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Effect of the Blade Pitch on the Performance of Small Wind Turbine Exposed to Wind Stream of Various Angles of Attack

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Abstract

In wind turbines, several parameters can affect the productivity of the turbine, such as wind velocity, rotor area, blade aerodynamic design, and blade pitch. In this paper, the effect of various pitch angles for a small wind turbine was investigated. A system of two metal stands with same height is installed (i.e. on the same axis of streaming), the first stand holds an air blower which imitates the wind with constant air blowing. The other, holds a small wind turbine consists of a DC motor and metal hub (steel bush) with 3-blades with equal radial distance (120°). The pitch angle was adjusted at a certain degree of inclination (10°) in which the turbine starts to rotate, then readings of power and rotational speed were collected. The process then repeated with another 3 different angles (15°, 20°, and 25°). At the end, a fixed pitch angle degree was adjusted, and then the lowest and highest air velocity that affecting the blades rotation were measured.

1. Introduction

Wind has a huge and destructive energy. The energy can be powerful enough to uproot trees and blows down power lines or even destroys buildings. Moreover, the storms can cause a wide range of vandalism and sometimes a national disaster as shown in Figure (1). However, this energy can be transformed into beneficial power (electrical) by wind power plants or (WPPs) [1].

Therefore, the wind that we can feel its streaming has to be harnessed and translated into a useful form of energy. The instrument that makes this change is a wind turbine rotor, which is attached to an electrical generator. Due to the wind energy formula, which is related to the cube of wind velocity, the power obtained from this phenomenon could be huge.

Several parameters control the procedure of changing the kinetic energy of the wind into electrical energy by wind turbine. However, pico wind turbines have not been widely covered by literature [2]. This paper will investigate these parameters, namely the effect of pitch angle and wind speed on the generated power in pico wind turbine.

Figure (1). Massive destruction of trees and buildings due to windstorm.

Rotation Principle
The main issue of wind energy is that air is a fluid and it reacts to the principle of fluid dynamics. Like water, air circulates and moves in the same manner and they both work in the same mathematical methods of fluids [3].

There are two main forces that generate during the air flowing, the drag and lift forces. The main phenomenon is the relative difference in velocities between the object (stationary or moving) and the air (stationary or moving). The object here resembles the blades of wind turbine by decreasing the air velocity to harness as much as we can of the kinetic energy of air [4]. Two principle are emerged in this process, which are:

- Drag principle.
- Lift principle.

Drag Principle
The non-effective principle of rotating the blades of a certain turbine is the drag principle. The drag force is created when any object (such as blades) is in the same directional line of the streaming fluid. Drag force generates when the flat or inclined (curved) area of one side of the blade is exposed to air while covering the other and the resulting force begins to rotate the blade. The Savonius wind turbines are prime example of using such force as shown in Figure (2) [5].

Figure (2). Multiple types of Savonius wind turbines.

The creation of drag force is the result of the viscous frictional forces by air flowing on the aerofoil surface facing towards and against the stream flow. The wind pulls the blades on the direction of streaming or blowing. Thus, with the blades fixed along the central shaft, and has limited degree of linear moving, therefore, it cannot move linearly and they are pulled and turned to a rotational movement [6].

If we consider the drag force as (D), which can be obtained by finding the power (P) harnessed by an object with certain surface area (A), with certain moving velocity (v) due to the impacting of air stream of laminar air velocity (v_0):

$$\mathbf{P = D \times v_r} \quad \dots (1)$$

Where: Vr: relative velocity obtained by v_0-v.

Lift Principal

Most of large electricity generating in WPPs work on the method of lift force. This force is suitable to all streamlined objects as shown in Figure (3).

