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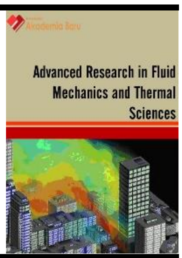

Study on Performance Improvement of the Savonius Wind Turbine for Urban Power System with Omni-directional Guide Vane (ODGV)

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ABSTRACT

The performance of a Savonius wind turbine was studied for urban power system application. The aim of the study was to analyze the effect of Omni-Directional Guide Vane (ODGV) on rotor performance. The wind tunnel experiment had been carried out on a Savonius rotor model. The ODGV was placed around the Savonius rotor in order to increase the ambient wind velocity to the wind turbine. The tests were performed at a different ODGV slope angle and incoming wind direction. The maximum power coefficient (C_{pmax}) obtained was 0.125 at 60° wind direction. The maximum power coefficient of a Savonius wind turbine with ODGV was 21.46% higher than the Savonius wind turbine without ODGV. The result showed that the ODGV had the potential to increase the performance of the Savonius wind turbine.

1. Introduction

The Finnish engineer Sigurd Savonius in 1925, created the Savonius wind turbine. It was classified as a vertical axis wind turbine and drag-type machine. However, for some angular positions of the rotor, there may be lift contributions on the torque release mechanism, as evidenced by values of the tip speed ratio greater than one [1,2,3,4]. The Savonius wind turbines can be an alternative to reduce the electrical load in urban environments. Urban environments require more electrical energy and generally have many high-rise buildings, making it an attractive option for wind turbine deployment [5,6,7,8]. The Savonius wind turbines laid out in tall buildings are increasingly in demand as part of the appropriate technology for Micropower applications. However, urban environments generally have low wind speed problems and frequent turbulence [5]. Also, the wind speeds were always changing, and the directions were not always the same [9]. Ricci *et al.,* state that some of the advantages of Savonius wind turbines are able to operate in turbulent and volatile wind conditions

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in urban environments [10]. However, according to Soo *et al.*, the Savonius turbines have a lower efficiency than other types of turbines [11]. Previous studies Savonius turbine power coefficients were reported in the range of 0.10-0.25 [10,12].

The Savonius wind turbine has low efficiency, therefore, to improve the performance of Savonius wind turbine, some researchers added devices around the vertical wind turbine, for example, a deflector plate. The addition of the deflector plate in principle reduces the negative torque occurring in one of the blades, thereby increasing the total turbine torque [13]. However, simple deflector plates cannot receive the wind from any direction, while wind conditions in urban environments generally experience turbulence. So to overcome the problem developed another device, the Omni-directional Guide Vane (ODGV). ODGV can receive the wind from all directions and then directs airflow to the turbine rotor to improve efficiency.

Chong *et al.,* make ODGV integrated with vertical H-rotor wind turbines [5]. Guide vane used amounted to 4 pairs with a flat plate profile that was placed on the cone plate on the top and bottom. Each pair of the guide were vane 20^o and 55^o angle. The turbine rotor used with the Wortmann FX63-137 airfoil profile of 5 blades. The research was conducted experimentally on wind tunnel and simulation using Fluent 6.3 software. Wind tunnel experiments used wind direction variations in the directions 0^o, 30^o and 60^o. Wind tunnel test results, ODGV were able to increase the speed of rotation of the turbine rotor by 182% at wind speed 6 m/s. With load applications, turbines with ODGV rotate stably at 144 rpm with maximum torque of 23.64 mN.m and produce an output power of 0.4352 W. Thus, the augmentation ratio (with ODGV to no ODGV) was 1.87 times at RPM And 3.48 times on power [5].

The next ODGV model was developed by Nobile *et al.,* by integrating the stator vane and the Darrieus wind turbines [14]. The vane stator used with the airfoil profile of NACA 0018 was eight blades. The stator vane was arranged vertically around the turbine and mounted on the conical surface at the top and bottom. While the number of Darrieus rotor used as many as three blades and had a profile airfoil NACA 0018. Simulation results conducted with 2D ANSYS CFX software shows the coefficient of the Darrieus wind turbine torque increased by 30-35% compared without stator [14,15].

The purpose of the study was to investigate the effect of ODGV design and wind direction to the performance of the Savonius wind turbine. The research experimental method was used to predict the performance of the turbine. The research was examined the effect of wind direction angle to achieve the best direction for ODGV. The variations of wind direction angles were refered to the references from Chong *et al.*, i.e., 0^o, 30^o and 60^o [5]. After obtaining the experimental results, the known of the effective ODGV design was improved the performance of Savonius wind turbines.

