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The Effect of Improved Gear System And Blades Number on The Performance Coefficient of Savonius Vertical Axis Wind Turbine

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Abstract

The gear system and turbine design features play a significant role in the overall performance of a wind turbine. In this work, the effect of the improved gear system on the power output by the rotor blades in performance coefficient of vertical axis wind turbine VAWT is explored. Operation of VAWT at higher blade speed ratios offers numerous important advantages over low blade speed ratio but suffer from thrust drag that degrades their performance. The four blades Savonius VAWT were designed, constructed, and investigated in order to determine the power output. The calculated theoretical power was found to be 350.00watt at wind speed of 7.66m/s; and, an extracted power from the wind was experimentally noted as 270.00watt at the speed of 7.64m/s. The performance coefficient of the two power outputs at almost same speed was 0.69 at an altitude of 523m above sea-level.

Keywords: Renewable energy, wind power, vertical axis wind turbine, rotor shaft, plastic gear.

1.0 Introduction

The rising greenhouse gas emission from fossil fuel energy resources and the uncertainty of global energy supplies have necessitated the exploration of alternative renewable energy sources for power generation. Most developed countries and emerging economies have adopted a renewable energy target in their energy mix. Power extraction from wind has achieved significant improvement over the decade, making it more economically competitive over other renewable energy sources for power generation.

Wind is a natural phenomenon related to the movement of air masses caused primarily by the differential solar heating of the earth's surface [1]. Wind is a classical example of a stochastic variable; due to this stochastic nature. Wind energy cannot be controlled, but can be managed. This is because wind power is available only when the wind speed is above a certain threshold [2]. Wind energy is simply the energy derived from wind power in the form of electricity. Wind power generation requires good turbine generators that convert the wind energy into electricity.

Wind power is abundant, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation and uses little precious land [3, 4]. Any effects on the environment are generally less problematic than those from other energy sources. As of 2010, wind energy production was over 2.5% of worldwide power generation, growing at more than 25% per annum largely due to technological advances and better understanding of wind characteristics, such that the overall generation cost per unit of energy has come down to the cost of power generated by using high grade coals and/or natural gas [2, 5, 6, 7].

Nigeria is endowed with abundant human and natural resources with solar and wind exploration potentials [8]. However, over dependence on conventional energy sources has led to near total collapse of the industrial sector due to insufficient energy supply. There is also very low accessibilityofrenewable energy services in the domestics, commercial and the industrial sector, despite the enormous potential [9, 10]. The lack of access to energy services has not only led to the collapse of many industries, but had also ledto poor participation of the private sector in theproductive sector of the Nigerian economy [1].

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Energy is one of the desirable tools that governs our lives and promotes civilization. The social and economic health of the modern world depends on sustainable supply of energy. However, intensive and uncontrollable developments of human civilization and industrialization have had great negative impact on the environment as well as on energy resources[11].The Renewable energy resources, if properly harnessed have the potential of meeting global energy demand and can turn the economy ofnations including Nigeria to battle socioeconomic and technological problems.

1.1 Wind Energy Technologies

Current advances in wind power generation technologies still leaves room for improvement with a view to raise the efficiency in order to make wind energy a competitive energy source in our desire to promote sustainable energy development.The main advantages of electricity generation from renewable energy sources, such as wind, are the absence of harmful emissions, very clean and almost infinite availability of wind that is converted into electricity [12]. Wind generation has been described to be one of the mature and cost effective resources among different renewable energy technologies [13].
Two common designs of wind turbines are the vertical axis wind turbine (VAWT) and the horizontal axis wind turbine (HAWT). Although the VAWT was the first ever wind turbine to be used for harnessing wind energy, researchers of the modern era lost interest in it due to the initial perception that VAWT cannot be used for large scale electricity generation. But, a closer look on the conceptsleads towards the fact that VAWTs are suitable for electricity generation in the conditions where traditional HAWTs are unable to give reasonable efficiencies such as high wind velocities and turbulent wind flows. Another major advantage is that VAWTs areomni-directional, accepting wind from any direction without any yawing mechanism [14]. Most of the reported wind turbine designs employ two or three rotor blades.The turbine assembly is divided into two tiers with two or three blades in each tier. The two-tiers are shifted by an angle of 90◦. Wind turbines with four rotor blades are now being investigated due to their flexibility and potential for improved efficiency. The new configuration has same mechanism of torque generation as like other Darrieus rotors that has greater advantage than two and three blades respectively [15].
The aim of this work was to design,construct, and evaluate the performance coefficient of four blades Savoniusvertical axis wind turbine (VAWT)using plastic gear to improve rotor blades speed.

