Renew. Energy Environ. Sustain. **1**, 36 (2016)

DOI: 10.1051/rees/2016043

Renewable Energy and Environmental Sustainability

Available online at:
www.rees-journal.org

RESEARCH ARTICLE

OPEN ACCESS

Influence of the side-by-side arrangement on the performance of a small Savonius wind turbine

Choon-Man Jang[1,*], Sang-Moon Lee[1], Reeho Kim[1], and Jang-Ho Lee[2]

[1] Korea Institute of Civil Engineering and Building Technology, Environmental and Plant Eng. Res. Div., Goyang-Si 411-712, Republic of Korea

[2] Kunsan National University, School of Mechanical and Automotive Engineering, Kunsan-Si 573-701, Republic of Korea

Abstract. Scaled-down Savonius turbine rotors arrayed side-by-side are introduced to analyze the effects of design parameters on the performance between turbine rotors. Unsteady flow simulation and experimental measurement have been performed to compare turbine performance and validate the numerical simulation of the turbine rotor. Commercial code, SC/Tetra, which uses an unstructured grid system, has been used to solve the three-dimensional unsteady Reynolds-averaged Navier–Stokes equations. Single turbine rotors and two turbine rotors arrayed side-by-side were numerically analyzed. The distance between rotor tips is 0.5 times the rotor diameter. Throughout the numerical simulation, the power coefficient obtained by the time-averaged result of unsteady flow simulation was found to be in good agreement with the experimental result. A discussion on the design parameters using both a single and arrayed turbine rotors is presented based on the results of the unsteady flow simulation, including the flow field, power coefficient, velocity and vorticity contours.

1 Introduction

The Savonius small wind turbine driven by drag force offers many advantages: it is simple, robust, and has a low cut-in velocity and small vibration. Small wind turbines have been widely used for residential electricity generation due to their low noise. Experimental and numerical simulations have been performed in order to clearly understand their internal flow, and to increase turbine efficiency [1]. Wenehenubun et al. [2] carried out an experimental study to investigate the effect of the number of blades on the performance of a model of a Savonius wind turbine. They showed that the turbine with three blades has the best performance at a high tip speed ratio. Dobrev and Massouh [3] captured the instantaneous flow field and velocity vectors at the inside and around the Savonius rotor using a particle image velocimeter (PIV) system.

Although the measured velocity fields are similar to the results obtained using numerical simulation, it is difficult to capture a detached vortex structure through a numerical simulation. Jaohindy et al. [4] and McTavish et al. [5] showed the internal flow and performance data of a Savonius turbine through steady and unsteady numerical simulation. They pointed out that the shear stress transport (SST) k–ω turbulence model was an effective approach to analyzing the turbine rotor.

Golecha et al. [6] studied the effects of the distance between two Savonius turbine rotors, placed one in front of the other, on the turbine performance. They found the optimal distance between the two rotors that would maximize the turbine performance.

Wake generated at the front turbine affects the following turbine rotor and the rotating direction of the rotor, thus changing turbine performance.

Most of the studies mentioned above describe the performance of Savonius turbines without considering the effects of the rotation direction of turbine rotors arrayed side-by-side.

In the present study, the influence of the side-by-side arrangement on the performance of scaled-down Savonius turbine rotors arrayed side-by-side are analyzed through unsteady flow simulation and compared to the results of experimental measurements.

2 Specifications of the test Savonius turbine

Figure 1 shows the design specifications of the Savonius wind turbine rotor used in the present study. Two simple semi-circular turbine blades are symmetrical with respect

* e-mail: jangcm@kict.re.kr

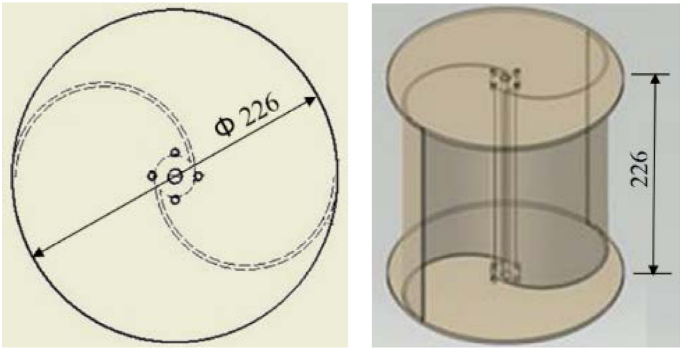


Fig. 1. Configuration of scaled-down Savonius turbine rotor.

