Performance of Crossflow Wind Turbine by the Variation of Blade Slope and Diameter Ratio

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Abstract: Crossflow wind turbines have a good ability to capture wind, so it is very suitable to be developed in areas with low wind speeds. The efficiency of a crossflow wind turbine is taken from two sides, so its turbine has high efficiency. The first side is when the wind enters the turbine pushes the front face of the blade, and the second side is when leaving the turbine, the wind pushes the rear face of the blade. In designing a crossflow wind turbine, design parameters can affect the height or low performance of the turbine. The main objective of this study was to determine the flow characteristics and performance of crossflow wind turbines. The turbine is designed with a diameter ratio of 0.5 and a blade slope of 90˚. The number of blades used as a test is 18 blades. Turbines were simulated with at 3 m / s of wind speed on TSR 0.1 – 0.5. The results obtained from this study are wind flow visualization and cross-flow wind turbine performance parameters. The crossflow wind turbine performance parameters are power coefficient, moment coefficient, and tip speed ratio.

1 INTRODUCTION

Nowadays, much development is being carried out on vertical axis wind turbines placed on the roofs of high rise buildings. The idea was developed because urban communities consume a lot of electricity so that alternative energy is needed to overcome the swelling of the use. TASV research has several advantages in the form of construction with relatively low cost, operating at a low tip speed, and does not require high wind speeds to spin (Latif, 2013). The main advantage of TASV is that the turbine does not have to be directed towards the wind to be effective so that it is suitable for areas with varying wind directions. TASV consists of several types of rotors, one of which is a crossflow type wind turbine. The crossflow rotor type of wind turbine is a vertical wind turbine with a simple type of rotating wheel due to the force of drag (Dharma, 2016).

In the design of wind turbines, there are several design parameters that can affect the performance of the turbine, including the number of blades, geometric design, wind speed, and the shape of the turbine blades. Geometry design is still an interesting concern for the design development of crossflow wind turbines. Turbine geometry is expressed in the form of aspect ratio. The aspect ratio is the ratio between the outer diameter and inner diameter of the turbine or the ratio of the outer diameter and height of the turbine. The effect of aspect ratio on the performance of a wind turbine can increase the power coefficient. Savonius type vertical axis wind turbines with greater aspect ratio show good performance due to low losses (Mahmoud, 2012). Similarly, a crossflow wind turbine that has an aspect ratio of the outer diameter of the turbine to a large turbine height (D / H) has low losses (Akwa et al., 2012).

The influence of geometry design on crossflow wind turbines has a very important role in performance. One of the influential geometry designs is the diameter ratio. The diameter ratio in the crossflow wind turbine is the ratio between the diameter of the inside and the outside diameter. In making cross-flow wind turbines with diameter ratio variations of 0.58, 0.63, 0.68 and 0.73 where each variation is tested with wind speeds of 2 m / s and at TSR 0.1-0.4 with intervals of 0, 1 Turbines with a diameter ratio of 0.68 and number of blades of 20 produce the highest power coefficient of 0.5 at TSR 0.3 (Purbaningrum, 2016).

The number of blades affects the turbine solidity. Turbines with a certain number of blades will produce a good performance. High turbine

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solidity produces low CP and vice versa. Low solidity indicates a higher tip speed ratio. At a low TSR, the blade does not strongly affect the flow of air through the wind surface area. Increasing the number of blades in savonius wind turbines results in low rotor torque. Therefore the number of blades must be increased (Qing'anli et al., 2016). A certain number of blades is likely to benefit the rotor in wind extraction (Akwa et al., 2008). The determination of the number of blades is determined based on the advantages and disadvantages of the number of blades. Increasing the number of blades will improve airflow and reduce the number of blades, which leads to lower friction between wind currents and turbine blades (Mandis et al., 2008).

An experimental test on a cross-flow wind turbine is carried out by varying the ratio of the diameter and the number of blades. The variation of the diameter ratio used was 0.58, 0.63, 0.68, and 0.73, while the variation in the number of blades used was 16, 20, and 24. Testing was carried out at wind speeds of 3 m / s to 4 m / s. Experimental test results show that the configuration between the diameter ratio of 0.68 and 20 blade number is the best configuration that has a power coefficient of 0.049 and a torque coefficient of 0.185 (Susanto, 2017).

