ISSN 2347 - 3983
Volume 8. No. 6, June 2020
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter65862020.pdf
https://doi.org/10.30534/ijeter/2020/65862020

The Study of the Savonius Wind Turbine Blade Performance Integrated on the Doom Roof Type Building

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ABSTRACT

The wind turbine, a high potential renewable energy that available install directly in the location of energy demand.it can reduce energy loss due to the transmission. Installation of the wind turbine integrated with a building has a significant problem due to the efficiency and noise. In the urban area, the high building and particular roof design can be amplified the wind speed. In present research aim to investigate Savonius wind turbine with addition slotted blade, that suitable integrated with the doom roof type building. The research was conducted by an experiment method in an open type wind tunnel, and the best variable of the experiment becomes the input of Computational Fluid Dynamic (CFD) simulation, the Savonius wind turbine integrated on the doom roof type. The experimental variables are slotted angle blade 5°, 10°, and 15° degree, and wind speeds are arranged 3 m/s to 9 m/s. The validation of simulation is observed by comparing with the experimental result. In the simulation, the ratio of the doom geometry is a comparison between diameter to the high of the doom. The doom ratios is 1.5, and the position installation is on the top of the doom. The result found that the highest power coefficient is achieved to 0.291 and the torque coefficient to 0.776 by the 6m/s of wind speed. The slotted angle blade of 5° obtained as the optimum configuration in a low tip speed ratio. The 1.5 doom roof ratio is considered the highest performance of CFD in both of the top and side installation. This experiment result can become a reference to implemented the installation on the doom roof type such as mosque in urban areas with low wind speed

Key words: Doom roof, Power coefficient , Savonius wind turbine, Slotted blade, Tip speed ratio, and Torque coefficient.

1. INTRODUCTION

Ecofriendly electricity can be generated by wind energy as alternatives to renewable energy. The wind energy has highly potentially implemented at the location that energy is used. Many research has a design wind turbine to convert wind energy into electric energy. Kragten [1] and Bitar et al. [2] investigated the traditional wind turbine design, a horizontal axis wind turbine have several disadvantages; they are poor efficiency in the low speed of the wind, relative high noise, and required tall towers. The enormous requirement of electrical energy location is urban environments, and commonly, it has many high-rise buildings. However, the wind conditions in urban areas were turbulent, and the relatively low wind speed. Also, the wind speed is always changing, and the direction is not always the same [3].

The wind turbine suitable for integrating with a building in an urban area and have more optimal in low-speed wind turbines. The savonius wind turbine is a vertical axis wind turbine (VAWT) that has low initial speed and low maintenance cost. The Savonius wind turbines integrated with tall buildings are increasingly in demand as micro electric generating applications [4].

Various research of the Savonius wind turbine blade design has been studied to improve rotor efficiency and performance. Ricci et al. [5] investigate some of the advantages of Savonius wind turbines are: able to operate in turbulent and multi-directional wind conditions, especially in urban environments. However, according to Roy et al. [6], The Savonius turbines have a poor efficiency than other types of turbines but work with optimal efficiency at low speed. The characteristic of Savonius wind turbines that the number of savonius blades to achieve the best efficiency at low speed are two compare with three or four blades [7]. Previous research of Savonius turbine power coefficients are achieved in the range of 0.10-0.25.

Kacprzak et al. [8] studied about the modifications of the blade in the savonius wind turbine are developed by the researcher to improve rotor efficiency and performance. Research by Alexander and Holownia [9] found the effects of blade ratio, overlap blade, and the spacing distance between the turbine blade by the experiment in the wind tunnel.

Savonius wind turbines with an overlap blade can increase the performance by allowing the wind to flow into the gap between the overlapping blade and between the two blades,

then the wind pushes the reverse blade and reduced negative torque. The savonius wind turbine with addition overlap blade and space between blade were achieved power coefficient increased by 38.5% [10].
The improvement of the performance of the Savonius wind turbine was observed by added a deflector plate around the half of wind turbine swap area and amplified wind speed by the specific shape of the building. The principle of both the deflector plates and amplified wind speed reduces the negative torque and increasing the total turbine torque by adding more wind speed [11]. Commonly a small wind turbine installation in the rooftop of the building will provide the faster wind speed. The noise became a significant problem for a horizontal wind turbine.

