https://doi.org/10.1051/matecconf/201815902014

The Influence of Guide Vane to the Performance of Cross-Flow Wind Turbine on Waste Energy Harvesting System

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Abstract. The purpose of this experiment is to know the influence of a single guide vane position and angle to the performance of a cross-flow wind turbine. The cross-flow wind turbine was positioned at the discharge outlet of a cooling tower model to harness the discharged wind for electricity generation. A guide vane was used to enhance the rotational speed of the turbines for power augmentation. Various position and angle of attack of the guide vane were tested in this experiment. To avoid negative impact on the performance of the cooling tower fan and to optimize the wind turbine performance, the turbine position on the discharge wind stream was also studied. The result showed that cross-flow wind turbine with a guide vane attached at the right position had a higher coefficient of power than cross flow turbine without guide vane. A cross-flow wind turbine with the guide vane at the position of 150 mm from the center and 30° angles had the highest coefficient of power of 0.49. Comparing to the wind turbine without guide vane, the coefficient of power of the cross-flow wind turbine was increased about 84.3%.

1 Introduction

Nowadays, the wind energy becomes an energy resource that has the fastest growth in the world. According to Global Wind Energy Council by the end of 2015, the global cumulative installed wind capacity by the end of 2015 was 432,883 MW [1]. Unfortunately, the countries that located near the doldrums cannot harness the wind energy as much as the sub-tropic countries. In the Southeast Asian countries such as Indonesia, the wind speed is low (< 4 m/s) and inconsistent throughout the year [2]. Only in a certain location in the Eastern Islands and along the Coast Line, that may have average wind speed more than 5 m/s.

In the city and urban area, the energy consumption is very high. In Indonesia extracting energy from natural wind in the urban area is not feasible because besides the average wind speed is low, there is strong turbulence that caused by the high rise buildings. On the other hand, most of the high-rise buildings in the big city, such as hotels, malls, and office buildings use air conditioning system. The cooling tower of the air conditioning system usually produces exhaust air that has consistent and strong wind speed. A big cooling tower

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can produce wind speed up to 18 m/s at a distance of 0.3 m above the cooling tower outlet [3,4,5]. A small size of wind turbine generator is possible to be installed on the cooling tower exhaust system.

Although Horizontal Axis Wind Turbine (HAWT) is highly developed and widely used in the world, recent research has indicated that Vertical Axis Wind Turbine (VAWT) has higher power density [6]. The disadvantage of most classical wind turbines is not able to start at low wind speed (2-3 m/s). A Savonius wind turbine can operate at low wind speed, but it has a low maximum efficiency [7,8]. A cross-flow wind turbine that is similar to the Banki Water Turbine is relatively a new design of VAWT that is very fast starting in low wind speed [9,10]. It also has high maximum power coefficient [10]. In this study, a cross-flow wind turbine was installed on the cooling tower model.

Unfortunately, the output wind speed of the cooling tower fan is not uniform. At the center of the fan produce the lowest wind speed, and then increase to the maximum at near to the edge of the fan corresponds to the rotor radius [11]. To overcome this non-uniform wind velocity, in this research the influence of a single guide vane, in various horizontal position and angle, to the wind turbine performance was studied. The power consumption of the cooling tower fan was also studied.

2 Experimental Details

The purpose of this experiment was to determine the optimum angle of a single guide vane and its horizontal position to increase the performance of the wind turbine at the outlet of an exhaust air system. A scaled cooling tower model was fabricated to represent an exhaust air system. The model has an axial flow fan with 900 mm diameter and powered by 630 Watt rated motor. The body of the model is similar to the common counter-flow cooling tower. Figure 1 depicts the cooling tower model with a cross-flow wind turbine installed on the outlet. The design of the model was based on the previous research [2,3,4,5,11], but it used a different type of wind turbine.

