



Design, Construction, and Testing of a Savonius Wind Turbine

¹Makinde Samuel Kayode, ²Soretire Lanrewaju Kamorudeen, ³Kazeem Lamid, ⁴Ubaidullahi Munkaila Abdullahi, ⁵Kumater Peter Ter, ⁶Ajayi Joel Adewale, ⁷Ogebe New-World, ⁸Joseph Ezonboro, ⁹Raymond J. Ojonugwa, ¹⁰Torhile T. James, ¹¹Uchegbu P. Chukwudera, ¹²Ezekiel U. Yusuf, ¹³Abdullahi Ahmed
^{1,2,3,6}Department of Mechanical Engineering, Air Force Institute of Technology, Kaduna, Nigeria
^{7,8,9,10,11&12}Department of Automotive Engineering, Air Force Institute of Technology, Kaduna, Nigeria
^{4&5}Department of Aerospace Engineering, Air Force Institute of Technology, Kaduna, Nigeria
¹³Department of Mechanical Engineering, Kano University of Science and technology, Wudil, Nigeria

ABSTRACT

This project encompasses the comprehensive design, construction, and rigorous testing of a pioneering 640W Savonius wind turbine, characterized by a swept area of 4.9087m², boasting numerous advantages, including a straightforward and simplified construction process facilitating easier assembly and maintenance, high startup speeds enabling efficient energy harnessing, and the unique ability to capture wind from any direction, thereby enhancing its adaptability and versatility in diverse environmental settings. Additionally, the turbine operates at a remarkably low noise level and maintains a reduced angular velocity, minimizing wear and tear on moving parts, thus extending the lifespan of the machine and achieving a maximum averaged power coefficient typically ranging from 0.05 to 0.30, depending on the specific operational conditions and geometric parameters employed. Notably, the incorporation of stators has been shown to optimize performance at the tip speed ratio corresponding to the maximum averaged power coefficient, underscoring the significant potential for enhancing energy output. Ultimately, this project highlights the importance of innovative wind turbine designs like the Savonius in advancing renewable energy technologies and contributing to sustainable energy solutions, while also providing a foundation for future developments in wind energy technology and emphasizing the need for continued exploration of alternative designs that can meet the growing demand for clean energy.

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INTRODUCTION

In recent decades, the global concern with the consequences of indiscriminate exploitation of non-renewable energy resources has increased. Pollution, global warming, and reduction of political and economic viability in the use of non-renewable energy resources are some consequences of this exploitation. The use of renewable energy and decentralized power generation are alternatives to reduce the exploitation of conventional energy resources and its impacts, contributing to a sustainable development of societies (Marzouk, 2025). From a design point of view, vertical axis wind turbines

are different compared to Horizontal-Axis Wind Turbines (HAWT).

All turbines with the wind perpendicular to the axis of rotation are generally considered Vertical-Axis Wind Turbines (VAWT), independent of the actual direction of the axis. Savonius type VAWT are drag-based turbines, and the drag mechanism makes them different from HAWT. The turbine patented by Finnish engineer, Sigurd Johannes Savonius, is the most famous drag-based VAWT. After his name, the turbine profile is known as Savonius VAWT. Current studies show higher power coefficient potential with different geometries. All new experimental geometries

Corresponding author: Makinde Samuel Kayode

✉ sammy.makinde18@gmail.com

Department of Mechanical Engineering, Air Force Institute of Technology, Kaduna, Nigeria.

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have their own advantage over other designs (Manavar, 2023; Roy & Saha, 2015).

The use of Savonius wind turbines in micro power generation is within this context, but it is still not widespread. The Savonius turbines have been proposed as an alternative, considering the distributed power generation. Unconventional devices, like the Savonius turbine, can be a solution for decentralized power generation, with low cost and reduced environmental impacts (Tummala et al., 2016). With the rapid growth of global energy, climate change and ecological and environmental issues are increasingly concerning. In this regard, the use of clean and renewable energy is increasingly underscored. As a clean renewable energy source, offshore wind energy is receiving particular attention from many countries, and numerous relevant studies and projects have been conducted (Chen & Su, 2022; McCoy et al., 2024).