Meanwhile, a tower as Wind Amplified Rotor Platform (WARP), has been observed to increase the performance horizontal axis wind turbine by Weisbrich et al. [12]. An aerodynamically designed toroidal-shaped amplifier module was vertically installed on core a tower, in the building. Each module has two rotors, typically 2-3 meters in diameter. The low wind flow to the toroidal shape and the wind speed increase in both the right and left modules, where the smaller wind turbines were installed. The founder claims that the circular tower can amplify the wind speed up to 65% [13].

The Spiral shape of the tower has been investigating by a researcher, the principle of the amplified wind was similar to the WARP The four mounted turbines are generating more than 4.5 times as much energy than if the turbines were standing alone [12]. The spiral shape of the tower can increase the wind speed and reduce the cost by decreasing the swept area of the wind turbine.

Ragheb [14], installed A helical design of vertical wind turbine horizontally on the top of the roof. The wind was amplified by the angle of the roof. Then the wind was flow on the lower of the roof, while the roof inclines, then the wind flow moved to the upper of the roof and concentrated on top of the roof. The higher wind speed on the roof was converted by vertical axis wind turbines that install horizontally. The roof design also similar to a deflector that can decrease negative torque by covering half of the swept area of the wind turbine [15].

The number of public buildings with doom roof designs such as mosques is enormous, especially in Indonesia. However, the shape of the public building, especially the doom roof type, is not observed yet by the researcher and the modifications of Savonius wind turbine using the slotted blade are required more observation. The result of this study can be a reference, how the Savonius wind turbine design, performance, and installation in the doom roof type building.

1.1 Experiment Method

The study was done by an experimental method in a wind tunnel and CDF simulation to know the performance of the installation in the doom roof type. The wind tunnel is the open type air circulation and powered by an impeller fan in the suction area on the back of the tunnel to provide streamline controlled wind speed. The data were collected the Prony brake instrument to calculate dynamic torque. The Tachometer and the anemometer are used to calculate air velocity and rotation speed on Savonius wind turbines. The following in Figure 1, illustrates the schematic installation of the wind tunnel.

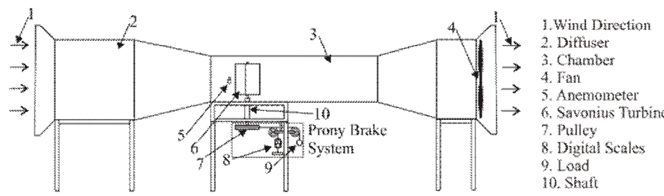


Figure 1: The illustration of the schematic wind tunnel installation

After the data were collected, the calculation processed can provide the value of the tip speed ratio, torque coefficient, and power coefficient. The number blade of Savonius wind turbine designs used in this study amounted is two consisting of 4 turbines with slotted blade angles in both blades and a conventional savonius blade turbine. The variables in the present research are the slotted angle β = 5°, 10°, and 15° degree. The variable of wind speed are controlled stable of 3 m/s, 6 m/s, 7 m/s, 8 m/s and 9 m/s. The turbine design can be seen in Figure 2.

There are several important parameters to determining the performance of a wind turbine, tip-speed ratio (λ), and power coefficient (Cp). The tip-speed ratio is the velocity ratio between the tangential velocity of the rotor tip and free stream (wind) velocity Eq. (1) whereas the power coefficient is usually used to measure the performance of a wind turbine.

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

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

The Cp represents the percentage of wind energy that can be converted into mechanical energy. The Cp can be determined by using Eq. (2)

$$c_p = \frac{P}{0.5 \rho S v^3} \tag{2}$$

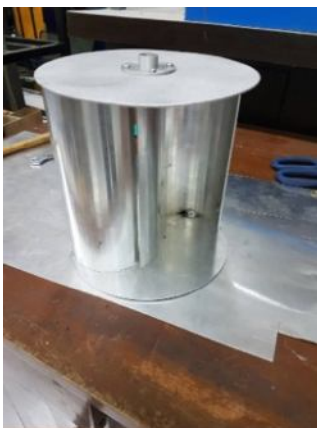
where,
ρ = Air density (kg/m3)

v = Air velocity (m/s)
S = Rotor swept area (m2)
cp = Power coefficient
P = Turbine output power (Watt)

The Ct represents the percentage of wind energy that can generate the amount of force in a direction perpendicular to the distance of the rotation center. The geometry of the savonius wind turbine was illustrated in Table 1 and Figure 2.

