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Experimental Study of Wind Turbine Power Generation Utilizing Discharged Air of Air Conditioner Blower

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Abstract: The world's energy demand has become unbridled in the past years. The increasing demand for conventional energy sources (fossil fuels, nuclear) became under tremendous pressure which is resulting from continuous use of it. This continuous use leads to a scarcity of fossil fuels. This has sparked widespread research in the field of unconventional energy sources such as hydro energy, wind energy and thermal energy. Wind can be used as a renewable energy to generate the electrical energy. In the current study, the wind of the air conditioning exhaust has been utilized as a renewable energy to generate the electrical energy. The wind speed is relatively stable every time, this feature encourages the use of air conditioning exhaust. Different wind speed for three types of air conditioning 1HP, 2HP and 3HP was investigated experimentally. The maximum wind speed with 3 HP was 7.1 m/s and 7.2 m/s with anemometer attached to the blower of air conditioner at distance 24 cm on the left and right of the middle of air conditioner blower, respectively. The wind turbine has the ability to convert the wind energy of blower into electrical energy. The wind turbine, Savonius type L, was connected together with direct current (DC) generator and alternating current (AC) generator and fixed inside the Perspex duct. The Perspex duct was connected to the air conditioning exhaust. It was obtained the AC generator can generate voltage 35 V, current 0.51 A and output power14.28 W with adopting 3 HP capacity air conditioner. While the DC generator can generate 46 V, current 0.32 A and output power 14.72 W with adopting 3 HP capacity air conditioner. The generated electrical energy can be used for operating small devices that is need low amount voltage or to turn on the LED lights.

Keywords: air conditioning exhaust, AC and DC power generators, power generation, Savonius type L wind turbine.

1. Introduction

The economic growth resulting in increased the energy demand around the world. Therefore, research on a kind of energy that is available and less pollution became very important matter to study and discuss, like renewable energy. Compared to fossil energy the renewable energy has many advantages. Currently the world is dependent on various sources for power generation like crude oil, coal and natural gas. The energy crisis represented the main problems of all countries which is resulting from oil depletion (which leads to oil price inflation). Therefore, it is important to evaluate fossil energy use to preserve energy security in the world with looking for other energy sources like renewable energy which can replace fossil energy. Many researchers seek to develop and improve well-known the sources of energy like solar energy and wind energy[1-3]. Due to the need to mitigating the climate change and achieving energy sustainability the wind energy and the other sources of renewable energy, are expected to grow potentially in the coming decades [4]. Wind energy compared to other renewable energy or sustainable energy like geothermal energy, is clean energy, easy to maintain and low cost. While the geothermal energy, for example in Indonesia which has geothermal potential of 28,910 MW, but many constraints as air and water pollution, high cost impede utilizing this renewable energy[5]. Wind can be defined as a natural phenomenon which result from atmosphere heating by the sun, and irregularity of the Earth's surface, rotation Earth [6]. The big masses of air moving on the surface of earth resulting in the available energy of wind. The kinetic energy of wind received by the blades of wind turbine which are converted to mechanical form or electrical form depending on the final using. Many researchers were studied and discussed the air conditioners exhaust wind. These studies focused on the applied wind turbine design specifications[7]. The surrounding conditions have an important factor for selection the type of wind turbine for power generation. Also, choice applicable turbine needs to take into account the blades number of turbine which is affected by the wind speed[8]. The turbine should not be rotate heavy due to wind; therefore, the aerodynamic characteristics should be considered during a turbine [9-10]. The wind energy used for power generation and also can be integrated with other sustainable technology like Solar Chimney (SC) and Reverse Osmosis (RO) system in desalination plants [11]. Al-Ghriybah *et al.*[12] were investigated Savonius rotor wind turbine numerically with different angles of inner blade (180°, 160°, 140°, 120°, and 100°). The numerical results show that the maximum power coefficient (*Cp*) was 0.1885 at when the inner blade of 120° and fixed parallel with rotor tip. After that Al-Ghriybah[13] investigated Savonius rotor wind turbine numerically by varying the blade thickness using ANSYS Flunet software. The improved model shows a 40% performance enhancement in the maximum power coefficient. Ibrahim and Yoshida [14] were investigated the performance of horizontal axis wind turbine over a steep 2D hill experimentally and numerically. The experimental and numerical results explain that that the 2D hill has a great effect on the power coefficient.

