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Influence of Omni-Directional Guide Vane On The Performance of Cross-flow Rotor for Urban Wind Energy

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Abstract. Vertical axis wind turbine like cross-flow rotor have some advantage there are, high self-starting torque, low noise, and high stability; so, it can be installed in the urban area to produce electricity. But, the urban area has poor wind condition, so the cross-flow rotor needs a guide vane to increase its performance. The aim of this study is to determine experimentally the effect of Omni-Directional Guide Vane (ODGV) on the performance of a cross-flow wind turbine. Wind tunnel experiment has been carried out for various configurations. The ODGV was placed around the cross-flow rotor in order to increase ambient wind environment of the wind turbine. The maximum power coefficient is obtained as $C_{pmax} = 0.125$ at 60^o wind direction. It was 21.46% higher compared to cross-flow wind turbine without ODGV. This result showed that the ODGV able to increase the performance of the cross-flow wind turbine.

Keywords: VAWT, Cross-flow wind turbine, Urban area, ODGV

INTRODUCTION

Wind energy can be utilized to be converted into electrical energy through wind turbines. Before the wind turbine is installed it is necessary to study the potential of wind energy in the area. This is because the availability of wind energy in one place becomes an important condition for the wind turbine to operate optimally. According to Hasan et al. [1], the wind speed in Indonesia is between 2 to 6 m / s. So the wind energy generator that can be used from small scale (10kW) to medium (10-100kW). Nominal wind power capacity in Indonesia of 1.06 MW of total power generation in 2009.

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 [2]. Wind turbines laid out in tall buildings are increasingly in demand as part of an appropriate technology for micropower applications (Walker 2011). However, urban environments generally have low wind speed problems and frequent turbulence [2]. In addition, the wind speed is always changing and the direction is not always the same [3].

To adjust the wind characteristics in urban environments, a vertical axis of Savonius and cross-flow types can be selected. Both turbines are the right choice because of the characteristics of the wind in an urban environment and are easy to create. Ricci et al. [4] state that some of the advantages of Savonius wind turbines are: able to operate on turbulent and volatile wind conditions in urban environments. But according to Soo et al. [5] Savonius turbines have a lower efficiency deficiency than other types of turbines. Previous studies have averaged Savonius turbine power coefficients between 0.10-0.25[4]. Another vertical wind turbine that has characteristics similar to the Savonius turbine is a cross-flow wind turbine. The cross-flow turbine adopts the design of the Banki water turbine. Based on the results of research Dragomirescu [6], obtained the coefficient of torque and power better than Savonius turbine.

The main problem with vertical wind turbines is low performance. To improve the performance of vertical wind turbines some researchers did add 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 [7]. 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 has the ability to receive the wind from all directions and then directs airflow to the turbine rotor so as to improve efficiency.

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Chong et al. make ODGV integrated with vertical H-rotor wind turbines. Guide vane used amounted to 4 pairs with a flat plate profile that is placed on the cone plate on the top and bottom. Each pair of guide vane has 20° and 55° 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°, 30° and 60°. Wind tunnel test results, ODGV able to increase the speed of rotation of 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) is 1.87 times at RPM And 3.48 times on power [2].

The next ODGV model was developed by Nobile et al. by integrating stator vane and Daerius wind turbines. The vane stator used with the airfoil profile of NACA 0018 is 8 blades. The stator vane is arranged vertically around the turbine and mounted on the conical surface at the top and bottom. While the number of rotor Daerius used as many as three blades and has a profile airfoil NACA 0018. Simulation results conducted with 2D ANSYS CFX software shows the coefficient of Daerius wind turbine torque increased by 30-35% compared without stator [8].

In this study will be made ODGV with reference to the design made by Chong et al [2]. Some of the variables that distinguish the designs from previous studies include guide vane angle, blade arrangement, dimensions and turbines used. The layout and the number of blades refer to the design of Nobile et al. that places 8 blades around the turbine [8]. The blade profile uses a flat plate arranged vertically. ODGV dimensions are adjusted to the size of the turbine. The turbine rotor is used using and cross-flow. The cross-flow wind turbine rotor configuration refers to the reference of research conducted by Dragomirescu [6]. The purpose of this study was to investigate the effect of ODGV design and wind direction on the performance of cross-flow wind turbines. To predict the performance of wind turbine in this research using an experimental method. Because ODGV is capable of receiving the wind from all directions, this research will also examine the effect of wind direction angle. The variations in wind direction angles used in this study refer to the references from Chong et al. [2], ie 0°, 30° and 60°. While the wind speed variations used are 3 m/s to 5 m/s. After obtaining the experimental results known the most effective ODGV design to improve the performance of cross-flow wind turbines.

