International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 01 Jan 2024, pp: 452-457 www.ijaem.net ISSN: 2395-5252

An Experimental Investigation on the Effects of Rotor Blade Number on Electricity Generation of Savonius Wind Turbine

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Date of Submission: 20-01-2024 Date of Acceptance: 30-01-2024

ABSTRACT: The Savonius wind turbine is a popular vertical axis wind turbine (VAWT) known for its ability to operate at low wind speeds and accept wind from all directions. However, due to inherent design limitations, it has lower efficiency compared to other wind turbine configurations. This paper presents an experimental investigation on the effects of rotor blade number on the electricity generation of Savonius wind turbines. The study involved constructing and testing three Savonius wind turbines with varying numbers of blades: two blades, three blades, and four blades. To measure and compare the performance of the turbines, several parameters were examined, including AC voltage, coefficient of power, tip speed ratio, and efficiency. The experimental setup included a data logger consisting of an NI DAQ USB-6008 and a PC running LabVIEW software for measuring the instantaneous voltage. Furthermore, the wind speed was measured using a PST-TL017 PROSTER digital anemometer., while RPM was measured using A FERVI C070-Contact and Optical Digital Tachometer. A wind blower was employed to spin the Savonius wind turbine rotors. The results of the experiments indicated that the two-bladed Savonius wind turbine rotor provided the highest voltage of 4.8V, the highest coefficient of power of 0.19, and has an efficiency of approximately 20%. This research contributes to the existing body of knowledge by investigating the influence of rotor blade number on the performance of Savonius wind turbines. Moreover, the findings offer valuable insights into the optimal design of Savonius rotors for electricity generation, aiding engineers in selecting the most efficient configuration for specific applications.

KEYWORDS: Electricity Generation, Number of Rotor Blades, Renewable Energy, Savonius Wind Turbine.

I. INTRODUCTION

The growing awareness of climate change and environmental pollution is fueling the transition to renewable energy sources like wind, water, and sunlight. Ongoing research is dedicated to enhancing the efficiency and widening the range of applications for clean energy devices. Among these devices is the Savonius type of Vertical Axis Wind Turbine (VAWT), which is notable for its ability to start operating at lower wind speeds compared to conventional Horizontal Axis Wind Turbines (HAWTs). Various development initiatives share the common goal of enhancing the energy production capabilities of these devices [1]. Wind turbines generate electricity by utilizing the power of the wind to drive an electric generator. The conversion of mechanical energy from the wind turbine rotor into electrical energy is accomplished using a generator shaft coupled with the rotor shaft. The generator operates based on Faraday's law of electromagnetic induction, which states that a conductor moving in a magnetic field produces an induced EMF. Generators can produce either AC or DC, depending on the application [2]. Wind turbines can be classified into two general groups: vertical axis wind turbines (VAWT) and horizontal axis wind turbines (HAWT). The Savonius wind rotor belongs to the vertical axis group and was patented by the Finnish engineer

Sigurd Savonius in 1929. The Savonius wind turbine appears to be appealing and promising for generating electricity in urban areas and regions with low wind speeds. Although the Savonius rotor has advantages such as low cost, simplicity, and reliability, its efficiency is lower compared to other vertical axis wind turbines. As a result, numerous studies have been conducted to improve its efficiency [3]. This research will experimentally investigate the effect of rotor blade number on electricity generation of a Savonius wind turbine. In similar research conducted by Mahmoud NH [4], evaluations were made on two-bladed, three-bladed, and four-bladed geometries for Savonius rotors. The results indicated that the two-bladed Savonius rotors exhibited high efficiency compared to the three- and four-bladed rotors. Moreover, in a similar study conducted by Alit [5], it was concluded that a wind turbine with two blades produces stable rotation, resulting in the best performance compared to three and four blades. Furthermore, another similar research was carried out by MH Ali [6] in which two-bladed and three-bladed rotors were compared. The research found that a two-bladed rotor is more efficient than a three-bladed rotor. Additionally, in a similar research, Ragheb [7] stated that the ideal tip speed ratio (TSR) is influenced by the quantity of rotor blades. A wind turbine with fewer blades captures the maximum power from the wind at a higher speed. On the other hand, similar research was conducted by F. Wenehenubun [8] on a Savonius wind turbine model in a wind tunnel and simulation using ANSYS 13.0 software. The study concluded that the number of blades influences the rotation of the wind turbine rotor models. It was discovered that the three-bladed rotor exhibits the best performance at higher tip speed ratio compared to both the two-blade and four-blade counterparts.

