FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 6 No. 6, December, 2022, pp 76 - 88
DOI: https://doi.org/10.33003/fjs-2022-0606-1143

CONSTRUCTION AND PERFORMANCE EVALUATION OF TWO STAGED THREE BLADED SAVONIUS VERTICAL AXIS WIND ENERGY CONVERSION SYSTEM

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ABSTRACT

This study is intended to increase the rotor performance of the Savonius wind rotor, by increasing the numbers of blades of the already existing two blades Savonius vertical axis wind turbines (VAWTs) to three which was designed to increase the Savonius wind rotor performance. Two stage three bladed wind turbine system has been designed and constructed. The system was made up of six split drums which were welded together to form a concave shape to capture wind from all directions, with a shaft to pass through the midst of the welded drums which was then mounted on a tower of about 15 m high, which in turn will cause the rotor to rotate. This was then connected to a 12 V Generator. The wind turbine converts the kinetic energy available in the wind to produce electricity, using the Generator with output power of 60 W. The results obtained showed that the system was able to accept wind from any direction and commenced rotation as soon as the wind speed of 3.3 m/s (cut in) was available at the site. The minimum and maximum power outputs of 5.14 W and 13.34 W, corresponding to wind speeds of 7.2 m/s and 9.4.5 m/s were recorded respectively. Similarly, for a rotation per minute of 811 rpm a voltage of 7.14 V was generated. Hence for a two stages three blades Savonius the performance was 12.2 %, as against a single stage two blades Savonius whose performance was 7%, a deviation of 5.2 %.

Keywords: Horizontal axis wind turbine, kinetic energy, Savonius wind Rotor, Torque, wind power

INTRODUCTION

The lower aerodynamic performance of Savonius vertical axis wind turbines (VAWTs) makes it not much preferred and used as compared to other high-speed wind rotors like the Horizontal Axis wind turbines (HAWTs). Wind energy has been the most potential alternative source for renewable energy. This is because it is pollution free and abundantly available in the earth's atmosphere. The attention giving to wind energy has been growing and many investigators/researchers have introduced and developed cost effective and reliable wind energy conversion systems (Leschinger, 2010). In practice, however there are many challenges introducing wind turbines into the community because of less wind energy sources and noise pollution. Noise can be generated from the moving parts of the machine if not well lubricated. There are two types of wind machines, namely, horizontal axis machines and vertical axis wind machines. The later machine is useful in a site where the wind direction is constantly changing. Since the shaft is vertical, the gear box and the generator were placed near the ground so that the tower does not need to support it and hence, more accessible for maintenance (Gupta and Gordon, 2006). They are difficult to mount on towers and hence, they were installed near the base, like a building rooftop (MacRae, 2007). Since they are located closer to the ground than horizontal wind machines, the arrangement can take advantage of the natural constructions and surrounding buildings to tunnel the air and increase the wind velocity.

The 3-bladed savonius wind turbine is more stable mechanically than the 2-blades. This is because the two blades are in line, it becomes almost difficult to accept wind from all directions (Neij, 2008). As the turbine is rotated due to changes in the wind direction, this will cause an unbalanced twisting force on the tower. Vibrations usually occur whenever an unwanted twisting feed back into the blades (Rajkumar, 2004). Whenever the speed of the twisting matches the natural vibration frequency of the blades, there could be catastrophic mechanical failure. As a result of this, 2-blade turbines usually have to be rotated slower than those with more blades (Rajkumar, 2004).

However, in order to improve on the already existing two Blade Savonius wind turbine, the present study is focused on the fabrication of three blade Savonius wind turbine to generate power. It is also reasonable to know that adding more than two blades on a wind turbine rotor will enhance extraction of more power. Rotor efficiency increases if three blades are used, rather than two (Rachman, 2013).It also has the capacity to function in a wide range of wind conditions (turbulence level, wind speed), the electrical equipment can be placed at ground level. It has Low noise emission, high starting torque, Simple and cheap to construct.

The features as stated above makes the Savonius three blade wind turbines suitable for the needs of residential use. However, Savonius turbines are not free from drawbacks such as relatively low efficiency and rotational velocity. Therefore, nowadays much effort is directed towards constantly seeking better designs that assure rotor performance improvement. Some of them also use computational fluid dynamics (CFD) methods for this purpose. The purpose of the study is to (i) fabricate a two staged savonius vertical axis wind turbine system with each of the stage made up of three blades (ii) investigate the performance when the wind turbine was mounted on two stages so as to allow the blades to accept wind from any direction.

Theory of Wind Energy Conversion

The fundamental to analyzing the aerodynamics of a rotor and to obtain information about its power generation, it is paramount to start by considering that a wind turbine works by converting the kinetic energy of a wind flow into electricity, following several steps:

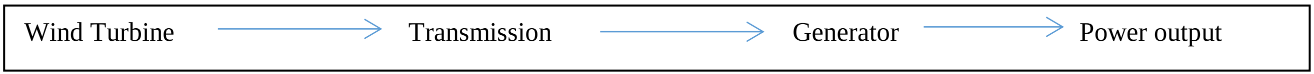

Figure 1: Kinetic theory of wind turbine

Figure 1 shows how kinetic energy of the wind is converted to Electrical energy from the wind flow the turbine gets the energy to rotate the blades. The energy produced by this rotations is given to the main shaft (or to a gearbox) and from there to the electrical generator, that provide the electricity to the grid.

Betz Law

The maximum power that can be harnessed from a wind turbine in an open flow was calculated using the Betz law. The kinetic energy of moving air is known as wind energy. The power of the wind is usually expanded as:

$$P = \frac{mgx}{t} = \frac{dE}{dt} = F\frac{dx}{dt} = Fv \qquad (1)$$

In equation (1), m is the mass of moving air and v is the velocity, and the rate of work done (power) of the wind, $\frac{dE}{dt}$ is the rate of wind energy and F is the force.

By substituting the force F estimated above into the power equation, this will give the power extracted from the wind:

$$P = \rho \times S \times V({v^2}_1 - {v^2}_2) \qquad (2)$$

where ρ is the density of the wind in (kg/m^3), the wind distance, S is measured in (m), V is the wind volume in (m^3) while $v_1 - v_2$ is the difference in the wind speed in (m/s)

The method of kinetic energy can be used to estimate the power. Applying the conservation of energy equation to the control volume yields

From the continuity equation, a substitution for the mass flow rate yields the following

$$P = \frac{1}{2}\rho\, S\, V({v^2}_1 - {v^2}_2) \qquad (3)$$

The expressions for power are absolutely valid; one was derived by examining the incremental work done and the other by the conservation of energy. By equating the two expressions we have

$$P = \frac{1}{2}\rho\ S\, V({v^2}_1 - {v^2}_2) = \rho\, S\, V^2\ (v_1 - v_2) \qquad (4)$$

By careful examination of the two equated expressions gives an interesting result in this form.

$$V = \frac{1}{2}\ (v_1 + v_2) \qquad (5)$$

Hence, the wind velocity at the rotor may be taken as the average of the upstream and downstream velocities. (This is arguably the most counter-intuitive stage of the derivation of Betz' law.)

Power in the Wind

The Kinetic power of the wind is described by:

$$P_{kin} = \frac{1}{2}mv^2 \qquad (6)$$

where;

P_{kin} = kinetics power [W];

m = mass flow =ρ × $A \times v$ [kg/s] (7)

v = speed [m/s];

The frequency distribution of the wind speed differs at different sites, but it fits quite well with the Weibull distribution. An example of how measured data fit the Weibull distribution is shown in the figure 2 (Pill and Yong, 2001). Other studies on Weibull distribution include the study carried out by Akpootu and Fagbemi (2022). In their study, they investigated the projecting ability of two-parameter Weibull distribution function for Accra, Ghana using monthly mean wind speed data for fifteen years. In another study, Akpootu et al. (2022) investigated the projecting ability of two-parameter Weibull distribution function for Warri and Port Harcourt located in the Coastal region of Nigeria using monthly wind speed data for thirty one years.

