The Effect of Blade Thickness and Number of Blade to Crossflow Wind Turbine Performance using 2D CFD Simulation

Fauzi Wikantyoso, Dini Oktavitasari, Dominicus Danardono Dwi Prija Tjahjana, Syamsul Hadi, Bambang Pramujati

Abstract*— *Crossflow wind turbine is vertical axis wind turbine that has high coefficient of power (Cp). The simulation aimed to understand the effect of blade thickness and blade number of vertical axis wind turbine with cross flow runner to enhance the performance of wind turbine. The turbine had 2.6 mm; 10 mm; 15 mm; and 20 mm blade thickness, and 18, 20, and 22 blades number. Simulation was done in two-dimensional analysis using ANSYS-Fluent. Tip speed ratio was varied in the range of 0.1 to 0.5 with constant inlet velocity of 2 m/s. The effect of blade thickness and blade numbers to torque and coefficient of power were analyzed and compared. It has been found that the highest coefficient of power was 0.5 at tip-speed ratio of 0.2, blade maximum thickness of 20 mm and blade number of 22.

Index Terms* — *wind energy, VAWT, crossflow wind turbine, blade thickness, number of blades, CFD simulation

I. INTRODUCTION

In harvesting wind energy, horizontal axis wind turbines are mostly used in high wind velocity. The HAWTs can be operated in high tip speed ratio therefore have high efficiency [1], [2]. Unfortunately, they are not suitable to be used in low speed wind, because HAWT have low initial torque. Another disadvantage of the HAWTs, they need yawing mechanism to follow the direction of the wind and have relatively complex design. On the other hand, most of the vertical axis wind turbines (VAWTs) are usually known to have better performance in low wind speed and able to operate omni directionally. The VAWTs have high initial torque so that they may have low cut-in speeds and more working hours [1].

Developing small-scale wind turbines that able to operate in the very low range of TSR have become the focus of recent studies. Recent study also shows that a VAWT with crossflow runner in the field test can have C_p of 0.30 [3]. It is considerably higher than other types of VAWT. It is because the turbine crossflow has a series of circular blades. So that the airflow will pass through runner twice, and the efficiency becomes higher [4, 5]. Another study also proposes a VAWT with crossflow runner as a solution for wind turbines that operate at low wind speed [6]. However, the performance of turbine crossflow can be upgraded by paying attention to some factors such as thickness and the number of blades. The performance of turbine can also be affected by the number of the blade. This is because, with the more blade, the amount of torque obtained by the turbine will be more and more [7]. In general, by increasing the number of blades, the available kinetic energy of the stream is more efficiently converted to mechanical energy by the blades. However, if the number of the blade is too much, and the distance between the blades becomes too tight, it causes the back pressure. It makes the derivation of the turbine's efficiency [8]. On the VAWT with the airfoil shape blade, the thickness of the airfoil can affect the performance of the wind turbine. The changing of the airfoil thickness will affect the coefficient of lift and drag. For each addition of airfoil thickness, lift coefficient will decrease and drag coefficient will increase [9]. The ratio of lift and drag will affect the performance and the optimal working speed of the turbine [10].

In the present paper, a numerical study is made to understand the effect of blade thickness and number to crossflow wind turbine performance. The performance of the turbines is predicted by carrying out 2-dimensional dynamic simulations.

II. GOVERNING EQUATIONS

The equation used in CFD (*Computational Fluid* Dynamics) modeling is the basic equation of fluid mechanics such as:

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (1)$$

Incompressible Navier-Stokes Equation (2 Dimensional):
X-Axis (horizontal axis)

$$\rho\left(\frac{\partial \mathrm{u}}{\partial \mathrm{t}} + \mathrm{u}\frac{\partial u}{\partial x} + \mathrm{v}\frac{\partial u}{\partial y}\right) + \rho g_x - \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + v\frac{\partial^2 u}{\partial y^2}\right) \qquad (2)$$

Y-Axis (vertical axis)

$$\rho\left(\frac{\partial \mathrm{v}}{\partial \mathrm{t}} + \mathrm{u}\frac{\partial v}{\partial x} + \mathrm{v}\frac{\partial v}{\partial y}\right) + \rho g_y - \frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial y^2} + v\frac{\partial^2 v}{\partial y^2}\right) \qquad (3)$$

The parameters used in determining the performance of the wind turbine is the coefficient of the moment (*Cm*) and coefficient of power (*Cp*).

