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An experimental study on the performance of Savonius wind turbines related with the number of blades

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Abstract

Wind energy is the most abundantly available clean form of renewable energy in the earth crust. Wind turbines produce electricity by using the power of wind to drive an electric generator. There are two kinds of wind turbines according to the axis of rotation to the ground, horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). VAWTs include both a drag type configuration like Savonius wind turbine and a lift-type configuration like Darrieus wind turbine. Savonius wind rotor has many advantages over others in that its construction is simpler and cheaper. It is independent of the wind direction and has a good starting torque at lower wind speeds. The experimental study conducted in this paper aims to investigate the effect of number of blades on the performance of the model of Savonius type wind turbine. The experiments used to compare 2, 3, and 4 blades wind turbines to show tip speed ratio, torque and power coefficient related with wind speed. A simulation using ANSYS 13.0 software will show pressure distribution of wind turbine. The results of study showed that number of blades influence the performance of wind turbine. Savonius model with three blades has the best performance at high tip speed ratio. The highest tip speed ratio is 0.555 for wind speed of 7 m/s.

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Keywords: vertical axis wind turbines; Savonius type; rotor blades; tip speed ratio; coefficient of power

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1. Introduction

One of the prime commodity in modern civilization is energy. The amount of energy consumption has become the indicator for the standard of living and the degree of industrilization. At present, nearly ninety percent of the world's energy come from the combustion of fossil fuels, i.e. coal, petroleum oils, natural gas, etc. People use fossil fuels to meet nearly all of their energy needs, such as powering vehicles, producing electricity for light and heat, and running factories. On the other hand, energy resources from earth's fossil energy are limited and also the global production of petroleum oils will come beyond their peak in the next decades. The population growth will make the need of energy becomes higher and also the price of fossil fuels. At the same time there is a problem with the global climate change as a result of carbon-dioxide and sulfur-dioxide emission from the burning of fossil fuels. Using renewable energy as a cost-effective and reliable low carbon energy sources is becoming an important objective of energy policy in the world. Renewable energy is a climate-friendly energy due to the absence of emission detrimental to the environment. The International Energy Agency reported that only a very small proportion of the energy comes from nuclear and hydro-power, and a much smaller portion from renewable energy sources such as solar, wind, biomass, geothermal and tidal waves [1].

Wind is an environment friendly source of energy that has got huge potensial to satisfy energy needs for people and also to mitigate the climate change from greenhouse gasses emitted by the burning of fossil fuels. It was estimated that roughly 10 million MW of energy are available in the earth's wind. The International Energy Agency (IEA) showed the global cumulative wind power capacity worldwide in Fig. 1 based on the projection in the 2004 World Energy Outlook report [2]. Wind turbine is used to change wind energy into mechanical energy (such as wind mill and moving height) and generate electricity.

The turbines are classified to two categories, horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs). If. HAWT has a horizontal axis of rotation, then VAWT has a vertical axis of rotation. VAWT has more simple structure and installation than that HAWT. The generator of VAWT is placed at the bottom of central shaft on the ground and the tower do not need to support it. The turbines are useful in different speed and direction of wind [3]. In contrast, VAWTs have low pressure coefficients, therefore the scope for major research on VAWT rotors is to improve their performance. VAWT rotors have different types, such as Savonius rotor, and (eggbeater) Darriues, or H-Darrieus rotor as shown in Fig. 2 [4].

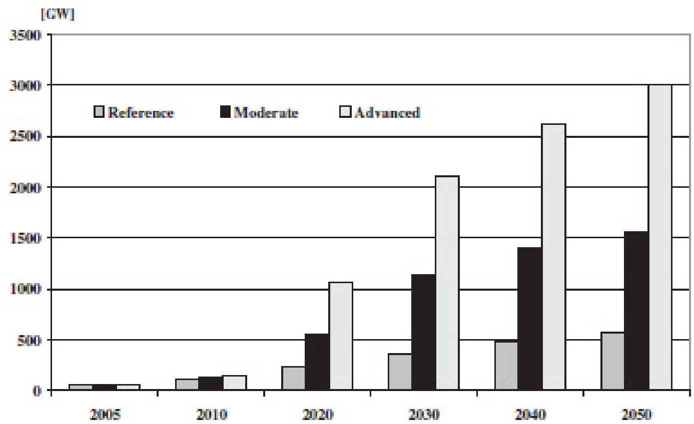


Fig. 1. Global cumulative wind power capacity worldwide [2].