II. METHODOLOGY

A. Rotor Blade Configurations:

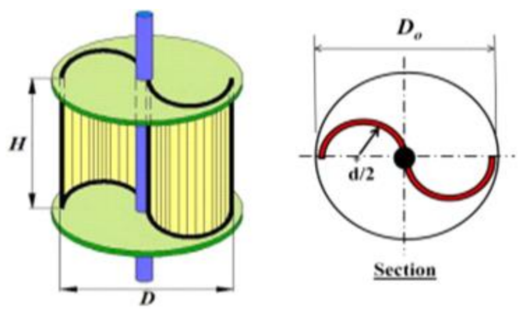

Fig. 1: Schematic Diagram of a Two-Bladed Savonius Wind Turbine Rotor [6]

The swept area for the Savonius wind turbine is calculated using the following equation: **As** = $H * D$ [7] ....(1). Where H, represents the height of the rotor = 0.06m, and D, represents the diameter of the rotor = 0.12m. The height and diameter of a Savonius rotor is illustrated in fig. 1. All the 3 Savonius rotors used in this experiment are having the same height and diameter. Therefore, the swept area for each rotor can be calculated as: H*D = 0.06m*0.12m = $0.0072m^2$. Additionally, each Savonius wind turbine rotor has an aspect ratio (Ar), which is defined as the ratio of the height to the diameter of the wind turbine rotor:

Ar = $\frac{H}{D}$........(2) [7]. Also, in equation (2), H represents the height of the rotor, and D represents the diameter of the rotor, as shown in fig. 1. All the three Savonius rotors used in the experiment are having the same aspect ratio. Therefore, the aspect ratio for each rotor can be calculated as: Ar = $\frac{H}{D} = \frac{0.06m}{0.12m} = 0.5$.

A mini and portable Savonius wind turbine was constructed and used in the experiment. The wind turbine system was tested using a two-bladed Savonius rotor, a three-bladed Savonius rotor, and a four-bladed Savonius rotor at different times. The rotors were designed and constructed with the same swept area and aspect ratio, as shown in fig. 2

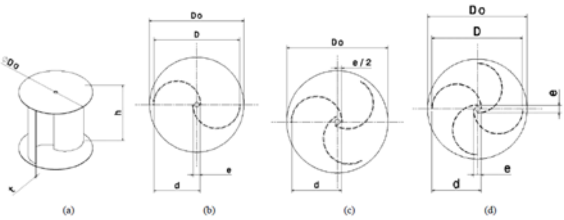

Fig. 2: (a) Design of the Savonius Wind Turbine Rotor Model and the Cross Section of (b) Two-Bladed (c) Three-Bladed, and (d) Four-Bladed Savonius Rotors. [8]

