Experimental Evaluation of Wind Fan Performance Run by Mixed Flows:

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ABSTRACT

Solar power systems (SPS) utilize solar energy and wind energy to produce electrical energy. In a typical solar updraft power system, the air flow enters the collector radially and exit through the chimney axially. However, the existing wind turbine operates at such that the air enters and exits in the same direction either axial-axial or radial-radial. The main objective of this study is to determine the characteristic of wind fin run by mixed flows through experimental investigation. The scopes of this study include fabrication of new unit of designed wind turbine and experimental setup to determinate wind velocity approaching the turbine, rotational speed of turbine, and electrical output power. From the experimental data collected, the characteristic curve of each of the case can be established in terms of power coefficient and tip speed ratio. In comparison of the different designed wind turbine in litruture, the new wind turbine with new blade orientation show a better efficiency. The speed of the rotating blade plays an important role in extracting the power from the wind

turbine. In the future study, a comprehensive study on other profiles and types of turbine blades can be done to find a better efficiency wind turbine.

Keywords Wind energy; Wind turbine; Mixed air flows; Power coefficient.

Introduction:

Renewable energy such as solar and wind energy can be used to reduce environmental problems and support the demand of energy as they are reliable, widely available and relatively cheap and efficient [1, 2]. This has led to the study of solar updraft power system which is commonly known as solar chimney power plant (SCPP), and recently the solar vortex engine (SVE) which utilizes solar radiation to impose air flow from the surrounding. Today, there is a lot of research on SPS which uses solar and wind energy as renewable resource to generate power. A SUPS is commonly known as SCPP, and recently the solar vortex engine (SVE) which utilizes solar radiation to impose air flow from the surrounding [3, 4]. There are three important parameters in SUPS; collector, chimney, and turbine. Solar radiation from the sun heats the ground and the thermal energy from the ground is transferred by convection to the air into the collector. Due to heat transfer, the warm air expands and causes an upward buoyancy force in the chimney forces air to exit through the turbine [5]. The flow configuration in the updraft solar power system is that air flow enters radially from the peripheral of the collector and exits axially through the chimney. However, the existing wind turbine operates at such that the air enters and exits in the same direction either axial-axial or radial-radial. SCPP has a lot of advantages in comparison to other power production technologies as the technology utilize both direct and indirect solar radiation, no cooling water required for the operation and the ground act as a natural heat storage [6-8]. The technology is simple and uses renewable energy source; solar radiation which reduce the emission of greenhouse gases. The power generated is thought to be a good alternative to replace the non-renewable resources. However, there are also some disadvantages of SCPP. The main concern is the cost of investment to build the solar updraft power system as it required a very large collector area and a very high solar chimney. In addition to that, the efficiency is low as energy is lost to the surrounding during several process of energy conversion [9]. The principle of SCPP involves the absorption of solar energy using the collector to heat air which is the working fluid. The temperature change result in rising of the air caused by an upward buoyancy force due to density variation through the chimney. The continuous stream of kinetic energy from the air rotates the wind turbine. Generator coupled with the wind turbine converts the kinetic energy into mechanical energy and finally into electrical energy [10]. There are two types of wind turbine, horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). HAWT rotates the blade parallel to the ground meanwhile VAWT rotates the blade perpendicular to the ground. The orientation of the rotor is one of the most fundamental decisions in designing a wind turbine. HAWT is very common as it is able to generate high capacity of power, has improved capacity, and has potential impact on the climate conditions. Nevertheless, VAWT is able to accept wind form any direction and the maintenance for this turbine is relatively low and easier compared to HAWT [11]. Wind turbine is designed to generate maximum power from the wind at minimum cost. Wind turbine extract energy from wind by leveraging aerodynamic principles of lift and drag. The magnitude of lift and drag force depends on the shape of the blade, orientation of the air flow, and velocity of the air flow. Lift force is at right angle to the direction of the air flow whereas drag force is in line with the direction of the air flow [12]. The operating principle of aerodynamics in a wind turbine is similar to the wings of an aeroplane and can be explained by Bernoulli's principle. There are a few factors that have to be taken into consideration in order to design an efficient wind turbine. Besides considering the aerodynamic operating principle, design or wind turbine blade, and material of the wind turbine blade is important to provide strength and stiffness [7]. The blade must be made of materials which have high stiffness to ensure aerodynamic performance, low density to minimize mass and long-fatigue cycles [13, 14]. Example of materials used to produce wind turbine blades includes metal, plastic, wood, and composite [15]. Number of blades and rotational speed are among the considerations in designing the wind turbine blades. Typically, wind turbine has no more than three blades and rotational speed at the tips is moving at seven to ten times of the wind velocity. At high rotational speed, blade will become aerodynamically inefficient, noisy and cause hazard to birds. On the other hand, at low rotational speed, swirl in the wake and tip losses will reduce the efficiency of the wind turbine [16]. The main objective of this study is to determine the characteristic of wind fin run by mixed flows through experimental investigation. The scopes of this study include fabrication of new unit of designed wind turbine and experimental setup to determinate wind velocity approaching the turbine, rotational speed of turbine, and electrical output power.

