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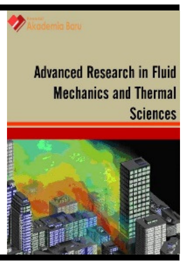

Experimental study on performance of low speed wind turbine for application in Malaysia

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ABSTRACT

Voluminous advancement that has been made in the last few decades in developing Complementary Metal Oxide Semiconductor (CMOS) components has drastically impacted the power requirements of portable wireless electronic devices or even of small consumed-power electrical appliances. Reduction in power consumption requirement together with the wind condition in Malaysia has opened the opportunity of developing environmental energy based power sources that can utilize locally available wind to generate sufficient magnitude of electrical power required for charging the commonly utilized wireless electronic devices. Motivated by this emerging need and the opportunity to demonstrate self-sustainable systems, this research work in this article will cover the design, fabrication and performance evaluation of low speed wind turbines. A test rig is established and be placed in the suction-typed subsonic wind tunnel available at Faculty of Mechanical Engineering, UTM, for measuring the aerodynamic loadings and corresponding electrical power of the tested wind turbine. From the findings, the designed small-scaled wind turbine has maximum power coefficient of 58% at the optimal tip speed ratio of 4.55, has low cut-in wind speed of 2.3m/s and manages to generate mechanical power of 1.28W and electrical power of up to 24.73mW at the wind speed of 3.1m/s.

Keywords:
Small wind turbine, Renewable energy, Wind energy, Power generation

1. Introduction

Wind energy is now the world's fastest growing natural energy source. Recently our neighboring countries; Thailand and Indonesia, show their great interest of wind energy as one of the renewable energy to generate power. Apart from that, European countries see wind as nature's energy which has clean power that essential for reducing the devastating effects of climate change, and protecting the natural environment for future generations. Nature's energy is not like the traditional fossil fuel, which is never run out. Wind turbine is a device that can extract wind energy and change to mechanical energy then convert to electrical energy. Nowadays, there are various studies done on

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developing wind turbine as an alternative solution to generate electrical power. However, most of the studies only focusing on large-scaled wind turbine which is a little bit differ from small-scale wind turbine. Thus, small-scaled wind turbine is still in old notch.

Large-scaled wind turbine will give higher amount of electrical power if compared to small-scaled wind turbine due to its size. Regarding to this, most of the studies are done by focusing on developing and optimizing large-scaled so that maximum power extraction from the wind can be archived. Many studies done previously focus on large-scaled wind turbine, there are a few or less number of studies done based on small-scaled wind turbine. Hence, the optimization of small-scaled wind turbine for now is still under old notch. Small-scaled wind turbine can extract energy from wind and then can be used for typical household appliances. In addition, with extensive advancement has been made in the last few decades in reducing the power consumption for small electronic devices, this situation has opened the possibility of developing environmental energy based power sources that can utilize locally available wind to generate sufficient magnitude of electrical power required for charging the commonly utilized small electronic devices.

A wind turbine is a device that extracts kinetic energy from the wind and converts it into mechanical energy [1]. Wind turbines can be separated into two basic types determined by which way the blades rotate. A wind turbine that has blades rotating around a horizontal axis is more common is known as Horizontal Axis Wind Turbine. Meanwhile the wind turbine that has blades rotating around a vertical axis wind turbines are less frequently used is known as Vertical Axis Wind Turbine. A wind turbine may vary in its components depend on the features that want to include in a wind turbine. There are several basic components of a wind turbine such are blade, rotor, shaft, gear box, generator, yaw mechanism, brake system, controller, and sensor. However, the components used in wind turbine can be varied due to its feature and function. The dynamic interaction involving the forces of the wind and the response of wind turbine determines the amount of kinetic energy that can be extracted. Three main areas which known as aerodynamics, mechanical and electrical engineering are involved [2]. Among the wind turbine developed in recent years that involved conservation of mechanical to electrical power has high cut in speed that do not suit well with Malaysia wind speed conditions [3]. Normally a small wind turbine will produce small power and big wind turbine produced greater power. However, small wind turbine has different aerodynamic behaviour compared to big wind turbine. The aerodynamic behaviours of wind turbine are primarily influenced by Reynolds Number of the airfoil used for the wind turbine blade [4].

The aim of this project to develop a systematic test rig for measuring wind turbine aerodynamic coefficients and carry out the performance analysis of small-scaled wind turbine. In order to achieve the objective that was stated, performance measurement for various wind turbine and rotational speed, blade components for measuring force and moment and sensitivity of the used balanced components outputs were carried out.