EXPERIMENTAL EQUIPMENT AND MEASUREMENT METHOD

The experimental set-up of a structural test bench supporting the ODGV and cross-flow wind turbine, fan blower, and measurement devices. Fig.1 shows the schematic diagram of the experimental apparatus. In the experiment, a wind tunnel comprised of a fan blower and square discharge of 700mmx700mm was used. The wind velocity adjusted with variable a switch with range 3m/s-9 m/s. A generator assembled vertically at the low position on a test wind turbine. The generator load uses the 5-watt bulbs. The output power of generator measured by a multitester that connected to the generator. The rotational speed measured by digital photo tachometer.

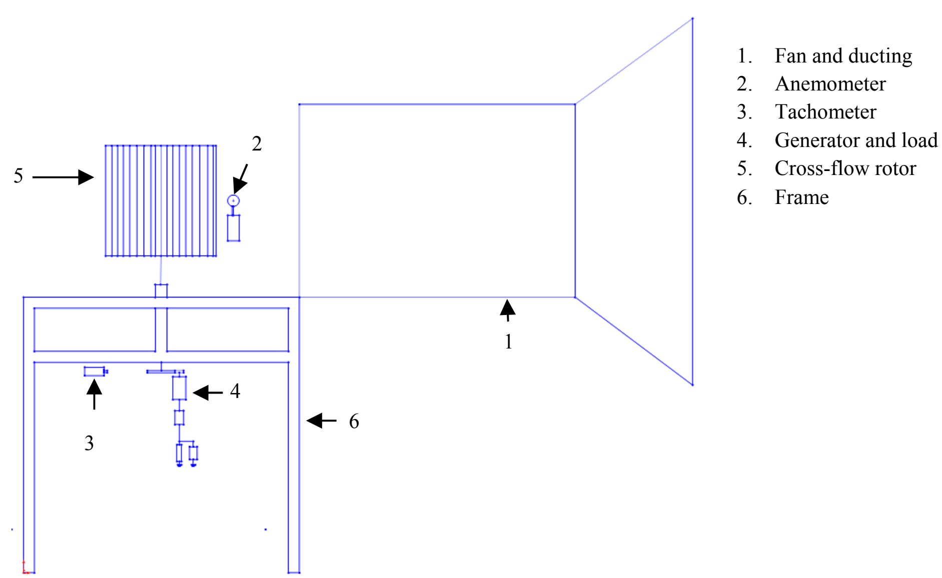


Figure 1. Details of experimental apparatus

The wind direction inclined in 0º, 30º, and 60º, in order to study the wind direction on the performance of cross-flow wind turbine.

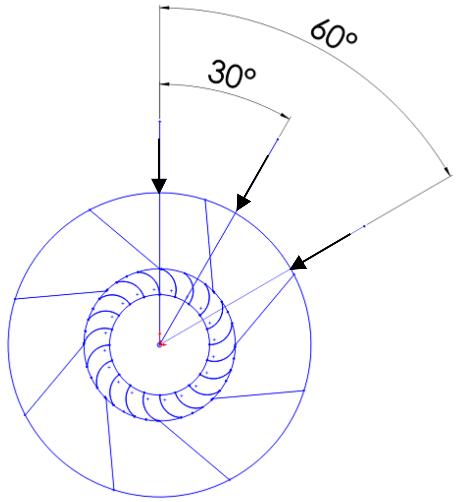


Figure 2. Wind direction

The measurement of the velocity distribution to study the effect of wind direction on the velocity distribution in front of cross-flow wind turbine. The velocity distribution at the ODGV inlet was measured by using an anemometer.

