Study on benefit of guide vane for vertical axis wind

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Abstract. Guide vane was introduced to overcome the problem of high turbulence intensity due to the high rise building in the urban area. The guide vane is a fixed aerofoil that directs air into the moving wind turbine. Guide vane borders the Vertical Axis Wind Turbine (VAWT) and improves the VAWT performance by increasing the wind velocity, decreasing turbulence intensity and increasing torque because it acts as wind concentrator and wind shielding to an optimum angle before it interacts with turbines. This project is based on the VAWT on the College of Engineering (COE) building in Universiti Tenaga Nasional (UNITEN). This VAWT had been fabricated in CREO software to study the benefit of guide vane onto it and the design of guide vane also was constructed by using similar software. SOLIDWORKS Flow simulation was used to analyze the performance of the VAWT. The simulation had been done by simulation of VAWT without and with guide vane to study the benefit and analyze the flow characteristic of the guide vane towards wind turbine. The simulation result shows that the presence of guide vane increase wind speed by maximum 0.0051 m/s and torque increment is about seven times from VAWT without guide vane. Other than that, decreasing of turbulence intensity value also detected in flow simulation result. To sum up, guide vane had the potential to be installed in the urban area because it improves the power output of the wind turbine.

1. Introduction
Nowadays, 539,581 MW of wind energy capacity had been installed by global at the end of 2017. Thus, wind energy is the second fastest-growing source of electricity in the world [1]. Wind energy does not cause pollution because it does not generate atmospheric emission that can release acid, smog or greenhouse gas. Moreover, wind energy is completely free as it does not have the market for the supply and demand that can be used by anyone. The installation of wind energy requires only a small land footprint because it towers high above the ground and the area around the base can be used for other activities such as agriculture. For small and large-scale distribution, wind power is an alternative and attractive application. Therefore, others advantages of wind energy are modular and scalable because to find application in a large wind farm and distributed power generation is possible [2].
Installation of the wind turbine in the urban area in Malaysia has many deficient such as frail wind condition and high turbulence intensity due to the rise of a high building. Most urban areas are recorded to have a wind velocity of 4 m/s and below. In wind energy, velocity is one of the important parameters to get higher power performance of wind turbines based on the formula of calculating the wind power. In the other hand, the presence of turbulence intensity due to high rise building will affect the performance of the wind turbine because higher turbulence intensity affiliate with an unstable condition and will decrease the wind speed. Thus, the wind energy system for urban areas needs to overcome these disadvantages.

The wind turbine can be categorized into two types which are an aerodynamic force and design of wind turbine. The aerodynamic force of wind turbine also can be divided into two types which are drag force and lift type. In term of design, the wind turbine can be classified into two types which are Horizontal Axis Wind Turbine (HAWT) which use drag force and Vertical Axis Wind Turbine (VAWT) which use lift force. The advantages of VAWT over HAWT are operated in silent operation, easy to maintain, lower construction cost and does not require yaw mechanism to turn the rotor against the wind in turbine system because it can receive the wind from all directions [3, 4].

Guide vane is one of the technologies that had been researched to overcome the issues of installation of the VAWT in the urban area. Basically, guide vane is the fixed aerofoils that direct air into the moving turbine to improve VAWT performance in the urban area. Other than that, the guide vane also has a low center of mass make it relatively more stable and can alter natural wind flow pattern around VAWT by the venturi effect [2]. Some of the researchers also found out that, guide vane can act as the wind concentrator, wind shield, protect the turbine from high velocity wind and act as a nozzle to increase the torque. Based on previous research, the guide vane is designed around the VAWT to overcome the turbulence condition and weak wind in urban areas. The guide vane is built of the lower wall, upper wall, shape and numbers of guide vane.

Normally, there are three or four pair of guide vane and each pair have their own tilted angle or leading angle that varies from 0° to 90° but the researchers usually use 20° and 55° because of higher optimization than others. In designing the guide vane, the inner diameter, outer diameter and length of guide vane is design based on the dimension of the VAWT. The lower and upper wall is used to fix the entire guide vane at a certain position around the VAWT. Each pair of guide vanes is position around the cylinder with an equal spacing which design to guide oncoming wind towards wind turbine [5].

2. Methodology
In this study, the dimension of the vertical axis wind turbine was taken from existing design located on the rooftop of COE building at UNITEN by using the measuring tape and Vernier caliper to fabricate the design in CREO software as shown in Figure 1. For the guide vane, the design had been made based on the existing VAWT on COE building that consists of 4 pairs of guide vanes with the tilt angle of 55° and 20° as shown in Figure 2.