2. Methodology

In order to design wind turbine blade that could extract maximum power from flow wind, there are some theories used to design the blade covers Actuator Disc Model (ADM), Blade Element Theory (BET), Blade Element Momentum Theory (BEMT), and Minimum Induced Loss (MIL). The availability of the wind speed in Malaysia, as well as the rotor size, and the stability of the rotor are also considered in the blade design. The details of the equation systems and design procedures used can be found in [6]. Fig. 1 shows the model of designed blade based on the BEMT. Summary of the designed blade is listed in Table 1. The details of cambered thin plate 8312 profile are 80% of maximum camber, 30% maximum camber occurred from leading edge, 12% maximum thickness in function of the chord length.

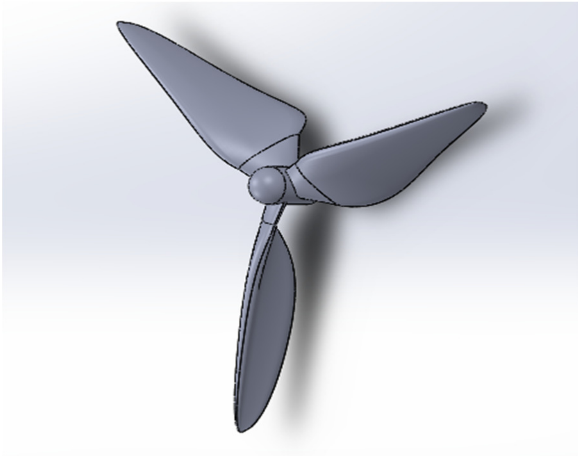

Fig. 1. The model of the designed wind turbine

The model of wind turbine test rig was drawn using Solidworks software. Designed wind turbine dimension is 25 cm (width), 65 cm (long) and 70 cm (height). Height of designed wind turbine was adjusted to be in the centre of the wind tunnel. The designed wind turbine shows in Fig. 2. Details of components used in wind turbine are shown in Table 2.

Table 1
Summary of the designed blade I

No.	Parameters	Details
1	Blade Geometry	Cambered Thin Plate 8312
2	Blade total diameter	40 cm
3	Blade length)	17 cm
4	Neck length	1.5cm
5	Hub diameter	3cm
6	Material	ABS plastic
7	Blade number	3
8	Angle of attack	5°
9	Max chord length	5.8 cm
10	Software used	CATIA& SOLIDWORKS

The wind tunnel testing was done in the wind tunnel at FKM Aeronautic Laboratory (Aerolab). Different wind speed was tested on the designed wind turbine. The pitot tube was connected to the digital manometer in order to determine the wind speed before it passes the blades. Micro-processing tachometer was used to measure the rotation speed of the blade. Reflector sticker with the ability to reflect the received light was affixed to the blades in order to reflect back the signal transmitted from tachometer.

The blades were glued to the end of the shaft to avoid connection loss due to separated blades fabricated. Another end of the shaft connected to the sleeve and connected to the torque sensor in order to measure the torque produced by the blades. The bicycle brake system was used in this experiment to vary the blade angular speed. Induced voltage and current from the generator were measured by using a digital multimeter.

Table 2
Components of designed wind turbine I

No.	Component
1	Wind turbine blade
2	Sleeve
3	Torque sensor
4	Brake system
5	Generator
6	Bearing
7	Wind turbine test rig
8	Torque sensor stand

Digital multimeter was connected to the generator in parallel arrangement in order to measure the induced voltage while another multimeter was connected in series arrangement to measure current produced. Additional multimeter was connected in parallel to the resistance box to confirm the voltage induced same with the voltage drop at the resistance box. Fig. 3 below show the schematic diagram of the testing setup. Testing was conducted in wind tunnel at FKM Aerolab with testing section 560 cm (length) x 140cm (width) x 140cm (height). Wind tunnel that used can provide speed of wind between 1 m/s to 3.1 m/s. Fig. 4 shows the wind tunnel used to test designed wind turbine.