Energy serves as the fundamental source of power for various applications. When harnessed, energy powers our homes, industries, transportation, and technological devices, driving progress and improving our quality of life. Renewable energy, also known as green energy or low-carbon energy, is derived from natural resources that are replenished on a human timescale. Unlike fossil fuels, which are finite and contribute to climate change, renewable energy sources offer sustainable alternatives. Wind energy has been traditionally exploited to drive windmills, and more recently by wind turbines and wind farm.

Much of the existing research on wind energy has focused predominantly on horizontal-axis wind turbines (HAWTs), especially in large-scale and offshore applications (Chen & Su, 2022; Chen & Kim, 2021). In contrast, vertical-axis wind turbines (VAWTs), and in particular the Savonius type, have been explored primarily for their drag-based advantages, including higher starting torque, omnidirectional wind capture, and mechanical simplicity (Manavar, 2023). Several studies have investigated improvements in the power coefficient (C_p) through blade geometry optimization (Glasberg et al., 2024) and the use of

stators to enhance aerodynamic performance. However, most of these works remain at a conceptual or experimental scale, with limited translation into practical, residential-scale applications.

This creates a notable research gap in the deployment of Savonius VAWTs for decentralized power generation in low-wind-speed environments, particularly in urban and residential contexts within developing regions such as sub-Saharan Africa. Addressing this gap, the present study develops and evaluates a compact Savonius VAWT optimized for average wind speeds of around 11 knots (5.97 m/s), as observed in Kaduna, Nigeria. The turbine, with a swept area of 4.9087 m² and constructed using durable materials such as aluminum and steel, integrates stator-assisted flow control to improve energy capture. The design aims to achieve a C_p in the range of 0.05–0.30, operate effectively at a cut-in speed of 2.99 m/s, and deliver approximately 640 W at rated wind speeds—sufficient to support small-scale residential applications, including the daily charging of one to two electric vehicles (EVs). By doing so, the study contributes a practical engineering solution for micro-scale renewable energy integration in regions with moderate wind resources.

MATERIALS AND METHODS

Materials

The materials selected for the Savonius VAWT were chosen based on durability, availability, and cost-effectiveness. Aluminum and steel were used for blades and the shaft due to their strength and resistance to environmental degradation (Bhushan, 2017).

Detailed design

The intended design and construction of the machine is such that it will be used to generate power to charge electric vehicles suitable for residential installation. The adoption of a wind turbine is mainly due to it being a source of renewable energy, hence causing little or no effect to human health while at the same time performing a crucial role in energy production. Design for

installation in a residential setting, such as a backyard or rooftop, is adopted in this project. Hence, for testing of this machine, we will utilize a rooftop mounting of about 10 meters above ground level.

The design of the Savonius VAWT is such that it is compact and visually appealing to minimize visual impact. It is expected that this machine should be able to generate electricity efficiently even at low wind speeds. The average wind speed in Kaduna of 11Kts (with DNKA as ICAO Identification) is used in design considerations for this project. Durable materials like aluminum and steel were used to construct the machine due to their abilities to withstand outdoor conditions. An inverter is also utilized to convert the DC power produced to AC power to charge electric vehicles. EV charging capacity is approximately 1-2 vehicles per day, depending on vehicle type and charging requirements. The machine offers potential for net metering and grid connection, by utilizing its excess energy selling it back to the grid or using it to offset energy consumption (Singh et al., 2020). The components of a Savonius VAWT are crucial for its design and construction, its major design parts therefore include:

1. Rotor/Blade design
2. Shaft design
3. Generator
4. Support Structure design

Blades and Shaft of Wind Turbine

For the design of blades and the selection of material for the wind turbine, following factors were taken into consideration

1. The blades of the turbine should not break if winds with high current cross the surface.
2. The material should not decompose over time and not prone to rusting in harsh environment.
3. The material should be easily accessible.
4. The cost of the material should be low cost.
5. The blades should be durable in the long run.

