Journal of Research in Science, Engineering and Technology
Volume 10, Issue 1, March 2022, pp. 53-60

Journal of Research in Science, Engineering and Technology

www.researchub.org

Design Principles and Environmental Impacts on Wind Energy

Gurunadh Velidi

Department of Aerospace Engineering, University of Petroleum and Energy Studies, India

Abstract

Wind energy is a well-known renewable energy source, accounting for 6% of worldwide power generation. This paper presents a comprehensive discussion of wind turbine blade design and explains how today's wind turbines almost never employ horizontal axis rotors. The concepts of modern wind turbine blade aerodynamics design are explored in depth, including blade shape/number of planes, blade selection, and optimal angle of attack. This paper discusses the fundamental concepts of design parameter selection and multi-aerodynamic configurations in the aerodynamic design of a horizontal axis wind turbine (HAWT) producing system. Based on a comparison of Wilson and Schmitz wind turbine aerodynamic design methodologies, the best design approach HAWT based on Schmitz is given. The basic understanding about wind turbines is summarised in this document, which also includes a comprehensive overview of the wind energy system and a discussion of wind energy's environmental implications.

Keywords

Turbine, Airfoil, angle of attack, Rotor, Wind Turbines, Renewable Energy, Aerodynamics

1. Introduction

The wind is renewable, but because of its constant variations in intensity and direction, it is unpredictable and unreliable. As a result, the fundamental goal of a wind turbine designer is to increase aerodynamic efficiency or power extraction from the wind. Wind turbines must be enormous and tall to create practical quantities of electricity, but they must also be properly built and manufactured to perform effectively, which makes them pricey (Dong et al., 2009). The wing may be turned by the wind, and it receives power from the generator attached to it. From the root to the tip, the blade has a large number of airfoil cross sections of various sizes and shapes. The wind turbine blades are turned by a basic airfoil technique. This means that when a fluid passes over an airfoil, it produces a lift force (Hansen, 2000). This

*Corresponding author: Gurunadh Velidi, Department of Aerospace Engineering, University of Petroleum and Energy Studies, India

E-mail address: guru.velidi@gmail.com

Received 19 December 2021 / Accepted 25 March 2022
DOI: https://doi.org/10.24200/jrset.vol10iss01pp53-60

spin, however, cannot be directly connected to a generator since wind turbine blades normally rotate at a relatively low rpm due to noise and mechanical strength concerns. As a result, the gearbox's speed is raised before connecting to the generator. To obtain a high-speed ratio, a gearbox is utilized (Spera 1994). During highly windy circumstances (cutoff speed=80km/hr), a break is situated within the nacelle and is utilised to restrict the spinning of the wind blades. The direction of the wind might change at any time. As a result, a velocity sensor on the top of the nacelle is employed to monitor the wind speed and direction (Jenkins et al., 2021). An electronic controller receives the divergence in wind direction and provides a suitable signal to the yawning mechanism to fix the inaccuracy. The nacelle is rotated by the yawn motors, ensuring that the wind turbine is constantly facing the wind.

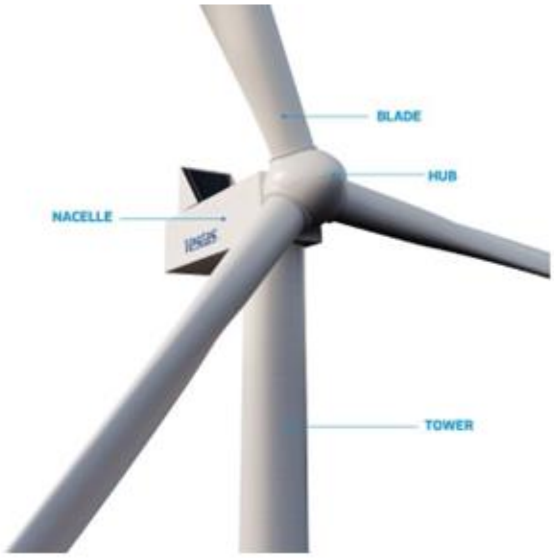

Figure 1:Wind blades (Earth, 2021)

2. Types of wind turbines:

2.1. Horizontal Axis

The Horizontal Wind Turbine (HAWTprimary)'s rotor and generator shaft are placed on top of the tower and must face the wind. They feature gears that transform the blades' sluggish revolution into quicker rotation, allowing them to drive generators (Freudenreich and Argyriadis, 2007).