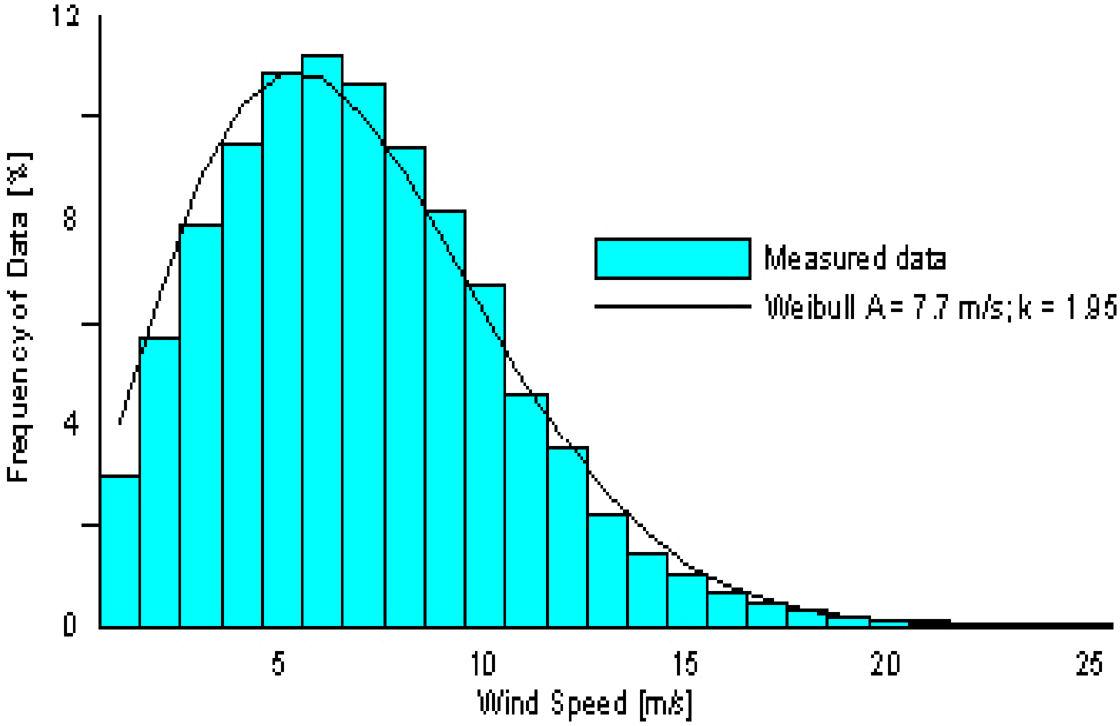

Figure 2: The Weibull distribution frequency for wind speed at various locations (Pill and Yong, 2001).

The wind turbine swept area is calculated in different ways, according to the geometry of the rotor.

For a VAWT, the swept area is described by:

$$A = d \times h \qquad (8)$$

where d = diameter of the rotor [m], h = length of the blades [m];

The formula of the power in the wind can be written also as:

$$P_{kin} = \frac{1}{2} \times \rho \times A \times v^3 \qquad (9)$$

It is well known that the density of air varies with the height above sea level and temperature. The value of 1.2 kg/m^3 is regarded as the standard value for the density of air at sea levels.

Power Coefficient

When a wind turbine is crossed by a flow of air, it can get the energy of the mass flow and convert it in rotating energy. Based on the Betz' law, this conversion has a limit. This law mathematically shows that there is a limit during this kind of energy conversion that cannot be passed. This limit has been explained using the power coefficient C_p and is given by:

$$C_p = \frac{P}{P_{kin}} \qquad (10)$$

$$C_p = \frac{P}{\frac{1}{2} \times \rho \times A \times V^3} \qquad (11)$$

where C_p = Power coefficient, P = Actual Electrical Power (W) and P_{kin} = Kinetic power of the wind (W)

The coefficient C_p represents the amount of energy that a specific turbine can absorb from the wind. Numerically the Betz' limit, for a VAWT, is 12/27 which is approximately equal to 45 %. It means that, when a wind turbine operates in the best condition, the wind speed after the rotor is 1/3 of the wind speed.

The value of the coefficient C_p is affected by the type of wind turbine and the value of the parameter λ, which is named tip speed ratio and is described by:

$$\lambda = \frac{\omega \times r}{v} \qquad (12)$$

where ω = rotational speed of the turbine [rpm], r = radius of the rotor [m] and v = undisturbed wind speed [m/s];

During each cycle, the oncoming fluid velocity varies. The maximum velocity is found for $\theta = 0^0$ and the minimum is found at $\theta = 180^0$, where θ is the Azimuthal or orbital blade position. The angle of attack, α, is the angle between the incoming air speed, v, and the blades chord. The resultant airflow generates a changing, positive angle of attack to the blade in the upstream zone of the machine.

For geometrical considerations, the resultant air speed flow and the angle of attack is

$$v = U\sqrt{1 + 2 \leftthreetimes \cos\theta + 0} \qquad (13)$$

$$\alpha = \tan^{-1}\left(\frac{\sin\theta}{\cos\theta + \leftthreetimes}\right) \qquad (14)$$

where

$$\leftthreetimes = \frac{\omega r}{U} \qquad (15)$$

Various types of wind turbine have different value of optimal wind speed ratio and optimal coefficient of power. Savonius rotor usually presents an optimal (λ) value around 1, as shown in figure 3 (Woods, 2013)

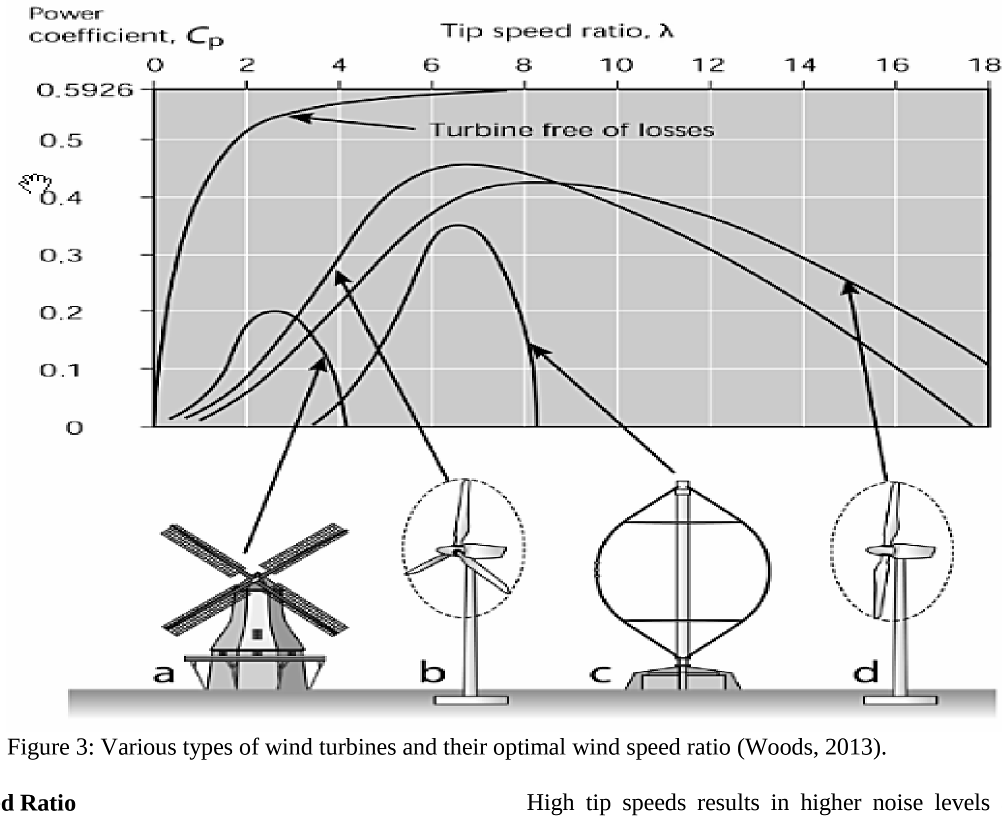

Figure 3: Various types of wind turbines and their optimal wind speed ratio (Woods, 2013).