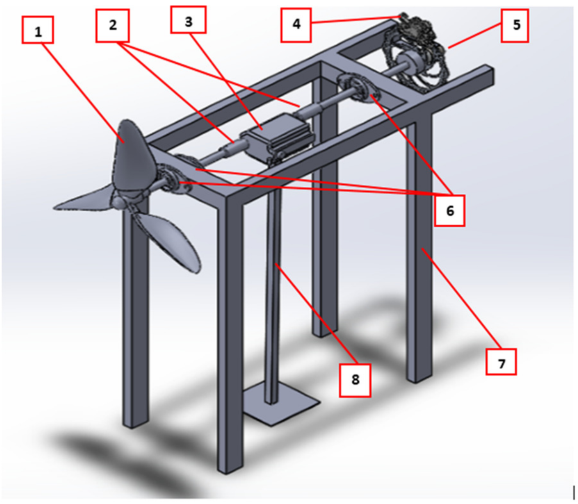

Fig. 2. Details of the test rig for wind turbine performance evaluation

In this study, the generator was selected based on the output mechanical power or torque of the blade. This is the vital part otherwise the selected generator will only start to produce electrical power at higher wind speed. In order to obtain maximum electrical power as possible, volt-RPM ratio and amperage rating of the generator would be also stuck. Higher volt-RPM ratio is required to obtain higher voltage generated by the generator. High amperage rating is another factor that included in selection of generator to optimize the current produced. However, the starting torque of the generator also needs to be considered otherwise the wind turbine only will start to produce electrical power at high wind speed. In this study, permanent magnet motor from brand Minebea (MXN13FB11H) was selected to be used as a generator. This motor was selected as it has low starting torque, it can easily rotate by only apply low turning force by hand. This motor is 12 V rated voltage motor. Fig. 5 below show the generator used.

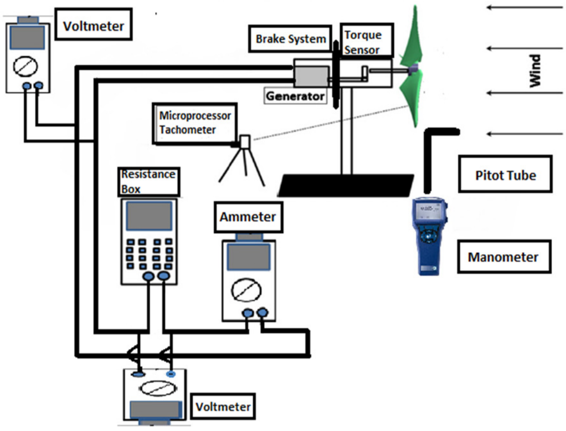

Fig. 3. Schematic diagram for testing setup

The testing done based on average Malaysia wind speed condition. Wind speed in range of 1.0 m/s -3.1 m/s used in testing to test performance of designed wind turbine. From the tested wind speed, wind power is calculated. Brake system used to vary the angular speed of the blade. Torque reading from the torque sensor is recorded. From the torque and angular speed of the blade, the mechanical power produced calculated. Coefficient of power also calculated based on wind power and mechanical power obtained. Besides, tip speed ratio also calculated based on obtained data. Varies of electrical load resistance applied to generator used. Corresponding induced voltage and current produced from the generator based on applied electrical resistance at fix wind speed recorded and the electrical power calculated according to the electrical power equation.

Fig. 4. Wind tunnel used for testing

3. Results and Discussion

Before the experimental conducted, there are two calibrations that are formerly done i.e. calibration of torque sensor and calibration of ~~the~~ generator. These two calibrations were done in order to understand the behaviour of the torque sensor and the generator used. The designed small-scaled wind turbine was tested without load. No external or additional load was applied to the WT in this testing. First of all, the generator was not attached to the WT to conduct this test. Then, the generator attached to WT and acted as a load to WT. From the testing done, it was found that the designed small-scaled wind turbine has 2.0 m/s cut in speed before the generator attached. On the contrary, the cut in speed for designed WT increase up to 2.3 m/s after the generator is attached. Fig. 6 shows the corresponding result from testing done.

Fig. 5. Generator used in the testing

The designed wind turbine was tested at different wind speed to determine the angular speed and mechanical power produced by the blade at particular condition. Microprocessor tachometer is used to measure the angular speed of the blades. Mechanical power obtained is the product of toque and angular speed of when blades are running without any external load. Torque of the blades obtained from the torque sensor used. Formula to calculate the mechanical power shows below together with the example of calculation of toque at 0.017 Nm and angular speed of 652 RPM. Fig. 7 shows the results for themechanical power by fabricated small-scaled wind turbine.