Mauro *et al.*[15] were investigated numerically by ANSYS Fluent a ducted Savonius wind turbine to evaluate the effect of the blockage effects on rotor performance. The paper demonstrates the great potentialities offered by the use a Savonius wind turbine in Oscillating Water Column devices. The Savonius rotors appeared to be very suitable for this kind of applications for many reasons, such as these rotors are very simple to build and they are unidirectional respect to the incoming flow. Nimje and Gandhi [16] were designed and developed a wind turbine with small scale to investigate it at high wind speeds. They used bag filter to get clean high velocity exhaust air pass through the duct so as to reduce environmental pollution. They utilized the exhaust air to generate the electrical power. They were evaluated the performance of the wind turbine experimentally and numerically.

Chong *et al.*[17] utilized the advantages of discharged exhaust air of cooling towers in commercial buildings, vertical axis wind turbines (VAWTs) were adopted and fixed above the cooling tower to generate the electricity. Peng *et al.* [18] investigated the power performance of twin VAWTs using CFD simulations by changing their configuration parameters including the airfoil section (NACA), solidity ratio, pitch angle, rotational direction, and turbine spacing. The results show that the C_P values increased by 13% and 8% for the optimal and worst configurations of the twin VAWTs, respectively. The generated electrical power can used for building lighting or other purposes. Méndez and Bicer[19] utilizing new integrated system for the production the electricity and freshwater. The results show that the applied integrated system can produce a total energy efficiency of 52.53% with the water discharge and 52.51% with storing the water.

The current study shows that we can utilize the wasted energy of the discharged air of air conditioner blower for electrical power generation. This study aims to investigate and study the performance of Sivunos L type turbine experimentally with different average inlet velocity through utilizing air conditioning exhaust air with AC and DC power generator. The future work can be improved by adopting and investigating different types of wind turbine and using high speed discharged air sources with modified air ducts to get higher electrical power generation.

2. Research methodology

2.1 Theory of wind turbine

Research in wind turbine design is very important to get high level of efficiency, therefore many researches were conducted in this field. Various shapes of wind turbines were designed and simulated in Simulink to get the suitable design for working conditions [20-23]. Equation (1) represents the generated potential kine48tic energy from the movements of wind.

$$\Delta E_K = \frac{1}{2}mv^2 = \frac{1}{2}\rho A \Delta x v^2 \quad (1)$$

The generated power via the applicable turbine can be written as in equation (2) when $\Delta x = \Delta t$, [23-26]:

$$P = \Delta E / \Delta t \quad (2)$$

The power can be found to the area of (*A*) as in equation (3):

$$P_{wind} = \frac{1}{2}\rho A v^3 \quad (3)$$

The cylinder volume movement in wind speed as shown Figure 1.

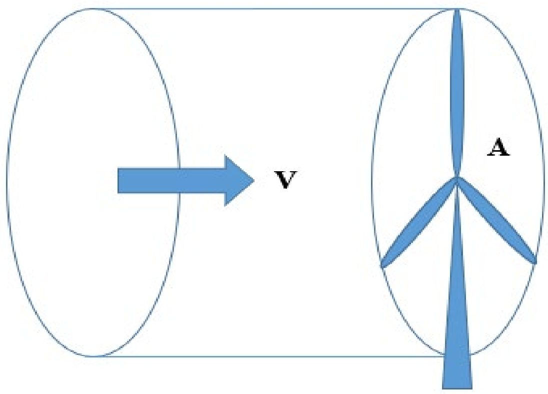

Fig. 1: Cylinder volume movement in wind speed.

The value of wind turbine power coefficient C_P, which is a portion of turbine power resulting from wind sweeping through the turbine, taken from the Albert Betz (German scientist) represents 16/27 or 59.26% and named Betz Limit [27-30]. From this figure it can be estimating theoretically that the wind turbine rotors with horizontal axis can achieved the maximum efficiency. Also, the calculation of the total power written as below:

$$P = C_P P_{wind} = C_P \frac{1}{2}\rho A v^3 \quad (4)$$

The power of turbine effected by various factors such as the ability of turbine to preserve its initial state which is named the turbine moment of inertia, and the other factor is the weight of turbine.

