Design of a novel and efficient lantern wind turbine

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Abstract. Wind turbine generates renewable energy when the forces acted on the turbine blades cause the rotation of the generator to produce clean electricity. This paper proposed a novel lantern wind turbine design compared to a conventional design model. Comparison is done based on simulation on coarse and fine meshing with all the results converged. Results showed that the pressure difference on the surface of novel design lantern wind turbine is much higher compared to the conventional wind turbine. Prototype is already manufactured and experimental result would be discussed in a separate future publication

1. Introduction

The lantern wind turbine is novel designed wind turbine that has multiple blades instead of one blade. Wind turbine is a type of renewable energy. It generates electricity when wind blow that acted as force on the blades of the wind turbine which causes the rotor to rotate produce electricity. United kingdom has the target to achieved 15% of energy consumption which came from renewable energy by 2020 [1]. The renewable energy reduces the use of natural gas (hydrocarbon fossil fuel) to generate electricity. The fossil fuel produces carbon dioxide and carbon monoxide during the incomplete combustion, which lead to environmental pollution [2]. Wind turbine reduces the usage of natural gas (hydrocarbon fossil fuel). In comparison, wind turbine system is capable of producing 5-8GWh of energy annually, which is equal to 1 tonne of burning coal to produce electricity.

As a result, the big and large wind turbine, known as wind farms with high renewable energy source had currently carried out by many countries [3]. However, the conventional wind turbine is huge consume a lot of space. It requires distance to be maintained when these wind turbines are placed. The diameter of a wind turbine can be larger than 124 m with the height of 200 m [4]. The huge and big conventional wind turbine has taken up lots of spaces and a distance is required to place another wind turbine next to it [5]. The development of wind power plant which taken up a lot of space have a direct impact towards citizen and road accessibility. Wind power plant project is usually time consuming therefore it requires the cleaning of lands for development in the particular area, which has the possibility of significant degradation and effects in quality of the ecosystem [6].

The purpose of this study is to reduce the large wind turbine to a smaller scale and improve its efficiency. The concept of this lantern wind turbine is obtained from the airplane nacelles[7]. This wind turbine has been produce with circular blades instead of just normal wind turbine blades. This
increases the volume of wind turbines, which allow aerodynamic lifting. This study embarks on determining the pressure and velocity distribution over wind turbine on a smaller scale wind turbine. Table 1 shows the nomenclature of this paper.

| Symbol | Name                                      |
|--------|-------------------------------------------|
| HAWT   | Horizontal axis wind turbine              |
| VAWT   | Vertical axis wind turbine                |
| P      | Power (W)                                 |
| F      | Force vector (N)                          |
| $\lambda$ | Tip speed ratio                  |
| $v$    | Wind speed (m/s)                         |
| $\omega$ | Blade revolution per minutes (rad/s)    |
| $R$    | Radius of the wind turbine (m)           |
| $\bar{x}$ | Mean (average values)                  |

2. Aerodynamic consideration
The basics theory of lantern wind turbine is related to aerodynamics. Aerodynamics is the interaction between the motion of air and the airfoil design with a curved surface on the top and flat surface at the bottom. When the laminar flow of air passes through the airfoil, the speed above the airfoil is higher which produces lower pressure. The airfoil has a lower speed below it; these differences produce high pressure, which leads to lifting where the airfoil is lifted perpendicular to the direction of the wind flow. Lantern wind turbine is design with circular airfoil. High pressure outside the circular airfoil and lower pressure inside the airfoil create a boosting lifting effect for lantern wind turbine. The tip speed ratio is the ratio of the tip speed of the blade and the velocity of the wind flow [8].

$$\lambda = \frac{\text{tip speed of the blade}}{\text{wind speed}}$$

$$\lambda = \frac{\omega R}{v} \quad (1)$$

Where;
$\lambda$ is tip speed ratio, $\omega$ is the blade revolution per minute, $R$ is the radius of the wind turbine and $v$ is the wind speed.

3. Betz's law
Albert Betz (1919) concluded that a wind turbine, which generates electricity through a rotor, the rotor of the wind turbine cannot convert more than 16 over 27 of kinetic energy to mechanical energy [9]. Betz limit results shows that utility-scale wind turbines can be achieve at peak 60% to 70%.

