

Flow-driven simulation on variation diameter of counter rotating wind turbines rotor

Y. Fredrika Littik¹, Y. Heru Irawan², and M. Agung Bramantya^{3*}

^{1,3}Department of Mechanical & Industrial Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia

²Mechanical Engineering, STTNAS Yogyakarta, Indonesia

Abstract. Wind turbines model in this paper developed from horizontal axis wind turbine propeller with single rotor (HAWT). This research aims to investigating the influence of front rotor diameter variation (D_1) with rear rotor (D_2) to the angular velocity optimal (ω) and tip speed ratio (TSR) on counter rotating wind turbines (CRWT). The method used transient 3D simulation with computational fluid dynamics (CFD) to perform the aerodynamics characteristic of rotor wind turbines. The counter rotating wind turbines (CRWT) is designed with front rotor diameter of 0.23 m and rear rotor diameter of 0.40 m. In this research, the wind velocity is 4.2 m/s and variation ratio between front rotor and rear rotor (D_1/D_2) are 0.65; 0.80; 1.20; 1.40; and 1.60 with axial distance (Z/D_2) 0.20 m. The result of this research indicated that the variation diameter on front rotor influence the aerodynamics performance of counter rotating wind turbines.

1 Introduction

Application of wind energy as an alternative energy using wind turbines have been carried out in Indonesia. Wind turbines are used as a power generation system that converts kinetic energy of wind into mechanical energy to drive an electric generator.

Horizontal axis wind turbine propeller type with single rotor is a wind turbine models commonly used in Indonesia. Single rotor wind turbine according to the blade diameter is divided into micro (≤ 0.1 m), small scale (0.1 m < diameter ≤ 1 m), medium scale (1 m < diameter ≤ 5 m), and large scale (> 5 m).

The ideal maximum power coefficient of wind turbine dual rotor through actuator disk theory is 64%. Assuming a ratio of the axial velocity on the first rotor is 0.2 and 0.6 on the second rotor. Kumar et al [4], based on the theory of momentum (Betz limit), the maximum energy conversion efficiency of single rotor wind turbine about 59% while the counter rotating wind turbine with the same swept area increased to 64%.

Various research has been conducted to investigating the influence of diameter rotor using computational fluid dynamics (CFD) aims to analysis aerodynamics performance in wind turbine rotor, both numerically and experimentally demonstrated that ratio of the diameter influenced the performance of counter rotating wind turbine. However, variations in the diameter of the rotor used is still partially in a generally simulation methods. In this research uses the fixed axial distance between front rotor and rear rotor, k- ω turbulence models (SST), the solution method Coupled-Scheme and simulation Flow-Driven for analyze aerodynamics performance of rotor wind turbine.

2 Methodology

2.1 Computational Fluid Dynamics (CFD)

Computational fluid dynamics (CFD) used to indicate the numerical solution of the different governing equations of fluid flows. It aims to calculate and analyze a problem that exists. In this case the computer is used as a medium for doing calculations in the form of iteration. CFD consists of three equations set the basis of the calculation process performed computer. The basic principle of a CFD is discretized set into the algebra equations that can be solved by a computer. Equation set in CFD consists of conservation of mass that show in equation (1) and conservation of momentum in equation (2), (3), (4), can be written in Cartesian coordinates as follows:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{V}) \quad (1)$$

$$\frac{\partial(\rho u)}{\partial t} + \nabla \cdot (\rho u \vec{V}) = -\frac{\partial \rho}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x \quad (2)$$

$$\frac{\partial(\rho v)}{\partial t} + \nabla \cdot (\rho v \vec{V}) = -\frac{\partial \rho}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho f_y \quad (3)$$

$$\frac{\partial(\rho w)}{\partial t} + \nabla \cdot (\rho w \vec{V}) = -\frac{\partial \rho}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + \rho f_z \quad (4)$$

Where t is the time, ρ is the density of the fluid, u is the velocity of a fluid particle, ∇ is the divergence, V is volume, τ is the viscous stress tensor, and f is represents of the inertial forces.

Three phases of the problem analysis in CFD consist of preprocessor, solver, and post-processing. The simulation conducted using k- ω turbulence model. This

* Corresponding author: bramantya@ugm.ac.id

model performs well with free shear flows, flat plate boundary layer flows, complicated adverse pressure gradient flows and separated flows.

2.2 Counter rotating wind turbines

Lee et al [5], a counter rotating wind turbines (CRWT) is the development of a dual rotor horizontal axle wind turbine, having two rotors rotating in opposite direction on the same axis. The Counter rotating wind turbine model design used in the research can be seen from Table 1.

The independent variables used in this study are variations on wind speed (u) of 4.2 m/s with the variation in the rotor diameter of the front and rotor ratios (D_1/D_2) 0.65; 0.80; 1.20; 1.40 and 1.60. The controlled variable is the ratio of axial distance between two rotors (Z/D_1) is 0.20 m.