2. Methodology

In this study, the ODGV design was made based on Chong *et al.,* design [5]. However, there were differences in some design parameters. Some of the variables that distinguished the designs from previous studies include guide vane angle, blade arrangement, dimensions and turbines used. The layout and the number of blades referred to the design of Nobile *et al.,* that places eight blades around the turbine [14]. The blade profile used a flat plate arranged vertically. The ODGV dimensions were adjusted to the size of the turbine. The Savonius wind turbine rotor configuration referred to the research conducted by Ricci *et al.,* [10].

The experimental setup of a structured test bench supported the ODGV, a Savonius wind turbine, fan blower, and measurement devices. Figure 1 shows the schematic diagram of the experimental apparatus. In the experiment, a wind tunnel comprised of a fan blower and a square discharge of

700mm x 700mm was used. The wind velocity adjusted with variable a switch in the range of 3 to 9 m/s. A generator was assembled vertically at the low position on a tested wind turbine. The generator load used the 5-watt bulbs. The electrical current as the output power of the generator was measured by a multitester. The rotational speed was measured by a digital photo tachometer.

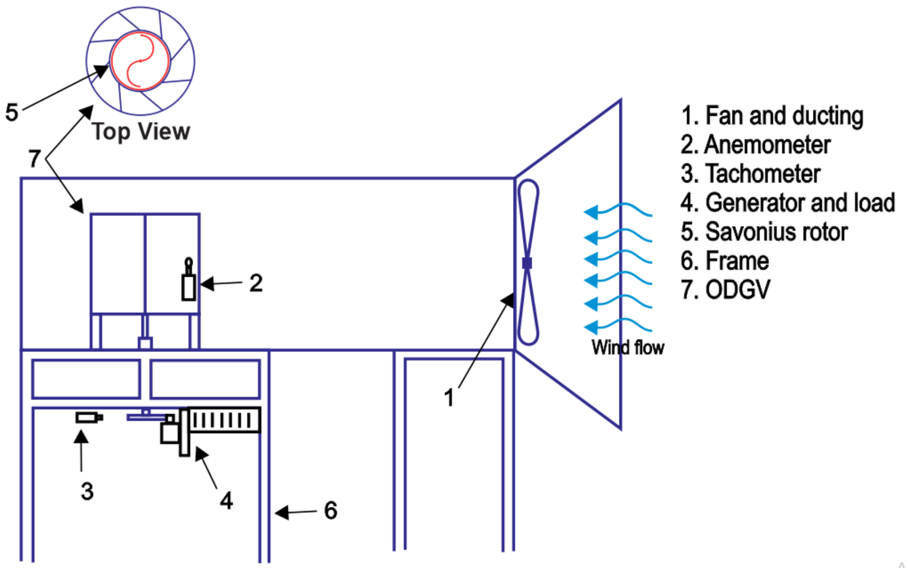


Fig. 1. The details of the experimental apparatus

The test was performed with a different wind direction angle (0°, 30°, and 60°), in order to study the influence of wind direction on the performance of the Savonius wind turbine (Figure 2 and Figure 3).

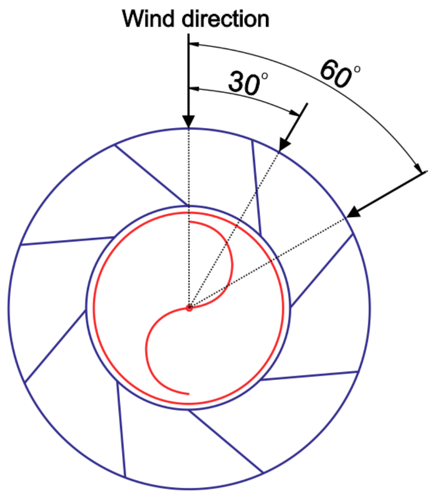


Fig. 2. Wind direction

The measurement of the velocity distribution was conducted to study the effect of wind direction on the velocity distribution in front of the Savonius wind turbine. The velocity distribution at the ODGV inlet was measured by using hand held anemometer.

