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Optimization of Vertical Axis Wind Turbine (VAWT) Performance Using Venturi Effect (VE)

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Abstract

This study investigates the venturi effect to otimize the performance of VAWT in low wind speed conditions. The study indicates adding a secondary blade attached to the main blade of the vertical axis wind turbine to increase the lift force by amplifying the lift velocity vector form between the two blades. The Venturi Effect (VE) is proposed to take effect between main and secondary blade so that the additional blade will be in different positions with respect to the main blade in order to get the optimum position and distance. The simulation analysis using ANSYS CFD was proposed in this study to evaluate the velocity and pressure contours and wind velocity streamlines by applying an average wind velocity measured from a weather station at a starting value of 2 m/s. The variation of the rotational speed of the vertical axis wind turbine was presented to have high effect in the power generated by the rotor of the turbine. The analysis of force vectors of drag, lift, and tangential have been presented to get the optimum position of the secondary blade. The increasing in rotational speed of the developed wind turbine as compared with the original wind turbine was found to be 31% under the minimum wind velocity value of 2m/s.

Keywords: Wind Energy; Wind Turbine; Vertical Axis Wind Turbine; Venturi Effect; Simulation

1. Introduction

The kinetic energy that is generated from the movement of air in the atmosphere could be utilized in the generation of electricity by using the fundamental wind turbine [1]. The wind energy enhanced an important applications many decades ago by using this type of free energy in the grinding or sailing as well as water irrigation [2]. As the recent researches on this field of green energy which is considered as environment friendly with zero effect on the depletion of ozone; the mechanical energy obtained by the wind turbine blades is converted to useful electrical energy [3]. The principle upon this type of power generation could be obtained by the rotating blades which are connected to the rotating shaft in which is then connected to the generator. There are two types of wind turbines could be divided according to the axis of rotation into horizontal and vertical axis wind turbines [4]. One of the most reliable advantages of vertical axis wind turbine is the ability of catching wind in any direction, while in horizontal axis wind turbine where the turbine should be in a position perpendicular to the direction of the wind [5]. Another advantage is the ability of this type of turbine to generate electrical power even at steady state, hence there is no power fluctuating like in horizontal axis wind turbine. In terms of very important parameter that is influencing the performance of the vertical axis wind turbine is the blade design and configuration. The blades could be made as simple as a flat blade without any twist [6]. Therefore, for high performance and efficiency, [7] the blade could be twisted to a form that gain more wind forces acting on it. In 1977, Streedbart and Singbji designed [8] a new model of wind turbine where as it synchronized with a generator to estimate the aerodynamic effect on the load. The structure of that model as well as the power generator was also synchronized to the vertical axis wind turbine. FORTRAN code used in this study to analyse the aerodynamic effect of the turbine. The results obtained from the numerical analysis then validated with experimental data. The development of vertical axis wind turbine takes an effect to enhance the output efficiency by increasing the forces acting on the blades. Badawy in 2000 presented a new configuration of vertical axis wind turbine by adding a shroud to the main frame [9]. The mathematical analysis of this study was built under the assumption that estimates the ratio of shrouding and the diameter of the shrouded area. The results obtained from that experiment compared to the conventional vertical axis wind turbine had more efficiency as the output power increased. Mathematical investigation of a ducted wind turbine was presented by Kelly in 2003 [10]. The development of vertical axis wind turbine was obtained by integrating the turbine into the building to create a duct surrounding the wind turbine blades. This configuration leads to increase the wind speed acting on the blades by utilizing the venturi effect. The simulation analysis used in this study estimated the wind speed around each blades and the effect of duct in the performance of the wind turbine [11].

Considering the mentioned background brief about several analyses of wind turbine used to generate electricity; this study presents a new concept of vertical axis wind turbine by adding new blades attached to the main blades. This configuration could lead to increase the aerodynamic effect of wind forces acting on turbine blades. The attached blades take the effect to create venturi effect (VE) between the main and secondary blade. The simulation analysis using ANSYS CFD was obtained to enhance the effect of adding the blades under minimum wind speed.

