

# Review of Savonius Wind Turbine Performance in Low Wind Speed Region (Nigeria)

## **ABSTRACT**

Electricity is important to the economic development of a country. The power supply in Nigeria is unstable, unreliable and inadequate. The power supply challenges pose a major constraint in the economic growth of the nation, as the population continues to increase. There is an increase in demand of power supply and no significant change in the power generation. The problem in the power sector has to be seriously and effectively addressed. Renewable energy presents opportunity for power generation for industrial and domestic use, and one of such source is the wind energy. This review examines the design consideration and methodology of a savonius wind turbine and its performance. From the results of the computations a detailed specification was obtained. The height of the rotor was 1200 mm and the blade thickness was 2.5 mm. Also, from computations, the suitable diameter of the blade was 600 mm. The wind turbine was tested and the test result shows that at moderate wind speed of about 2.3 - 4.6 m/s, the voltage generated was 0.76 – 2.20 V even though the rotor was not mounted at an elevated height. The voltage produced was directly proportional to the wind speed with Coefficient of determinant  $R^2 = 0.9518$ . This indicates that even at places with low wind speed in Nigeria, a reasonable amount of energy can be generated using a vertical axis wind turbine.

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## SYMBOLS AND NOTATIONS

<b>Symbols</b>	<b>Description</b>	<b>Unit</b>
$A$	Swept Area	$m^2$
A.R	Aspect ratio	-
$C_p$	Coefficient of performance	-
$D$	Rotor diameter	m
$f$	Frequency	Hz
$H$	Rotor height	m
$N_1$	Estimated rpm of the rotor	rpm
$P_e$	Extracted power	W
$P_g$	Generator Power	W
$P_w$	Wind power	W
RPM	Revolution per minute	rpm
$t$	Rotor thickness	mm
$V$	Volume	$m^3$
$v$	Average wind speed	$m/s^2$
$\eta$	Overall efficiency	-
$\rho$	Wind density	$Kg/m^3$

$\lambda$	Tip speed ratio	-
$\omega$	Angular velocity	rad/s

## **KEYWORDS**

Wind turbine, vertical axis wind turbine, savonius turbine, low wind speed, renewable energy, small-scale wind, energy conversion

# CHAPTER ONE

## INTRODUCTION

In Nigeria, domestic homes have been left to fend for their energy needs. Therefore, most have resolved to the use of power generating sets, this is not really a good solution as the economic effects due to frequent purchase of petrol is not desirable. In Nigeria, over 60 million people own generators to provide electricity for their homes and businesses (BBC News, 2013)

Also the emissions from generating set is not environmental friendly as the release of carbon (from the exhaust gas) into the atmosphere contributes to global warming and makes a major increasing contribution to the total anthropogenic greenhouse effect (Sharma, 2006). This among many other reasons has incited efforts to find viable energy alternatives. Other alternatives like large scale use of bio-fuels, solar energy (through the use of solar cells/panels), geothermal energy (terrestrial heat from the earth), and wind power can be used for the generation of electricity.

Wind energy is a very good alternative since there is wind everywhere and there is enough wind to satisfy most of the people's energy requirements. Wind turbines can produce electricity by converting wind energy into kinetic energy through a blade contained in the turbine and rotating the shaft on the generator.

Savonius wind turbine is the preferred form of wind turbine for Nigeria because of the low wind speed in the region. The Savonius wind turbine has a lot of advantages over the conventional vertical axis wind turbine, which include: easy manufacture of blades, repair and maintenance. No tail or yaw device for the wind direction is necessary because the rotor blade is installed vertically to the ground, it

can generate power at relatively low wind speed and it is easy to install (Onawumi et al., 2011)

This review aims to provide a comprehensive assessment of a savonius wind performance in a low wind speed region. The paper examines types of wind turbine, with focus on vertical axis wind turbine, principle of operation of a savonius wind turbine, design consideration and methodology, and performance review. This study seeks to contribute to discussions on enhancing the performance of savonius wind turbine in low wind speed regions.

