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Design and Construction of H-Type Wind Turbine for Biu Community in Borno State Nigeria

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Abstract

The global demand for sustainable energy sources has intensified the exploration of wind energy, especially for rural and off-grid communities. This study focuses on the development of a small-scale H-Type vertical-axis wind turbine (VAWT) as a viable solution for decentralized power generation in Biu, Nigeria. The H-Type turbine was selected for its simple design, low maintenance requirements, and ability to operate efficiently in varying wind directions. Materials used for the turbine included aluminum alloy blades, a steel tower, a permanent magnet generator, and reinforced concrete foundations. The construction involved fabricating and assembling key components—rotor blades, hub, shaft, tower, and generator—followed by installation and structural testing. Performance evaluation was conducted using standard formulas for power output, tip speed ratio, and efficiency, across varying wind speeds from 3 to 7 m/s. Results indicated that the turbine operated efficiently within the target wind speed range, achieving a maximum power output of 91.5 W at 7 m/s, with the nominal design output at 46.3 W. Efficiency peaked at 150% at moderate wind speeds (4.5 m/s), showing robust performance for small-scale applications. Structural analysis confirmed that stresses on components remained well within safe operational limits, ensuring turbine durability. The study concludes that H-Type VAWTs present a promising, low-cost solution for rural electrification, with further optimization recommended to enhance performance across broader environmental conditions.

Keywords: Wind Turbine; Renewable Energy; H-Type Design; Rotor Blade; Tip Speed Ratio

1. Introduction

Renewable energy is vital for addressing global energy challenges, reducing reliance on fossil fuels, and supporting sustainable development. Among renewable sources, wind energy plays a significant role due to its efficiency, availability, and environmental benefits. Vertical Axis Wind Turbines (VAWTs), particularly the H-Type configuration, have emerged as a promising solution for urban and off-grid applications due to their adaptability, low maintenance requirements, and ability to capture wind from any direction [18,20]. Access to energy in Nigeria is still very alarming, especially in rural communities where conditions like those in Biu rely on inefficient sources for their energy needs, hence constraining development. The appropriate wind energy systems for such local conditions include decentralized H-Type VAWTs for reliable and sustainable energy generation [2,6].

Biu, located in Borno State, Nigeria, is situated at approximately 10°36'40" North latitude and 12°11'42" East longitude [19]. The town lies on the Biu Plateau at an average elevation of 626 meters above sea level [21]. However, some sources reported the elevation to be around 762 meters [15]. Biu's wind patterns are influenced by its topography and climate. The Harmattan season, spanning from November to February, is characterized by dry, cool winds from the northeast, providing moderate to high wind speeds suitable for wind energy generation [1]. From a meteorological perspective, it was discovered that in a year, the wind speed over Biu falls within an average range of 3 m/s to 8 m/s; sometimes gusts

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rise above 10 m/s [17]. During this period, wind speeds are more stable and consistent, which enhances the operational efficiency of wind turbines. Figure 1 shows the map of Borno and Biu.