1. Experimental Implementation

Experimental investigation was carried out to choose the best performance by the variation of twist angles for blades. The mixed flow wind turbine was designed with small size; its size was changed from 0.55× 0.55 m2 to 0.7× 0.7 m2 with varying the yaw angles (fixing angles) of blades with the rotation hub, from 45o to 70o, respectively. The number of blades used in these models is 8. The material utilized to build the turbine is Aluminium in form of sheet with thickness 1.5 mm. The dimensions of the vertical wind tunnel used in this experiment are displayed in Figure 1. It has two parts; the first part is the frustum (2.2 m base diameter, 0.2 m head diameter, and 0.2 m height) located at the base and a cylindrical duct (0.2 m diameter and 0.7 m height) connected to the head of the cone. The second part is the rotational rotor (F1 and F2) that rotates around a perpendicular axis.

The main function of the fan is to replicate the air flow from the surrounding into the wind tunnel. In these experiments, a total of four fans were used to vary the velocity of wind approaching the turbine within the range of 0.8-4.3 m/s. For better results, it is required to measure the followings: the starting point of rotation for each model of turbines to select which one has a low starting velocity in order to be chosen in the system of the low wind plant, the wind speed using portable thermo-anemometer, while the rotational speed for the turbine using Tachometer, digital force gauge is used to record the rotator force of turbine and finally the torque was calculated. While the output power, through a current and voltage generated from the turbine connected to motor were measured using AVO-meter.