2.0 Theoretical Background

The theoretical energy possessed by the wind flowing at a certain velocity can be expressed mathematically as;

$$Power = Pt = \frac{1}{2}\rho S v^3 \qquad (1)$$

The performance of the Savonius wind turbine is determined by the coefficient of performance (C_p). It is theoretically defined as the ratio of the aerodynamic power generated by the wind turbine to the power possessed by the wind incoming on the surface of the rotor.

$$C_p = \frac{P}{W} \qquad (2)$$

2.1 Design of the Blades

The aerodynamicefficiencyincreaseswiththe number and the nature of the blades. The blades thickness is obtained from Eqn. (3) where

$$B = \frac{N.\sigma}{D} \qquad (3)$$

Where$B$ = the blade's thickness, N = number of blades (4),D = rotor diameter (7cm),
σ= is proportionality constant whose value is $0.28m^2$ for maximum value of $C_{p.}$
Using Euler's theorem, the force exerted by the wind in the rotor is given by Eqn.4 as

$$F = \rho S v\ (v_1 - v_2) \qquad (4)$$

whereρ =The density of air (1.26kgm^{-3}),S =The cross section of the rotor blade,
v =The average velocity of the wind andv_1 =Velocity of the upstream wind flow
v_2 = Velocity of the downstream wind flow
The cross section area, S, of the rotor blade is given by

$$S = \pi r h \qquad (5)$$

Where$r$ = radius of the rotor blade (9.5cm), h = the height of the blade and
S =the area of the blade
Therefore,

$$F = 1.26 \times S \times v \times\ (v_1 - v_2)$$

The torque induced in the blade is given in [15] as

$$\tau = \frac{2\kappa\rho U}{B} \qquad (6)$$

Whereτ = the stress induced (torque) in the rotor blades, κ = the kinematics viscosity (2.5 x 10^4), ρ = the density of air (1.26kgm^{-3}),B = the thickness of the blade,
U = the velocity on boundary layer.
Power extract by the blade is given in [10] as

$$P = \frac{1}{4}\rho S v^3 (1 - b^2)(1 + b) \tag{7}$$

WhereS = cross sectional area,v= the free stream speed,ρ = the density of the air, and
b = interference factor.
The kinetic power content of the undisturbed upstream wind is also expressed in [12] as

$$W = \frac{1}{2}\rho S v^3 \tag{8}$$

The rotor Tip Speed Ratio (TSR) depends on the blade airfoil profile used, the number of blades, and the type of wind turbine.
The TSR is a dimensionless factor and is defined by Eqn. 9 as

$$TSR = \frac{Speed\ of\ rotor\ tip}{Wind\ speed} = \frac{\omega r}{v} \tag{9}$$

Whereω = angular frequency, r = radius of the rotor, and v = the wind velocity.

3.0 Methodology

The simple model construction of the blades placed at an angle of $90^0$to each other which allow the torque τ to force the airfoil from the top view of the air to spin the rotor is shown in Fig. 1.

(a) (b)

