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PERFORMANCE OF A SAVONIUS TURBINE WITH WINGLET-INSPIRED DEFLECTORS

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ABSTRACT

Deflector is one of the augmentation devices with an excellent power improvement effect on Savonius turbines. However, a flat deflector that is normal to the incoming flow can induce unfavorable vortex formation which affects the flow stability upstream of the turbine, leading to low performance. Therefore, in this study, a winglet-inspired deflector has been adopted and tested at various configurations in a wind tunnel experiment. It is found that the forward winglet configuration results in the highest coefficient of 0.25 (11.4% improvement) and it also improves the self-starting characteristics of the turbine. The deflector with winglet in forward reduces the sudden change in pressure and increase the traveling path of the flow, thus reduces the vortex strength and improves the flow stability upstream the turbine.

KEYWORD

Savonius turbine, deflector, power performance, self-start, renewable energy.

INTRODUCTION

Wind is one of the renewable energy resources that plays a substantial role in generating clean electricity. For a small scale and low cost wind turbine system, Savonius turbine is regarded as the most suitable option due to its simple design, good self-starting characteristics, and low development and maintenance costs (Wong et al., 2017). However, the turbine suffers from low efficiency since it has to overcome negative torque on its returning blade. In order to solve this problem, various methods have been studied such as optimizing the turbine geometry and implementing augmentations devices (Tian et al., 2022a and Marinić-Kragić et al., 2022).

A deflector is one of the augmentation devices which typically mounted upstream of the Savonius wind turbine where its purpose is to divert the incoming flow away from the returning blade, hence reducing the negative torque on the blade (Tian et al., 2022b). With the addition of a deflector on the advancing blade side, the incoming flow can be directed towards the blade thereby increasing the net torque and power performance of the turbine. It has been reported that the turbine's performance can be improved by 150% with the use of two flat deflectors (Kailash et al., 2012). However, the implementation of deflectors could create a wake zone with high turbulence intensities, especially the one that is mounted upstream of the returning blade side (Fatahian et al., 2022a). This scenario could remarkably affect the flow dynamics around the turbine; hence it could deteriorate the turbine's performance. Fatahian et al. (2022b) reported that a strong vortical structure was formed downstream of a circular cylinder deflector as the flow separated from the deflector, thus creating flow instabilities around the Savonius wind turbine.

The vortex formation downstream of the deflector is related to a bluff body problem and it could also exist for a flat deflector, particularly the one that is oriented normally to the incoming flow. For the flat deflector case, the vortex is generally generated as the flow separated at the edges or tips of the deflector (Guini and Green, 213). There are several methods that can be used to control and suppress such vortex formation such as winglets. A winglet is a device used to reduce the tip vortices of an aircraft wings. Recently, several researchers have adopted this method on vertical axis wind turbines of Darrieus type (Laín et al., 2018 and Zhang et al., 2019) and it was found that the winglet can result in power improvement effect on the wind turbines. The same method can be adopted on a deflector-augmented Savonius turbine to reduce vortices downstream of the flat deflector by attaching a winglet on each vertical edge of the deflector.

Therefore, the present study aims to investigate the effects of winglet-inspired deflector on the performance of a Savonius wind turbine. In order to fulfil the objectives, a wind tunnel experiment has been conducted by testing different configurations of the winglet-inspired deflector. The results obtained from the experimental study are compared with that of the flat deflector without the winglet which serves as a baseline.

MATERIAL AND METHODOLOGY

The winglet was adopted for the deflector positioned upstream of the returning blade (called the returning blade deflector). The vertical edges of the returning blade deflector were modified by adding the winglet, as shown in Figure 1(a). Based on the previous studies, the winglet was designed such that its cant angle, $\varphi = 45°$ (Lynch et al., 2018) whereas its length, l was set to be 30 mm in order to avoid collision between the deflector and the turbine. The deflector itself has a height, $h = 132$ mm, width, $w = 183$ mm, and thickness, $t = 5$ mm. The winglet-inspired deflector was made from polylactic acid (PLA) filament in a three-dimensional printing process. A returning blade deflector without the winglet and advancing blade deflector were also fabricated using the same process. In this study, the configurations of the winglet with respect to the incoming flow was varied as shown in Figure 1(b).

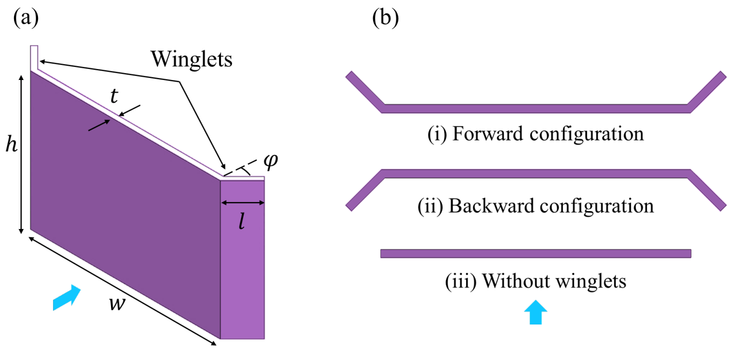

Figure 1. (a)Winglet-inspired deflector design and (b) the configurations of the winglet where the deflector without the winglet serves as the baseline for comparison.

As for the turbine, a conventional two-bladed Savonius wind turbine was considered for the performance analysis. Details on the geometrical design and dimensions of the turbine can be found in Salleh et al. (2020). The turbine and the deflectors were mounted inside the test section of a close-circuit wind tunnel. According to Salleh et al. (2020) the deflector angles for the advancing blade deflector and returning blade deflector were 30° and 90°, respectively as shown in Figure 2.