B. Experimental Setup:

The experimental set-up consisted of a mini Savonius wind turbine with variable blade numbers exposed to a wind speed of 11 m/s. A Paul Anthony Hair dryer-2000W was used for blowing the wind that spins the rotor blades positioned approximately 3 cm away from the rotor blades. The number of rotor blades was varied to 2, 3, and 4 blades and tested separately under the same wind speed as the independent variable in the experiment. The wind speed was measured using a PST-TL017 PROSTER digital anemometer. A 10Ω resistor was connected to the wind turbine's output as a load resistor. A data logger comprised of an NI DAQ USB-6008 was connected to the terminals of the load resistor to measure the instantaneous voltage across the load. The data logger's output was connected to a PC running LABVIEW software via a USB cable, which was used to monitor the instantaneous voltage and export the results to an Excel sheet for future analysis. A FERVI C070-Contact and Optical Digital Tachometer was used for measuring the RPM. The result exported to the Excel sheet was used to plot a bar chart comparing the voltage generated by the 2-bladed, 3-bladed, and 4-bladed Savonius wind turbines. This bar chart served as a visual representation of the electricity generation performance across the various rotor configurations. The experimental set-up is shown in fig. 3.

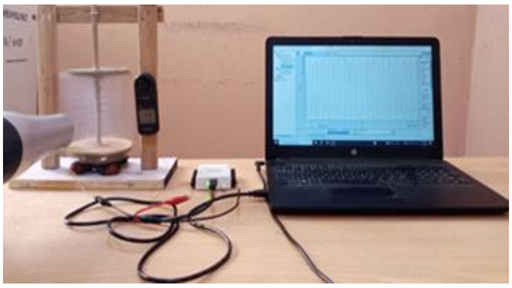

Fig. 3: Experimental Set-up

- **CALCULATIONS**

The available power in the wind (PA):

$$PA = \frac{1}{2} * \rho * A * U^3 \quad \text{......... (3)}$$

Where: **PA** = Available Power of the wind or the input power in Watts, **ρ** = Air Density (about 1.225 kg/m^3 at sea level), **A** = Swept Area of the Blades (m^2), and **U** = Wind speed.

The swept area for each of the three Savonius rotors used in this experiment is: 0.0072m· Also all the three rotors were tested under the wind speed of 11 m/s. Therefore, the available wind power that can be extracted by each of the three wind turbine rotors throughout the experiment is:

$$\text{Available Power (PA)} = 0.5 * \rho * A * U^3$$

$$= 0.5*1.225*0.0072*11^3$$

$$= 5.87 \text{ Watts.}$$

The coefficient of power (Cp):

$$Cp = \frac{\text{Electrical power (PE)}}{\text{Available power (PA)}} \quad \text{..........(4)}$$

Where:
Cp = the coefficient of power,
PE = the electrical power, and
PA = Available Power of the wind

The electrical power (PE):

$$PE = V^2/R \quad \text{.........................(5)}$$

Where: PE represents the electrical power or the output power in Watts, V is the voltage, and R_L, is the load resistance. However, since the voltage generated by the wind turbine is alternating current (AC), the effective or RMS (Root Mean Square) value of the voltage:

$$\text{RMS value} = \frac{Peak\ voltage}{\sqrt{2}} \quad \text{.............(6)}$$

Therefore, the RMS voltage generated by:

- Two-bladed rotor $= \frac{4.8}{\sqrt{2}}$ = 3.4V
- Three-bladed rotor = $\frac{3.1}{\sqrt{2}}$ = 2.2V
- Four-bladed rotor $= \frac{2.1}{\sqrt{2}}$ = 1.5V

$$\therefore \quad P_E = \frac{Vrms^2}{R}$$

Where: PE = Electrical power,
VRMS = Root Mean Square Voltage,
R = the load resistance

Therefore, the electrical power (PE) generated by:

- Two-bladed rotor $= \frac{3.4^2}{10}$ =1.156 W
- Three-bladed rotor = $\frac{2.2^2}{10}$ = 0.484 W
- Four-bladed rotor $= \frac{1.5^2}{10}$ = 0.225 W

While:

The Coefficient of Power, $Cp = \frac{\text{Electrical power (PE)}}{\text{Available power (PA)}}$

Therefore, the coefficient of power (Cp) for:

- Two-bladed rotor $= \frac{1.156}{5.87}$ = 0.1969
- Three-bladed rotor $= \frac{0.484}{5.87}$ = 0.0825
- Four-bladed rotor $= \frac{0.225}{5.87}$ = 0.0383