Tip Speed Ratio

The **tip-speed ratio**, λ, or **TSR** for wind turbines is the ratio between the tangential speed of the tip of a blade and the actual velocity of the wind, $\mathcal{V}$. The relationship between the tip-speed ratio with efficiency and the optimum varying with blade design is given by the expression.

$$\lambda = \frac{Tip\ speed\ of\ blade}{wind\ speed} \qquad (16)$$

High tip speeds results in higher noise levels and require stronger blade due to large centrifugal forces (F)

$$F = \frac{mv^2}{r} \qquad (17)$$

Tip –speed, $u = \omega R$

$$\lambda = \frac{\omega R}{v} \qquad (18)$$

ω in the expression is the shaft rotational speed in radian/second. R is the shaft radius in meters and v is the wind speed in m/s.

It is vital to design wind turbines that will match the angular velocity of the rotor with wind speed so as to ensure optimal or maximum efficiency of the rotor (Christou, 2007). A rotor rotating slowly will allow the wind to pass undisturbed through the gaps between the blades. In a fast rotating rotor, the rotating blades will act as a solid wall which will obstruct the wind flow, again reducing the power extraction (Mullet, 2014). Wind turbines have to be designed to operate at their optimal wind tip speed ratio to extract as much power as possible (Castro and Lee 2013). Wind tip speed ratios are mostly dependent on their designed turbine being used, rotor airfoil profile uses, and the number of blades being used.

Basically, a high tip speed ratio, or TSR, is desirable because it will result in high shaft rotational speed which is necessary for efficient operation of an electrical generator, resulting in more electrical production (Veigh, 2011). But high TSR can result in erosion, noise, vibration, starting difficulties if the shaft is stiff to start rotation, drag and tip losses resulting in poorer efficiency of the rotor and excessive rotor speeds would result in runaway turbine, which could lead to catastrophic failures and even destruction (Lombardi, 2010).

The rotation of the turbine drives a shaft which through a gear box drives a power generator which generates current through the principle of electromagnetic induction. The shaft, gearbox and generator are found in the nacelle. The nacelle is able to revolve about a vertical axis so as to optimally direct the turbine to face the prevailing wind. The electric current thus generated is converted to a higher voltage via a transformer at the base of the tower.

The harnessed power from the wind is proportional to the cube of wind speed up to a theoretical maximum of about 59 % (Lantz, 2006). Nevertheless, today’s wind turbines convert only a fraction of the available wind power to electricity and are shut down beyond a certain wind speed because of structural limitations and fear for wear and tear (Gielen, 2014).

Power regulation is the tendency of a system to provide near constant voltage over a wide range of load conditions. To ensure fluctuation minimization and to control the power flow (Holttinen, 2013). At lower wind speeds, variable rotor speed regulation is used to smooth out power output.

Study Area

The study area adopted is Sokoto and has been described by Akpootu and Iliyasu (2017) as a dry Sahel surrounded by sandy savannah and isolated hills. Rainfall in Sokoto State just like other regions of Nigeria is dominantly controlled by the movement and pulsation of the Inter-Tropical Discontinuity (ITD) (Ilesanmi, 1971). The two distinct seasons in Sokoto, are the wet and dry seasons. The dry season usually start from October, and may last to April in some parts and could extend to May or June in other parts. The wet season in most parts of the state begins in May and could last to September or October. The harmattan, a dry, cold and fairly dusty wind is observed in the state between November and February (Akpootu and Iliyasu, 2017).

MATERIALS AND METHOD

Materials

Materials used are: wood (flat 4x4 timber, and a board of diameter 1.2 m), iron such as (2 inch) angle iron, three drums each of diameter 0.5 m, shaft of length 2.3 m and diameter of 5 cm, rotor of diameter 4 cm and 3.2 m long, pipes and flat brazing iron), paints, ball bearings, nuts, guard wires, cutting gas torch, arc welding machine, a generator, paints cement and concretes.

However, this wind turbine consists of three basic parts: the rotor blades, the tower and the generator. Other materials used for data collection are thermo anemometer, tachometer, and multimeter.

Method

The Blade Construction

The blades where made from three drums that was split into two equal halves and welded together to form the desired curvature of the Savonius blade. This is paramount because the radius of the blade is directly proportional to the swept area. Larger blades tend to have greater swept area and thus catch more wind with each revolution. The blade used in this design has the following dimension. Height value = 2.3 m, width value = 1.4 m and thickness = 0.64 cm. The blade is coupled to the shaft which rotates with the blade when hit by wind current.

The Shaft Construction

A **shaft** is a rotating machine element that is usually circular in cross section, used purposely for the transmission of power from one part to another, or from a machine which produces power to a machine which absorbs power. The shaft was constructed out of mild steel. The dimensions of the shaft are as follows: diameter = 5.2 cm, height = 2.9 m and thickness = 8.1 mm.

Shroud Construction

The shroud was made from wood and was cut into a circular-like board with a diameter of 1.2 m. which was knotted to the both ends of the Savonius blades to enable enclosure of the blades for safety measures and other necessary applications.

Tower Design and Construction

In designing the tower, a special kind of iron called angle iron was used. The base was constructed and built out of 2 inch angle iron; it was built to make sure that it can withstand the weight of the turbine and speed of the wind from any direction to evade vibration and noise from the turbine. The base or stand is constructed only with a cast or angle iron, strong enough to withstand any resistance at any wind speed in Nigeria (Sokoto). Similarly, about 0.89 m of the base iron was buried in the ground, this is done in other to give the tower stability and firmness. The tower was made up of 48 angle irons of various dimensions. However, the base of the tower has the following dimensions: length of the base 4.2m, breadth of the base 2.3 m and height of the base 3.7 m. The irons were welded together to construct the tower. The tower is indeed viewed as the most important aspect of the wind turbine. The tower is 14.2 m from the ground level. The tower used in this study requires climbing. A form of a ladder was constructed within the tower for climbing.

Although the tower's steel parts (which are also known as Angle Iron**)** are manufactured in the factory and not in the site, however, they are usually assembled on site. The parts were bolted and welded together before erection, during this process the tower was kept horizontal until placement. A crane lifts the tower into position (but where there are no cranes, human effort was employed), all bolts were tightened, and stability was tested after completion

Coupling of the Whole System

To assemble wind turbine one must bear in mind the following;

i A tower to get it up into the wind

ii The blade, and
iii The generator.

The Savonius blade which is carrying the shaft was first coupled with the shrouds and later to two ball bearings, one at the top while the other at the bottom respectively, the ball bearings was adequately greased to reduce friction and ensure a full speedy rotation of the rotor. The rotor of 3.2 m long was placed inside the shaft and knotted together with the rotor ends both placed inside the two ball bearings at the opposite ends of the rotor. It was then carried up and welded with the base (stand) and a hole was drilled through the angle iron under the base to provide an extension of the rotor to the generator. The rotor extension was about 0.7 m long which passes through the drilled hole from the main rotor of the wind turbine to the generator. The used generator was held stable with the aid of guard wires. Figure 4 shows the schematic and dimensional view of the turbine, while figure 5 shows all the above mentioned components assembled for the system's performance evaluation under the prevailing wind condition at the site.

Experimental Tests and Measurements

Tests were conducted between the month of January and February, 2016 from 9:00 am to 5:00 pm within the period of consideration it was observed that the wind speed is usually stronger during this season, for the simple Savonius wind turbine. The values of the wind speed were measured by the thermoanemometer, while the turbine speed was measured by using the digital tachometer. Similarly, the voltage generated by the generator was measured with the aid of the multimeter.