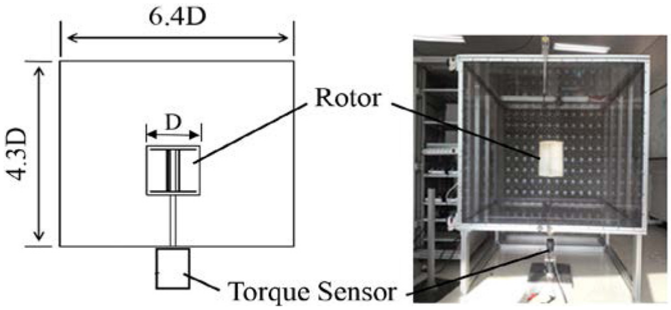


Fig. 2. Experimental apparatus.

to the axis of rotation. Rotor diameter, D, and height have the same value of 226 mm. That is, the aspect ratio is 1.0. The rotor was manufactured using a high-precision three-dimensional printer.

The Savonius rotor is a vertical axis wind turbine that operates due to wind drag forces on advancing and returning buckets. The rotor has many advantages: high static and dynamic moment, robustness, low noise and low cost.

3 Experimental apparatus and numerical simulation

Figure 2 shows the layout and picture of the experimental apparatus for measuring turbine rotor torque. As can be seen, the torque sensor directly connected to the rotor is installed at the outside of the wind tunnel. The length of the wind tunnel is 2034 mm. 96 small fans are attached at the tunnel inlet to control the air flow rate.

To provide a uniform flow with constant turbulence intensity at the upstream of the turbine rotor, a mesh was installed following the inlet fans. Turbulence intensity at the present wind tunnel is in the range of 3–5%. Inlet flow velocity and turbulence intensity are measured using a hot-wire anemometer. The rotating frequency of the rotor is determined with a tachometer. Measured data is transmitted to a computer via a data acquisition system (NI USB 6210).

A commercial CFD code, SC/tetra [7], which employs a discontinuous mesh, has been used to solve the governing equations of the three-dimensional steady and unsteady flow around the wind turbine blades. SST model [8] with a scalable wall function was employed to estimate the eddy viscosity.

Figure 3 shows the computational domain and details of the computational grid. The distance between turbine rotor and outlet is maintained at 6.5D to allow the development of wake flow following the rotor. A tetrahedral element is imposed where the prism element having six layers is introduced near the blade walls. The whole grid system in the present simulation has about 800,000 nodes. In terms of the boundary conditions, a velocity of 4.9 m/s is specified at the inlet, and natural outflow condition is imposed at the outlet.

4 Array of turbine rotors

In the present study, the effects of installation distance between two turbine rotors arrayed side-by-side on the performance of the rotors is analyzed through an unsteady flow simulation. The installation distance between two turbine rotors, "d", is defined in Figure 4.

The distance between turbine rotor tips is 0.5 times the rotor diameter. Turbine rotors are located symmetrically with respect to the x axis. The rotational directions and the tip speed ratio (λ) have been fixed as clockwise direction and 0.6, respectively.

5 Results and discussion

5.1 Validation of numerical simulation

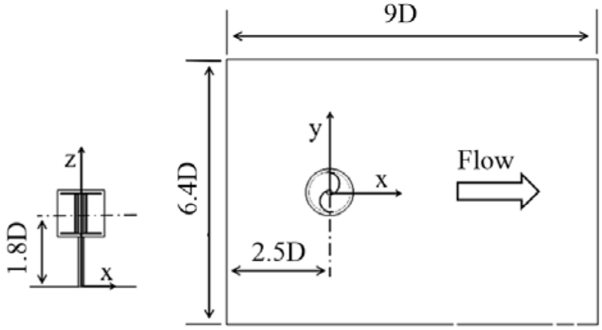
To validate the present numerical simulations, the power coefficient (C_P) is compared to the experimental results with respect to tip speed ratio, as shown in Figure 5. Results of the unsteady numerical simulation are obtained through phase averaging, excluding the transitional feature.