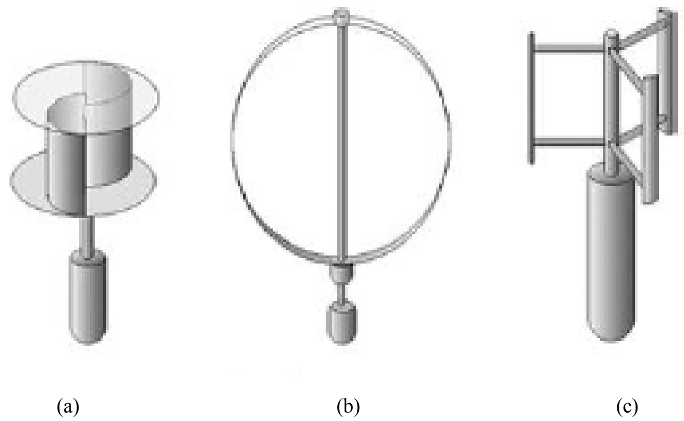


Fig. 2. VAWT turbines: (a) Savonius rotor; (b) Darrieus rotor; (c) H-Darrieus rotor [4].

Savonius type wind turbine, also called S-rotor, was originally invented and patented by Finnish engineer, Sigurd J. Savonius in 1931. The turbine made of two halves cylinder and then moving the two semi cylinder surfaces side-ways along the cutting plane like the letter S (see Fig. 2a). The two semicircular surfaces, called blades or buckets, are mounted on a vertical axis perpendicular to the wind direction with the gap at the axis between the blades or the overlap. The Savonius turbine works like a cup anemometer or a drag-based device. The ratio of the blade tip speed to wind speed is less than unity because the returning blades on the downwind side can never travel faster than the wind. Savonius investigated the performance of thirty different model of S-rotors in the wind tunnel and open-air [5]. He reported a maximum power coefficient (Cp) of 0,31 from wind tunnel experiments while reported a maximum Cp of 0,37 from open-air tests. In the last half of century, many researchers had experimentally investigated the performances of different designs of Savonius wind turbines and obtained that the number of Cp in the range of 0,15 to 0,35 [6-10]. This paper aims at studying the effect of number of blades on the performance of the Savonius vertical axis wind turbine through wind tunnel test and simulation using ANSYS 13.0 program.

2. Wind turbine theory

As a simplest turbine, Savonius wind turbine works due to the difference of forces exert on each blade. The concave part to the wind direction caught the air wind and forces the blade to rotate around its central vertical shaft. Otherwise, the convex part hits the air wind and causes the blade to be deflected sideway around the shaft. The blades curvature has less drag force when moving against the wind or F_{convex} than the blades moving with the wind or $F_{concave}$ as seen in Fig. 3 [11]. Hence, concave blades with more drag force than the other half cylinder will force the rotor to rotate.

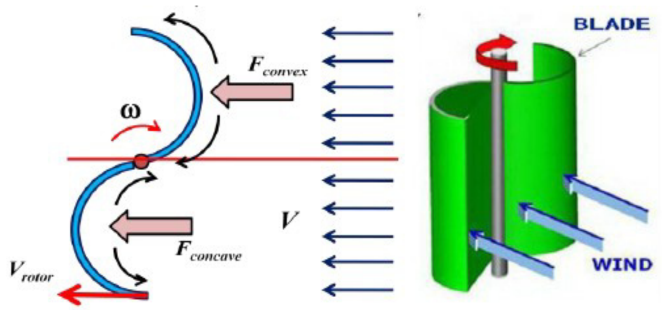


Fig. 3. Two blades Savonius wind turbine with the drag forces [11].