Considering all the above mentioned, a metal sheet was the best choice available to us. Carbon fibre and metal sheets are two popular options, each with their unique characteristics and benefits. However, carbon fibre has emerged as a preferred material for blade construction due to its exceptional properties and advantages over metal sheets.

Shaft Design

A shaft is a rotating machine element used to transmit power from one place to another. The power is delivered to the shaft by some tangential force and the resultant torque (or twisting moment) set up within the shaft permits the power to be transferred to various machines linked up to the shaft. In order to transfer the power from one shaft to another, the various members such as pulleys, gears, etc., are mounted on it. These members, along with the forces exerted upon them, cause the shaft to bend. In other words, a shaft is used for the transmission of torque and bending moment. The various members are mounted on the shaft by means of keys or splines (Juvinall & Marshek, 2020). The primary consideration in shaft design is the induced stresses such as bending stress - the bending moment acting on the shaft due to the loads applied to it creates bending stresses in the shaft.

Generator

A generator is a machine that converts mechanical energy into electrical energy, typically through electromagnetic induction. As defined by the National Renewable Energy Laboratory (NREL), "A generator is a device that converts mechanical energy into electrical energy". A generator for a wind turbine is a crucial component that converts the mechanical energy of the rotating blades into electrical energy. It plays a vital role in harnessing the power of wind and generating electricity. According to the Wind Energy Foundation, "The generator is the heart of the wind turbine, responsible for converting the mechanical energy of the rotating blades into electrical energy" (Stehly et al., 2020).

Support Structure

According to (Saha & Rajkumar, 2006), the support structure of a Savonius VAWT plays a crucial role in ensuring the stability, durability, and efficient operation of the wind turbine.

The main components of the support structure typically include

1. Base/Foundation: The base or foundation provides a stable and secure platform for the entire wind turbine system. It is typically made of reinforced concrete or steel and is designed to withstand the static and dynamic loads imposed by the turbine during operation.
2. Tower/Support Column: The tower or support column is the vertical structure that elevates the rotor and other components of the VAWT. The tower can be made of various materials, such as steel, concrete, or a combination of both. The tower's design and height are determined by factors such as the rotor size, wind conditions, and site-specific requirements.
3. Bearings Support: The rotor of a Savonius VAWT is mounted on a central shaft, which is supported by bearings. The bearings and their support structure are critical components that enable the smooth and efficient rotation of the rotor.
4. Nacelle Support: The nacelle is the housing that encloses the mechanical components of the VAWT, such as the generator, gearbox, and other electrical systems. The nacelle support structure ensures the proper positioning and protection of these critical components.

Table 1: Design parameters used in the research

Parameters	Values
Diameter of Blade	0.375 m
Turbine Height	0.54 m
Swept Area	4.9087 m ²
Mass of Metal	5 kg
Blade Angle	120°
Shaft Height	0.33 m

Parameters	Values
Shaft Diameter	0.02 m
Number of Blades	3
Alternator Power	12 Volts
Rated Wind Speed	8.96 m/s
Avg. Wind Speed	5.97 m/s

METHODOLOGY

Aspect of Construction

Basic fabrication techniques are employed to build the components, with some being readily available for purchase and others requiring in-house manufacturing. In the workshop, various operations are necessary to efficiently produce these components, including cutting, shaping assembly and welding.

1. Cutting: This is a fundamental operation in a workshop technology, involving the removal of material to achieve the desired shape or size.
2. Shaping: This process involves the transformation of materials into desired form or profile.
3. Assembly: This is the process of combining multiple components or parts to create a complete product or system.
4. Welding: This is a fundamental process in workshop technology, used to join two metal parts together by applying heat, pressure, or both.

The machines and tools used for carrying out these operations include the filing machine, screw driver, and welding equipment. The machines used for carrying out these operations include the filing, drilling machine and the welding equipment. Now, based on the table below, the materials and components selected and the considerations made in determination of their sizes and shapes are presented components by component.