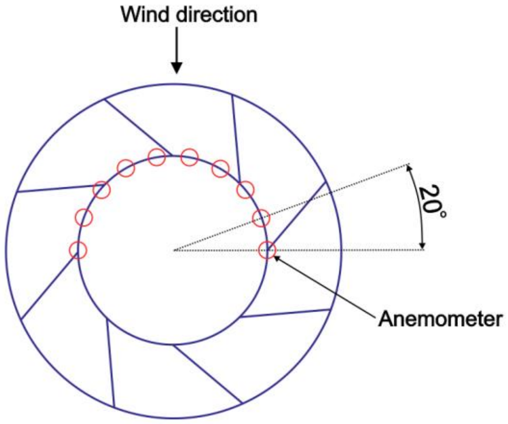
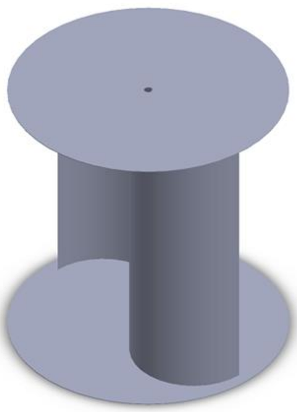
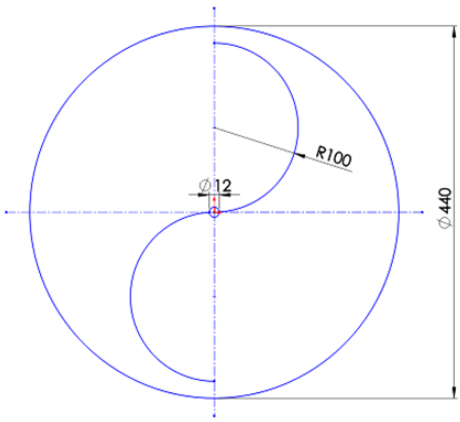


Fig. 3. Wind direction

The Savonius type turbines with two semi-circular blades were used in the research. Figure 4 illustrates the geometrical parameter of the Savonius wind turbine. The rotor was constituted by blades and end plates characterized by the height of H = 400 mm, end plate diameter of $D_{endplate}$ = 440 mm, and the rotor diameter of D_r = 264 mm. These designs corresponded to rotors studied by Ricci *et al.,* [10]. Primary dimension of the Savonius Rotor is shown in Table 1.





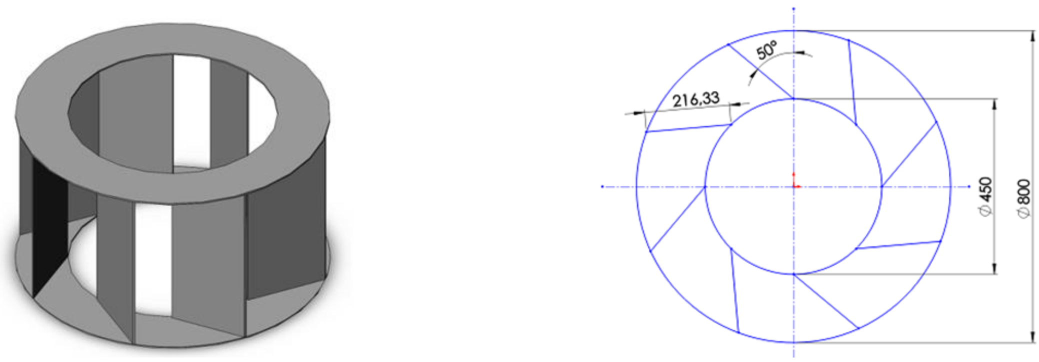
(a) (b)

Fig. 4. (a) Model of the Savonius wind turbine (b) The geometrical parameter of the Savonius wind turbine

Table 1
Primary dimension of the Savonius rotor

Parameter	Value
Endplate diameter ($D_{endplate}$)	440 mm
Rotor diameter (D_r)	400 mm
Height (H)	400 mm
Aspect ratio (D_r/H)	1
Overlap ratio	0 mm
Shaft diameter	12 mm
Total bucket	2
Material	Aluminium
Plate thickness	1.5 mm

Figure 5 shows the geometrical parameter of ODGV. The ODGV has an inner diameter, D_{in}= 450 mm, outer diameter, D_{out}= 800 mm and guides vane angle of 50° to the normal line. The ODGV was set around the Savonius rotor. In The experiment, the ODGV was inclined against the main flow as θ=0°, 30°, and 60°, to study the influence of wind direction on Savonius wind turbine performance. Primary dimension of the model of ODGV is shown in Table 2.