The performance of Savonius wind turbine can be expressed in the form of torque coefficient (**C_t**) and the coefficient of power (**C_p**) in comparison with the tip speed ratio or *TSR* (**λ**). *TSR* is a parameter related with rated wind speed and rotor diameter. As the ratio between the speed of tip blade and wind speed through the blade, *TSR* can be determined as [12].

$$TSR = \lambda = \frac{V_{rotor}}{V} = \frac{\omega . d}{V} \quad (1)$$

where V_{rotor} is the tip speed or the peripheral velocity of rotor (m/s) ; ω is the angular velocity of rotor (1/s) ; d is the diameter of the halves cylinder of rotor (m), and V is the wind speed (m/s).

The coefficient of torque or C_t is defined as the ratio between the actual torque develop by the rotor (T) and the theoretical torque available in the wind (T_w) as,

$$C_t = \frac{T}{T_w} = \frac{4\,T}{\rho\, A_s\, d\, V^2} \quad (2)$$

where ρ is the density of air (= 1.225 kg/m^3) ; T is the torque (Nm), and A_s is the swept area of blades = the rotor height x the rotor diameter (m^2).

The coefficient of power of a wind turbine (C_p) is the ratio between the maximum power obtained from the wind (P_t) and the total power available from the wind (P_a) as,

$$C_p = \frac{P_t}{P_a} = \frac{P_t}{\frac{1}{2}\rho\, A\, V^3} \quad (3)$$

where the maximum power of wind turbine is determined as

$$P_t = T\,\omega \;\; (Watt) \quad (4)$$

The relationship between the power coefficient C_p and the tip speed ratio *TSR* or λ as an effect of solidity of the wind turbine performance is shown in Fig. 4 [13]. The curve shows that single blade of wind turbine has smaller solidity and the shape of curve C_p relatively flat which caused by higher drag force. The three blades wind turbine gave optimal solidity with C_p maximum and the result it produces more energy.

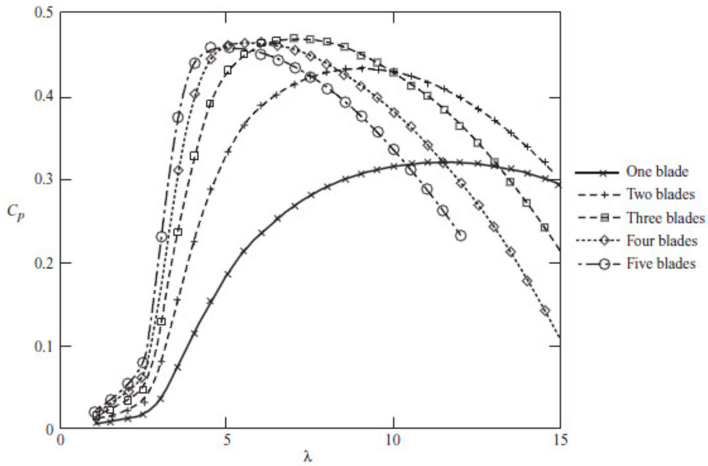
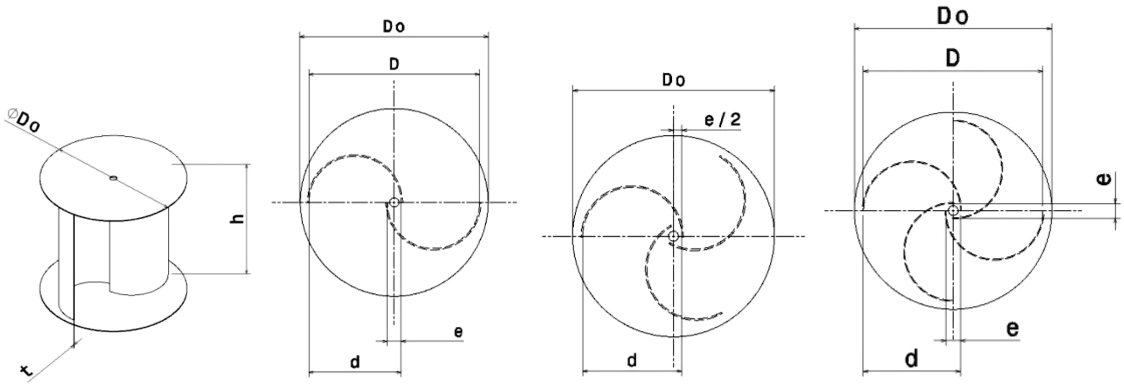


Fig. 4. The curve of power coefficient Cp and tip speed ratio λ of wind turbine.