Table 1: Primary Dimension of Savonius turbine

Parameter	Value
Endplate Diameter ($D_{endplate}$)	220 mm
Rotor Diameter (D_r)	200 mm
Height (*H*)	200 mm
Aspect Ratio (D_r/H)	1
Shaft Diameter	6 mm
Total Bucket	2
Material	Alumunium
Plate Thickness	0.8 mm



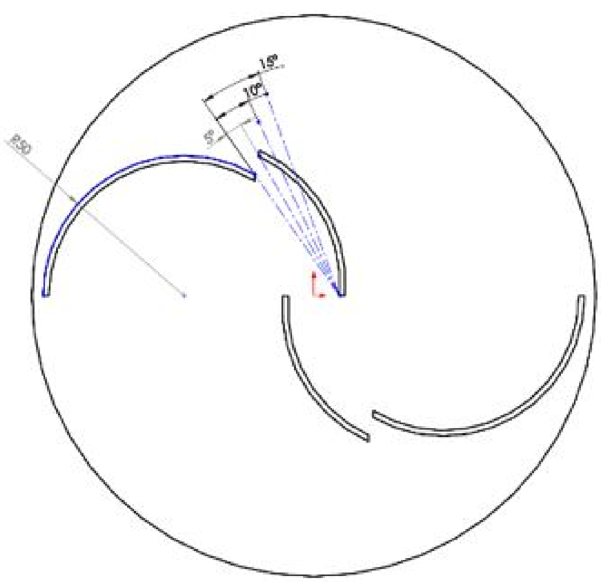


Figure 2: The specimen of the Savonius wind turbine and the Technical drawing.

1.2 Numerical Simulation Method

The Numerical simulation In the current study, the equation of conservation mass and momentum were solved numerically to analyze the steady of compressible flow in the three-dimensional doom roof models. The three-dimensional Naiver-Stokes for a compressible flow was illustrated Eq.(3) below.

Continuity equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \quad (3)$$

The x, y, and z momentum equations were given by :

$$\frac{\partial(\rho u)}{\partial t}+\frac{\partial(\rho u^2)}{\partial x}+\frac{\partial(\rho uv)}{\partial y}+\frac{\partial(\rho uw)}{\partial z}=-\frac{\partial \rho}{\partial x}+\frac{1}{Re_f}\left[\frac{\partial \tau_{xx}}{\partial x}+\frac{\partial \tau_{xy}}{\partial y}+\frac{\partial \tau_{xz}}{\partial z}\right]$$

$$\frac{\partial(\rho v)}{\partial t}+\frac{\partial(\rho uv)}{\partial x}+\frac{\partial(\rho v^2)}{\partial y}+\frac{\partial(\rho vw)}{\partial z}=$$

$$-\frac{\partial \rho}{\partial y}+\frac{1}{Re_f}\left[\frac{\partial \tau_{xy}}{\partial x}+\frac{\partial \tau_{yy}}{\partial y}+\frac{\partial \tau_{yz}}{\partial z}\right]$$

$$\frac{\partial(\rho w)}{\partial t}+\frac{\partial(\rho uw)}{\partial x}+\frac{\partial(\rho vw)}{\partial y}+\frac{\partial(\rho w^2)}{\partial z}=$$

$$-\frac{\partial \rho}{\partial z}+\frac{1}{Re_f}\left[\frac{\partial \tau_{xz}}{\partial x}+\frac{\partial \tau_{yz}}{\partial y}+\frac{\partial \tau_{zz}}{\partial z}\right] \quad (4)$$

