shaft to rotate the magnetic field, inducing a winding of copper wire to produce electrical energy. Torque and rotation speed are the mechanical output of the rotor which affects the load of work and generator speed to produce electricity [1]. The electricity produced can be used for home, industrial or office purposes. A single stand-alone small wind turbine can be used to generate electricity power for a single home or light street [2] The small wind turbine is a micro-scale power plant where the energy produced is lower than 1500 watts [3].

Wind turbines are divided into two types based on the drive shaft direction namely Vertical Axis Wind Turbines/VAWT and Horizontal Axis Wind Turbines/HAWT [4] [5]. Horizontal-axis wind turbines have higher power efficiency advantages over vertical axis wind turbine [6]. The power efficiency of the wind turbine is measured by

the power coefficient (C_p). However, the research results show that VAWT has advantages for areas with low wind speeds [7]. Another advantage of VAWT is not require the yaw system of wind turbines to orientate the wind turbine rotor towards the wind, it has better construction stability and is silent. In terms of increasing the efficiency of power produced by wind turbines, it is necessary to design low-speed generators that operate at low rotation [8]. The HWAT has a horizontally oriented rotary axis usually having three blades and is designed to face the wind. The VAWT has a rotating axis that is aligned vertically and is designed to utilize kinetic energy from all directions. Both have their advantages and disadvantages [9]. HWATs are the most popular wind turbine choice and have received more funding for research and development because they offer significant advantages over VAWT. HWAT has greater efficiency than VAWT when extracting energy from wind forces due to its design which allows it to extract energy through a full rotation of the blades when placed under a consistent wind flow. Even though VAWT has not received as much attention as HWAT in its research and development, VAWT has several significant advantages compared to HWAT. Unlike HWAT which must face wind flow all the time to provide optimal output, VAWT is omnidirectional and can receive wind from all directions [10].

VAWT is the best choice for installation in low-speed and more turbulent wind environments such as urban areas because they can generally start producing power at low wind speeds [11]. Systems for VAWT such as gearboxes and other equipment can be packaged together and installed closer to the ground, eliminating the need for additional costs for maintenance and are easier to control. VAWT also has the advantage that the sound it makes is lower than HWAT

[12] [13]. VAWT is inefficient in high-speed wind environments because they have very low starting torque and problems with their dynamic stability [14]. VAWT is also susceptible to backtracking because some of its blades move against the wind until they travel back into the wind stream to be pushed back. Previous studies and patents comparing VAWT and HWAT have shown mixed results.

Wind turbines are classified based on the rotational speed into two parts, namely the wind turbine with variable speed (VSWT) and fixed speed wind turbines (FSWT). A VSWT is a wind turbine that is mainly designed to operate over a wide range of rotor speeds and can provide primary frequency regulation. a FSWT is a wind turbine with a rotor rotation at a constant angular speed. The changes in the speed are determined by the gear ratio, number of generator poles and system frequency. FSWT has several advantages of the use of cheap power electronic circuits, a simple system, and low maintenance. However, FSWT has weaknesses, in that the turbine cannot operate at varying wind speeds, so the energy produced cannot achieve maximum efficiency and small energy [15].

The use of new renewable energy is still very low which can be utilized by society in Indonesia [2] [16] [17]. The society still has limited knowledge regarding the use of new and renewable energy, including the use of windmills as an energy source. Countries in Europe and America have well-developed wind energy conversion systems so energy is cheaper than conventional energy. The use of renewable energy is not only a way to obtain energy but is also necessary to build a clean environment for human life and its ecosystem [18][19][20]. Vertical axis wind turbines can handle various problems of small wind turbines in one product. In the past, it was usually only

an inefficient turbine that was capable of producing a little noise. Turbines placed close to each other result in lower performance, especially in horizontal axis wind turbines [21].

The pumpkin-shaped vertical wind turbine uses aerodynamics and an innovative design with an airfoil shape to create a small wind turbine that can be used in areas with low winds. Its higher efficiency compared to turbines of the same class allows it to generate electricity at lower wind speeds. This allows the turbines to be installed cost-effectively for better performance in suitable locations. The wind turbine that is applied on site has a unique shape like a pumpkin (*Cucurbita moschata*) when it rotates, so this turbine is called a pumpkin wind turbine. Wind turbine blades have an important role in converting wind energy into mechanical energy [22] and many models have been developed by researchers. In this paper, the pumpkin wind turbine blades with varying blade numbers of 2, 3, 4 and 5 provide different performance at varying wind speeds.

