Comparative Study of Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT)

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Abstract

Wind energy is one of the free and clean renewable energy resources that is playing a gigantic role towards a reduction in the use of fossil fuel that harms our environment. This paper presents a comparative study of the Horizontal Axis Wind Turbines (HAWTs) and Vertical Axis Wind Turbines (VAWTs) which are used for generating electrical power from the wind. The two types of wind turbines were compared based on their configurations, advantages, disadvantages, and application areas as well as the swept area. The horizontal axis wind turbine was found to be more effective than the vertical axis wind turbine because its efficiency is greater than 70% compared to the vertical axis wind turbine's efficiency of between 50% and 60%. While vertical axis wind turbines are used in urban areas at locations like the tops of tall buildings, roadside dividers, railway tracks, and other similar locations because they operate at low wind speeds and accept wind from all directions, horizontal axis wind turbines are used in many countries for small and large power projects. The results of this research will help users choose and install the right wind turbine in the right place.

Keywords: - *Horizontal Axis Wind Turbine, Renewable Energy, Vertical Axis Wind Turbine.*

I. INTRODUCTION

Man has been harnessing the kinetic energy of the wind since the dawn of time. From sailing ships, grinding grain, pumping water, and powering sawmills to the most recent technology, generating electricity. The technique has been used in different ways for thousands of years (Sheet, 2005). The word "windmill" refers to the first machines that used wind energy as a source of energy to grind grains. These machines are now referred to as "wind turbines" because they can be used for a variety of purposes, including generating electricity and pumping water (Paraschivoiu, 2002). A wind turbine is a device that directly transforms the kinetic energy of the wind into electrical energy. The windmill, on the other hand, converts the kinetic energy of the wind directly into mechanical energy (Manwell et al. 2010).

II. TYPES OF WIND TURBINE

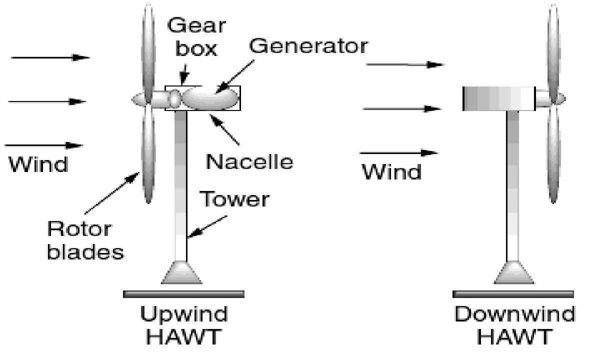
There are two (2) main types of the wind turbine; they are Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT).

A. HORIZONTAL AXIS WIND TURBINES

These are the types of wind turbines that are designed in such a way that their rotor blade is mechanically coupled to a horizontal generator shaft. Moreover, these types of wind turbines are normally made up of two, three or more rotor blades. Meanwhile, horizontal axis wind turbines are classified into Up-wind and Down-wind.

- **Upwind:** this is designed in such a way that the wind strikes the rotor blades first before it strikes the tower. Nowadays, the majority of the horizontal axis wind turbines are constructed with this form of structure. This turbine must be inflexible and placed at some distance from the tower. The basic advantage of this turbine is that it can avoid the wind shade behind the tower. On the other hand, it incorporates a yaw system since its rotor faces the wind all the time (Reddy et al. 2015).

- **Downwind:** this is designed in such a way that the wind strikes the nacelle and tower first before it strikes the rotor blades. Moreover, the Yaw system is not involved in this type of horizontal axis wind turbine. The rotors and nacelles are arranged so that the nacelles allow the wind to pass in a controlled way (Reddy et al. 2015). The upwind and downwind wind turbines are shown in figure 1.



1. *Figure 1: Upwind and Downwind Horizontal Axis Wind Turbines (Baghzouz, 2000).*

B. VERTICAL AXIS WIND TURBINES

These are designed in such a way that their rotor blades are mechanically connected to a vertical generator shaft. Meanwhile, vertical axis wind turbines are classified into Drag based, those with Savonius rotor and Lift based, those that have a Darrieus rotor.

- **Savonius wind turbine (Drag based vertical axis wind turbine):** this type of wind turbine is named after a Finnish Engineer in the person of Sigurd J.S who invented it in 1922 even though numerous attempts for designing similar wind turbine had been made by others in the past centuries (REUK, 2006). The Savonius Wind Turbine is shown in figure 2.

Figure: 2 Savonius wind turbine (Darling, n.d)

It is made up of 2 or more blades with a semi-cylindrical shape. Savonius wind turbines have elevated starting torque and excellent self-starting ability. On the other hand, they have a low power coefficient and low rotating speed [8].

