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Experimental Investigation on The Wake Effect of Crossflow Wind Turbines

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ABSTRACT

An optimal design of an aligned configuration using a vertical axis wind turbine especially a crossflow wind turbine to increase rate and power production is one of the problems in wind energy. In the present work, an experimental investigation is presented to evaluate the impact of the wake effect on the dynamic performance of an aligned configuration and compared characteristics of the crossflow wind turbine for 12 x 12 number of blades. In arrays, the spacing parameters of the crossflow wind turbines were conducted with three different spacings (1D; 2D; and 3D) where a crossflow wind turbine was operating downstream of a co-rotating pair. The crossflow wind turbines arranged in inline configurations. Experiments were carried out in a closed-circuit WT-30 aerodynamic laboratory wind tunnel in a ratio velocity of 7.51 m/s. Measurement data of each wind turbines were reported in terms of dimensionless power coefficient (CP) and torque coefficients (CT) for dynamic performance analysis. The experimental results were aligned configuration spacing and the number of blades affects enhancement aerodynamic performance of the downstream crossflow wind turbines. The best performance turbine spacings in aligned configurations are 3D. Wind flow has a distance to be streamlined.

1. Introduction

Nowadays, wind energy has been received much attention as renewable energy [1]. Optimization techniques for enhancing the performance of the renewable energy system are the concern of the researchers [2]. Vertical axis wind turbine (VAWT) configurations can be harvested wind energy more efficiently. Of particular interest has been the spatial and rotational configuration of the turbines which determines the nature of the interaction between the turbines and thus the overall power output of the configurations [3].

The crossflow wind turbine can accept flow from any direction [4], generator often positioned on the ground, low noise emissions [5]. It can attain a high-power coefficient, of about 0.45, comparable to those of horizontal axis wind turbines in V = 2 m/s wind conditions [6]. To increase the efficiency of wind turbines, crossflow wind turbines must be installed together in aligned configuration to

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obtain power station [7]. The aligned configuration efficiency is limited by spacing constraints owing to turbulence or wake effect in the downstream. When one turbine is placed behind another turbine the total acquired energy by the downstream turbine will be less than the upstream turbine due to the wake effect [8]. The positions of turbines in an aligned configuration are adjusted freely so that the wake effects could be further reduced and more wind energy could be captured [9]. In other words, the wake effect is the key factor affecting the low efficiency of wind power production [10].

The objective of this study is not only to investigate the performance of crossflow wind turbines in 7.51 m/s but also developed an experimental tested for spacing optimization for a crossflow wind turbine array to maximize aligned configuration performance. Design crossflow wind turbines have maximum efficiency when 12 blades were used [11]. We conducted experiments in a WT-30 aerodynamic laboratory wind. Measurement data dimensionless parameters were the tip speed ratio, the power coefficient, and the torque coefficient.

2. Experimental Apparatus and Methods

The wind tunnel has a test section with a dimension 0.3 m x 0.3 m. Wind velocity can be adjusted from 0 m/s to 30 m/s. As shown in Figure 1, the crossflow wind turbine design adapted from Dragomirescu geometry of the crossflow runner. These dimensions of the crossflow wind turbine are 200 mm in diameter and 200 mm in height. Moreover, the design values were determined to be those giving maximum efficiency [12]. The twelve bladed crossflow wind turbine is selected in this study. Previous studies proved that the turbine with twelve blades produces the highest coefficient of power [13].

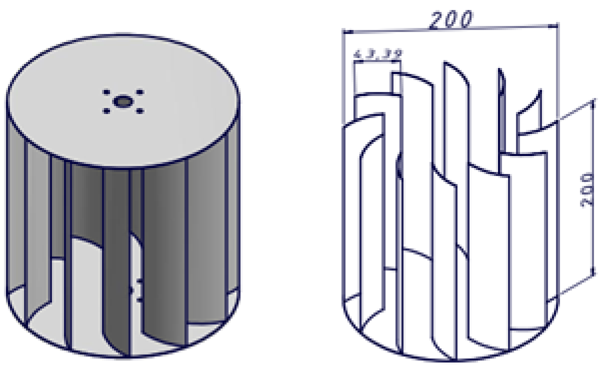


Fig. 1. Size of crossflow wind turbine (mm)

Measurements with three different distances were performed. Crossflow wind turbine was placed 1D, 2D, and 3D in the aligned configuration shown in Figure 2.

