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Research paper

Analysis of Savonius Rotor Performance Operating at Low Wind Speeds Using Numerical Study

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Abstract

This paper investigates the sensitivity of time step and time increment on the performance of 180-degree twist helical Savonius rotor using commercial computational fluid dynamic code based on flow-driven method. The best combination of time step and time increment was first determined by comparing simulated rotational speed with the actual rotor speed generated by wind speed of 5 m/s. Other rotational speeds at 2, 3, 4 and 6 m/s are then predicted based on this condition. The results show that time step and time increment have a significant impact on the accuracy of the predicted rotor rotational speed (RPM). A small time increment and a large time step require longer computational time but in return give closer rotor RPM to the actual experiment. On the contrary, a larger time increment with smaller time step dramatically reduced the computational time but resulted in poor rotor RPM prediction. The results also show that the closest RPM predicted by this analysis is when the time step and time increment were at 8000 and 0.0015 seconds respectively. This paper concludes that an accurate prediction of rotor rotational speed can be achieved by setting the right combination of time step and time increment.

Keywords: *CFD, Flow Driven, Savonius, Sensitivity study.*

1. Introduction

There has been a growing interest in technology for harvesting wind energy in low density wind energy countries like Malaysia in recent years. To this end, solar-wind turbines have been proposed for electrification of street lightings and other low powered devices. Savonius rotors which are categorized as vertical axis wind turbine (VAWT) have been proven to be performing well in low wind speeds condition compared to horizontal axis wind turbine (HAWT) [1]. In addition to ease of manufacturing, VAWTs have an excellent ability to operate at low tip-speed ratio [2][3].
The performance of such Savonius rotor can be evaluated by several methods. The common test used is aerodynamic performance test and numerical study. The Aerodynamic performance test requires wind tunnel [3] which is time consuming and could lead to high cost in fabrication of an appropriate measurement system [4]. Due to the complexity of flow structure and high cost of experimental test, a numerical study via Computational Fluid Dynamics (CFD) is getting very popular [5].
There are several aspects need to be considered when performing a numerical study. The accuracy of this analysis is dependent upon choosing the right parameters. Besides, the use of right turbulence model will also determine the accuracy of the simulation result [5]. The domain size, grid or mesh size and time step should be taken care by sensitivity study or independency test [5][6]. K. Rogowski and R. Maroński [7] suggested that the optimum domain size should be 10 times larger than rotor diameter. A smaller domain size will result in an overestimated value of power coefficient. Sufficient meshing density near the rotor is important to estimate power coefficient accurately [8].
This paper focuses on performing numerical analysis on a helical Savonius with 180-degree twist angle by manipulating the time step and time increment operating at a wind speed ranges from 2 m/s to 6 m/s. The output rotational speed (RPM) generated at various wind speeds are compared with the experimental result. This study used a commercial computation fluid dynamic code, AcuSolve.

2. Savonius Rotor

A typical helical Savonius rotor is shown in Figure 1. The power, P generated by such a rotor can be written as

$$P = T.\omega \quad (1)$$

where T = Torque generated by rotor, N.m and ω = angular velocity, rad/sec. Torque of rotor is the product of rotor moment of inertia, ‘I’ with angular acceleration, ‘α’. i.e.

$$T = I.\alpha \quad (2)$$

It is known that the angular velocity increases with increasing wind velocity but the torque tends to drop after reaching the optimum tip speed ratio (TSR) of about 1 as in (3).

$$TSR = \omega .\ r / U \quad (3)$$

where, r is the rotor radius and U is the incoming wind velocity. Since the rotor is expected to operate at below TSR of 1, only angular velocity or rotational speed is considered in this study as a measure of performance.

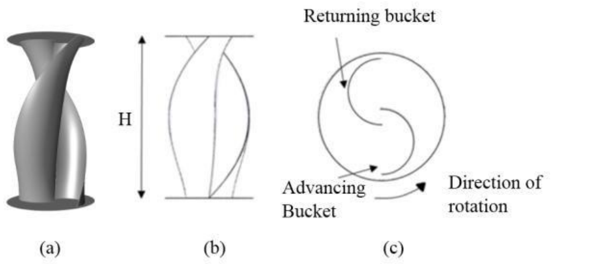

Fig. 1: (a) CAD model of Helical Savonius rotor using Solidworks, (b) Side view, H = height of the rotor, (c) Top view – the circle represents the end plate.

