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Wind tunnel interference effects on power performance of small Darrieus wind turbines

* Houigab Jeong[1)], Seungho Lee[2)] and Soon-Duck Kwon[3)]

[1),2),3)] *KOCED Wind Tunnel Center, Department of Civil Engineering*
Chonbuk National University, Chonju, Chonbuk 561-756, Korea

[3)] sdkwon@chonbuk.ac.kr

ABSTRACT

The effect of blockage ratio on wind tunnel testing of small vertical-axis wind turbine has been investigated in this study. Height of the three-blade vertical axis wind turbine was 0.4m and rotor diameter was 0.35m. We measured the wind speeds and power coefficient at three different wind tunnels where blockage ratios were 3.5%, 13.4% and 24.7% respectively. The test results show that the measured powers have been strongly influenced by blockage ratio, generally increase as the blockage ratio increases. The maximum power at higher blockage ratio has been obtained at relatively high tip speed ratio compared with that at low blockage ratio. The measured power coefficients under high blockage ratio can be improved from proper correction using the simple correction equation based on blockage factor. In present study, the correction error for power coefficient can be less than 2%, however correction effectiveness reveals relatively poor at high blockage ratio and low wind speed.

1. INTRODUCTION

The wind power system is getting larger and larger to improve the economic efficiency and showing significant annually growth in wind farms. Small wind power system that can be used in power supply of residential building or streetlight has been growing steadily while the wind power system has been growing focused on enlargement. Standards of small wind turbine generator are different in various countries, but IEC61400-2 has defined small wind turbine as rotor swept area is less than 40m^2 and producing electricity at voltage blow 1000 AC or 1500 DC.

There are two types of wind turbines that can be separated by axis of rotation: horizontal axis and vertical axis. The vertical axis wind turbines can generate electrical power irrespective of wind direction at low wind speed than horizontal axis. For this reason they are being often applied to urban areas and its demand is increasing.

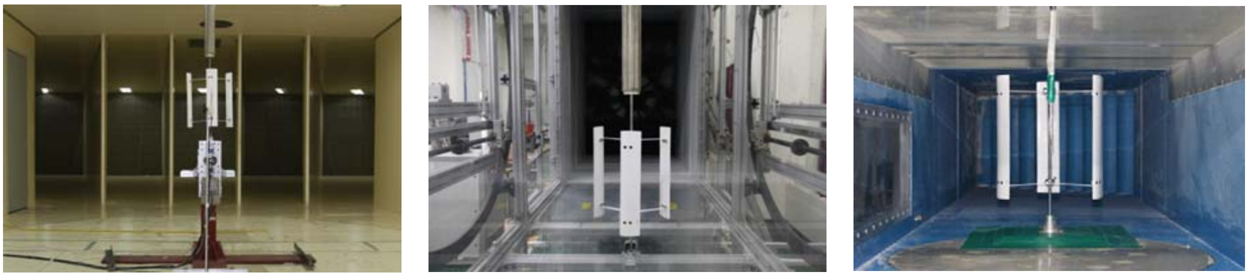
The field test is the only way to verify the power performance of large wind turbines. However, the wind tunnel test can be applicable to small scale wind turbines, and has advantages to reduce the cost and the time in comparison with the field test. In the

[1)] Graduate Student (Presenter)
[2)] Senior Researcher
[3)] Professor (Corresponding Author)

wind tunnel tests of small wind turbines, the blockage effect which is created by limited cross section area of wind tunnel test section can lead to distortion of the power performance of wind turbine. Therefore, it is necessary to check wind speed and generated power by blockage ratio.

The blockage effects of wind turbine have been investigated by several researchers. Most of them were study for horizontal-axis wind turbine and Savonius type(Hirai 2008, Kamoji 2008, Chen 2011, Ross 2011), yet investigation for Darrieus type has been seldom found.

In this study, the effect of blockage ratio on wind tunnel testing of small vertical Darrieus type wind turbine has been investigated. We measured the wind speeds and power coefficient at three different wind tunnels in order to change the blockage ratios. Test results and simple correction method are provided in this study.



(a) Wind tunnel-A (b) Wind tunnel-B (c) Wind tunnel-C

Fig. 1 Wind turbine in wind tunnels.