In addition to the diameter ratio, the geometrical design that influences the performance of the crossflow wind turbine is the slope of the blade. The sop blade determines the direction of angina coming, which can be extracted well by the blade of the turbine. The slope of the turbine blade is very influential on the power generated in the wind turbine. One of the wind turbine designs by varying the angle of the blade and the radius of the blade's curvature is tested to determine its effect on the power produced. The test results show that the crossflow turbine with a 45º turbine blade tilt angle produces greater power than the 60º and 90º blade tilt angles under all curvature radius conditions. While the turbine curvature radius has the characteristics of each at each angle of the turbine tilt. Crossflow wind turbines with a blade radius of 60 mm curvature at a 45 ° angle variation of the blades produce a maximum power of 2.47 watts at a wind speed of 4.31 m / s and a CP of 0.41 at a TSR of 0.76 (Barriyah, 2016).

Wind turbine performance parameters are represented in dimensionless numbers, CP, CT, and TSR. CP, or commonly known as the power coefficient, is the difference between measured turbine power and theoretical turbine power. TSR or tip speed ratio is the value of the difference between the rotor tip speed and free wind speed. For certain nominal wind speed, TSR will affect the rotational speed of the rotor. Because of this description, the research carried out focuses on the angle of the blade, the ratio of the diameter and the number of blades simulated at various wind speeds.

2 SIMULATION METHODS

Computational fluid dynamics (CFD) is the tool used to determine the numerical solution of the equation governing fluid flow and other physical processes with the help of computer computing. The principle is to complete the calculation of the fluid flow equation in the form of certain covering the desired area. The area is often called with cells, and the process of division is called meshing. A cell constitutes a control calculation that will be carried out by the application. In each cell will The calculation is done with domain restrictions and boundary conditions that have been determined. This principle is used in the calculation process by using computer computing assistance (Hirsch, 2007).

Preprocessing is the process of defining the geometry of the model to be a computational domain, making the mesh and defining boundary conditions in the research conducted. Pre-processing is the first step in analyzing a CFD model. Before a model can be analyzed, the geometry of the model must be defined first into the computational domain. Then make a meshing in accordance with the geometry and analysis to be performed. Finally, defining boundary conditions and the nature of the fluid to be used. This information is used as a solution to the problem of fluid flow that is defined for each node in each cell. The accuracy of the results of data processing by CFD is governed by the number of cells in the grid. In general, a large number of cells make CFD results have better accuracy, but with computing costs, that also becomes more. The following picture is a vertical axis wind flow type turbine model used in this study shown in Figure 1.

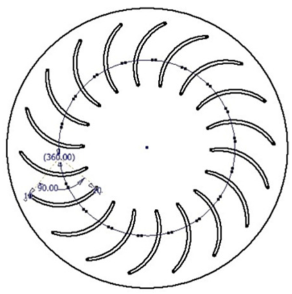

Figure 1. The model of Crossflow wind turbine

CFD solver is processing and calculation of the conditions that have been set during pre-processing. At this stage, a numerical computational process is carried out using the finite volume numerical method. The first step is the integration of the governing equations of fluid along with all the governing volumes of the domain. The equation is then discretized, which involves the substitution of various finite difference approaches to the integrated flow equation so that the integral equation can be converted into algebraic equations. The equation is then solved using the iteration method, so a solution is obtained.

The domain stage is the domain formation in the crossflow type wind turbine geometry model. There are two forms of domains, namely rotating domains and static domains. The rotating domain is located in the outer diameter of a circular wind turbine, and this domain is used as a path in the rotating motion. The fixed domain or static domain, which functions as the location of the fluid flow, this domain does not move, as shown in the following Figure 2.

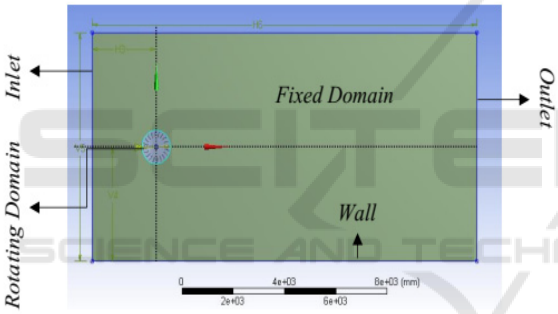

Figure 2. The domain of the wind turbine modeling

The results of the study were validated by 2D modeling to ensure that the modeling created was an accurate representation of the real phenomenon being modeled. The domain used at the time of the study was divided into two parts, namely the fixed domain and the rotating domain. The shape of the fixed domain is a rectangle with a length of 15000 mm and a width of 7500 mm. The rotating domains are circular in diameter in accordance with the research wind turbines; namely, crossflow type wind turbines and rotating domains are located on the axis of symmetry fixed domain with a distance of 2500 mm from the inlet or the left end.

