EXPERIMENTAL STUDY OF STABILITY LIMITS OF WIND TURBINE BLADES SUBJECTED TO SITE SPECIFICATION CONDITIONS

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Abstract

In our planet earth, there is lot of natural energy source which makes it very comfortable for human life to live and survive. Among these energy sources is the wind energy. This free energy source comes with challenging characteristics i.e. it's very unpredictable because the strength of wind and its direction is dynamic. To produce useful amounts of power, wind turbines generally need to be large and tall, this makes the wind turbine blades longer and slender too, which is a great source of instability. Therefore, the need to experimentally determine the stability limit of wind turbine blades for different operating condition and the study location is important. In this study, three different materials (Al-alloy, wood and PVC) were used to fabricate the blades and was installed on the hub of mini HAWT at three different angles (5°, 10°, 15°) and wind speeds (2, 4, 6)m/s to analysed the stability limit of the blades. The experiment was on a static motion, where the deflection of the blades were analysed, simulated on Solidworks and recorded. In all cases tested, the data collected indicated that the PVC blade produced highest deflection of 11.41mm which is equivalent to 3.8% of the blade length. The blade is stable because this is less than 5% of the blade length. The Al-alloy and wood blade produced 1.6% each which makes them more stable. Al-alloy produce the lowest deflection of 0.0006293mm with low wind speed of 2m/s at an angle of 5°**.** The good agreement between the deflections computed by the Solidworks package and the experimental data has been used in the validation process where it indicates that the research can be used to estimate the stability limit of a wind turbine blade.

Keywords: Wind turbine; Blade; Stability; Deflection; Energy.

1.0 INTRODUCTION

In our planet earth, there is lot of natural energy source which makes it very comfortable for human life to live and survive. Among these energy sources is the wind energy. The wind energy is the fastest growing booming energy source in the world. In order to use the greater extent of the wind energy source, the engineers around the world are working with maximum efforts to rectify the challenges faced while trying to use the valuable renewable energy source of the world. Since early recorded history, people have harnessed the energy of the wind. Wind energy propelled boats along the Nile River as early as 5000 B.C. By 200B.C, simple windmills in china were pumping water, while vertical- axis windmill with woven reed sail were grinding grain in Persia and the Middle East (Lowa Energy Center, 2016). In recent years, wind energy has drawn more attention due to the increasing prices of fossil fuels and improving economic competitiveness of wind turbines relative to conventional generation technologies. Today, wind energy has been developed into a mature, competitive, and virtually pollution-free technology. Usually a typical large, utility scale wind turbine can produce 1.5 to 4.0 million kWh annually and operates 70-85% of the time (Balat, 2009). Global wind energy production set a new record in 2011, reaching 239 GW, 3% of total electricity production (WWEA, 2012). It is predicted that by 2020 it will increase to 10% of global electricity production (Compositesworld, 2012). The wind turbine structures are designed to covert the wind energy into electricity or other forms of energy. A windmill for generating electricity is characterized by the blade which is attached to the hub, via a shaft and gearbox, the generator and the tower structure. The blades convert the wind energy into rotary mechanical movement, the wind is slow and therefore a gearbox is used to increase the rotary motion of the shaft to that of the generator. The components of windmill structure (see figure 1).