The standard k-ε turbulence model was used to simulate the turbulent flow phenomenon [19]. The rate dissipations and turbulence kinetic energy were described by :

$$\frac{\partial(E_\gamma)}{\partial t}+\frac{\partial(uE_\gamma)}{\partial x}+\frac{\partial(vE_\gamma)}{\partial y}+\frac{\partial(wE_\gamma)}{\partial z}=$$

$$-\frac{\partial(u\rho)}{\partial z}-\frac{\partial(v\rho)}{\partial z}-\frac{\partial(w\rho)}{\partial z}+\frac{1}{Re_f Pr_f}\left[\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}+\frac{\partial q_z}{\partial z}\right]+$$

$$\frac{1}{Re_f}\left[\begin{array}{c}\frac{\partial q_x}{\partial x}(u\tau_{xx}+v\tau_{xy}+w\tau_{xz})+\frac{\partial}{\partial z}(u\tau_{xy}+v\tau_{yy}+w\tau_{yz})+\\ \frac{\partial}{\partial z}(u\tau_{xz}+v\tau_{yz}+w\tau_{zz})\end{array}\right] \quad (5)$$

1.3 Boundary Condition

The geometry of the doomed roof model was varied and interpreted as the ratio of the doom. The ratio of the doom is a comparison between diameter to the high of the doom; they is 1.5, and a turbine without a doom roof as validation to the experiment. The wind speed also arranged from 3 m/s, 6 m/s, 7 m/s, 8 m/s and 9 m/s. The simulation conducted in a box shape with the boundary condition that defines environment pressure walls. The simplified box size was 20 x 20x 40 m. See Figure 3.

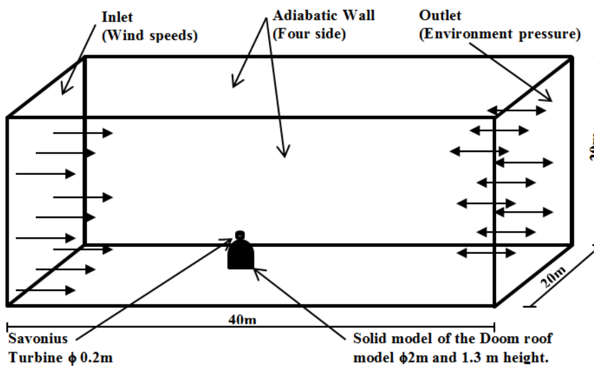


Figure 3 : The boundary condition in the numerical simulation

1.4 Boundary Condition

In this study, the simulation models are validated by the best variable in the experiment. The step for validation of simulation; first remodeling the specimens of the experiment, then set the equation approaches and the input simulation variable similar to the variable in an experiment, then generate the size of the mesh and run the iteration until convergence.

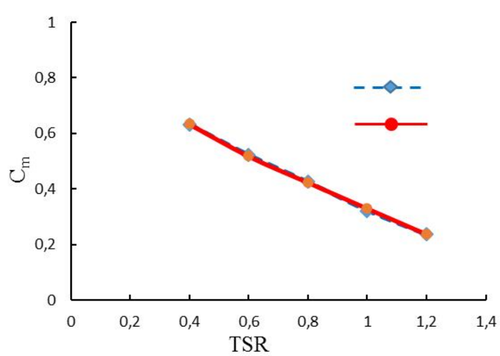


Figure 4: The validation of the simulation using the experiment result, the different is less than 8%.