3. Experimental set up

The experiment used a model of Savonius wind turbine with two, three and four blades as shown in Fig. 5. The model of wind turbine was built with overlap ratio (e : d) equal to 0.15 ; aspect ratio (D : h) equal to 1.0 and end plate parameter (D_0 : D) equal to 1.1 [14].



(a) (b) (c) (d)

Fig. 5. Design of wind turbine model (a) and the cross section of turbines with (b) two blades (c) three blades, and (d) four blades.

Dimensions of the blades of Savonius wind turbine model are diameter of blades (*d*) = 200 mm ; gap (*e*) = 0.15 x d = 0.15 x 200 = 30 mm ; rotor diameter (*D*) = 200 + 200 – 30 = 370 mm ; rotor height (*h*) = 370 mm ; end plate diameter (D_0) = 1.1 x D = 1.1 x 370 = 407 mm ; and thickness of blades and end plates (*t*) = 2 mm.

The model of Savonius wind turbine were performed in a low speed open circuit wind turbine as shown in Fig. 6. The low speed wind tunnel was started to produce wind and an anemometer measured the velocity of wind. When the wind produced by wind tunnel pushed the blades (halves of cylinder) of the model, the rotor of wind turbine will rotate. The rotation of rotor was measured by tachometer and noted three times of experiments. Each experiment with two, three and four blades respectively used the speed of wind from 1 to 10 m/s. The torque of wind turbine was also measured by a torque meter related with the speed of wind. The specified speed of wind from the wind tunnel (1 to 10 m/s) were determined based on the assumption that small wind turbine, like the model of Savonius wind turbine, will tend to split in angular motion if using high speed wind. High speed of wind exerts high pressure on blades causing the rotation of rotor may exceed its design limit and become difficult to measure.

(a) (b)

Fig. 6. (a) Wind tunnel, and (b) Savonius wind turbine model.

4. Results and discussion

Results of the experiments indicated the relationships between wind speeds and tip speed ratio or actual torque as shown in Fig. 7 and Fig. 8. Fig. 7 shows that the three blades wind turbine model has the highest tip speed ratio. In general the three wind turbine models have significant tip speed ratio at lower wind speed and more stable at wind speed of 7 m/s. It means that the wind turbine models has optimal rotational speed at the wind speed above 7 m/s. Tip speed ratio is related with the performance of rotational speed of wind turbine rotor. Wind turbine with higher rotation will result in higher tip speed ratio. Three blades wind turbine model has the highest tip speed ratio at 0.555 with the wind speed of 7 m/s.

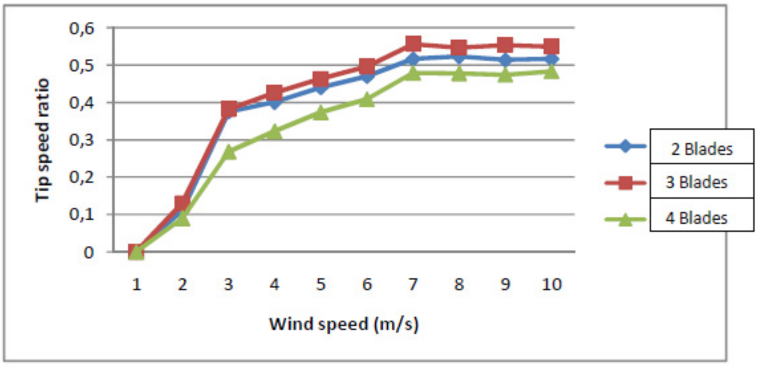


Fig. 7. Tip speed ratio related with wind speed (m/s) in wind tunnel.