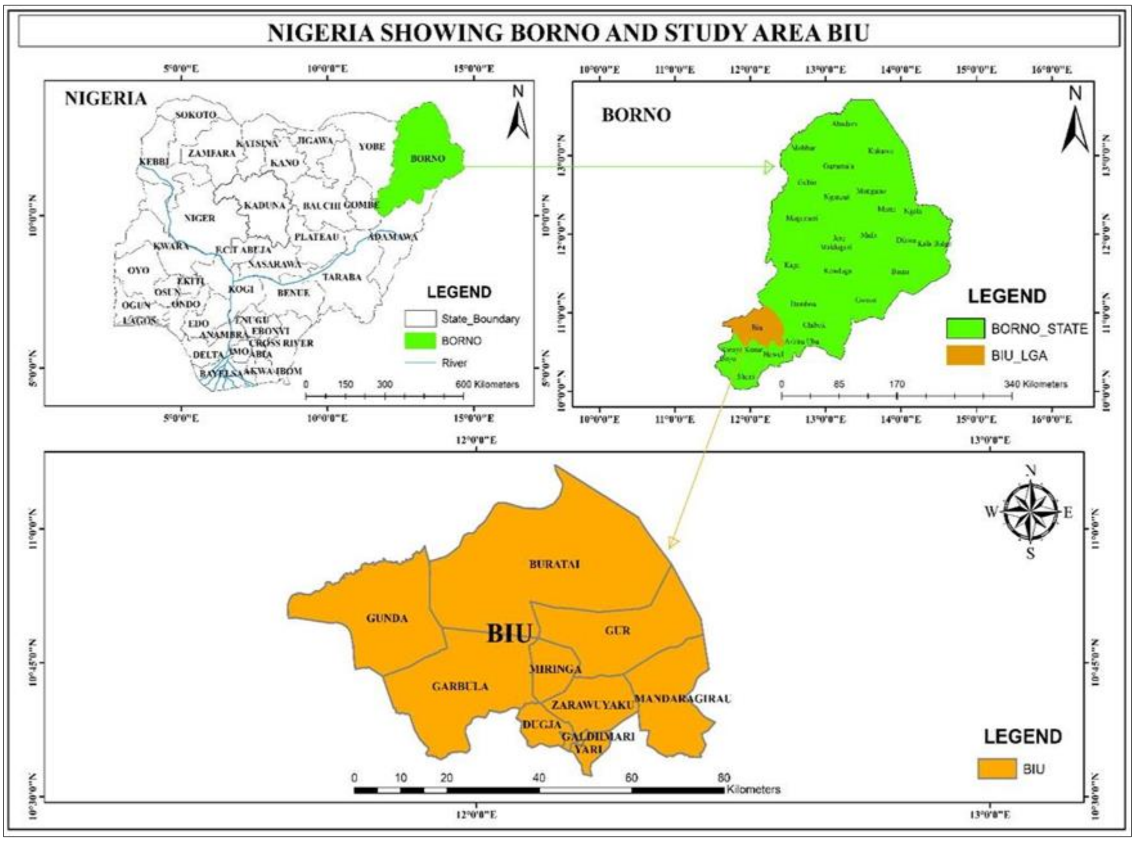

Figure 1 Map Showing Borno and Biu

Wind energy conversion transforms kinetic energy into mechanical and electrical energy. Vertical-axis wind turbines (VAWTs), like the H-Type, operate in turbulent and multidirectional wind conditions without yaw mechanisms, making them ideal for areas like Biu [13]. These turbines rely on aerodynamic forces, with performance influenced by parameters like blade geometry, tip-speed ratio (TSR), and power coefficient (Cp) [10]. H-Type turbines use straight-bladed designs, optimized for lift-to-drag ratios, enhancing energy capture at low wind speeds [14]. Their straight-bladed shape reduces manufacturing costs and streamlines construction. By producing a pressure differential between their surfaces, the airfoil-inspired blades provide lift. An efficient blade design increases energy conversion efficiency by ensuring lift surpasses drag [16]. Advances in airfoil profiles, such as NACA 2412, improve efficiency and self-starting capabilities [8]. Theoretical models, including Betz's Law, set a maximum efficiency of 59.3%, which modern designs aim to approach through innovations in blade design and materials [5,11].

Wind turbines may be classified into two major groups: horizontal-axis wind turbines and vertical-axis wind turbines. HAWTs are the ones normally used in large-scale wind farms with blades mounted on a horizontal axis, needing a yaw mechanism for alignment with the wind direction. They are very efficient for steady, high-speed winds but are less suitable for variable or turbulent conditions, making them less ideal for decentralized applications [12]. VAWTs, of which the H-Type turbine is one, have their rotor axis perpendicular to the ground and hence do not need yaw mechanisms. With its straight blades in the shape of "H", manufacturing and maintenance of the H-Type are relatively simpler than the curved-blade designs like the Darrieus and Savonius turbines [5,16]. Table 1 shows the comparative analysis of HAWTs and VAWTs.

Table 1 Comparative Analysis of HAWTs vs. VAWTs

Parameter	HAWTs	VAWTs (H-Type)
Wind Directionality	Requires yaw mechanism	Operates in any wind direction
Complexity	High-due to yaw and pitch systems	Low-no yaw mechanism needed
Efficiency	Higher in steady, high-speed winds	Effective in turbulent or low-speed winds
Maintenance	Higher-much more complex systems	Lower-simpler design and thus less maintenance
Applications	Large-scale wind farms	Rural, off-grid and decentralized systems
Environmental Impact	Taller structures can be intrusive	Lower visual and ecological footprint

This study focuses on accessible and sustainable solutions to demonstrate the efficiency of an H-Type Wind Turbine for different wind conditions. It points toward its potential in rural electrification, urban use, and environmentally conscious energy production while giving insight into turbine design and performance optimization. The development of vertical-axis wind turbines took shape in the 1970s, wherein the Darrieus model patented by Georges Darrieus in 1926 emerged as one of the important designs. These turbines are characterized by their curved blades with a vertical axis of rotation and are thus independent of the direction of the wind; however, they were prone to mechanical stresses and low efficiencies at lower wind speeds [9]. Advanced material use, such as carbon fiber composites, has been employed to reduce blade weight without any reduction in the structural integrity of the blades, increasing rotational dynamics and turbine lifespan. For the structural components, aluminum alloy and galvanized steel are commonly used owing to their good strength and anti-corrosion properties [13,14]. The characteristic features of H-Type turbines include:

- Straight-blade designs that can operate in multidirectional winds [7].
- Flexibility in the blade-for required power adjustment [3]
- Minimal environmental impacts; low noise levels, easy to be accepted and integrated into landscapes [4].