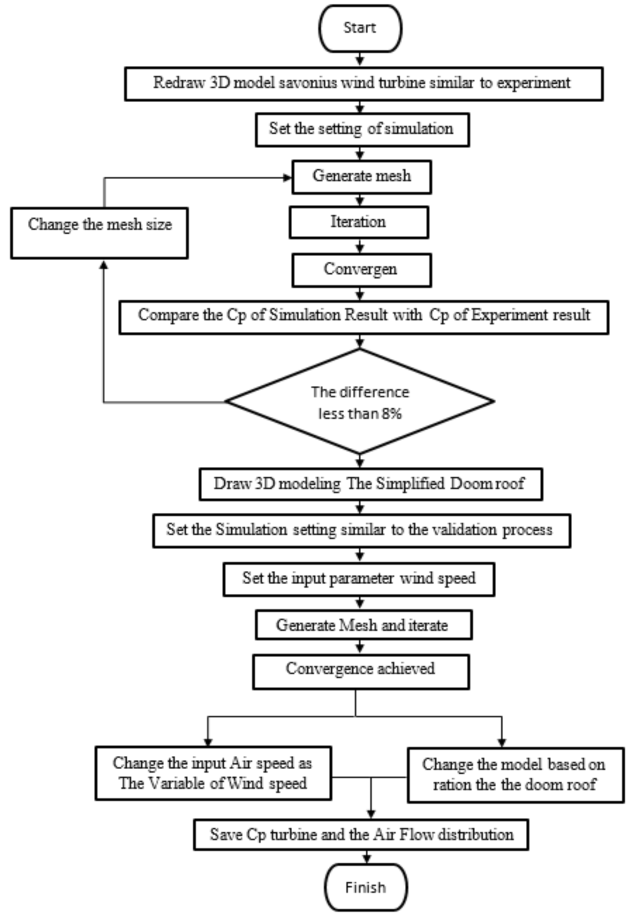


Figure 5: The flowchart of the research that describes the correlation between experiment and simulation

The result of the simulation is the coefficient of the moment, then compare to the experiment result. If the difference between simulation and the experiment is more than 8%, then decrease the size of the mesh and repeat the iteration continues until the difference between simulation and experiment result in less than 8%. After that, input the wind speed variables as an interpretation of tips speed ratio and then compare the result with the experiment. The graphic of the coefficient moment from the simulation and the experiment is described in Figure 4.

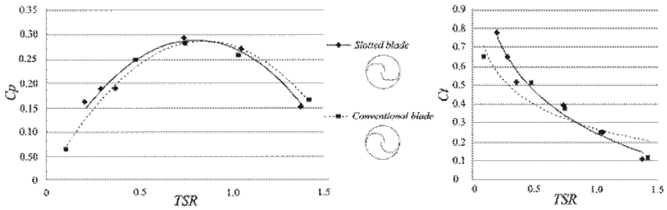
1.5 The flowchart of the research

The correlation between the experiment and the simulation method of the study of the Savonius wind turbine sees a flow chart of research in Figure 5.

2. RESULT AND DISCUSSION

The comparison between the savonius wind turbine with a slotted blade and conventional blade .

A comparison of power coefficient and torque coefficient on savonius wind turbine with a slotted blade against savonius wind turbine with a conventional blade can be seen on the Figure 6.



(a) (b)

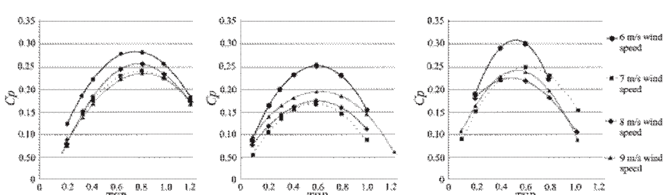
Figure 6 : (a) The trend line of Power Coefficient towards Tip speed ratio and, (b) The trend line of Torque Coefficient towards Tip Speed Ratio

The graph in Figure 6 (a) shows that Savonius wind turbines with slotted blades have higher power coefficients. The highest power coefficient is achieved by 0.291 of power coefficient for savonius wind turbines with a slotted blade and a 0.282 power coefficient for conventional savonius wind turbines, the addition of the slots on the turbine blade rising the power coefficient by 3.2%.

The graph in Figure 6 (b) shows that the highest torque coefficient of the Savonius wind turbine with a slotted blade is achieved to 0.776. Meanwhile, the conventional of the savonius blade is lower up to 0.652. In this research, the increased 19.02% of the torque coefficient was obtained compare to conventional savonius blades. The addition of slots in the savonius turbine blade has increased the pressure obtained in the swept area on the savonius wind turbine blade. This pressure creates the savonius wind turbine with a slotted blade that has a higher moment value compared to conventional blades and resulted in decreasing the negative torque. It was also found that savonius wind turbines with slotted blades increase performance on savonius wind turbines at a low tip speed ratio, similar to the result of the research by Ni et al., [20].