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The value of *Cm* is defined as follow:

$$\mathrm{Cm} = \frac{M}{0.25\rho v_\infty^2 D_1 S'} \quad (4)$$

where M is the positive moment that moves the turbine. And the value of Cp is defined as follow:

$$\mathrm{Cp} = \lambda Cm \quad (5)$$

III. RESEARCH METHODOLOGY

In this study, the crossflow wind turbine type is modeled by a 2D transient with the density of the fluid turbulent flow 1.2048 kg/m^3 and the pressure 1.7979 x 10^{-5} Pa. The crosslink turbine with a diameter of 1000 mm is placed on the symmetry axis at a distance of 2500 mm from the left end. The rectangle has a length of 15000 mm and a width of 7500 mm. The modeling domain can be seen in **Error! Reference source not found.**.

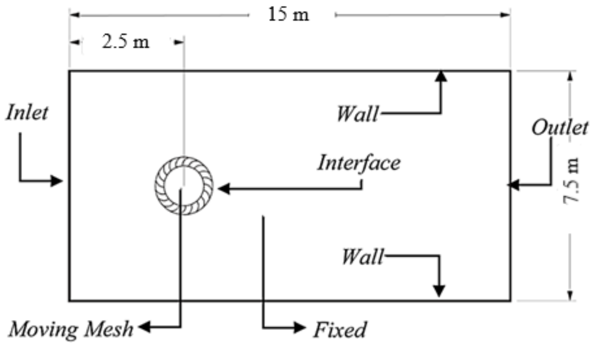

Fig. 1 Modelling domain

The domain can be divided into two subdomains, they are fixed and rotating. Rotating subdomain is spinning-made by using a sliding mesh method so that it can make a model the spinning turbine with constant speed. The fixed subdomain is made motionless and has length and width 7 times of the turbine's diameter to make the air friction in the wall doesn't affect the airflow around the turbine.

The left side of the fixed subdomain is modeled as inlet with the speed of entrance wind constantly at 2 m/s. The right side is modeled as a pressure outlet with relative static pressure 0 Pa. The top and bottom sides along with the blade on the wind turbine crossflow are modeled as wall and being applied with no-slip wall. The wind turbine crossflow which is on the axis-symmetric domain modeled in spin with the rotation speed at 0.4 rad/s, 0.8 rad/s, 1.2 rad/s, 1.6 rad/s, dan 2.0 rad/s.

Meshing that is used is triangular meshing and rectangular meshing. Triangular meshing is used for almost all the part of the domain except the part near to the turbine blade and interface. The part is using rectangular meshing so that meshing on that part becomes smoother and the computation result is more accurate. The meshing result can be seen in **Error! Reference source not found.**

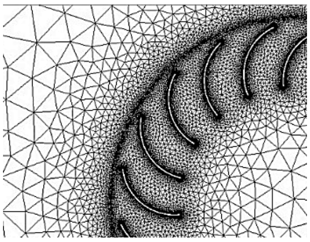

Fig. 2 The result of meshing

This research aims to see the effect of the blade thickness at 2.6 mm, 10 mm, 15 mm, and 20 mm and the number of the blade for 18, 20, and 22 towards the value *Cm* and *Cp.*

The calculated blade's thickness is in the middle of the blade with the edge of the blade is made of the constant thickness. The variations of blade thickness can be seen in Fig. 3.

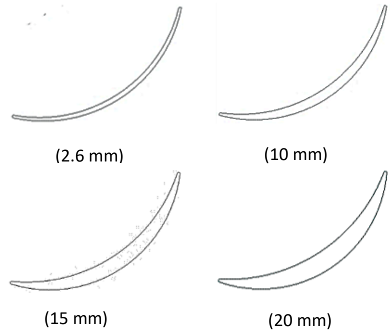

Fig. 3 The variations of blade thickness

IV. RESULT AND DISCUSSION

The turbulence model *k-ε realizable* is made for finishing the simulation of wind turbine *crossflow*. This turbulence model is often used because of its application to the complex flow such as *swirl* flow, flow separation, and secondary flow because of the vortex formation. The value of *Cm* of the wind turbine modeling with the blade thickness at 2.6 mm and the number of blade 20 is validated by comparing the result of Dragomirescu's research [4]. The validation result can be seen in

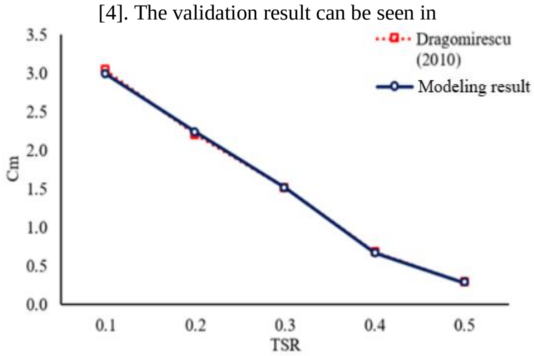

Fig. 4.

