Performance of a Small-sized Savonious Blade with Wind Concentrator

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Article Info	ABSTRACT
	This paper presents the performance of a fabricated small-sized Savonious wind turbine with two blades. The design of Savonius vertical axis wind turbine (VAWT) was based on Malaysia wind speed condition. Meanwhile, the design of wind concentrator was based on the dimensions and the constant airflow of an air compressor. From the experimental testing in a laboratory, it was found that the proposed Savonious turbine has best performance when tested using wind concentrator. To conclude, airflow from air compressor can be increased when the proposed wind concentrator is used and hence increasing the proposed VAWT performance in terms of its angular speed (ω), tip speed ratio (TSR) and the generated electrical power (PE).

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1. INTRODUCTION

Energy has always been the most important asset for the economy and social growth development of a country. It is no longer viewed as affluence as it used to be but it has become a compulsion in our everyday life. As in Malaysia, the dominant source of energy is still very much sustained by fossil fuels for the past 100 years. It is also caused by the absentees of suitable replacement for the fossil fuels as the main source of energy which can fulfil the consumer's energy requirement for the usage of electricity. According to the current rising trends of fuel prices, especially the crude oil price in the world market, somehow it affected the price of consumer's total electricity bills where it becomes one of the burdens they needed to bear in terms of living cost nowadays. The Malaysian Government comprehended the potentials of some renewable energy resources such as hydro, wind, solar, geothermal and tidal wave where most of these renewable energies are not fully utilized as an option to ensure the sustainability of energy resources [1]. Between all those available renewable energy, the chosen green energy that has the potential to be developed in coming years in Malaysia is solar and biomass energy. For tidal and wind, they are less popular. This is due to the problem of their potential resources. Nowadays, the air-conditioner system already been built in many buildings either in workplace or residential. The air streams that flow out from the air-compressor which is one of part of air-conditioner system is quite constant, as long as it is operated. The air flow from this air-conditioner system will be spreaded to the open air freely. Hence, it will be useful to be benefitted if it could be used as the energy source for a wind turbine. However, the air velocity from the air compressor is low where the range of air velocity is between 0.58 m/s to 1.37 m/s. Thus, it is very signifant to find a way on how to increase the air velocity from the air-compressor such as using wind concentrator [2] besides designing and developing a

suitable wind turbine for this application. For low wind resources, it is common to use Savonious vertical axis wind turbine (VAWT). Savonious VAWT is generally not a self-starting wind turbine and has low power coefficient. In static condition, Savonious VAWT requires additional mechanism to allow the rotor to rotate before starting the turbine [3], [4]. It is therefore, appropriate Savonious VAWT system must be designed carefully for such air-compressor.

2.   RESEARCH METHOD
In this section, the method for the Savonious VAWT and the wind concentrator designs will be explained briefly. Both components have their own sgnificance in producing good wind turbine.

2.1. Wind Concentrator Design
Before designing the blade, the suitable unit of air-conditioner compressor and its dimension should be determined and measured. After executing some survey in UTM's area, we decided to select an aircompressor that had been installed at P16, FKE as the energy source. The outlet dimension of the aircompressor is equal to the dimensions of the inlet of the wind concentrator; height (H1) and width (W2). To increase the inlet's of air stream velocity to the rotor, concentrator nozzle was considered as shown in Figure 1. By installing a wind concentrator to the wind turbine, it may increase the efficiency of the turbine about 10% to 20% when using a single-stage rotor with the dimensions of α=45° and β=15°. 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 [5], [6]; negative moment produced by the action of the wind on the convex part will be cancelled out and it offers the possibility of increasing the movement and efficiency of the rotor.
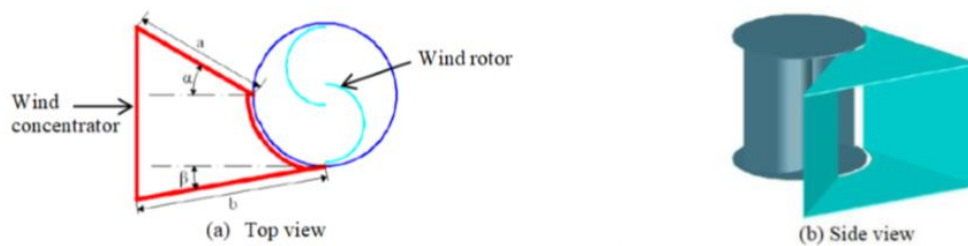

Figure 1. The design of wind concentrator [6]

Study in [7] 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 [6]. The functions are listed as follows; it amplified the wind's velocity and 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 1 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.