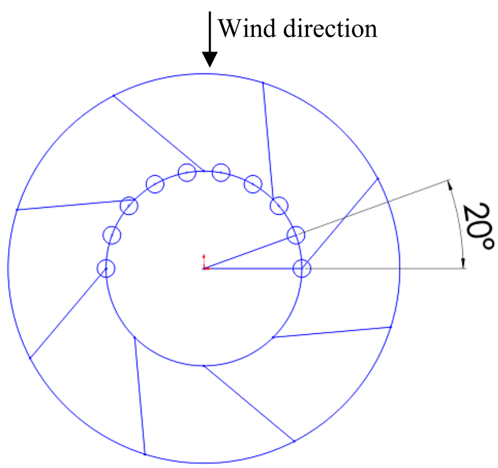
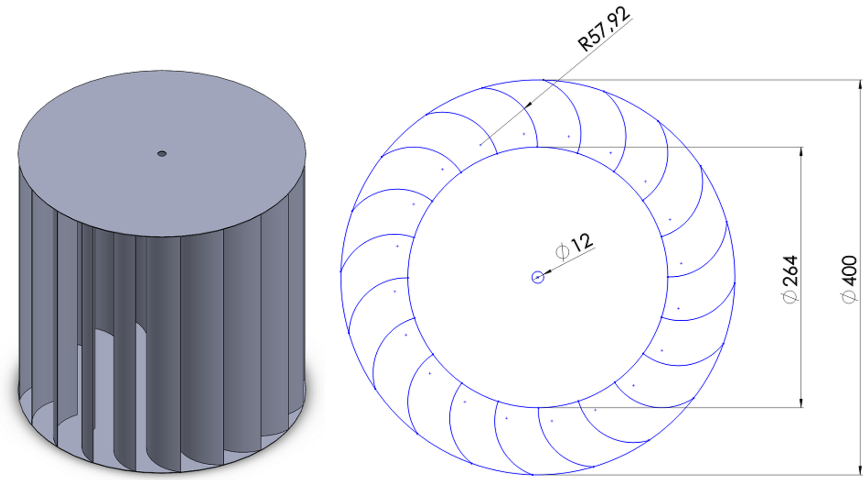


Figure 3. Measurement position of velocity distribution

A rotor used in the experiment and its dimensions are shown in Figure 4 and Table 1. A thin circular blade was used. The blade number was Z=20, outer diameter was D_1=400 mm, inner diameter was D_2 = 264 mm. In Fig. 4. illustrate the geometrical parameter of the cross-flow wind turbine. This rotor is constituted by blades and end plates characterized by the height was H = 400 mm, the outer diameter was D_{out} = 400 mm, the inner diameter was D_{in} = 264 mm, and the inner/outer diameter ratio was D_{in}/D_{out} = 0,66. These design directly corresponded to rotors studied by Dragomirescu [6].



(a) (b)

Figure 4. (a). Model of the cross-flow wind turbine (b). Geometrical parameter of cross-flow wind turbine

Table 1. Primary Dimension of Cross-flow Rotor

Parameter	Value
Outer diameter (D_{out})	400 mm
Inner diameter (D_{in})	264 mm
Diameter ratio (D_{in}/D_{out})	0,66
Height (H)	400 mm
Shaft diameter	12 m
Rim width	68 m
Blade radius (r)	58,17 mm
Angle between blade (θ_b)	18°
Total blade (z)	20

Fig. 5 shows the geometrical parameter of ODGV. This ODGV has inner diameter D_{in}= 450 mm, outer diameter D_{out}= 800 mm and guide vane angle 50°. The ODGV were set around the cross-flow rotor. In this experiment, the ODGV was inclined against the main flow as θ=0°, 30°, and 60°, in order to study the influence of wind direction on cross-flow wind turbine performance.

