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EXPERIMENTAL INVESTIGATION OF SAVONIUS WIND TURBINE BLADE FOR LOW WIND SPEED REGION

Norzaima Nordin[a,*], Muhamad Nur Alif Nadzri[b], Baizura Bohari[a], Mohd Rashdan Saad[b], Maidiana Othman[c]

[a] *Department of Aeronautical Engineering and Aviation, Faculty of Engineering, National Defence University of Malaysia, Sg. Besi Camp, Kuala Lumpur, Malaysia*
[b] *Department of Mechanical Engineering, Faculty of Engineering, National Defence University of Malaysia, Sg. Besi Camp, Kuala Lumpur, Malaysia*
[c] *Department of Civil Engineering, Faculty of Engineering, National Defence University of Malaysia, Sg. Besi Camp, Kuala Lumpur, Malaysia*

*Corresponding author: norzaima@upnm.edu.my

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ABSTRACT

In this study, a small-scale wind turbine blade for the application in a low wind speed region was experimentally investigated. Savonius wind turbine design was selected and evaluated based on the feasibility of low wind speed at the National Defense University of Malaysia (UPNM). Six different Savonius Wind Turbine Blade (SWTB) designs were selected to investigate the effect of the number of blades, diameters, and types of materials. A wind tunnel experiment was carried out to investigate the performance of the wind turbine blades with different parameters. The experimental results were analyzed based on power coefficient (Cp), wind speed (V), tip speed ratio (TSR), torque coefficient (Ct) and electric power output (Pe). It was found that the number of blades and diameter were the most significant factor in designing SWTB. For this particular study, the least number of blades with the bigger diameter were more significant to increase the Cp values. The material factor was least significant to the design as this experiment verified that all the models produced the highest peak of Cp corresponding to the wind speeds. The effectiveness of this experiment was concurred by the highest power output produced.

Introduction

A wind turbine is widely utilized in several countries as renewable energy and an alternative to produce electrical energy for human needs. This was elevated by the global cumulative capacity of wind power generation had increased 20 times over the past ten years. Therefore, it will be important for the development of wind turbine technology. Generally, there are two types of wind turbine; Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). Previous research established that VAWT design could be used in a small-scale application of wind turbines compared to HAWT design [1–3]. These remarkable advantages of VAWT make it easier to maintain and be used for low wind speed condition applications.

Although wind turbine technology has gradually developed in most countries, it is still rarely found in Malaysia. Malaysia is one of the countries which experiences low wind speed conditions and the wind speed varies according to certain regions and months. The distinction of the wind speed is due to the difference in ground elevation. Generally, higher ground elevations have stronger wind speeds compared to lower ground elevations. This is due to the fact that different ground elevation may affect the speeds of the wind blows that will specify the performance of the wind turbines. To design a wind turbine, it is important to note that the parameters of the wind turbine blades play a key role in its performance. The function of the wind turbine blades is to capture the flow of the wind to make the blade rotate and produce power generation. The number of turbine blades plays a major influence on the power generation of the wind turbine [3-4]. Hence, there is a need to obtain the relationship of the blade design to the performance of VAWT in low wind speed conditions [5].

VAWT connsists of two main types: Darrieus and Savonius vertical wind turbines which are commonly used in the industry [6-7]. Savonius VAWT has a s-shaped rotor blade when observed from the top. This VAWT is a drag type device due to the blades not having an aerofoil shape. For Darrieus VAWT, the shape of the rotor blade looks like an egg-eater from the side view. This VAWT is a lift type device because it has an aerofoil shape at the rotor blade. In this study, Savonius Wind Turbine Blade (SWTB) was chosen based on its ability to operate under low wind speed conditions and higher starting torques than Darrieus Wind Turbine Blade [5–9]. This study aimed to investigate the SWTB performance according to UPNM wind speed conditions. Experimental investigation of the Savonius blade was performed on different parameters of the Savonius blade design; the number of blades, diameter size and materials. All designs were tested using a wind tunnel to compare the performances of the wind turbine in terms of the power coefficient (Cp).

