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Savonius Wind Turbine Performances on Wind Concentrator

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ABSTRACT

The air streams from the outlet of an air compressor can be used to generate electricity. For instance, if a micro-sized Vertical-Axis Wind-Turbine (VAWT) is installed towards the airflow, some amount of electricity can be generated before being stored in a battery bank. The research's objectives are to design, fabricate and analyze the performance of Helical Savonius VAWT blade rotors, which is tested with and without using a wind concentrator. The Helical Savonius VAWT is tested at 0 cm without the concentrator, whereas the blade rotor is tested at concave-blade position when using the concentrator. The blade and the wind concentrator designs were based on the dimensions and the constant airflow of the air compressor. The findings suggested that the blade produced its best performance when tested using wind concentrator at concave-blade position in terms of angular speed (ω), tip speed ratio (TSR) and the generated electrical power (P_E). The findings concluded that the addition of wind concentrator increases the airflow which then provided better performances on the blades.

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1. INTRODUCTION

Since the potential of wind energy in Malaysia is low, the most suitable type of wind turbine is used is the VAWT. Despite it's ability to produce only low power efficiency, there are various ways to amend the power coefficient in VAWT. One of them is by showing the ideal construction or by selecting the optimal number of the rotor blades. Furthermore, installing a wind concentrator to the VAWT will cancel the negative moments which affecting the rotational movements of the rotor and increases the speed of the air at the entrance of the rotor. Therefore, it will resulted in improving the VAWT's power coefficient [1].

Wind concentrator is one of the designs that can compresses wind on a low velocity, and improve the wind velocity eventually as the wind passes through the concentrator. As the speed of winds in Malaysia is quite low, the idea of designing a wind concentrator may improve the speed of wind and increases the performance of the wind turbine as the wind flow across the rotor blade. This study will be using VAWT as it is suitable for low wind speed condition and the sensitivity to the changes of the direction of the wind or velocity is high [2].

Hence, the use of wind concentrator in this study to increase the performance of VAWT is important. Besides, designing small scale wind concentrator is convenient for personal usage to reduce the electricity costs as it helps on generating power supply to the small appliances in the household.

1.1. Type of performances on wind turbine

S. Mathew [1] stated that the energy available in the wind is basically the kinetic energy of heavy masses of air going over the earth's surface. When considering the kinetic energy of air stream available in the wind turbine, the expression of energy per unit time which representing the theoretical power (P_T) and the actual power or known as electrical power (P_E) can be expressed as:

$$P_T = \frac{1}{2}\rho_a A_R v^3 \quad (1)$$

$$P_E = VI \quad (2)$$

where ρ_a is the density of air and A_R is the cross-sectional area of the rotor. Meanwhile, V and I are voltage and current generated by the motor. Based on Equation 2, the factors which influenced the power available in the total wind flow are the air density, cross-sectional area of wind turbine's rotor and air velocity (v).

However, when a wind stream passes through a wind turbine, the turbine cannot fully extract the wind power completely as some parts of its kinetic energy are being transferred to the rotor and the air that leaves the turbine carries all the remainders aside. The actual power produced by a rotor can be decided by the efficiency or usually known as the power coefficient (C_P). Thus,

$$C_P = \frac{2P_T}{\rho_a A v^3} \quad (3)$$

When using the Betz equation, M. Ragheb and A. M. Ragheb [2] stated that the highest power coefficient produced by a wind turbine is 0.593. But after taken into account some other details such as the frictional losses, blade surface roughness and mechanical deficiencies under practical condition, the power that can be extracted is approximately 35% to 45%. Meanwhile, H. A. Yanto et al. [3] and W. S. Widodo et al. [4] found out that the optimum power coefficient under practical condition is 0.3.

The tip speed ratio (*TSR*) is the ratio of the velocity of the rotor tip to the wind velocity. It can be expressed as

$$TSR = \frac{\omega R_R}{v} \quad (4)$$

where ω is the speed of blade rotor in radius and R_R is the radius of the rotor.

1.2. Savonius VAWT

The conventional wind turbine is often used by researchers to complete their studies. However, some researchers had introduced a Helical-shape blade Savonius wind rotor and done some studies on its performances. It has many advantages over others as the constructions are simpler, cheaper, independent of the wind direction and has a good starting torque at lower wind speeds with positive coefficient of static torque [5],[6]. Z. Zhao et al. [7] and A. Damak et al. [8] stated that the performance in terms of C_P using Helical-bladed Savonius compared to Conventional Savonius was improved from C_P = 0.15 and C_P = 0.16 respectively, to the same value of maximum C_P = 0.20. There are four types of Helical rotors with different twisted angles as shown in Figure 1. The twist angles are 90°, 180°, 270° and 360° respectively.