2. Problem identification and basic principle

The requirement of wind speed for small scale wind turbine is less than the commercial horizontal axis wind turbine. Therefore, vertical axis wind turbine is reliable in several places as it could obtain electrical power from any wind direction [12]. In Malaysia, low wind speed occurs in several sites as the average speed of the wind is 2 m/s [13]. Figure 1 represents the average wind speed in different weather stations distributed in several sites. The wind speed values represented in this figure show that in many station the velocity of the wind could reach 2-3 m/s. Hence, this value is not enough to start the wind turbine, as the minimum cut-in speed in most of vertical axis wind turbine is 2.5 m/s [14]. Therefore, there is a need to design and develop a new wind turbine that could be operated in these low wind speed area.

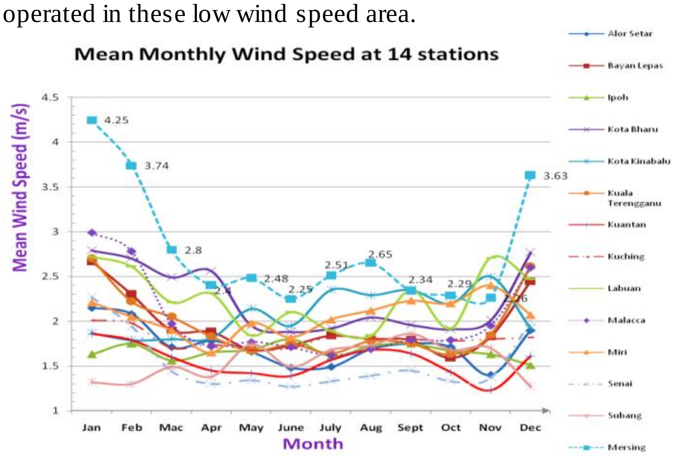

Fig. 1 Average annual wind speed in 14 stations

3. Methodology

In order to verify the mathematical model of wind speed and air flow characteristics on the vertical axis wind turbine, the drag and lift force configuration on wind turbine blades shall be considered. Figure 2 represents the top view of wind turbine blades in different rotational positions subjected to wind speed with the effect of drag and lift forces.

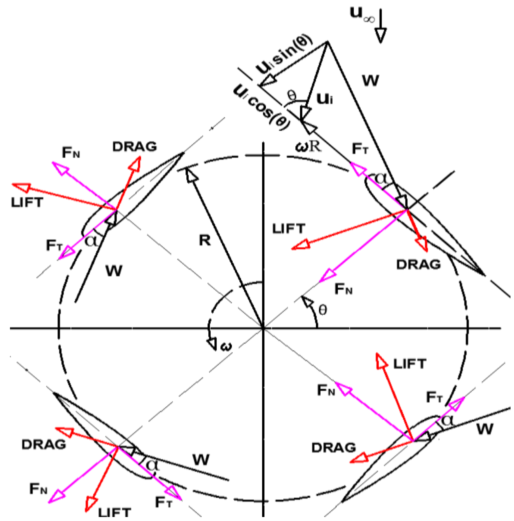

Fig. 2 Forces and velocity analysis in vertical axis wind turbine

To enhance the effect of adding new blades to the vertical axis wind turbine, the control volume of the area between main and secondary blades were obtained. Figure 3 shows the top view of this control volume with the air flow acting on the two blades.