- **Darrieus wind turbine (Lift based vertical axis wind turbine):** This type of wind turbine is named after Georges D, a French Aeronautical Engineer who invented it in 1931. Lift type has an elevated power coefficient but it is not self-starting. Darrieus wind turbine is sub-classified into a different form. They include H-type, Delta type, Diamond type, Y-type and Phi type (Sun et al. 2016). The Darrieus wind turbine is shown in figure 3.

Figure 3: Darrieus wind turbine (Brighthub, n.d)

III. ADVANTAGES AND DISADVANTAGES OF HORIZONTAL AXIS AND VERTICAL AXIS TURBINES

Some of the advantages and disadvantages of the two types of wind turbines are stated by (Dang, 2009) and (Gu, 2020). as follows:

A. ADVANTAGES OF HORIZONTAL AXIS WIND TURBINE

1. It has a variable blade pitch that gives an optimum angle of attack to the blades of the turbine. Allowing the angle of attack to be remotely adjusted gives greater control, so the turbine collects the maximum amount of wind energy for the time of day and season.
2. It has a tall tower base that enables the wind turbine to have access to the stronger wind in sites with intermittent wind speed. In some wind shear sites, every ten meters up, the wind speed can increase by 20% and the power output by 34%.
3. The power generation efficiency of a HAWT is greater than 70% due to more wind flow usage and all the blades are in operation. As such, it has a less aerodynamic loss.
4. It has a high blade rotation speed due to the heavyweight of the blade.
5. It has high commercial availability
6. More wind farm application because its high efficiency makes it more attractable

B. HORIZONTAL AXIS WIND TURBINE DISADVANTAGES

1. It is challenging to carry the tall towers and blades, which might be 90 meters long. Up to 20% of the cost of the equipment can go toward transportation.
2. It is challenging to install tall HAWTs; to do so, you need experienced workers and expensive, tall cranes.
3. To carry the bulky gearbox, generator, and blades, a sizable tower must be built.
4. Although filtering can reduce it, tall HAWTs may induce reflections that influence the side lobes of radar installations and create signal clutter.
5. Due to their height, HAWTs are conspicuously visible across a wide region, which alters the landscape's aspect and occasionally sparks local opposition.

6. It has a high vibration level
7. It has a high noise level of around 5-60db due to a high vibration level
8. It requires strong wind speed due to heavyweight of the blades
9. It requires high cut-in wind speed
10. It has to turn around and face the wind direction
11. It has a large effect on the environment due to the large swept area and high noise level.
12. It has a high installation cost because all its major components are on the tall tower. As such, strong tower construction is required to carry the heavy blades, gearbox and generator.
13. It has a high maintenance cost because all its major components are on the tall tower

C. ADVANTAGES OF VERTICAL AXIS WIND TURBINE

1. It is capable of operating at wind speeds as high as 42 m/s and operates well in wind speeds as low as 3 m/s.
2. Effective in all wind directions: A vertical axis wind turbine, also known as an omnidirectional wind turbine, can capture wind from all directions without the need for complicated, heavy, or expensive directing devices.
3. It is smaller than HAWT.
4. Maintenance and transportation are easy while the construction, maintenance and transportation costs of VAWT is low.
5. They do not require any yawing and wind direction sensing or even pitch varying mechanism
6. The generator is typically situated closer to the ground. Therefore, during maintenance or repair, a crane is not required.
7. Low risk for human and birds because its blades move at relatively low speed
8. It has a low vibration level
9. It has low noise of around 0-10db due to a low vibration level
10. It has a small effect on the environment due to the small swept area and low noise

D. DISADVANTAGES OF VERTICAL AXIS WIND TURBINE

1. Due to dragging force most of the VAWTs are only half efficient. The power generation efficiency is around 50-60% because of less wind flow usage and partial blades are in operation.
2. To hold it up, a Guy wire is needed (it is almost obsolete and heavy).
3. Because of its proximity to the ground, it might not be able to generate as much energy as HAWT at the same position and height.
4. They are rarely used on the wind farm application due do their lower efficiency
5. It has a low commercial availability
6. It has a small blade rotation speed due to the lower weight of the blade.

IV. APPLICATION AREAS OF HORIZONTAL AXIS AND VERTICAL AXIS WIND TURBINES

The following are the application areas of the HAWT and the VAWT by (Kumar et al. 2018) and (Wilke et al. 2020).

A. APPLICATION AREAS OF THE HORIZONTAL AXIS WIND TURBINES

1. They are utilized in numerous nations for small and large power projects.

2. The only type of wind turbines used for the majority of commercial installations worldwide are those with a horizontal axis.

B. APPLICATION AREAS OF THE VERTICAL AXIS WIND TURBINES

2. They are recognized as a viable option to harness the energy of the wind in urban areas
3. They perform very well under the weak and unstable wind areas
4. Because of their small size, VAWTs can be mounted on top of tall buildings, roadside dividers, railway tracks, and other locations for local electricity generation.