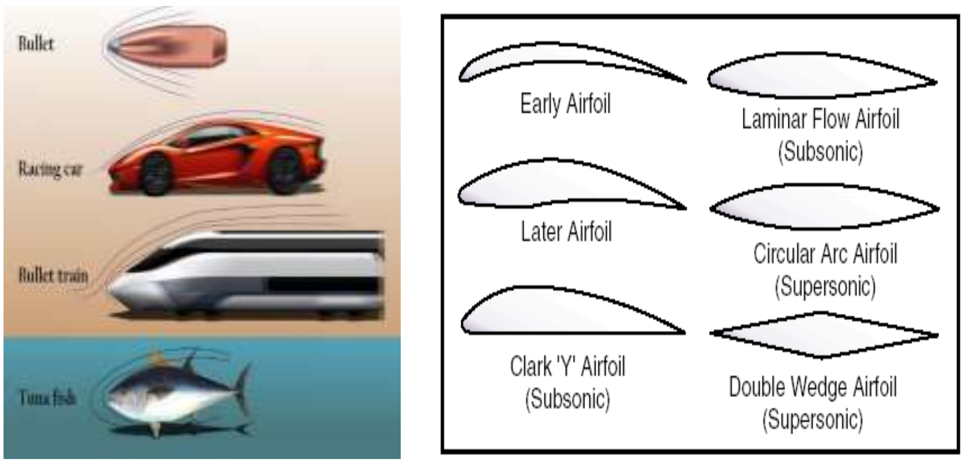

Figure (3). Different streamlined objects.

These objects (which are called streamlined) have the property of decreasing drag force, and the fluid flow around them in smooth and stream like lines, like fish, airplanes, and blades section airfoils.

When we make a comparison by using a streamlined object, the forces generated by lift airfoils are far higher than those of drag ones with the same exposed area as shown in Figure (4) [7].

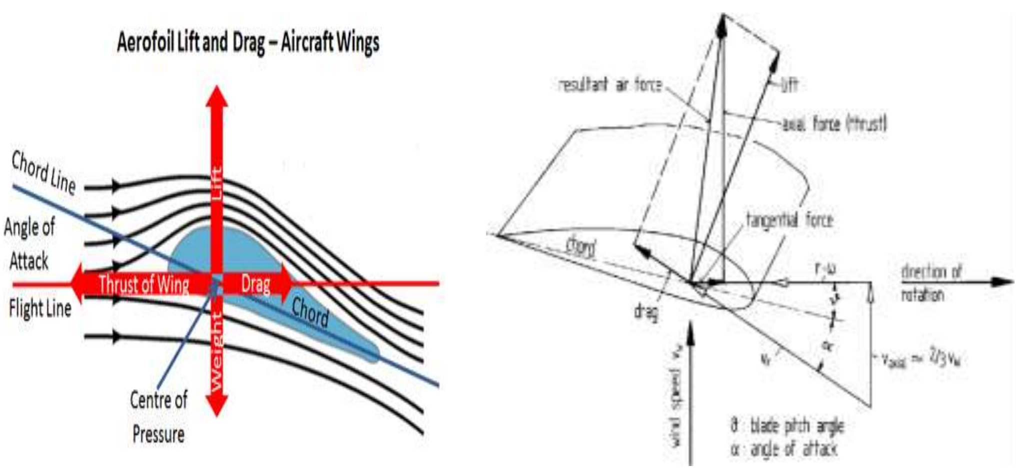

Figure (4). Aerofoil lift action.

In addition, as a fact, all the WPPs work on the principle of lift to generate electricity. If we look to the blades shape and in contrary to drag turbines, the lift principle turbine blades are aerodynamically fabricated and show resemblance in profile to those of an aircraft. When we cut the lift principle blade, the cross section is streamlined and symmetrical with distinctive two edges, the thicker that faces the air stream called leading edge and the thinner edge on the far end called the trailing edge [8].

The imaginary line that divides the section into two halves attaching the sides of leading and trailing edges is called the mean camber line. The straight and center line that attach the two edges are called the chord line (c). There is a center point (C) along the chord line about 25% from the leading edge of the aerofoil (this distance is variable depending on the airfoil section shape). At this point, all the forces on the blade are concentrated [9].