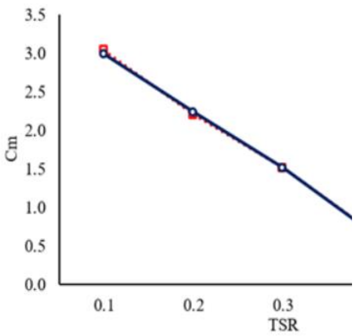

Fig. 4 The comparison of Cm value

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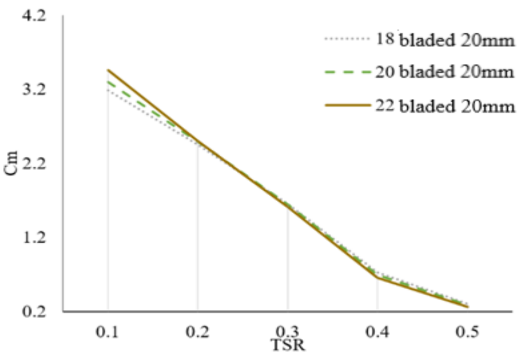
The Effect of Blade Thickness

The effect of blade thickness towards the value of Cm and Cp was observed from five different tip speed ratio (TSR). The observed blade thickness variations were at 2.6 mm,

10 mm, 15 mm, dan 20 mm. The existence of the thickness of the blade affects the Cm and Cm value. The Cm value of all the turbine with different variations of blade thickness has decreased as the addition of TSR. Generally, the turbine with the blade thickness of 20 mm has the best Cm. The chart of Cm value towards TSR can be seen in



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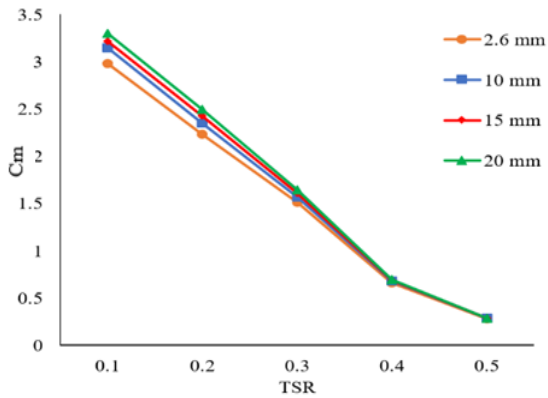


Fig. 5 The correlation between Cm and TSR on the variations of the blade thickness

For each blade, thickness has a different number of maximum Cp value on the different TSR. The turbine with the blade thickness of 2.6 mm and 10 mm have the highest value of Cp on TSR 0.3. On the other hand, the turbine with the blade thickness of 15 mm and 20 mm have the highest Cp on TSR 0.2. Overall, the highest value of Cp is 0.499 for the turbine with the blade thickness of 20 mm. The chart of Cp value for all the variations can be seen in Fig. 6.

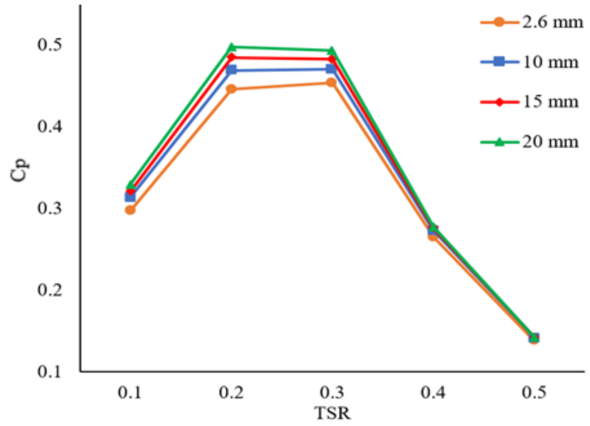


Fig. 6 The correlation between Cp and TSR on the variations of the blade thickness

The value of *Cm* and *Cp* is affected by some aspects. One of them is the conversion of the kinetic energy on the blade. The blade thickness is affecting the conversion of the kinetic energy of the turbine's blade. The more kinetic energy is converted, the less speed of exit from the blade. The value of *Cm* and *Cp* will increase. Turbine with the blade thickness at 20 mm has the greatest decrease in speed. The chart of difference between the entrance speed and the exit speed of the first level blade can be seen in Fig. 7.