2.1.1. HAWT Types

1. **Upwind Turbine**: The wind machine's fan blades are pointing in the direction of the wind. The fundamental benefit of the windward design is that the shadow cast behind the tower is avoided. The great majority of wind turbines are built in this manner. The wind, on the other hand, begins to travel away from the tower before it reaches it, despite the fact that the tower is round and smooth. As a result, each time the propeller passes through the tower, the wind turbine's output is drastically diminished. The primary drawback of wind turbines is that the rotor must be strong and placed far away from the tower (which some manufacturers find challenging) (German Wind Energy Association, 2008). A wind generator also needs a swing mechanism to keep the blades pointing in the direction of the wind.
2. **Downwind Turbine**: A downwind gadget's rotor is positioned on the tower's lee side. If the rotor and nacelle are built in such a way that the nacelle follows the wind passively, they have the potential benefit of no longer requiring a yaw mechanism. The fact that a downwind device can be made lighter than an upwind gadget is its primary benefit. The rotor passing under the tower's

wind shadow causes a variation in wind power, which is a negative. In comparison to an upwind position, this may result in lower fatigue stresses at the turbine (Dong et al., 2009).

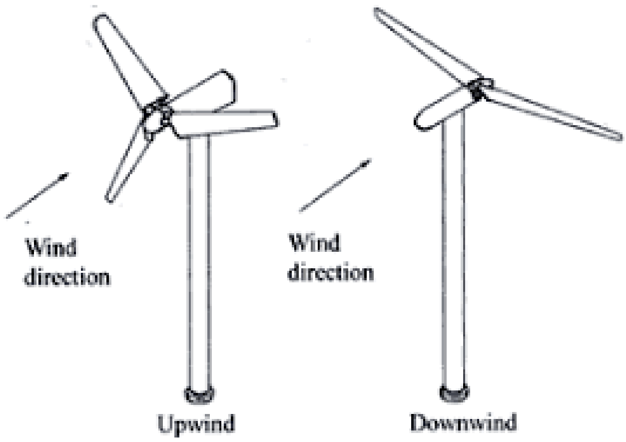

Figure 2: Wind flow direction on blades (Earth, 2021)

2.1.2. Vertical Axis:

Vertical axis wind turbine (VAWT)s primary rotor turbine is is horizontally aligned with the wind, whereas the wind turbine's major components are placed at the base. The generator and gearbox are near to the ground in this layout, making maintenance and repair easier (Dong et al., 2009). Because the VAWT does not need to be oriented to the wind, no wind sensor or navigation devices are required.

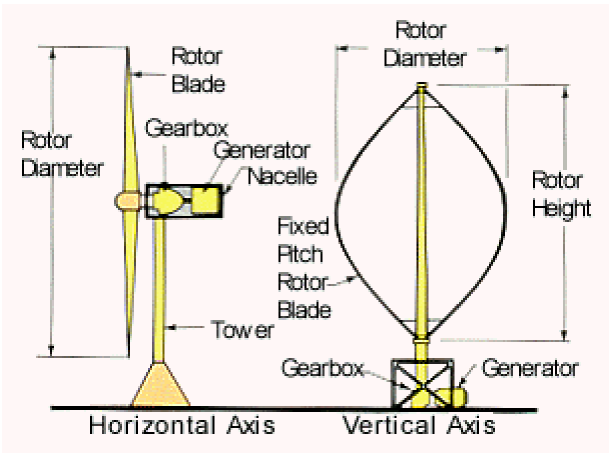

Figure 3: Wind turbine configurations (Igetcol, 2022)

A wind turbine blade's performance is determined by the torque, drag, and lift it produces. These variables are influenced by the size and shape of the blades, as well as the number of blades and their pitch [9].

2.2.1. Drag

The force of drag, also known as air resistance, acts on the blades, slowing them down. When there is a headwind, the drag increases. Wind turbine blades must be streamlined for maximum air circulation. The area facing the apparent wind may be changed by changing the angle of the blades. As a result, the blade with a 1020-degree angle has substantially less drag than one with a wider angle. With increasing wind speed, drag increases as well. The greater the drag force experienced by an item as it travels through the air, the quicker it goes. Because the blade tips move through the air considerably quicker than the blade base, this is especially critical for wind turbine blades. Wind turbine blades change form and angle over the length of the blade to decrease drag at the blade tips. By bending or twisting the blade and tapering it throughout its length, we may lower the drag force, resulting in the most efficient wind turbine blade design (Muneer et al, 2005).