4. CFD simulation for Flow Simulation, fluid flow from one direction (wind turbine is rotating)
Table 2 shows the setting parameter of flow simulation. table 3 shows the setting for boundary condition of airflow over wind turbine. Velocity flow is set as 5, 6, 7, 8 and 9 (m/s) as the wind speed flowing through wind turbine. The rotation of the wind turbine is set as constant 2 rad per second, which is 19.1 (rpm). Solving mode, which is a serial and parallel mode. Serial mode is used in this case and the meshing process used for this study are auto meshing with the level of meshing set to the maximum of 8 (fine mesh) The minimum wall thickness and minimum gap size for meshing is set as
0.033m. All the result converged before 400 iteration. Table 4 shows the study condition which is the calculations end upon convergence and it is set to stop when iteration reached 1000. Coarse result is not discuss here, most of the journal has proven that fine meshing has more accurate reading compared to experimental result.

| Parameter               | Value                                                                 |
|-------------------------|----------------------------------------------------------------------|
| Finish condition        | All satisfied                                                        |
| Maximum iteration       | 1000                                                                |
| Goal convergence (Goal's criteria) | min velocity x-axis, max velocity x-axis, average velocity x-axis, min velocity y-axis, max velocity y-axis, average velocity y-axis, min velocity z-axis, max velocity z-axis, average velocity z-axis, normal force x, normal force y, normal force z, force x, force y, force z, frictional force x, frictional force y, frictional force z, torque x, torque y and torque z |

5. Design with AutoCAD®
The anemometers, rotor Darrieus-H and lantern wind turbine are drawn with Auto-CAD® for numerical simulation comparison purposes. To determine the flow condition through simulation, the wind turbine has 60 cm length of radius. All model are design with the same length of radius.

5.1. Dimension
The figure 4 and figure 5 show the dimension of lantern wind turbine. The lantern wind turbine is designed with circular aerodynamic shape with a gap distance of 2 cm between each blade.

![Figure 1. Market wind turbine design of Rotor Darrieus-H](image1)

6. CFD simulation The Flow Simulation Solver fluid flow under rotational condition
### Table 5: flow velocity and wind turbine rotation

| Detail                      | Rotor Darrieus-H | Lantern wind turbine |
|-----------------------------|------------------|----------------------|
| Velocity of 5m/s with 2 rad/s rotation | ![Image](image1) | ![Image](image2) |
| Velocity of 6m/s with 2 rad/s rotation | ![Image](image3) | ![Image](image4) |
| Velocity of 7m/s with 2 rad/s rotation | ![Image](image5) | ![Image](image6) |
| Velocity of 8m/s with 2 rad/s rotation | ![Image](image7) | ![Image](image8) |
Based on the result obtained from simulation the lantern wind turbine actually has very high shows the formation of unsteady vortices shed which form at the centre of the lantern wind turbine. This unsteady shed vortices leads to vibration and reduces the performance of the wind turbine.

In horizontal view, the flow condition with blue colour shows the airfoil vortex wake this increases the drag on the blade performance. The wind turbine design of Rotor Darrieus-H with velocity of 5m/s with 2 rad/s rotation shows a smooth pressure distributions flow on the blades and slight vortices wake at the centre of rotation. The velocity of 6m/s with 2 rad/s rotation shows that Lantern wind turbine the average wind speed rotating velocity of Lantern wind turbine is equal to the surrounding velocity this lead to the difference between the results compared to other results. The wind turbine design of Rotor Darrieus-H still shows a smooth pressure distributions flow on the blades and slight vortices wake at the centre of rotation. The wind turbine design of Rotor Darrieus-H shows an increase of vortices wake on the blade as the velocity increases and reduces in vortices wake at the centre of rotation of the wind turbine. Overall distributions still shows that it has a highly stable velocity flow distribution with low changes.

7. **CFD simulation contour view**

**Table 6:** flow velocity and wind turbine rotation contour view

| Velocity of 5m/s with 2 rad/s rotation |
|----------------------------------------|
| ![Diagram 1](image1.png)               |
| ![Diagram 2](image2.png)               |

**Figure 3. Lantern wind turbine design**

![Diagram 3](image3.png)
| Velocity of 6m/s with 2 rad/s rotation | ![Image](image1.png) | ![Image](image2.png) |
|--------------------------------------|----------------------|----------------------|
| Velocity of 7m/s with 2 rad/s rotation | ![Image](image3.png) | ![Image](image4.png) |
| Velocity of 8m/s with 2 rad/s rotation | ![Image](image5.png) | ![Image](image6.png) |
| Velocity of 9m/s with 2 rad/s rotation | ![Image](image7.png) | ![Image](image8.png) |
The pressure difference on the blade of lantern wind turbine is much lower in all the result shown above compared to darreis-H wind turbine. There is an obvious pressure difference on the darries H wind turbine which is red and green color. More likely for lifting to take place. Lantern wind turbine is more likely to have drag force acting on the blade compared to lifting force.

8. Conclusions and recommendations

The result generated based on rotational flow both shows that darries H wind turbine has higher tendency to create rotation compared to the lantern wind turbine since it has higher pressure difference. The study is done based on small scale wind turbine. Prototype is already manufactured, it should be compared simulation and experimental results.

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