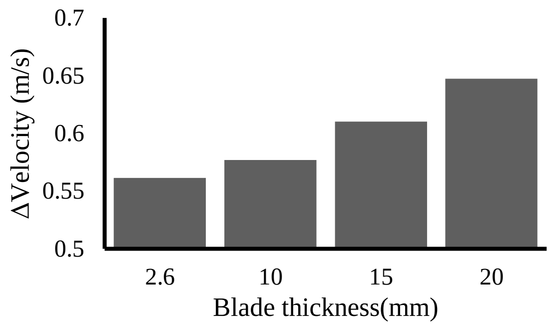


Fig. 7 The difference of speed in the first level blade

The impact of the number of blades

The value of *Cm* of all the turbines with the number of the blade of 18, 20 and 22 are increased as TSR increases. The turbine with the number of blades of 22 is better than the other on TSR 0.1 and 0.2. On the other hand, the turbine with the blade number of 18 is better on TSR 0.4 and 0.5. The chart of *Cm* value for TSR on the turbine with the blade thickness of 20 mm can be seen in

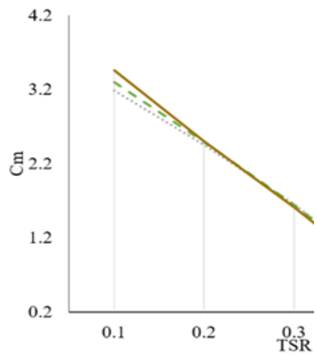


Fig. 8.

The value of *Cp* from the variation of the blade also show the same thing. The turbine with the blade number of 22 has the highest value of *Cp* on TSR 0.2. Meanwhile, the turbine with the blade number of 18 has the highest *Cp* value on TSR 0.3. The chart of *Cp* value for TSR on the turbine with the thickness at 20 mm can be seen in Fig. 9.

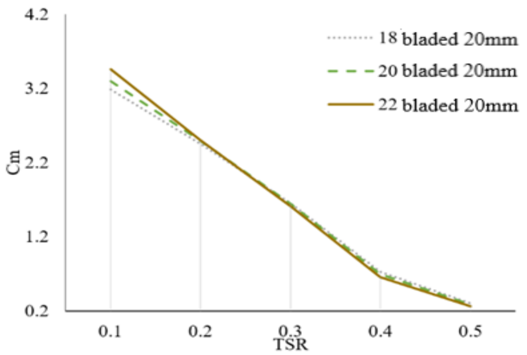


Fig. 8 The correlation between Cm and TSR in the variations of blade number

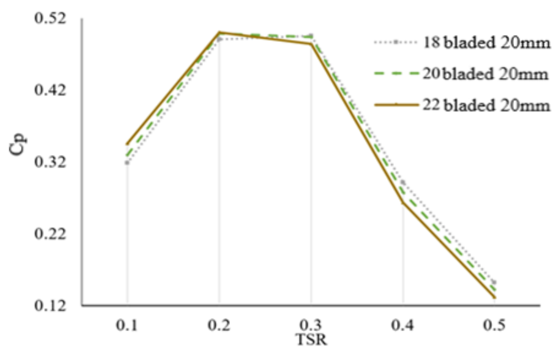
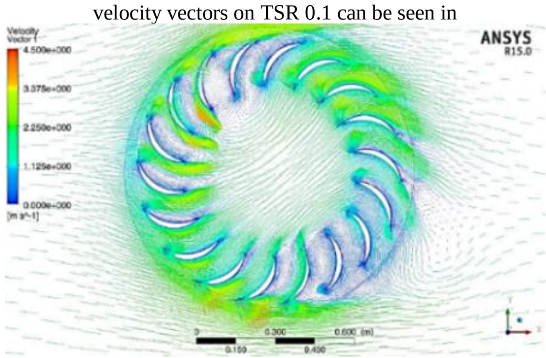
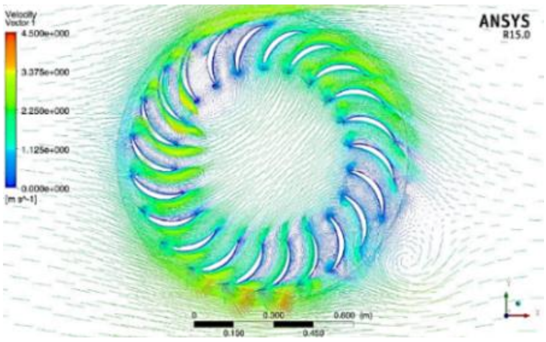