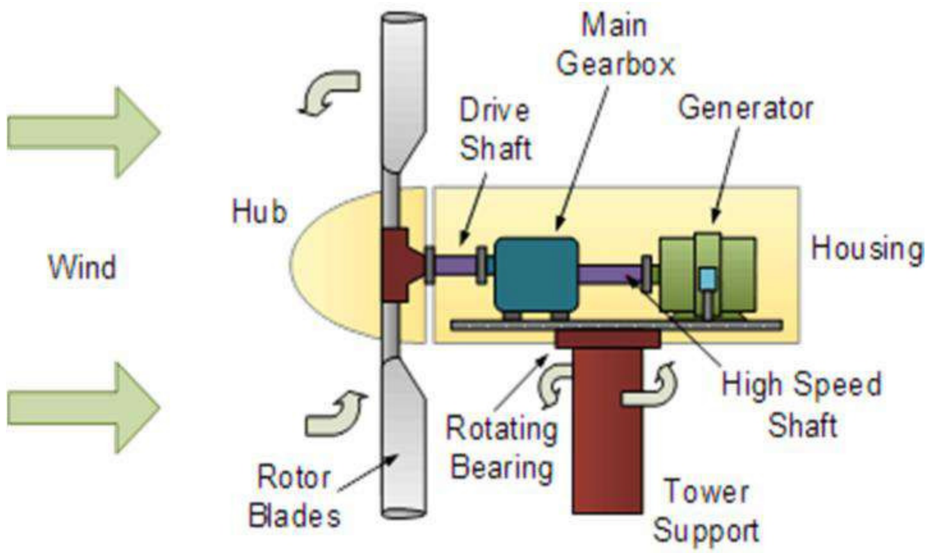

Figure 1: Components of the Windmill.

For efficient harvest of wind energy resources, the blades are required to be long and slender but also fixed at one-end. Thus functional requirement for a wind turbine blades create room for vibration of the blade structure. One of the efforts of vibration on engineering structures such as wind turbine blades is instability, which will lead to decrease in blade performance and eventual failure of the blade. (Ali & Velraj, 2013). For a wind turbine the wind impact a fatigue load on wind turbine structure such as the blade, therefore the blade must be design to sustain the continuous vibration forces and therefore work within an imputable stability limit. Three factor that affects wind turbine losses, i.e. the gear box which account for about 1% loss, the generator which account for 10% loss and the wind turbine blades which account for the rest losses. This huge loss in wind turbine performance is due to the blades performance itself, i.e. is structural geometry. The expected lifetime for a blade is usually 20 years for large wind turbines, and less than 20 years for small wind turbines (Clausen, 2000). In the wind turbine industry, many materials have been used for blades, including metals, plastics, wood and composites (Mandell, 2003).Many researchers have studies the wind turbine blade performance base on its stability and vibration, (Cacciola, 2012) and (Hernandez, 2008).

2.0 MATERIALS AND METHOD

2.1 Materials

The experimental design, experimentation and method of data analysis adopted in this research. First, a blade shape was chosen and produced from three different materials and installed on a mini HAWT for experimentation. Then, the stability analysis was performed on the experimental data obtained. Also, a 3D model of the blades of different materials at three different angles was produced and a solidworks simulation was performed on them. The equipment used for the experiment is fan, wind Anemometer and measuring device.
The materials, components and their specification used in this research are listed in table1

Table 1: Materials

S/ No	Components	Material	Specification
1	Blades`	PVC, AL-alloy, wood	(300 × 30)mm
2	Hub	Aluminum	(30mm)diameter/40mm
3	Turbine tower and base	PVC	250mmx4, 600mm

2.2 Study Location

The wind turbine performance is dependent on the turbine site characteristics such as high average wind speed, sufficient separation from noise-sensitive neighbor, good site access and landscape designation. The site for this experimentation is school of infrastructure, process engineering and technology,(sipet) federal university of technology, Minna. And the site characteristics are presented in table 2.

Table 2: show the site characteristic

S/No	Characteristics	Values	Remarks
1.	Average wind speed	4.3 m/s	Good
2	Noise separation	≥ 200m	Poor
3.	Good site access	≥ 20m	Very Good
4.	Landscape designation	Nill	Moderate

2.3 Blade Design

The following steps were adopted for the design:

1. The power output, P=cpɳ(1/2)$\rho\pi R2V3$ (Ajay, 2018)
2. Choose the suitable tip speed ratio. Normally 4<λ<10 can be used for power generation
3. Determine the number of blades, B such that the structural dynamic problems should reduce. The table 3 shows the required number of blades of the rotor with appropriate tip speed ratio.