Post-processing is the final step in CFD analysis. At this stage, the results of the numerical computations that have been made are visualized and documented in the form of images, curves, and animations.

The stage of meshing involves the division of objects into smaller parts. To obtain an accurate simulation, the meshing was made according to the predicted flow pattern changes that will occur. The following were the meshing processes (Figure 3).

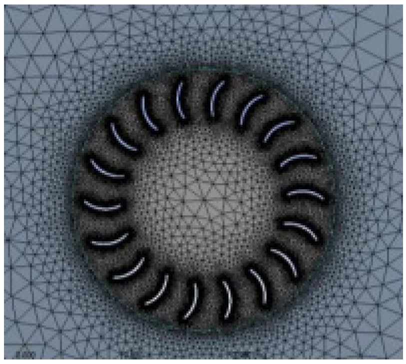

Figure 3. The meshing pattern of the turbine

The process of meshing aims to divide the solution domain into smaller parts. The amount of this division will determine the accuracy of the results of numerical computations performed. The finer the meshing results, the results of numerical computation will be more accurate later, but the numerical computation time will be relatively longer. The quality of triangular meshing can be measured using a metric mesh.

The energy available in the wind is the kinetic energy of most of the mass of air that moves above the earth's surface. Wind turbine blades receive kinetic energy and then convert it into mechanical or electrical energy depending on end-use. The efficiency of converting wind to other useful forms of energy depends on the efficiency with which the rotor interacts with wind flow (Hau, 2006). Wind power can be written with the following equation:

$$P = 1/2\ \rho\ A\ v$$

The theoretical power available in the wind flow is in Equation 4.1. Whereas turbines cannot change the power of the wind as a whole. When the flow of wind passes through the turbine, some of its kinetic energy is transferred to the rotor, and the air leaves the turbine. This efficiency is usually expressed as a power coefficient (Cp). Thus, the power coefficient of the rotor can be defined as the ratio between the actual power available at the wind as follows :

$$c_P = \frac{2P_T}{\rho_a\, A_T v^3}$$

A comparison between the actual torque produced by the rotor with the theoretical torque produced by the turbine was expressed by the torque coefficient (CT). So CT was stated as follows.

$$c_T = \frac{2T_T}{\rho_a A_T v^2 R}$$

The ratio between the tip rotor speed and wind speed is expressed as a tip speed ratio (λ). So that,

$$\lambda = \frac{C_P}{C_T} = \frac{R\,\Omega}{v}$$

Where Ω is the angular velocity. The power coefficient and torque rotor coefficient can vary with the tip speed ratio. Optimal TSR is a condition where the most efficient energy transfer occurs, and the power coefficient is at its maximum point (CP max).

3 RESULTS AND DISCUSSION

Torque Coefficient (CT) is one of the dimensionless parameters useful to show the value of the moment or torque in a wind turbine simulation. At the beginning of the simulation, the situation is not steady due to the iteration less is produced, and more iteration is needed to achieve a steady-state. The time taken for the torque coefficient value relatively stable is taken in 10-15 s. From Figure 5 shown that the research data taken for research starts from 10-15 s.

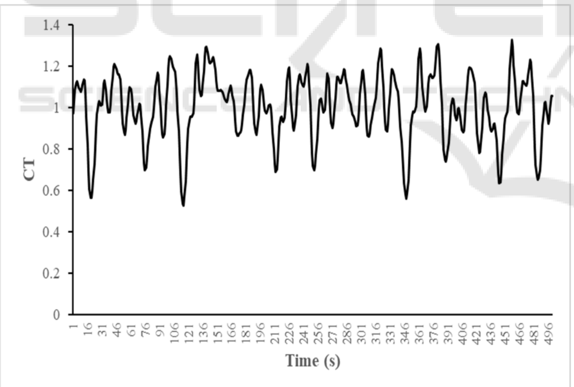

Figure 5. Data of torque coefficient

It had been matter because the value is quite stable so that the average value can be determined used for further calculations. Here was the result of simulation results cross-flow wind turbine with 18 blades and 90° blade slope with a diameter ratio of 0.5.