In the current system the turbine still the main part of power generation by converting the mechanical energy to of wind to electrical energy. When choosing a turbine, it should be considering the wind characteristics and the type of turbine because there are vertical and horizontal turbines depending on their position view.

2.2 Design of Experimental Test Rig

The experimental test rig consists from the main parts, outdoor unit (air conditioning blower), wind turbine Savonius type L, duct from Perspex with 1500 mm length and cross section by 500 mm height x 500 mm width, two small AC and DC electric generators and measurements tools (anemometer for velocity measurements, current and voltage measurements). The design specifications of the investigated turbine are: turbine height 300 mm, turbine diameter A: 40 cm, B: 30 cm, C: 14 cm, D: 19 cm and the turbine shaft from iron with a diameter of E: 2 cm connected to the bearing on the on the top and bearing on the bottom.

Also, the investigated turbine has 6 blades made from Aluminum with 2 mm thickness. The ends of blades were inclined with ϴ = 45°. The turbine scheme as shown in Figure 2 and Figure 3.

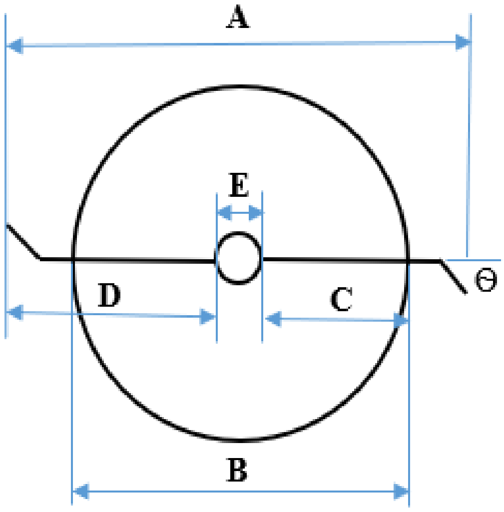

Fig. 2: Schematic diagram of wind turbine from top view.

Fig. 3: Wind turbine - Savonius type L.

The turbine was fixed inside the duct on the upper wall and lower wall of duct via ball bearing and iron pipe. The generator was connected to the rotating turbine through the plastic gears as shown in Figure 4. The duct with the turbine was connected to the air conditioning blower to start rotating turbine and get the readings of velocity and then the output current from generators. The experimental setup of the experimental test rig as shown in Figure 5.

Fig. 4: Perspex duct with Savonius type L wind turbine.

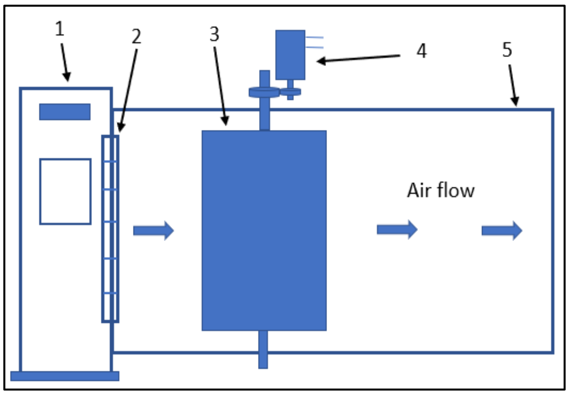

Fig. 5: Experimental setup of the experimental test rig, 1) outdoor unit of air conditioner, 2) air conditioner blower, 3) wind turbine, 4) AC and DC generators, 5) perspex duct.

3. Results and discussion

The experimental results of wind turbine with different average inlet velocities will be present and discusses in this section. The horizontal wind speed and direction of the air conditioner exhaust wind which enters the connected Perspex duct was measured first. The experimental work and measurement were started by measuring the wind speed from the center of blower of air conditioner by 50 mm to the left and 50 mm to the right until distance 250 mm. Also, the measurements were carried out every 50 mm in front of the air conditioning blower to the distance of 400 mm as display in Figure 6.