2.2.2. Lift

The aerodynamic force that permits aircraft and helicopters to fly is known as lift. As they spin through the air, wind turbine blades feel the same force. The force of lift balances the force of drag, allowing a turbine blade to move through air molecules more effectively. A well-designed wind turbine blade's primary purpose is to create as much lift as possible while reducing drag. The form of the blade, the speed of the air travelling through it, and the angle of the blade relative to the apparent wind all determine the amount of lift a blade or wing can provide (Chandel et al., 2016).

2.2.3. Torque

Torque is a force that causes anything to turn or spin. Wind turbine blades are similar to large levers that are turned by the power of the wind. The force multiplied by the distance equals torque. As a result, the longer your blades are, the more torque you'll be able to create. When the torque created by your blades is increased, the drag they face as they revolve is frequently increased as well. Longer blades, for example, will create greater torque and drag. In general, increasing the number of blades increases torque and drag. As a result, it's critical to adapt the blade design to the load application (Romeo et al., 2008).

2.2.4. Twist

The closer it gets to the blade's tip, the quicker it goes through the air, producing a greater apparent wind angle. As a result, the blade must have a helix along the length of it, with the tips facing away from the base (Celik, 2013). From root to tip, the twist is generally 10-20 degrees. The requirement to twist the blade has implications for productivity.

3. Wind turbine blade design

The oldest form of blade is the flat blade, which has been used on windmills for thousands of years. Flat blades, on the other hand, are becoming less and less frequent since they push against the wind and the wind pushes against the blades (Tech, 2008). The propellers act like giant paddles moving in the opposite direction, pushing against the wind, causing slow rotation, earning them the nickname propellers based on drag. Curved blades, on the other hand, have mostly supplanted flat wide blades in recent years.

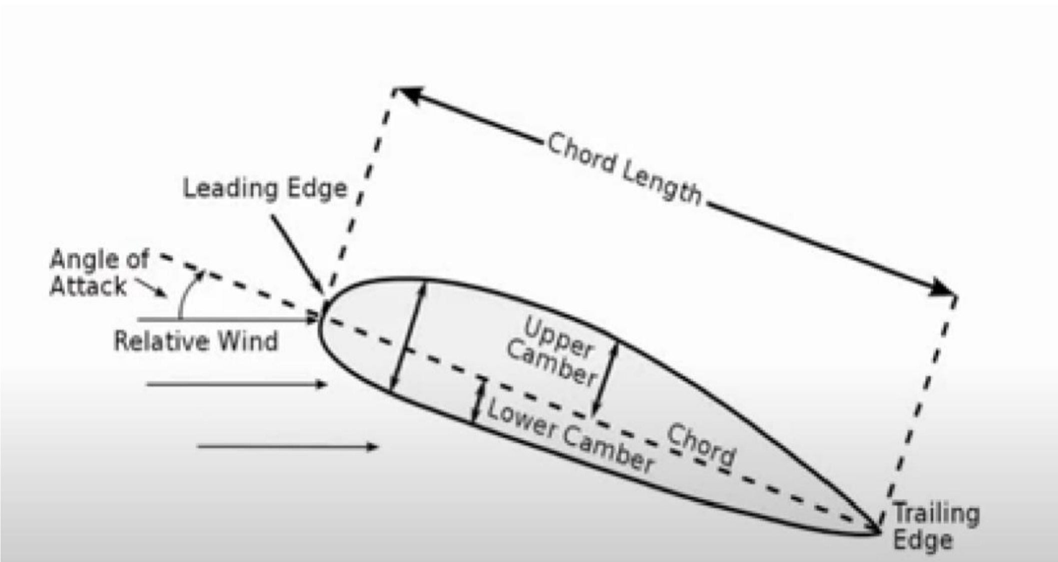

Figure 4: Airfoil Nomenclature (Timmer and Bak, 2013)

The leading edge refers to the forward segment of the airfoil, whereas the trailing edge refers to the back. At the leading and trailing edges, the top and lower surfaces of the airfoil meet [15]. The chord line, commonly known as the c chord, runs from the airfoil's leading edges to the bottom edges. The chord line divides the airfoil's top and bottom surfaces. The intermediate camber is determined by plotting the locations that lie between the upper and lower surfaces. The angle at which relative airflow impacts an airfoil is known as the angle of attack (). The vector that indicates the relative velocity of the aeroplane and the atmosphere (Johnson et al., 2016), created by the chord of the wing and the relative direction of the wind.