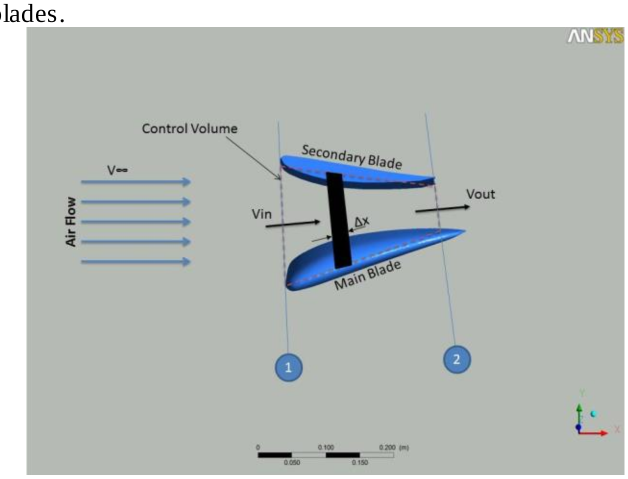

Fig. 3 Control volume of area between main and secondary blades

The area between the blades represents the duct profile to create venturi effect (VE) between them. Bernoulli's analysis is used to obtain the relation between the wind speed entered the front section and the exiting wind speed. The assumptions made in this analysis were the flow of air is considered as incompressible, homogenous, and in steady state condition.

Giovanni Battista Venturi (1746-1822) [15], fined the effect of venturi according to Bernoulli's equation as the acceleration of flow velocity in the shrinkage section is obtained from the following equation:

$$P + \frac{1}{2}\,\rho\,V^2 + \rho\,g\,h = constant \qquad (1)$$

From the above equation, in terms of pressure and velocity:

$$P_1 - P_2 = \frac{1}{2}\,\rho\,(V_2^2 - V_1^2) \qquad (2)$$

And hence,

$$A_1 V_1 = A_2 V_2 \qquad (3)$$

From the equations presented above, it was found that the most effective parameter is the velocity of air. Therefore, increasing wind velocity could increase the output power generated by the wind turbine as it is related directly to the kinetic energy obtained.

$$KE = \frac{1}{2}\,m\,V^2 \qquad (4)$$

Where the mass of air flowing in the control volume could be obtained from the following equation:

$$m = \rho\,A\,V \qquad (5)$$

By substituting the mass of air in equation 4, the new formula of kinetic energy will be:

$$KE = \frac{1}{2}\,\rho\,A\,V^3 \qquad (6)$$

The amount of air expressed in equation 6, is proportional to the density of air and the swept area of the wind turbine blade. The density of air is 1.225 kg/m^3 as this value is constant, and the swept area of the blade is equal to ($\pi D^2/4$). Therefore, the kinetic energy could be written as:

$$KE = 0.48(D^2 V^3) \qquad (7)$$

4. Results and discussions

The concept of venturi vertical axis wind turbine (V-VAWT) was taken into consideration in the mathematical and simulation analysis. ANSYS CFD Simulation tool was used to obtain the velocity of air between main and secondary blades and enhancing the position of the secondary blade.

The force analysis of the new proposed concept was taken into consideration to fulfill the effect of both forces in the two wind blades altogether. The analysis of the lift, drag, and the tangential velocity vectors has been successfully computed at different angles of attack of the secondary blade using a 300 W VAWT. The profiles of velocity stream can be seen from Figure 4 and the amplified velocity after the secondary blades attached can be seen in Fig 5a and Figure 5b, respectively. As can be observed from the figures, the wind speed has been attenuated to almost 1.45 times of the original wind speed without the secondary blade.

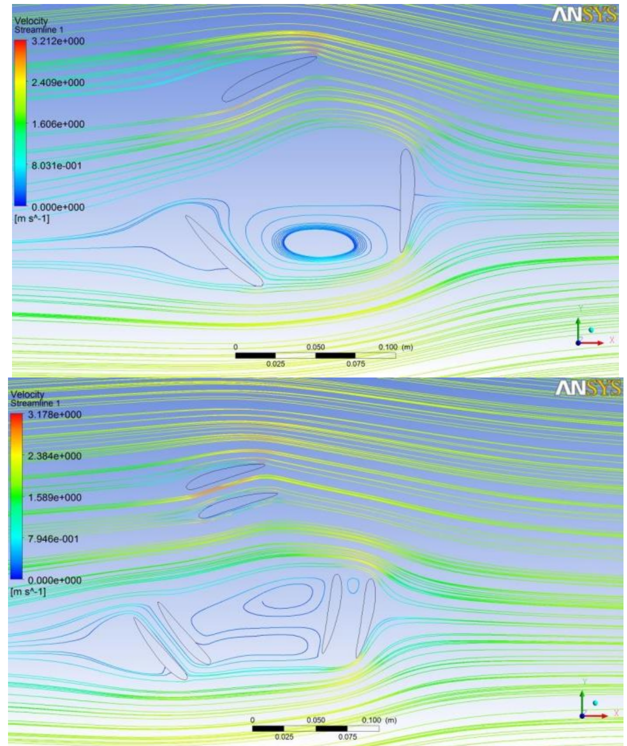

Fig. 4 Profile of velocity streamlines of original and developed vertical axis wind turbine