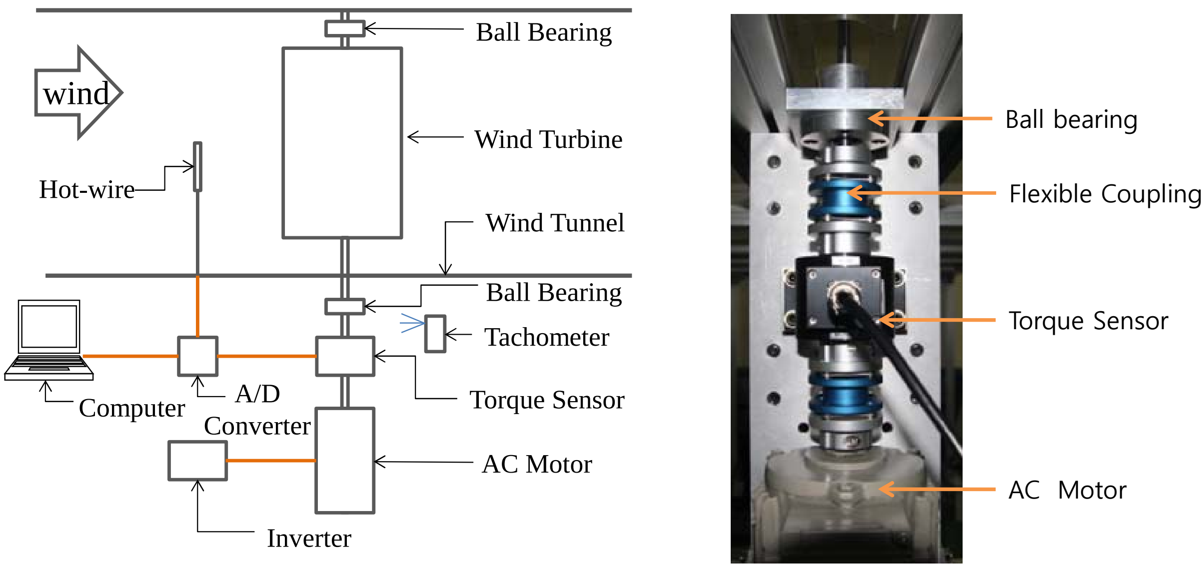
2. WIND TUNNEL TESTS

The present study used vertical Darrieus wind turbine with 3-blades of NACA4415 airfoil. The height of wind turbine blade was 0.4m and rotor diameter was 0.35m. Maximum thickness and chord length of each blade were 12.5mm and 75mm respectively. Fig. 1 shows the wind turbine models installed in three wind tunnels.

Table 1 Wind tunnels and corresponding blockage ratio.

Wind tunnel	Circulation type	Width (m)	Height (m)	Length (m)	Wind speed (m/s)	Blockage ratio (%)
A	Closed circuit	5	2.5	20	0.5 ~ 30	3.5
B	Open circuit	1	1.5	5	0.3 ~ 30	13.4
C	Closed circuit	0.9	0.6	4	0 ~10	24.7

To change the blockage ratio only, the same wind turbine model was installed at three different wind tunnels in KOCED Wind Tunnel Center in Chonbuk National University, Korea. Blockage ratios were 3.5%, 13.4% and 23.4% respectively. Tests were performed at wind velocity of 5m/s. The detailed specifications of wind tunnels are shown in Table 2.



(a) Diagram of the measurement system (b) Substructure of model

Fig. 2 Experimental setup.

Fig. 2 shows measurement system and substructure of model. As shown in Fig. 1, only blade part was installed inside the wind tunnel and vertical-axis shaft that support the blade was held by ball bearing. This shaft was finally connected to the AC motor through the torque sensor which measured mechanical torque generated by wind. Tip speed ratio (TSR) of rotating blades was controlled using inverter and AC motor. We measured wind speed at 0.9m upstream of the rotor. Blockage factor (*BF*) and Power coefficient (C_P) can be obtained from the measured data using the following relations.

$$BF = \left(\frac{U_T}{U_F} \right)^3 \tag{1}$$

$$C_P = \frac{T^{WT}\omega}{\frac{1}{2}\rho A_S U_F^{\ 3}} \tag{2}$$

where U_F is free stream wind speed, U_T is tunnel wind speed at the rotor, T^{WT} is mechanical torque acting on the wind turbine rotor, ω is rotor angular speed, ρ is density of air and U_S is rotor swept area.