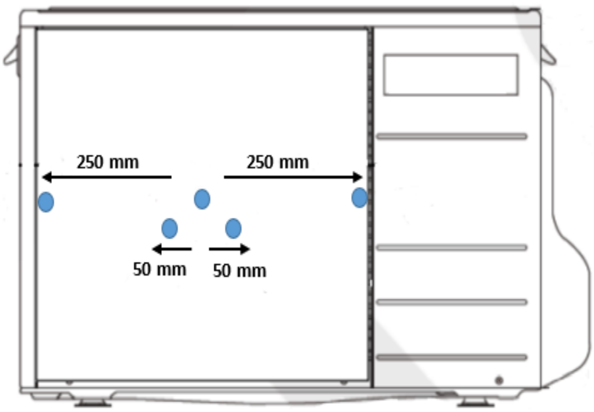

Fig. 6: Air conditioner front view with the locations of anemometer measurements.

3.1 Experimental results

The experimental work and measurements have been done on different power capacity air conditioner 1 HP, 2 HP and 3 HP. Figure 7 shows the photo of experimental test rig, air conditioner, Savonius type L turbine, generator and Perspex duct. The turbine was fixed inside the Perspex duct and the duct was connected to the outdoor unit of air conditioner in front of the blower to turn the wind turbine. After that the output wind speed of the blower was measured and the test is done on the wind turbine.

Fig. 7: Experimental test rig.

The AC and DC generators were connected to the wind turbine to complete the testing with the three types of air conditioners 1 HP, 2 HP and 3HP. Figure 8 shows the measurements of air speed (wind speed), with adopting type 1 of 1 HP power capacity, when the anemometer fixed in front of blower with different distance 0,10, 20, 30, 40 cm. In addition to measurements at points 0, 5, 10, 15, 20, 25 cm from the center of blower to the both right and left side walls of duct. The measurements of air conditioner wind speed show that the high speed was measured when the anemometer attached to the blower at 24 cm distance from the center of air blower on the left and right with 5.1 m/s and 5.3 m/s, respectively. Also, the measurements show that the wind speed values were decreased with increasing the distance of anemometer position from the air blower.

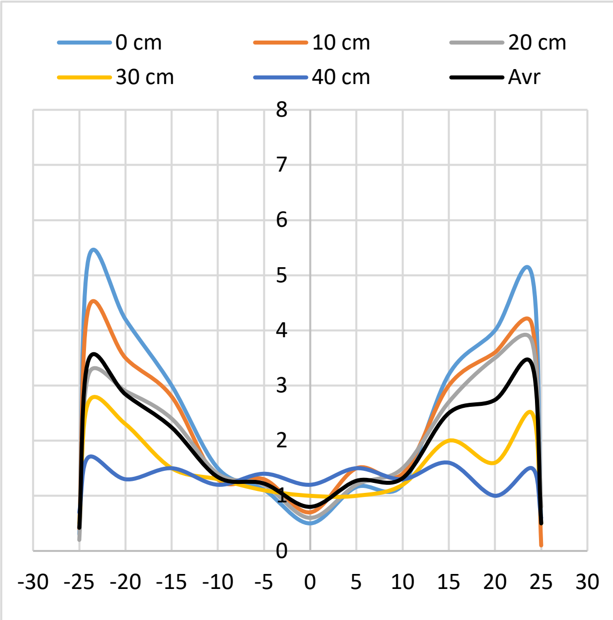

Fig. 8: Wind speed of air conditioner with a capacity of 1 HP.

Figure 9 shows the measurements of air speed for adopting air conditioner type 2 of 2 HP power capacity with a high speed 6.6 m/s and 6.4 m/s on the right and left of blower, respectively, with attached anemometer to the air blower at 24 cm on the right and 24 cm on the left from the center of air conditioner blower. Also, the results show that the wind speed was increased with moving the anemometer from the center of air blower to the side walls of duct, while it was decreased with moving the anemometer far away from the inlet section of the duct. The maximum values of wind speed were 6.6 m/s, 5.4 m/s, 4.1 m/s, 3.2 m/s and 2 m/s at 0 cm, 10 cm, 20 cm, 30 cm and 40 cm, respectively.