The wind turbine's performance can be evaluated by examining the tip speed ratio (TSR), which is determined by the ratio of the rotor's end velocity to the wind velocity. This ratio is crucial in determining the power coefficient and the overall efficiency of the rotor or turbine system [9].

$$\text{The tip speed ratio } (\lambda) = \frac{\pi DN}{60U} \quad \text{.............. (7)}$$

Where:

N, is the revolution per minute (rpm), D is the diameter of the rotor, λ is the tip speed ratio (TSR), and U, is the wind speed.

The RPM was measured using a FERVI C070-Contact and Optical Digital Tachometer where 106.27 RPM, 70.58 RPM, and 49.75 RPM were obtained for the 2, 3, and 4-bladed rotors respectively.

Therefore, the λ or tip speed ratio (TSR) for:

$$\text{2-bladed rotor} = \frac{3.142*0.12*106.27}{60*11} = 0.06$$

$$\text{3-bladed rotor} = \frac{3.142*0.12*70.58}{60*11} = 0.04$$

$$\text{4-bladed rotor} = \frac{3.142*0.12*49.75}{60*11} = 0.03$$

The efficiency of the wind turbine can be calculated using the following formula:

$$\eta = \frac{PE}{PA} *100\% \qquad (8)[10]$$

Therefore,

$$\eta_1 \text{ (for 2-bladed rotor)} = \frac{1.156}{5.87} *100\% = 19.7\%$$

$$\eta_2 \text{ (for 3-bladed rotor)} = \frac{0.484}{5.87} *100\% = 8.2\%$$

$$\eta_3 \text{(for 4-bladed rotor)} = \frac{0.225}{5.87} *100\% = 3.8\%$$

D. Abbreviations and Acronyms

- Ar: Aspect ratio
- As: Swept area
- Cp: Coefficient of power
- PA: Available power
- PE: Electrical Power
- R_L: Load resistor
- RMS: Root mean square
- Ꝓ = Air density
- Ƞ= Efficiency
- U = Wind speed
- V= Voltage
- λ = Tip speed ratio

III. RESULTS AND DISCUSSION

The experimental investigation aimed to examine the effects of rotor blades number on the electricity generation of the Savconius wind turbines. Three different configurations of Savonius rotors were constructed, each having a different number of blades (2, 3, and 4). The rotors were designed with the same aspect ratio and swept area, and they were subjected to a constant wind speed of 11 m/s. Figure 4 displays the amplitude voltage of 4.8V AC when a two-bladed rotor was used. In contrast, figure 5 illustrates an amplitude voltage of 3.1V AC when a three-bladed rotor was tested. Furthermore, figure 6 shows an amplitude voltage of 2.1V AC when a four-bladed rotor was used during the experimental investigation. Additionally, figure 7 provides a comparison of the output voltages generated by two, three, and four-bladed Savonius wind turbines. The results indicate that the two-bladed Savonius wind turbine generated the highest amplitude voltage of 4.8V AC. Moreover, figure 8 showcases the coefficient of power versus tip speed ratio for the Savonius wind turbine rotors. It reveals that the two- bladed rotor exhibited the highest coefficient of power at 0.19 as well as the highest tip speed ratio at 0.06. This was followed by the three-bladed rotor with a coefficient of power at 0.08 and a tip speed ratio of 0.04. Subsequently, the four-bladed Savonius rotor had a coefficient of power of 0.04 and a tip speed ratio of 0.03. Furthermore, figure 9 presents a bar chart illustrating the efficiencies of the three Savonius rotors tested at a wind speed of 11 m/s. The results indicate that the two-bladed rotor achieved the highest efficiency of 19.7%, compared to the three-bladed rotor, which had 8.2%, and four-bladed rotor, which had 3.8%. This result suggest that the two-bladed design is more efficient in harnessing wind energy and converting it into electrical energy.