The study of wind flow characteristic and performance of VAWT with and without guide vane was conducted in SOLIDWORKS flow simulation. The 3D model of VAWT without and with guide vane was imported to SOLIDWORKS by using the Standard for the Exchange of Product (STEP) file which was one of the CAD data exchange system. Then, add-ons the flow simulation into the SOLIDWORKS software and to start the simulation wizard tool was used. The purpose of the SOLIDWORKS flow simulation in this project is to obtain the wind velocity, torque, turbulence and understand the flow structure of VAWT with and without guide vane. Table 1 shows the summary of SOLIDWORKS flow simulation condition before running the simulation.

The computational domain (wind tunnel) was set up around the blade of VAWT to have optimum simulation result. In order to obtain the output parameter which was wind velocity, torque and turbulence, these parameters were selected in the global goal of analysis. After that, a new parametric study was added to compare the result of output parameter between VAWT without and with guide vane by making the inlet velocity as an input parameter that varies from 1 m/s to 5 m/s. Then, the
simulation was run to attain the desired output parameter. Additionally, the flow characteristic of VAWT without and with guide vane was acquired after simulation was finished by adding velocity cut plot analysis in the simulation.

![3D design of VAWT](image1)

**Figure 1.** 3D design of VAWT a) VAWT without guide vane b) VAWT with guide vane.

![3D design of guide vane](image2)

**Figure 2.** 3D design of guide vane a) Front view of the basic design guide vane b) 3D view of basic design guide vane.

| Table 1. Summary of SOLIDWORKS flow simulation condition. |
|----------------------------------------------------------|
| SOLIDWORK Flow Simulation Condition                      |
| Density                                                  | 1.225 kg/m³ |
| Pressure                                                 | 101,325 PA  |
| Inlet X-Velocity                                         | 5 m/s       |
| Inlet Y-Velocity                                         | 0 m/s       |
| Inlet Z-Velocity                                         | 0 m/s       |
| Analysis Type                                            | External    |
| Working fluid                                            | Air         |

In order to study the benefit of the guide vane to the wind turbine on the COE building in UNITEN, there are several data need to be analyzed from the SOLIDWORKS flow simulation such as flow behavior and performance of VAWT with and without guide vane. Besides that, SOLIDWORKS flow simulation was applied to investigate the aerodynamic performance of the VAWT and specification of the flow. From previous research, the different wind speed was used to forecast power coefficient, $C_p$ or can be defined as the efficiency of VAWT. Thus, power analysis is used to describe power coefficient which can improve the efficiency of VAWT [6].
In power analysis, wind power can be expressed as:

\[ P_{in} = \frac{1}{2} \rho A V^3 \quad (1) \]

Where \( \rho \) is air density (kg/m\(^3\)), \( A \) is swept area (m\(^2\)) and \( V \) is wind velocity (m/s).

The power output of the VAWT;

\[ P_{out} = T \omega \quad (2) \]

Where \( T \) is torque (Nm) and \( \omega \) is angular velocity in revolution per minute.

The power output of VAWT cannot be fully recovered for mechanical power because wind energy is the kinetic energy of air. Next, the coefficient of power is the fraction of the power output extracted from the power in the wind by the VAWT and defined as;

\[ C_p = \frac{P_{out}}{P_{in}} \quad (3) \]

Usually coefficient of power is present as a function of the tip ratio which is the ratio of the speed of the ending tip of the VAWT blade to the wind speed and can be expressed as;

\[ TSR = \frac{\omega R}{V} \quad (4) \]

Where \( \omega \) is angular velocity in rad/s, \( R \) is the radius of the wind turbine in m and \( V \) is wind velocity in m/s. In addition, the angular velocity of VAWT was needed to calculate the power output of VAWT. Therefore, from the velocity and angular velocity data collection, the value of Tip Speed Ratio (TSR) was estimated to be two, five, six and seven because based on Figure 2 darrieus wind turbine has TSR value of two to seven. After that, angular velocity was calculated by using formula;

Before calculating the angular velocity by using formula, the measured angular velocity needed to divide by three because tachometer detected the rotation of three blades during the experiment. Then, the error of angular velocity between experimental and theoretical was calculated by using formula;

\[ \text{% error} = \frac{\text{Measured Angular Velocity} - \text{calculated Angular Velocity}}{\text{calculated Angular Velocity}} \times 100 \quad (5) \]