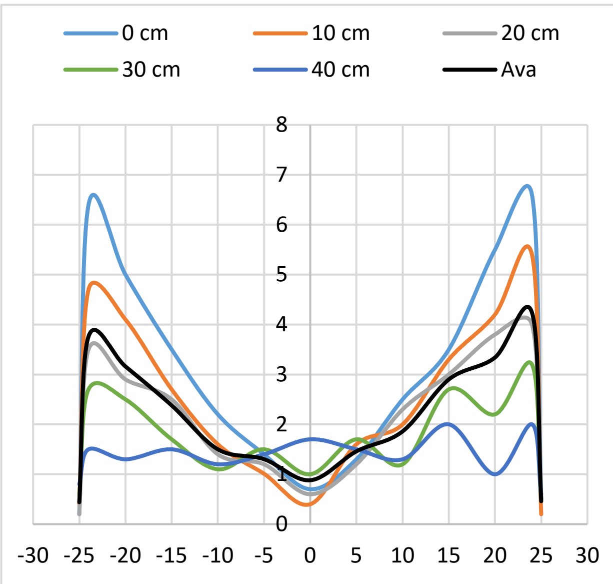

Fig. 9: Wind speed of air conditioner with a capacity of 2 HP.

The high wind speed of 3 HP capacity air conditioner was 7.1 m/s and 7.2 m/s on 24 cm to the left and right on the middle of air blower, respectively, and attached anemometer to the blower as shown in Figure 10. It can be notice that the behavior of wind speed curves in this figure similar to the two previous figures with different values. The wind speed of discharged exhaust air of air conditioner with 3 HP was higher than 1HP and 2HP capacity. The maximum value was 7.2 m/s of 3 HP compared to 6.6 m/s and 5.3 m/s of 1HP and 2HP, respectively.

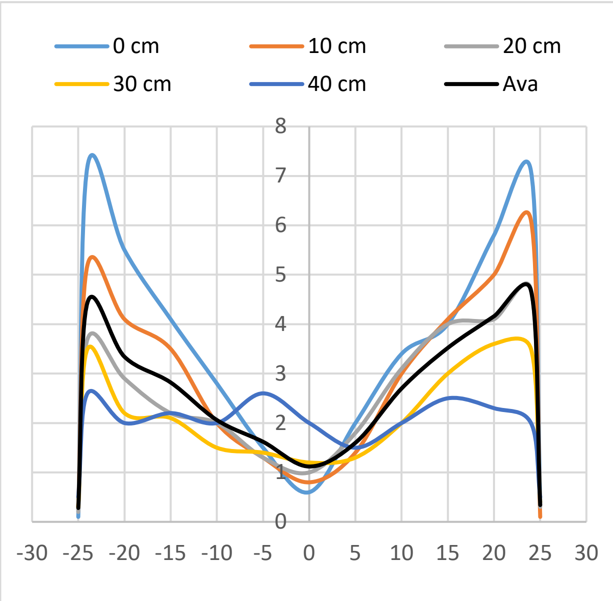

Fig. 10: Wind speed of air conditioner with a capacity of 3 HP.

Also from these figures, it is clear that average high wind speed was on the end of the blower and the average low wind speed is located at the middle of the blower.

All the measurements have been done with steady state of turbine, i.e., with stable rotation of turbine. Figure 11 explain the relation between the output voltage (V) and the output power (W) generated by the AC and DC generators with consumed power (HP) 1 HP, 2HP and 3 HP. It is clear the values of output voltage and output power was increased with increase the consumed power for both AC and DC generators. Figure 12 shows the relation between the output current (A) and the consumed power (HP) of 1HP, 2HP and 3HP for both AC and DC generators. The behavior of curves show that the output current was decreased with small values by increase the consumed power for both AC and DC generators.

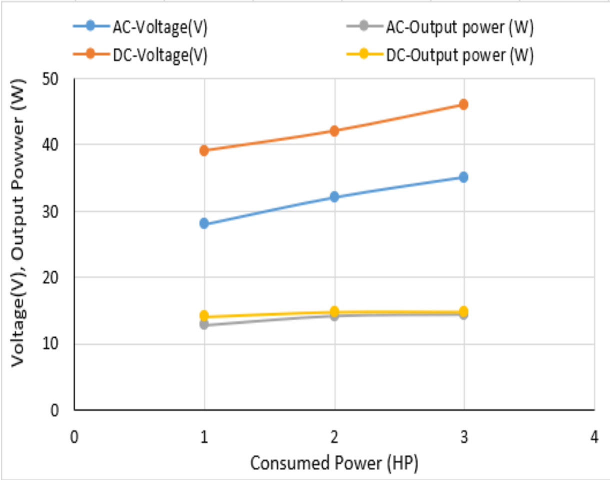

Fig. 11: Output voltage and output power from AC and DC generators with a capacity of 1 HP, 2HP and 3 HP.