# CHAPTER TWO

## OVERVIEW

### 2.1 Types of Wind Turbine

Wind turbines can rotate about either a horizontal or vertical axis, the former being both older and more common. Two major types of wind turbine are :

Horizontal axis wind turbine [HAWT] and Vertical axis wind turbine [VAWT] (Guzzeta et al., 2007)

#### 2.1.1 Horizontal axis wind turbine

The horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of its tower, and must be pointed in the direction opposite to the direction of the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor (Bhatia, 2014). It has a gearbox, that makes the slow rotation of the blades more suitable to drive an electrical generator and for faster rotation. Since a tower produces turbulence behind it, the turbine is usually positioned upwind of its supporting tower. The turbine blades are made stiff to avoid high winds pushing the blades into the tower. Additionally, the blades are placed at a considerable distance in front of the tower and are sometimes tilted forward into the wind a small amount. Turbines used in wind farms for commercial production of electric power are usually three-bladed and pointed into the wind by computer-controlled motors. These have high tip speeds of over 320 km/h (200 mph), high efficiency, and low torque ripple, which contribute to good reliability. The blades are usually colored white for daytime visibility by aircraft and range in length from 20 to 40 meters (66 to 131ft) or more (Bhatia, 2014)

### **2.1.2 Vertical axis wind turbine**

Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically. One advantage of this arrangement is that the turbine does not need to be pointed into the wind to be effective, which is an advantage on a site where the wind direction is highly variable. It is also an advantage when the turbine is integrated into a building because it is inherently less steerable. The generator and gearbox can be placed near the ground, using a direct drive from the rotor assembly to the ground-based gearbox, improving accessibility for maintenance (Barnard, 2014). The key disadvantages include the relatively low rotational speed with the consequential higher torque and hence higher cost of the drive train, the inherently lower power coefficient, the 360 degree rotation of the aerofoil within the wind flow during each cycle and hence the highly dynamic loading on the blade, the pulsating torque generated by some rotor designs on the drive train, and the difficulty of modeling the wind flow accurately and hence the challenges of analyzing and designing the rotor prior to fabricating a prototype (El Bassam et al., 2013).

When a turbine is mounted on a rooftop the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of a rooftop mounted turbine tower is approximately 50% of the building height it is near the optimum for maximum wind energy and minimum wind turbulence (El Bassam et al., 2013).

### **2.2 Types of Vertical Axis Wind Turbine**

The vertical axis wind turbine [VAWT] can be further divided into:

Darrieus Wind Turbine and Savonius Wind Turbine (Ragheb, 2015).

### **2.2.1 Darrieus wind turbine**

This turbine (Darrieus, otherwise known as Eggbeater) was named after the French inventor, Georges Darrieus (ABB Group, 2011). They have good efficiency, but produce large torque ripple and cyclical stress on the tower, which contributes to poor reliability. They also generally require some external power source, or an additional Savonius rotor to start turning, because the starting torque is very low. The torque ripple is reduced by using three or more blades which results in greater solidity of the rotor. Solidity is measured by blade area divided by the rotor area. Newer Darrieus type turbines are not held up by guy-wires but have an external superstructure connected to the top bearing (Castellano, 2012).

There is no net rotational force when the rotor is stationary, even if the wind speed rises quite high the rotor must be spinning to generate torque. Thus the design is not normally self starting. It should be noted, however, that Darrieus rotors will self start under extremely rare conditions (for a lightly loaded, three bladed rotor under steady wind), Darrieus rotors can self-start, so some form of brake is required to hold it when stopped (Chattot et al., 2015).

### **2.2.2 Savonius wind turbine**

Savonius turbines are one of the simplest turbines. Aerodynamically, they are drag-type devices with two (or more) scoops that are used in anemometers, Flettner vents (commonly seen on bus and van roofs), and in some high-reliability low-efficiency power turbines (Zingman et al., 2007).

They are always self-starting if there are at least three scoops. Looking down on the rotor from above, a two-scoop machine would look like an "S" shape in cross

section. Because of the curvature, the scoops experience less drag when moving against the wind than when moving with the wind. The differential drag causes the Savonius turbine to spin. Because they are drag-type devices, Savonius turbines extract much less of the wind's power than other similarly-sized lift-type turbines. Much of the swept area of a Savonius rotor may be near the ground, if it has a small mount without an extended post, making the overall energy extraction less effective due to the lower wind speeds found at lower heights (Chattot et al., 2015). A typical savonius wind turbine is shown in fig 2.5

A new curtaining arrangement was introduced to improve the performance of Savonius wind rotors. The curtain arrangement was placed in front of the rotor to avoid negative torque opposite the rotor rotation. The geometrical parameters were designed to increase the performance. The rotor with different curtain arrangements were tested out of a wind tunnel and its performance was compared with that of the conventional rotor. The maximum power coefficient of the Savonius wind rotor is increased to about 38.5% with the optimum curtain arrangement. The experimental results showed that the performance of Savonius wind rotors could be improved with a suitable curtain arrangement. (Burcin et al., 2008).