Figure 5 shows that the power coefficient obtained through unsteady numerical simulation agrees well with the experimental results, although the steady numerical simulation has a difference around the tip speed ratio of 0.9. The power coefficient obtained by unsteady numerical simulation has a maximum error of 5% in comparison with the experimental data. Considering this difference, only the unsteady numerical simulation was used.

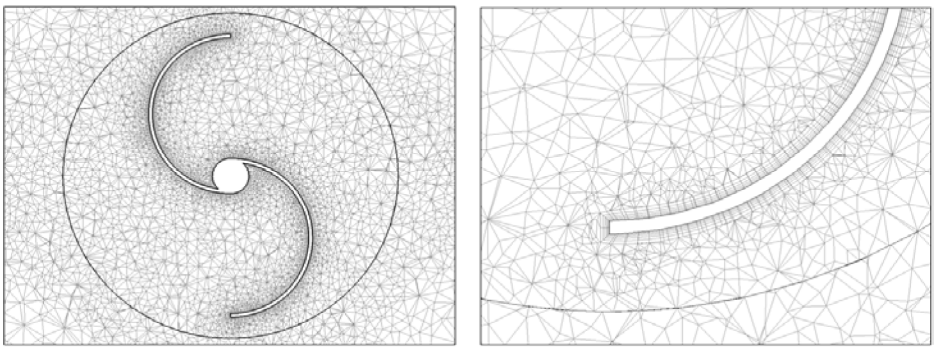
5.2 Influence of the side-by-side arrangement on the performance of the turbines

To understand the performance of the arrayed Savonius turbines, the power coefficient is compared to that of the single turbine rotor in Figure 6. It is noted that the power coefficient of the arrayed turbines is about 7% lower than that of the single turbine.

For the arrayed turbine rotors, WT2 has a slightly higher power coefficient than WT1. As shown in Figure 6, a sinusoidal variation of the power coefficient over time is clearly observed for the single turbine rotor, although a locally deformed pattern is generated at the rotation angles between 180 and 300 degrees.



(a) computational domain



(b) computational grid system

Fig. 3. Computational domain and grid system. (a) Computational domain. (b) Computational grid system.

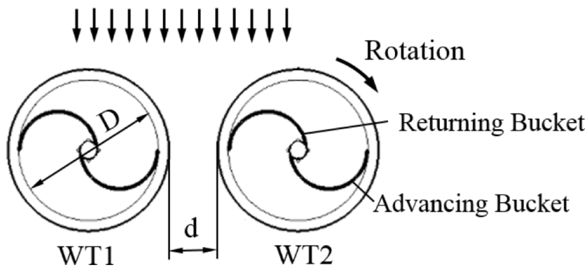


Fig. 4. Definitions of design parameters for rotors arrayed side-by-side.

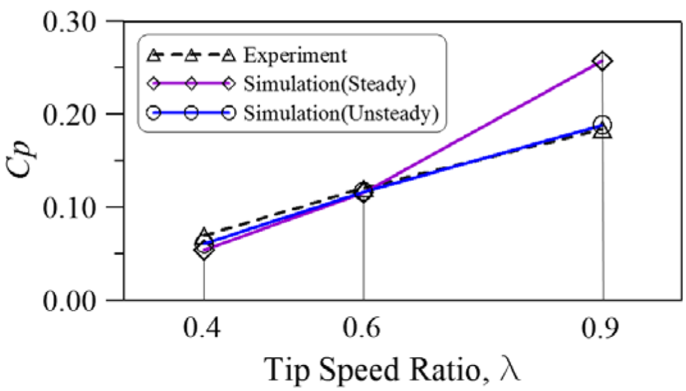


Fig. 5. Comparison of experimentally and numerically obtained power coefficients.