(a) (b)

Fig. 5. (a) The model of ODGV (b) The geometrical parameter ODGV

Table 2
Primary dimension of the model of ODGV

Parameter	Value
The outer diameter (D_{out})	800 mm
The inner diameter (D_{in})	450 mm
Height (H)	400 mm
Diameter ratio (D_{in}/D_{out})	1.7
Guide vane angle (α)	50°
Total vane (z)	8
Material	Aluminium
Plate thickness	1.5 mm

There are several important parameters in determining the performance of a wind turbine, the tip-speed ratio (λ), power coefficient (C_p), and torque coefficient (C_t). Tip-speed ratio was the velocity ratio between the tangential velocity of the rotor tip and free stream (wind) velocity in Eq. (1). The performance of a wind turbine was measured by the power coefficient. The c_p represents the percentage of wind energy that can be converted into mechanical energy. The C_p can be determined by using Eq. (2). The C_t represents the percentage of the measured toruqe to the theoretical torque.

$$\lambda = \frac{\pi D n}{60 v} \tag{1}$$

where, λ = tip speed ratio = TSR, D (m) = rotor diameter, n (rpm) = rotor rotational speed, and v (m/s) = wind velocity.

$$C_p = \frac{P}{0.5 \rho S v^3} \tag{2}$$

where, ρ (kg/m³) = air density, v (m/s) = air velocity, S (m²) = rotor swept area, C_p = power coefficient, and P (Watt) = turbine output power.

$$C_t = \frac{T}{0.5\pi v^2 S.R} \tag{3}$$

where R (m) = rotor radius, v (m/s) = air velocity, S (m^2) = rotor swept the area, C_t = torque coefficient, and T (N.m.) = torque.

3. Results and Discussion

3.1 The Performance of Open Savonius Rotor

The curve of power coefficient (C_p) and torque coefficient (C_t) of the Savonius wind turbine without ODGV are shown in Figure 6 that were obtained by experimental study. The curve of the power coefficient of the Savonius wind turbine described like a parabola. The power coefficient of the Savonius wind turbine increased with an increase in the wind speed, and then achieves the maximum point of 0.073 at the λ (TSR) = 0.52, and then decreased.

Based on the results of previous research conducted by Ricci *et al.,* the Savonius wind turbines with (D = 384 mm) dimensions were able to achieve C_{pmax} of 0.245 at TSR 0.6 [10]. The characteristics of the graph obtained from the test in the study were not the same as previous research due to the different methods of study. The study by Ricci *et al.,* was done in a close circuit environmental wind tunnel (EWT) which gave much more uniform and higher wind velocity [10]. In this study, the fan as the wind source produced swirl and turbulence that reduced the uniformity and gave inconstant wind velocity.