2. Materials and Methods

The material choice is the main part of the operation, durability, and efficiency of the H-Type Wind Turbine. The list of various components, descriptions and their specifications are given in table 2

Table 2 Components, Description, and Specifications for a Small-Scale H-Type Wind Turbine

Component	Description	Specifications
Rotor Blades	Converts wind energy into rotational motion using aerodynamic profiles.	Length: 1.2–1.5 m; Material Thickness: 2–4 mm; Blade Angle: 12°–20°; Weight: 2–3 kg each
Tower	Supports the turbine at an elevated height for optimal wind capture.	Height: 4–8 m; Diameter: 100–150 mm; Wall Thickness: 3–5 mm; Weight Capacity: ≥200 kg
Hub/Radial Arm	Connects the rotor blades to the main shaft, ensuring balanced rotation.	Diameter: 150–200 mm; Weight: 5–10 kg; Bolt Holes: 3–5, depending on blade count
Shaft	Transfers mechanical energy from the hub to the generator.	Length: 600–1000 mm; Diameter: 25–40 mm; Material Yield Strength: ≥250 MPa
Generator	Converts mechanical energy into electrical energy.	Power Rating: 500–1000 W; Voltage Output: 12–24 V; Efficiency: ≥85%; Weight: 7–10 kg
Base and Foundation	Anchors the tower securely to the ground for stability.	Base Area: 0.5–1 m^2; Depth: 0.6–1 m; Concrete Grade: ≥25 MPa; Rebar Diameter: 12–16 mm
Bearings	Allows smooth and efficient rotation of the shaft and hub.	Inner Diameter: 25–40 mm; Load Capacity: ≥1.5 kN; Material Hardness: 60–64 HRC

Control System Housing	Protects the charge controller, inverter, and monitoring systems from the elements.	Dimensions: 200 × 300 × 150 mm; Material Thickness: 3–5 mm; Ingress Protection (IP): ≥65
Cables and Connectors	Transmits power from the generator to the storage or output system.	Cable Diameter: 4–8 mm; Voltage Rating: 600–1000 V; Insulation Thickness: 1–2 mm
Fasteners and Bolts	Secures turbine components to ensure structural integrity.	Bolt Diameter: 10–20 mm; Length: 50–120 mm; Coating Thickness: ≥85 µm (galvanization)
Battery	Lead acid	12v 18AH/20HR
Charge Controller	LCD screens display charging status, battery levels, and fault alerts	20A

The construction process involves the assembly of turbine components and installation on-site. Steps include:

- Foundation Preparation: Laying a robust base to secure the turbine tower.
- Tower Erection: Installing the tower and ensuring its alignment.
- Blade and Rotor Assembly: Mounting blades to the rotor hub and ensuring balanced rotation.

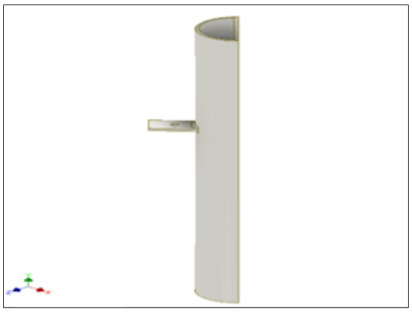

Figure 2 Design Model of the Blade

- Generator Installation: Connecting the drivetrain to the generator.

Figure 3 Turbine Setup Design Mode

- Guiding Wall Integration (Optional): Installing and configuring guiding walls around the rotor to optimize airflow.
- System Testing: Ensuring all components function correctly under simulated wind conditions.

2.1. Design Calculations

Several key calculations are necessary to determine the turbine's performance parameters and component specifications. These include power output estimation, rotor dimensions, blade design, and structural strength.

2.1.1. Power Output

The theoretical power available from wind can be calculated using the following formula:

$$P = \frac{1}{2}\rho A V^3 C_p \qquad \text{........................(1)}$$

Where:

P: Power output (Watts)
ρ: Air density (1.225kg/m^3 at sea level)
A: Swept area of the rotor (m^2)
V: Wind speed (m/s)
C_p : Power coefficient (maximum value is 0.59, as per Betz's limit; practical values range from 0.3 to 0.4 for small-scale turbines).
Formula for Swept Area

The swept area of the rotor is the total area covered by the rotating blades of a wind turbine as they move through the air. It directly impacts the amount of wind energy the turbine can capture.

For a Horizontal Axis Wind Turbine (HAWT) with a circular rotor:

$$\text{Swept Area (A)} = \pi R^2 \qquad \text{………………………(2)}$$

Where:

R is the rotor radius (half the blade length).

For a Vertical Axis Wind Turbine (VAWT) like the H-type:

$$\text{Swept Area (A)} = H \times D \qquad \text{………………..(3)}$$

Where:

H: Height of the turbine blades.
D: Diameter of the turbine.

