Effect number of blades on the performance of h-Darrieus wind turbine with NACA 0018 air foil

Yogie P Sibagariang¹, Wahyu Hamdani², Koki Kishinami³ and Himsar Ambarita⁴

¹Mechanical Engineering Department, Universitas Sumatera Utara, Medan 20155, Indonesia
²Sustainable Energy Research Centre, Universitas Sumatera Utara, Medan 20155, Indonesia
³Mechanical Engineering Department, Muroran Institute of Technology, 27-1 Mizumoto, Muroran 8585, Hokkaido, Japan

⁴Email: himsar@usu.ac.id

Abstract. Wind energy is renewable energy and can be used as an alternative energy source. To harvest wind energy, wind turbines are used. The low power coefficient of the vertical axis wind turbine (VAWT) is one of its drawbacks. To overcome this, numerical research was carried out using a variation of the blade on NACA 0018. CFD-Fluent use in this research with turbulent model $k - \varepsilon$. The number of blades 3, 4, 5, and 6 each tested at a tip speed ratio of 1.8. The result of the simulation is plotted and discussed as contour velocity, the maximum power coefficient obtained at the number blades 5 is 0.589.

1. Introduction

Many potential renewable energy sources are abundant and can be used. One of them is wind power. Wind power can be harvested using wind turbines. There are various types of wind turbines in the field. Wind turbines can be divided into two types based on their axis of rotation, Vertical Axis Wind Turbines (VAWT) and Horizontal Axis Wind Turbines (HAWT). Various research has been done to increase the performance of H-Darrieus wind turbine. Lee et al conducted experimental and numerical research of 500 W vertical axis wind turbine to investigate aerodynamic performance, results demonstrate that when solidity increases it causes the power coefficient to increase at low tip speed ratio (TSR) [1]. Haitian et al numerically investigated effect flow-deflecting-gap (FDG) blade on aerodynamic characteristics of vertical axis wind turbine, the results show FDG decrease optimal TSR and improve the power coefficient at low TSR [2].

Hamdani et al conducted numerically studies effect of TSR on H-Darrieus Wind Turbine. Numerical simulations run with tip speed ratio from 1.65 to 1.8. Result show that tip speed ratio strongly affected power coefficient [3]. Hao Su et al. [4] conducted experimental investigation vertical axis wind turbine with pitching and self-starting function, results show use of auxiliary blade has a significant impact on power performance of wind turbine. Pramono et al. [5] numerically investigated the effect of chord length on the performance H-Darrieus wind turbine, it was concluded that the chord length greatly affected the power. Hashem et al. [6] studied numerically aerodynamics performance increment of H-
rotor Darrieus wind turbine, the results show that S1046 a sectional profile has a highest power coefficient. Omar et al. [7] conducted numerical simulation using ANSYS Fluent code to study of Darrieus wind turbine with slotted airfoil blades. Results show the slotted airfoil significantly increases the power coefficient and torque coefficient, at TSR 2 slotted turbine has a power coefficient is 0.3 and maximum torque coefficient of 0.15 at TSR 2. Abdalrahman et al. [8] has numerical research by controlling the pitch angle to increase output power wind turbine using ANSYS Fluent, results demonstrate that use multilayer perceptron artificial neural network (MLP ANN) has a highest power than conventional controller. Ali et al. [9] conducted numerical research of wind turbine aerodynamic performance with instantaneous tangential velocity (ITV) effect, finding show that ITV has a negative value for single blade, and positive value for three blades.

From the various literatures above, many things affect the performance of wind turbines. And there has not been much discussion related to the power coefficient specifically in the NACA 0018 model. This research was conducted numerically to determine the effect of the number of blades on the power coefficient in the model mentioned above.

2. Mathematical model and method
In this study, the type of wind turbine used is the vertical axis wind turbine shown in Figure 1(a). The wind turbine used is the NACA 0018 airfoil and is shown in Figure 1(b). 2-dimensional geometry with a rotating region is constructed as in Figure 1(c). The specifications of the wind turbines used are shown in Table 1. To get the results mentioned above, a 2 D model is built as shown in Figure 1(a) in this research, the development of H-Darrieus VAWT will be used as a model to be investigated. The developed H-Darrieus VAWT is shown in Figure 1(a).