Comparisons with the previous studies were carried out to study the performances of the Savonius wind turbine with different numbers of blades [1, 9-11]. Ali in [11] performed two different configurations of Savonius wind turbines with a different number of blades (two and three blades). The results showed that the two-blade Savonius wind turbine was more efficient than the three-blade in terms of Cp produced. This revealed that when the number of blades increased, the rotations of the Savonius blade became slower and affected the Cp values. For the Savonius VAWT, the diameter size of the blade design can affect the performance of the wind turbine [12-14]. The increases in the blade's diameter size will increase the swept area of the blade, allowing the blade to extract more volumes of wind flow [13]. Thus, the wind turbine blade will rotate faster compared to the small diameter sizes of the blade in which as a result produce higher Cp values. The turbine blade materials also play a vital role in wind turbines production as the turbine blade material should possess high stiffness, low density, and long fatigue life [15]. Apart from that, the different material properties also influence the performance of the wind turbine in terms of Cp produced due to the different masses of each material [15].

Methodology

In this study, the process started with a wind feasibility study in order to confirm the wind speed ranges to be tested. Then, the turbine blade was designed and fabricated accordingly to the selected geometry and material selection. Finally, wind tunnel testing was performed and analyzed.

Wind Feasibility Study

A wind feasibility study was performed around UPNM areas using an anemometer (Benetech Gm816 Digital) device. Several locations were selected at different elevations from sea level (1 m – 90 m). The measurements were collected started from 6 am until 6 pm with a time interval every two hours. Fig. 1 illustrates the result of the wind feasibility study in UPNM areas. The result presented that the average wind speed in the UPNM area was 2 m/s and it can be validated with previous study results within the range of 1 m/s – 4 m/s [15].

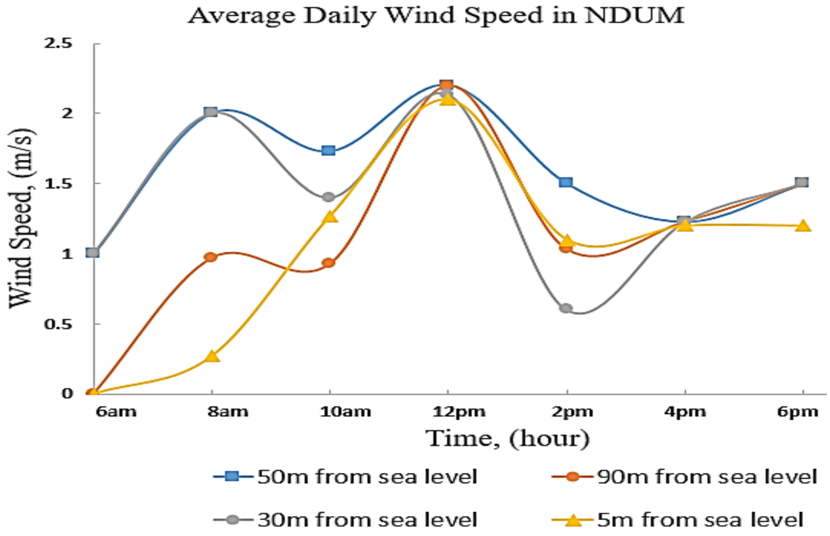


Fig. 1: UPNM wind feasibility study

Savonius blade design

The design of the Savonius wind turbine was created by using SolidWorks software. This design was made with a three-dimensional (3D) model with an actual dimension. Fig. 2 (a-d) illustrates the Savonius wind turbine blade model with different parameters.

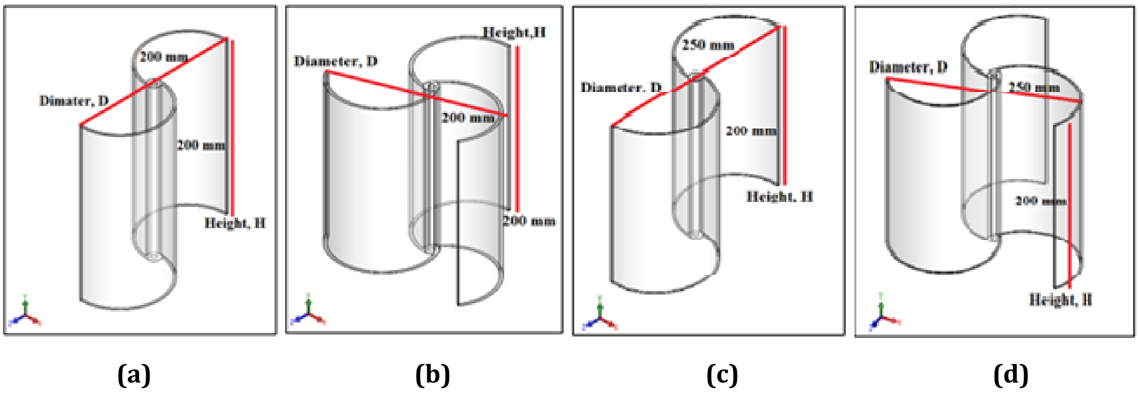


Fig. 2: Savonius wind turbine blades with dimension (a) 200 mm two-blades, (b) 200 mm three-blades, (c) 250 mm two-blades and (d) 250 mm three-blades