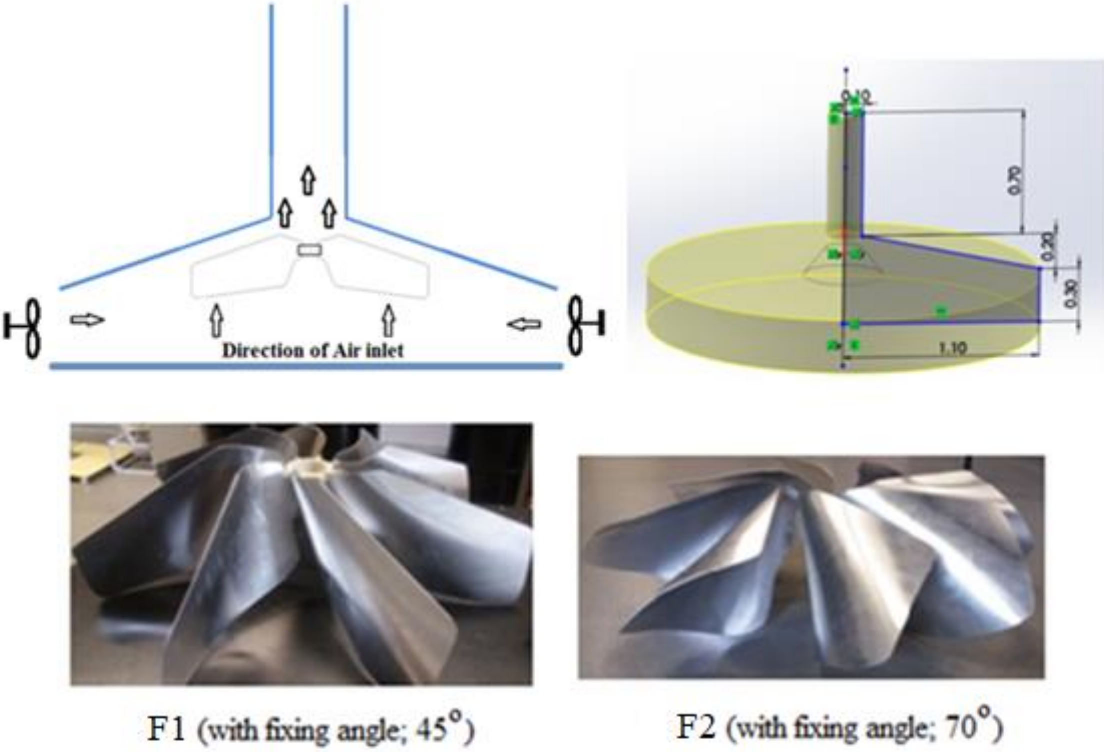

Fig. 1. . Schematic drawing of the experimental setup and photos of real design of blades.

1.1. Aerodynamic Analysis

Drag of the blades mid span section, which is dependent on wind speed (Uw) [m/sec], blade velocity (Ub) [m/sec], angle of blade entry (λ) [deg], surface finish, and yaw angle (α) [deg] (fixing angle with hub), as shown in Figure 2. While the angle of entry is dependent on blade twist and pitch. The angular speed is (ω) [rad/sec] and rotor diameter (r) [m]. The tip speed ratio (δ) defined as the relationship between rotor blade velocity and relative wind speed [17]:

$$\delta = \frac{U_b}{U_w} = \frac{\omega . r}{U_w} = \frac{CP}{CT} \quad (1)$$

Also, tip speed ratio (δ) is known as ratio between a power coefficient (*CP*) and torque coefficient (*CT*) [18]. The actual power of rotor is chosen as the efficiency where the power will be transferred to the rotor.

Wind turbine efficiency is usually as a power coefficient (*CP*). So that, the *CP* of rotor can be definited as the ratio between actual powers on available wind flow is:

$$CP = \frac{2P_o}{\rho_a A U_w{}^2} \qquad (2)$$

And torque coefficient (*CT*) is:

$$CT = \frac{2T_o}{\rho_a A U_w{}^2 . r} \qquad (3)$$

Where, *Po* is the outcome power of turbine [watt], *To* is a torque [N.m], and *A* is a projected area [m^2]. The tip speed ratio plays an important role to consider in selecting different design aspects such as efficiency, torque, mechanical stress, and aerodynamics. So the efficiency of a turbine, aerodynamic and centrifugal stresses are increased with higher tip speed ratios [19]. Generally, aerodynamic performance is main feature for efficient rotor design. Aerodynamic lift is the force assigned to the production of the energy generated by the turbine, so it is necessary to increase this power using the appropriate design. While friction generates the resistive drag force that also impedes blade movement, so must be reduced [20]. Then, a lift to drag ratio is:

$$Light\ to\ Drag\ ratio = \frac{C_l}{C_g} \qquad (4)$$

Mathematically is difficult to predict by the coefficient for the lift and drag (C_l and C_g) of blade. While traditionally turbines are tested experimentally with factors correlating lift and drag at given angles of entry and different Reynolds numbers [21]. The aerodynamic lift and drag produced are resolved into useful thrust (F) [N] in the direction of rotation absorbed by the generator and reaction forces (T) [N], as shown in Figure 3.