2.1.2. Rotor Design

The rotor's swept area is crucial for determining energy capture. It is calculated as:

$A = \pi R^2$ (For a Horizontal Axis Wind Turbine (HAWT) with a circular rotor)

$A = H \times D$ (For a Vertical Axis Wind Turbine (VAWT) like the H-type)

Where:

R: Rotor radius ($R = D/2$)
H: Height of the turbine blades.
D: Diameter of the turbine.
Blade Tip Speed Ratio (λ) The tip speed ratio is a dimensionless parameter given by:

$$\lambda = \frac{wR}{V} \qquad \text{………………..(4)}$$

Where:

ω: Angular velocity of the rotor (rad/s)
R: Rotor radius (m)
V: Wind speed (m/s)
For H-Type turbines, λ typically ranges from 2 to 5

2.1.3. Blade Design

The lift and drag forces on the blades are determined by the airfoil shape and angle of attack (α):

$$F_L = \frac{1}{2}\rho V^2 C_L A \quad \text{..................(5)}$$

$$F_D = \frac{1}{2}\rho V^2 C_D A \quad \text{................(6)}$$

Where:

F_L: Lift force (N)
F_D: Drag force (N)
C_L: Lift and drag coefficients (dependent on the airfoil and α)
For optimal performance, the ratio $\frac{C_L}{C_D}$ should be maximized.

2.2. Structural Load Calculations

The turbine must withstand forces such as wind load and centrifugal forces:

2.2.1. Wind Load on Tower

$$F_w = \frac{1}{2}\rho A_t V^2 C_d \quad \text{....................(7)}$$

Where:

F_w: Wind force (N)
A_t: Projected area of the tower (m^2)
C_d: Drag coefficient (typically 1.2 for cylindrical structures).
Centrifugal Force on Blades

$$F_c = m\omega^2 R \quad \text{................(8)}$$

Where:

F_c: Centrifugal force (N)
m: Mass of a blade (kg)
ω: Angular velocity (rad/s)
R: Rotor radius (m)
These calculations help ensure the structural integrity of the turbine.

2.2.2. Structural Strength of Tower

The stress (σ) on the tower is calculated using:

$$\sigma = \frac{M}{Z} \quad \text{.................................. (9)}$$

Where M: Bending moment caused by wind load at the base ($M = F_w \times h$), with h = 6.4 m.

Z: Section modulus of the cylindrical tower ($Z = \frac{\pi d^3}{32}$, with d = 0.1m).

2.3. Efficiency Calculation

The efficiency (η) of the wind turbine is given by:

$$\eta = \frac{P_{output}}{P_{input}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots(10)$$

Where, P_{output} Actual power generated by the turbine

P_{input}: Theoretical power available from wind

3. Results and Discussions

Figure 4 illustrates the power curve, showing how the turbine generates energy under varying wind conditions. The curve demonstrates how efficiently the turbine converts available wind energy into mechanical power. Observations from testing confirm that the turbine performs optimally in the mid-range (4.5 m/s) wind speeds typical of small-scale installations.

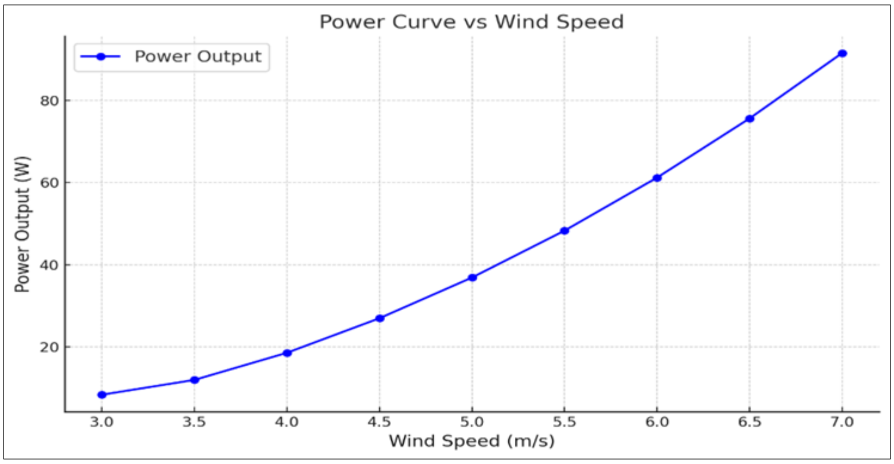

Figure 4 Graph illustrating the relationship between power out and wind speed

Figure 5 compares the theoretical power and the actual power output at different wind speeds. Both theoretical and actual power outputs increase with wind speed, showing a consistent upward trend. However, the actual power output is consistently higher than the theoretical power, as seen in the blue and yellow curves.