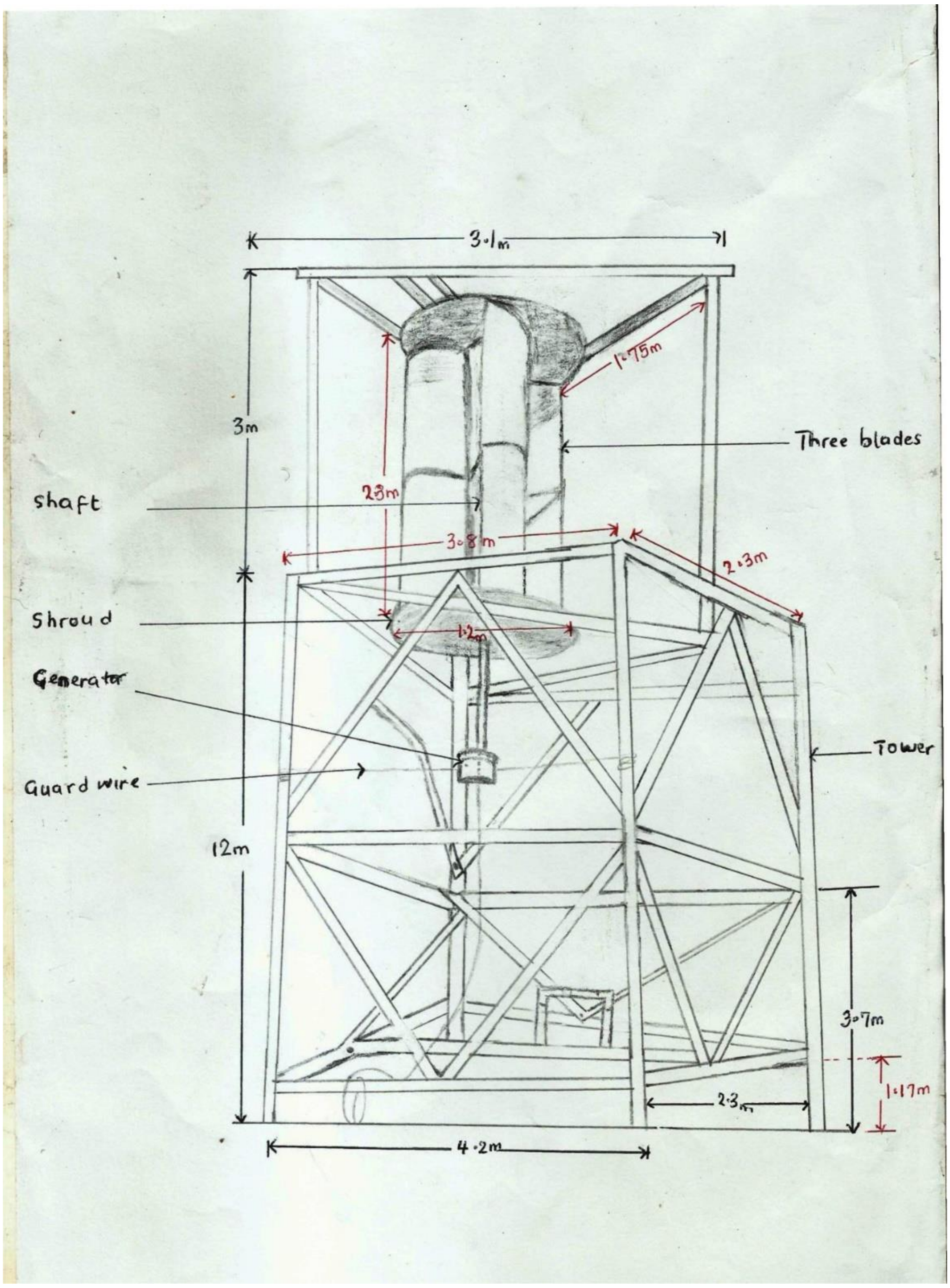

Figure 4: The Schematic and dimensional view of the three bladed Savonius wind turbine.

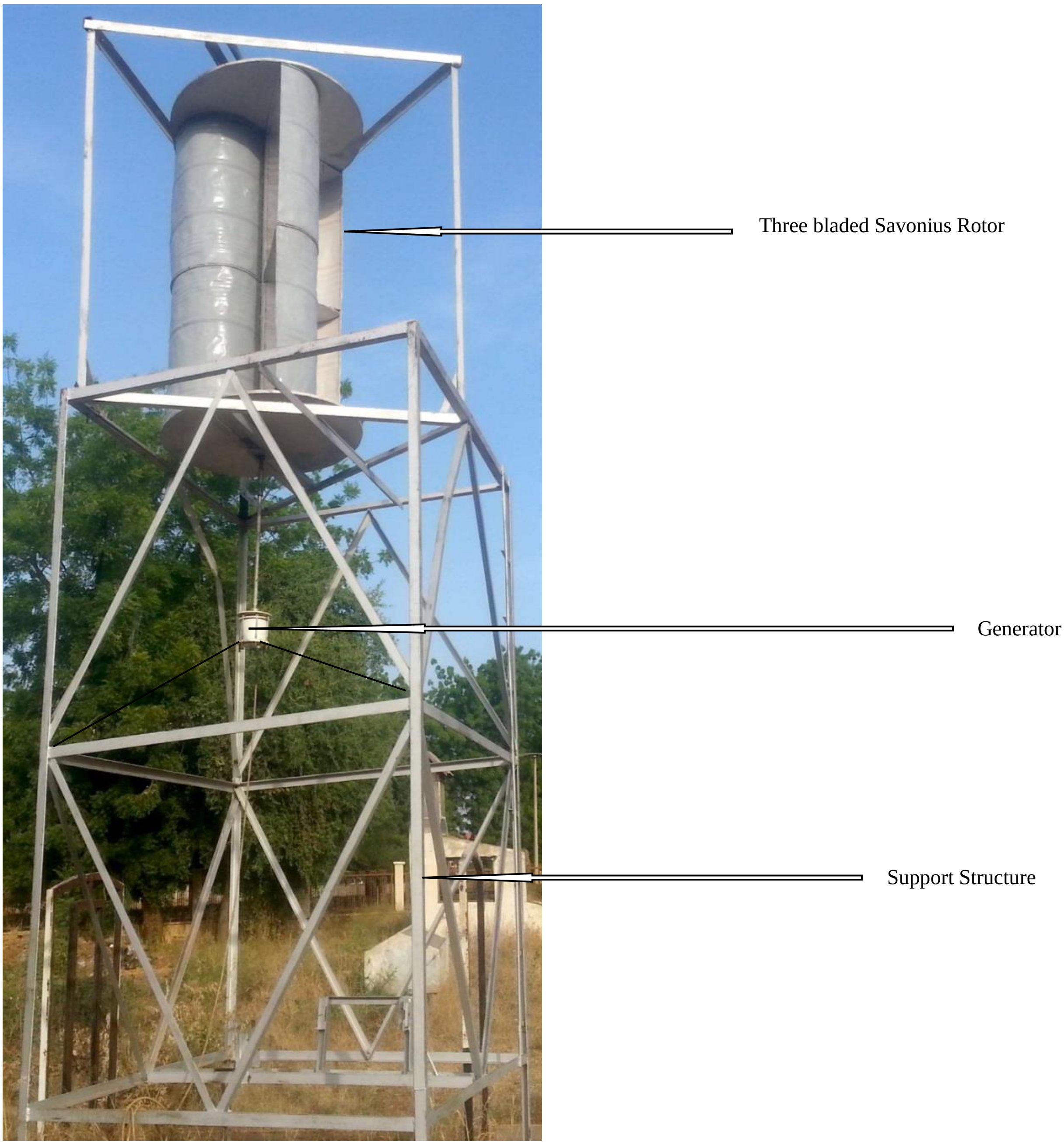

Figure 5: The Constructed two staged Savonius Three Bladed Wind Turbine.

RESULTS AND DISCUSSION

After the installation, the system was able to respond to prevailing wind speed at the site. The correct functioning of the constructed system was observed during the testing and recorded results were discussed accordingly.

Characteristics of the Wind Speed and Wind Power at the Site

Investigation of the whole data spread revealed that the site's wind speeds ranged between 2.5 m/s and 11.2 m/s across the period of consideration. Figure 6b shows the wind speed distribution and the wind power with respect to time of day taken at the site to first practically asses the wind potential for testing the system. Every wind turbine design has a cut-in wind speed, a rated wind speed, Ohunakin et al. (2011). The result obtained and the long term data gotten from the statistical analysis of wind speed in Sokoto based on Weilbull and Rayleigh distribution functions as studied by Argungu et al. (2011) shown in figure 6(a) revealed that sufficient wind speed is available for the expected cut-in and rated speed of 3.3 m/s and 12 m/s respectively. From figure 6(a) it is shown clearly that Sokoto experience higher wind speed within the month of January and February. This is one of the major reasons why the tests were carried out within this period.