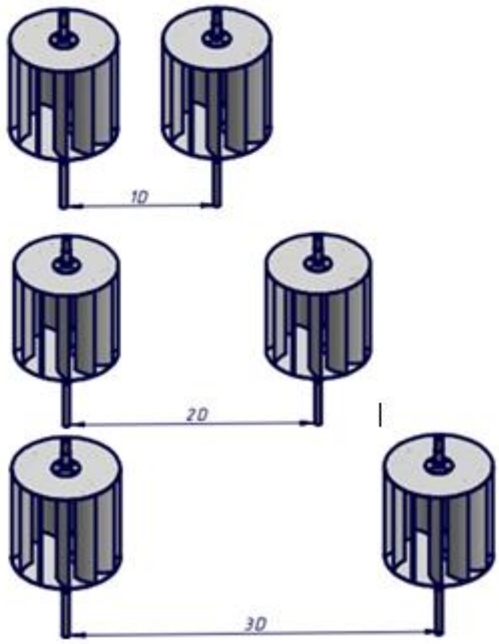
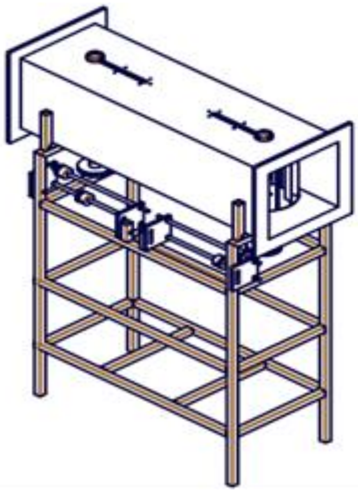


Fig. 2. Aligned configurations (D = turbine diameters)

Figure 3, shows the test section design of the closed-circuit WT-30 aerodynamic laboratory wind tunnel and the positions wind turbine with aligned configurations [14].



Description	WT-30 SUBSONIC WIND TUNNEL
Test section	0.3 m x 0.3 m
Air speed	0 -30 m/s
Power	4 KW/380VAC/3 Phase

Fig. 3. Test section

An anemometer was used to measure the wind speed in the upstream turbine. It shows in Figure 4.

Description	Extech HD350
Air velocity range	1 to 80.00 m/s
Basic accuracy	±1% FS

Fig. 4. Pitot tube anemometer

The rotational speed of the crossflow wind turbine was measured with a digital tachometer KW0600563 model described in Figure 5.

Description	KW0600563
Contact test range	2 to 20,000 rpm
Non-contact test range	2 to 99,999 rpm
Accuracy	± 0.05% + 1

Fig. 5. Tachometer

For measuring the power of engine, the dynamic torque exerted on the rotor shaft was measured with a rope brake dynamometer which consists of one, two or more rope wound around the rim of a pulley (or flywheel) fix rigidly to the shaft of the crossflow wind turbine whose power is required to be measured [15]. Figure 6 shows rope break dynamometer.

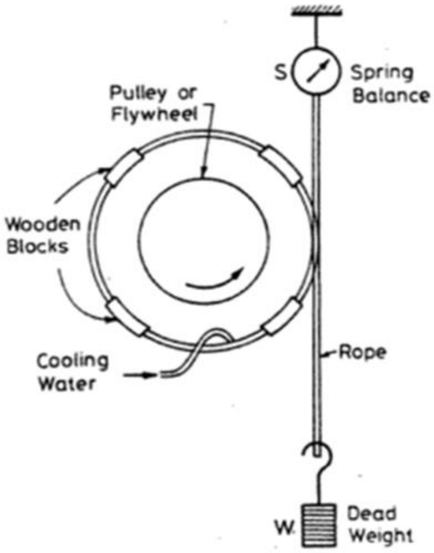


Fig. 6. Rope brake dynamometer [14]