2 METHODOLOGY

2.1 Wind Speed Measurement at Mount Ireng

Mount Ireng is the location where a vertical wind turbine with a single pole will be placed as a lighting generator. Mount Ireng is located in Pengkok Village Patuk District Gunung Kidul Regency Special Region of Yogyakarta. Mount Ireng has an altitude of about 200 meters above mean sea level. Even though the mountain is not very large, the position of the mountain is still higher compared to the areas in the location village, so it has a wide view in that direction. With an unobstructed area towards the east and south positions, the Mount Ireng area gets quite large gusts of wind from the South direction where the South direction is the south coast area of Yogyakarta which is approximately 20 km away. Figure 1 shows a map of the location of Mount Ireng. Mount Ireng is a tourist destination with an attractive sunrise panorama. At night, the location of Mount Ireng is completely dark, so lighting is needed for tourists waiting for the sunrise the next day. A suitable energy source for lighting in this area can be obtained from wind energy. Therefore, wind turbines were installed as a solution for lighting in the area.



Fig. 1. Map of the location of Mount Ireng as a test site for vertical axis wind turbines for lighting.

Mount Ireng as a research test location for wind turbines requires a survey of wind speeds at that location. Because wind is a source of kinetic energy from wind turbines. Another test is measuring wind speed at the location. Figure 2 shows the results of wind speed measurements at the Gunung Ireng location, Pengkok Patuk Village, Gunung Kidul, Yogyakarta.

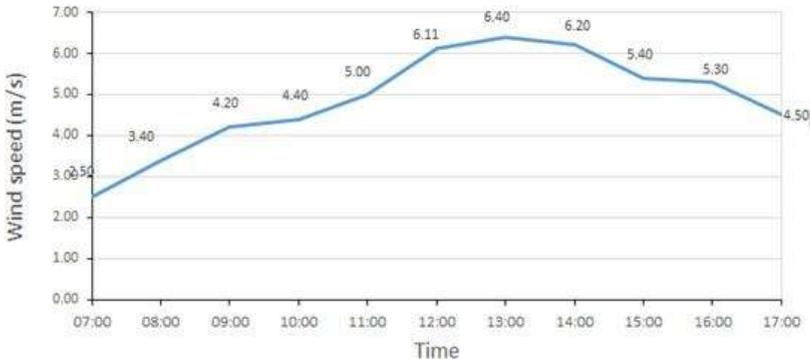


Fig. 2. Wind measurements at the research location on September, 11 2021.

2.2 Wind Turbine Blade Performance

Tip speed ratio/TSR is one of the indicators of the performance of a wind turbine. TSR is the ratio between the speed at the blade tip and the wind speed. The blade tip speed is the angular speed of the shaft times the blade length. The angular speed is obtained from shaft rotation which is measured using a tachometer while wind speed is measured using an anemometer. The power coefficient (C_p) is defined as the ratio of the power converted by the wind turbine relative to the kinetic energy that is obtained from the wind speed. The Betz coefficient suggests that a wind turbine system can convert a maximum of 59.3 per cent of the energy in an undisturbed wind stream [23]. The power of wind turbine is determined by density of wind, area of blades and wind speed, while the power output is obtained from torque and angular speed of the shaft of wind turbine.

Vertical axis wind turbine blades have various shapes and sizes that have been developed. Wind turbine blades greatly determine the electrical power produced, from small-scale ones with a small power output to large-scale ones that produce up to megawatts of electricity. The shape of the blade also determines the rotational speed of the wind turbine. In terms of the shape of the blade, it will also determine the weight and strength of the construction of the blade itself against wind forces. The wind turbine that is applied on site has a unique shape like a pumpkin when it rotates. So this turbine is called a pumpkin wind turbine as shown in Figure 3.