Fig. 9 The correlation between Cp and TSR in the variations of blade number

The result above shows that the turbine with a smaller number of the blade will be better on TSR 0.4 and 0.5. On the other hand, the turbine with a greater number of the blade is better on TSR 0.1 and 0.2. The tendency above is in accordance with the reference [11], that the higher TSR of a turbine then it will reach the optimum performance value with the less number of the blade. It is because, at the high rotation, the air will be getting more difficult to enter the gap between the blade. The distance between the blades will be less if the number of the blade is high. The velocity vectors on TSR 0.1 can be seen in

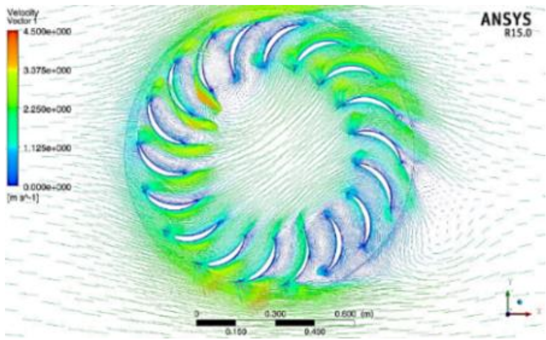


18 Blades

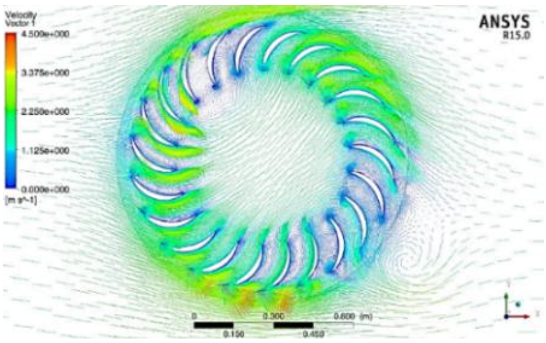


22 Blades

Fig. 10.



18 Blades



22 Blades

Fig. 10 The velocity vectors on TSR 0.1

The velocity vectors analysis shows that in turbines with 22 blades, have more blades that interact with airflow and generate positive moments. The positive moment makes the number of *Cm* and *Cp* on the wind turbine with the number of the blade at 22 is better on TSR 0.1 and 0.2. On the other

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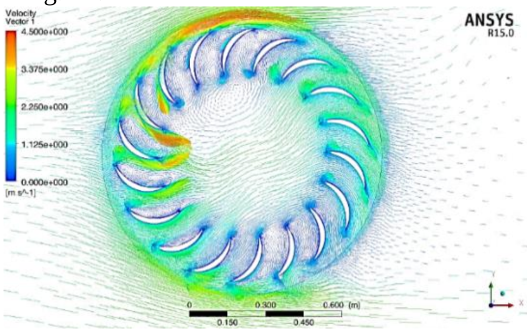
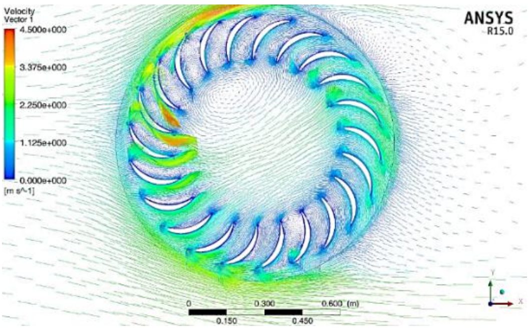
hand, it does not happen for TSR 0.4 and 0.5. It is because the fast turbine rotation makes the air more difficult to enter the gap between the blades to produce the positive moment so that the turbine with the blade number of 22 which has the smallest gap between the blades will have the lowest value of *Cm* and *Cp*. The speed vector on TSR 0.5 can be seen in Fig. 11.



18 Blades



22 Blades

Fig. 11 The speed vector of turbine on TSR 0.5

CONCLUSION

Based on the study and analysis of the blade thickness and the blade number of crossflow wind turbine, it can be concluded that the turbine with the blade thickness of 20 mm has the torque coefficient and power coefficient higher than the other turbines that tested with the same numbers of blade. The turbine with the blade number of 22 has a better power coefficient on the lowest TSR while the turbine with the blade number of 18 has the power coefficient better on the highest TSR.

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