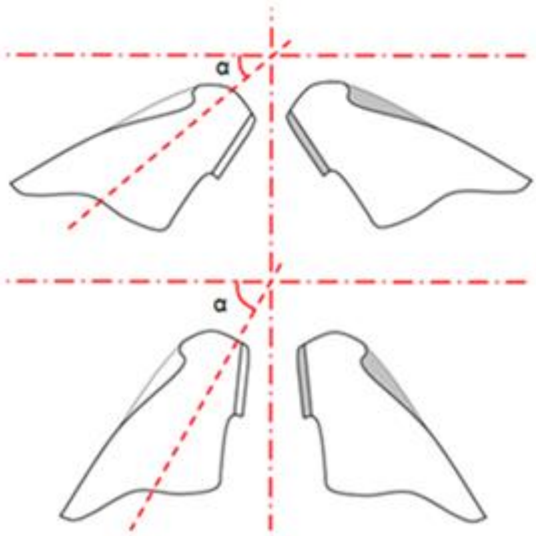

Fig. 2. . A new shape of turbine blade and region classification.

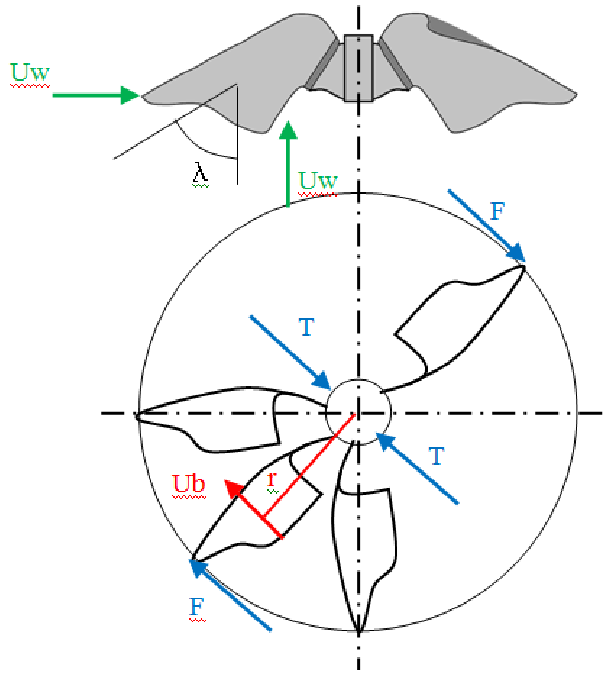

Fig. 3. Aerodynamic analysis at a blade element.

2. Results and Discussion

Based on the experimental data collected, graph of the working speed against the wind speed and graph of power coefficient against tip speed ratio were plotted and each of the wind turbines are denoted by the symbols shown in

Figure 4. From figure, the both small and big wind turbine with blade orientation of 45 degrees show the relation of a normal wind turbine whereas the rotational speed increases with the increase of wind speed. On the other hand, the small turbine with blade orientation of 70 degrees shows a linear line where the rotational speed is constant with increasing wind speed.