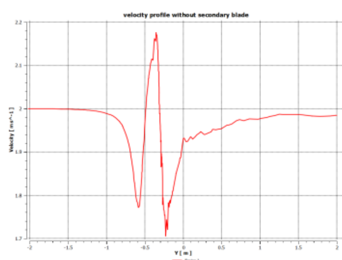

Fig. 5a Velocity profile without secondary blade.

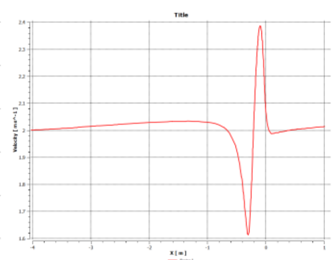

Fig. 5b Velocity profile with secondary blade.

The analysis of the flow stream can also be seen from Figure 6 showing the differences of the velocity vectors between primary blades with and without the secondary blades of a typical 3 blades of a 300 W VAWT. It shows the amplified wind speed with the secondary blades attached. However, the position of the secondary blades with respective to the primary blades need to be considered to optimize the pressure difference and hence the lift effect of the wind turbines. This can be seen from Figure 7 below.

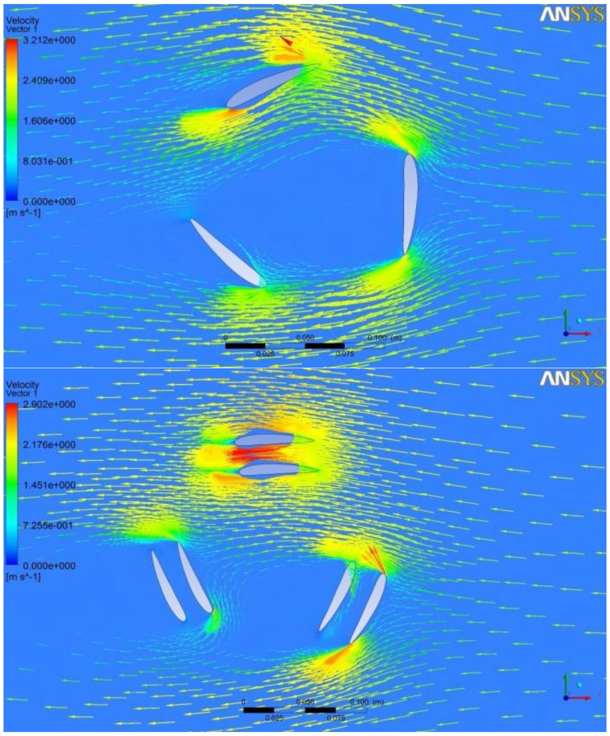

Fig. 6 Air velocity vectors with and without secondary blades

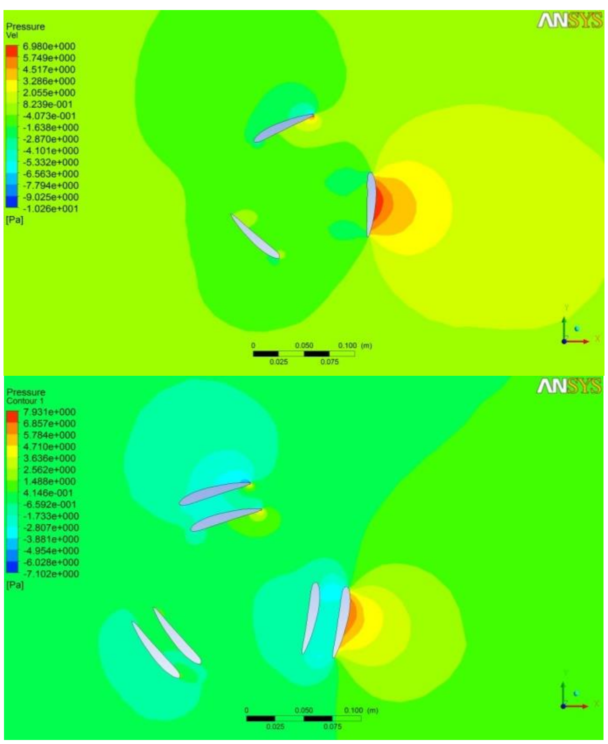

Fig. 7 Pressure distribution with and without secondary blade

6. Conclusions

This study demonstrated the optimization and development of vertical axis wind turbine by adding secondary blades attached to the main blades. The secondary blades will take the effect creating venturi area to accelerate the wind speed and forces acting on the blades. The developed vertical axis wind turbine was analysed in ANSYS CFD simulation to get the optimum position and distance between the main and secondary blades to enhance high performance and efficiency. It was found that the velocity created in the venturi area could increase by 13%, whereas the velocity obtained from the conventional wind turbine was 2 m/s, while in the venturi vertical axis wind turbine the wind velocity could reach 2.4 m/s. the improvement of this vertical axis wind turbine concept leads to increase the power output generated from the rotor.

Abbreviations

A	Swept area (m^2)
D	Diameter (m)
g	Gravitational acceleration constant (m/s^2)
h	elevation (m)
KE	Kinetic energy (J)
P	Pressure (Pa)
V	Wind velocity (m/s)
ρ	Air density (kg/m^3)

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CESD-Net is a major global initiative in energy and sustainable development. The objective of network is to promote energy and sustainable development in commonwealth countries.