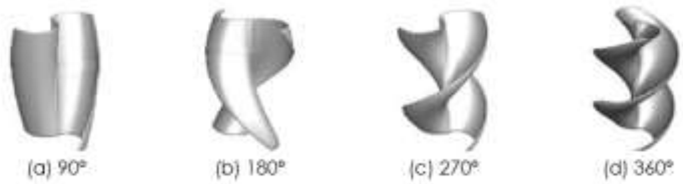


Figure 1. The four types of Helical rotor with different twisted angles [7]

From [7]-[8] findings, they mentioned that, the highest performance was achieved by the Helical rotor with the angle of 180° and with this configuration, the rotor has some downwind surface parts that exposed to the wind at any rotational angles. It also produces a continuous positive torque which gives better performance than the Helical rotor with other twist angles.

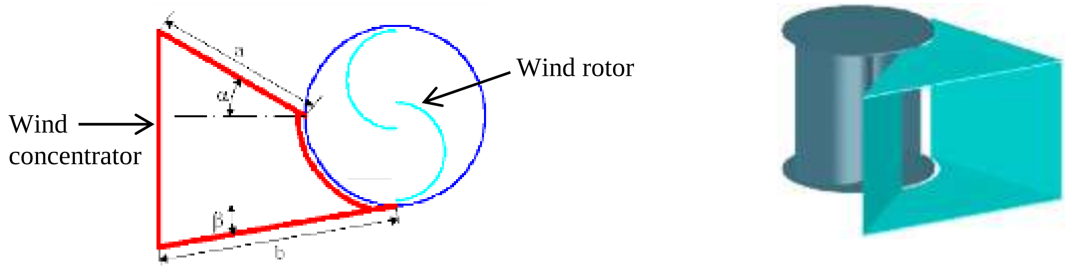
1.3. Number of Rotor Blades

The number of blades of the rotor should be minimized to two blades only. M. H. Ali [9] and A. Kadam and K. Patil [10] found that the two-bladed Savonius wind turbine is more efficient and has a higher power coefficient compared to a three-bladed Savonius wind turbine under the same test condition. It is because as the number of blades increases, it will also increase the drag on the surfaces when the wind flows around them. This will cause the reverse torque to increase and causing the net torque working on the blades of Savonius wind turbine to decrease. The evidence of using two blades was also supported by [7]. When *TSR* = 0.8, the C_P for two-bladed rotor is 0.165 while three-bladed rotor is 0.12. It has proved that if the number of blades was increased from two to three, the power coefficient of the wind turbine rotor will decreases.

1.4. Wind Concentrator

Rus L. F. [11] had designed a concentrator nozzle to the Savonius rotor in order to increase the inlet's of air stream velocity to the rotor which is shown in Figure 2. In his research findings, he also claimed that installing a wind concentrator to the wind turbine may increase the efficiency of the turbine about 10% to 20% when using a single-stage rotor with the dimensions of α = 45º and β = 15º. As the concentrator nozzle is focused on the direct airflow which only overs the concave blade, the advantages of using this design are as follows [8],[11]:

a. The negative moment produced by the action of the wind on the convex part will be cancelled out.
b. It offers the possibility of increasing the movement and efficiency of the rotor.



(a) Top view (b) Side vie

Figure 2. The design of wind concentrator [11]

A study conducted by J. A. Orasa et al. [12] had introduced a design of a subsonic nozzle in order to produce a constant pressure drop and considering moist air as principal fluid. This convergent nozzle has almost similar functions with the ones as in Rus L.F. [11]'s study. The functions are listed as follows:

a. It amplified the wind's velocity.
b. It prevented negative torque where it can act as a barrier for wind striking on the blade's concave part of the rotor.