![Figure 1. VAWT and CFD model](image)

| **Table 1. Turbine specifications** | **Name** | **Value** | **Unit** |
|-----------------------------------|----------|-----------|----------|
| Blade Profile                     | NACA 0018| -         |          |
| Diameter Rotating Region          | 1.5      | m         |          |
| Tip Speed Ratio                   | 1.8      | -         |          |
| Pitch Angle                       | 60       | degree    |          |
In this study, a numerical study was conducted using Ansys Fluent's Computational Fluid Dynamic software. The dimensional model used is a two-dimensional model and turbulence model uses the k-epsilon model because this model has sufficient stability, economy and accuracy for various types of turbulent flow. In this study, the simulation is the variation of the number of wind turbine blades from 3, 4, 5 and 6, with a constant tip speed ratio of 1.8 and inlet wind speed 4 m/s. The governing equation used such as the continuity equation and momentum equation are written as follows [10]

\[
\rho \frac{D u_i}{Dt} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_i} \left[ \mu \left( \frac{\partial u_i}{\partial x_i} + \frac{\partial u_j}{\partial x_j} - \frac{2}{3} \frac{\partial u_i}{\partial x_i} \right) \right] + \frac{\partial}{\partial x_j} \left( -\rho u_i u'_j \right)
\]  

(1)

The Reynolds-stresses equation is written as follows

\[
-\rho u_i u'_j = \mu_t \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) - \frac{2}{3} \left( \rho u_i + \mu_t \frac{\partial u_i}{\partial x_i} \right) \delta_{ij}
\]  

(2)

The standard \( k - \varepsilon \) turbulence equation proposed by Launder and Spalding [11] can be used to solve the above equation and with the addition of the two equations for turbulent kinetic energy( \( k \)) and turbulent dissipation rate \( \varepsilon \) are written as follows:

\[
\rho \frac{Dt}{Dt} = \frac{\partial}{\partial x_i} \left( \mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_i} + G_k + G_b - \rho \varepsilon - Y_m
\]  

(3)

\[
\rho \frac{D \varepsilon}{Dt} = \frac{\partial}{\partial x_i} \left( \mu + \frac{\mu_t}{\sigma_{\varepsilon}} \right) \frac{\partial \varepsilon}{\partial x_i} + C_{\varepsilon} \frac{\varepsilon}{k} \left( G_k + C_{3_k} G_b \right) - C_{\varepsilon} \rho \frac{\varepsilon^2}{k}
\]  

(4)

\( G_k \) is the turbulence kinetic energy generated due to the average velocity gradient, \( G_k \) is the turbulence kinetic energy generated due to buoyancy, \( C_{1_k}, C_{2_k}, C_{3_k} \), and \( C_\mu \) are constants. \( \sigma_k \) is turbulent Prandtl number for kinetic energy and \( \sigma_{\varepsilon} \) is turbulent Prandtl number for dissipation rate.

In the equation above, two types of viscosity are found, namely actual dynamic viscosity and turbulent viscosity (\( \mu_t \)). The turbulent viscosity equation is written as follows:

\[
\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}
\]  

(5)

In the simulation process, all the governing equations are discretized based on the finite volume method, the SIMPLE algorithm is used to combine the velocity fields and with other fields. The iteration process on ANSYS Fluent will stop if the continuity and \( k \) and \( \varepsilon \) residual reaches a value less than \( 10^{-2} \) or reaches a constant value.

3. Results and discussions

3.1. Numerical validation

To ensure that the results of the numerical simulation are acceptable, the validation has been carried out experimentally, airfoil is tested in wind tunnels with different angles of attack from \( 0^\circ \) to \( 12^\circ \) to obtain lift coefficients. The comparison between experimental and simulation results is shown in Figure 2. The experimental results are marked with a blue line and the simulation results are marked with a red line. The figure shows the difference between the simulation and the experimental at an angle of attack more than \( 7^\circ \). Whereas at the angle of attack below \( 7^\circ \) the simulation results are in accordance with
experimental. Therefore, the numerical method is acceptable and used to investigated the effect of the number of blades.