Factors affecting the performance of a Savonius rotor include end plates, aspect ratio, bucket spacing and overlap, number of buckets and rotor stages [2]. The additional augmentation device without changing the blade design parameter also can lead to a better wind turbine performance [9]. The effects of those parameters on rotor performance have been studied by several researchers. The addition of end plates on both end of Savonius rotor increases the performance of the rotor. The end plates prevent the wind from concave side; advancing bucket (please refer to Figure 1 (c)), to the external flow. Thus giving enough pressure difference between two buckets of the rotor to continuously rotate [2]. The end plates also increase the amount of air capture by the rotor buckets [10]. The best dimension for the end plates is 1.1D which 10 % larger than the rotor diameter [1, 2].

2.1. Geometry model

The Savonius rotor with two semi buckets that are placed 180-degree apart and attached to end plates is used in this study. Its aspect ratio is two. Basic geometrical parameters of the rotor are given in Table 1.

Table 1: Basic parameter of Savonius rotor

Parameter	Value
Height, H	1 m
Diameter, D	0.5 m
Overlap ratio	0.242
Twist angle	180-degree
Rotors thickness	0.003 m
End plate diameter	1.1D
End plate thickness	0.002 m

2.2. Savonius wind turbine fabrication

The model of the Savonius rotor parts were fabricated by using 3D printer. The completed rotor blades were then covered with carbon printed sticker as shown in Figure 2. The end plates are made of 0.002 m aluminium with 0.55 m in diameter. The weight of the assembly is about 4.0 kilograms.

Fig. 2: Savonius rotor with 180-degree twist angle model fabricated using 3D printer.

3. 3-D Domain and Boundary Condition

The 3D computational domain shown in Figure 3 is basic component of the geometry used for the numerical study. The rectangular domain is referred to a fixed domain and the cylindrical domain is called a rotating domain [6] as shown in Figure 3. The rotor is placed inside the rotating domain. The size of domain is 16D x 16D x 30D whereas D is the rotor diameter.

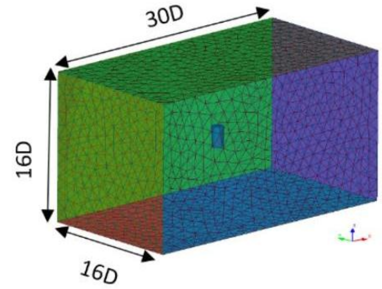

Fig. 3: 3-D computational domain with x, y and z dimension in term of rotor diameter.

3.1. Mesh Generation

The rotor is set to mesh size of 0.01 m while the computational domain is set to 0.05 m mesh size. The mesh generated for the fixed domain and rotating domain with denser mesh around the rotor is shown in Figure 4. Three level of boundary layer with 1.3 growth rate was defined around the rotor surface with the first layer height of 0.001 m to ensure a smooth transition of the mesh size throughout the domain. The total number of 1,339,710 elements generated based on this parameter setup.

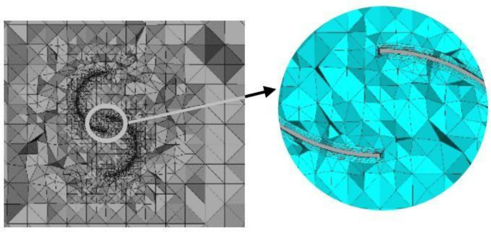

Fig. 4: Sectional view of the mesh generated in the computational domain. The boundary layer formation around the rotor surface

3.2. Boundary Condition

Details of the boundary conditions are shown in Figure 5. The rotor surface is set as non-slip wall. The input parameter at inlet, wall of the fixed domain, the interface between two domains, and outlet are defined as shown in Table 2. The inflow velocity was set to 5 m/s as initial input parameter. At this stage, the proposed two quantities to be manipulated i.e. time step and time increment merit further explanation. Time step is the total number of iterations to be performed by the solver in order to achieve the desired solution. Time increment or number of iterations on the hand is the time interval in seconds required to capture the flow field features within the time step. Therefore, the total simulation time is obtained by multiplying time step with time increment. A different combination of time step and time increment is given in Table 3. At present study, the experimental rotational speed at 5 m/s wind speed was first compared with the simulated RPM. The parameter which produces the least error is used to predict the rotor RPM at various wind speeds.