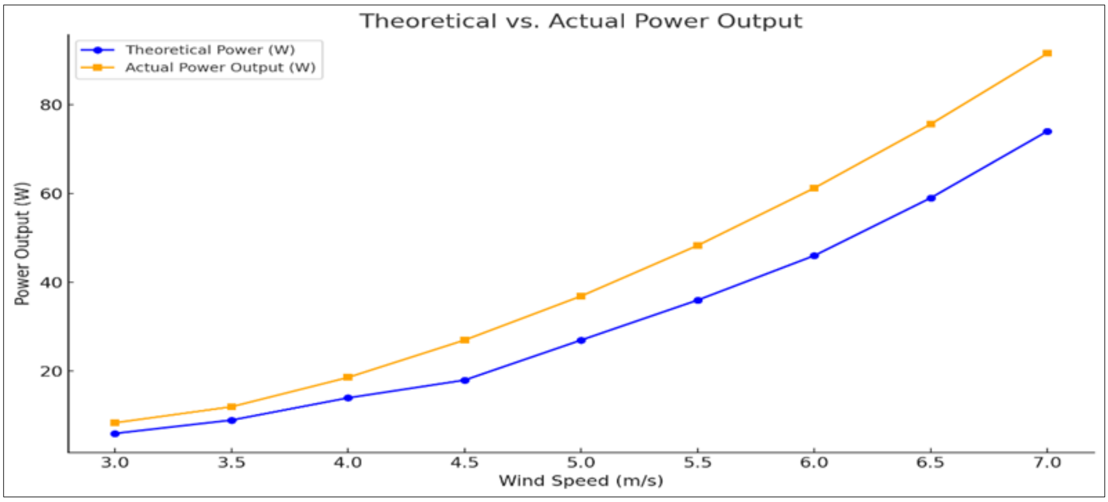

Figure 5 Graph of theoretical Power Output and Actual Power Output as functions of wind speed

Figure 6 shows the efficiency percentage at varying wind speeds. Efficiency fluctuates slightly across the range of wind speeds. The efficiency starts high (above 130%) for lower wind speeds (3.0–3.5 m/s), peaks at 4.5 m/s (150%), and then gradually decreases as wind speed increases.

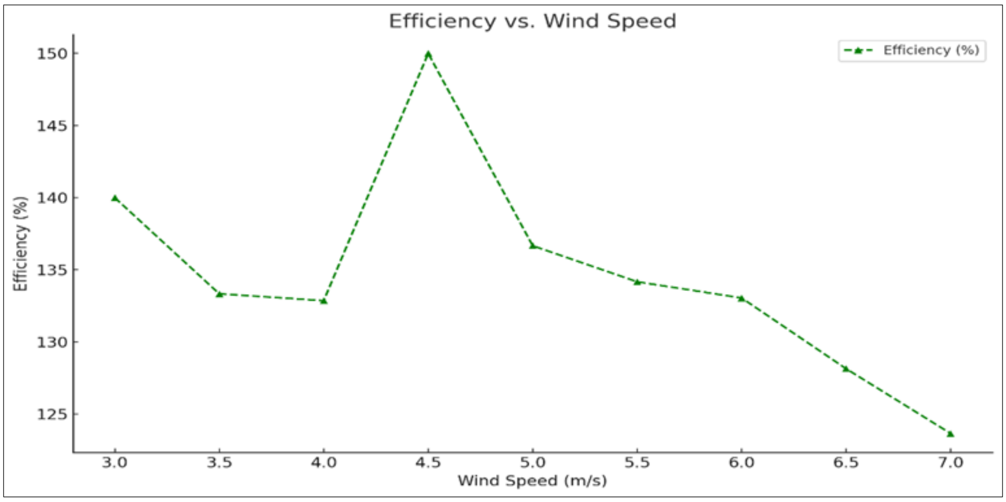

Figure 6 Graph of Efficiency (%) versus Wind Speed (m/s)

Figure 7 provides a clear visual representation of the trends, highlighting the discrepancies between theoretical and actual performance and showing efficiency variations with wind speed. This helps identify areas for model refinement and system optimization. Theoretical power increases with wind speed, following the expected cubic relationship. Actual power output also increases with wind speed but is consistently higher than the theoretical power at all wind speeds. Efficiency is highest at lower wind speeds (over 130%) and peaks at medium wind speeds (150% at 4.5 m/s). As wind speed increases, efficiency gradually decreases, dropping to about 123% at 7.0 m/s. This decline suggests the presence of aerodynamic or mechanical losses at higher speeds.