Table 3 λ and number of blade (Ajay, 2018)

B	(^j: λ
8-24	1
6-12	2
3-6	3
3-4	4
1-3	>4

2.3.1 Determination of The Swept Area

The blade swept area determine the blade radius and it is directly related with the wind turbine power generated and the density of air and the mean wind speed as shown in equation 1.

$$P = \frac{1}{2}\rho A v^3 \quad \text{(Boateng, 2014)} \qquad (1)$$

But, the swept area is given as follows;

$$A = \pi R^2, \qquad (2)$$

Therefore, the power becomes;

$$P = \frac{1}{2}\rho\pi R^2 v^3 \qquad (3)$$

Where; A = swept area
v= mean wind speed
P= power coefficient
ρ = density of air (1.23 kg/m^3)

2.3.2 Determination of The Tip Speed Ratio

The design tip speed proportion is characterized as the connection between rotor cutting edge speed and the wind speed,

$$\lambda = \frac{\omega R}{v} \qquad (4)$$

Where;λ = design tip speed ratio
r = radius at each stations of the blade
w = wind velocity $= \frac{v}{R}$ (rad/s)

3. Experimental Design

The objectives of this experimental design are to determine the stability limit of wind turbine blade material and at what blade angle does this limit is just enough. The factors under consideration are blade materials, wind speed, blade angle and the response is the amplitude of deflections of the blade. (See table 4).

Table 4: List of experimentation and their levels

Levels	Factor 1 (Materials)	Factor 2 (angle)	Factor 3 (speed)
1	Wood (M1)	5° (A1)	2m/s (S1)
2	Plastics (M2)	10°(A2)	4m/s (S2)
3	Al-alloy (M3)	15° (A3)	6m/s (S3)

Figure 2: pictorial view of the mini-HAWT

3.0 Experimental Procedure

The experimental station was set up as shown in figure 2 to provide an easily reproducible method of testing how the stability limit of wind turbine blade referring with the materials and the angle of inclination of the blades. The base of the turbine was secured to the table using tape; and the fan was positioned directly in front of the turbine, making sure that the turbine blades were fully immersed in air flow from the fan. In order to vary the wind speed, the fan was moved away from the turbine from 1m to 3m, using 1m as increment. The wind speed produced under the low, medium and high settings were measured at each position respectively, using digital wind anemometer and the amplitude of vibration (deflection) was measured with the aid of a vibration sensor and control unit. The front face of the fan and the turbine were set upward in the vertical plane. Thus air blown by the fan moved in the horizontal direction and when strong enough it caused the turbine blades to spin about the horizontal axis of the turbine. The angle of inclination of the blade was successively set to 5°, 10°, and 15°. At each angle tests were run using each of the three materials of the blades, as shown in figure 3.

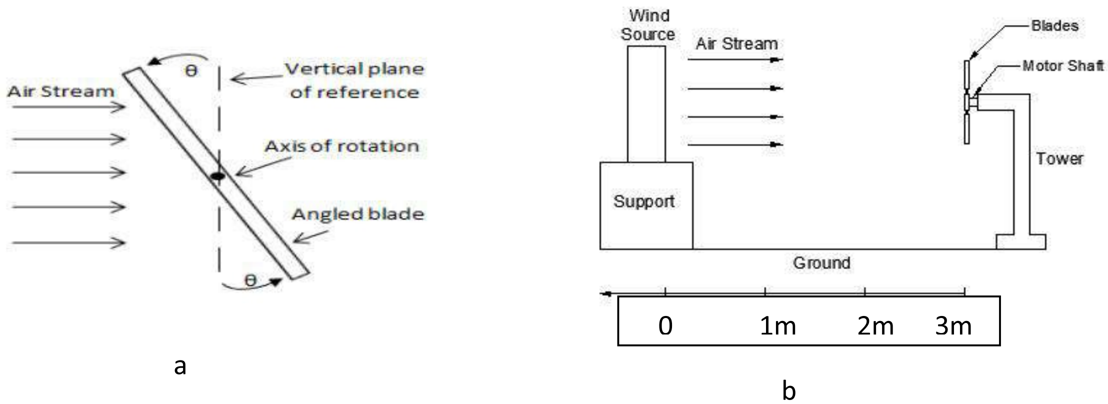

Figure 3.Experimental setup.

4.0 Results and Discussions

4.1 Experimental results

Table 5: Design results of the experiment.