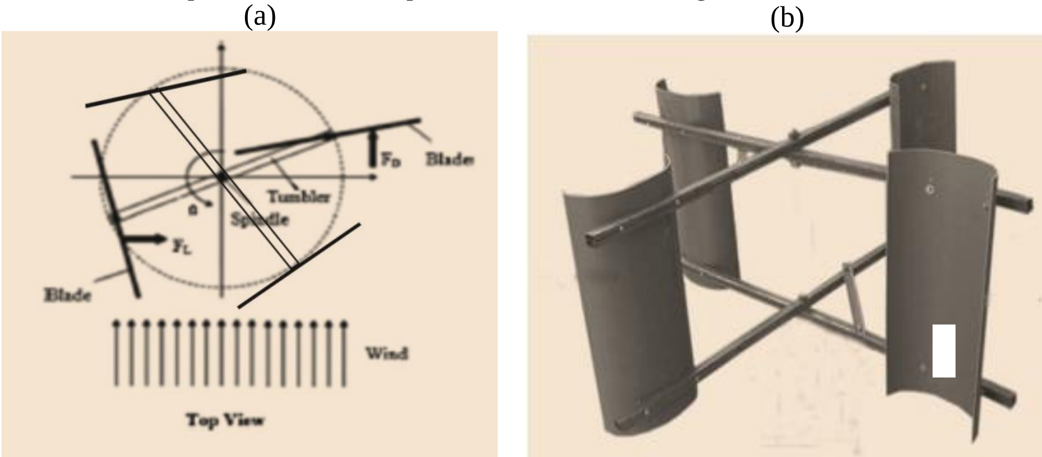

Fig 1: The blade (a) prototype and (b) construction 40cm long with the diameter of 19cm of the chord

The Figure 2, below shows the constructed rotor blades, the shaft of the rotor in the magnetic field region and plastic gear used to move the rotor faster.

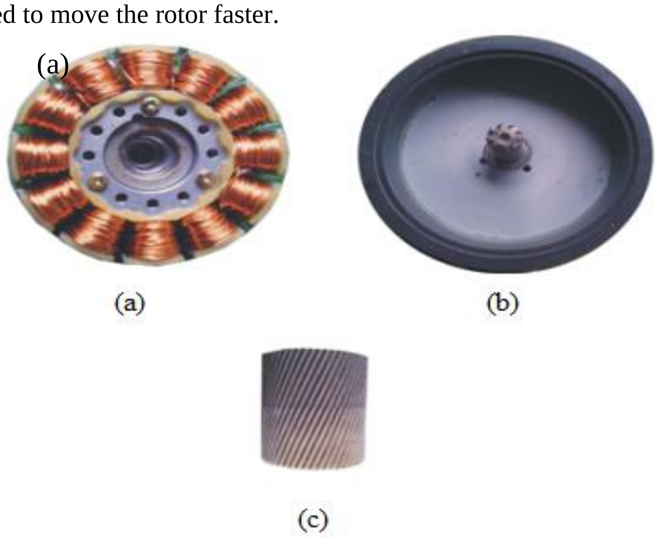

Fig. 2: (a) the constructed rotor blade prototype, (b) the rotor shaft in the magnetic field, and (c) the plastic gear used in the rotor shaft.

The blades thickness B, cross section S, and tip speed ratio TSR were determined using equations (3), (5), and (9) respectively.
Furthermore, after assembling the above materials in order to make the generator workable the complete construction of the rotor is shown in Fig. 3.

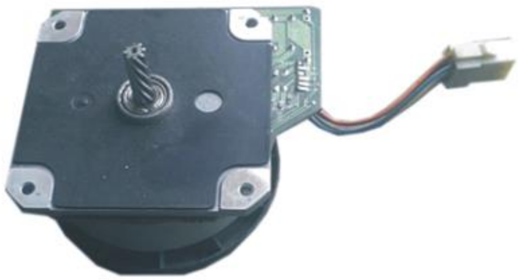

Fig. 3: The completed rotor

3.1 Measurements and Instrumentation

The complete constructedSavonius four blades vertical axis wind turbine was placed at an altitude of 523m above the sea level. The mechanical power of the turbine was determined by measuring thewind speed at the upstream and the downstream of the blades usingpropeller type digital anemometer. The wind temperature around the blades was measured using digital thermometer daily for two month.
Finally, in order to test the performance of the vertical axis wind turbine (VAWT), the blades and constructed rotor were assembled together to complete the constructed turbine. The turbine is shown in Fig. 4.

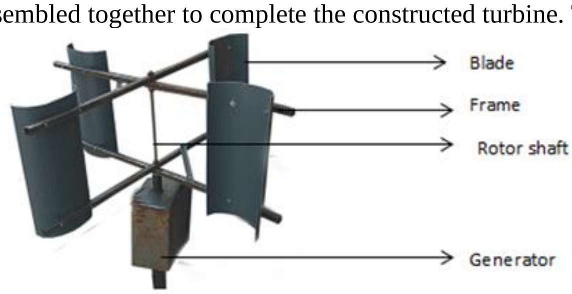

Fig. 4: Complete construction of the VAWT

4.0 Results and Discussion

The four blades performance coefficient was categorized into two groups based on the experimental results. The different performance coefficients (C_p) were obtained by adjustingthe wind turbine's rotational speed of the improved gear system. The power coefficients were based on power extracted by the wind and the calculated power by using theoretical methods.
Figure 5. below determined the numerical power and the extracted wind power when the turbine was placed at an altitude of 523m above sea level.