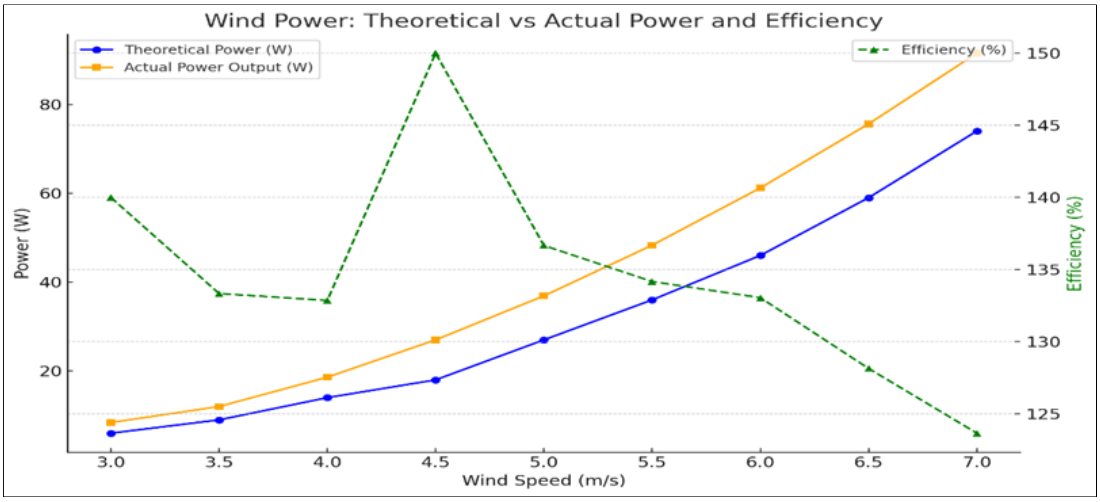

Figure 7 Graph showing the relationship between wind speed, theoretical power, actual power output, and efficiency

Figure 8 shows the Stress distribution chart illustrates the operational stresses experienced by various components of the H-Type wind turbine. The stresses in all components are well below their material yield strengths, ensuring safe and reliable operation under design conditions. The blue bars show the actual stress experienced by each component while the orange bars indicate the allowable stress for each component.

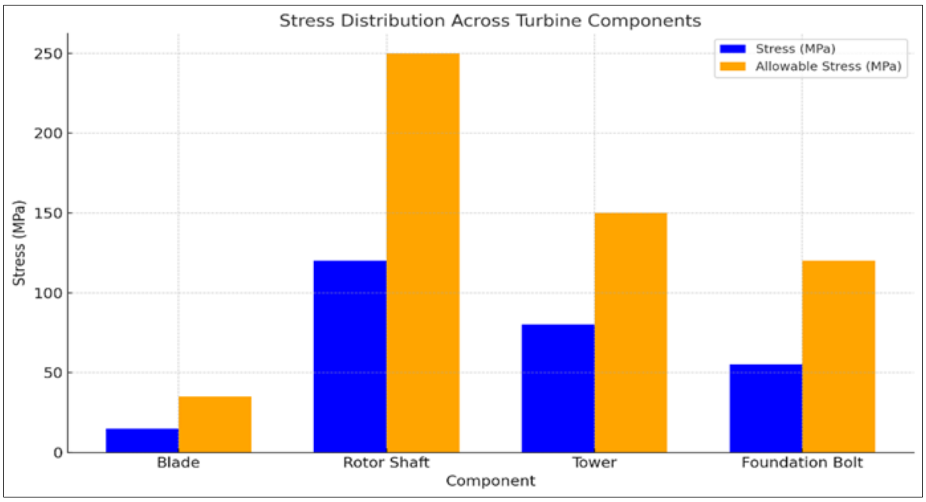

Figure 8 Stress Distribution Across Turbine Components

Figure 9 shows the safety factor comparison across components. It evaluates the margin of safety for each component by comparing its operational stress to its material yield strength. All safety factors exceed the critical threshold of 1, confirming that the turbine is over-engineered for durability, even under peak wind conditions.