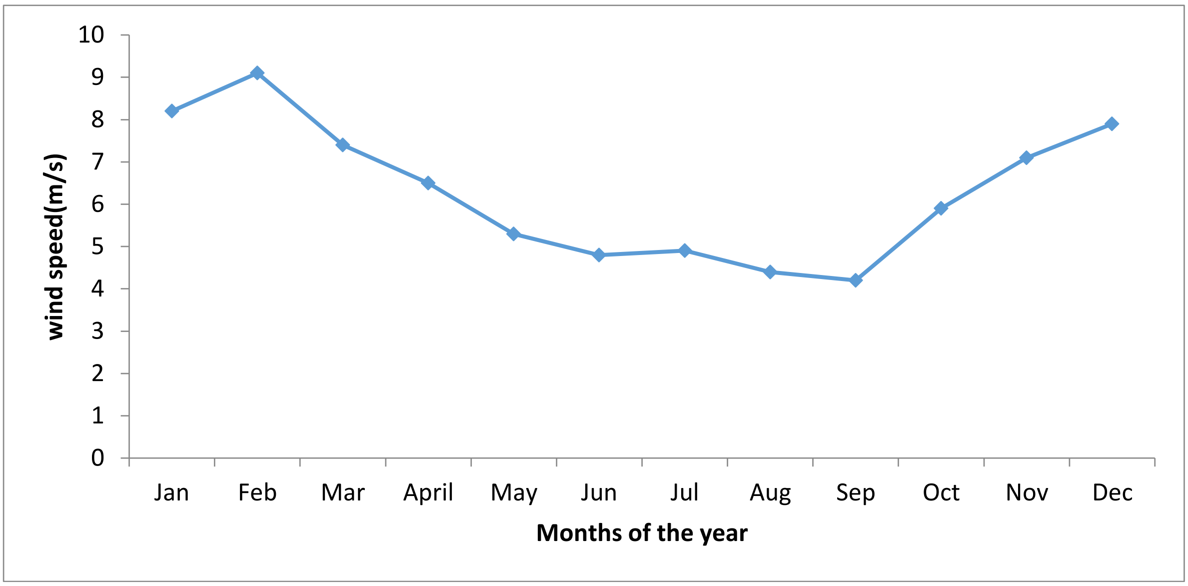

Figure 6 (a): Average monthly wind speed for Sokoto

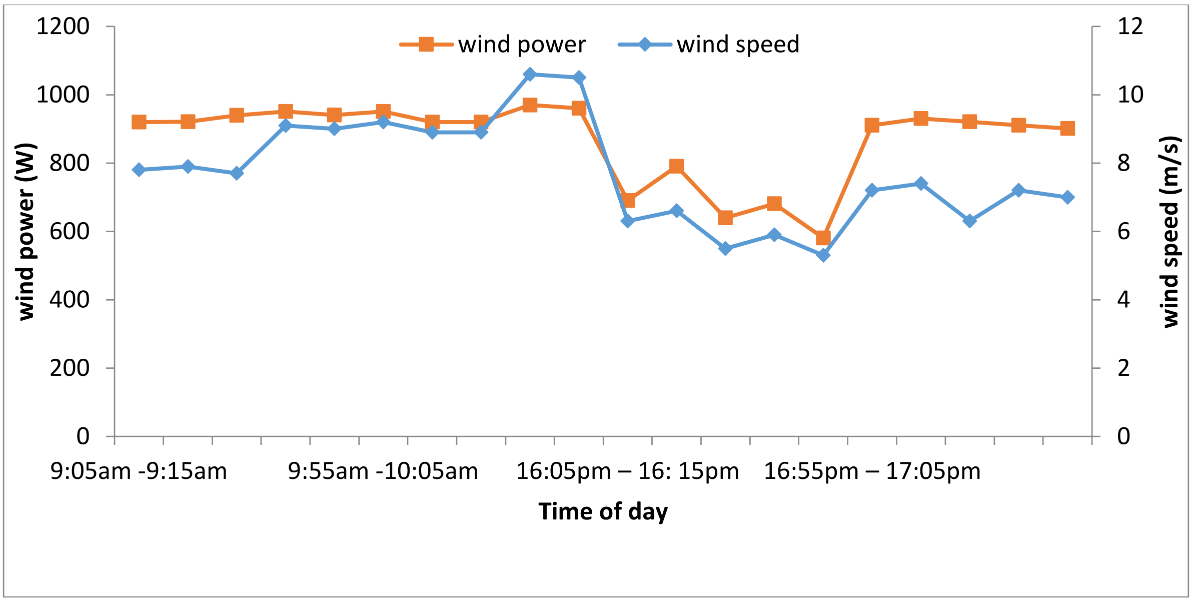

Figure 6(b): Wind speed and wind power versus time of day

From figure 6a, at the cut-in wind speed of 3.3 m/s and 4 m/s as shown in the figures above the blades start to turn and a trickle of electricity starts to be produced. Around cut-in, the generator was used as a motor to help the wind overcome inertia and start the blades turning. At the rated wind speed, the turbine is able to generate electricity at its maximum, or rated capacity.

The wind speed is extremely important for the amount of energy a wind turbine can convert to electricity. The energy content of the wind varies with the cube (the third power) of the average wind speed, if the wind speed is twice as high it contains $2^3 = 2 \times 2 \times 2 =$ eight times as much energy.

Now, the question would be that why does the energy in the wind vary with the third power of wind speed? Actually, from everyday knowledge one may be aware that if you double the speed of a car, it takes four times as much energy to brake it down to a stationary. (According to Newton's second law of motion). In the case of the wind turbine we use the energy from braking the wind, and if we double the wind speed, we get twice as many slices of wind moving through the rotor every second, and each of those slices contains four times as much energy, as we learned from the example of braking a car.

The graph in figure 6c shows that at a wind speed of 5.3 m/s we get a power (amount of energy per second) of 580.88 Watts per square metre exposed to the wind (the wind is coming from a direction perpendicular to the swept rotor area) and an output power of 8.98W. At 10.6 m/s we get almost 1.7 times as much power, i.e. 970 W/m^2, and an output power of 15.5 W.

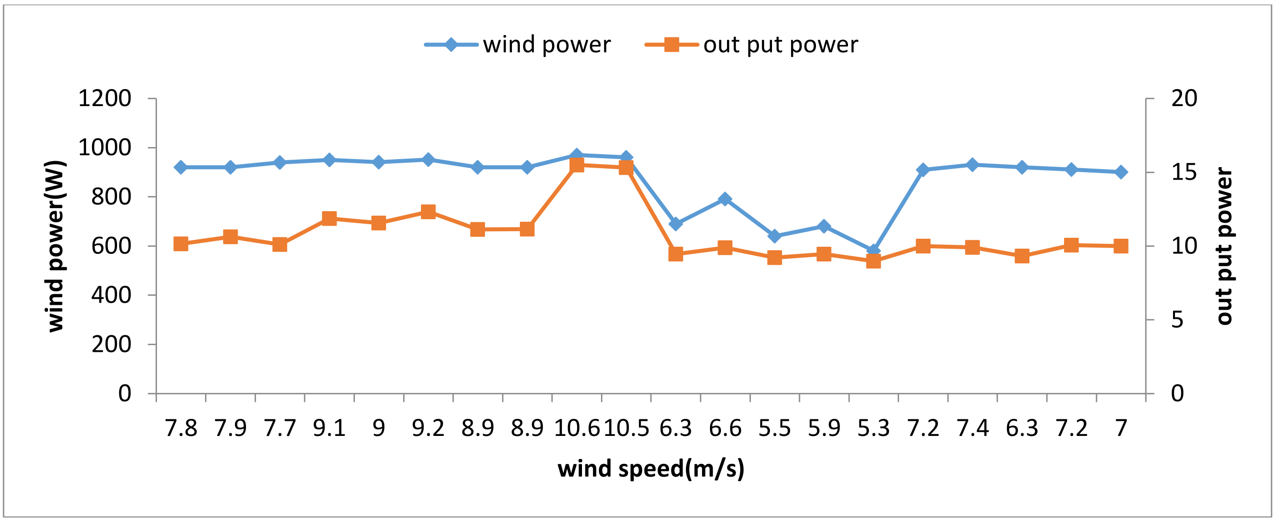

Figure 6(c): The wind (input) power and output power versus wind speed

Performance Coefficient and Tip-Speed Ratio of the System

This has the advantage that the rotor speed in the generator is constant. Thus, the frequency of the AC Voltage is fixed. This makes it possible for the wind turbine to be directly connected to a transmission system. However, from figure 7, we can see that the power coefficient is a function of the tip-speed ratio. By extension, the efficiency of the wind turbine is a function of the tip-speed ratio. Ideally, one would like to have a turbine operating at the maximum value of at all wind speeds. This means that as the wind speed changes, the rotor speed must change. At a wind speeds of 6.6 m/s and TSR of 0.48 an increment of 11.4 % on stable free running rotational speed of the rotor was achieved. The maximum power coefficient 13.1 % was obtained when the wind speed reached 9.7 m/s at a TSR of 0.52. From the figure it can be seen that the maximum power extraction occur at the optimal tip speed ratio. The uncaptured power is caused by the fact that the tip speed ratio is not constant as well as the inherent inefficiency and losses in the turbine.