The detail configuration of the guide vane is shown in Fig. 2 (a). The guide vane dimensions were 80 mm width and 380 mm length. There were seven horizontal positions of the guide vane, in the range of -150 mm to +150 mm, with a distance of every position of 50 mm. The 0 mm was inline vertically with the axis center of the wind turbine. In every position, the angle of the guide vane was varied to 5 different angles; there were 30^o, 45^o, 60^o, 75^o and 90^o. The turbine position on the discharge wind stream was also studied. In this experiment, various horizontal positions of the wind turbine were also studied. The variations were 0 mm to 400 mm from the center of the cooling tower fan (Fig. 2 (b)).

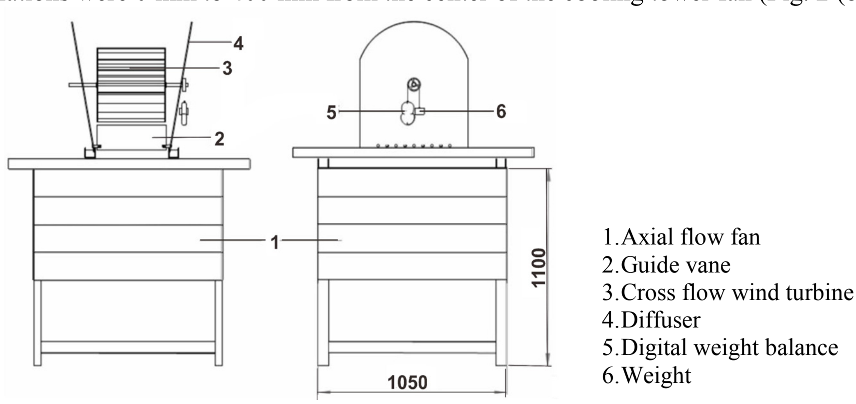
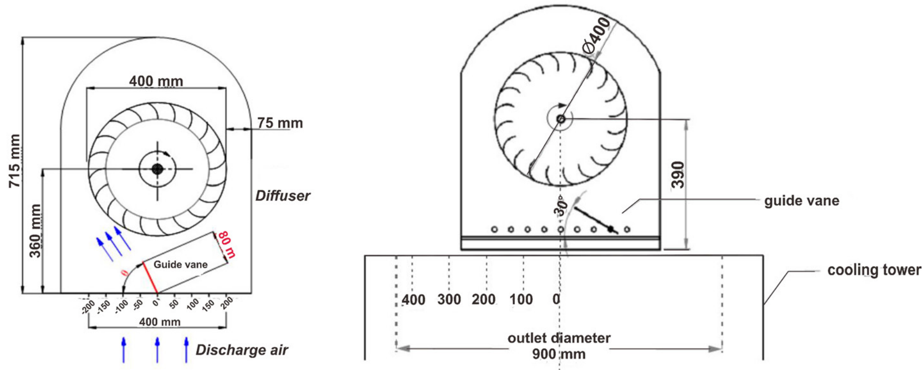


Fig. 1. The test rig of the wind turbine and cooling tower [12].



(a) Guide vane position (b) Wind turbine position

Fig. 2. Guide vane position and turbine position about the center of cooling tower fan.

The wind turbine used in the experiment was a cross-flow wind turbine. This type of the wind turbine was selected because it has a high coefficient of power (C_p), simple and compact construction and can work in any direction of wind speed [10]. The outside diameter of the wind turbine was 400 mm, and the inside diameter was 293 mm. The cross-flow wind turbine has 16 blades. The length of the rotor blade was 380 mm and had a radius of 40 mm.

The data taken from the experiment were the power consumption of the fan motor, the average velocity of the fan, the rotation speed and the torque of the wind turbine shaft. The torque of the shaft was measured by using the prony brake.

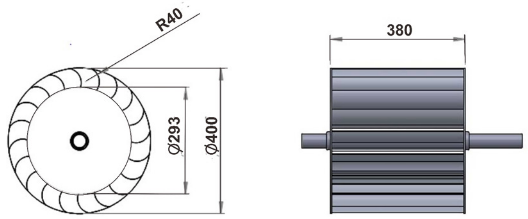


Fig. 3. The cross-flow wind turbine

3 Result and Discussion

The profile of the wind speed output of the cooling tower is shown in Fig. 4. The wind speed profile shows that the minimum speed occurred in the center. The maximum speed achieved at about 400 mm from the center. Due to the no-slip condition, at a position closed to the edge of the fan housing, the wind speed was decreased. The result shows similarity with the previous research [11].