Two blades rotor is more stable in operation than three or more rotor blades, the power coefficient increases with increasing the aspect ratio (Kadam et al., 2008). Another study about the Combination of Savonius and Darrieus type of Vertical Axis Wind Turbine (VAWT) rotors, which indicates that the combination possess many advantages over their individual designs, like low starting torque, high power coefficient, low cut-in wind speed etc. The present Darrieus-Savonius rotor can be suitably placed in the built environment where it can harness more power from wind

and, at the same time, would self-start in low wind condition prevalent in such environment (Sharma et al., 2014).

Savonius wind turbines do perform well at low wind speeds with cut in speed at around 2.5 m/s (Ali, 2013). It was confirmed in an experimental study, that 3 blades perform better at higher Tip Speed Ratio (Wenehenubun et al., 2015). The shape factor of rotors has an effect on the power coefficient of a savonius wind turbine, when an optimum shape factor (about 0.4) is used, the power coefficient is doubled when compared to a conventional rotor. It was also observed that a higher Reynold's number, all rotor exhibit better power coefficient (Priyadumkol et al., 2019).

It is perceived that research on parameters such as aspect ratio (AR), overlap ratio and number of blade can be studied to arrive at a satisfactory level of performance, although adding an extra set like obstacle shielding, curtain or conveyor deflector improve the performance of Savonius wind turbines. These developed designs of Savonius have made this rotor system very complex and dependent on the direction (Zemamou et al., 2017). Two rotor sections, each with a slight overlap and positioned with a 90 degrees angular offset would provide maximum performance. Two stages geometry of a savonius turbine has a better aerodynamic performance than the three stages, with the exception of starting torque (Sheldahl et al., 1978).

The use of end plates significantly increased performance and raised the tip-speed ratio at which optimal performance occurred. A negative offset would allow improvements in performance (Sayers, 1985). The use of a wind booster would increase the blade power of a turbine, which would lead to an increase in the power of the turbine (Yohana et al., 2019). Negative pressure on the backside of the returning blade is detrimental to the overall performance of the turbine (Fujisawa et al., 1992).

Power coefficient is strongly dependent on the tip speed ratio, as the tip speed ratio moves closer to its optimum value, the performance would increase significantly (Abraham et al., 2012).

Turbine aspect ratio is obtained by dimensionalizing the turbine's height  $H$ , by its diameter  $D$ . Savonius rotors with high aspect ratios have low losses due to the effect of tips and bucket. An aspect ratio of about 2.0 gives a good result on the performance of savonius rotors. A null bucket spacing gives the best performance of a savonius rotor with semicircular profile buckets, the optimum size for the bucket overlap is about 10-30% of the bucket chord size (Akwa et al., 2012). Addition of valves (which would allow passage of air from the convex side to the concave side of the bucket, reducing the bucket drag) to the wind turbine would significantly increase the power coefficient of the turbine (Saha et al., 2008). The addition of a stator in form of a deflector blade (that flows into the concave side of the advancing rotor bucket (Mohamed et al., 2011).

Helical Savonius wind turbines have a positive static torque coefficient for all rotor angles and better performance than conventional savonius wind turbines. Circular end plate is the best choice for maximizing power and torque coefficients for helical savonius wind turbines. The use of both upper and lower circular end plates would lead to a significant increase in power coefficient (Jeon et al., 2015). Savonius turbine rotors without overlap ratios are better in operation than those with overlap ratios (Mahmoud et al., 2012). An experiment on savonius wind turbine geometry showed that the optimum geometries for a savonius rotor corresponding to its blade geometry are as follows : gap size of 0, overlap ratio of 0, aspect ratio of 0.77, blade shape parameter of 0.2 and blade arc angle of 135 (Modi et al., 1989).