3.2. Velocity field

The simulation results in the form of a velocity field are shown in Figure 3. Simulation carried out 4 different number of blades. In Figure 3(a) shows the velocity contour at the number of blades 3 and Figure 3(b) shows the contour velocity at the number of blades 5. The blue colour in Figure 3(a) and Figure 3(b) shows the lower velocity, while the colour from yellow to red indicates the higher velocity. From the figure, it can be seen that the velocity decreases when it is in the airfoil rotating area and is dominant in blue, while on the contrary, in the outer rotating area velocity increases and is dominated by yellow and red. This difference in velocity produces power in the turbine. The effect of the number of turbine blades can be seen by comparing Figures 3(a) and 3(b). In Figure 3(a), after the wind leaves the turbine rotating area, the dominant colour is green, which indicates the velocity is still high compare to Figure 3(b), the wind velocity after turbine rotating area dominant blue, which indicates a relatively lower velocity. The lower wind velocity leaving the turbine rotating area, the more wind energy is extracted into power. The effect of the number of blades on the performance of the turbine can also be seen in Figure 4. This figure shows the wind velocity leaving the turbine rotating area for all the number of turbine blades tested against the position. An increase number of blades, causes wind velocity leaving the turbine rotating area decreases. The increase in the number of blades allows more energy to be extracted in the turbine rotating area, so that the turbine power increase. The wind velocity leaving the turbine rotating area at the number of blades 5 is lower than the number of blades 6.
Figure 3 Contour velocity for 3 and 5 number of blades

Figure 4 Velocity of the wind leaving the turbine at different number of blades

3.3. Power coefficient

The power coefficient is calculated using the wind velocity leaving the turbine rotating area. The power coefficient (\( c_p \)) is calculated by the following equation:

\[
c_p = \frac{P}{P_0} = \frac{1}{2} \left[ 1 - \left( \frac{v_2}{v_1} \right)^2 \right] \left[ 1 + \frac{v_2}{v_1} \right]
\]

(6)

The parameter \( P \) is the mechanical power extracted from the wind, \( P_0 \) is the power in the wind flow, \( v_1 \) wind velocity leaving turbine rotating area, \( v_2 \) wind velocity before entering turbine rotating area. Comparison of the number of blades, resulting in a different wind velocity leaving the turbine, and the resulting power coefficient calculated by equation (6) is also different. The comparison can be seen in Table 2, from table it can be seen that the maximum number of blades is 5.

| Number of Blades | \( v \) (m/s) | \( C_p \)   |
|------------------|-------------|-----------|
| 3                | 2.005       | 0.562     |
| 4                | 1.753       | 0.581     |
| 5                | 1.556       | 0.589     |
| 6                | 1.667       | 0.5854    |
4. Conclusions
Numerical research on the effect of the number of blades on the turbine performance has been carried out with variations in the number of blades, tip speed ratio 4. The simulation results are acceptable because they are compatible with the experimental results that have been carried out. Velocity contour has been shown and discussed, the simulation results indicate that the number of blades 5 has the highest coefficient of power among the number of blades tested and has a lower wind velocity leaving the turbine than the others.

References
[1] Lee Y T and Lim HC 2015 Renewable Energy 83 407-415.
[2] Zhu H, Hao W, Li C and Ding Q 2020 Renewable Energy 158 370-387.
[3] Hamdani W, Sihombing H V, Ambarita H and Kishinami K 2020 IOP Conference Series: Materials Science and Engineering 851 012033.
[4] Su H, Dou B, Qu T, Zeng P and Lei L 2020 Energy Conversion and Management 217 113012.
[5] Pramono I, Ambarita H and Kishinami K 2019 IOP Conference Series: Materials Science and Engineering 648 012030.
[6] Hashem I and Mohamed M H 2018 Energy 142 531-545.
[7] Omar S M, Ahmed A I, Ahmed K E, Amr A A and Ahmed M R E 2020 Energy Conversion and Management 5 100026.
[8] Abdalrahman G, Melek W and Lien F S 2017 Renewable Energy 114 1353-1362.
[9] Ali S, Lee S M and Jang C M 2018 Energy Conversion and Management 171 1322-1338.
[10] Ambarita H, Siregar M R and Kawai H 2018 IOP Conference Series: Materials Science and Engineering 343 012025.
[11] Launder B E and Spalding D B 1974 Computer Methods in Applied Mechanics and Engineering 3(2) 269 – 289.
[12] Abbot I H and Von Doenhoff A E 1959 Theory of the Wing Sections (New York: Dover Publication Inc).