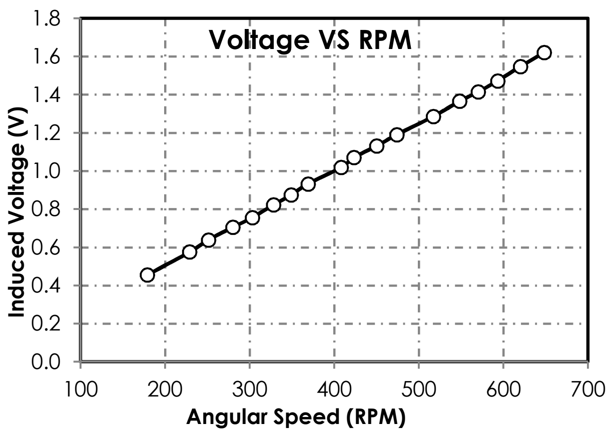

Fig. 6. Relationship between Induced Voltage and Angular Speed

Mechanical power is defined as the product of torque and angular speed of the turbine blade. The angular acceleration was calculated using the wind tunnel experimentation as per described in Section 2.0. The blade of wind turbine was held stationary until wind speed in the wind tunnel was stabilized and then it was allowed to rotate and accelerate freely to its maximum constant speed. For experimental case, the mechanical power created by rotor blade is influence by bearing friction, wake formation and some random errors. Whereas the CFD simulation case, the power produced by blade with lot of theoretical assumption during setup. Fig. 7 shows the mechanical output produced at different tested speeds. From Fig. 7, the results present the mechanical power produced by the blades increase as the wind speed and angular speed increase. The blades produced the highest range mechanical power at 3 m/s which is between 0.6 W and 1.161 W and the blades produced the lowest range mechanical power at 1.5 m/s which is between 0.011 W and 0.109 W. The plot of power coefficient versus tip speed ratio is made, as per in Fig. 8, in order to identify the response of the wind turbine under various operating conditions.

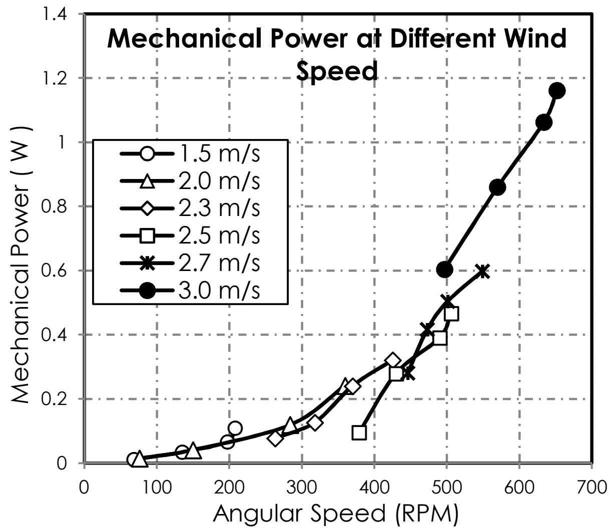

Fig. 7. Mechanical power of small-scaled wind turbine at different wind speed

Fig. 8 shows the coefficient of power versus tip speed ratio of Small-Scaled Wind Turbine at various wind speed between 0 to 3 m/s. It can be observed that the coefficient of power initially increases with the increase of the tip speed ratio, reaches maximum later and then decreases. This can be explained by noting that when tip speed ratio is small, it corresponds to a situation when turbine is rotating very slowly at almost all the wind passes across the blades without much power transfer.

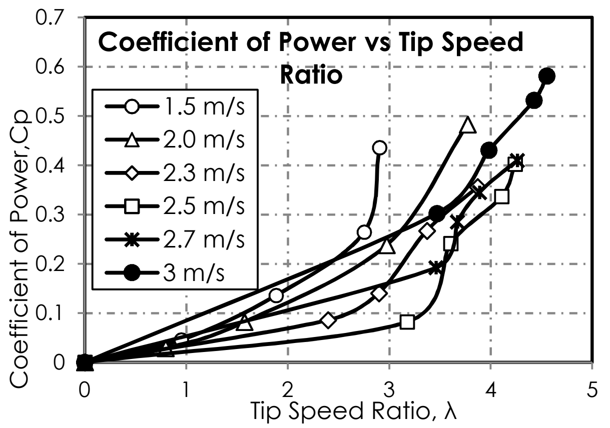

Fig. 8. Power coefficient variations with tip-speed ratio for different wind speeds

On the other hand, when tip speed ratio is too large, the fast moving blades appear like a solid disc and thus coefficient of power decreases. Tip speed ratio directly affects the power output of a wind turbine and thus it is very crucial to assess its optimal value. The tip speed ratio of the large scale wind turbines is normally between 7 and 10. However, for the small-scaled wind turbine, low TSR in the range of 2 to 4 has been suggested for achieving reliability and noiseless driving [7]. The overall performance of a small-scaled wind turbine relies upon its component. Fig. 9 shows the RPM of the blades under different loading conditions at six different wind speeds. The angular speed of the blades decreases as the electrical load applied increase as shown in Fig. 9.