V. FACTORS TO BE CONSIDERED WHEN DESIGNING HORIZONTAL AXIS AND VERTICAL AXIS WIND TURBINES

There are a number of elements that must generally be considered when developing a wind turbine. In order to convert wind energy into electrical energy, numerous mechanical and electrical parts are used in the design process. The technique is also constrained by a variety of factors, with the design's future economic viability being the most important of these. The turbine need to be more cost-effective in producing power than its rivals (fuel, gas and coals, and other renewables). The cost of energy is influenced by a variety of factors. The cost of the turbine and the annual energy productivity are the two most important factors. Installation and operational costs are among the other expenses. To keep costs down, the components of the wind turbine must be as light as possible while still being able to endure adverse weather conditions and require little maintenance. (Óskarsdóttir, 2014).

VI. SWEPT AREA OF HORIZONTAL AXIS AND VERTICAL AXIS WIND TURBINES

The swept area can be defined as the area of the circle formed by the rotor blades of the wind turbine as they sweep through the air. One needs to know the swept area of the wind turbine to calculate the total power or available power in the wind that hits the rotor blades of the wind turbine. The formula of available power in the wind is shown in equation (1)

$$P = \frac{1}{2} \times \rho \times A \times V^3 \quad \text{……… (1)}$$ (Khandagale et al 2017).

Where: **P** = Power (Watts)

ρ = Air Density (about 1.225 kg/m^3 at sea level)

A = Swept Area of Blades (m^2)

V = Velocity of the wind

A. SWEPT AREA OF THE HORIZONTAL AXIS WIND TURBINE

The swept area of the horizontal axis wind turbine (A) can be found using the same formula used in finding the area of a circle as shown in equation (2):

$$A = \Pi r^2 \text{ or Area } = \Pi \left(\frac{D}{2}\right)^2 \quad \text{…….. (2)}$$ (Khandagale et al 2017).

Where: Π = 3.14159

r = radius of the circle. This is equal to the length of one of the rotor blades.

The swept area of the Horizontal Axis Wind Turbine (HAWT) is shown in figure 4.

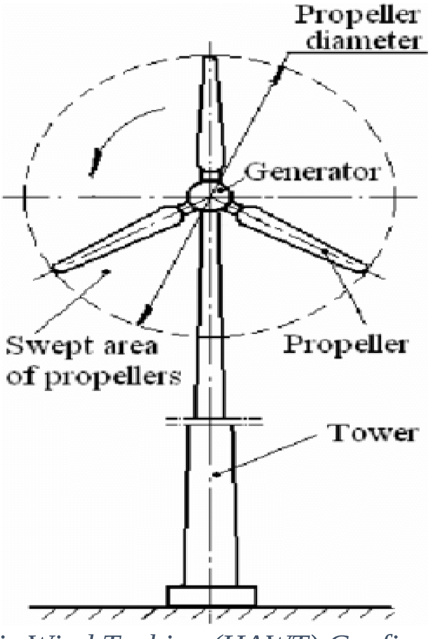


Figure 4: Horizontal Axis Wind Turbine (HAWT) Configuration (*Khammas,2006).*

B. SWEPT AREA OF VERTICAL AXIS WIND TURBINE

The height and diameter of the two vertical axis wind turbines (Darrieus and Savonius wind Wind Turbines) rotor blades are illustrated in figure 5. Moreover, the swept area of the vertical axis wind turbine can be found using equation (3).

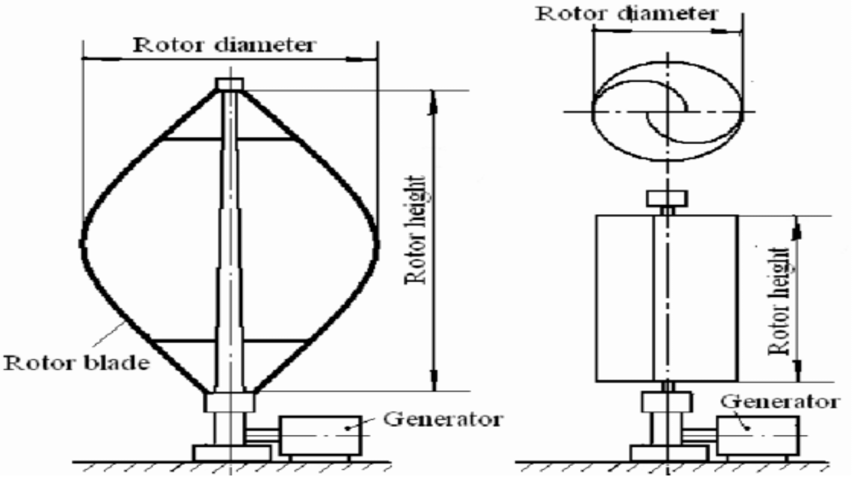


Figure 5: Darrieus and Savonius Axis Wind Turbines (VAWTs) Configurations (Khammas,2006).