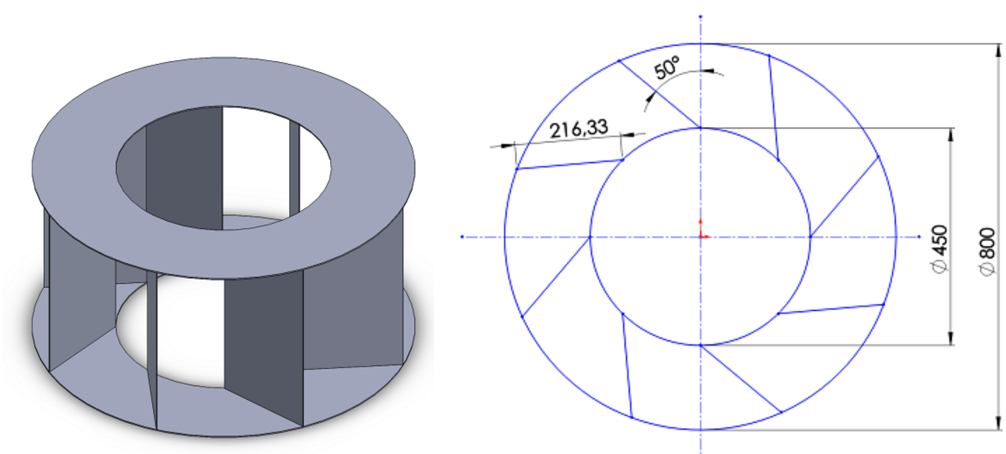


Figure 5. (a). Model of ODGV (b). Geometrical parameter ODGV

Table 2. Primary Dimension of Cross-flow Rotor

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

RESULT AND DISCUSSION

Effect of ODGV Design on the Performance of Cross-flow Wind Turbine

The curve of power coefficient (C_p) and torque coefficient (C_t) of the cross-flow wind turbine without are shown in Fig. 6 obtained by experimental study. The curve of power coefficient of the cross-flow wind tubine described like a parabola. The power coefficient of the cross-flow wind turbine was low at a low wind speed, increased with an increase in the wind speed, and became maximum (C_{pmax}=0.11) at the TSR 0.67 and then decreased. The torque coefficient has a negative slope against the increase in the wind speed.

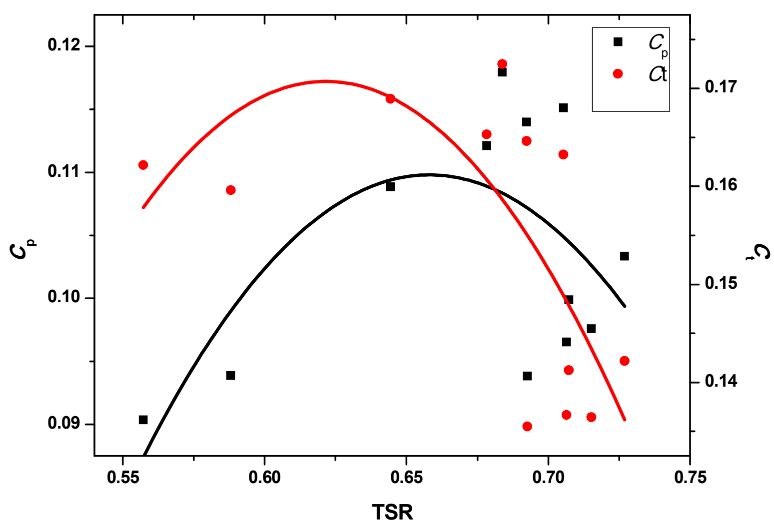


Figure 6. Performance curve of cross-flow wind turbine

Fig.7 shows the velocity distribution in the front of cross-flow wind turbine. To analyze the performance of cross-flow wind turbines prior to 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. This measurement aims to analyze the velocity of the airflow at half the circumference of front of the cross-flow wind turbine with and without ODGV. Fig. 7 shows the velocity distribution at half of the circumference of the front of the turbine. Based on Fig. 7, it is found that the average wind speed is highest in the circumference of θ <100º. The region θ <100º is a cross-flow turbine inlet channel. In the case of cross-flow wind turbines, the air flow is 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 $\theta = 100^o$ the wind speed is at its lowest point. This is because the wind velocity distribution profile coming out of the fan outlet is at its lowest point in the center. Furthermore, in the circumference region $\theta > 100^o$ the average velocity is lower than the region $\theta < 100^o$. The peripheral region $\theta > 100°$ is the convex blade area of cross-flow wind turbines. In this region, the turbine blades cannot receive airflow due to airflow over convex blades. The convex valve exposed to the airflow will produce a drag force which generates a negative torque so as to reduce the positive torque on the axis of the wind turbine axis. This problem causes the performance of wind turbines cross-flow is low 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.