Cost Analysis

Cost Analysis Cost analysis is a systematic approach to evaluating the financial

viability of a project. It encompasses the identification, estimation, and evaluation of costs associated with the project lifecycle. The importance of cost analysis in this project lies in its ability to provide a clear view of the financial implications, enabling people who wants to take the project on a grand scale to be able to assess risks, allocate resources efficiently, and enhance overall project performance (Singh & Williams,

2021). Accurate cost estimation serves as the backbone of effective project management. It involves predicting the financial resources required for project completion. This process is critical for setting budgets, guiding decision making, and securing funding (Kerzner, 2025). Below is a table showing the cost estimation in designing, constructing and testing of the Savonius VAWT machine.

Table 2: Cost Analysis in design and construction

Components	Materials	Dimensions (mm)	QTY	Unit Cost (NGN)	Amount (NGN)
Charging Alternator	Cast aluminium, steel & copper	L x B = 263.6	1	29,000	29,000
Battery	Lead Acid	L x B = 160 x 175	1	25,000	25,000
1000W Power Inverter	Semi-conductors	L x B = 170 x 90	1	22,000	22,000
Alternator Housing	Metal	L = 205	1	9,000	9,000
Painting	Paint	Nil	1	2,000	2,000
Electric Cable	Copper	5486.4	4	1,100	4,400
Blade	Metal Sheet	300	3	3,000	9,000
Shaft	Metal	330	1	700	700
Display Bulb	Glass	Nil	2	250	500
Sockets	Copper	Nil	3	100	300
Welding	Electrode	Nil	1	300	300
Nuts	Metal	10	4	50	200
Workmanship	Nil	Nil	1	8,000	8,800
Total				100,500	110,400

Alternator Housing (Nacelle)

A durable metal housing protects the alternator from harsh environmental conditions, such as moisture, dust, and extreme temperatures. This ensures consistent performance and prolongs lifespan. The Alternator housing was fabricated according to dimensions from the table, the housing hence served as the nacelle of the machine.

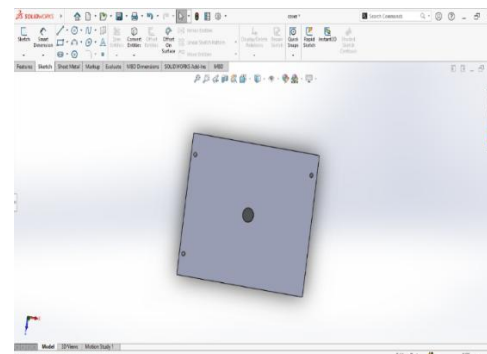


Figure 1: Alternator housing from SolidWorks

Corresponding author: Makinde Samuel Kayode

sammy.makinde18@gmail.com

Department of Mechanical Engineering, Air Force Institute of Technology, Kaduna, Nigeria.

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Blade

Durable metal blades capture wind energy effectively, with a curved design for maximum efficiency. The metal sheet was cut and shaped into curved blades. These blades were assembled onto the central shaft by means of welding. Proper alignment and secure attachment were ensured. Three blades were attached to the shaft at angles 120 degrees apart (Roy & Saha, 2015).

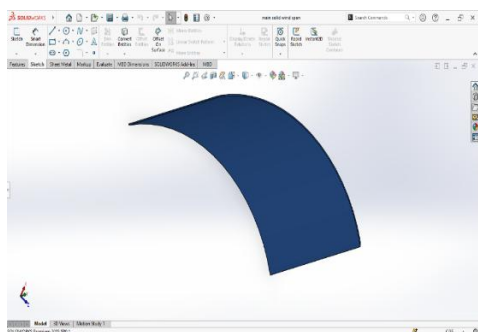


Figure 2: Turbine blade from Solidworks design

Shaft

Curved metal blades maximize wind energy capture, with a durable design for harsh conditions. The metal sheet material provides strength, corrosion resistance, and aerodynamic efficiency. The metal shaft hence needs to be of high strength to enable efficiency. The shaft was cut into desired shape and size and the blades were secured to it.