S/No	DESIGN PARAMETER	VALUE
1	Power output(W)	10watt
2	Design tip speed ratio	1
3	Number of blade	3
4	Blade swept area	271 ≈ 300mm
5	Blade length	300mm

In all cases tested, the data collected indicated that the maximum deflections of turbine with PVC blade produced highest deflection of 11.41mm at average wind speed of 4m/s with an angle of 10˚, its shows that a maximum deflection 11.41mm, which is equivalent to 3.8% of the blade length. The blade is stable because this is less than 5% of the blade length. The Al-alloy blade and wood blade produced 1.6% each which makes them more stable. The Al-alloy blade also produced the minimum deflection of 0.0006293mm with low wind speed of 2m/s at angle of 5˚. The wood blade and Al-alloy blade produced the same deflections 0.01879mm at high wind speed of 6m/s with the same angle of inclination 15˚. However, as the angles increased, the deflection produced by the Al-alloy blade increased. The wood is similarly to that of Al-alloy but the PVC deflections increases at 10˚, and decreases at 15˚.

4.2 Solidworks simulation result

The wind turbine blades were subjected to a static analysis with the experimental wind speed and angles. The results shows that the fixed end of the blades were subjected to different stresses, while the yield strength of the plastic used is 54MN/mm^2 wood 120MN/mm^2 and Al-alloy 324MN/mm^2. Figure 4 is displacement results of the PVC blade with a maximum deflection of 7.702e-002mm. Figure 5 and 6 are the displacement results of Al-alloy and wood blade at equal wind speed and angle(15˚), shows that the same maximum deflections of 2.506e-003mm were obtained. The Al-alloy and wood look more stable than the PVC.

The general shape of the plot of the deflection versus the angle of inclination is shown in Figure 7. A hypothetical line has been added to the plot, in order to represent the general form of the curve that would have been expected, the Al-alloy exhibits a linear relationship because is Isotropic in nature. While the wood and PVC exhibited a non-linear relationship because they are Anisotropic in nature.