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The 1st International Conference on Energy, Environment and Economics (ICEEE 2016) was held at Heriot-Watt University, Edinburgh, EH14 4AS, UK, 16-18 August 2016. ICEEE2016 focused on energy, environment and economics of energy systems and their applications. More than fifty eight delegates from 31 countries with diverse expertise ranging from energy economics, solar thermal, water engineering, automotive, energy, economics and policy, sustainable development, bio fuels, Nano technologies, climate change, life cycle analysis etc. made conference true to its name and completely international. During conference total 51 oral presentations and six posters were shared between delegates. The presentations showed the depth and breadth of research across different research areas ranging from diverse background. ICEEE2016 aimed:

- To identify and share experiences, challenges and technical expertise on how to tackle growing energy use and greenhouse gas emissions and how to promote sustainability and economical, cost effective energy efficiency measures.

In total 11 technical sessions and two invited talks both from academia and industry provided insight into the recent development on the proposed theme of the conference. Preparation, organisation and delivery of the conference started from July 2015 and further co-ordinated by vibrant team of Conference Centre, Heriot Watt University. Conference organisers would like to acknowledge support from the sponsors particularly World Scientific Publication ltd and its team members for the delivery of the conference. Organisers are also thankful to all reviewers who contributed during peer review process and their contributions are well appreciated. At the end and during vote of thanks following awards have been announced and we would like to congratulate all well deserving delegates.

- Best Paper –Academia: Amela Ajanovic, EEG, TU Vienna, Austria
- Best Paper – Student : Christian Jenne,University of Duisburg-Essen, Germany
- Best Poster – Student: Yoann Guinard, University of New South Wales, Sydney, Australia
- Best Poster – Academia: E. Salleh, Universiti Kebangsaan Malaysia, Malaysia
- Active Participation Award - Yoann Guinard, University of New South Wales, Sydney, Australia

At the end we would like to extend our gratitude to all of you for your participation and hopefully welcome you again during ICEEE2017.

Editors:
Dr. Singh is Senior Scientist at Indian Agricultural Research Institute, New Delhi, India. Her area of expertise are bio energy and bio fuels, environmental engineering, carbon accounting and renewable energy integration for rural development.
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