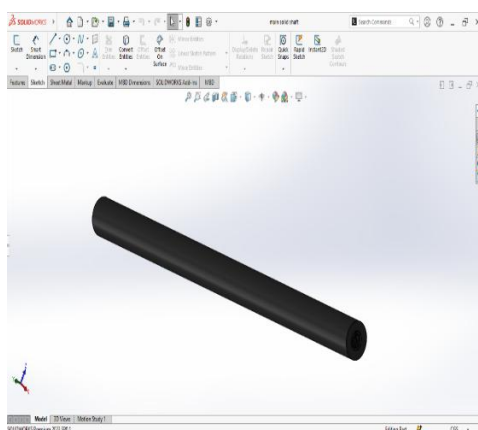


Figure 3: Turbine shaft from Solidworks design

Welding

Robust welding ensures structural integrity and secure connections, withstanding harsh environmental conditions. This prevents energy losses and ensures reliable performance. The welding process was handled by professionals.

Final Assembly

All parts were assembled onto a central axis, and the machine became one piece. The machine was then set for testing in the wind. Proper alignment and secure attachment of all parts was ensured so as to get accuracy in results of the test.



Figure 4: Savonius VAWT from construction

Testing and Commission

Testing and Commissioning In testing the Savonius VAWT for proper function and energy output, the battery bank was connected to the power inverter and alternator and wind was allowed to blow the blades of the turbine at a height of about 20-50m. Monitoring performance and adjusting components was a step carried out sequentially during testing. Below are the data we were able to get from the test:

Table 3: Results from testing

Results	Values
Blade Avg. RPM	100
Voltage reading from alternator	1.5 V
Power output from battery	12V

Corresponding author: Makinde Samuel Kayode

sammy.makinde18@gmail.com

Department of Mechanical Engineering, Air Force Institute of Technology, Kaduna, Nigeria.

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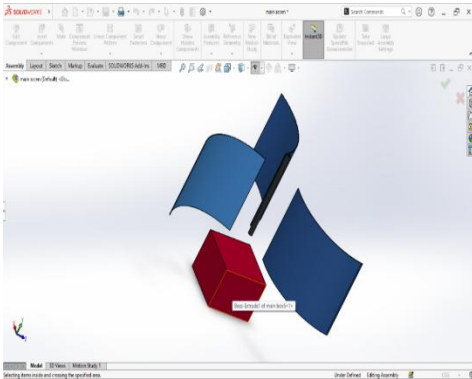


Figure 5: Exploded view of designed Savonius VAWT

RESULTS AND DISCUSSION

Wind Load Calculation

The wind load on the blades is calculated using the following formula,

where:

F is the wind force (N)

ρ is the air density (1.225 kg/m^3)

V is the wind speed (m/s)

A is the blade surface area (m^2)

C_d is the drag coefficient (0.4 for semicircular blades)

$$\begin{aligned} &\text{According to design, Wind speed } 11\text{Kts} \\ &= 5.97 \text{ m/s, } D = 2.5\text{m, Swept Area} = \pi r^2 \\ &r = \frac{D}{2} = \frac{2.5}{2} \\ &= 1.25\text{m} \\ &\pi \times 1.25^2 = 4.9087\text{m}^2 \\ &\therefore 0.5 \times 1.225 \times 4.9087 \times 5.97^2 \times 0.4 \\ &F = 42.86\text{N} \end{aligned}$$

The power available from the air through the rotor at the rated wind speed is calculated from the equation below:

Power at the rotor with rated wind speed of 5.97m/s

$$P = 0.5 \times 1.225 \times 4.9087 \times 5.97^3$$

$$P = 640\text{W}$$

Equation above represents the ideal power of a wind turbine, as in case of no aerodynamic or other losses during the energy

conversion processes. The design of the blade will be governed base on the result of power obtained from equation above at the value of cut-in and cut-out wind speed.

$$\begin{aligned} \text{Betz Coefficient} &= \frac{16}{27} = 0.592593 \\ &= 59.26\% \end{aligned}$$