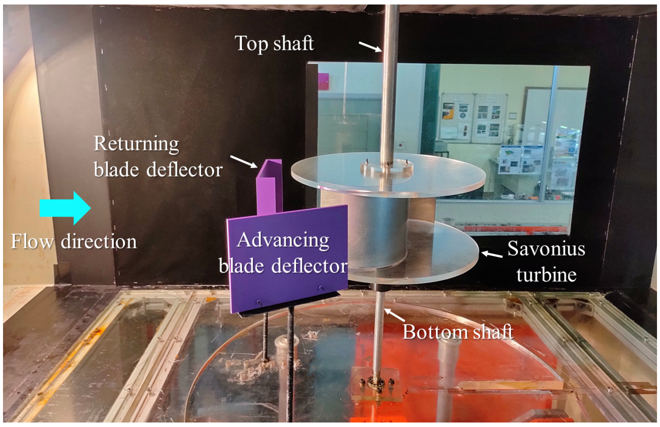

Figure 2. Experimental setup inside the test section of the wind tunnel.

The experiment was conducted at an airflow speed, $U = 7$ m/s (Reynolds number, $Re = 1.48 \times 10^5$). In order to quantify the turbine's performance, the static torque, T_s and the dynamic torque, T of the turbine was measured using a rope brake dynamometer at various blade angle, θ and tip speed ratio, λ, respectively. The turbine's performance was analyzed in terms of coefficient of static torque, C_{T_s} and coefficient of power, C_P given as Eq.(1) and Eq.(2).

$$C_{T_s} = \frac{T_s}{\frac{1}{4}\rho H D^2 U^2} \tag{1}$$

$$C_P = \frac{T\omega}{\frac{1}{2}\rho H D U^3} \tag{2}$$

where ρ is the air density, H is the turbine's height, D is the turbine's diameter, and ω is the angular speed of the turbine. In this experiment, the relative uncertainties for C_{T_s} and C_P were 2.25% and 2.36%, respectively.

RESULT AND DISCUSSION

Figure 3(a) shows the C_P against λ of the Savonius turbine with various winglet configurations. By configuring the winglet forwardly, the turbine exhibits the best power performance with the maximum of $C_P = 0.25$ at $\lambda = 0.80$, i.e., 11.4% improvement compared to the baseline. In contrast, the turbine's performance deteriorates with the winglet configured backwardly where the maximum of $C_P = 0.25$ at $\lambda = 0.68$, i.e., 7.4% lower than that of the baseline. Configuring the winglet at the deflector's vertical edges reduces a sudden change in pressure behind the deflector and at the same time increases the travelling path of the incoming flow. It is inferred that these two factors weaken the vortex formation behind the deflector, hence resulting in a better power performance. On the other hand, since the winglet cant angle, $\varphi = 45°$, the backward configuration increases the bluntness of the deflector which promotes flow separation with a stronger tip vortex. This scenario leads to flow instability that results in power deterioration.

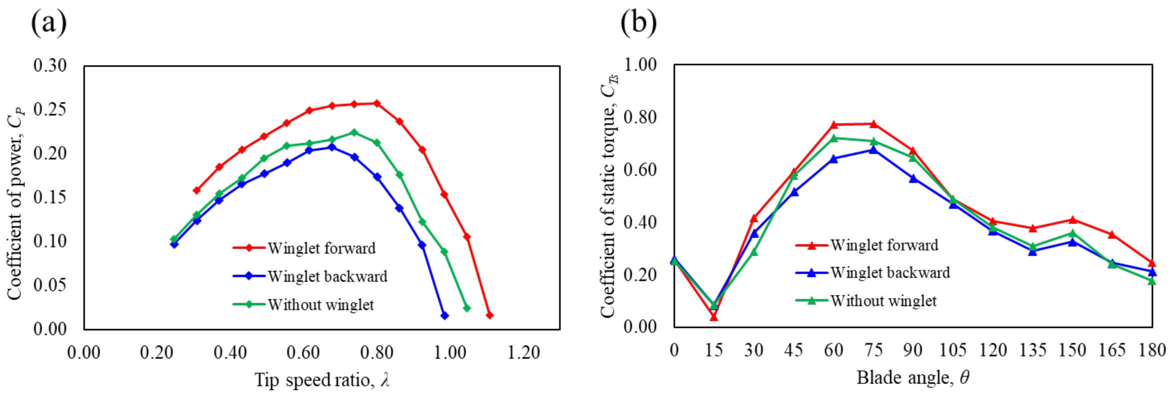

Figure 3. (a) Power performance of the Savonius turbine and (b) self-starting characteristic with various winglet configurations.

The effect of winglet configuration on the self-starting properties of the Savonius turbine can be analyzed based on the C_{T_s} against θ curve, as shown in Figure 3(b). The Savonius turbine with winglet of forward configuration has the highest C_{T_s} at almost all blade angles as compared to those of the backward winglet and without the winglet. High C_{T_s} values indicate the turbine has a better self-starting characteristic. The forward winglet configuration probably minimizes the flow instability which reduces energy loss due to vortex formation. Hence, incoming flow with a larger momentum can be captured by the turbine, resulting in larger C_{T_s} values.

CONCLUSION

In the present study, the effect of a winglet-inspired deflector on the performance of a Savonius turbine has been analyzed. An experimental study had been conducted in a wind tunnel where the winglet-inspired deflector was positioned upstream of the returning blade at various configurations. It is found that the forward winglet configuration results in the best power performance with 11.4% relative to that of without the winglet. Besides, the self-starting properties of the turbine has also improved with the forward winglet configuration.

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