$$\rho_{a1}A_1v_1 = \rho_{a2}A_2v_2 \tag{1}$$

Some parameters considered during designing the wind concentrator as shown in Figure 2 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 had to be improvised for the purpose of this study by also considering the Bernoulli's equation 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 [8].
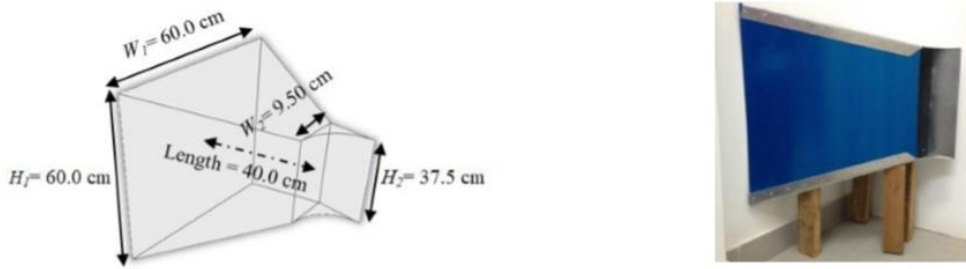
Figure 2. Wind concentrator design's dimension (left: schematic, right: built)

2.2. Savonious VAWT Design

In [8], [9], they mentioned that two-bladed Savonius VAWT is more efficient and has a higher power coefficient compared to a three-bladed Savonius VAWT 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 [10], [11]. When tip speed ratio (TSR)=0.8, the power coefficient (Cp) 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.Hence, in this study, the number of blades of the rotor was minimized to two blades only.

To determine the radius and height of the Savonious blade, we need to refer again the dimension of the wind concentrator that has been explained previously. By relating such dimension and also the predicted output, the radius is determined first by using equation (2) [12], [13], where P_m is mechanical power, ρ is air density, C_p is power coefficient and U is wind speed. Finally, the design for Savonious VAWT is as shown in Figure 3.
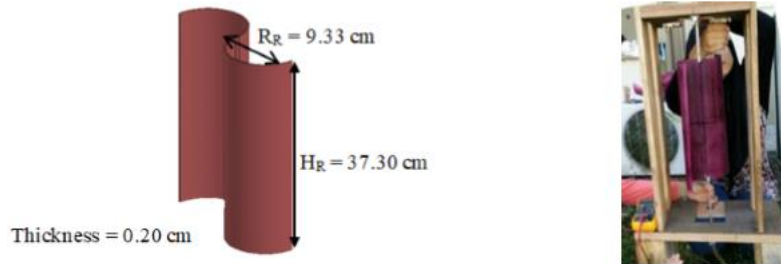
$$P_m = 0.5\rho R^2 C_p U^3 \qquad\qquad (2)$$

Figure 3. Dimension of the proposed Savonius blade with two blades

Polylatic acid (PLA) plastic was chosen as the material for developing the blade rotors. It was produced by using the three-dimensional (3D) printing machine. PLA plastics are environmental friendly material, produce no harmful fumes and less time needed during 3D printing processes were conducted.

2.3. Experimental Testing

The experimental testings that have been done in the laboratory are as follows:
a. Wind speed measurement at different positions; at 0 and 30 cm in distance
b. Wind speed measurement with and without wind concentrator
c. Rotational speed, current and voltage measurement based on condition in (1) and (2) above.

3. RESULTS AND ANALYSIS

In this section, the results of the concentrated wind speed when wind concentrator is used will be given. Besides, the results of the turbine speed rotation, generated current, generated voltage and the generated power also will be demonstrated when the proposed Savonious VAWT is tested at centered-blade position and the concave-blade postion, with existence of wind concentrator.

3.1. Wind Speed Concentration

Table 1 shows the results of the measured wind airflow from the air compressor when tested without and with wind concentrator.

Table 1. Results of the Wind Speeds at Different Positions

No of measurement	Without wind concentrator		Witht wind concentrator
	0 cm	30 cm	
1	0.64	0.86	0.93
2	1.16	0.78	1.04
3	1.24	0.68	1.35
4	1.04	0.58	1.26
5	0.58	0.56	1.37
6	0.6	0.8	0.84
7	1.51	0.76	0.91
8	0.87	0.67	0.84
9	0.76	0.74	0.85
10	0.92	0.66	0.9
Average	0.932	0.71	1.029

For the testing without wind concentrator, results are given when the reading is measured at 0 cm distance and 30 cm distance. From the table, it can be summarised that wind speed measured at 0 cm from the air compressor has higher wind speed compared to 30 cm in distance. Wind speed is reduced by 23.8% with 30cm distance. However, when the proposed wind concentrator is used, the wind speed can be concentrated more where the speed can be increased up to 10.41%.