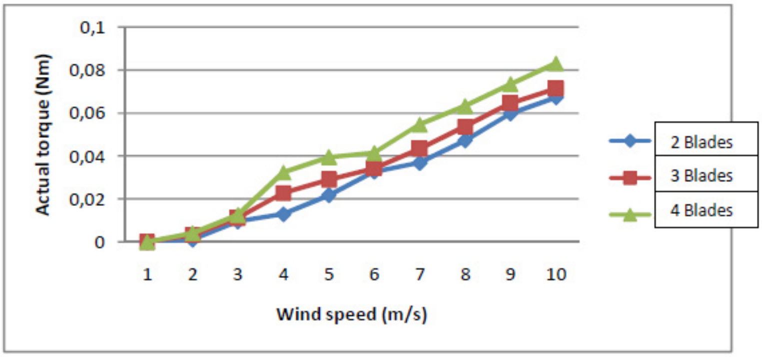


Fig. 8. Actual torque of wind turbine rotor for different wind speeds.

Fig. 8 shows the relationship between the actual torques of the shaft of wind turbine models for different wind speed. Four blades wind turbine model has higher torque than that two or three blades wind turbine. Wind turbine model with four blades has more drag force at any position when the wind rotor is in rotational position. Wind turbine rotor with more number of blades will deliver higher torque for the shaft of the turbine. Number of blades related with the solidity of wind turbine, higher solidity will give also higher torque for the wind turbine.

The deviation of drag forces caused by pressure differences on the blades of Savonius wind turbine will be shown using ANSYS 13.0 software. The simulation was assumed on steady flow with the wind speed of 10 m/s. Fig. 9 shows pressure distribution for wind turbine rotor with two blades (a), three blades (b) and four blades (c). Pressure on concave blades is higher than pressure on convex blades with result that the deviation of drag forces will rotate the rotor. As shown in Fig. 9 (a) and (b), pressure in front of blades is higher than that at the back and wind turbine rotor will rotate. The more blade surfaces with higher pressure is found in four blades wind turbine as seen in Fig. 9

(c). It makes that four blades wind rotor has highest torque compared with other wind turbine rotor. Pressure differences between the area in front and at the back of wind turbine blades are determined as in Table 1.

