Experimental study on horizontal axis wind turbine with splitted winglets

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Abstract

Human needs increasing over years, energy is needed to fulfill the daily life. In the other hands, source of energy such as coal is decrease and become less and less. There is a renewable energy that can made from wind source. Wind energy can be obtained by using some tools such as wind turbine. Wind turbine is a device that used to convert wind energy into electricity. Wind turbine has developed to many variation. One of variation that added to the wind turbine especially on their blades is splitted winglet. This additional variation is an adaptation from recent aircraft. The advantages of using this typical of winglets on aircraft is increasing the lift coefficient and decreasing drag coefficient. The function of splitted winglet on wind turbine blades is to minimize the backflow on the tip of blades. This research expectation is turbine will get better performance. Comparing the turbine with the blade without winglets, with winglets and with splitted winglets. Turbine with the blades without winglets gives best performance among all the turbine variations. The air flow hit the turbine at 6 m/s, the performance of turbine without winglets give Cp about 5.2E-1. With the same velocity of airflow, the turbine with winglets and splitted winglets give Cp about 4.7E-1 and 2.1E-1.

1. Introduction

Nowadays, most of power plant that produce electricity from coal which is its source is decreasing over the years. Following by human needs of electricity to fulfill their life is increasing every time. One of solution that can solve this problem is by using renewable energy such as wind energy. Wind energy can be converted to make an electricity by using wind turbine. There are so many kind of wind turbine. From the axis of rotation, there are horizontal axis wind turbine and vertical axis wind turbine. Horizontal axis wind turbine give some advantages such as for using of area, fees, and noise. The turbine performance affected by external and internal factor. The external factor come from the ambiance condition including weather. The internal factor that affected in turbine performance come from turbine component such as blades, tail, generator, and its transmissions. Blades make the rotation of turbine to make an electricity. This device can make the turbine’s performance become better by adding some variation. One of the variation that can added into the blades is splitted winglet. Splitted winglet is the innovation from blended winglet that added by another winglet in the against direction. This additional variation is adapted from the recent aircraft. The purpose of adding this variation is to enhance the performance so that there are minimize the back flow on the blade. From the research [1] the wings or aircraft with splitted winglet has better performance than wings of aircraft using blended winglet or single winglets.
This study is comparing wind turbine with blade with splitted winglets, fixed winglets, and no winglets. The performance of wind turbine can be shown by value of coefficient of performance by their tip speed ratio.

2. Methodology
Geometry that used in this paper is rotor of wind turbine with three blades. Wind turbine rotor with three blades give better performance [2]. This three blades rotor show better performance with Cp about 5.2 when the TSR in 4 until 5. Cp is coefficient performance which show the performance of rotor wind turbine. TSR is tip speed ratio which show the ratio of speed on tip of blade to the velocity.

The blade with splitted winglets dimension adapted form blade with sigle winglets a with additional other winglets in the against direction. The splitted winglets ratio is h2 is 0.4 times h1 [3]. Where h1 is the main winglets and h2 is the side winglets. The position of h1 or main winglets is in the same direction with the air flow with span angle 70°. The h2 or side winglets position is against the main winglets with span angle 52°.

![Blade with splitted winglets](image)

**Figure 1.** Blade with splitted winglets

Other additional method is using twist. Twist is the additional method in the segment of airfoil that construct blade with different angle of twist, dimension or chord length, and distribution of the segment. Twist give variable angle of attack through the length of the blade. Twist angle is an angle that given to the each segment of airfoil. Twist angle distribution is based on aerodynamic behavior of each individual airfoil at a certain angle of attack [4].

\[
\beta(r) = \frac{2}{3}arctan\frac{R}{r\lambda} - \alpha_D
\]  

(1)

The airfoil variation is defined by the chord length. The chord length is the size of chprd in every segment of chord. The airfoil with different chord and twist angle is distributed based on the length of the blade [5]. The size of each blade is 12 cm and the hub radians is 3 cm.

\[
c(r) = \frac{16\pi r}{BG_1} \sin^{n^2} \left( \frac{1}{3} tan^{-1} \left( \frac{R}{\lambda r} \right) \right)
\]

(2)

So, the rotor diameter is 30 cm. From the equation above [5], The segment distribution is counted on excel and described in table below. In the table 1 from research [6] we know that longer segment position from the hub, smaller chord we get. The variation of twist angle is different in each segment.

The experiment of wind turbine is using wind tunnel. Wind tunnel is a testing tools for watching aerodynamic condition of instrument. The output of wind tunnel testing is torque and angular velocity. The rotor tested by turbine stand that using gear box that has ratio of 1:3.5.