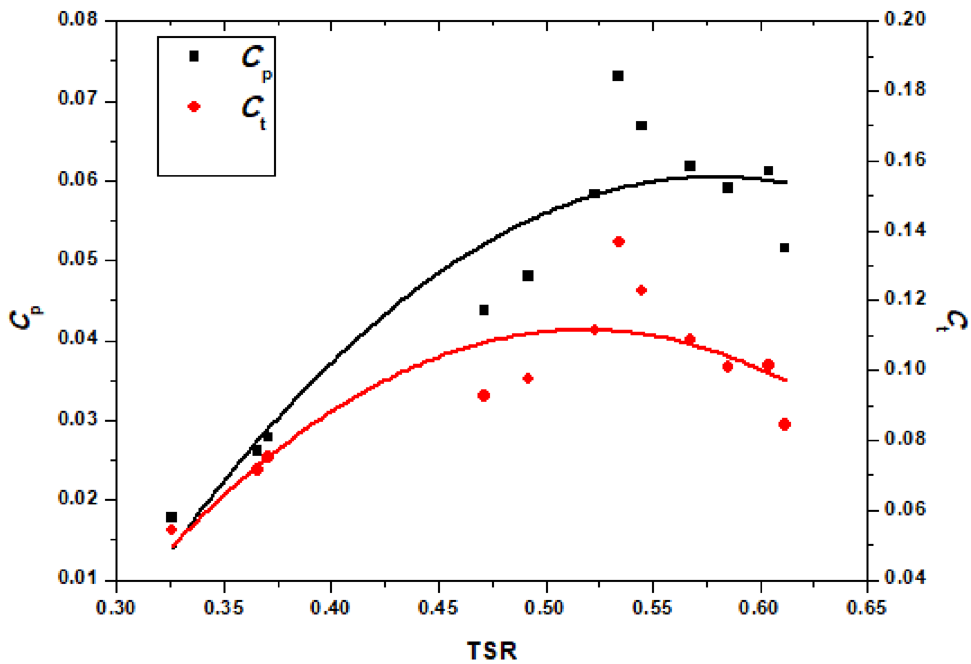


Fig. 6. The performance curve of the Savonius wind turbine

Figure 7 shows the velocity distribution in the front of the Savonius wind turbine. To analyze the performance of Savonius wind turbines before the installation of ODGV, the velocity distribution measurements were made on half of the turbine front portion of 10 points with an angle ranging from 0° to 180° at an average wind speed of 4.25 m/s. The aims of measurement have analyzed the velocity of the airflow at half the circumference of the front of the Savonius wind turbine with and without ODGV. Figure 7 shows the velocity distribution at half of the circumference of the front of the turbine.

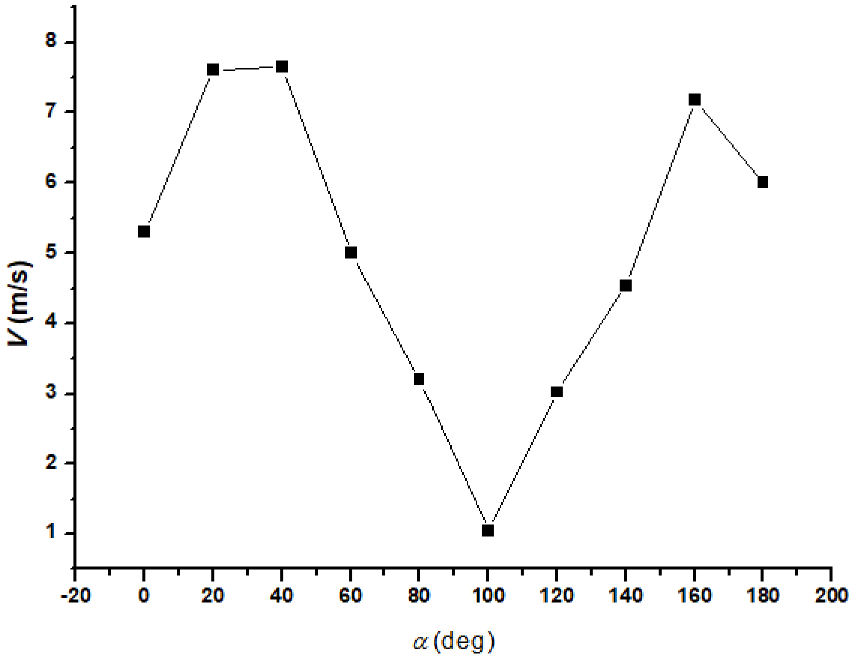


Fig. 7. Velocity distribution in front of the Savonius wind turbine without ODGV

Based on Figure 7, it was found that the average wind speed was highest in the circumference of θ <100°. The region θ <100° was a Savonius turbine inlet channel. In the case of Savonius wind turbines, the air flow was directed at a diagonal angle to the turbine, so the inlet angle formed by the wind source does not correspond to the inlet angle of the turbine blade. At the point θ = 100° the wind speed was at its lowest point due to the wind velocity distribution profile coming out of the fan outlet was at its lowest point in the center. Furthermore, in the circumference region θ> 100° the average velocity was lower than the region θ <100°. The peripheral region θ> 100° was the convex blade area of Savonius wind turbines. The turbine blades cannot receive airflow due to airflow over convex blades. The convex blade exposed to the airflow will produce a drag force which generates a negative torque to reduce the positive torque on the axis of the wind turbine axis. The problem was effected to the low performance of wind turbines Savonius and needs to be improved with the help of ODGV devices. The ODGV was designed to block the airflow, preventing the rotor from rotating, and increasing the incoming flow rates in the rotor.

3.2 The Effect of Wind Direction on the Performance of Savonius Wind Turbine with ODGV

To study the effect of the wind direction on the performance, ODGV was arranged in three angles against the incoming wind, i.e., 0°, 30°, and 60°. Fig. 8 shows the power coefficient obtained by the experiment under the condition that the ODGV was inclined by incoming wind direction θ: 0°, 30° and 60°. The maximum power coefficient of wind direction angle θ=60° was the highest, at Cp =0.084 and it increased 41,34% compared to the Savonius open rotor. On the other hand, it was shown in Figure 8 below, that the power coefficient of θ=0° was not effective for increasing the power coefficient.