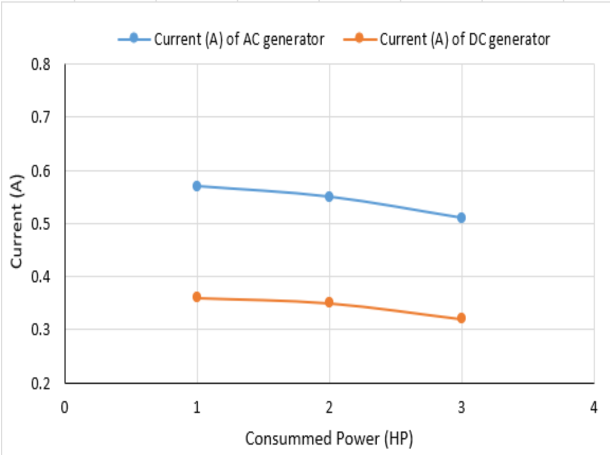

Fig. 12: Output current from AC and DC generators with a capacity of 1 HP, 2HP and 3 HP.

In the test with AC generator, it was obtained that the output current and voltage is 0.57 A and 28 V, respectively, with 1 HP capacity air conditioner. With 2 HP and 3HP capacity air conditioner the output voltage 32 V and 35 V and the output current 0.55 A and 0.51 A, respectively, as listed in Table 1. While the output current and voltage, with testing by using DC generator, are 0.36 A and 39 V with 1 HP capacity air conditioner.

With 2 HP and 3 HP capacity it was found that the output current 0.35 A and 0.3 A and the voltage is 32 V and 35 V from the DC generator, respectively. Table 2 shows the measurements of AC generator, the listed values of current (A) and voltage (V) were used for the calculations of the output power (W), with 0.8 which represents the power factor (cos phi) on the generator. While table 3 has the measurements values of output current (A) and the output voltage (V) parameters used to find the DC generator output power (W).

Table 1: Output power from AC generator

Consumed Power (HP)	Output Voltage (V)	Output Current (A)	Output Power (W)
1	28	0.57	12.76
2	32	0.55	14.08
3	35	0.51	14.28

Table 2: Output power from DC generator

Consumed Power (HP)	Output Voltage (V)	Output Current (A)	Output Power (W)
1	39	0.36	14.04
2	42	0.35	14.7
3	46	0.32	14.72

4. Conclusions

The Savonius type L turbine has been investigated experimentally inside Perspex duct, by connecting the duct to the discharged exhaust air of air conditioner for utilizing the exhaust air velocity to rotate the wind turbine. The output values of the current and voltage of the AC generator and DC generator is affected by the amount of average velocity of blower of air conditioner. With adopting 3 HP capacity air conditioner the AC generator can generate voltage 35 V, current 0.51 A and output power 14.28 W. While the DC generator can generate 46 V, current 0.32 A and output power 14.72 W with adopting 3 HP. The generated output power can be utilized to turn on the surface-mount device light emitting diode (SMD LED) because these lights need low amounts of voltage around 3V until 12V DC. The advantage of applying this technology in the houses is no more wasted energy from using the air conditioner. Also, the lights outside or inside the houses can be turn on by utilizing this wasted energy. For the future work, it can be investigating other types of wind turbine that have simpler design and lighter weight which resulting in faster rotating and then higher voltage production.

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Nomenclature

A	blade sweep area (m^2)
AC	alternating current (Ampere)
DC	direct current (Ampere)
E_K	kinetic energy generated by turbine (Joule)
P	power (W)
P_{wind}	wind power (W)
v	speed of wind (m/s)
m	moving air mass (kg)

Greek symbols

ρ	Air density (kg/m^3)

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