Figure 5 shows the power of the turbine on the various horizontal position of the wind turbine related with the center of the fan. The result shows that without the guide vane the wind turbine produced maximum power of 1.83 W, at 300 mm turbine position. The turbine best position is primarily related with the position of blades that produce positive torque to the turbine, which are about 400 mm from the center. The maximum power of the wind turbine related to the highest wind speed of the fan that occurred near the edge of the fan. The velocity of the wind at this position was 5.97 m/s. Based on the result, the wind turbine was fixed at this position for following guide vane variations.

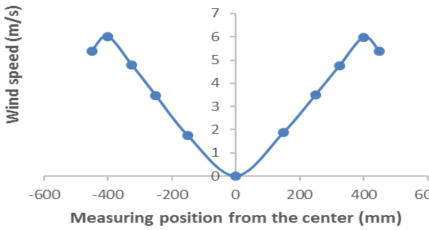


Fig. 4. Wind speed profile at the cooling tower outlet.

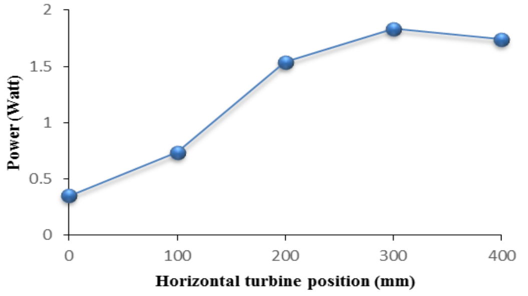
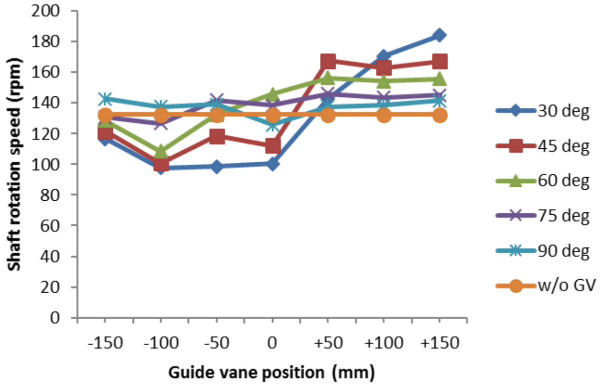
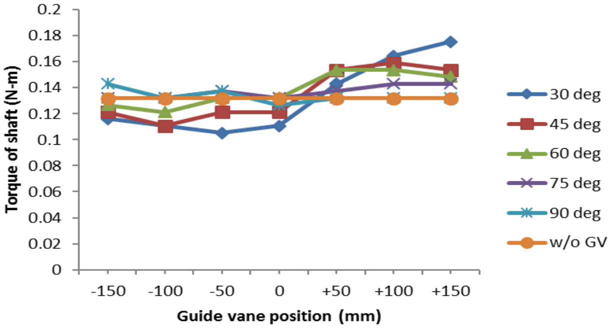


Fig. 5. The power of the wind turbine without guide vane on various horizontal positions.



(a) The rotation speed



(b) Torque

Fig. 6. The rotation speed and torque of the wind turbine shaft on various guide angle and position.

By setting the position of the wind turbine at 300 mm position, the influence of the guide vane angle and position to the shaft rotation speed and torque is shown in Fig. 6. The coefficient of power (cp) chart depicted in Fig. 7, also shows the same trend. There is no guide vane angle that could be superior in every position. The guide vane with 30° angle shows that it had the lowest rotation speed (Fig. 6.a) and torque (Fig. 6.b) for the position from -150 mm to below +100 mm. However starting from +100 mm position the 30° guide vane angle had the highest rotation speed, torque, and cp. At this position, the 30° guide vane angle was able to deliver maximum wind speed to the blades of the wind turbine. The maximum cp achieved by the cross-flow wind turbine was 0.49.