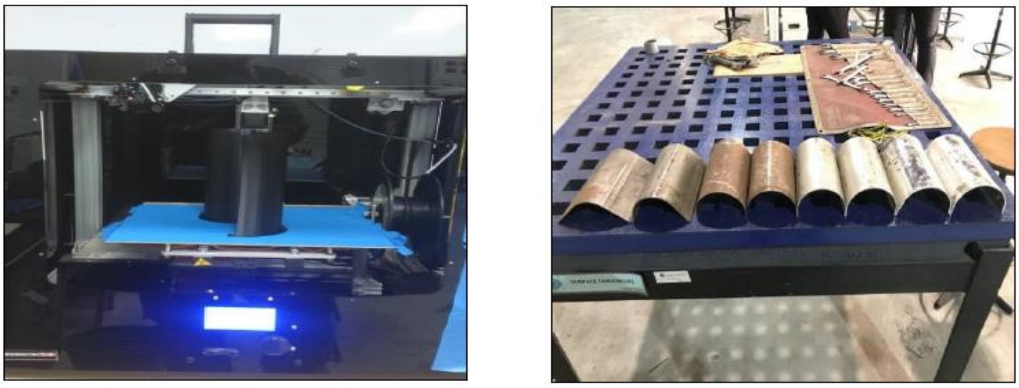
Fabrication

For the fabrication of the blade models, three different materials were selected to evaluate the significance of material selection for rotating blade performances. The properties of each material were presented in Table 1. The fabrication of the Savonius wind turbine consisted of three stages: forming, finishing, and assembly process.

In stage 1, the Savonius wind turbine blade was fabricated using the 3D printer for plastic material. This method was used because it was easy to conduct the shape of the design that was chosen. The rolling machine was used in order to shape the Savonius wind turbine blade for mild steel and aluminium material. A rolling machine was used to make the semicircle curve for the Savonius blade design. Fig. 3 (a-b) illustrated the Savonius with a different material used.

Table 1: Properties of blade materials.

Material	Stiffness, GPa	Mass, kg
ABS Plastic	3.5	0.24
Aluminium	70	0.53
Mild Steel	206	0.59



(a) **(b)**

Fig. 3: (a) ABS plastic (b) mild steel and aluminium

In stage 2, the surface finishing process of the model was conducted for all materials. For plastic material, some excessive surface produced during the printing process made the model rough. Therefore, sandpaper was used in order to make the surface smoother. For the mild steel and aluminium, the grinding machine was used as surface finishing. In stage 3, the assembly process of the Savonius wind turbine was performed by referring to the safety margin of the wind tunnel test section. Two ball-bearing were screwed into both bases in order to connect the lower base and the upper base of the wind turbine model. The ball bearing was also used to make the shaft frictionless when rotate. Each blade was assembled into the shaft in order to be able to connect with the generator as shown in Fig. 4 and Table 2 shows a six (6) configuration of blade model with a different number of blades, diameter and materials.