$A = H * D$ ……… (3). (Du, 2016).
Where: H = Height of the rotor
D = Diameter of the rotor

VII. EFFICIENCIES OF HORIZONTAL AXIS AND VERTICAL AXIS WIND TURBINES

In a similar research, carried out by (Azevedo et al. 2015), the total efficiencies (power coefficient, generator efficiency and rectifier efficiency) of the two wind turbines (HAWT and VAWT) were compared and the experimental result shows that the total efficiency of the HAWT system provides higher efficiencies except during low wind speeds as shown in figure 6.

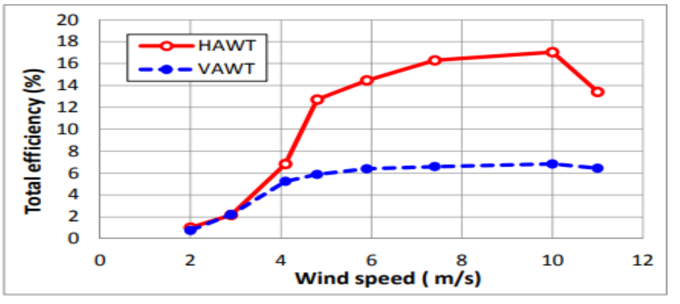


Figure 6: Total efficiency for HAWT and VAWT Systems (Azevedo et al. 2015).

V. CONCLUSION

This paper presents a comparison between the horizontal axis wind turbines (HAWTs) and the vertical axis wind turbines (VAWTs). In conclusion**,** each wind turbine is designed to be used in a variety of locations. The horizontal axis wind turbines are installed at the wind farms in many countries for small and large power projects, while vertical axis wind turbines are used in urban areas on top of tall buildings, roadside dividers, railway lines, and other locations because they operate at low wind speeds and accept wind from all directions.

REFERENCES

Azevedo, J., & Mendonça, F. (2015). Small scale wind energy harvesting with maximum power tracking. *AIMS Energy*, *3*, 297-315.

Baghzouz, Y. (2000). Characteristics of wind power systems.

Dang, T. (2009, October). Introduction, history, and theory of wind power. In *41st North American Power Symposium* (pp. 1-6). IEEE.

Darling, David. *Savonius Turbine*. http://www.daviddarling.info/encyclopedia/S/AE_Savonius_turbine.html. Accessed 20 Dec. 2022.

Du, Y. (2016). *An Orthogonal Savonius-type Wind Turbine: Design and Experiments* (Doctoral dissertation, Case Western Reserve University).

Gu, Y. (2020). Characteristics and Performance of Vertical-Axis Wind Turbine (VAWT). *Global Journals of Research in Engineering*, *20*(J3), 15-22.
https://www.brighthub.com/environment/renewable-energy/articles/92978
Visited on 14/03/21

Khammas, F. A. (2006). Optimization of Design of Vane Type Wind Turbine.

Khandagale, M. R., & Marlapalle, M. B. (2017). Design & Analysis of Savonius VAWT for 50W Rated Power output. *Int J Eng Res Gen Sci*, *5*, 189-200.

Kumar, R., Raahemifar, K., & Fung, A. S. (2018). A critical review of vertical axis wind turbines for urban applications. *Renewable and Sustainable Energy Reviews*, *89*, 281-291.

Manwell, J. F., McGowan, J. G., & Rogers, A. L. (2010). *Wind energy explained: theory, design and application*. John Wiley & Sons.

Óskarsdóttir, M. Ó. (2014). *A general description and comparison of horizontal axis wind turbines and vertical axis wind turbines* (Doctoral dissertation).

Paraschivoiu, I. (2002). *Wind turbine design: with emphasis on Darrieus concept*. Presses inter Polytechnique.

Reddy, K., Dagamoori, K., Sruthi, A. P., Apurva, S. N., & Naidu, N. M. L. (2015). A Brief Research, Study, Design and Analysis on Wind turbine. *J. Mod. Eng. Res*, *5*, 26.

"Savonius Wind Turbines." *REUK.Co. UK*, 20 Dec. 2022, http://www.reuk.co.uk/wordpress/wind/savonius-wind-turbines/

Sheet, B. B. (2005). Wind Turbine Technology.

Sun, X., Chen, Y., Cao, Y., Wu, G., Zheng, Z., & Huang, D. (2016). Research on the aerodynamic characteristics of a lift drag hybrid vertical axis wind turbine. *Advances in Mechanical Engineering*, *8*(1), 1687814016629349.

Wilke, A., & Welfens, P. J. (2020). *Urban Wind Energy Production Potential: New Opportunities* (No. disbei287). Universitätsbibliothek Wuppertal, University Library.