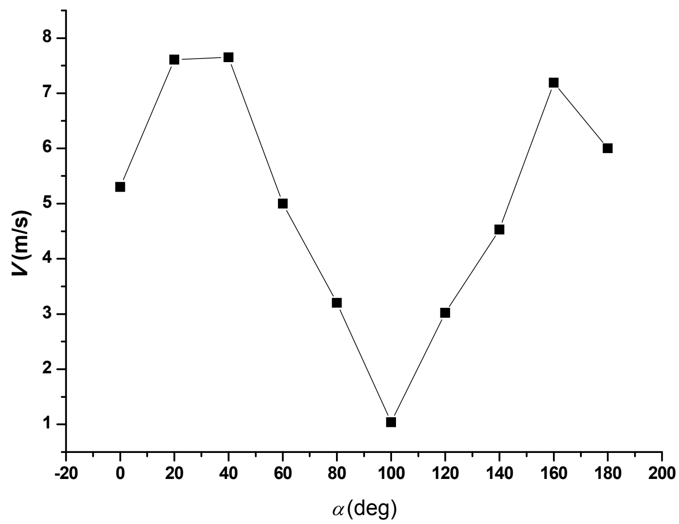


Figure 7. Velocity distribution in front of cross-flow wind turbine without ODGV

Figure 8 shows the curve of C_p and C_t versus TSR when the ODGV are installed. The maximum C_p is around 0.125 at TSR of 0.75. The C_p increases about 12.47% compared to cross-flow wind turbine without ODGV. The wide range of TSR which corresponds to high efficiency is suitable for electricity generation.

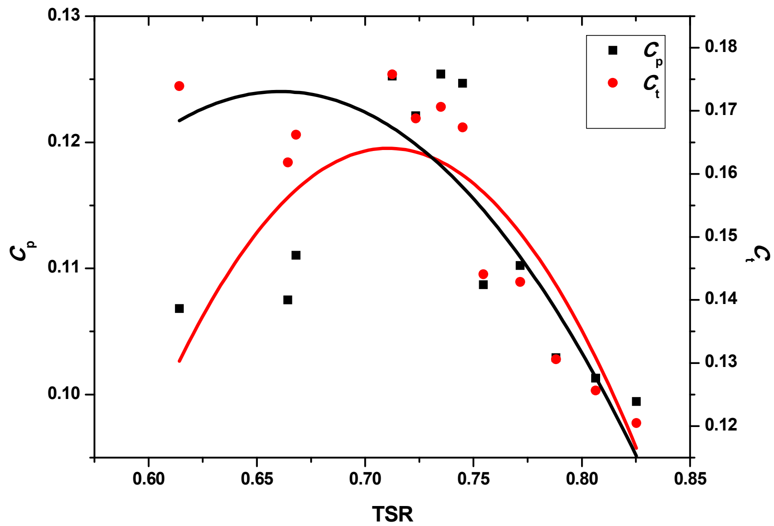
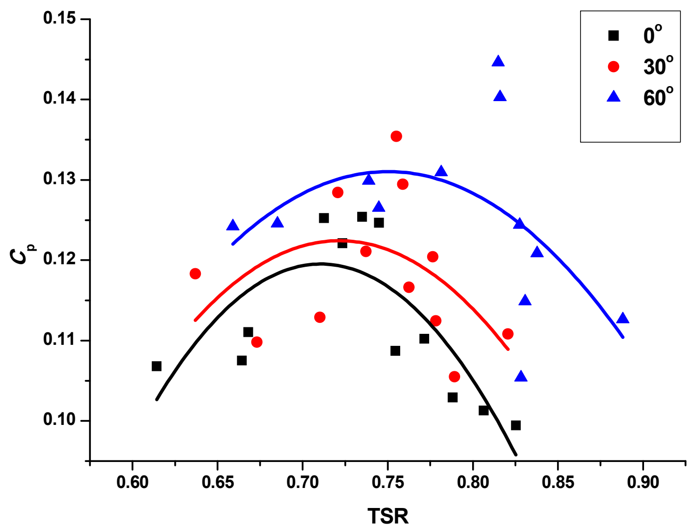