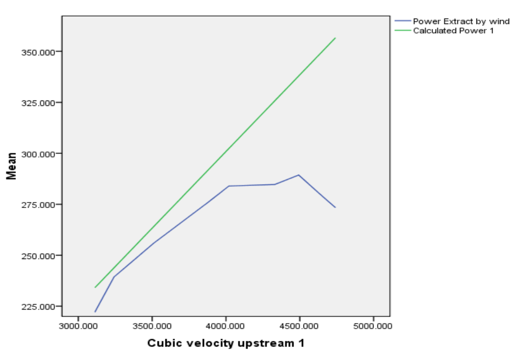

Fig. 5: The variation of calculated power and power extract by the wind with cubic wind speed upstream 1 of four blades VAWT

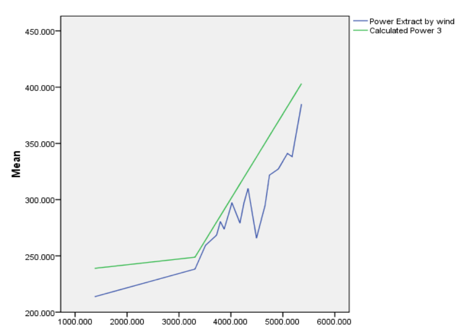

Fig. 6 The variation of calculated power and power extract by the wind with cubic wind speed upstream 1 of four blades VAWT

The numerical value of the calculated power was found to be 350.00 watts at a speed of 7.66m/s. Conversely, the maximum power extracted by wind was 270.00 watts at a speed of 7.64m/s. Although the output is inferior compared with theoretical power calculated, it is clearly shows the trend that the improved gear system and the number of blades has notable impact as they increase the performance at a very low speed. This is attributedto a reduce resistance that affect the blade's rotation. The wind speed range was almost the same for both the calculated power and the power extracted by the wind using the designed gear system with a coefficient of about 0.69 meaning that about 69% of the power was extracted.

At wind speed of 8.43 m/s, the power generated by the turbine blades was 430.00 watts.This resulted in a dropof the performance coefficient. This perhaps can be attributed to turbulence as the wind speed increased. When the weather was normalized, usually at room temperature (20℃), the power reached the apex stage of about 490.00 watts at wind speed of 8.31m/s, an increase of performance coefficient was significantly observed of about 75% as in figure 6. Noticeably, for an improved speed ratio by the use of gear system the power decreaseswith the position by which the turbine was installed.

At an altitude of 512m above the sea level and wind speed of about 6.95 m/s, the maximum power obtained was 240.00 watts as shown in Figure 6.

While the position of the turbine was unchanged the extracted power was varied in the upstream to be 390.00 watts at the wind speeds of 8.09m/s as shown in Fig. 6.

In practical application, the height is one of the major design parameters to improve the speed of the rotor blade in order to harness more energy [16]. Comparing the result of the model with the configurations of the bare rotor without the shroud (cowl) and with bare rotor shrouded with a cowl, the maximum power was attained at maximum speed of about 27.7 m/s to rotate the rotor blade [17]. Then, from the results obtained using the plastic gear of the model, the maximum speed was about 20.1 m/s for the four blade rotor as compared to that of three blades of 19.2 m/s. Thus, from the forgoing, it was evident that the use of improved gearing gives more efficient and accurate result compared to cowling to increase the blade rotor speed [18].

5.0 Conclusion

The result suggested the performance coefficient of the VAWT with the improved gear system has significantly increased and operate at low wind speed flow and responds to environmental dynamic change. Initially, the gear system and the four blades VAWT increase the maximum thrust coefficient which would result in more energy extracted from the flow and increased power generated by the turbine.

This study make possible to use the gear system by wind turbine designers to prepare and produce turbines with overall higher efficiency. However, it is important to note that the performance depends on parameters such as height, altitude, wind speed and geographical features surrounding the location. In the future, this research will be further explored by enhancing the number of teeth of the gear in effective mechanical operation and observing the flow structures in an open environment.

6.0 References

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