2.1 The Power Coefficient in Various Wind Speed of Slotted Blade Savonius Wind Turbine

The savonius wind turbine in the experiment, the best value of Power Coefficient (CP) 0.291 is obtained on savonius wind turbines with a slotted angle 50 at 6 m/s velocity. See Figure 7 (a). Also can be seen on wind turbine 100 and 150 are achieved the highest 0.244 and 0.213 of Power Coefficient (CP).

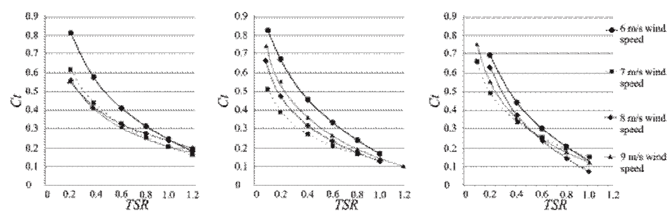


(a) (b) (c)

Figure 7: The Comparation of Power Coefficient of Savonius Wind Turbine (a) 50 degree of slotted blade, (b) 100 degree of slotted blade, and (c) 150 degree of slotted blade.

The tips speed ratio (TSR) is an interpretation of wind speed. In the Figure 7 shows that the 6 m/s wind speed has the highest power coefficient (CP). It was the best configuration for the savonius wind turbine in the current research. The graph also shows that trendline the correlation of TSR and CP, where the increase of TSR increased to the CP, then after achieving the peak point, the increase, TSR resulted in a decrease in the CP.

The savonius wind turbines characteristics are similar to the research of Ferrari et al. [21] that the correlation between TSR and Cp was the opposite parabolic graph. The power coefficient was reduced due to increase the turbine rotation; in another word, the increase, negative torque is more significant than the increase of power coefficient , the Savonius wind turbines optimal work in low TSR. The Savonius wind turbine is reached the highest turbine efficiency in the range between 25% to 35% of the total wind energy available [21].



(a) (b) (c)

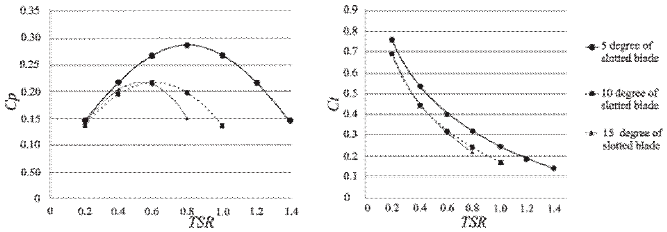
Figure 8 : The comparison the Torque Coefficient of Savonius Wind Turbine (a) 50 degree of slotted blade, (b) 100 degree of slotted blade, and (c) 150 degree of slotted blade.

2.2 The Torque Coefficient in Various Wind Speed of Slotted Blade Savories Wind Turbine

In Figure 8 shows that the value of the Torque Coefficient (CT) is decreasing while the TSR is increased. The highest torque coefficient is reached at 6 m/s wind speed. The torque coefficients in 50, 100, and 150 degrees of slotted angle are 0.792, 0.769, and 0.667, respectively. The trendline of CT is decreased rapidly by the increase of TSR and become stable near horizontal at 0.1 of CT. It means the wind energy converted onto the increase of rotating turbine then decrease the torque.

2.3 The Performance of The Savonius Wind Turbine in Various Slotted Angle Blade

In the current research, 6 m/s of the wind speed in savonius wind turbine with all test slotted angles. Further research on the ratio of each angle on the wind turbine can be seen in the Figure 9.



(a) (b)

Figure 9: The performance of the savonius wind turbine with a various slotted angle. (a) The Power Coefficient towards Tip speed ratio (b) The Torque Coefficient towards Tip speed ratio

The illustration in Figure 9 (a) shows that a savonius wind turbine with 5^0 The degree of slotted angle blade is the highest power coefficient. It obtains the power coefficient up to 0,291, while 10^0 and, 15^0 The degree of slotted angle blade is reached 0.244 dan 0.213 power coefficient. In Figure 9 (b) described that the Savonius wind turbine with 5^0 Of the slotted angle, the blade is obtained the most significant torque coefficient of 0,796. Meanwhile the 10^0 and, 15^0 degree of slotted angles blade are achieved 0,769 and 0,667 power coefficient, respectively.