The positive peak torque on the blade of a savonius turbine can be increased by reducing the blade's ellipticity. The optimum value for the blade arc angle of a savonius turbine is 160 which would give a coefficient of performance 8.37% higher than that of a conventional savonius wind turbine (Mao et al., 2015). Torque variation on the angular positions of the rotor blade and lower efficiency are the major drawbacks of the savonius wind turbine, to overcome these, a set of blades called secondary blades are placed in front of concave side of the main rotor blades. This improves the efficiency and the torque value increases along angular positions (Thiyagaraj et al., 2016). Installing a curtain in the upstream flow of a savonius wind turbine and the rotor without shaft can increase the coefficient of performance significantly (Al-Kayiem et al., 2016).

A considerable improvement in the performance of savonius rotor can be achieved by using multiple quarter blades instead of single blade (Sharma et al., 2016).

## **2.3 Major Components of the Savonius Wind Turbine**

The Savonius wind turbine consist of the following components:

i. Rotor Blades, ii. Shaft, iii.. Bearing, iv. Generator, and v. Base.

### **2.3.1 Rotor Blades**

This is a crucial and basic part of the wind turbine, it captures the wind and converts its kinetic energy into the rotation of the shaft. Wind turbine blades have on aerofoil – type cross section and a variable pitch. While designing the size of blade, it is required to know the weight and cost of blades (Venkata, 2016)

### **2.3.2 Shaft**

This component rotates as a result of the impact of wind on the rotor blade, it is joined to the blades by riveting (Abdul et al., 2016). While designing the shaft of blades, it should be properly fitted to the blade. The shaft should be as possible as less in thickness & light in weight.

### **2.3.3 Bearing**

For the smooth operation of Shaft, bearing mechanism is used. To reduce friction, the two ends of shaft are pivoted into the same dimension bearing (Vincent, 2017)

### **2.3.4 Generator**

This component converts rotational mechanical energy to electrical energy (US DOE, 2018). For generation of electricity from the Savonius wind turbine, a dynamo which has the capacity to light a bulb of 12 V would be used.

### **2.3.5 Base**

This is the part that holds all other components of the turbine, it serve as the main frame and support for the turbine.

## **2.4 Mechanism of Operation of Savonius Vertical Axis Wind Turbine**

The blades of the Savonius VAWT start rotating due to the drag experienced when the wind impacts on it, causing the shaft to rotate producing a torque which is transmitted to the rotor pulley (Zemamou et al., 2017). In order to transmit rotary motion from the rotor pulley to the generator pulley, a belt drive is adopted for the

turbine. The rotary motion transmitted to the generator pulley causes to the generator to rotate, thereby converting mechanical energy to electrical energy.

# CHAPTER THREE

## METHODOLOGY

### 3.1 Functional Requirements

In other to develop the design concept for the project, the following functional requirements were proposed:

- i. the rotor should have a rigid structure capable of withstanding vibration;
- ii. the generator should be able to generate a voltage of (at least) 12V at a speed of 140 rpm;
- iii. the turbine should be located where there are little or no wind breakers (hindrances to the flow of air to the rotor blades); and
- iv. the turbine should be able to rotate at a wind speed of 3.129m/s.

### 3.2 Material Selection

In selecting materials for the execution of the chosen design, consideration would be given to materials that would give the best results based on requirements such as; service requirement, fabrication requirement, availability and economic importance.

**Table 3.1: Materials Selected for Fabrication**

S/N	COMPONENT	MATERIAL	MATERIAL JUSTIFICATION
1	Blades	Mild steel	Low density, machinability, affordability and availability
2	Shaft	Alloy steel	It possess a reasonable strength and availability in the market
3	Bearing	Stainless steel	Easily accessible, strength and for rotational movement
4	Generator	N/A	Generate voltage at very low rotational speed.
5	Base	Steel	Durable, strength and availability in the market

### **3.4 Machining Methods**

Most of the parts used for the production of the Savonius vertical axis wind turbine were machined in the workshop. Lathe machine was used for turning the mild steel sheet to specific dimensions before assembly process. Boring machine was used to bore holes into the rods and parts that were assembled using different sizes of drill bit to achieve the required diameter.