3. TEST RESULTS

Fig. 3 shows the relationships between blockage factor and tip speed ratio under three different blockage ratio. As shown in figure, blockage factor decreases as tip speed ratio and blockage ratio increases. This is because flow of the air is more interrupted at high tip speed ratio condition.

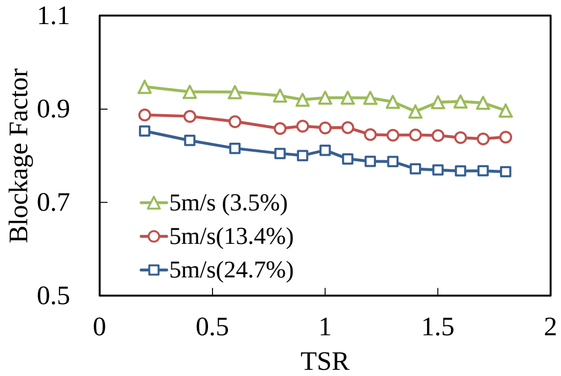
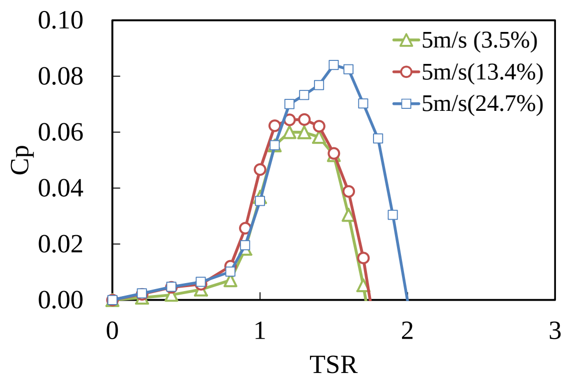


Fig. 3 Relationships between blockage factor and tip speed ratio.

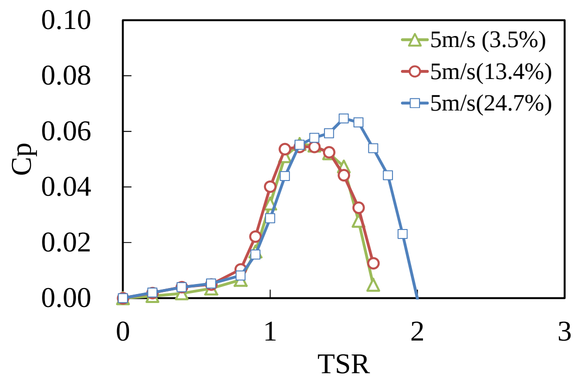
Fig. 4 shows the relationships between power coefficient and tip speed ratio before and after correction. Maximum power coefficient and optimal tip speed ratio increase as the blockage ratio increases. The maximum power at higher blockage ratio has been obtained at relatively high tip speed ratio compared with that at low blockage ratio. These results indicate that the power coefficient was significantly overestimated by blockage effect. Therefore we corrected the power coefficient using simple correction equation based on blockage factor.

$$C_{PF} = C_{PT}\left(\frac{U_T}{U_F}\right) \quad (3)$$

where, C_{PF} is power coefficient in free stream and C_{PT} is power coefficient in the wind tunnel. As shown in Fig. 4(b), the power coefficient is improved significantly after correction based on Eq. (3). However the correction effectiveness reveals relatively poor at high blockage ratio and low wind speed.



(a) Before correction



(b) After correction

Fig. 4 Relationships between power coefficient and tip speed ratio for three different blockage ratio.

4. CONCLUSIONS

Wind tunnel test was performed in order to investigate power performance of small vertical-axis wind turbine by blockage ratio. The maximum power coefficients and the optimum tip speed ratio have been strongly influenced by blockage ratio, generally increased as the blockage ratio increases. These represent that the power performance of wind turbine was overestimated under high blockage ratio. The measured power coefficients under high blockage ratio can be improved from proper correction using the simple correction equation based on blockage factor. In present study, the correction error for power coefficient can be less than 2%, however correction effectiveness reveals relatively poor at high blockage ratio and low wind speed.

ACKNOWLEDGEMENT

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