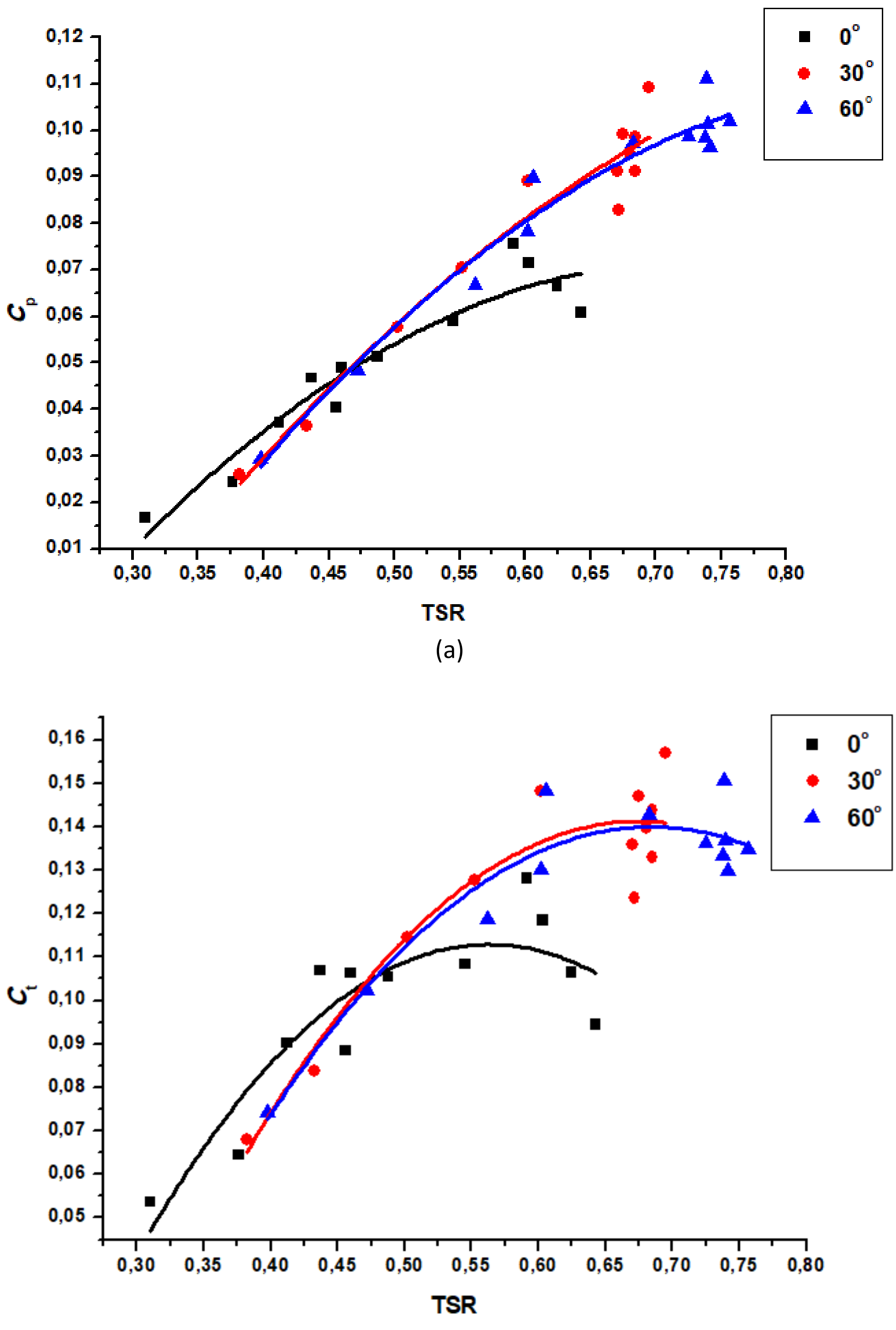


Fig. 8. The Effect of wind direction on the performance, (a) C_p Curves (b) C_t Curves

The increment of C_p and C_t was appered to ODGV caused by three reasons. First, the increment of C_p and C_t due to the airflow when it enters the ODGV blades directly toward the inlet blade of the Savonius turbine. Secondly, the wind speed passing through the ODGV blades was experienced a throttling effect, i.e., the narrowing of the ODGV outlet resulting in the increased of wind speed. Third, in the circumference region θ>100°, the ODGV blade impedes the airflow so that the convex side of the Savonius turbine blade was protecthe results in a reduction of negative torque on the turbine shaft. The phenomenon corresponds to the opinion of Natapol *et al.,* which states that the increase in the rotational v the throttling effect and the air flow guiding [2].

