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The Study of the Influence of the Diameter Ratio and Blade Number to the Performance of the Cross Flow Wind Turbine by Using 2D Computational Fluid Dynamics Modeling

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Abstract. Cross flow turbine can be one of the alternative energies for regions with low wind speed. Collision between wind and the blades which happened two times caused the cross flow turbine to have high power coefficient. Some factors that influence the turbine power coefficient are diameter ratio and blade number. The objective of the research was to study the effect of the diameter ratio and the blade number to the cross flow wind turbine performance. The study was done in two dimensional (2D) computational fluid dynamics (CFD) simulation method using the ANSYS-Fluent software. The turbine diameter ratio were 0.58, 0.63, 0.68 and 0.73. The diameter ratio resulting in the highest power coefficient value was then simulated by varying the number of blades, namely 16, 20 and 24. Each variation was tested on the wind speed of 2 m/s and at the tip speed ratio (TSR) of 0.1 to 0.4 with the interval of 0.1. The wind turbine with the ratio diameter of 0.68 and the number of blades of 20 generated the highest power coefficient of 0.5 at the TSR of 0.3.

INTRODUCTION

The use of wind as a renewable energy has become more interesting. Generally wind turbine divided into two categories, i.e., horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). Most of the wind energy power plants use the HAWT type for harvesting the wind energy. Because the HAWT works well in high speed wind and has high efficiency. However the HAWT does not work effectively in low speed wind. On the other hand, although it has low efficiency, the VAWT has high starting torque that makes the turbine capable to operate at low wind speed.

The popular types of VAWT are Savonius and Darrieus wind turbine. The Savonius wind turbine can operate at very low wind speed, but it also has very low efficiency. The Darrieus wind turbine has high efficiency, close to the HAWT type, but it does not have self-starting ability. To overcome the limitation of the Savonius and Darrieus, a cross flow wind turbine can be used as an alternative. The cross flow wind turbine, inspired by Banki water turbine, can be operated at low speed wind [1, 2, 3]. The cross flow wind turbine has high initial torque, high power coefficient (C_P), and because of its simple design, it also easy to be manufactured [4].

Power coefficient of a wind turbine is influenced by several factors, such as number of rotor blades and diameter ratio. In Banki turbine, increasing diameter ratio will increase the distance of transfer energy from first to second stage, as a result will influence the turbine efficiency [5]. The correct number of blade rotor can also increase the efficiency of the turbine up to 12.93% [6].

The turbine performance can be tested and measured by using computational fluid dynamics (CFD) simulation to reduce the cost and time of the experiment. In this research the influence of the rotor blades number and diameter ratio of cross flow wind turbine to the power coefficient, were tested and studied by using 2 dimensional CFD model. The ANSYS-Fluent package software were used to run the simulation.

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IMPORTANT PARAMETERS

There are several important parameters in determine the performance of a wind turbine, tip-speed ratio (λ), power coefficient (C_P) and torque coefficient (C_m). Tip-speed ratio is velocity ratio between tangential velocity of the rotor tip and free stream (wind) velocity (Eq. 1).

$$\lambda = \frac{\pi D n}{60 v} \tag{1}$$

where,

λ	= *Tip speed ratio*
D	= Rotor diameter (m)
n	= Rotor rotational speed (rpm)
v	= Wind velocity (m/s)

Power coefficient and torque coefficient are usually used to measured the performance of a wind turbine. The C_P represent the percentage of wind energy that can be converted into mechanical energy [7]. The c_P and c_m can be determined by using Eq. 2 and 3.

$$c_m = \frac{M}{0.25 \rho v^2 D_1 S} \tag{2}$$

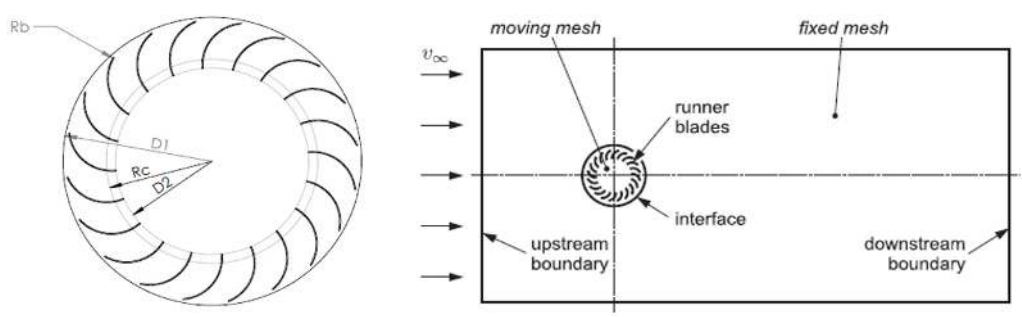
$$c_p = \frac{P}{0.5\, \rho\, S' v^3} \tag{3}$$

where,

c_m	= Torque coefficient
M	= Torque (Nm)
ρ	= Air density (kg/m^3)
V	= Air velocity (m/s)
D_1	= Turbine outside diameter (m)
S	= Rotor swept area (m^2)
c_p	= Power coefficient
P	= Turbine output power (Watt)