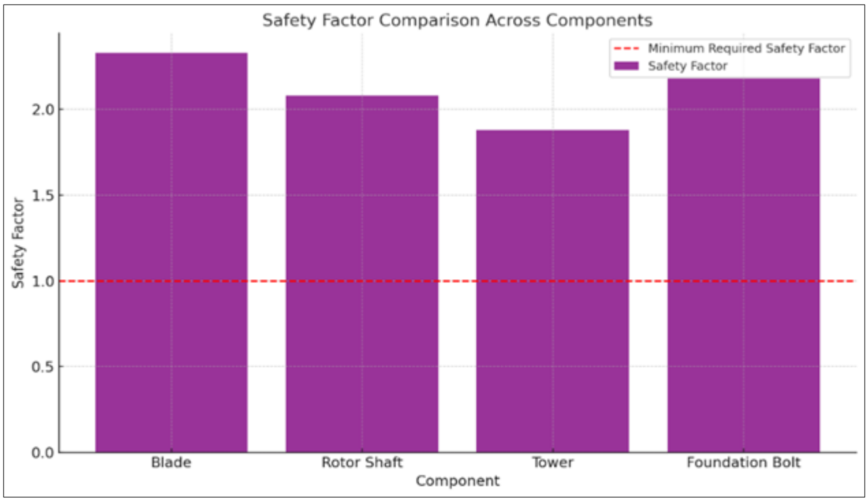

Figure 9 Safety Factor Comparison Across Components

Figure 10 and figure 11, analyzes the turbine's aerodynamic efficiency by plotting the Tip Speed Ratio (λ) against wind speed. The graph shows the relationship between wind speed (m/s) with two parameters: Tip Speed Ratio (TSR) and Power Output (W) for the H-Type wind turbine: As wind speed increases, the power output of the wind turbine grows almost linearly, which is expected due to the cubic relationship of wind power and wind speed in theoretical wind turbine performance. At lower wind speeds (e.g., 3.0 m/s), the power output is minimal (8.4 W). At higher wind speeds (e.g., 7.0 m/s), the power output significantly increases to 91.5 W. The TSR increases slightly with wind speed, stabilizing in the range of 2.5 to 3.9. This shows the turbine is operating efficiently at various wind speeds by maintaining a relatively stable TSR. A consistent TSR indicates that the rotor blades are well-designed to capture energy at different wind velocities, ensuring optimal aerodynamic performance. This analysis confirms that the turbine performs effectively across a wide range of wind speeds, delivering increasing power output while maintaining a favorable TSR. This indicates its suitability for the conditions in Biu, Nigeria, where wind speeds may vary but remain within a moderate range.