Figure 7 shows the velocity and vorticity distributions of the single and the arrayed rotors at different time moments. High velocity is observed at the tip of the advancing blade for the single rotor due to the velocity of rotation in a clockwise direction at 180 degrees. Although the velocity at the tip of the advancing blade of WT2 is higher than that of the single rotor due to a blockage effect caused by the arrayed rotors, the high velocity of the neighboring rotor (WT1) affects the returning blade of WT2. This flow interference between the arrayed rotors induces flow instability, thus generating a larger wake flow that has high vorticity compared to the single rotor. The aerodynamic interaction between the two rotors adversely affects the performance and generates the larger downstream vortical flow.

6 Conclusions

Unsteady numerical simulation for Savonius turbine rotors arrayed side-by-side was performed to evaluate the turbine performance in comparison to the performance of a single turbine. The turbine performance obtained by the time-averaged result of unsteady flow simulation was found to be in good agreement with the experiment result. The power coefficient of the arrayed turbine rotors is about 7% lower than that of a single turbine rotor. This is mainly the result of flow interference between arrayed rotors, which induces flow instability and a larger wake flow having high vorticity.

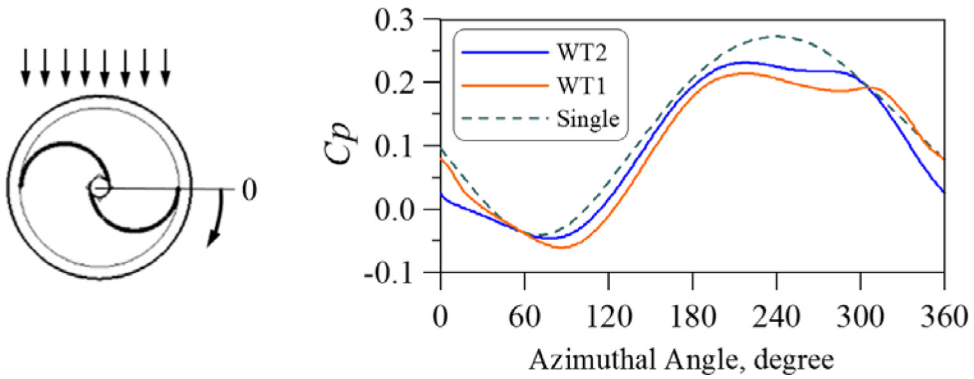


Fig. 6. Power coefficient with respect to azimuthal angle for $\lambda = 0.6$.