Velocity that used on this study is about 0-7 m/s. The velocity is based on fan frequency that controlled on inverter. The consideration of using the velocity is because of the capability of turbine that influence the strength of the material that built the turbine.
Table 2.1 Detail Of Geometry Data Input

| Segment | r/ (cm) | c/ (cm) | Twist β (°) |
|---------|---------|---------|-------------|
| 1       | 3.20    | 3.80    | 28.13       |
| 2       | 4.14    | 3.59    | 22.06       |
| 3       | 5.09    | 3.32    | 17.53       |
| 4       | 6.04    | 3.04    | 14.11       |
| 5       | 7.00    | 2.79    | 11.46       |
| 6       | 7.95    | 2.56    | 9.35        |
| 7       | 8.90    | 2.36    | 7.63        |
| 8       | 9.85    | 2.18    | 6.21        |
| 9       | 10.81   | 2.03    | 5.02        |
| 10      | 11.76   | 1.89    | 4.00        |
| 11      | 12.71   | 1.77    | 3.12        |
| 12      | 13.66   | 1.67    | 2.36        |
| 13      | 14.62   | 1.57    | 1.70        |
| 14      | 15.62   | 1.48    | 1.08        |
| 15      | 15.95   | 1.45    | 0.88        |

Figure 2. Rotor turbin angin saat pengujian

In this study also using variation of pitch angle. Pitch angle known by pitch control that is on the beginning part of blade. This variation purpose is to increase the performance by adjusting the pitch angle of blades in the fluctuate air flow condition [7] as shown on figure 3.

Figure 3. Pengaturan sudut pitch di pangkal blade
(Source: Advances in Wind Power. InTech Jnanez Trdine 9, 51000. Rijeka, Croatia.)
Blade Element Momentum (BEM) is a simulation method by theory that used for comparing experimental product. The method works by dividing blade into some segment. BEM method calculate the change of performance of wind turbine in the variation of pitch blade angle in two dimension [8].

There is three vectors of velocity that affect the force that produce by airfoil in the segment of blade as shown on figure 2.

\[
\begin{align*}
\text{Relative velocity } (V_{rel}) & = V_o (1-\alpha) \\
\text{Relative velocity } (V_{rel}) & = \text{product of air velocity vector } (V_o) \text{ with angular velocity } (\omega r), \text{ and inflow angle } (\phi) \\
\text{inflow angle } (\theta) & \text{ that is angle between relative velocity and angular velocity, inflow angle is sum of angle of attack } (\alpha) \text{ and pitch angle } (\theta). \\
\end{align*}
\]

Axis torque total is the sum of all \( M_{i,i+1} \) contribution along one blade multiply by sum of blade.
\[
M_{tot} = B \sum_{i=1}^{N-1} M_{i,i+1}
\]

Sum of torque is multiply by angular velocity then power will calculated by equation below.
\[
P = \omega M_{tot}
\]

3. Result and Discussion
The experiment result is about angular velocity and torque. This data is processed into tip speed ratio and coefficient of performance. Tip speed ratio is ratio on the tip of baldes In the free air flow. For the certain air velocity, TSR will influence the rotor speed. Lift typical of wind turbine has more higher TSR than drag typical of wind turbine.

The result of the processed data is shown in figure 5. The graph show experimental data of characteristic wind turbine in Cp to TSR. In the variation of 0 degree of pitch angle, the performance of wind turbine give the highest value of Cp among other variation. But the TSR that can make the turbine rotate is high. The TSR factor is the speed of air flow that affect the rotation of turbine and the torque. The peak of Cp not yet given in this variation. This condition happened because of this variation must be tested in the high speed of airflow. But in the variation of 10 degree of pitch angle. The turbine can rotate in the minimum air flow velocity.

Compared by BEM (Blade Element Momentum) that is calculation method. This method is calculated based on the TSR that produced by the experimental data calculation process. In this BEM, the graph that shown in figure 5, 0 degree variation give best performance among all variation on Cp. But this variation only works on high TSR condition. This phenomenon is occurred same as experimental process.

In the previous research [9] that compared between turbine without winglets, with fixed winglets, and with splitted winglets. The splitted winglets didn’t get well performance between them. Turbine without winglets give best performance among them. As shown at the figure 6.
Figure 5. Experimental and BEM Data of Characteristics Wind Turbine 
\(C_p\)-TSR

Figure 6. Visualisasi aliran kecepatan udara 5 m/s pada blade turbin angin (a) tanpa winglets (b) dengan winglets (c) dengan splitted winglets

In the blade a the vectors show minimum blue vectors than the vectors that happened in the blade b and c. This blue vectors show backflow air in the tip of blades. The backflow air is the air that move back and hit another air flow. The air flow that hit will decrease the velocity of its flow. So, in the tip of blades makes the lift force decrease and increase the drag force. This condition makes the torque lower. In the wind turbine smaller drag that happen small engine that required [8].

4. Conclusion
This research is successfully by doing experiment about horizontal axis wind turbine using wind tunnel testing. The additional of splitted winglets do not give better performance than blade without winglets.
The backflow on the tip of blade the torque decrease. But in some condition there are several conclusion that we get:

1. Performance of wind turbine with splitted winglets will increase when it used in high TSR with 0 degree of pitch angle.
2. Pitch angle 0 degree can’t rotate the turbine with splitted winglets in minimum TSR.
3. 10 degree of pitch angle variation can be starting torque and changes of pitch angle also used for braking function.
4. Phenomenon that shown in CFD simulation show that the back flow in the tip of blade with splitted winglets that can cause the performance of turbine decrease.

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