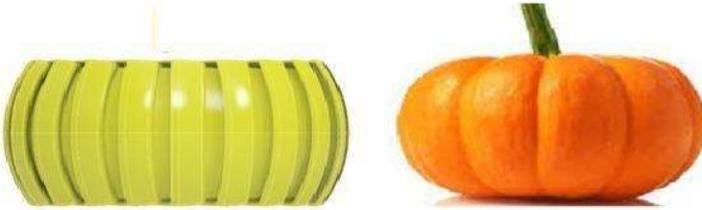


Fig. 3. The vertical wind turbine blade design when rotating resembles a pumpkin, giving an aerodynamic performance.

This deep vertical wind turbine uses curved blades with an airfoil cross-section with a half-open back. This blade can reduce backtracking when rotating against the wind because the cross-section is in the form of an airfoil. A blade with a half-open back can catch more wind when the blade moves in the direction of the wind, thus producing greater thrust. The cavity on the blade is reinforced with an I-profile structure on the inside so that it becomes more sturdy. In this study to get a large tip speed ratio using a variety of 2, 3, 4 and 5 blades. The cross-sectional shape of the blade is NACA 63-415 which has a large cross-sectional size. NACA 63415 is generally used in wind turbines that experience multiple angles of attack [24]. The cross-sectional shape of the NACA 63-415 airfoils can be seen in Figure 4, where the airfoil was generated by the airfoil-tool [25]. The design of the blade is a half-open airfoil at the back (upper chamber line). Figure 5 shows the design of a blade for the vertical axis wind turbine. The opening of the upper chamber line gets more abigest drag force for the blade.

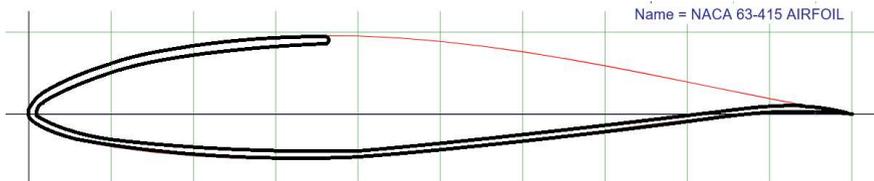


Fig. 4. Cross section of NACA63-415 airfoil with half of open the upper chamber line [25]

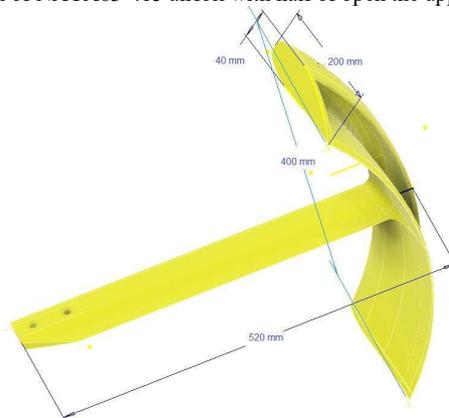


Fig. 5. Design the blade with a curved shape and airfoil cross-section.

3 RESULTS

The test results of a pumpkin wind turbine with variations in the number of blades as an influence of wind speed on rotation can be seen in Figure 6. The test results show that the rotation increases with increasing wind speed.