The study also claimed that when using a convergent nozzle rotor, the speed can be significantly increased, and so does the power coefficient. Another finding from the study also stated that the conservation of energy in a nozzle can be termed as Bernoulli's equation as shown in Equation 5 where it can be defined that the sum of all forms of wind flows are same at the same point; however, this requires the sum of kinetic energy and potential energy to be kept constant. Based on this equation, v_1 can be considered as the inlet velocity of the wind concentrator while v_2 is the outlet velocity of the wind concentrator.

$$\rho_{a1} A_1 v_1 = \rho_{a2} A_2 v_2 \tag{5}$$

2. EXPERIMENTAL

In this study, Helical Savonius VAWT was designed in order to determine the performances of the rotor blade; which includes the generated electrical power (P_E), angular speed (ω) and tip speed ratio (*TSR*). To fulfil the objectives of this study, there are some alternative ways to produce a better performance for VAWT. Using a wind concentrator had already been proposed where it will allow a better wind energy flow to the blade in order to get a better performance of VAWT. Instead of using wind as the only source of air stream, the additional source of air came from the air compressor of an air-conditioning system which can also becomes a great asset to be utilized. Therefore, the performances of Helical Savonius VAWT with and without using the wind concentrator can be investigated. The real hardware was fostered by referring to the proposed design and analysis of Helical Savonius VAWT blade rotor including the design of the wind concentrator.

2.1. Helical Savonius VAWT Blade Rotor Design

Some parameters considered during designing the Helical Savonius VAWT blade rotor as shown in Figure 3 were based on the lowest power rating among Light-emitting Diode (LED) which is from yellow or red-coloured LED. The maximum power rating is 44 mW where the voltage is between 1.8 V to 2.2 V and the current is at 20 mA by considering the optimum C_P which equals to 0.3 [3],[4] and the optimum aspect ratio ($\frac{Height\ of\ Rotor\ (H_R)}{Diameter\ of\ Rotor (D_R)}$) for micro-wind turbine is equals to 2 [4],[13]. Polylatic acid (PLA) plastic was chosen as the material for the fabrication of the blade rotors. It was fabricated by using a three-dimensional (3D) printing machine. PLA plastics are environmental friendly material, producing no harmful fumes and less time needed during the 3D printing processes.

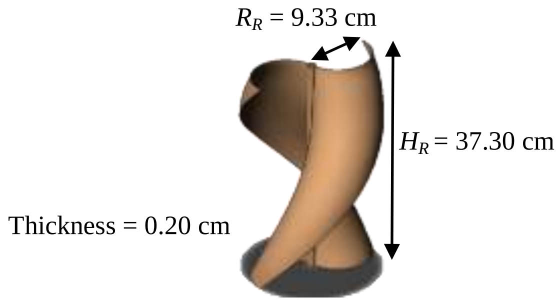


Figure 3. Design of Helical Savonius VAWT blade rotor

2.2. Wind Concentrator Design

Some parameters considered during designing the wind concentrator as shown in Figure 4 were based on the outlet dimensions of the air compressor and the HR and RR of the blade rotor design. The design of the wind concentrator in Figure 2 previously had to be improvised for the purpose of this study by also considering the Bernoulli's Equation (5) where the velocity of air can be increased when flowing through from a large to smaller area with a constant air density. The chosen material for fabricating the wind concentrator was aluminium because of its suitable material properties. Aluminium is light in weight, corrosion resistance, have good rigidity, a recyclable material, easy to construct and low in cost [9].

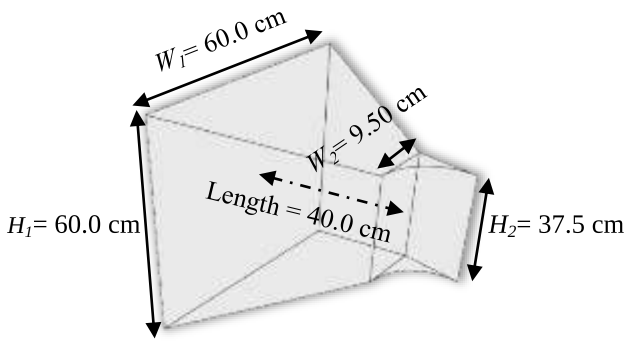


Figure 4. Wind concentrator design's dimension

3. RESULTS AND ANALYSIS

3.1. Comparisons of Wind Speed at Different Positions

The wind speeds produced by the air compressor were being measured at some different positions and the results were tabulated in Table 1. The blade rotor was not being used when determining the values of the wind speeds. Based on Table 1, the addition of the wind concentrator had caused the wind speed to increase approximately 10.41% from 0.932 m/s to 1.029 m/s compared to the wind speed produced without using the wind concentrator at 0 cm.