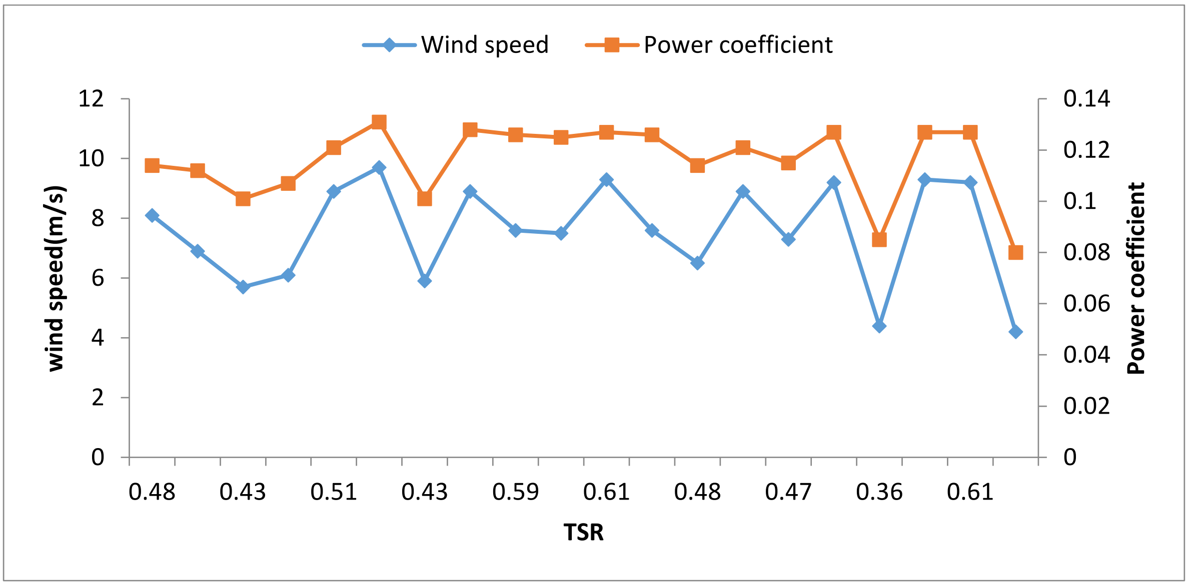

Figure 7: Performance coefficient and tip speed ratio

Performance Coefficient of the System, Input Power and Output Power

Although, the values of the power coefficient were calculated from equation 11, the coefficient of performance, C_P, also called the power coefficient of a wind turbine, is defined as the ratio of the power captured by the rotor of the wind turbine, divided by the total power available in the wind, just before it interacted with the rotor of the turbine (Mackken, 2002). Theoretically, the maximum value of the C_P is 0.593, and it is called the Betz limit. However, actual wind turbines have coefficients of performance that are much smaller than the Betz limit **(**Paraschivoiu, 2006). It can be observed that the coefficient of performance of the wind turbine increases as the wind speed increases until a critical speed is reached (10.6m/s). Performance decreases for speeds higher than this critical speed. The largest coefficients of performance with a value of about 0.016 is found to occur at a wind speed of 10.6m/s as shown in figure 8(a).

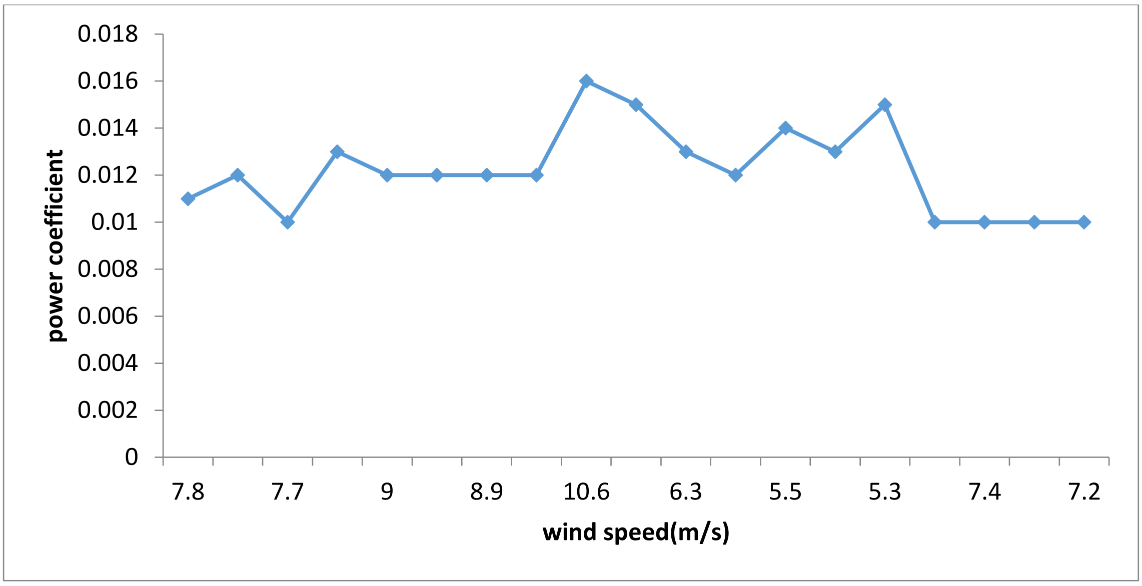

Figure 8(a): The wind speed versus power coefficient

Therefore, it terms of energy production, these results indicated that the advantage of turbines with three blades is primarily due to the fact that they are exposed to more wind energy because of the larger swept areas created by their rotors.It was also observed that for an input wind power of 980.43 W and an output power of 12.89 W the power performance of the turbine was at its maximum at a power coefficient of 0.0131. This is shown in (Figure 8b). These results further suggest that, when the turbines operate at their highest rotational speeds, the range of the input to output power that yielded excellent performance is wider in this case, suggesting that the reliability of performance is less sensitive to small changes in wind speeds.