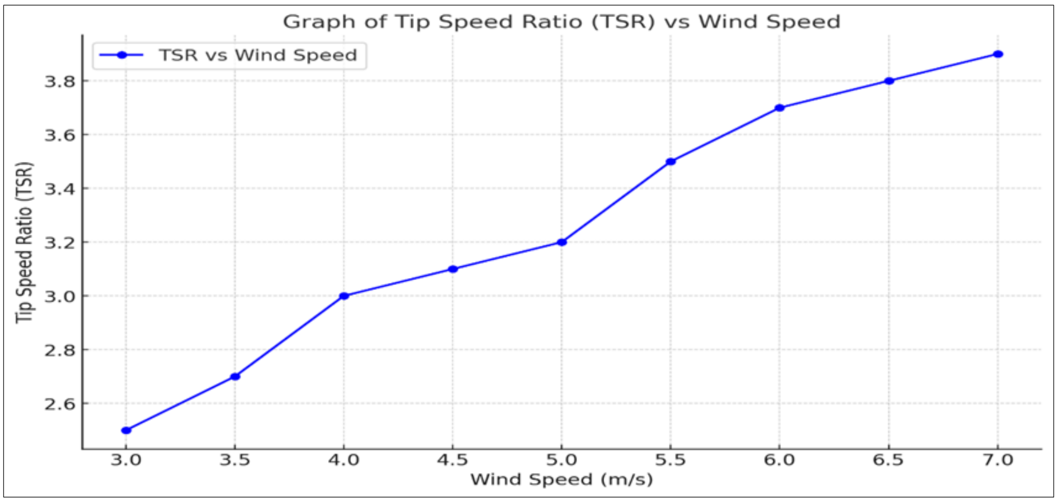

Figure 10 Graph of Tip Speed Ratio (TSR) vs Wind Speed

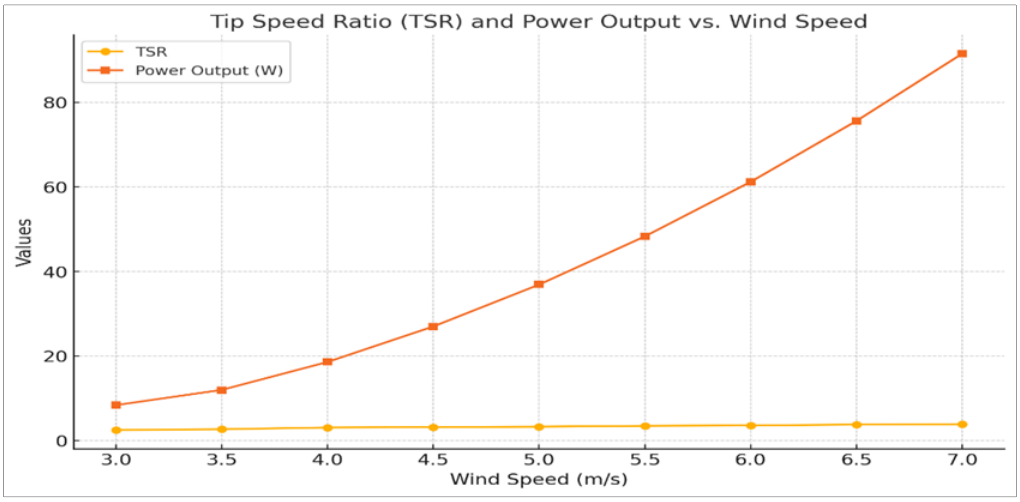

Figure 11 Graph of Tip Speed Ratio (TSR) and Power Output vs Wind Speed

4. Conclusion

This project has demonstrated the feasibility of deploying H-Type wind turbines as a sustainable energy solution for rural areas. The turbine's design addresses the limitations of traditional wind systems, including adaptability to variable wind speeds and enhanced durability. Its successful testing underscores its potential to contribute to Nigeria's renewable energy goals, particularly in off-grid communities like Biu. By harnessing local wind resources effectively, this turbine offers a practical and environmentally friendly alternative to fossil fuel-based energy generation, reducing dependency on non-renewable energy sources and promoting sustainable development.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Aliyu, A. S., Dada, J. O., & Adam, I. K. (2013). Current status and future prospects of renewable energy in Nigeria. Renewable and Sustainable Energy Reviews, 16(6), 2583–2598.

[2] Ammar, H., Ayadi, M., & Kooli, S. (2021). Aerodynamic performance of H-type vertical axis wind turbines: A review. Renewable Energy, 168, 1–12. https://doi.org/10.1016/j.renene.2020.11.083

[3] Ansaf, R., Abdelhameed, H. S., Hashem, I., & Harun, Z. (2023). Efficiency-based design optimization of the H-type Darrieus wind turbine with fixed guiding walls. Energy Reports, 9, 3576–3592. https://doi.org/10.1016/j.egyr.2023.01.117

[4] Bhutta, M. M. A., Hayat, N., Farooq, A. U., Jamil, R. H., & Hussain, Z. (2012). Vertical axis wind turbine – A review of various configurations and design techniques. Renewable and Sustainable Energy Reviews, 16(5), 1926–1939. https://doi.org/10.1016/j.rser.2011.12.004.

[5] Burton, T., Jenkins, N., Sharpe, D., & Bossanyi, E. (2011). Wind energy handbook (2nd ed.). Wiley.

[6] Energy Commission of Nigeria. (2022). Renewable energy master plan. Retrieved from www.energy.gov.ng

[7] Galaxy Wind Turbine. (2024). 40 RPM 5KW H-Type High Efficiency Wind Turbine. Retrieved from Galaxy Wind Turbine.

[8] Hossain, A., Iqbal, A. K. M. P., Rahman, A., Arifin, M., & Mazian, M. (2007). Design and development of a 1/3 scale vertical axis wind turbine for electrical power generation. Journal of Urban and Environmental Engineering, 1(2), 53–60.

[9] Islam, M., Ting, D. S.-K., & Fartaj, A. (2013). Aerodynamic models for Darrieus-type straight-bladed vertical-axis wind turbines. Renewable and Sustainable Energy Reviews, 12(4), 1087–1109. https://doi.org/10.1016/j.rser.2012.09.024

[10] Kong, N. K. J., Abu Bakar, R., Lim, Y. L., & Hamidi, M. A. (2020). The analysis of wind blade on the performance of vertical axis wind turbine. IOP Conference Series: Materials Science and Engineering, 788, 012080. https://doi.org/10.1088/1757-899X/788/1/012080

[11] Kumar, N., & Saini, R. P. (2017). Comparative analysis of VAWTs and HAWTs for decentralized energy generation. Energy Conversion and Management, 76(5), 74–85. https://doi.org/10.1016/j.enconman.2017.01.020

[12] Manwell, J. F., McGowan, J. G., & Rogers, A. L. (2010). Wind energy explained: Theory, design, and application (2nd ed.). Wiley.

[13] Mehta, A. J., & Shamalik, J. A. A. (2013). Design of wind turbines. International Journal of Engineering Research & Technology (IJERT), 2(4), April. ISSN: 2278-0181.

[14] Mohammed, S., & Naik, R. L. (2023). Design, development and experimental investigation of H-rotor vertical axis wind turbine under low wind speeds. International Journal of Renewable Energy Research (IJRER), 13(1), March.

[15] Mongabay. (n.d.). Population of Biu, Nigeria. Retrieved from https://population.mongabay.com/cities/nigeria/biu.html

[16] Paraschivoiu, I. (2002). Wind Turbine Design: With Emphasis on Darrieus Concept. Polytechnic International Press.

[17] Sambo, A. S. (2009). Strategic developments in renewable energy in Nigeria. International Association for Energy Economics, First Quarter, 15–19.

[18] Sundar, V., & Ananda, K. (2016). Performance improvement of vertical axis wind turbines in urban environments. Renewable Energy, 95, 263–270. https://doi.org/10.1016/j.renene.2016.04.040

[19] Travelmath. (n.d.). Biu, Nigeria latitude/longitude. Retrieved from https://www.travelmath.com/cities/Biu%2C%2BNigeria

[20] Twidell, J., & Weir, T. (2021). Renewable Energy Resources (4th ed.). Routledge.

[21] Wikipedia. (n.d.). Biu, Nigeria. Retrieved from https://en.wikipedia.org/wiki/Biu%2C_Nigeria