Figure 9 was found that the angle of the wind direction affects the performance of the Savonius wind turbine. When observed with the graph of speed distribution analysis in Figure 9, we found a relationship between Savonius wind turbine performance graphs against wind velocity in front of the turbine when using ODGV.

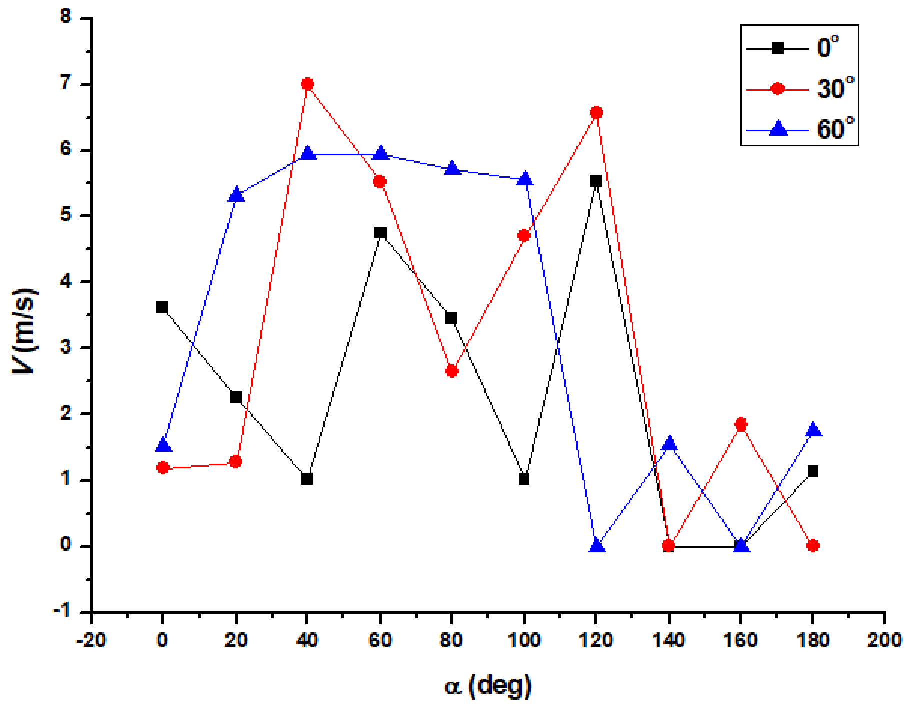


Fig. 9. Velocity distribution in front of a Savonius wind turbine with ODGV

Figure 9 shows the circumferential distribution of velocity in front of the Savonius wind turbine with ODGV. It was found in Figure 9 that the velocity with wind direction angle θ=60° was larger than the other wind direction case in the circumferential region α<100°. The inlet region of the Savonius turbine receives a greater airflow rate than the other two cases. In the circumferential region α>100 the wind speed was low, it caused by the ODGV prevent airflow hit the blades. On the other hand, the pressure in front of the convex side of the Savonius wind turbine blades was decreased. The low pressure in front of the convex side turbine blades reduces the negative torque on the turbine shaft, thus increasing the efficiency.

4. Conclusions

In order to increase the performance of the Savonius wind turbine, ODGV were designed, and a performance test was conducted, and the following concluding remarks were obtained.

i. The power coefficient increased 0,66-41,34% compared to the Savonius open rotor and the flow conditions around the Savonius wind turbine was improved.
ii. The effect of wind direction was important to get optimum performance in real condition.