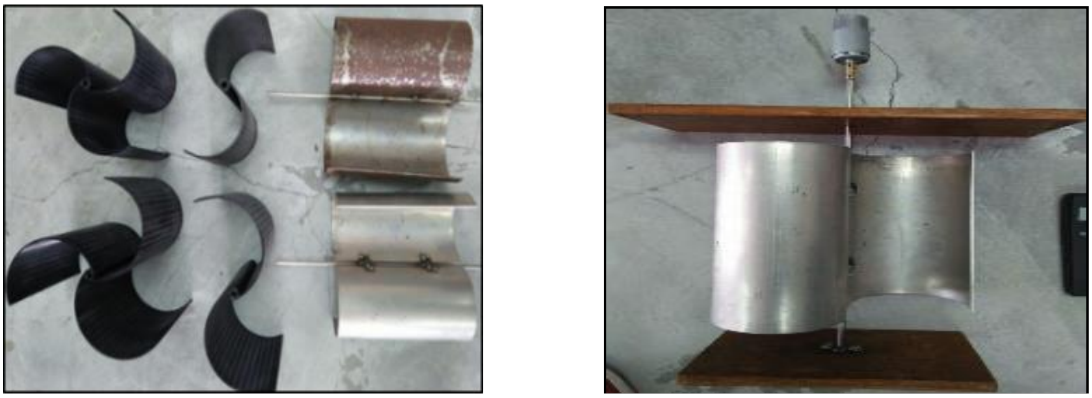


Fig. 4: Six models of Savonius wind turbine blade design and assemble design

Table 2: Savonius blade design models

Model	Material	Number of blades	Diameter, mm
Model 1	Plastic	2	200
Model 2			250
Model 3		3	200
Model 4			250
Model 5	Mild Steel	2	250
Model 6	Aluminium		

Wind tunnel test

Initially, the safety margin set-up during the experiment needs to be considered in order to perform a wind tunnel test. This is important in order to ensure the diameter and height of wind turbine blades are in the acceptable margin in a wind tunnel test section as well as to reduce error while collecting data. Fig. 5 show the flow chart of the safety margin set-up in the wind tunnel test section.

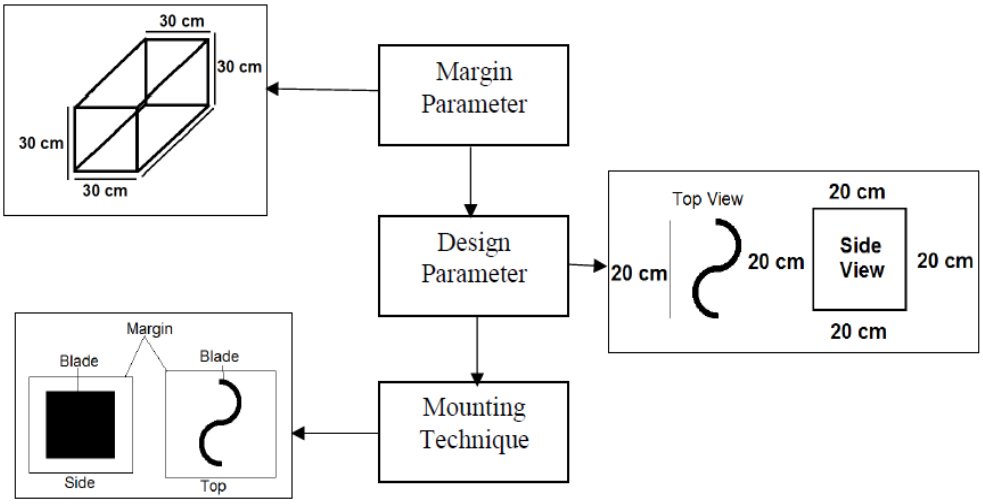


Fig. 5: Flow chart of the safety margins set-up

The testing for all models of Savonius blade was conducted using UPNM's wind tunnel lab facilities as shown in Fig. 6. The Savonius blade was installed into a test section of the wind tunnel. Two measuring equipment were used; a tachometer to measure the rotor speed of the blade and a multimeter to measure the power output. All the data were collected and the calculations were performed using MATLAB software. Wind tunnel specifications as shown in Table 3.

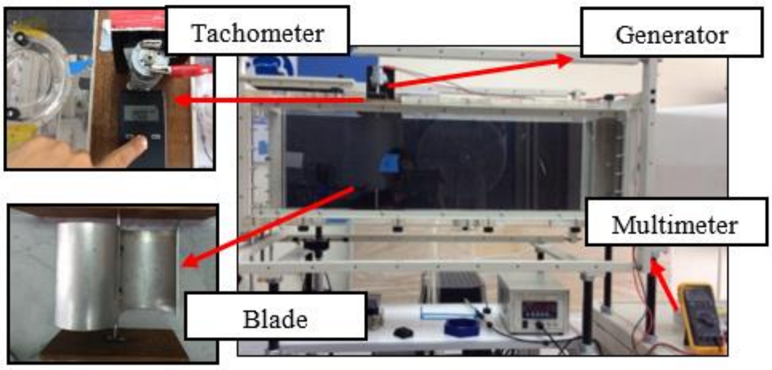


Fig. 6: Position of Savonius wind turbine blade in the wind tunnel

Table 3: Specifications of the wind tunnel

Specification	Detail
Model	LongWin 9300R
Type	Open-loop suction
Test Section Margin	0.3 (w) x 0.3 (h) x 1.0 (l) m
Maximum Speed	105 m/s