MODELING METHOD

Ansys Fluent package software was used to run the model. The cross flow wind turbine was modeled in 2-D, with 1000 mm outside diameter (D1), 146.8 mm blade radius and 20 blades, as shown in Fig. 1 (a). The computational domain of the model (Fig. 1 (b)) has 10 m long and 5 m wide and consists of fix domain as exterior and rotating domain as turbine rotor. Mesh motion was applied to the rotating domain to make the model realistic. Constant wind velocity of 2 m/s was applied to all of the model. The continuity and momentum equation were solved together with the turbulence model equation of realizable k-ε. The realizable k-ε was chosen because it provide very good performance for flows involving separation, recirculation and rotation [3]. In this study the turbine diameter ratio (D2/D1) and blade number were varied. The diameter ratio of 0.58, 0.63, 0.68 and 0.73 were simulated. The best performance of the diameter ratio then simulated in 16, 20 and 24 blades number variations. Each variation was also tested in TSR of 0.1 to 0.4 with 0.1 interval.



(a) (b)

Figure 1. (a) Geometry of the rotor and (b) Computational domain.

The model was validated by comparing the same turbine model to the result of Dragomirescu [3] at TSR 0.1. The comparison showed that the average error of torque coefficient (c_m) of the present studied model (Fig. 2) was only about 1.67%.

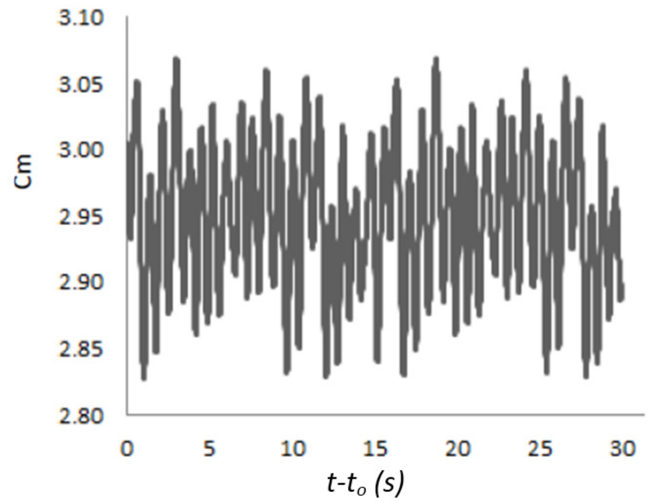


Figure 2. The torque coefficient for turbine with 20 blades, D2/D1 = 0.66 and TSR (λ) = 0.1.

RESULTS AND DISCUSSION

The c_m and c_p of the modelling results for various diameter ratio are depicted in Fig. 3. The results showed that the torque coefficient decreases as the TSR increase. On the other hand the coefficient of power increase until certain TSR, then it starts to go down. The best performance were shown by the turbine with diameter ratio of 0.68. Low diameter ratio would lead to wide radial rim of the turbine. The wider radial rim causes higher negative interaction between the wind to the turbine blade [3], as it is seen on the blades to the left and up (Fig. 4). By increasing the diameter ratio, the negative interaction will reduce. Whereas high diameter ratio could increase the distance of transfer energy between the first interaction of wind to the turbine to the second interaction. So that the second interaction would received less energy [5]. In addition, inner vortex would be built up inside the turbine, and the size would increase with the diameter ratio [3].