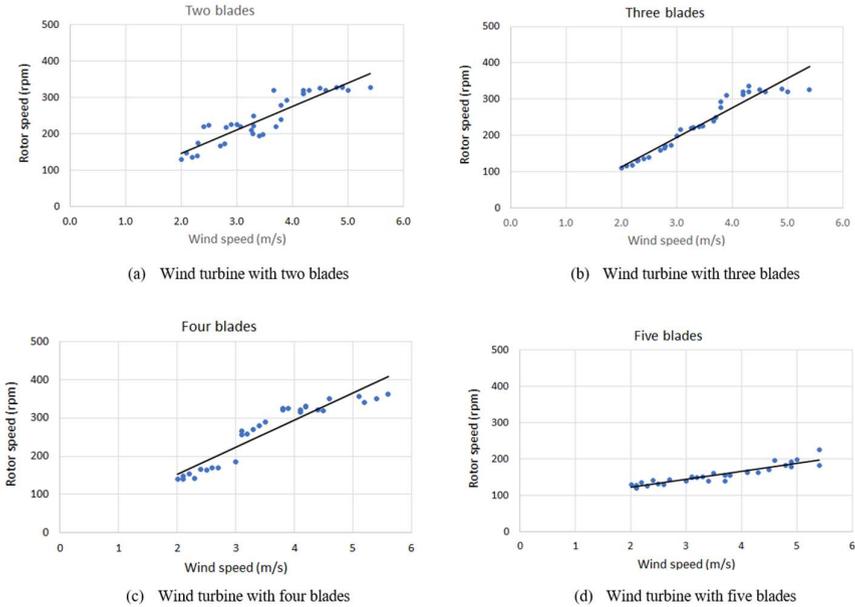


Fig. 6. Speed on wind turbine rotation with variations in the number of blades.

The wind speed of 4.1 m/s can produce a rotor speed of 317 rpm at three blades. The greatest performance is shown by a wind turbine with three blades where the largest tip speed ratio of 4.08 is obtained from variations in the number of blades. TSR measurements for each wind turbine with varying numbers of blades at the same wind speed can be seen in Figure 7. The TSR is an important factor in wind turbine design. TSR refers to the ratio between the speed of the tips of wind turbine blades divided by the wind speed. The wind turbine with three blades has the largest tip speed ratio of 4.08. The result is by following the theory of the relationship between power and wind turbine rotation speed, the greater the power generated, and the greater the rotation. Individual small wind turbines can be used to generate electricity on an energy small scale [26]. A wind turbine generator shows significant differences in power generation, depending on the installation area and the frequency of wind occurrence [13]. The application of small-scale wind turbines in the long term with the development of generator technology, and the utilization of wind energy is still promising[27].

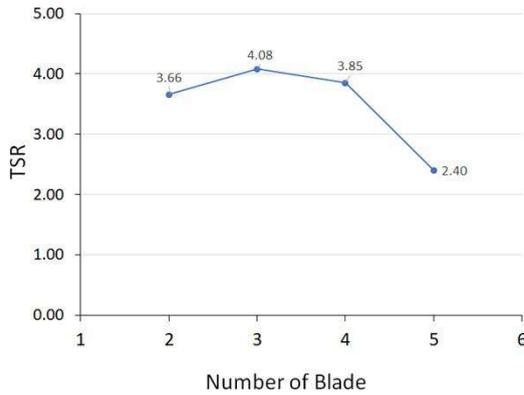


Fig. 7. The effect of the number of blades on the tip speed ratio/TSR.

Figure 8 shows the power output was generated by each turbine with the number of various blades as the effect of wind speed. The Wind turbine captures the kinetic energy of wind to convert it into mechanics and then to electricity power. The wind turbine blades are an important element in energy conversion in a system wind turbine because of their ability to capture energy from the wind. The configuration, number, and shape of the blades play an important role in determining their torque, rotation and power efficiency. The characteristics blade such as blade shape, tip speed ratio, angle of attack, materials used, and blade weight play an important role in determining the efficiency of wind turbines, too. The Betz limit states that a wind turbine cannot capture more than 59.3% of the wind's energy [23]. The results of this pumpkin wind turbine in Figure 9 show that the maximum efficiency expressed in C_p is 0.49 with three blades. Wind turbine with three blades, the angular momentum stays constant because when one blade is in front or behind, the other two are pointing at the same angle. So the turbine can rotate into the wind smoothly.

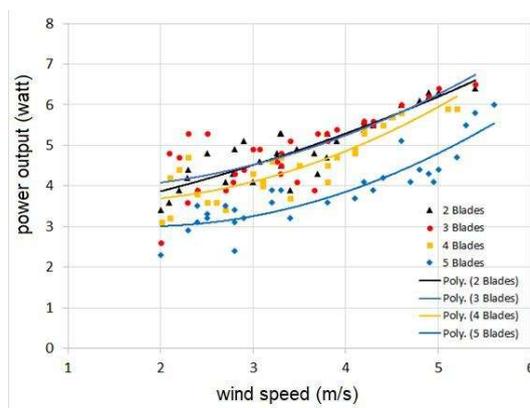


Fig. 8. The power generated by pumpkin wind turbine with various number of blades.