The similar result to Alaimo et al [23] that the slotted blade addition in the Savonius wind turbine reduces the negative torque due to the increase in turbine rotation speed. The 50 degrees of slotted angle blade allowing the wind flow into the gap between the overlapping blade and flow trough the center in between the two blades, then the wind pushes the reverse blade to reduce negative torque. Int, the opposite phenomenon for The 100 and 150 degrees of slotted angle blade that the leak out of capturing wind energy and pressure loss appear due to the gap, is relatively significant. The more significant the gap on the blade effected, the lower the performance of the savonius wind turbines can achieve.

2.4 The Simulation Result on The Roof Top

The slotted blade addition in the Savonius wind turbine reduces the negative torque due to the increase in turbine rotation speed. The 50 degrees of slotted angle blade allowing the wind flow into the gap between the overlapping blade and flow trough the center in between the two blades, then the wind pushes the reverse blade to reduced negative torque. In similar parameters are applied in the simulation.

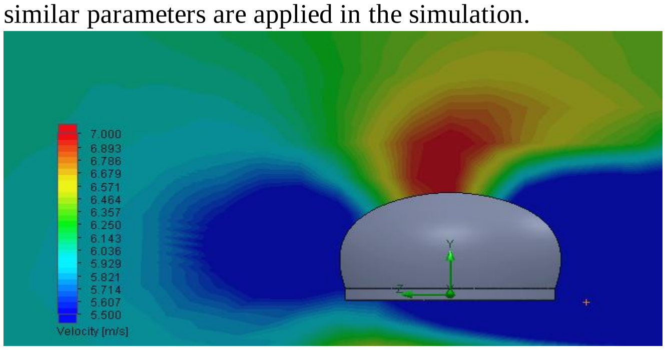


Figure 10: The wind speed distribution in the rooftop area before the wind turbine is applied.

In the simulation result in Figure 10 shows that the wind speed is 6 m/s and it became slowing down near the doom roof. The wind are guided by the surface of the doom and concentrated on the top of the doom. The speed on the top of the doom are amplified to 7.8 m/s. this phenomenon can be the potential position on the doom to apply wind turbine.

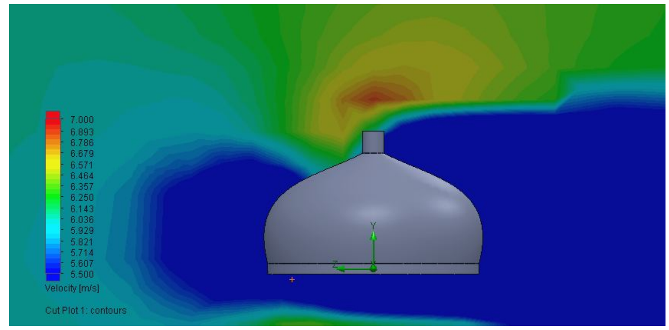


Figure 11: The wind speed reduces due to the wind energy converted into mechanical energy by wind turbine

3. CONCLUSION

The experiments and analyzing data calculations, it found that the angle of the slotted blade on the wind turbine affects the torque negatively and the power coefficient on the savonius wind turbine. The performance of the savonius wind turbine with slotted blade works optima at the lower tip speed ratio compared to conventional blade Savonius wind turbines. Savonius slotted blade wind turbine increases the power coefficient by 3.19% and torque coefficient by 19.02% compared to conventional Savonius wind turbine with the blade.

The higher the value of the slotted angle blade, will reduce the power coefficient and torque coefficient due to the leak out of capturing wind energy and pressure loss appear. The 50 degrees of slotted angle blade is the optimal angle that is allowing the wind flow into the gap between the overlapping blade and flow trough the center in between the two blades then, the wind pushes the reverse blade to reduced negative torque. In the simulation the wind turbine is reached 0.282 of coefficient performance and 0.32 of coefficient torque. The doom type of roof top building is the high potential to apply wind turbine due to the amplified wind speed

ACKNOWLEDGEMENT

The research was funded by PNPB of vocational study Sebelas Maret University.

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