3.1. Working Principle

Wind turbine blades, like aviation wings, raise due to their design. Low air strain forms on the canopy's most curved side, even as increased air strain presses against the opposing facet. The idea is to design the propeller such that it provides the right amount of thrust and propeller voltage required for optimal air deceleration and blade efficiency. As a result, the stop velocity ratio (also known as TSR) is crucial in wind turbine design. If the blades of a wind turbine are moving too slowly. Furthermore, if the rotor rotates too rapidly, the visible blades will seem as a powerful wind barrier. As a result, wind turbines are built with the highest pinnacle velocity ratio possible in order to capture as much power as possible from the wind. The range of blades within the wind turbine rotor is used to determine the appropriate head velocity ratio. The fewer the blades of a wind turbine, the quicker they should revolve in order to capture the most energy from the wind. The ideal head velocity ratio for a two-blade rotor is set 6, for a three-blade rotor it's set 5, and for a four-blade rotor it's set 3. By raising the rotor's rotational velocity and so creating more power, a highly green vane blade arrangement can improve those optimum values by up to 25%-30%. A well-designed traditional three-blade rotor should have a head velocity ratio of 6 to 7 (Islam et al., 2008).

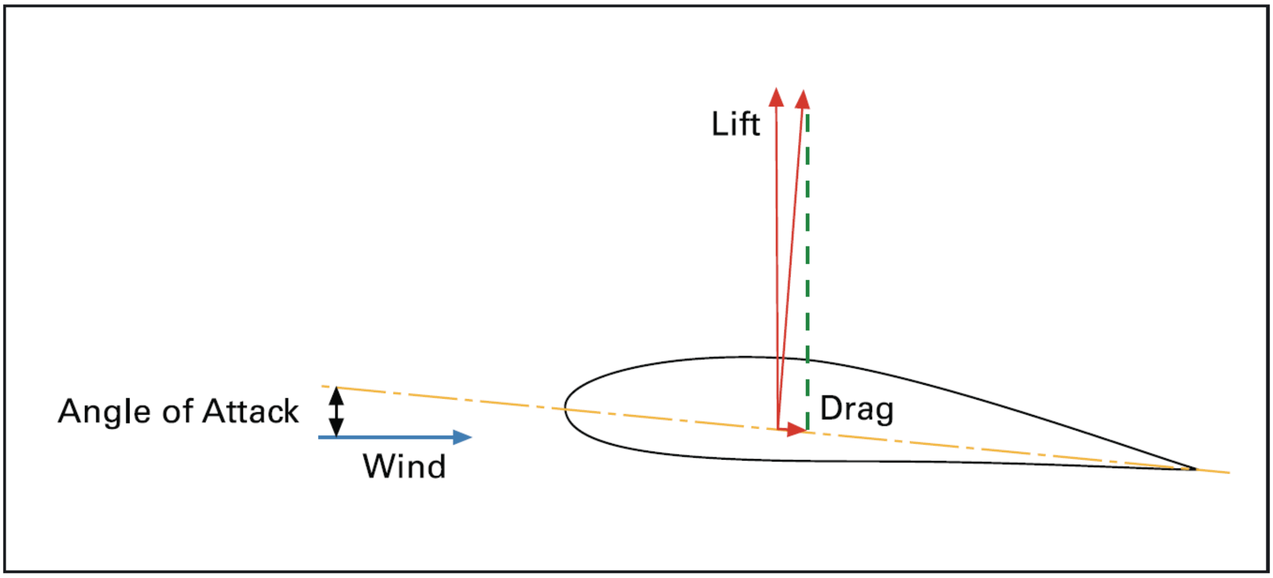

Figure 5: forces on Airfoil (Timmer and Bak, 2013)

The "angle of assault" is determined by the direction of the oncoming wind and the blade pitch in relation to the oncoming wind. Because the assault attitude is bigger, more carry is created; nevertheless, as the attitude increases larger, more than around 20, the blade begins to lose carry. As a result, there is a best-rotating rotor blade pitch attitude, and contemporary wind turbine rotor blades are twisted along their length, from a steep pitch at the foundation to an incredibly shallow pitch at the tip. Modern propellers are twisted 10 to 20 degrees from base to tip due of their speed. This lowers the angle of attack, moving the air from a relatively modest speed at the base to a much faster speed near the tip. The tip of the blade rotates faster than the base or midsection. The angle of attack is maximised along the length of the blade, resulting in maximum lift and spin.