Results and Discussions

Investigation on number of blades and diameter sizes

The investigation on the Savonius blade started with an experiment on the first four models (Model 1–4). This experiment was intended to investigate the relationship of blade parameters in terms of the number of blades and blade's diameters to the Cp performances. Fig. 7 shows the performance of the Savonius blade in different parameters. The graph observed that the 250 mm with two blades produced the highest Cp (0.28) than others. Higher Cp value of turbine improved the performance of the turbine. This result revealed that when the number of blades increased, the performance of Cp produced by the Savonius wind turbine decreased. This was due to the fact that the effect of blade number increment will increase the drag surface against wind flow [10]. This situation will produce the reverse torque that reduces the net torque of the Savonius Blade.

The diameter sizes of the Savonius blade also influenced the performance of the Savonius wind turbine. It was observed that model 2 (2 blades with a diameter of 250 mm) produced the highest Cp value compared with others. This result concurred that the blade extracted more wind flows as the diameter of the blade increased. This caused the blade to rotate faster compared to the smaller blade diameters. A similar finding has been observed with a previous study [12]. However, due to the restraint of the wind tunnel facility, this experiment limited the diameters not to exceed more than 250 mm. Two blades with a diameter of 250 mm were selected as the basis for the next experiment using other types of materials.

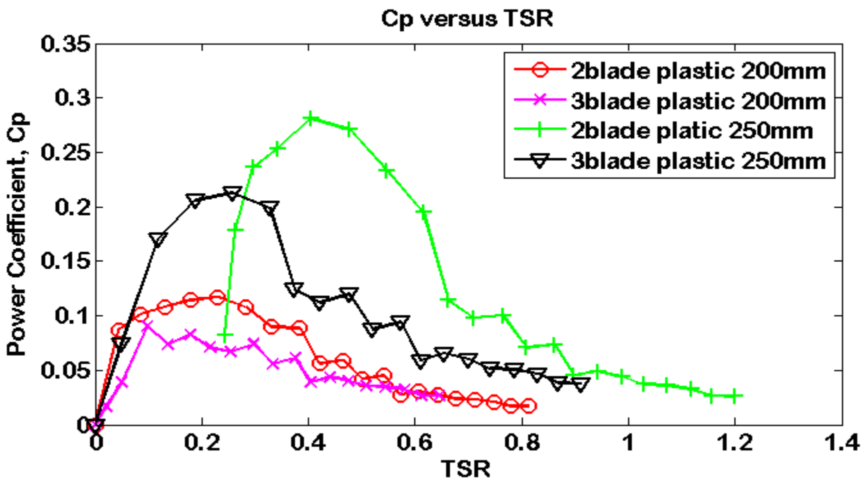


Fig. 7: Performance graph of the Savonius wind turbine blade in terms of different numbers of blades and diameter sizes

Investigation of materials used

The need to compare the other type of materials was due to the circumstance of the wind flows to the dynamic motion of the blade. The plastic blade was compared to the blade made of aluminium and mild steel, which have distinctive mass and stiffness. Fig. 8 illustrates the power performance of the Savonius blade in terms of the different materials used. In this experiment, it was found that the type of material contributed least significant for power performance as all materials have almost the same values of Cp. However, the plastic blade produced higher TSR because it was the lightest material compared with others. TSR can be defined as the efficiency of the blade speeds. Hence, higher TSR means that blade speed is higher and will produce a higher Cp value.

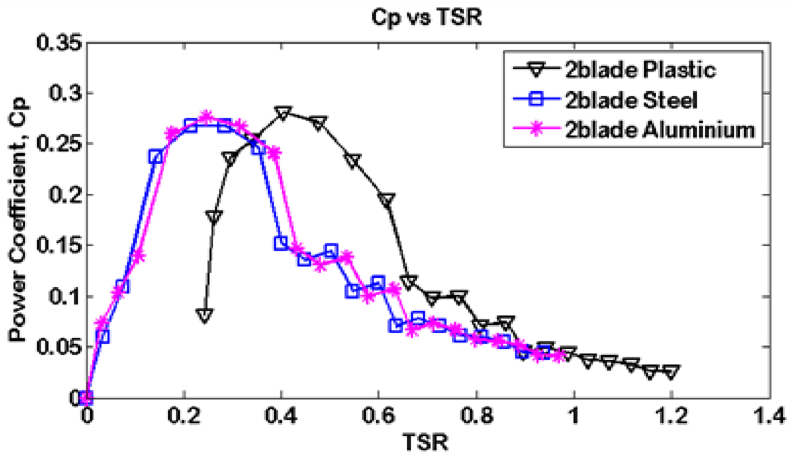


Fig. 8: Performance graph of the Savonius blade in terms of different materials usage