Table 2. Summary error of measured and calculated angular velocity

| Average TSR | 1   | 5   | 10  | 20  |
|-------------|-----|-----|-----|-----|
| 2           | 16.0106 | 14.5862 | 12.4537 | 9.9081 |
| 3           | 24.0158 | 21.8793 | 18.6805 | 14.8621 |
| 4           | 32.0211 | 29.1723 | 24.9074 | 19.8161 |
| 5           | 40.0264 | 36.4654 | 31.1342 | 24.7702 |
| 6           | 48.0317 | 43.7585 | 37.3611 | 29.7242 |
| 7           | 56.0370 | 51.0516 | 43.5879 | 34.6782 |

Another method to find the error of measured and theoretical of angular velocity is by using linear regression in Microsoft Excels. The data analysis was repeated three times by averaging the measured
angular velocity by 5 s, 10 s and 20. Table 2 shows the summary error of measured and calculated angular velocity obtained from the linear regression in Microsoft Excel. Based on the lowest error obtained in linear regression and calculated using formula, the TSR of that error was taken to calculate angular velocity by using simulation wind speed value. After that, the power output and power coefficient of VAWT were able to be calculated by using Equations 2 and 3.

3. Results and discussion

In this section the flow simulation results of VAWT with and without guide vane were compared and analyzed. Based on Figure 3, differentiation of wind flow towards VAWT with and without guide vane can be seen clearly in the figures above. VAWT without guide vane directly received the velocity from the initial and ambient condition which then after the turbine, the velocity decreases abruptly which varies from 1.357 m/s to 3.392 m/s. Meanwhile, for VAWT with guide vane, the velocity will decrease when reach close to guide vane but after it passes through guide vane, the velocity increases back before entering VAWT which varies from 1.357 m/s to 4.734 m/s. So, guide vane also increases the incoming speed before entering VAWT by venturi effect.

![Figure 3. Result of cut plot simulation a) VAWT without guide vane b) VAWT with guide vane](image)

Figure 4 shows the graph of the simulation result for VAWT with and without guide vane. Based on the graph of torque in Figure 4 (a), there is an increasing of torque value in VAWT with guide vane because of increasing of wind speed. Sometimes, during the simulation, the values of torque produce are in negative value, especially in x and z direction. Previous finding state that, at low speed, conventional Darrieus rotor with a fixed blade is not able to generate energy with the fact that the angle of tack is higher than the angle chock. Due to this, the force of the weak bearing pressure and with strong drag force will induce a negative torque [7].

From graph Figure 4 (b) shows that, VAWT with guide vane has lower turbulence intensity than VAWT without guide vane because guide vane itself act as wind concentrator to decrease the turbulence intensity, turbulence is an unpredictable weather phenomenon with an irregular motion of the air that can affect the performance. From previous research, higher turbulence intensity can decrease wind speed and wind performance. Researchers also mention that lower turbulence affiliated with the stable condition while high turbulence is affiliated with an unstable condition in which there are abrupt changes in wind speed with height. Besides that, maximum turbulence normally occurs close to the wind turbine [8].
Figure 4. Graph of simulation result for VAWT with and without guide vane a) graph of torque versus initial velocity b) graph of average turbulence intensity versus initial velocity

For the power performance analysis, the power output and power coefficient of VAWT with and without were plotted in Figure 5. Based on the graph in Figure 5 (a), the power output of VAWT increases with the presence of guide vane as the inlet velocity increase. The increase of power output was affected by torque and angular velocity because power output is directly proportional to the torque and angular velocity. With the increase of power output, the power coefficient of VAWT with guide vane also increase because power output is also directly proportional to the power output. As shown in Figure 5 (b) the graph of the power coefficient for VAWT with guide vane is higher than VAWT without guide vane.

Figure 5. Power performance result of VAWT a) Graph of power output versus Initial Velocity b) Graph of power coefficient versus initial velocity

4. Conclusion
As the conclusion, this study proved guide vane that surrounds a VAWT is designed to improve the performance of the wind turbine. The results also show that by using guide vane, the average velocity of VAWT increases because of the venturi effect which wind flow from a large area to a smaller area before it hits the wind turbine blade. The turbulence intensity decreases, and the torque increases due to the guide vane which acts as wind concentrator and wind shield that make the wind directly hit the turbine’s blade. The increasing of power coefficient of wind turbine because of increasing value of power output and torque. Based on the equation, the power coefficient is directly proportional to power output and power output is directly proportional to the torque.
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