In Figure (5), we see the pressure distribution along the blade section for different angles of attack (α). It is obvious that the pressure distribution around the blades changes whenever we change the angle of attack.

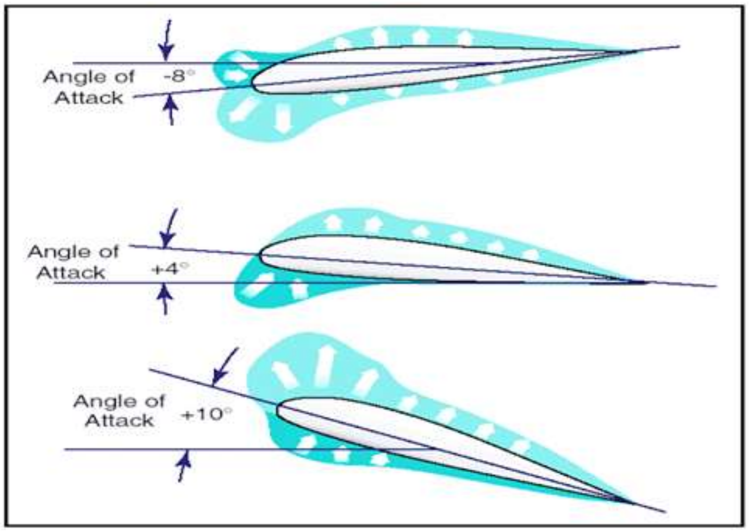

Figure (5). Different pressure distribution for different values of angle of attack.

The total energy harnessed by a wind turbine is the sum of generated electrical energy, rotational inertia energy, and energy heat losses [10]. The performance of any wind turbine is related to the following wind speed values:

- **Start-up speed:** by this speed, the rotor of turbine begins to rotate and certain value of voltage is being generated, and this value rises whenever the speed is accelerated.
- **Cut-in speed:** in this speed, the voltage is high enough for the turbine to be connected to the grid. This value varies between 2-4 m/s.
- **Rated speed:** by this speed, we reach the rated power for the turbine and it varies between 10-14 m/s.
- **Cut-off speed:** by this speed, we stop the rotor from rotating to protect it from damaging; this speed varies between 20-25 m/s.
- **Survival speed:** it is the value of speed in which the turbine stands without damage during the high wind such as storm, which could happen in the installation site during the turbine lifetime, this value ranges between 55-65 m/s [11].

2. Experimental Procedure

A small DC motor used to build a pico Horizontal Axis Wind Turbine (HAWT). The turbine hub is homemade steel bush. The hub diameter is 23 mm with inner bushing sliding on the generator shaft with a lock screw to guarantee the transition of the rotation movement to the shaft. In this bush, three screwed holes with diameter of 4 mm drilled. Three identical threaded beams were fabricated with a length of 190 mm each separated by 120° between each of them around the bushing outer diameter. These beams represent the support for a 180mm length of a PVC moving parts, which made the rotating blades. We applied a certain glue to attach the beams to the blades to make the blades. We used two nuts for each beam to lock it during rotation so that to prevent the blades from flipping.

We chose specific DC motor (12 V, 10 W) to represent the generator and we put the whole system (generator and blades) on steel structure, which here represents the turbine tower. Another steel structure was fabricated that we attach an electrical wind blower that gives us a constant wind stream of 45 m/s. We measured several distances and we chose a 750 mm between the two structures that gives us the highest output power with a wind velocity at these criteria about 11.5 m/s at the hub and this velocity becomes constant value in our research. A portable anemometer was used to record these values of wind velocities.

Different angles of attack were used so that we could obtain different readings. There was an initial starting of rotating angle, which could be obtained as a value of slightly higher than 5°, so the chosen values in this work were 10°, 15°, 20°, and 25°. Each time we fix the blades on a certain angle, we took the readings of current and voltage generated and the rotation velocity. The current and voltage generated was measured by clamp meter and voltmeter, respectively and the rotation velocity measured by a tachometer. The experiment setup and the used instruments are seen in Figures (6 & 7).