3.2. Design factors affecting the performance of Wind Turbine

1. **The number of blades:** Wind turbines with two blades are somewhat less efficient than those with three blades, therefore they must revolve quicker to achieve optimal efficiency. Similarly, two blades create more electricity than three blades, but they come with their own set of issues. Wobbling occurs because two-blade turbines are sensitive to gyroscopic accuracy. The entire turbine will be unstable as a result of this wobbling (Bhutta et al., 2012). This will put strain on the turbine's components, lowering its efficiency and shortening its lifespan. A two-blade wind turbine is 3 percent less efficient than a three-blade equivalent of the same diameter, according to new study. In addition, five-blade wind turbines significantly enhance yearly performance in places with unfavourable wind conditions (Zhang et al., 2010).
2. **Shape of the blade:** Fluid drift in a shifting system occurs at a different rate than the true rate, which is known as relative or evident pace. It's also the differential between blade speed and real drift speed. The airfoil's go sections are oriented in such a way that they are capable of performing at this high level of assault. Despite the fact that drift speed is constant along the blade's length, blade speed increases linearly as it approaches the blade's tip. As you go closer to the tip, the apparent pace becomes more aligned with the centre direction. As a result, the blade must be continually twisted to maintain a high-quality assault attitude during each go phase of the airfoil.
3. **Length of the blade:** With a longer blade, the wind turbine can extract more power, but the deflection of the blade tip owing to axial wind force rises as well. As a result, a haphazard rise in the blade's length may result in a blade-to-tower collision.
4. **Tower Height:** Tower height should be as high as feasible from the standpoint of power extraction. However, due to the difficulties of road transportation and structural design issues, the maximum tower height is limited (Müller et al, 2009).

4.1. Advantages of wind energy

Because wind energy does not harm the environment or generate hazardous waste, it is a viable option for power generation.

1. **Renewable:** Because wind energy does not deplete when utilised, it is renewable, and it can be found practically anywhere. Wind turbine technology can thus use the wind's natural and unlimited force to generate electricity for homes and businesses without fear of depletion.
2. **Zero Pollution:** Wind energy not only reduces CO_2, NO_x, and SO_2 emissions, but it also eliminates the need for fossil fuel-based power generation. As a result, the environmental and economic issues that are the primary causes of global warming, acid rain, and smog are alleviated. Using a one-megawatt turbine instead of one megawatt of fossil fuel energy might save almost 1,400 tonnes of CO_2. Wind power has the potential to help countries achieve energy self-sufficiency by offering undeniable economic benefits while also contributing to long-term prosperity.

4.2. Impacts of wind energy

While wind energy is a clean and renewable source of energy, the construction and operation of wind turbines has substantial environmental implications. The following are some of the drawbacks of utilising wind turbines to generate electricity:

1. **Land usage:** The quantity of land needed to erect a wind turbine is influenced by the project's size, location, and other factors. Because of the larger turbines and blades, offshore wind projects require more space than onshore wind projects. Despite the fact that wind turbines take up a

little amount of physical land, they require sufficient spacing between each blade and turbine, which can result in large-scale land consumption.

2. **Impact on Wildlife:** Wind farms have the potential to damage the natural habitat of a variety of animals. Wind farms often need the construction of new roads or the clearing of more land. This may result in the extinction of certain natural species. Furthermore, one of the most commonly mentioned negative effects of wind power is the harm to local animals, particularly birds and bats. Wind turbine blades revolve at tremendous speeds, posing a danger to flying animals such as birds and bats. Between 0.3 and 0.4 bird fatalities per gigawatt-hour are caused by wind farms (GWh). Furthermore,
3. **Noise pollution:** The wind turbine makes noise when it is in operation. The two main sources of wind turbine noise are mechanical noise from the gearbox and generator, and aerodynamic noise from the interaction of the wind turbine blades with the wind. Modern designs have been shown to alleviate noise concerns and deliver much calmer environments as technology has advanced.

5. Conclusion

It has been demonstrated that wind turbine technology has the ability to contribute to the United States' energy demands. Sites with sufficient wind energy might produce up to 10% of the country's electricity if completely used. Wind energy, like other forms of energy, has the potential to affect the environment by fragmenting, destroying, or otherwise damaging animal, fish, and plant habitats. Furthermore, flying species such as birds and bats may be endangered by the rotating turbine blades. Because wind energy has the potential to harm animals, and because these issues can stifle or prevent wind expansion in critical wind resource locations, difficulties with decreasing pollution are a major concern. The wind industry's primary goals are minimization, positioning, and licencing. Wind turbines may also be made more friendly to bird and bat populations thanks to technological improvements. Sensors are now available to enable wind farms detect birds and bats flying nearby, allowing the turbines to completely shut down. Additionally, some wind turbines have ultrasonic speakers that deter bats from flying too near to the blades when they are turned on.