3. Result

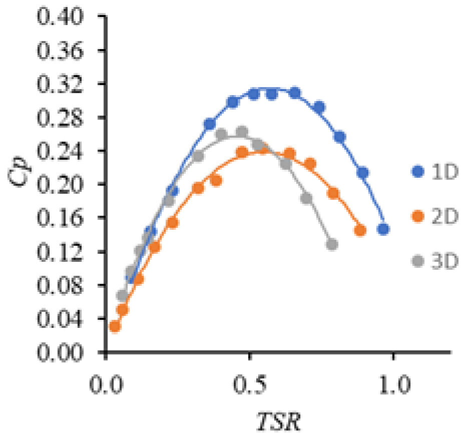
In this section, the results in terms of the power coefficient (Cp) and the torque coefficient (CT) of the crossflow wind turbine against the tip speed ratio (λ) is shown in Figure 6. The power coefficient (Cp) of the crossflow wind turbine described a parabola curve, in which the power coefficient was low at the tip speed ratio (λ) and increased according to the increase of the tip speed ratio and became maximum Cp at a specific tip speed ratio then turned to decrease slowly. Performance crossflow wind turbine in an aligned configuration measure depends on different parameters such as a number of blades and spacings. Measurements with three different spacings were performed. The measured results are well represented in Table 1.

Table 1
Measurement data of the crossflow wind turbine in an aligned configuration

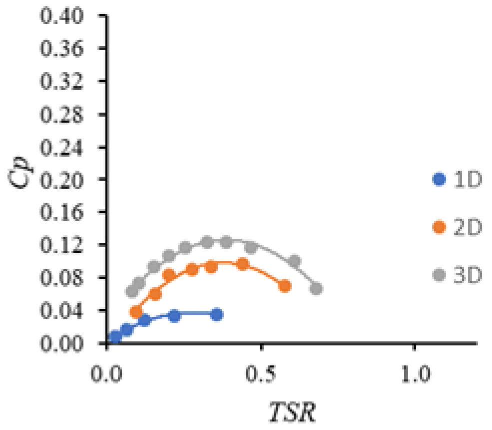
Spacings	Upstream Turbine			Downstream Turbines		
	Cp	TSR	P (Watt)	Cp	TSR	P (Watt)
1D	0.308	0.656	3.065	0.035	0.354	0.346
2D	0.243	0.542	2.413	0.096	0.438	0.953
3D	0263	0.472	2.615	0.124	0.324	1.232

Looking at Figure 7, it can be observed that the front crossflow wind turbine configuration presents substantially low values for power coefficients in spacings 3D. The inlet flow condition is important for the performance of the crossflow wind turbine and the role of each velocity and pressure region at the inlet of the rotor is different. Thus, the effects of flow conditions and incoming flow rates were investigated to clarify the optimum inlet flow condition [16].

When the distance increases to 2D, the power coefficient increases to 0.096. When the distance reaches 3D, the increases to 0.124. However, the increment is slightly from 1D to 3D, which means the recovery of the wake speed is getting better when the distance is larger. In the aligned configuration, the turbine wake regions are centered on the turbine rows and grow radially with distance downwind [17].



(a)



(b)

Fig. 7. Performance curve C_P as a function of TSR for wind speed 7.51 m/s (a) upstream turbine; (b) downstream turbine

The crossflow wind turbine needs the wind to flow to the concave side of the blades to have high positive torque. Also, the wake strength of the wind at the inlet of the turbine as low as possible to get high momentum on the first stage of the blades [18]. If the distance of the downstream turbine is to close to the upstream turbine, the exit wind from the upstream turbine will go to the convex side of the downstream turbine, therefore increase the negative torque. On the other hand, at certain position, i.e. 2D, the wake caused by the upstream turbine is still to strong that reduces the performance of the downstream turbine.

4. Conclusion

Results presented in this paper show that a crossflow wind turbine with spacings 1D; 2D; 3D and two kinds of speeds was proposed and performance tests. The best power coefficient for the upstream turbine in 1D equal to 0.308 with a speed of 7.51 m/s. Furthermore, The best power coefficient for the downstream turbine in 3D equal to 0.124 with a speed of 7.51 m/s.

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