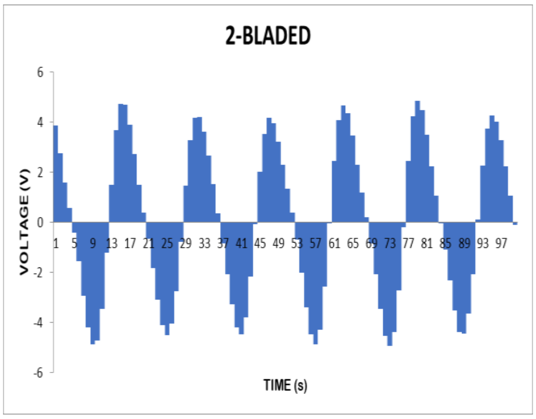

Fig. 4: The Output Voltage of a Two-Bladed Savonius Rotor at a Wind Speed of 11 m/s

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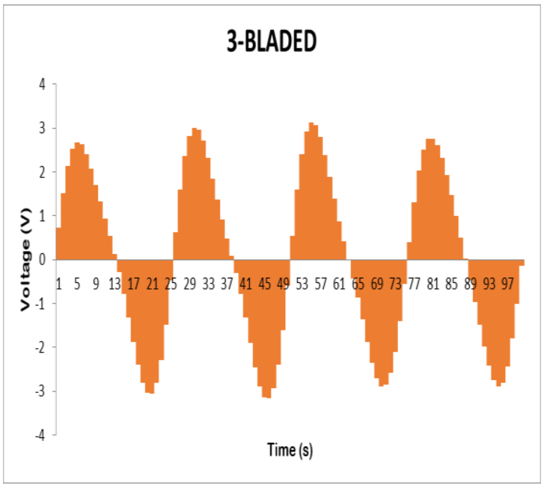

Fig. 5: The Output Voltage of a Three-Bladed Savonius Rotor at 11 m/s

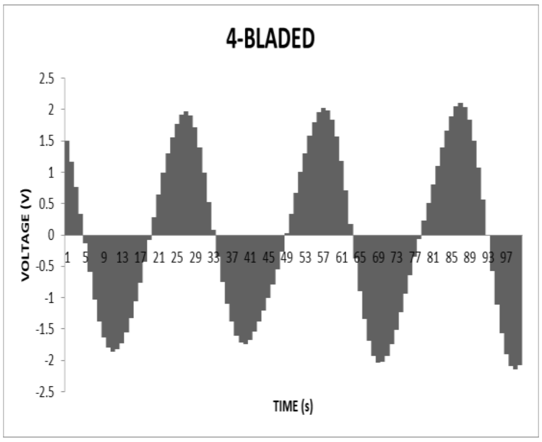

Fig. 6: The Output Voltage of a Four-Bladed Savonius Rotor at a Wind Speed of 11 m/s

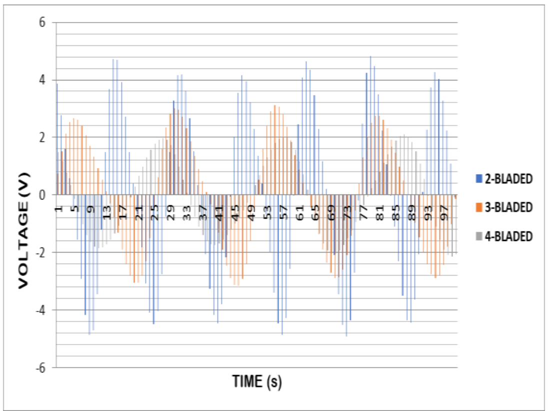

Fig. 7: Comparison of Output Voltages for Two-Bladed, Three-Bladed, and Four-Bladed Savonius Rotors at a Wind Speed of 11 m/s