The condition of the Savonious VAWT that adjusted at 0 cm and 30 cm distanceis depicted in Figure 4(a) and (b), respectively. Whereas, the condition of Savonious VAWT when positioned at concaveblade and center-blade when wind concentrator is used can be depicted in Figure 4(c) and (d), respectively.

(a) Without concentrator (0 cm distance)　(b) Without concentrator (30 cm distance)　(c) With concentrator (Concave-blade)　(d) With concentrator (Center-blade)

Figure 4. Condition of proposed Savonious VAWT

3.2. Proposed Output of the Proposed Savonius HAWT and Wind Concentrator

Figure 5 depicts the result of the blade speed in rad/s. At 0 distance, blade can rotate faster than blade positioned at 30 cm distance from the front end of the air compressor filter. Blade can rotate up to 89.347 rad/s without wind concentrator under this condition. With wind concentrator, at concave-blade position, turbine can speed faster (111.108 rad/s), leads 11.5% from the VAWT at center-blade position. This is relevant due to the reason of the concentrated wind speed when wind concentrator is used and also due to the larger exposed of the blade area when proposed VAWT is position at concave-blade.
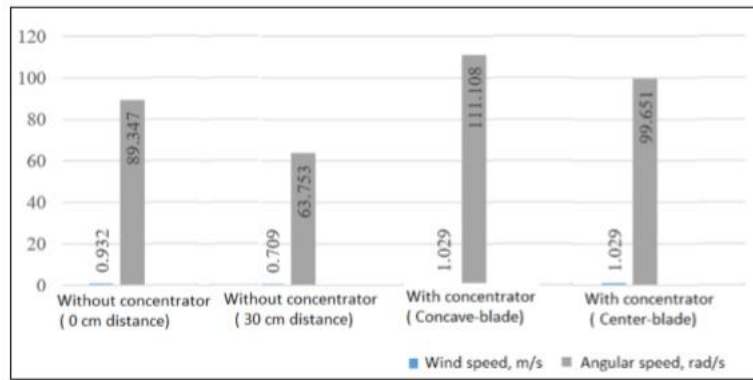
Figure 5. Blade rotation

Figure 6 shows the generated voltage, current and electrical power of the proposed VAWT system when tested with and without wind concentrator. From the figure, it can be seen that with proposed wind concentrator, proposed Savonious VAWT can produce current, voltage and electrical power around 152.8 mA, 27.4 mV and 4.187 mW, respectively. This data can be obtained when the turbine is positioned at the concave-blade. At center-blade position with wind concentrator, current, voltage and the electrical power can be produced in similar patterns. However, at such center-blade position, the generated output is lessening. At concave-blade position, current can be increased 9.6% compared to center-blade position. Meanwhile, voltage looks slightly smaller when turbine is positioned at concave-blade, compared to center-blade postion. However, in terms of generated power, it can be seen that with wind concentrator, energy can be generated more (4.187 mW) at concave-balde position. This is due to larger blade area can capture the concentrated wind flow from the air compressor at concave-blade position. In addition, wind flow was increased and more concentrated when wind concentrator is used. With generated output of 4.187 mW, only LEDs load can be lighted up. From the obtained results, there are so many rooms for improvement could be done in the near future, in particular in terms of current and voltage control, shafting system, appropriate generator, suitable power converter and etc.
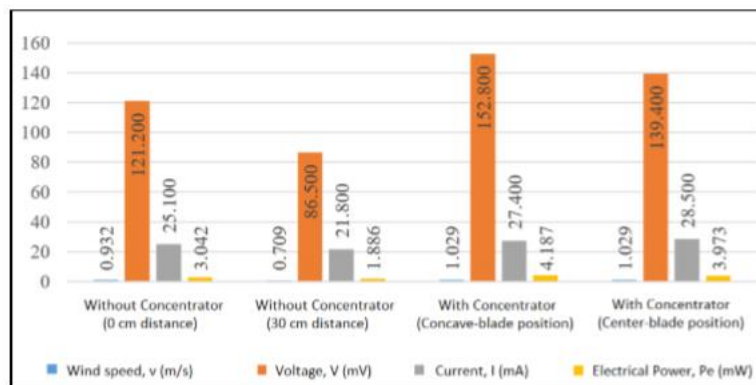

Figure 6. Generated voltage, current and electrical power at different conditions

4. CONCLUSION

In this paper, the approaches on how to design a small-sized Savonious VAWT and an appropriate wind concentrator have been explained briefly. From the experimental tests in the laboratory, it was found that, electrical power can be generated best when the proposed wind concentrator was used. It is also revealed that the proposed design (Savonious VAWT and wind concentrator) works well when tested at concave-blade position, compared to the blade that positioned at center point. At concave-blade position, turbine speed can be rotated up to 111.108 rad/s with TSR at about 10.074.

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