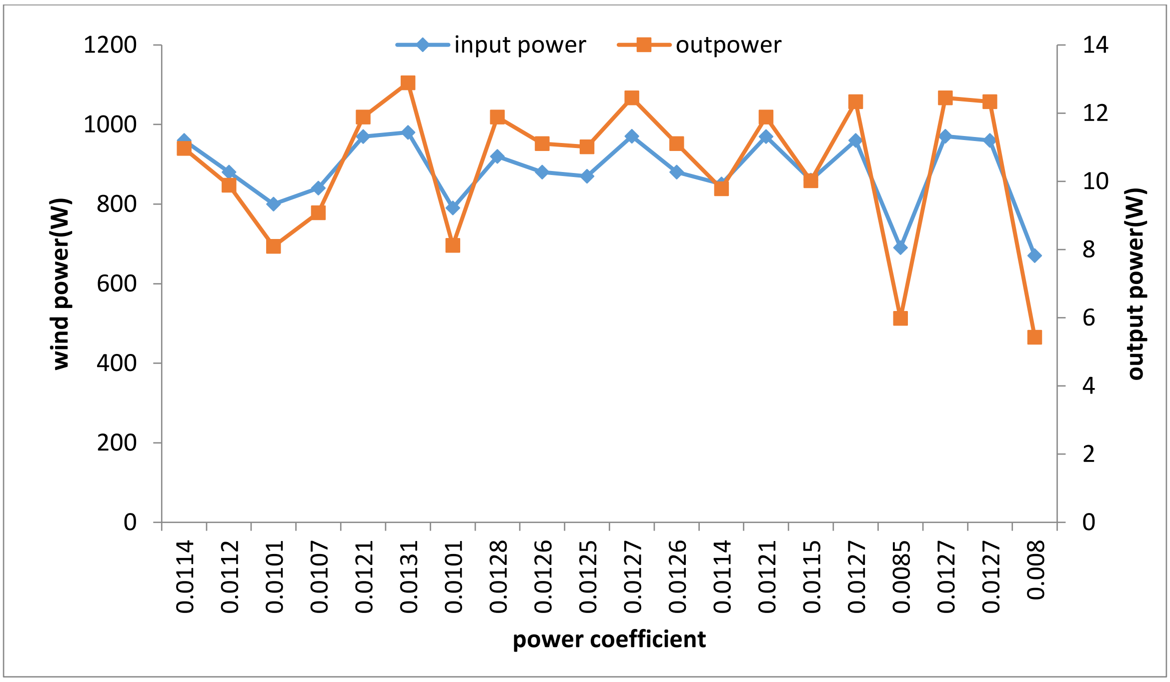

Figure 8b: The wind (input) power and output power versus power coefficient

Comparing Performance Coefficient of Two Blades One Stage to Three Blades Two Stage

In comparing the performance coefficient of one stage two blades with that of two stage three blades, the averages of the wind speed was used to do the comparison. Although the data of the one stage two blades rotor was gotten from a similar work carried out at the site and analyzed. As depicted in figure 9, the peak of power coefficient of the two blades decreases with the increase of rotor solidity; this implies that larger number of blades gives maximum power coefficient for lower angular speeds, using the power Coefficient of the three-bladed turbine as a reference, a 5 % performance increase is registered as against the two- bladed configuration. The consequence of number of stages is studied here for rotors of single and double stages at constant values of other studied parameters. As can be seen from figure 7 the two stages rotor gives higher specific power than single stage rotor. At an average wind speed of 8.1m/s, which is the highest wind speed for this study, the performance coefficient for both the three blades and two blades are found to be (0.132 and 0.09) respectively.

As already stated this is because the three blades have greater capacity to capture wind from all direction, furthermore the net drag force affected on rotor in three blades case is mostly higher than those for two blades. The three blades rotor gives higher mechanical power compared to the two blades rotor. The three blades rotor is more efficient also for other aspect ratios and for double stages rotor as shown in figure 9, it was observed that the three blades rotor gives higher performance than the two and for all aspect ratios as well as for single or double stages too.

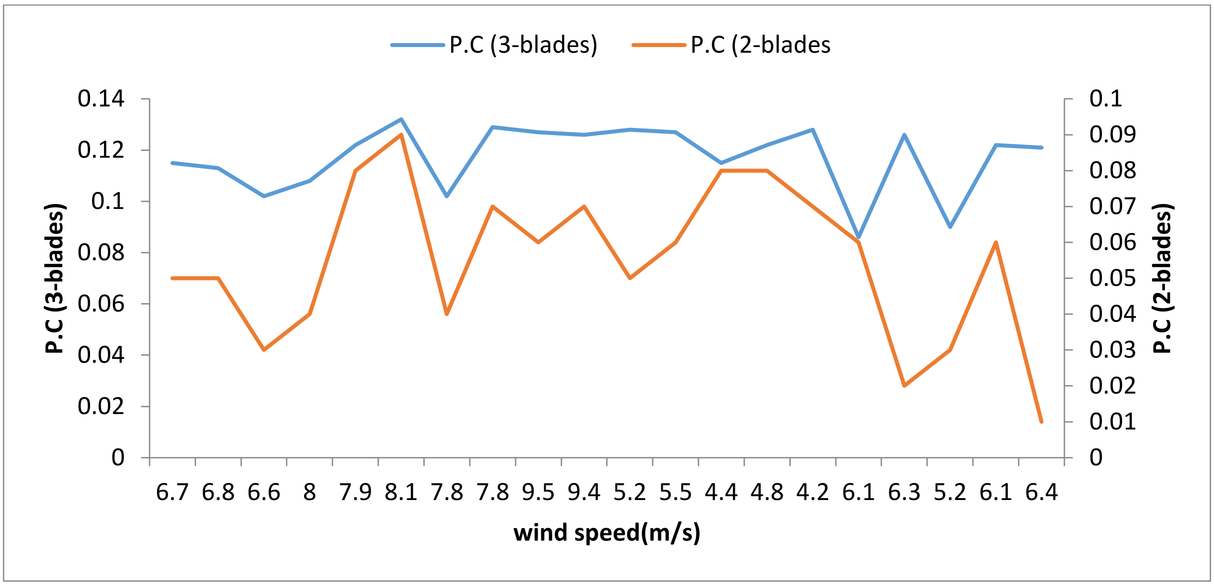

Figure 9: Comparing performance coefficient of two blades with that of three blades

Voltage and Current with Respect to the Wind Speed

Fig.10a shows the results obtained from the test of measuring voltage and the corresponding current with respect to wind speed. As depicted in Figure 10a that the output voltage and current levels generated from the proposed wind turbine will increase, if the values of wind speed increase (i.e. 5.14 V, 3.7 A and 7.14 V, 3.9 A for wind speed of 7.3 m/s and 9.7 m/s). The generated voltage and current levels vary dependent on the wind speed and reach high level in the wind range of 9.7 m/s to 10.2 m/s. The proposed turbine can generate high voltage (7.14 V) level between the ranges of (4.2 m/s to 9.7 m/s). Its line voltage is 5.8V at 589 rpm, but it can operate up to 889 rpm as shown in figure 10b. This speed is regarded as the maximum power operational point for the turbine and the generator. Generator power reaches 14.30 W at this point, and the maximum output voltage is 6.3 V as shown in figure 10c.