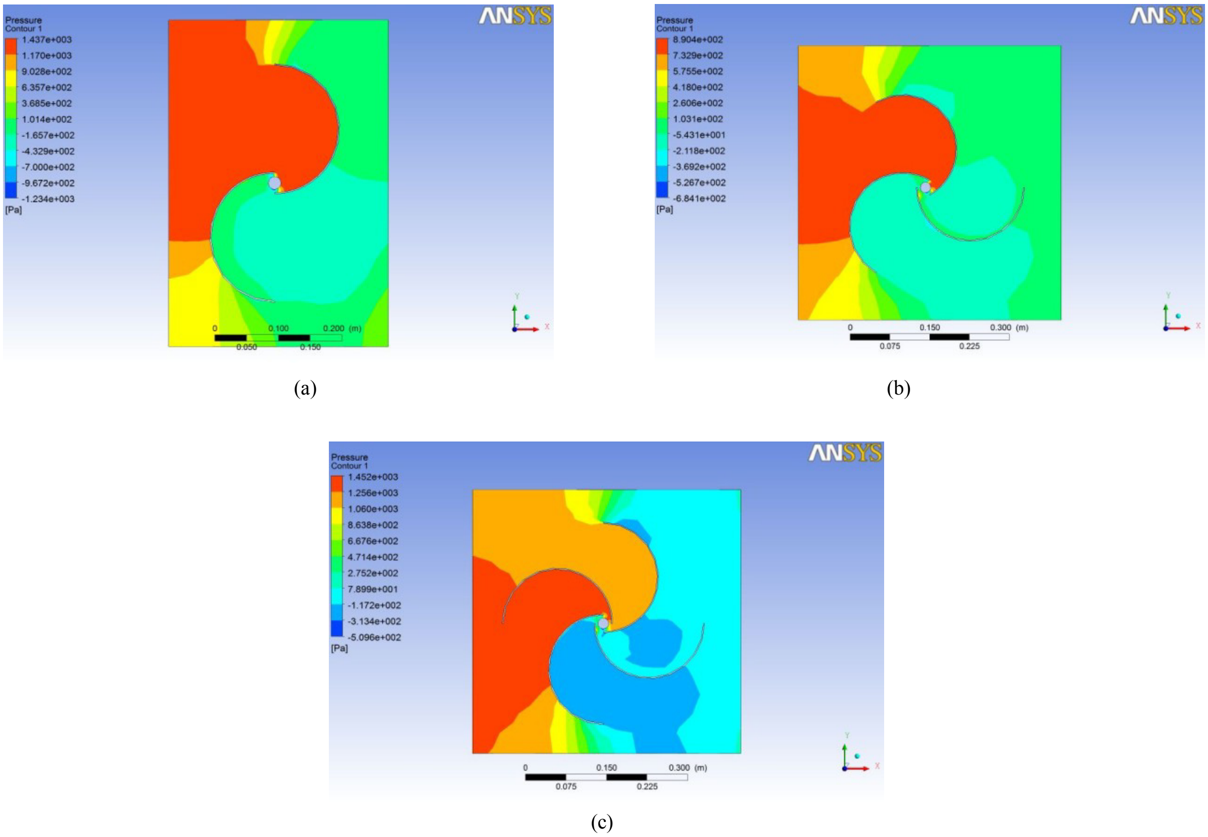


Fig. 9. Pressure distribution on (a) two blades, (b) three blades, and (c) four blades wind turbine rotor.

Table 1. Pressure differences between area in front and back of rotor.

Wind speed (m/s)	Pressure differences (Pa)		
	2 blades	3 blades	4 blades
1	12,808	8,207	13,3249
5	328,375	193,11	338,9
10	1335,7	787,21	1373,2

The variations of power coefficient C_p related with tip speed ratio are shown in Fig. 10. All types of wind turbine rotor have tendencies to be polynomial graphs. The two blades wind rotor shows that values of C_p will increase related with the increment of tip speed ratio or wind speed, but it produces less power. Compared with others, the four blades wind turbine rotor shows highest Cp at the tip speed ratio about 0.37 or wind speed of 6 m/s. However, after the wind speed of 6 m/s four blades wind turbine has low rotation and more decreasing power when the wind speed between 6 m/s to 8 m/s. Three blades wind rotor has better performance than four blades wind rotor. At wind speed 7 m/s to 10 m/s three blades wind turbine model shows power increase steadily and the rotation produced can exceed the rotation of four blades wind turbine. Three blades wind turbine model gives power more stable than that four blades wind turbine.

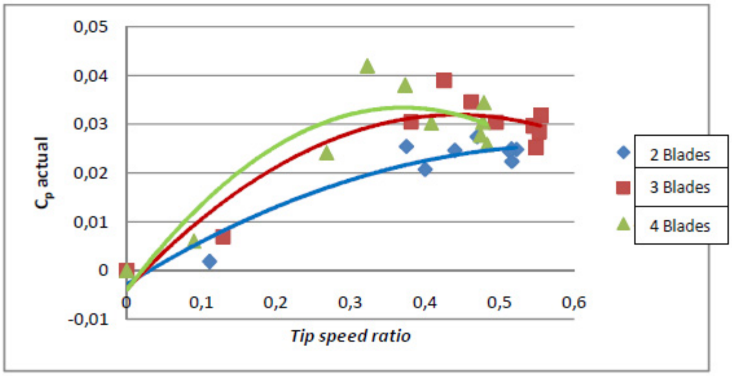


Fig. 10. Power coefficient C_p variation with tip speed ratio for two, three and four blades of Savonius wind turbine model.

5. Conclusions

Some conclusions on the experimental study of Savonius type wind turbine model in wind tunnel and simulation using ANSYS 13.0 are:

- Number of blades will influence the rotation of rotor of wind turbine models. The three blades wind turbine produces higher rotational speed and tip speed ratio than that two and four blades. The highest tip speed ratio is 0.555 for wind speed of 7m/s.
- Wind turbine rotor with four blades has high torque compared with two or three blades wind rotor.
- Four blades wind turbine has good performance at lower tip speed ratio, but three blades wind turbine has the best performance at higher tip speed ratio.

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