Table 1. Results of the wind speeds at different positions

Type of testing / No. of measurement	Without wind concentrator at 0 cm distance	With wind concentrator
1	0.64	0.93
2	1.16	1.04
3	1.24	1.35
4	1.04	1.26
5	0.58	1.37
6	0.60	0.84
7	1.51	0.91
8	0.87	0.84
9	0.76	0.85
10	0.92	0.90
Average	0.932	1.029

3.2. Comparisons of Helical Savonius VAWT On Different Types Of Testing

The data collected during some the tests conducted on Helical Savonius VAWT were the measurements of voltage, current and rotational speed (*RPM*). Figure 5 (a) shows the whole fabricated Helical Savonius VAWT without the addition of the wind concentrator, whereas Figure 5 (b) shows the fabricated Helical Savonius VAWT tested with the addition of the wind concentrator.

(a) Without wind concentrator

(b) With wind concentrator

Figure 5. Types of testing conducted on Helical Savonius VAWT

The bar chart diagram on the comparison of output power (P_E) and performances produced by the Helical Savonius VAWT in terms of ω and *TSR* are shown in Figure 5 and 6 respectively. Based on Figure 6, the output power or P_E can be calculated by using the formula in Equation 1.2. The highest P_E generated by the Helical Savonius VAWT was 4.187 mW at the highest wind speed when being tested with the wind concentrator at concave-blade position. *V* and *I* generated by the highest electrical power were 0.153 V and 27.400 mA correspondingly. Meanwhile, the lowest electrical power generated was 3.042 mW when being tested without the wind concentrator at 0 cm distance at the lowest wind speed. *V* and *I* generated by the lowest electrical power were 0.121 V and 25.100 mA.

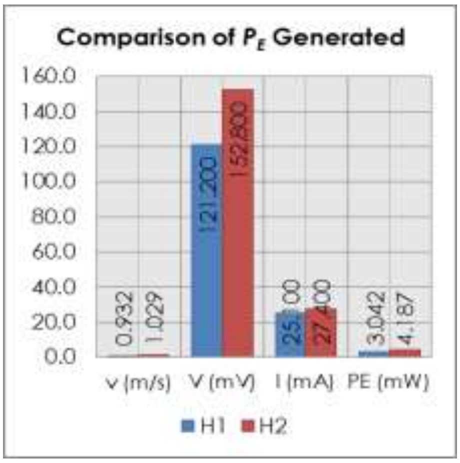


Figure 6. Bar chart on the comparisons of P_E generated on Helical Savonius at different types of testing

The TSR was calculated by using Equation 4. The lowest ω achieved based on Figure 7 was from the lowest v where it had produced *TSR* at 4.009. Since v was higher when being tested by using the wind concentrator, *ω* produced was the highest when it was tested at concave-blade position and the *TSR* was 6.168.

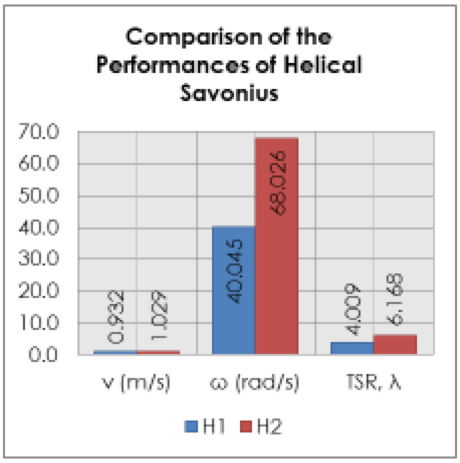


Figure 7. Bar chart on the comparisons of performances on the Helical Savonius in terms of *ω* and *TSR* at different types of testing

4. CONCLUSION

In conclusion, the objective of this study to design and fabricate the Helical Savonius VAWT blade rotor and a wind concentrator were achieved. The studies on performances of Helical Savonius VAWT with and without using a wind concentrator in terms of ω, TSR and generated P_E were successfully determined. This study comprised of two (2) types of tests on the Helical Savonius VAWT rotor which were conducted without using the wind concentrator at 0 cm and using the wind concentrator at concave-blade position. As the wind concentrator was installed in front of the air compressor, the wind speed amplified about 10.41% which were from 0.932 m/s to 1.029 m/s. The best performance was achieved when testing the Helical Savonius VAWT using the wind concentrator at the concave-blade position. The highest angular speed produced was up to 68.026 rad/s. As the angular speed produced after using the wind concentrator was higher compared to without using wind concentrator, it resulted in producing TSR = 6.168 at a higher level. From the researches conducted, it can be concluded that the existence of wind concentrator was able to increase the wind speed. Hence, increasing wind speeds will influence the performances of Helical Savonius VAWT blade rotor. In order to make some improvement on the performances of the Savonius VAWT, the recommended action that could be done is the materials used to fabricate the blade rotor should be from lighter and more durable. So, it is able to withstand any high pressure caused by the wind for some period of time.

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