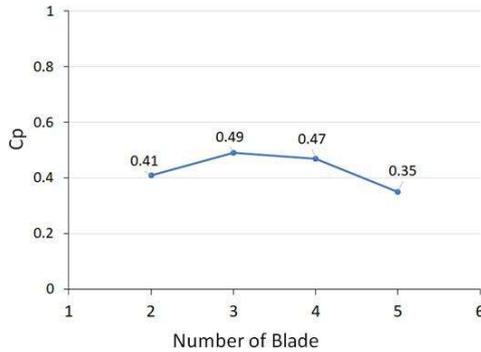


Fig. 9. Comparison between the performances pumpkin wind turbine (C_p) with various number of blade.

4 CONCLUSION

The pumpkin-shaped wind turbine is unique because it has performance that can be applied as a renewable energy source, based on the measurement results, the power output increases with increasing rotational speed of the turbine. The number of blades three gives the largest TSR value of 4.08 and the maximum efficiency power C_p of 0.49.

Acknowledgments. This work was funded by the Directorate General of Higher Education Research and Technology (Dirjen Dikti) of the Ministry of Education, Culture, Research and Technology of the Republic of Indonesia, in scheme Penelitian Terapan Unggulan Perguruan Tinggi (PTUPT). Special thanks are expressed to the Higher Education Service Institute Region V (LLDikti V) Yogyakarta and the Research and Community Service Institute (LPPM) Institut Sains dan Teknologi AKPRIND Yogyakarta.

REFERENCES

1. T. Boonsuk and A. Janon, "Dynamic simulation of a direct-coupling 3-blade vertical-axis hydrokinetic turbine with low speed generator," *Eng. Appl. Sci. Res.*, vol. 44, no. 4, pp. 249–253, 2017, doi: 10.14456/easr.2017.38.
2. J. Wavhal, R. Kulkarni, P. Kulkarni, and S. Gore, "Wind Power Generation," *Int. J. Adv. Electron. Comput. Sci.*, vol. 2, no. 2, pp. 31–37, 2015.
3. D. Y. C. Leung, Y. Deng, and M. K. H. Leung, "Design Optimization of a Cost-Effective Micro Wind Turbine," *Proc. World Congr. Eng. 2010 Vol.*, vol. II, 2010.
4. B. Neammanee, S. Sirisumrannukul, and S. Chatratana, "Development of a Wind Turbine Simulator for Wind Generator Testing," *Int. Energy J.*, vol. 8, pp. 21–28, 2007.
5. C. C. M. Chagas, M. G. Pereira, L. P. Rosa, N. F. da Silva, M. A. V. Freitas, and J. D. Hunt, "From Megawatts to Kilowatts A Review of Small Wind Turbine Applications, Lessons From The US to Brazil Enhanced Reader.pdf," *MDPI journals Sustain.*, vol. 12, pp. 1–25, 2020.