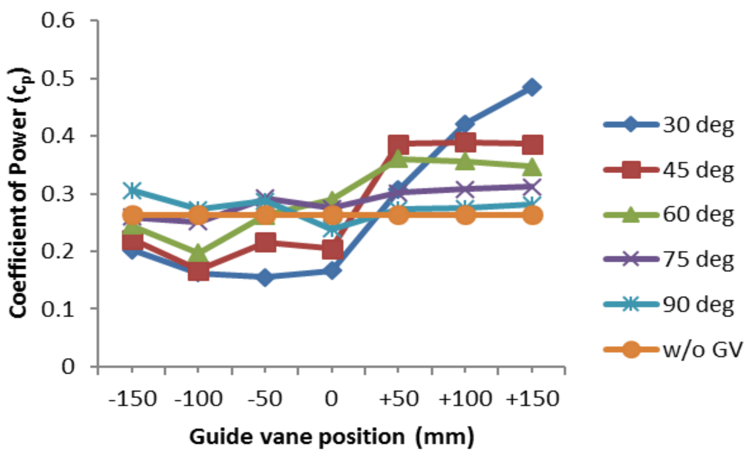


Fig. 7. The power coefficient of the wind turbine on various guide angle and position.

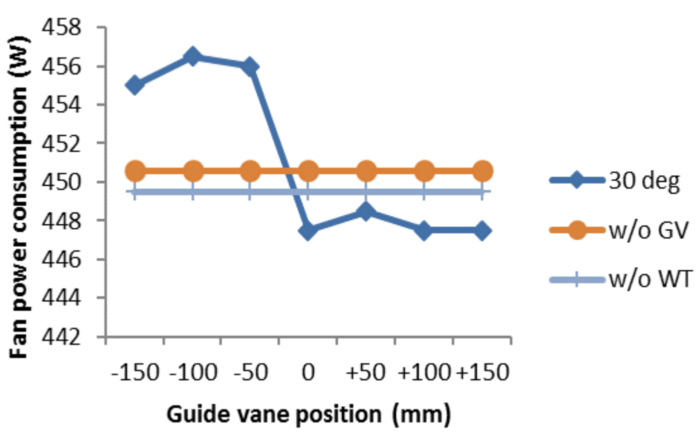


Fig. 8. The cooling tower fan power consumption in various condition.

The influence of the wind turbine installation to the electrical power consumption of the cooling tower fan is depicted in Fig. 8. The installment of the wind turbine increased the power consumption of the fan motor by about 0.24%. By adding the 30° guide vane to the installation, the power consumption of the fan could be reduced at guide vane positions of 0 to +150 mm. At these positions, the average reduction of the power consumption was about 0.39%. At 150 mm, the position for the highest cp, the reduction of the power consumption is 0.45%. It occurred because the speed of the turbine was higher than the incoming wind that created a suction effect. This condition was followed by the increased in wind speed of the intake and power consumption reduction of the fan motor [2]. In the condition, there is not any effect on the cooling tower performance, because the fan power of cooling tower remains constan.

4 Conclusion

As the conclusion, the experiment result showed that some energy from the exhaust of a cooling tower model could be recovered by attaching a cross-flow wind turbine on the cooling tower outlet. The cross-flow wind turbine with a guide vane attached at the right position had a higher coefficient of power than cross flow turbine without guide vane. A cross-flow wind turbine with the guide vane at the horizontal position of 150 mm from the center and 30° angles had the highest coefficient of power of 0.49. Comparing to the wind turbine without guide vane, the coefficient of power of the cross-flow wind turbine was increased about 84.3%.

This work was supported by DP2M DIKTI (Derectorate of Research and Public Service of Derectorate General of Higher Education) Ministry of Research, Technology and Higher Education Indonesia through the grant of Strategi Nasional (Stranas) 2017. The authors appreciate Danang Kurniawan for their experimental cooperation.

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