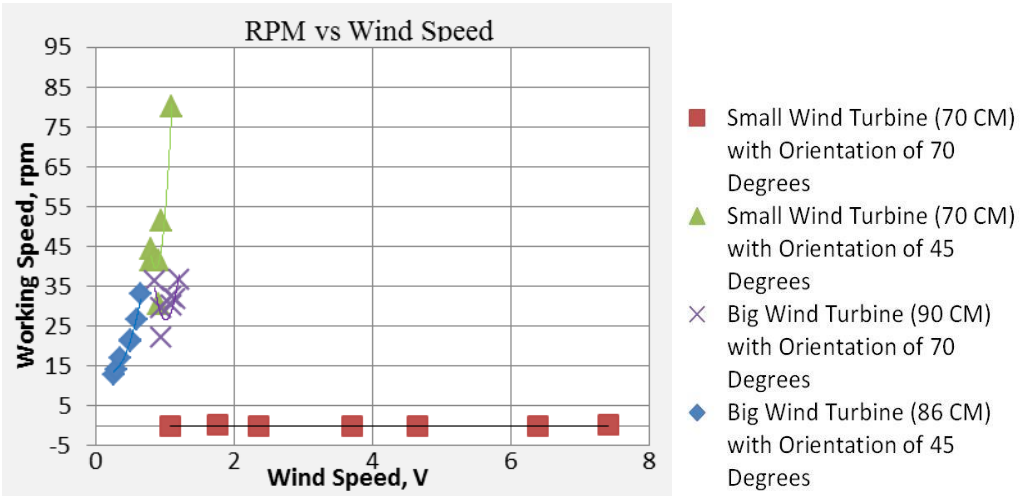

Fig. 4. Graph of working speed versus the wind speed for all cases.

According to Betz law, the maximum extracted power from the wind is at 59.3 %. In other research paper, the common extracted power from the wind is at about 45 %. From the Figure 5, the maximum extracted power from all the four designed wind turbines is only at about 2.5 %. The value is below the theoretical limit due to inefficiencies and losses caused by different type of blades profile..

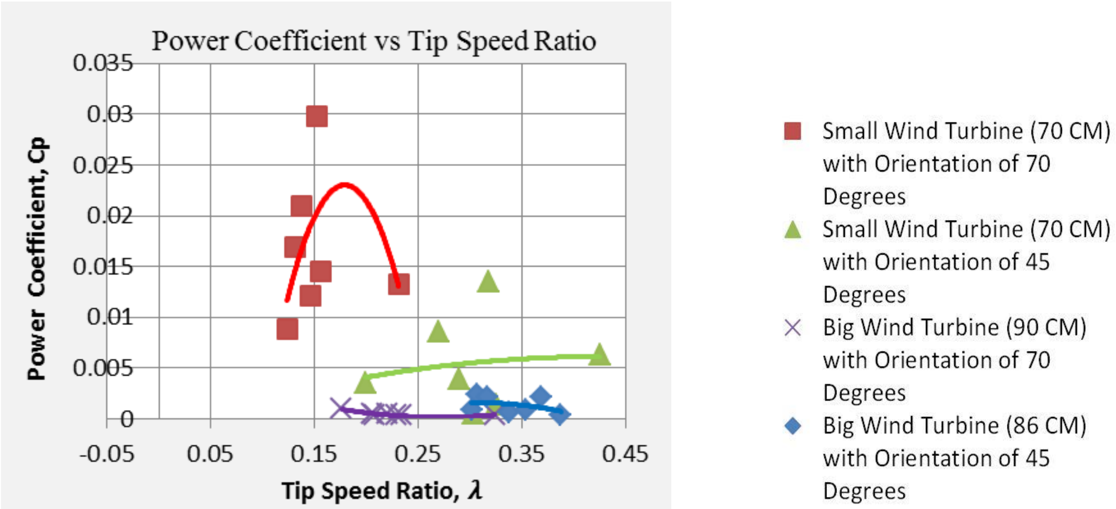

Fig. 5. Graph of power coefficient versus the tip speed ratio for all cases wind turbines.

Conclusion

In this present study, the experiment aims to study the characteristic of wind turbine through experimental investigation of two small and two big wind turbines, placed with an orientation of 45 degrees and 70 degrees. In this project, the small wind turbine with blade orientation of 70 degrees shows a better efficiency compared to the other designed wind turbines. The design of wind turbines is taken into consideration in order to achieve maximum or optimal efficiency. Most of the wind will pass unobstructed through the space between the turbine blades with minimum power extraction if the turbine blades turn too slow. On the other hand, the rotating turbine blades will act as a solid wall obstructing the wind flow thus reducing the power extraction when the turbine blades turn too fast. The following conclusions can be drawn from the analysis of the results:

- Increasing the fixing angle for blades increases the performance of wind turbine for a certain blades number (8 blades).
- The starting torque is dependent on the fixing angle for blade with the turbine rotor, in which the wind turbine with large fixing angles for blades is needed to the smaller starting torques

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