References

Dong, L., Liao, M., Li, Y., Song, X., & Xu, K. (2009, October). Study on aerodynamic design of horizontal axis wind turbine generator system. In *2009 International Conference on Energy and Environment Technology* (Vol. 1, pp. 841-844). IEEE.

Hansen, M. O. (2000). Wind turbine aerodynamics. *UK: James & James Ltd*.

Spera, D. A. (1994). Introduction to modern wind turbines. *Wind turbine technology: fundamental concepts of wind turbine engineering*, 47-72.

Jenkins, N., Burton, T. L., Bossanyi, E., Sharpe, D., & Graham, M. (2021). *Wind energy handbook*. John Wiley & Sons.

Freudenreich, K., & Argyriadis, K. (2007, July). The load level of modern wind turbines according to IEC 61400-1. In *Journal of Physics: Conference Series* (Vol. 75, No. 1, p. 012075). IOP Publishing.

German Wind Energy Association. (2008). Wind Energy Market 2007/2008. *Berlin, Germany*.

Dong, L., Liao, M., Li, Y., Song, X., & Xu, K. (2009, October). Study on aerodynamic design of horizontal axis wind turbine generator system. In *2009 International Conference on Energy and Environment Technology* (Vol. 1, pp. 841-844). IEEE.

DL-Manual, GH Bladed version3.8 user URL: manual, https://www.crackcad.com/gh-bladed-v3-8.

Muneer, T., Asif, M., & Munawwar, S. (2005). Sustainable production of solar electricity with particular reference to the Indian economy. *Renewable and Sustainable Energy Reviews*, *9*(5), 444-473.

Chandel, S. S., Shrivastva, R., Sharma, V., & Ramasamy, P. (2016). Overview of the initiatives in renewable energy sector under the national action plan on climate change in India. *Renewable and Sustainable Energy Reviews*, *54*, 866-873.

Romeo, L. M., Bolea, I., & Escosa, J. M. (2008). Integration of power plant and amine scrubbing to reduce CO2 capture costs. *Applied Thermal Engineering*, *28*(8-9), 1039-1046.

Celik, A. N. (2003). Energy output estimation for small-scale wind power generators using Weibull-representative wind data. *Journal of wind engineering and industrial aerodynamics*, *91*(5), 693-707.

Tech, M. I. J. S. (2008). Stuart Major, Terry Commins 2, and Annop Noppharatana 2.

Dincer, F. (2011). The analysis on wind energy electricity generation status, potential and policies in the world. *Renewable and sustainable energy reviews*, *15*(9), 5135-5142.

Johnson, Kathryn E., et al. "Control of variable-speed wind turbines: standard and adaptive techniques for maximizing energy capture." IEEE Control Systems 26.3 (2006): 70-81.

Islam, M., Ting, D. S. K., & Fartaj, A. (2008). Aerodynamic models for Darrieus-type straight-bladed vertical axis wind turbines. *Renewable and sustainable energy reviews*, *12*(4), 1087-1109.

Bhutta, M. M. A., Hayat, N., Farooq, A. U., Ali, Z., Jamil, S. R., & Hussain, Z. (2012). Vertical axis wind turbine–A review of various configurations and design techniques. *Renewable and Sustainable Energy Reviews*, *16*(4), 1926-1939.

Zhang, Q., Chen, H., & Wang, B. (2010). Modeling and simulation of two-leaf semi-rotary VAWT. In *Life System Modeling and Intelligent Computing* (pp. 389-398). Springer, Berlin, Heidelberg.

Müller, G., Jentsch, M. F., & Stoddart, E. (2009). Vertical axis resistance type wind turbines for use in buildings. *Renewable Energy*, *34*(5), 1407-1412.

Earth, Are Recyclable Wind Turbine Blades on the Horizon? - Earth911, *Earth911*, Mar. 11, 2021. https://earth911.com/eco-tech/are-recyclable-wind-turbine-blades-on-the-horizon/ (accessed Jun. 14, 2022).

Igetcol, "wind turbine configurations." https://www.igetcol.it/turbine.htm (accessed Jun. 14, 2022).

Timmer, W. A., & Bak, C. (2013). Aerodynamic characteristics of wind turbine blade airfoils. In *Advances in wind turbine blade design and materials* (pp. 109-149). Woodhead Publishing.,ISBN 9780857094261, https://doi.org/10.1533/9780857097286.1.109.