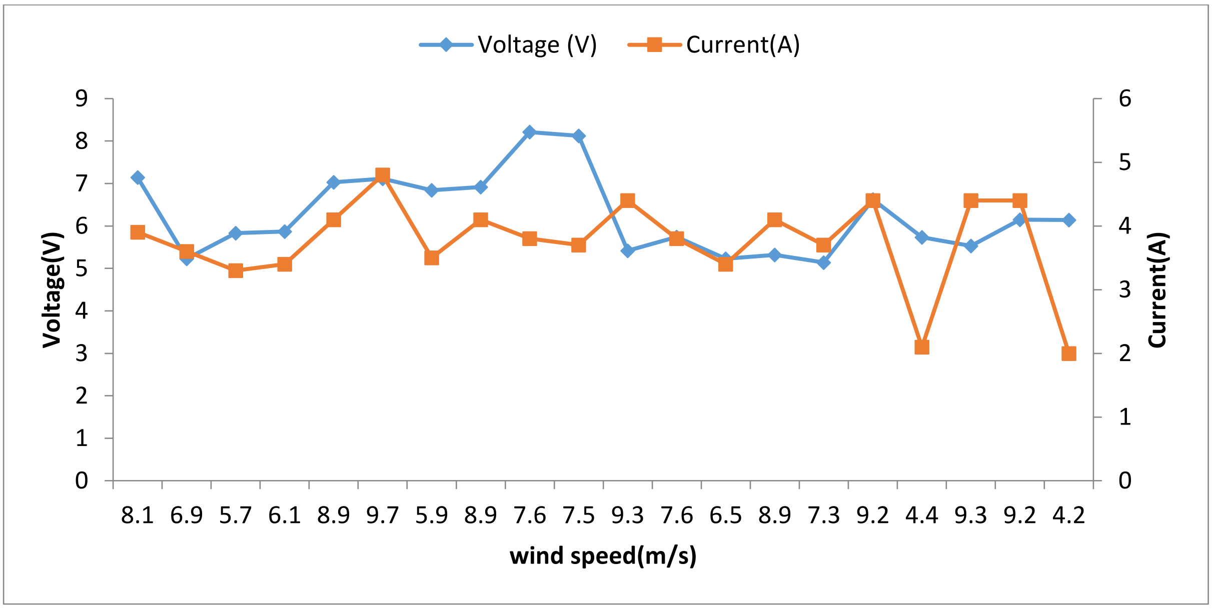

Figure 10a: Variation of voltage and current versus wind speed

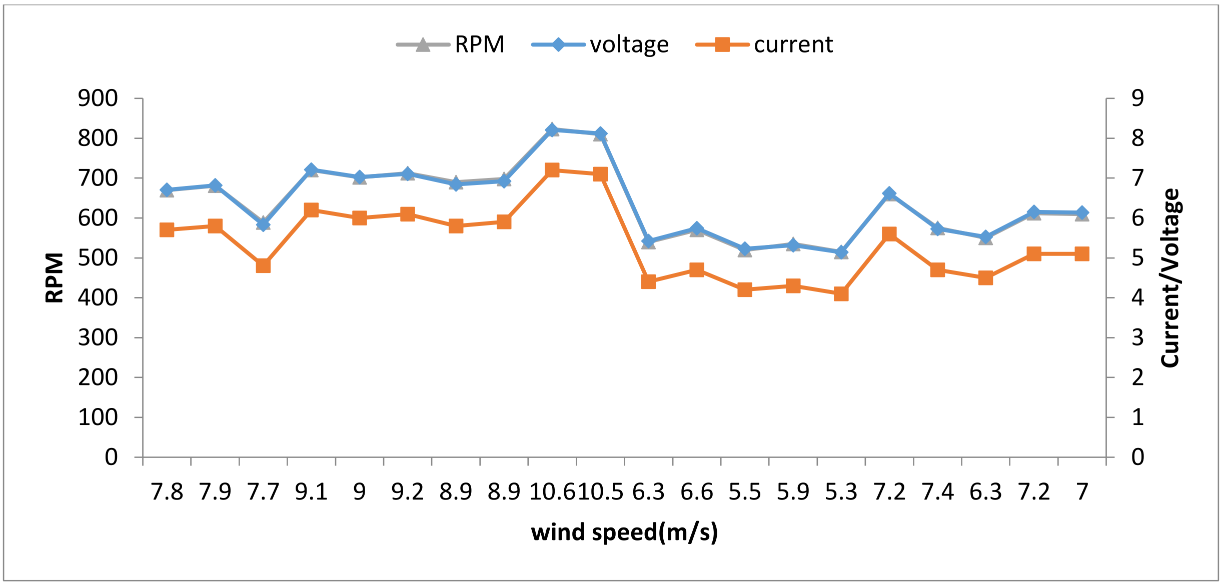

Figure 10b: RPM, current and voltage versus wind speed

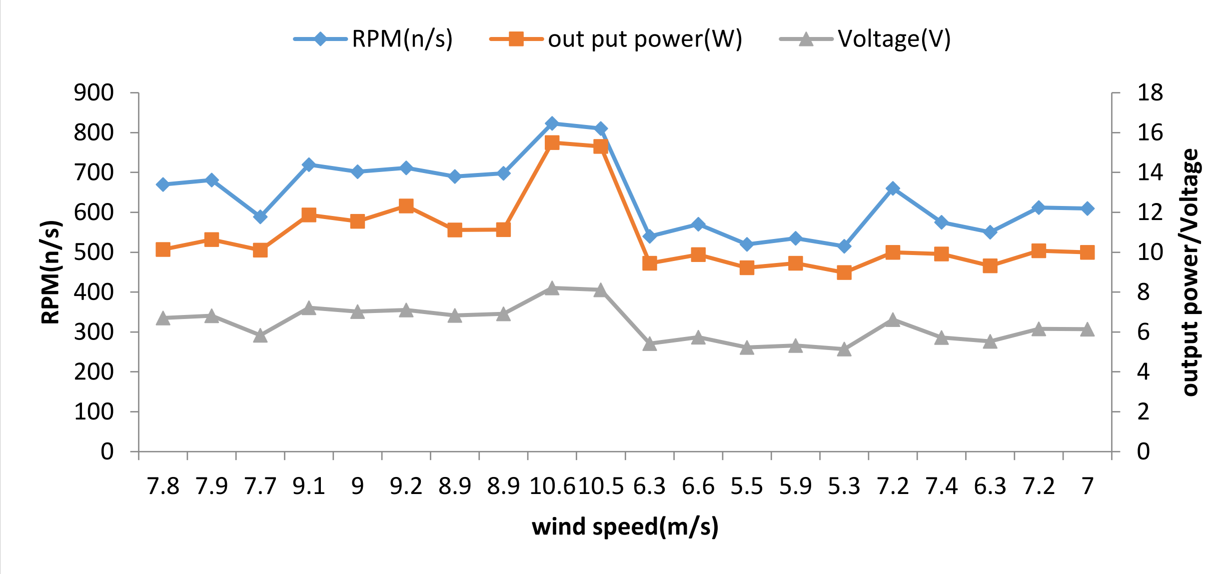

Figure 10c: RPM, output power and voltage versus wind speed.

Analyzing Wind Speed, Rotation per Minute, Calculated Power and Measured Power

The power that is extracted by the wind turbine relies mainly on the wind velocity and the rotational speed. Power curves at different wind velocities for turbines with fixed blades position are shown in Figure10c. The figure indicates that the maximal power can be captured from wind turbines only if they are of a variable speed type. Generator's speed is usually four times lower at the cut-in wind speed than at the rated velocity (Routledge, 2013). The wind speed determines the rotational speed of the wind turbine and the generator. As was earlier stated, Its line voltage is 7.14 V at a wind speed value of 8.1 m/s and at 811 rpm, but it can operate up to 920 rpm. This speed is considered as the maximum power operational point for the turbine and the generator. Generator power reaches 13.34 W at this point. By applying the formula in (equation 10) the calculated power was found to be 27.86 W, but the output voltage is 7.14 V. Cut-in speed of 2.9 m/s for a turbine is 125 rpm and it can produce 20 W (Routledge, 2013). But the generator voltage is only 8.4 V at this point. So this is the lowest input voltage for a converter.

The wind was one of the factors since it decreases and increases from time to time. Another major factor is humidity. Humidity is the measure of water content in a given volume of air. In situations of extreme humidity, water vapor in the air can lead to rusting of the turbine and other moving parts of the turbine.

However, the generator rating was 12 V but less than 8.1 V was measured by the multimeter. The procedure was repeated several times in order to check for unnecessary eventualities to correct the low output from the generator, but it was observed that the generator did not go above 7.14 V even when the value of wind speed reaches a maximum/peak of 11.7 m/s with 870 rpm on a different trial.

CONCLUSION

In this research a two stage three bladed savonius wind turbine has been designed and constructed for power generation and mounted on a 15 m mounting tower. The system was subjected to test and was able to generate 13.34 W of electricity at a wind speed of 8.1 m/s. And at this point the RPM of the turbine was measured to be 811 rpm and a voltage of 7.14 V was generated. Similarly, the coefficients of performance of the constructed two stage three blades savonius wind turbine and that of one stage two blades were calculated and compared using wind speeds that varied from 4.2 m/s to 9.4 m/s. The largest coefficients of performance were found to occur with wind speeds between 7.9 m/s and 9.4 m/s. i.e at a wind speed value of 7.9 m/s the coefficient of performance for the two stage three blades was 12.2% while that of the single stage two blades was 7 % a deviation of 5.2 %. Similarly, at a wind speed value of 9.4 m/s, the coefficients of performance were found to be 12.6 % and 8% respectively, a deviation of 4.6 %. Results showed that the turbine was capable of producing better coefficients of performance. Nevertheless, in terms energy production, these results indicate that the advantage of this turbine is not only in its efficiency, but also, in the larger areas swept by its rotor which exposes it to more incoming wind energy to begin with.

ACKNOWLEDGEMENTS

The authors appreciate the management and staff of the Sokoto Energy Research Center (SERC) for making all the relevant instruments, materials and data used in this study. The anonymous reviewer’s comments are also appreciated.

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