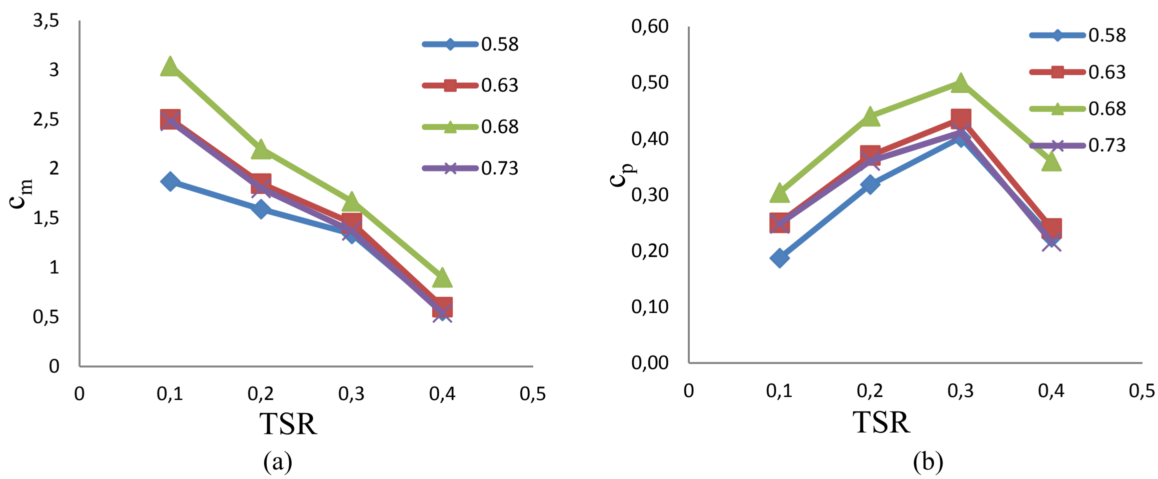


Figure 3. The torque coefficient (a) and power coefficient (b) dependence on TSR of the turbine on various diameter ratio.

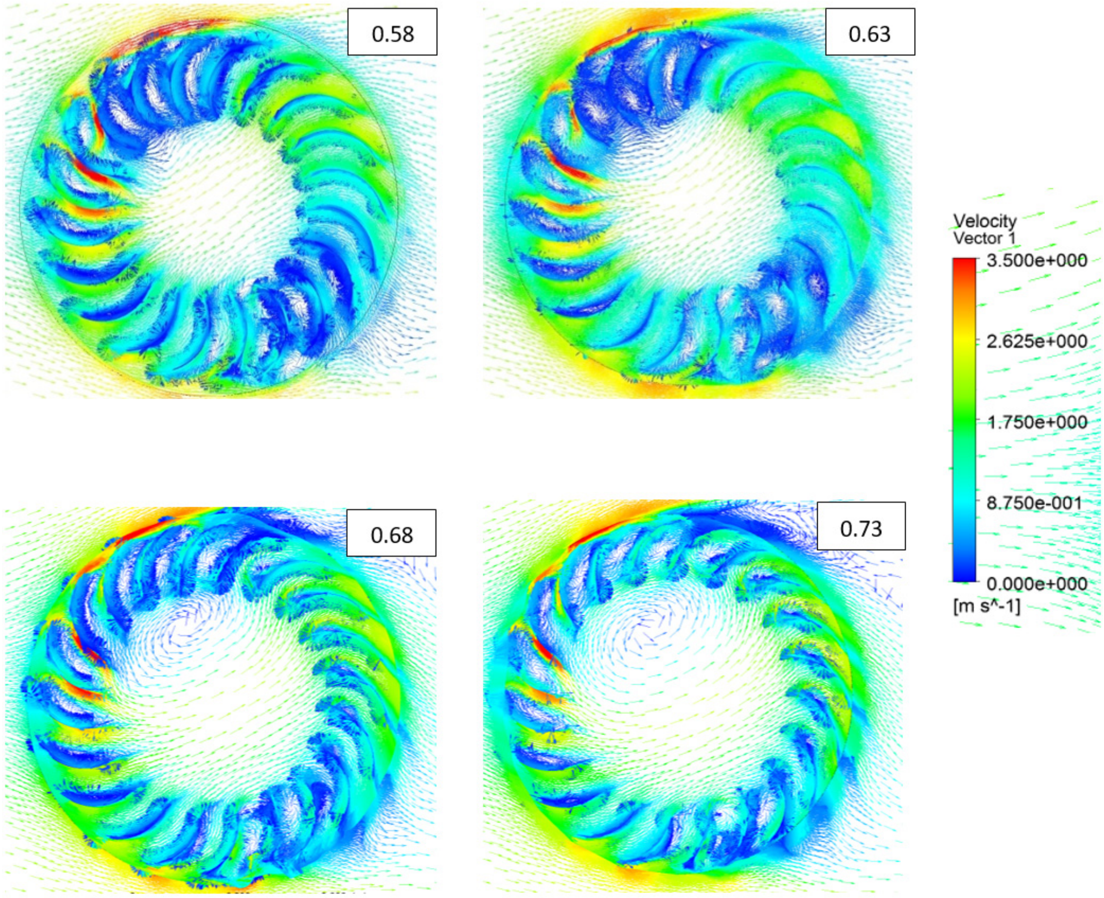
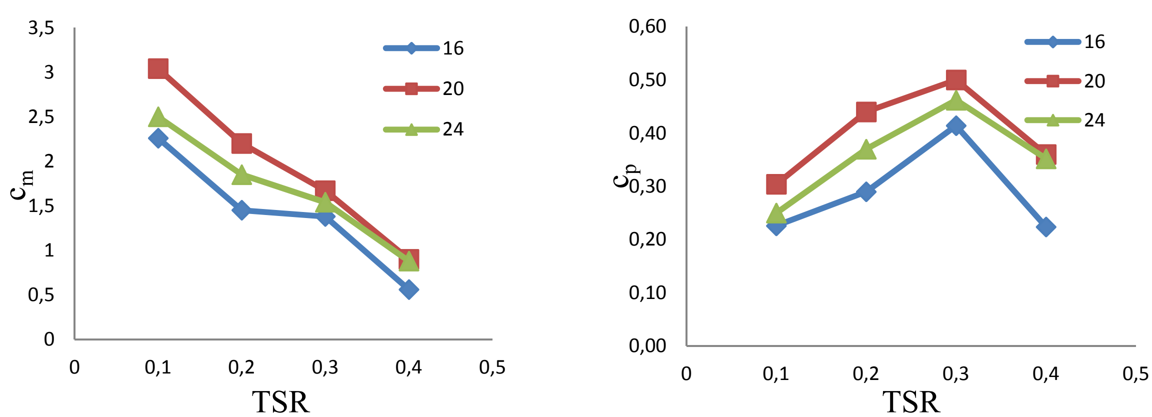