Figure (6). A photograph of the equipment setup.

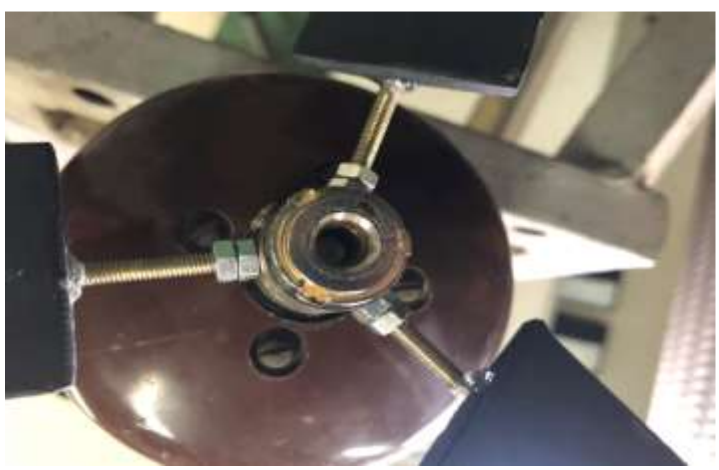

Figure (7). Blades pitch adjustment.

3. Results and Discussion

Figure (8) shows the relationship between the rotational speed (rpm) and the pitch angles (10°, 15°, 20°, and 25°). We can see from the figure that each time we choose a higher pitch angle we see a significant reduction in rotational speed. This is because the normal force on the blades increases due to the decrease in blades frontal area as the turbine blades become parallel to the inlet of the flow direction with each increase in pitch angle. Moreover, the significant increase in momentum causing a decrease in the rotational speed. It is also shown that the start-up speed of the used wind turbine is greater than 5° of pitch angle.

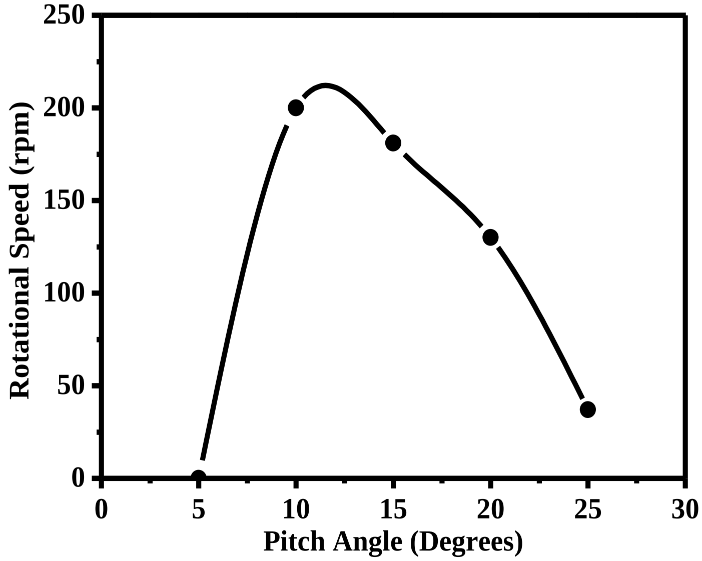

Figure (8). The relation between pitch (degrees) angle and rotational speed (rpm).

The same phenomenon is illustrated in Figure (9) with relation between the output power (W) and the pitch angles with the same behavior since output power is proportional with rotational speed in wind turbines. We can see that the optimum value of power is obtained at 10° pitch angle then it shows a decrease on the other angles due to the increasing amount of momentum generated and the reduction of rotational speed, respectively. Moreover, the decrease in power generated is due to the phenomenon of stalling, in which the lift force drops with higher values of angles of attack [12].