Fig. 9 shows the result of RPM against wind speed. From the result, the plastic blade was able to produce 100 RPM at the lowest wind speed of 1 m/s. Meanwhile, aluminium and mild steel were only able to produce 100 RPM at a wind speed of around 2 m/s. This confirmed that the plastic blade's self-starting torque was better compared to other materials.

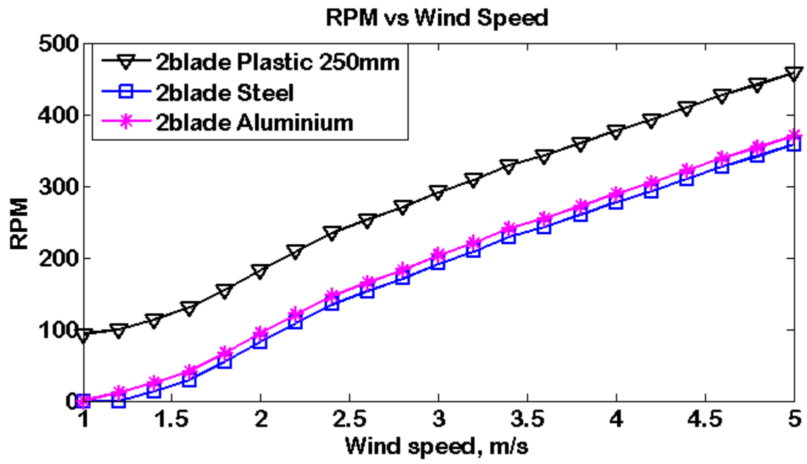


Fig. 9: Graph of wind turbine blade rotor speed versus wind speed

Apart from that, the effect of materials can be distinguished in terms of produced torque coefficient, Ct as shown in Fig. 10. This study has revealed that a mild steel blade produced the highest Ct compared to other types because of its highest blade mass. This result demonstrated that material with higher mass had advantages in terms of Ct.

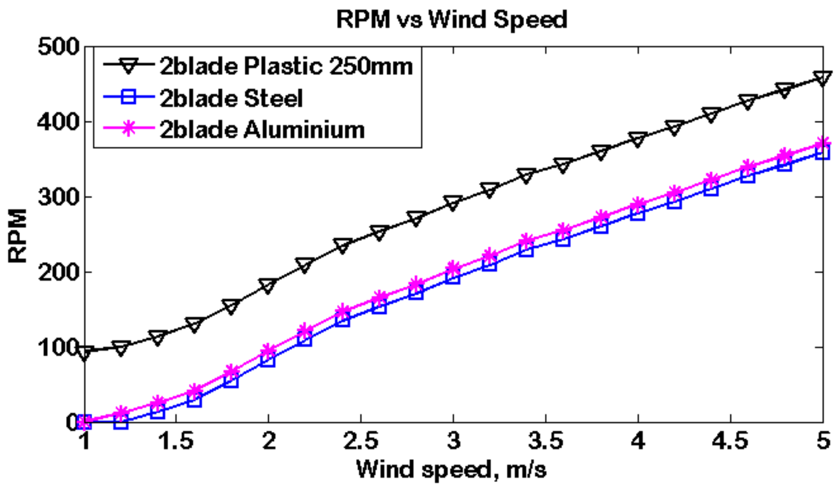


Fig. 10: Graph of the torque coefficient against tip speed ratios

Overall performance of the blade models

Fig. 11 shows the performances for all blade models of the Savonius rotor. At the low range of the TSR, the Cp values of all designs were increasing until they achieved one peak point before starting to decrease. At the high range of TSR, the Cp value decreased gradually. The main reason because at the high range of TSR (critical value of TSR), the Savonius blade rotated very fast relative to the wind speed flows. The Savonius blade was seen as a completely solid building, when the wind flowed through the solid building, no mass was transferred through the Savonius blades [16]. Hence, the wind has been insignificant to become the source of energy to move the Savonius blade anymore. This result highlighted that all Savonius wind turbine blade models were suitable for low wind speed, as shown in Fig. 11, due to the highest Cp produced at the range of low TSR.