Figure 8. Performance curve of cross-flow wind turbine with ODGV

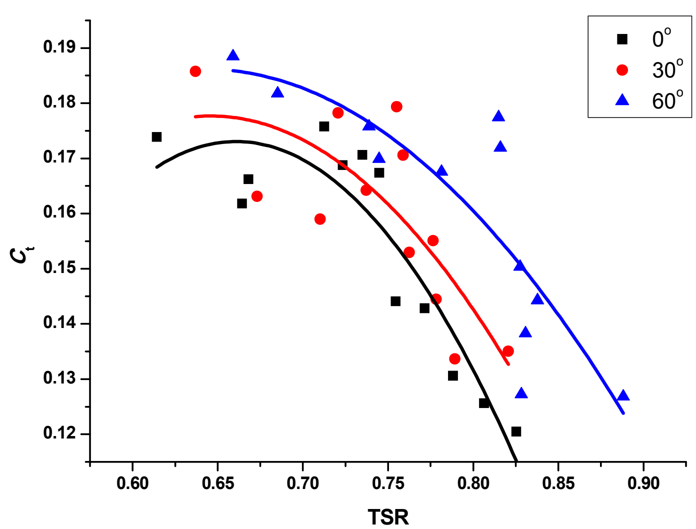
According to Fukutomi et al, the wind direction angle for the best cross-flow turbine is the closest to the angle of the turbine inlet [9]. The cross-flow wind turbine in this study has an inlet angle of 19.15^o while the inlet airflow angle that can be formed by ODGV is 40^o. Thus it shows that the inlet angle formed by ODGV does not approach the cross-flow turbine inlet angle. This is affect the speed triangle that impacts on the performance produced by the turbine.

Effect of Wind Direction on on the Performance of Cross-flow Wind Turbine

To study the effect of the wind direction on the performance, ODGV was arranged in three angles against incoming wind i.e. 0^o, 30^o, and 60^o. Fig. 8 shows the power coefficient obtained by the experiment under the condition that the ODGV was inclined by incoming wind direction θ:0^o, 30^o and 60^o. The maximum power coefficient of wind direction angle θ=60^o was the highest, at C_p =0.153 and it increased 24.7% compared to cross-flow wind turbine without ODGV. On the other hand, it was shown in Fig. 8 below that the power coefficient of θ=30^o and 0^o is not effective for increasing the power coefficient, but the performance is better than the cross-flow wind turbine without ODGV.



(a)



(b)

Figure 9. Effect of wind direction on the performance, (a) C_p curve (b) C_t curve

The increment of C_p and C_t is due to ODGV caused by three reasons. First, the increment of in C_p and C_t is due to the airflow when it enters the ODGV blades is directed toward the inlet blade of the cross-flow turbine. Secondly, the wind speed passing through the ODGV blades will experience a throttling effect, ie the narrowing of the ODGV outlet resulting in increased wind speed. Third, in the circumference region θ>100°, the ODGV blade impedes the airflow so that the convex side of the cross-flow turbine blade is protected from wind pressure. This 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 rotational velocity of VAWT is the reinforcement of the throttling effect and the air flow guiding [10].

The velocity diagram sketches in the inlet and outlet of the cross-flow wind turbine are shown in Fig. 9. The cross-flow wind turbine in this study has an inlet angle (β_1) 19.22° while the inlet airflow angle that can be formed by ODGV is 40°. Thus it shows that the inlet angle formed by ODGV does not approximate the inlet angle of the cross-flow turbine. According to Fukutomi et al, the wind direction angle for the best cross-flow turbine is the closest to the angle of the turbine inlet [9]. Thus, it can be concluded that the ODGV design is still not optimal to improve cross-flow turbine wind performance.