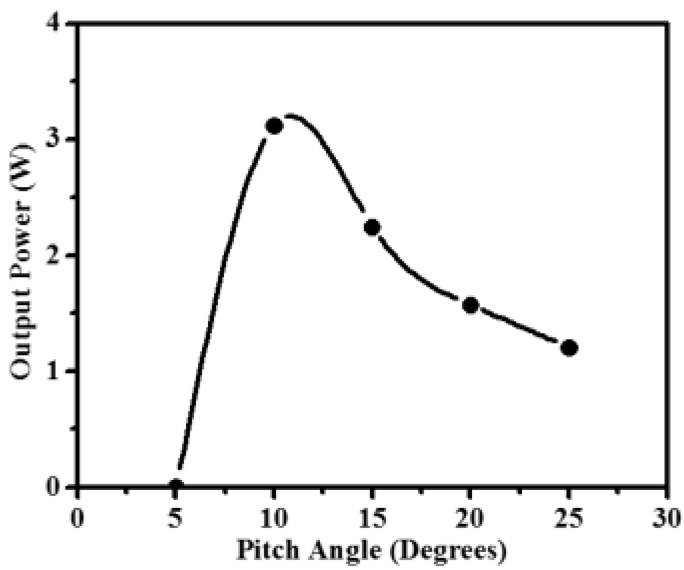

Figure (9). The relation between the output power and pitch angle.

Figure (10) shows the relation between the rotational speed and wind velocity [12]. We saw that the cut-in speed for these criteria (blade) about 175 rpm and 2 m/s respectively. In this speed, the turbine stars to generate reaching the peak (rated power) when rotation reaches approximately 265 rpm and wind velocity about 8 m/s for this kind of blades and with a certain pitch angle of 100 [12]. There is no magnetic or mechanical brake to turn off the turbine at high rotational speeds, so that a decrease in produced power can be seen in this figure.

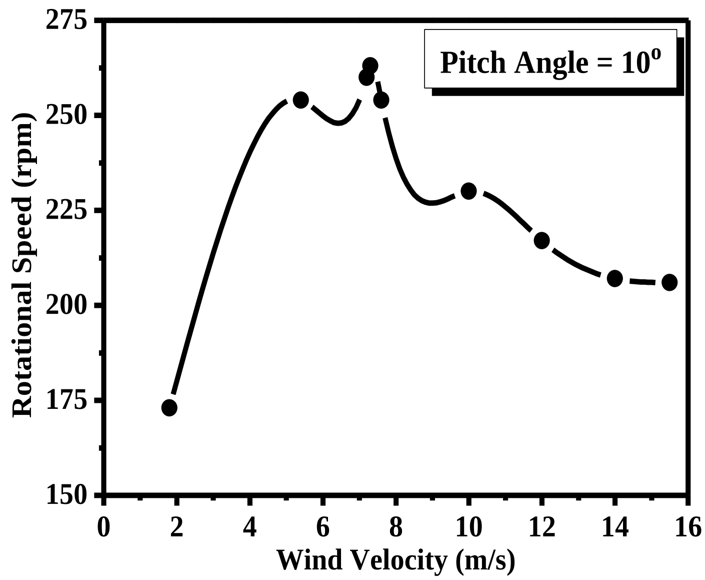

Figure (10). Relationship between wind velocity and RPM at pitch angle 10°.

4. Conclusions

From the above results, one can deduce that with a fixed wind velocity, there is an optimum pitch angle that gives us the highest wind generated power for a certain type of blade (in our case it was 10°) with wind velocity reaching 11.5 m/s with pitch angle related to wind velocity. Other angles higher than the optimum angle will produce lower power and as long as we go far from the optimum angle, the power produced starts to lower and eventually the turbine will stop. For optimum operation in field turbines, an automated pitch adjustment according to wind speed is necessary to optimize the turbine output power. In addition, any increase in angle values above the optimum pitch angle will increase the momentum produced and the new values could be useful for momentum applications, which depends on lower rotation [12].

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