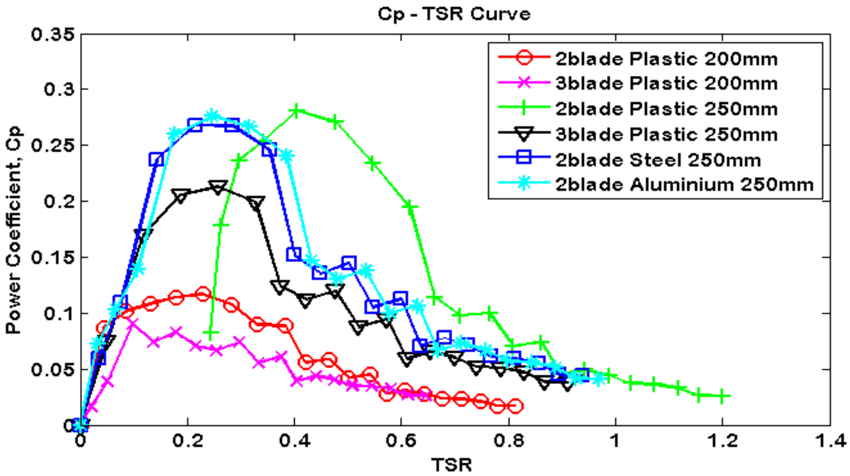


Fig. 11: The overall efficiencies of six Savonius wind turbine models

Electrical power for all models

In Fig. 12, the result showed that for all models, when wind speed increased, the generator output which produced electrical power was increased. In this study, the highest power output, Pe was found from model 2 which was a plastic two-blade with a 250 mm diameter with a value of 2.6 watts. In application, this electrical power amount can light up LEDs, 2-watt bulb, and small electrical appliances when an additional circuit boosts the output power produced from the Savonius wind turbine.

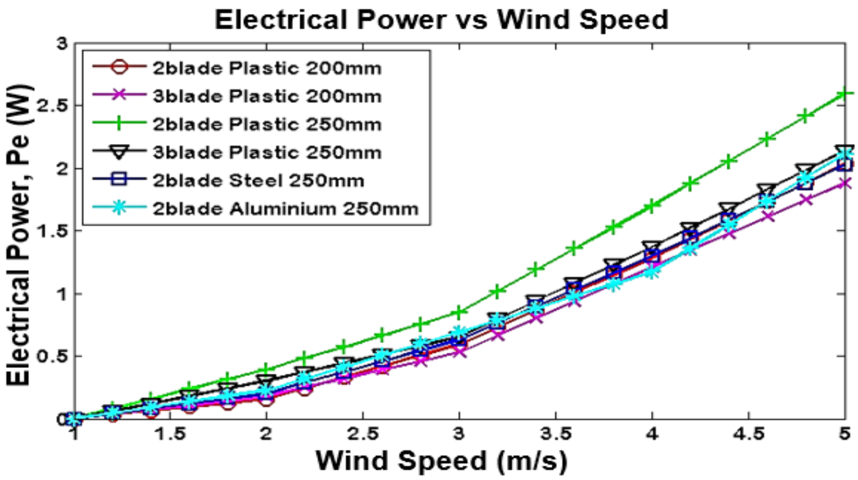


Fig. 12: Overall efficiencies of six Savonius wind turbine models

Conclusion

In conclusion, this experiment has successfully proved that the kinetic energy from the low wind speed area can be harvested to produce electrical power using the Savonius wind turbine design. However, it was observed that the selection of blade design and materials played a significant role to optimize power production. For each design, it was important to determine the critical TSR value because beyond this value, the kinetic energy from the wind could not be transferred to the blade anymore. This experiment could become exemplary work for the further development of wind turbines in low wind speed regions in Malaysia. Further studies and researches would be needed to optimize the design of the Savonius blade in terms of different parameters such as the shape of the blades and the number of stages of the blade. For the shape of the Savonius wind turbine blade design, one of the suggestions that can be done for further study was the Helical Savonius wind turbine. In terms of the different number of stages which were single-stage, two-stage and three-stage, the performances of Savonius wind turbines can be compared in terms of produced Cp to select the best design.

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