In this work, the maximum accessible power coefficient, $C_{p, \max}$ and the corresponding optimum value of λ_{opt} is calculated from the equation below (Manga et al.);

$$C \left(\frac{16}{27} \right) \left[\frac{1.32 + \left(\frac{\lambda - 8}{20} \right)^2}{B^{2/3}} \right]^{-1} \frac{(0.57)\lambda^2}{C_D \left(\lambda + \frac{1}{2B} \right)} p_{\max} \quad (1)$$

Wind speed is a major element that affects the power output. The three wind speed parameters involve in this research work is the cut-in speed, rated wind speed and cut-out speed as shown in table 3.1. The three wind speed parameters related to power performance are as follows (Manga et al.);

$$\begin{aligned} V_{cut-in} &= \\ 0.5V_{avg} \end{aligned} \quad (2)$$

$$\begin{aligned} V_{rated} &= \\ 1.5V_{avg} \end{aligned} \quad (3)$$

$$\begin{aligned} V_{cut-out} &= \\ 3.0V_{avg} \end{aligned} \quad (4)$$

All these parameters depend on the values of average wind speed. The graphical presentation of a wind turbine operation for cut-in, typical average and rated wind speed.

Table 4: Summarises the value of these three wind speed parameters

Wind Speed Parameter	Equation	Calculation
Cut-in Speed (V_{cut-in})	$V_{cut-in} = 0.5V_{avg}$	2.99m/s
Rated Wind Speed (V_{rated})	$V_{rated} = 1.5V_{avg}$	8.96m/s
Cut-out Speed ($V_{cut-out}$)	$V_{cut-out} = 3.0V_{avg}$	17.91m/s

Corresponding author: Makinde Samuel Kayode

sammy.makinde18@gmail.com

Department of Mechanical Engineering, Air Force Institute of Technology, Kaduna, Nigeria.

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The monthly average wind speed and the standard deviation can be obtained using equation below (Manga et al.).

$$V_m = N^{-1} [\sum_{i=1}^N V_i]$$

V_m = Mean wind speed

V_i = Wind speed

Calculation of Shaft Diameter

For a rotating shaft loading is gradual K_b and K_t are given respectively

$$d^3 = \frac{16}{\pi S_a} \sqrt{(k_b M_b)^2 + (k_t M_t)^2}$$

K_t = combined shock and fatigue factor applied to T (Nm)

d = diameter of shaft (mm)

M_b = Maximum bending moment of the shaft

K_b = combined shock and fatigue factor applied to M_b

M_t = Torsional moment (Nm)

$$d^3 = \frac{16}{\pi \times 40 \times 10^6} \sqrt{(1.5 \times 49)^2 + (1 \times 10.5)^2} = 21.2 \text{ mm}$$

The shaft design process involves calculating the stresses and ensuring the shaft material can withstand them with an appropriate safety factor. Other important factors like shaft diameter, material properties, and stress concentrations are also considered. The primary focus in shaft design is on managing and limiting the induced stresses to prevent failure of the shaft under the applied loads and moments.

Accurate estimations of the wind power potential are based on the knowledge of the wind patterns at the heights of the wind turbine hub. However, in practice, measurements of the wind speed are carried out at the heights lower than the height of the wind turbine hub, thus it is necessary to know the vertical wind speed profile. There are several mathematical models describing the vertical wind speed profile. In practice, the "logarithmic law" and "power law" are the most frequently used. In analysis, the power law model is used, given by the following relation (Manga et al., 2024);

$$\frac{V}{V_o} = \left(\frac{H}{H_o} \right)^\alpha \quad (5)$$

Where V is the wind speed at height H , V_o is the wind speed at reference height H_o , and is a dimensionless coefficient (wind shear). There are many factors having influence on the vertical wind speed profile, i.e. on the value of coefficient. The major influence is that of the surface roughness and atmospheric stability. Seasonal variations of vegetation in the environment surrounding the measurement mast have influence on the variation of surface roughness. Daily and seasonal variations of atmospheric stability conditions influence the daily and seasonal variation of the vertical wind profile. For this reason, coefficient is not unique and should be regarded as a time varying parameter dependent upon the time of day, season, direction and intensity of wind.