The maximum efficiency of the Savonius wind turbine with ODGV was still low, and the efficiency needs to be increased to 60-70% to generate electricity. On the other hand, the Savonius wind turbine with ODGV has some advantages in the urban environment: high torque, good self-starting ability, low noise, high stability and easy to manufacture. Therefore, we will continue studying to increase the efficiency with new design ODGV and changing the geometrical parameter of the Savonius wind turbine

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References

[1] Tartuferi, Mariano, Valerio D'Alessandro, Sergio Montelpare, and Renato Ricci. "Enhancement of Savonius wind rotor aerodynamic performance: a computational study of new blade shapes and curtain systems." *Energy* 79 (2015): 371-384.
[2] Korprasertsak, Natapol, and Thananchai Leephakpreeda. "Analysis and optimal design of wind boosters for Vertical Axis Wind Turbines at low wind speed." *Journal of Wind Engineering and Industrial Aerodynamics* 159 (2016): 9-18.
[3] Tjahjana, Dominicus Danardono Dwi Prija, Pradityasari Purbaningrum, Syamsul Hadi, Yoga Arob Wicaksono, and Dimas Adiputra. "The study of the influence of the diameter ratio and blade number to the performance of the cross flow wind turbine by using 2D computational fluid dynamics modeling." In *AIP Conference Proceedings*, vol. 1931, no. 1, p. 030034. AIP Publishing, 2018.
[4] Wicaksono, Yoga Arob, Dominicus Danardono Dwi Prija Tjahjana, and Syamsul Hadi. "Influence of omni-directional guide vane on the performance of cross-flow rotor for urban wind energy." In *AIP Conference Proceedings*, vol. 1931, no. 1, p. 030040. AIP Publishing, 2018.
[5] Chong, W. T., K. C. Pan, S. C. Poh, A. Fazlizan, C. S. Oon, A. Badarudin, and N. Nik-Ghazali. "Performance investigation of a power augmented vertical axis wind turbine for urban high-rise application." *Renewable Energy* 51 (2013): 388-397.
[6] Utomo, Ilham Satrio, Dominicus Danardono Dwi Prija Tjahjana, and Syamsul Hadi. "Experimental studies of Savonius wind turbines with variations sizes and fin numbers towards performance." In *AIP Conference Proceedings*, vol. 1931, no. 1, p. 030041. AIP Publishing, 2018.
[7] Susanto, Sandi, Dominicus Danardono Dwi Prija Tjahjana, and Budi Santoso. "Experimental tests of the effect of rotor diameter ratio and blade number to the cross-flow wind turbine performance." In *AIP Conference Proceedings*, vol. 1931, no. 1, p. 030042. AIP Publishing, 2018.
[8] Wibowo, Andreas, Dominicus Danardono Dwi Prija Tjahjana, Budi Santoso, and Marcelinus Risky Clinton Situmorang. "Study of turbine and guide vanes integration to enhance the performance of cross flow vertical axis wind turbine." In *AIP Conference Proceedings*, vol. 1931, no. 1, p. 030043. AIP Publishing, 2018.
[9] Pope, K., V. Rodrigues, R. Doyle, A. Tsopelas, R. Gravelsins, G. F. Naterer, and E. Tsang. "Effects of stator vanes on power coefficients of a zephyr vertical axis wind turbine." *Renewable Energy* 35, no. 5 (2010): 1043-1051.
[10] Ricci, Renato, Roberto Romagnoli, Sergio Montelpare, and Daniele Vitali. "Experimental study on a Savonius wind rotor for street lighting systems." *Applied Energy* 161 (2016): 143-152.
[11] Jeon, Keum Soo, Jun Ik Jeong, Jae-Kyung Pan, and Ki-Wahn Ryu. "Effects of end plates with various shapes and sizes on helical Savonius wind turbines." *Renewable energy* 79 (2015): 167-176.
[12] Kamoji, M. A., S. B. Kedare, and S. V. Prabhu. "Performance tests on helical Savonius rotors." *Renewable Energy* 34, no. 3 (2009): 521-529.
[13] Mohamed, M. H., G. Janiga, E. Pap, and D. Thévenin. "Optimal blade shape of a modified Savonius turbine using an obstacle shielding the returning blade." *Energy Conversion and Management* 52, no. 1 (2011): 236-242.
[14] Nobile, Rosario, Maria Vahdati, Janet F. Barlow, and Anthony Mewburn-Crook. "Unsteady flow simulation of a vertical axis augmented wind turbine: A two-dimensional study." *Journal of Wind Engineering and Industrial Aerodynamics* 125 (2014): 168-179.
[15] Shiono, Mitsuhiro, Katsuyuki Suzuki, and Seiji Kiho. "An experimental study of the characteristics of a Darrieus turbine for tidal power generation." *Electrical Engineering in Japan*132, no. 3 (2000): 38-47.