Figure 4. Velocity vector of the turbine for various diameter ratio on TSR = 0.3.

The turbine with diameter ratio of 0.68 then simulated for various blade number. The results are shown in Fig. 4. It can be seen that the turbine with diameter ratio of 0.68 achieved maximum performance on 20 blades. The maximum c_m and c_p achieved were 3.1 on TSR = 0.1 and 0.5 on TSR = 0.3 respectively. The Fig. 6 shows that less blade number would also reduce the positive interaction of the wind to the turbine runner. On the other hand, too many blades would increase the number of blades that give negative interaction.



(a) (b)

Figure 5. The torque coefficient (a) and power coefficient (b) dependence on TSR of the turbine with 0.68 diameter ratio on various blade number.

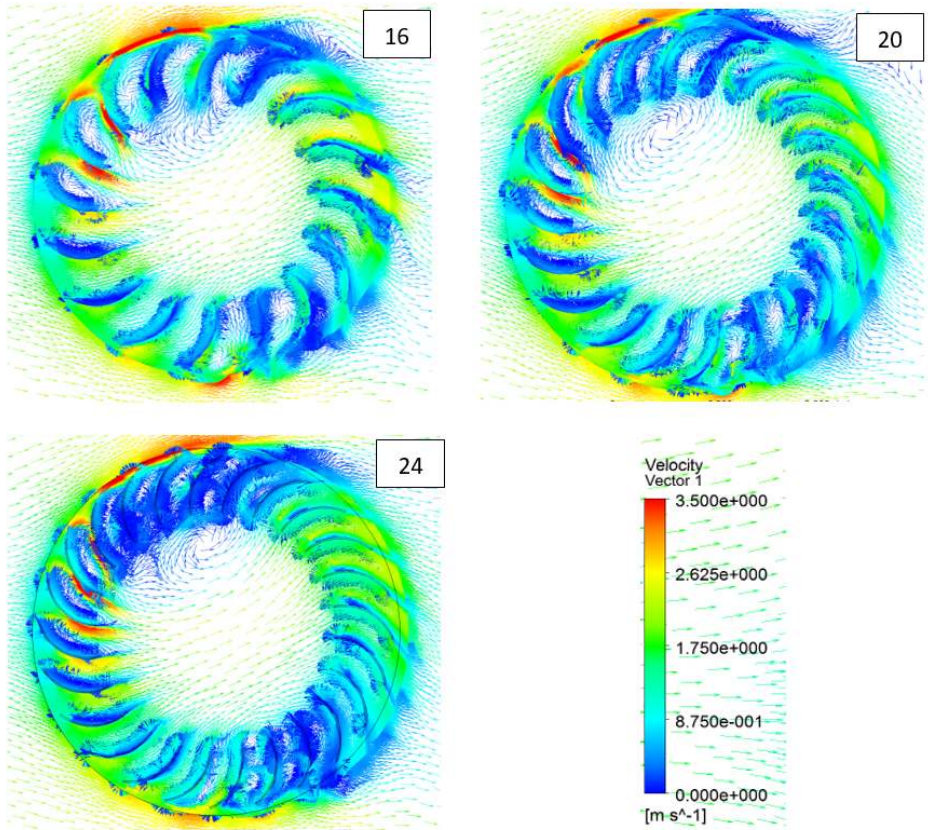


Figure 6. Velocity vector of the turbine for various blade number on TSR = 0.3.

CONCLUSION

The diameter ratio and the number of blades influence the torque coefficient, c_m, and power coefficient, c_p, of the cross flow wind turbine. Optimum diameter ratio and blade number should be selected to achieve the best performance. The maximum c_m of 3.1 and c_p of 0.5, produced by the crossflow wind turbine that has 0.68 diameter ratio and 20 blades.

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