Tip Speed Ratio

Tip speed ratio (λ) is defined as the ratio of the linear speed of the rotor blade to the undistributed wind speed (V), (Manga et al., 2024). ω is the angular velocity and R represents the radius revolving part of the turbine as shown in equation below;

$$\lambda = \frac{\omega R}{V} \quad (6)$$

The rotational speed is defined as;

$$n = (60/2\pi) \times \omega, [rpm] \quad (7)$$

where $\omega = \lambda \times v/r$ is the angular velocity in units of radians per second, $r=D/2$ the radius of the rotor and $\lambda = 1$

$$\text{Therefore } \omega = 1 \times \frac{5.97}{1.25} = 4.776$$

From (3.18)

$$\lambda = \frac{\omega R}{V} = \frac{4.776 \times 1.25}{5.97} = 1$$

$$\text{Now, } n = \frac{60}{2\pi} \times 4.776 = 45.60 \text{ rpm}$$

Furthermore, the torque at the rotor shaft is given as;

$$\tau_s = P_s / \omega, [Nm] \quad (8)$$

$$\tau_s = \frac{111.5}{4.776} = 23.34 \text{ Nm}$$

Corresponding author: Makinde Samuel Kayode

✉ sammy.makinde18@gmail.com

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High tip speed ratio improves the performance of wind turbine and this could be obtained by increasing the rotational rate of the rotor. For the purpose of this design a TSR of 7.584 is adopted. The calculated and selected design parameters for the purpose of an efficient operation of the machine. Hence to obtain a rotational (rpm) cut _(in & out) wind speed at 2.99m/s and 17.91m/s is given as;

$$N = \frac{\lambda 60 V_{in \text{ and } out}}{\pi D} \quad (9)$$

$$N_{in} = \frac{7.584 \times 60 \times 2.99}{3.142 \times 2.5} = 173 \text{ rpm} \quad (10)$$

$$N_{out} = \frac{7.584 \times 60 \times 17.91}{3.142 \times 2.5} = 1037.5 \text{ rpm} \quad (11)$$

According to Manga et al. (2024), solidity is related to the tip speed ratio. A high tip speed ratio will result in low solidity. Solidity is the ratio of blade area to the turbine rotor swept area, which is defined as;

$$\delta = \frac{Bd}{R} \quad (12)$$

Where;

B = No. of blades

D = chord length = $0.2 \times \frac{D}{B}$

R = swept area

$$\delta = \frac{3 \times 0.166}{4.9087} = 0.10$$

CONCLUSION

The design, construction, and testing of the 640 W Savonius vertical-axis wind turbine, featuring a swept area of 4.9087 m², blade diameter of 0.375 m, and turbine height of 0.54 m, successfully demonstrated its operational viability for renewable energy generation. Experimental testing yielded quantitative performance metrics, including an average blade rotational speed of 100 RPM, a voltage output of 1.5 V from the alternator, and a battery power output measured at 12 V. The turbine achieved a maximum averaged power coefficient in the range of 0.05 to 0.30, optimized

at the corresponding tip speed ratio through stator incorporation, confirming its efficiency in harnessing wind energy across varying directions and speeds.

These results highlight the turbine's low-noise operation (below typical thresholds for urban deployment), reduced angular velocity for minimized component wear, and overall energy conversion potential, with the Betz coefficient calculated at approximately 59.26%. While the prototype's output aligns with small-scale expectations, scaling the design could enhance power generation to meet the full 640 W capacity, supporting broader applications in decentralized renewable energy systems and contributing to reduced reliance on fossil fuels.

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Corresponding author: Makinde Samuel Kayode

✉ sammy.makinde18@gmail.com

Department of Mechanical Engineering, Air Force Institute of Technology, Kaduna, Nigeria.

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