Table 1. Properties of counter rotating wind turbines rotor.

Rotor	Front	Rear
Diameter (mm)	230	400
Position	Upwind	Upwind
Airfoil	NACA 0012	NACA 0012
Rotation	Clockwise	Counter clockwise
Material	Balsa wood	Balsa wood

2.3 Flow-Driven Simulation

Flow-driven simulation is a numerical approximation method used by the researcher to calculate the optimal angular velocity of both wind turbine rotor. Calculations are performed every time step until it reaches convergent and stable. This simulation uses the help of a six degree of freedom (6DOF) solver contained in ANSYS Fluent, to determine the direction of rotation of the wind turbine rotor. Using the force and moment imposed in this case the rotor to calculate the translational motion and rotational motion where its center of gravity has been defined.

Equation (5) is an integral form of the conservation equations contained in Flow-Driven simulation:

$$\frac{d}{dt} \int_V \rho \phi dV + \int_{\partial V} \rho \phi (\bar{u} - \bar{u}_g) \cdot d\bar{A} = \int_{\partial V} \Gamma \nabla \phi \cdot d\bar{A} + \int_V S_\phi dV \quad (5)$$

Where ρ is the fluid density, \bar{u} is the flow velocity vector, \bar{u}_g is the mesh velocity of the moving mesh, Γ is the diffusion coefficient, and S_ϕ is the source term of ϕ .

2.4 Setup and Solution Solver Simulation

The general setup used in this 3D simulation is a Transient Pressure-Based type, with turbulence model of SST $k-\omega$ As for the solution method used Coupled-Scheme with second order implicit and time step size 0.01. For mesh controls use advanced size function on Proximity and curvature with high smoothing sizing mesh. Quality inspection mesh should be taken to ensure no errors

during the iterative process, but it also affects the quality of the mesh generated numerical solutions. The steps in this simulation can be seen in the following fig. 1.

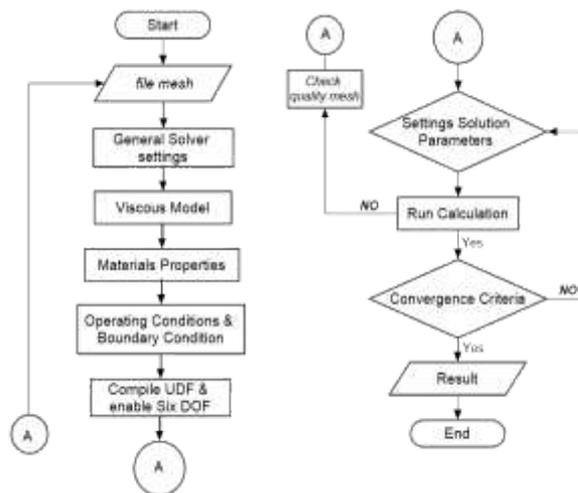


Fig 1. Simulation steps

3 Result and Discussion

The 3D simulation results of counter rotating wind turbines show that varying the rotor diameter ratio of front rotor to rear rotor with an incoming wind speed of 4.2 m/s, has an effect on the aerodynamics performance of the rotors.

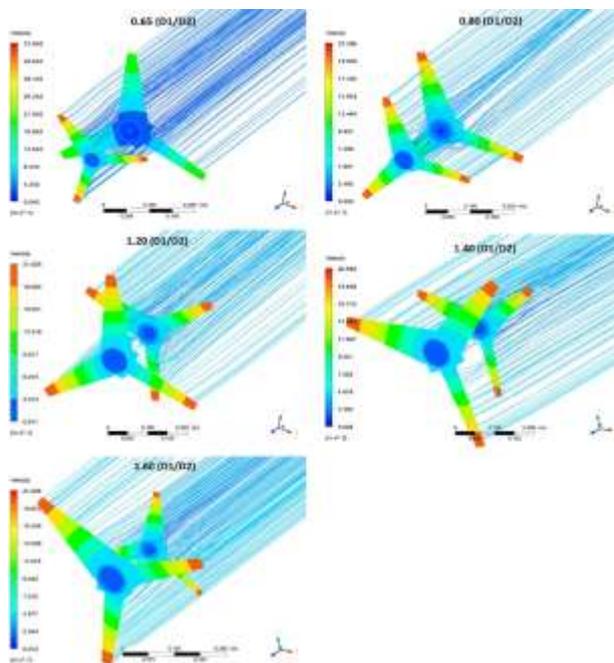


Fig 2. Result of the simulation in 3D contour of velocity

As shown in fig. 2, the wind velocity that occurs in the front rotor and rotor rear with a diameter ratio of 0.65 increases almost reaching 33.64 m/s (front) and 29.44 m/s (rear) in stable condition and optimal rotation speed. While the ratio of diameter 0.80 decreased wind speed on both rotor by 19.91 m/s, the ratio of diameter 1.20 wind velocity that occurred on the rotor increased by 21.03 m/

s due to the larger diameter of the rotor, the ratio of diameters 1.40 and 1.60 has a speed the highest wind is almost the same on both rotor pieces that is equal to 18.64 m/s and 18.67 m/s.