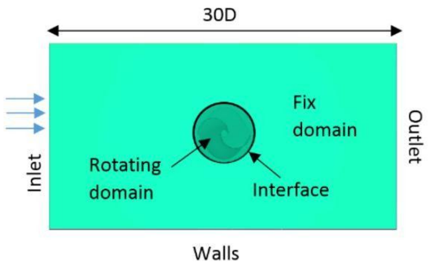

Fig. 5: Boundary condition and domain used in analysis

Table 2: Basic input parameters of analysis

Parameter	Boundary Condition
Inlet	Cartesian velocity on x-axis
Outlet	Atmospheric pressure
Wall	Slip
Interface	No boundary condition

Table 3: Time step – time increments pairs

Parameter	Time step	Time increments (sec)
1	300	0.1
2	600	0.0125
3	1200	0.00625
4	2400	0.0045
5	3000	0.003125
6	6000	0.002
7	8000	0.0015
8	10000	0.001

3.3. Numerical Method

The analysis presented in this paper was carried out using commercial CFD code, AcuSolve which is a finite element based solver running on a 16 core machine. The RANS turbulence model of Spalart Allmaras (S-A) was selected for faster computational time. Unlike other researchers, where the sliding mesh method is normally used, this study employed the flow-driven approach. This approach is based on the concept of rigid body dynamics hence the value of moment of inertia of the rotors is required. The main advantage of this approach is that it allows for easy and natural mapping between simulated and actual results.

4. Result and Discussion

The results of the sensitivity study for 5 m/s wind speed is shown in Figure 6. At this wind speed, the reference rotational speed generated by the actual experiment is 208 RPM. The blue curve shows the predicted RPM with respect to the different combination of time step and time increment pairs. Likewise, the percentage of errors from the reference RPM is given by the orange curve. It is clearly seen that the percentage of errors (more than 80%) is recorded at parameter 1 and it reduces dramatically to 5 % at parameter 7. At parameter 8, the predicted RPM is higher than the reference value. A combination of smaller time step and larger time increment which is characterized by parameter 1 seems far too a short time for convergence thus giving rise to large percent- age of errors. The larger time step is required to predict stable value of the rotor rotational speed while the smaller time increment is preferred in order to achieve an acceptable degree of accuracy. As the time step increases and time increment decreases, the errors appear to reduce to almost zero.

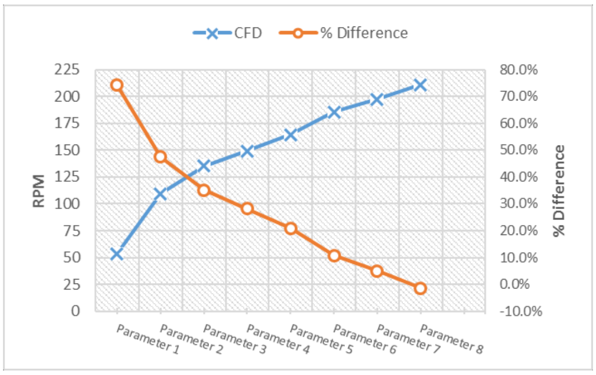

Fig. 6: Accuracy of predicted rotational speed at different testing parameters. RPM = angular velocity in unit of revolution per minute.

Table 4 shows the computational time for different parameters. Parameter 7 took 35 hours to obtain the accurate results using a 16 core machine. It may take longer for lesser core machine.