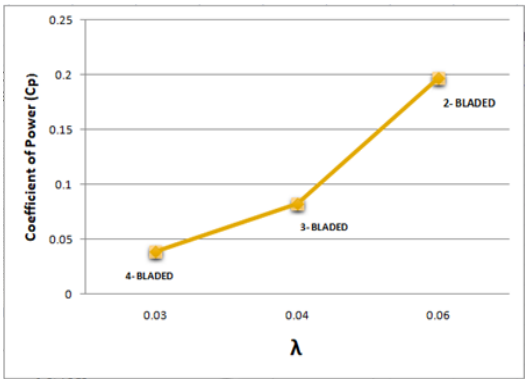

Fig.8: Coefficient of Power Vs Tip Speed Ratio for Savonius Wind Turbine Rotors

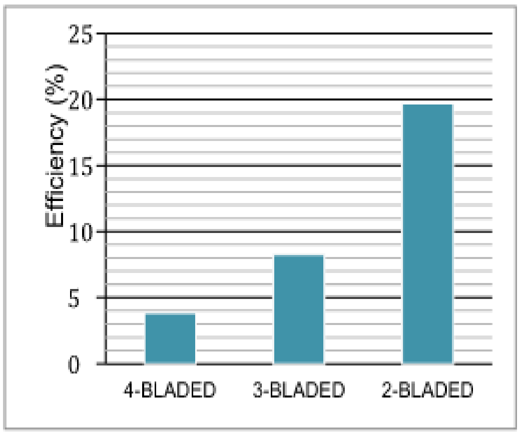

Fig. 9: Efficiencies for the 4, 3, and 2 Bladed Savonius Wind Turbine Rotors, all at a Wind Speed of 11m/s

IV. CONCLUSION

In conclusion, this experimental investigation examined how the number of rotor blades impacts the electricity generation of a Savonius wind turbine. The study involved constructing and testing Savonius rotors with 2, 3, and 4 blades, which all had identical aspect ratios and swept areas. The tests were carried out under a consistent wind speed of 11 m/s, and the performance of the rotors was assessed by measuring various parameters such as voltages, output power, coefficient of power, tip speed ratio, and efficiency. The findings revealed that the 2-bladed Savonius rotor outperformed its 3 and 4-bladed counterparts in terms of electricity generation. Specifically, the 2-bladed rotor produced an output voltage of 4.8VAC, an output power of 1.156W, a coefficient of power of 0.197, had a tip speed ratio of 0.06, and an efficiency of approximately 20%. These results support existing literature [4, 5, 6] that suggests 2-bladed Savonius rotors exhibit superior performance compared to rotors with a higher number of blades. Additionally, the research findings aligned with a statement made by [7], which asserts an inverse relationship between the number of blades and the tip speed ratio. Based on these outcomes, it can be concluded that increasing the number of blades in a Savonius rotor leads to a decrease in wind turbine efficiency. This reduction in efficiency can be attributed to the obstruction of wind flow caused by the additional blades. Therefore, for optimal electricity generation in Savonius wind turbines, a design with fewer blades, like a 2-bladed rotor, is recommended. This study enhances our understanding of how the number of rotor blades influences the performance of Savonius wind turbines, emphasizing the importance of considering blade configuration in wind turbine design. Further research in this field could explore other factors that may affect the performance of Savonius wind turbines and investigate strategies to enhance their efficiency.

ACKNOWLEDGMENT

We sincerely appreciate the management of Hussaini Adamu Federal Polytechnic Kazaure for recommending our research project to Tertiary Education Trust Fund (TETFUND). Their support and endorsement played a crucial role in securing funding for our research. Furthermore, we are immensely grateful to TETFUND for funding this research. Their funding has greatly contributed to the procurement of necessary equipment, materials, and resources required for the experimental investigations. We deeply appreciate their commitment to promoting and advancing academic research and development within the educational sector. Lastly, we would like to express our sincere appreciation to all individuals who directly or indirectly contributed to the successful completion of this research.

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