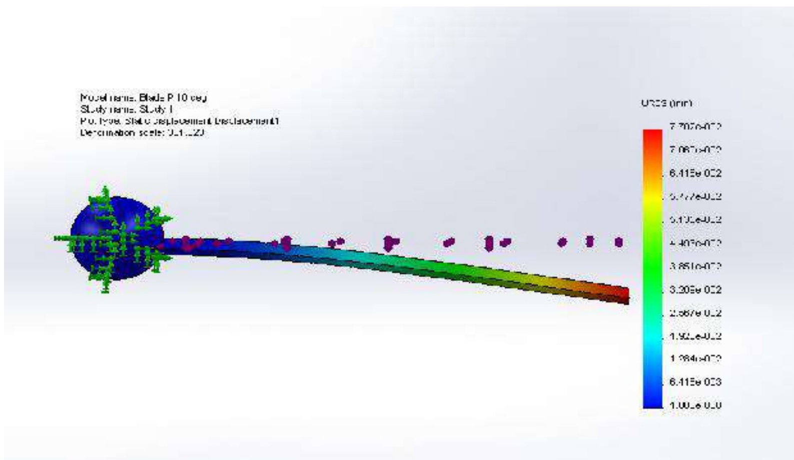

Figure 4: Static displacement of PVC blade at 10°

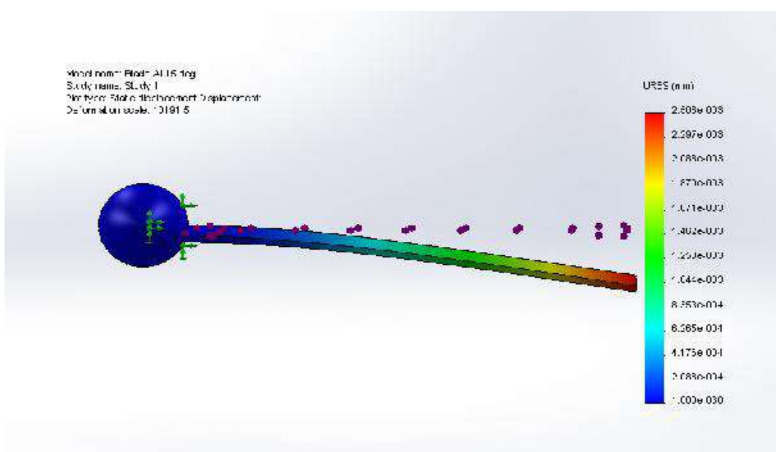

Figure 5: Static displacement of Al-alloy blade at 15°

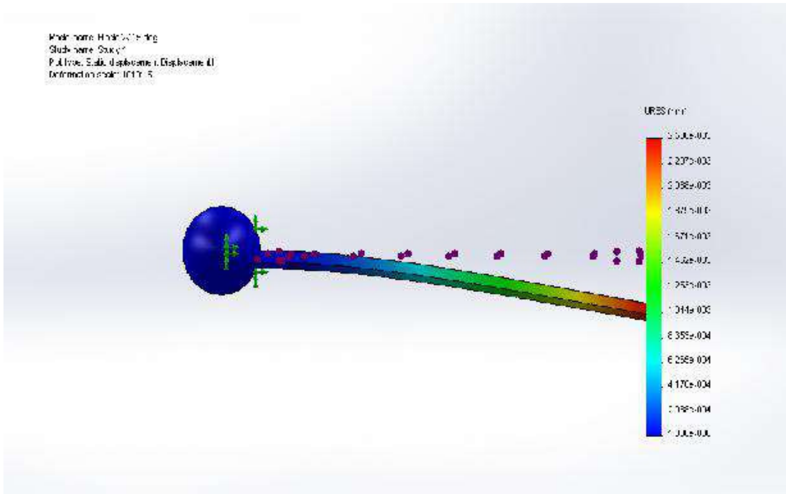

Figure 6 Static displacement of wood blade at 15°

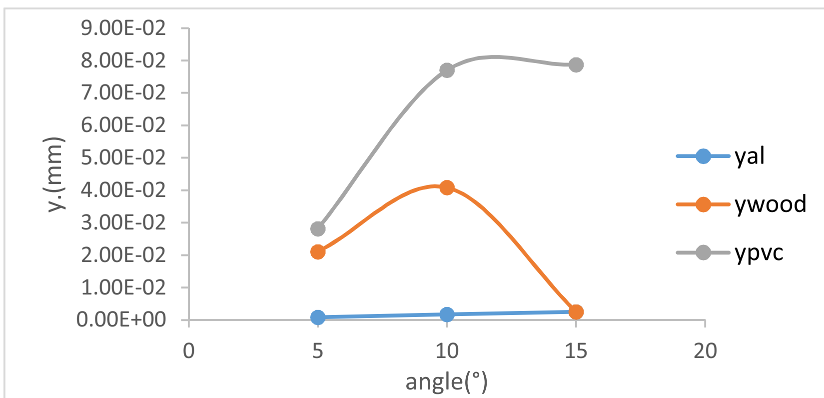

Figure 7 Graphical presentation of deflection of Al-alloy, wood and PVC blade.

5.0 Conclusion

The following conclusion can be drawn from the result obtained;

1. Fabricated blades from Al-alloy, wood and PVC were installed in a mini wind turbine hub at respective angles and were successfully tested based on experimental procedure and equipment. The testing demonstrated show that deflection produced by each blade material varied with the speed of the wind and the angle of inclination of the turbine blades. However, as the angles increased, the deflection produced by the Al-alloy blade and wood blade increased. While the PVC deflections increases at 10˚, and decreases at 15˚.
2. The stability limit of the turbine blades is estimated from experimental performed in deterministic conditions at discrete steps in wind speeds and angles. The stability limit is easily identified by percentages of the maximum deflections of the blades.
3. These findings support and confirm similar results that were obtained from simulation on solidworks .The Solidworks simulations computed shows the same as the deflections of

Al-alloy and wood increases as the wind speed and angle increases, while the PVC produced the maximum deflection at 10˚. This review has also shown that Al-alloy and wood maintain the same maximum deflections of 2.506e-003mm at an angle of 15˚, although in the experiment test the frequency was underestimated.

4. Detailed flow fields and frequency mode were also investigated using the Solidworks simulations. The good agreement between the deflections computed by the Solidworks package and the experimental data has been used in the validation process where it indicates that the research can be used to estimate the stability limit of a wind turbine blade.

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