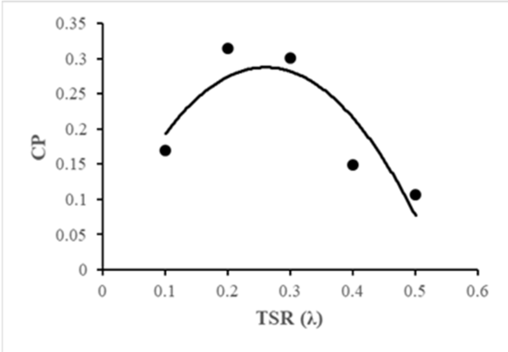

Figure 6. Data of power coefficient versus TSR

Choosing the right diameter and blade slope was needed for the wind turbine to produce the best power coefficient. The ratio of the diameter and angle of the blade was very influential on the value of the power coefficient due to the shape of the blade that changes the shape of the blade so that it can cause the amount of wind that hits the turbine blade to not flow through a cross-section that is too small or the wind can be hampered at a cross-section that is too large and will cause pressure reverse and can cause greater distance for energy transfer and increase turbulence so as to cause a decrease in the coefficient of power in the turbine. The selection of the right diameter ratio is one important aspect in producing a maximum power coefficient.

Rim radial is needed as the selection parameter. If rim radial larger, then the amount of wind that hits the blade will not be optimum because the wind cannot pass through a cross-section that is too large, which can cause back pressure so the power coefficient value will be small. However, if the width of the radial rim is too small, it will widen the energy transfer distance so that it gets bigger and increases turbulence, which causes the power coefficient to decrease (Mockmore, 1949).

From the results of simulations, the rotational speed of the turbine using an angle of 90° shown a decreasing value because the turbine angle had more upright. This is because the energy needed to move the first level blade is not too large so that the energy transmitted to crash into the next level blade will be of great value as well.

However, at a more upright blade, the energy needed to move the first level blade is greater so that when it is forwarded to the second level blade, it will be smaller so that it is likely that the flow of wind does not crash at the second level blade. The blade tilt angle variation is very influential and directly proportional to the magnitude of the speed relative to the blade and velocity (angle β), when the smaller the angle of the blade tilt, the smaller the angle β.

The results of the study show that when the β angle is small, the power generated is greater. This is because the value of the absolute wind speed coming out of the turbine is getting lower. When the wind speed coming out of the turbine is low, it means that the energy absorption carried out by the turbine is getting maximum.

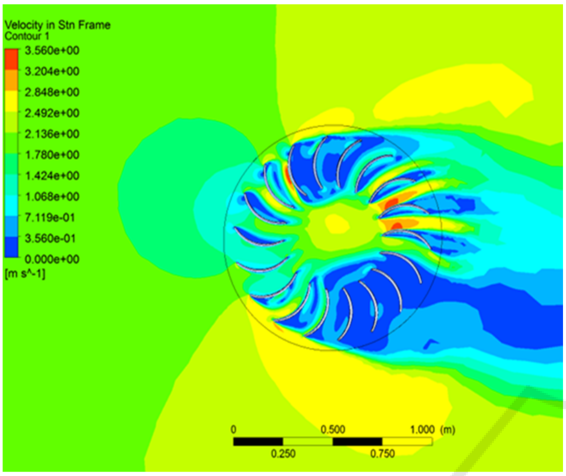

Figure 7. The flow contour of the cross-flow wind turbine

Figure 7 shows the speed contour produced by the simulation process. The results of the speed contour show that the process of extracting the kinetic energy of the wind in the crossflow wind turbine has a double interaction between the wind and the blades of the wind turbine. The first interaction occurred when the wind came in from the inlet to the turbine so that it hits the first level blade. Then the interaction of the two winds enters in the wind turbine crevices and exits crashing into the second level blades shortly before the wind exits leaving the wind turbine.

In this wind turbine variation in the second level blades, there is a lot of wind that is not well extrapolated and more out of the turbine blades so that the resulting performance is imperfect and not better than other variations. This can happen because, in the area of the second level, blades tend to turn. The red areas in the next level blades indicate an increase in speed in the blades. This, of course, happens because of the large number of blades and causes the blade gap to be narrow and the presence of pressure, gravitational force, and viscous friction on the turbine blade so as to produce high speeds at several levels of blade crevices.

4 CONCLUSION

Based on the crossflow wind turbine simulation results with a diameter ratio of 0.5, and the blade slope is 90˚, the maximum CP value is 0.32 at TSR 0.2. Turbines in the back experience an increase in speed caused by the flow of wind coming out of the face of the turbine faster due to turbine rotation. In the cross-flow wind turbine, there was negative torque that caused the rotation speed of the turbine hampered.

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