The highest wind speed occurs at the tip of rotor, either on the front or rear rotor at optimum rotation conditions. As for the lowest speed is in the hub of rotor, especially on the rear rotor.

Table 2. Comparison two model wind turbines.

Wind Turbines Model	Front Rotor		Rear Rotor	
	ω (rad/s)	TSR	ω (rad/s)	TSR
SRWT	-	-	120.30	5.73
CRWT (0.65 D1/D2)	290.62	9.00	110.03	5.24
CRWT (0.80 D1/D2)	139.71	5.32	108.18	5.15
CRWT (1.20 D1/D2)	87.29	4.99	104.91	5.00
CRWT (1.40 D1/D2)	74.74	4.98	103.70	4.94
CRWT (1.60 D1/D2)	65.53	4.99	98.06	4.67

Table. 2 shows the performance of wind turbines with single rotor and dual rotor. The angular velocity with a single rotor using rotor rear as a comparison with counter rotating wind turbines.

The simulation results obtained by a single rotor wind turbine (SRWT) has an angular velocity of 120.30 rad / s and TSR 5.73, this is more or less consistent with the assumption (TSR = 5-6) for a three-blade wind turbine. The counter rotating wind turbine with a diameter ratio of 0.65 has an angular velocity of the front rotor of 290.62 rad / s and TSR 9, this is because the rotational speed of the rotor is too high. As for the ratio of diameters from 0.80 to 1.60 TSR values ranged from 4 to 5, this is influenced by decreased angular velocity on the front rotor and rear rotor.

4 Conclusions

Counter rotating wind turbines with variations in diameter only the front rotor effect on wind turbine aerodynamic performance, judging by the wind velocity occurring at the rotor end of the front and rear following the change in diameter size from the front rotor to the same axial distance. At a ratio of diameter of 1.20 be it the front rotor and the rear rotor, has a high wind speed at the tip of rotor is 21.03 m / s. This shows the stability of the rotational speed at this diameter ratio better than the ratio of the other diameter, so also when viewed from the results of angular velocity and its TSR. The greater the number of blades on a wind turbine rotor, the greater the angular velocity and the decreasing TSR value.

References

1. C.J. Bai, W.C. Wang, Review of Computational and Experimental Approaches to Analysis of Aerodynamic Performance in Horizontal-Axis Wind Turbines (HAWT's), *Renewable and Sustainable Energy Reviews*, vol. **63**, pp. 506-519, (2016)
2. A.D. Hoang, C.J. Yang, Design and Performance Evaluation of a 10 kW Scale Counter Rotating Wind Turbine Rotor, *Journal of The Korean Society of Marine Environment and Safety*, vol. **20**, pp. 104-112, (2014)
3. S.N. Jung, T.S. No, K.W. Ryu, Aerodynamic Performance Prediction of a 30 kW Counter Rotating Wind Turbine System, Jeonju : ResearchGate, (2004)
4. P.S. Kumar, A. Abraham, R.J. Bensingh, and S. Ilangoyan, Computational and Experimental Analysis of a Counter Rotating Wind Turbine System, *Journal of Scientific and Industrial Research*, vol. **72**, pp. 300-306, (2013)
5. S. Lee, H. Kim, E. Son, S. Lee, Effects of Design Parameters on Aerodynamic Performance of a Counter Rotating Wind Turbine, *Renewable Energy*, vol. **42**, pp.140-144, (2012)
6. M.A. Bramantya, L. Al Huda, An Experimental Study on The Mechanics Power of Counter Rotating Wind Turbines Model Related with Axial Distance Between Two Rotors, *6th International Annual Engineering Seminar (InAES), Yogyakarta, Indonesia*, (2016)
7. L. Oggiano, CFD simulations on the NTNU wind turbine rotor and comparison with experiments, *Renewable Energy Research Conference, Energy Procedia* vol. **58**, pp. 111 – 116, (2014)
8. W.Z. Shen, V.A.K Zakkam, J.N. Sorensen, K. Appa, Analysis of Counter-Rotating Wind Turbines, *Journal of Physics: Conference Series* **75**, pp. 012003, (2007)
9. Y.H. Irawan, M.A. Bramatya, Numerical Simulation of The Effect of Axial Distance Between Two Rotors in Counter-Rotating Wind Turbines, *2nd International Conference on Science and Technology Computer (ICST), Yogyakarta, Indonesia*, (2016)