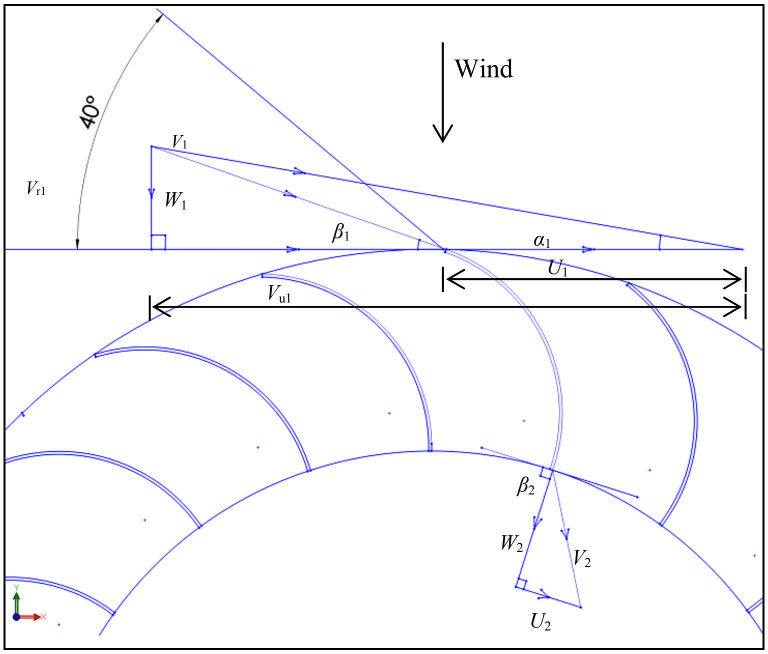


Figure 10. Velocity diagrams of cross-flow wind turbine

In Fig. 10, it is found that the angle of the wind direction affects the performance of the cross-flow wind turbine. When observed with the graph of speed distribution analysis in Fig. 10, we found a relationship between cross-flow wind turbine performance graphs against wind velocity in front of the turbine when using ODGV.

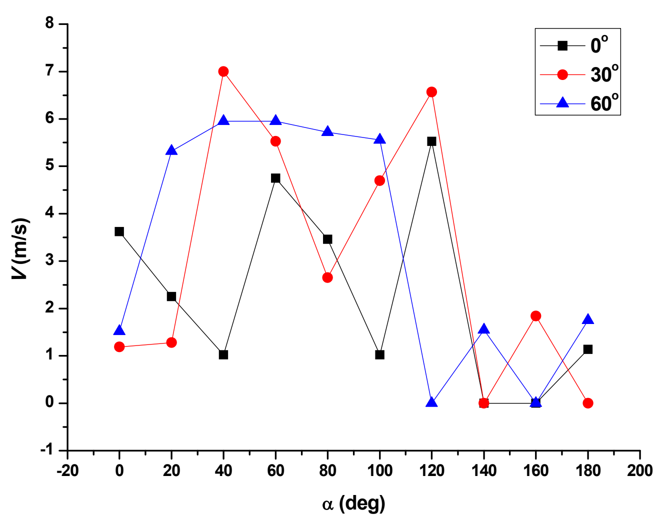


Figure 11 Velocity distribution in front of cross-flow wind turbine with ODGV

Fig. 11 shows the circumferential distribution of velocity in front of the cross-flow wind turbine with ODGV. It was found in Fig. 10 that the velocity with wind direction angle θ=60º was larger than the other wind direction case in the circumferential region α<100º. In this case, the inlet region of cross-flow receives a greater airflow rate than the two cases other. In the circumferential region α>100 the wind speed is low, it caused by the ODGV prevent airflow hit the blades. On the other hand, the pressure in front of the convex side of cross-flow wind turbine blades is decreased. The low pressure in front of the convex side turbine blades reduces the negative torque on the turbine shaft, thus increasing the efficiency of this case.

CONCLUSION

In order to increase the performance of the cross-flow wind turbine, ODGV were designed and a performance test was conducted and the folowwing concluding remarks were obtained.

1. The power coefficient increased 12.47-21.46% compared to cross-flow wind turbine without ODGV and the flow conditions around cross-flow wind turbine was improved.
2. The effect of wind direction is important to get optimize performance in real condition.
3. In order to increase the power coefficient, it is important to ensure that the relative flow angle at the rotor is close to the blade inlet angle.

The maximum efficiency of a cross-flow wind turbine with ODGV was still low, and the efficiency needs to be increased to 40-50% to generate electricity. On the other hand, the cross-flow wind turbine with ODGV has some advantages for urban environment: high torque, good self-starting ability, low noise, high stability and easy to manufacture. Therefore, we will continue studying to increase the cross-flow wind turbine efficiency with new design ODGV.

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