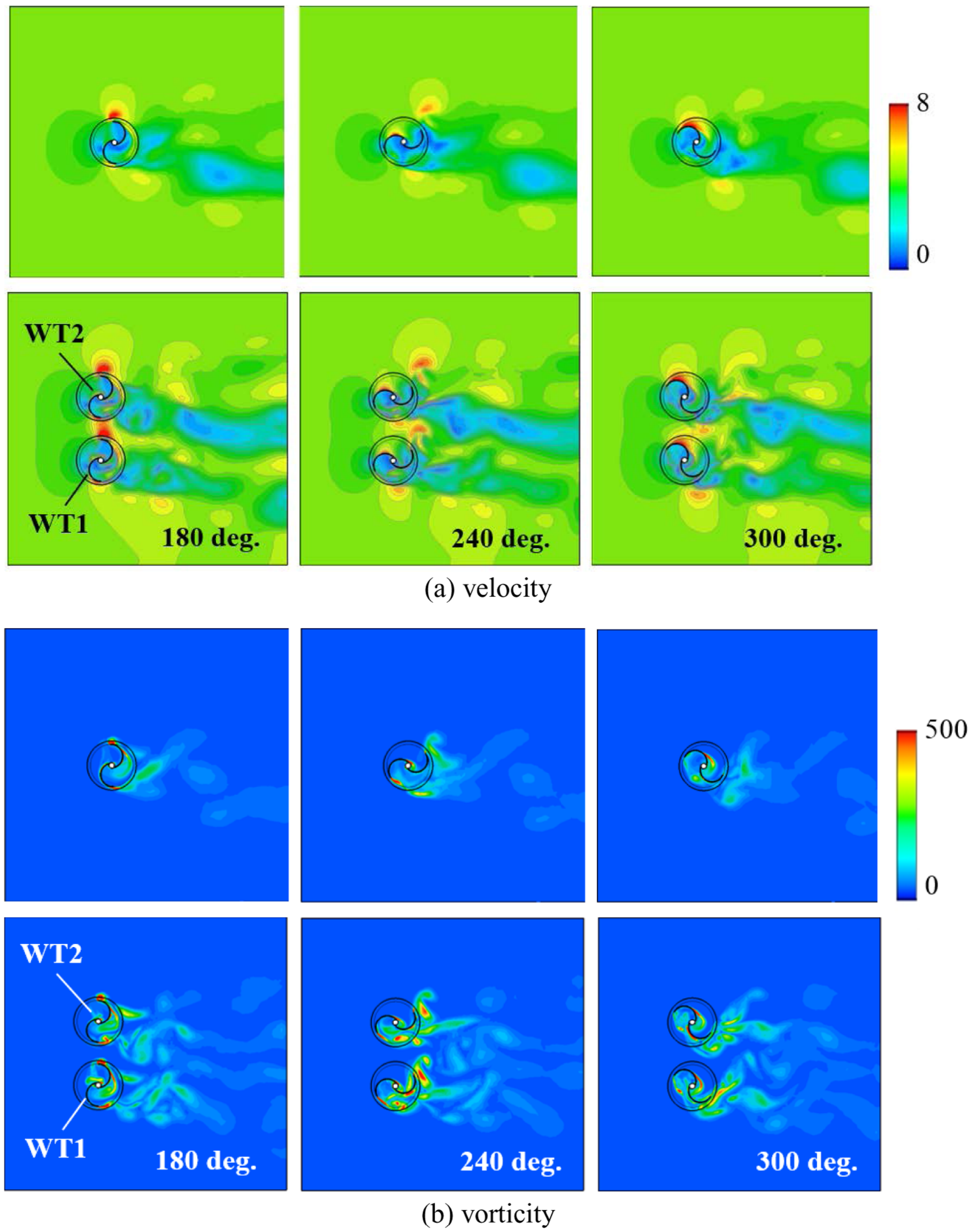


Fig. 7. Velocity and vorticity with respect to azimuthal angle for $\lambda = 0.6$. (a) Velocity. (b) Vorticity.

This study was supported with major project funding from the Korea Institute of Civil Engineering and Building Technology.

References

1. J.V. Akwa, H.A. Vielmo, A.P. Petry, A review on the performance of Savonius wind turbines, Renew. Sustain. Energy Rev. **16**, 3054 (2012)
2. F. Wenehenubun, A. Saputra, H. Sutanto, An experimental study on the performance of Savonius wind turbines related with the number of blades, Energy Proc. **68**, 297 (2015)
3. I. Dobrev, F. Massouh, CFD and PIV investigation of unsteady flow through Savonius wind turbine, Energy Proc. **6**, 711 (2011)
4. P. Jaohindy, S. McTavish, F. Garde, A. Bastide, An analysis of the transient forces acting on Savonius rotors with different aspect ratios, Renew. Energy **55**, 286 (2013)
5. S. McTavish, D. Feszty, T. Sankar, Steady and rotating computational fluid dynamics simulations of a novel vertical axis wind turbine for small-scale power generation, Renew. Energy **41**, 171 (2012)
6. K. Golecha, T.I. Eldho, S.V. Prabhu, Study on the interaction between two hydrokinetic Savonius turbines, Int. J. Rotat. Mach. **2012**, 581658 (2012)
7. SC/Tetra 9.0, *User Guide* (Software Cradle Co. Ltd., Osaka, Japan, 2010)
8. F.R. Menter, Two-equation Eddy-viscosity turbulence models for engineering applications, AIAA J. **32**, 1598 (1994)

Cite this article as: Choon-Man Jang, Sang-Moon Lee, Reeho Kim, Jang-Ho Lee, Influence of the side-by-side arrangement on the performance of a small Savonius wind turbine, Renew. Energy Environ. Sustain. **1**, 36 (2016)