Based on the testing result, the average wind speed to start the rotor blades occur at the positive pitch angle. The minimum velocity to turn the rotor blade for twisted blade of 10° is 2.0 m/s. The maximum performance for this test rig model is obtained at highest wind speed which is 3.0 m/s. This model produces 0.016 Nm torque, 1.169 W power and 0.51 power coefficients under tip speed ratio of 4.55. At low wind speed condition, the rotation speed is lower and produced low torque and power. The power generated through CFD simulation was higher than the experimental result. This is due to the fact that CFD simulation was assumed to be friction free with no blockage and disturbance. For the real situation and in wind tunnel testing, disturbance and blockage existed. Lastly, it is important to note that the actual power performance of the wind turbine found experimentally was much lower than its predicted value proposed by the design software. This study thus reiterates the fact that the low wind speed of Small-Scaled Wind Turbine cannot be design using the design tools that have been developed for conventional high wind speed large-to-mid scales wind turbines.

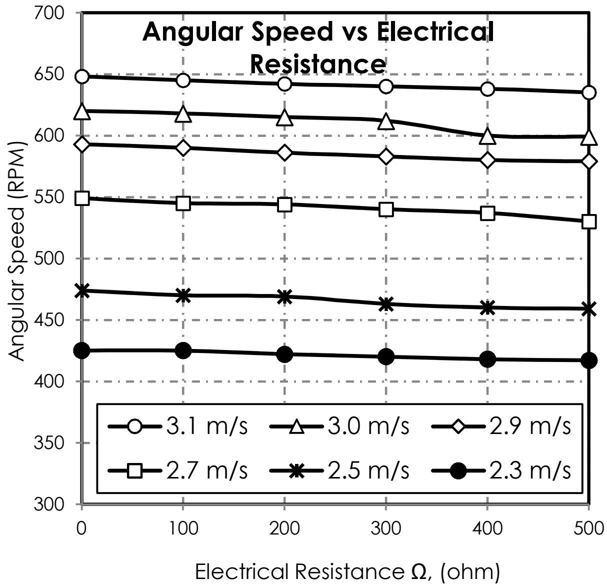

Fig. 9. Angular speed as a function of load resistance

Basically, when load is applied to a running generator, it delivers current which creates a magnetic force that opposes the rotation of the armature. The strength of the reacting magnetic force depends on the armature current which is ultimately determined by the magnitude of the load resistance [5]. Electrical load resistance that was applied to 12V the generator were varied at specified wind speeds. Digital multimeter was used to measure the voltage and the current that are induced from the generator. Fig. 10 shows the plotted graph for the results obtained. This testing revealed that the optimal load is 100 Ω at any different wind speed tested. The maximum power output was found to be 24.73 mW at optimal load of 100 Ω for the wind speed of 3.1 m/s.

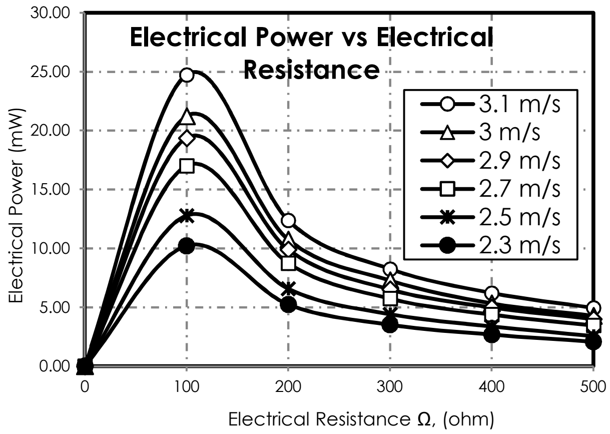

Fig. 10. Electrical power of small-scaled wind turbine at different load and wind speed

4. Conclusion

The performance of the wind turbine which operates under the range of wind speed in Malaysia (3 m/s - 5 m/s) has been successfully evaluated using the developed test rig. The major outcomes of the study can be summarized as below.

1. Wind tunnel experiment shows that designed small-scaled wind turbine has a maximum coefficient of performance of 58% at the optimal tip speed ratio of 4.55.
2. Small-scaled wind turbine has low cut-in wind speed of 2.3m/s and it is found to generate mechanical power of 1.28W and electrical power of up to 24.73mW at the wind speed of 3.1m/s.

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