Table 4: Computational time

Parameter	Time (hours)
1	1
2	3
3	6
4	12
5	14
6	23
7	35
8	44

Figure 7 compares the predicted rotational speeds based on parameter 7 with the actual experimental data. The results show a very close relationship between these two curves. With the exception of 2 m/s, errors recorded to 3, 4, 5 and 6 m/s are within 1 to 5 %.

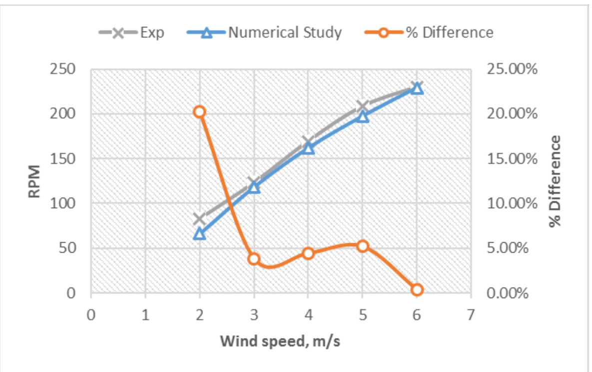

Fig. 7: Comparison of numerical and experimental result at various wind speeds.

5. Conclusions

The selection of right input parameters for CFD analysis is very important to ensure an acceptable accuracy of its results. In this study, it is shown that a combination of time step and time increment can yield a high degree of accuracy at the expense of higher computational time. The optimum parameter obtained is when time step and time increment are set at 8000 and 0.0015 sec respectively. This is equivalent to 12 seconds of actual rotor rotation. Sensitivity study must be done prior to selecting the best parameters for the analysis. Work is currently being undertaken to fully evaluate the rotor performance by computing the torque coefficient and power coefficient.

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References

[1] Belkacem B. & Paraschivoiu M., "CFD Analysis of a Finite Linear Array of Savonius Wind Turbines", *Journal of Physics: Conference Series*, 753, (2016).

[2] Akwa J. V., Vielmo H. A. & Petry A. P., "A review on the performance of Savonius wind turbines", *Renewable and Sustainable En- ergy Reviews*, Vol.16, No.5, (2012), pp.3054-3064.

[3] Ubando A., Maralit A., Nyanasengeran K., Timothy Pua M., Marcelino M., and Louie Moran R., "Computational Fluid Dynamics Analysis and Optimization of a Savonius Vertical Axis Wind Turbine for De La Salle University Campus", *Proceedings of the DLSU Research Congress*, Vol.3, (2015).

[4] Lee J., Lee Y. and Lim H., "Effect of twist angle on the performance of Savonius wind turbine", *Renewable energy*, Vol.89, (2016), pp.231-244.

[5] Shahizare B., Nik-Ghazali N., Chong W., Tabatabaeikia S., Izadyar N. & Esmaeilzadeh A., "Novel Investigation of the different Omni-direction-guide-vane angles effects on urban vertical axis wind turbine output power via three-dimensional numerical simulation", *Energy Conversion and Management*, Vol.117, (2016), pp.206-217.

[6] Alaimo A., Esposito A., Messineo A., Orlando C. & Tumino D., "3D CFD analysis of a Vertical Axis Wind Turbine", *Energies*, Vol.8, No.4, (2015), pp.3013-3033.

[7] Rogowski K. & Maroński R., "CFD computation of the Savonius rotor", *Journal of Theoretical and Applied Mechanics*, Vol.53, No.1, (2015), pp.37-45.

[8] Sharma S. & Sharma R. K., "Performance improvement of Savonius rotor using multiple quarter blades – A CFD investigation", *Energy Conversion and Management*, Vol.127, (2016), pp.43-54.

[9] Zemamou M., Aggour M. & Toumi A., "Review of Savonius wind turbine design and performance", Energy Procedia, Vol.141, (2017), pp.383-388.

[10] Mahmoud N. H., El-Haroun A. A., Wahba E. & Nasef M. H., "An experimental study on improvement of Savonius rotor performance", Vol.51, No.1, (2012), pp.19-25.