6. C. J. Bai, F. B. Hsiao, M. H. Li, G. Y. Huang, and Y. J. Chen, "Design of 10 kW Horizontal-Axis Wind Turbine (HAWT) Blade and Aerodynamic Investigation Using Numerical Simulation," *Procedia Eng.*, vol. 67, pp. 279–287, 2013, doi: 10.1016/j.proeng.2013.12.027.
7. M. Casini, "Small Vertical Axis Wind Turbines for Energy Efficiency of Buildings," *J. Clean Energy Technol.*, vol. 4, no. 1, 2016, doi: 10.7763/JOCET.2016.V4.254.
8. M. Dehshiri and A. Ketabi, "A coreless axial flux - switching generator for micro - wind turbine application," *Energy Sci. Eng.*, no. August, pp. 1–10, 2022, doi: 10.1002/ese3.1309.
9. W. T. Chong, S. C. Poh, A. Fazlizan, and K. C. Pan, "Vertical axis wind turbine with omnidirectional-guide-vane for urban high rise application," 2005.
10. L. Deisadze, D. Digeser, C. Dunn, and D. Shoikat, "Vertical Axis Wind Turbine Evaluation and Design. A Major Qualifying Project Report Submitted to the Faculty of the WORCESTER POLYTECHNIC INSTITUTE," pp. 1–81, 2013.
11. E. Banihani and A. Sedaghat, "Feasibility of Highway Energy Harvesting Using a Vertical Axis Wind Turbine," no. February, 2018.
12. D. Kim, B. Park, and J. Jang, "Wind Turbine Generator Efficiency Based on Powertrain Combination and Annual Power Generation Prediction," *Appl. Sci.*, vol. 8, pp. 1–11, 2018.
13. H. Jang, S. Kim, and D. Jeong, "Performance Prediction and Validation of a Small-Capacity Twisted Savonius Wind Turbine," pp. 1–12, 2019.
14. M. K. Johari, M. A. A. Jalil, M. Faizal, and M. Shariff, "Comparison of horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT)," no. October, 2018, doi: 10.14419/ijet.v7i4.13.21333.
15. R. Syahputra, K. Purwanto, and I. Soesanti, "Performance investigation of standalone wind power system equipped with sinusoidal PWM power inverter for household consumer in rural areas of Indonesia," *Energy Reports*, vol. 8, pp. 4553–4569, 2022, doi: 10.1016/j.egy.2022.03.145.
16. T. Rusianto, Sudarsono, S. Huda, and M. Suyanto, "Performance of Axial Generator for a Small Vertical Axis Wind Turbine," *J. Eur. des Systèmes Autom.*, vol. 56, no. 2, pp. 172–178, 2023.
17. Z. W. J. Al-Shammari, M. M. Azizan, and A. S. F. Rahman, "Grid-Independent PV – Wind – Diesel Generator Hybrid Renewable Energy System For A Medium Population : A Case Study," *J. Eng. Sci. Technol.*, vol. 16, no. 1, pp. 92–106, 2021.
18. A. Afandi, M. D. Birowosuto, and K. Comeliasari, "Energy-yield Assessment Based on the Orientations and the Inclinations of the Solar Photovoltaic Rooftop Mounted in Jakarta , Indonesia," *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 12, no. 2, pp. 6–12, 2022.
19. H. Nguyen, V. Nguyen, V. Ly, and T. Bui, "Biodiesel Produced from Pangasius Oil Operating a Diesel Engine : Case Study in Vietnam," *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 12, no. 2, pp. 477–482, 2022.
20. Z. Wu and H. Wang, "Research on Active Yaw Mechanism of Small Wind Turbines," *Int. Conf. Futur. Energy, Environ. Mater.*, vol. 16, pp. 53–57, 2012, doi: 10.1016/j.egypro.2012.01.010.
21. C. Jayaramulu, "Modeling and Analysis of a Small Wind Turbine Blade," *Int. J. Sci. Res.*, vol. 8, no. 4, pp. 1188–1191, 2019.
22. P. M. Kumar, K. Sivalingam, and T. Lim, "Review on the Evolution of Darrieus Vertical Axis Wind Turbine : Large Wind Turbines," pp. 205–223, 2019, doi: 10.3390/cleantechnol1010014.
23. K. A. Adeyeye, N. Ijumba, and C. Jonathan, "The Effect of the Number of Blades on the Efficiency of A Wind Turbine The Effect of the Number of Blades on the Efficiency of A Wind Turbine," 2021, vol. 801, pp. 1–8, doi: 10.1088/1755-1315/801/1/012020.
24. W. Z. W. Omar, M. M. A. Rahim, and T. M. M. Lazim, "A CFD Study of NACA 63415 with deployment of leading edge and trailing edge surface," no. July 2013, 2014.
25. <http://airfoiltools.com>, "Air foil tool." .

26. J. Wavhal, R. Kulkarni, P. Kulkarni, and S. Gore, "Wind power generation 1 1," no. 2, pp. 31–37, 2020.
27. A. A. Salami, A. Sénah, A. Ajavon, M. K. Kodjo, and K. Bédja, "Evaluation of Wind Potential for an Optimum Choice of Wind Turbine Generator on the Sites of Lomé , Accra , and Cotonou Located in the Gulf of Guinea," *Int. J. Renew. Energy Dev.*, vol. 5, no. 3, pp. 211–223, 2016.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