Grinding machine was be used for grinding the joints where arc welding is used during production and also on the machined parts so as to smoothen the edges of the generator housing. An electric hand cutting machine was used mainly for metal cutting. Other tools such as the try square, ball pin hammer, clipping hammer, and plier were also used in the course of the production.

### 3.5 Joining methods

The method of joining adopted in the generator housing was the arc welding method, this was to achieve permanent joints. Shielded arc welding was also used for some parts.

### 3.6 Design Consideration

The variables considered in designing component parts are given in Table 3.2.

**Table 3.2: Design Consideration**

S/N	Parameter	Symbol	Value or Constraint	Unit
i.	Aspect Ratio	A.R	2	-
ii.	Rotor thickness	T	2.5	mm
iii.	Rotor shaft diameter	$d_o$	40	mm
iv.	Wind density	$\rho$	1.25	kg/m <sup>3</sup>
v.	Average wind Speed	V	3.129	m/s
vi.	Coefficient of performance	C <sub>p</sub>	0.3	-
vii.	Velocity Ratio	V.R	8	-
viii.	Angular velocity	$\Omega$	14.43	rad/s

Source : (Hiren Tala et al., 2014; Akwa et al., 2012; NASA MERRA-2, 2001)

### **3.4 Design Calculation**

#### **3.4.1 Design Analysis**

##### **i. Rotor Blade**

###### **a) Rotor Height & Diameter**

The rotor blade is represented in the fig. 2.6. Aspect ratio is the ratio of rotor height to rotor diameter. For the design of a Savonius VAWT, A.R=2 (Hiren Tala et al., 2014), therefore the height and diameter of the rotor is given by equation (3.1) and (3.2) respectively.

$$H = A.R \times D \quad (3.1)$$

$$D = H/AR \quad (3.2)$$

Hence, the rotor height should be twice the rotor diameter, since the Aspect ratio is 2. The material for the Savonius rotor blade was mild steel for the entire rotor blade profile.

###### **b) Determination of Swept Area (A)**

The swept area was derived from the product of the height and diameter of the rotor, it is expressed as in equation (3.3);

$$A = HD \quad (3.3)$$

## ii. Wind Power

### a) Determination of Wind Power ( $P_w$ )

The power in the wind was computed using the concepts of kinetics. The wind mill works on the principle of converting kinetic energy of the wind to mechanical energy. The kinetic energy of the wind is given by equation (3.4), dividing the kinetic energy of the wind by time gives the wind power, given by equation (3.5).

$$\epsilon_{kin,wind} = 0.5V\rho v^2 \quad (3.4)$$

$$P_w = \frac{\epsilon_{kin,wind}}{\Delta t} = \frac{0.5V\rho v^2}{\Delta t} = 0.5\rho Av^3 = 0.5\rho HDv^3 \quad (3.5)$$

Where,

$\epsilon_{kin}$  = kinetic energy of the wind

V = volume of the rotor

$\rho$  = density of air

v = average velocity of air

T = change in time

A = Swept area

H = height of the rotor

and D = diameter of the rotor

### b) Determination of Extracted power( $P_e$ )

The extracted power is a product of the coefficient of performance and wind power this is expressed as in equation (3.6);

$$P_e = C_p P_w \quad (3.6)$$

The  $C_p$  according to Beltz limit for a vertical axis wind turbine is between the range of 0.25 to 0.3. For this design, 0.3 is chosen.

### c) Determination of Tip Speed Ratio( $\lambda$ )

The tip speed ratio (lambda  $\lambda$ ) is the ratio of the speed of the tip of the blades to the speed of the wind, given by equation (3.7):

$$\lambda = \frac{V_{tip}}{V_{wind}} = \frac{\omega D}{2V} \quad (3.7)$$

### d) Determination of Rotor RPM ( $N_1$ )

The rpm of the rotor was derived from equation (3.10):

$$N_1 = \frac{120f}{p} \quad (3.10)$$

where  $f$  is the frequency and  $p$  is the number of poles, the number of poles used was 2. Angular velocity  $\omega$ , a function of frequency is represented in equation (3.11), thereby making  $f$  subject of the formula in equation (3.12)

$$\omega = 2\pi f \quad (3.11)$$

$$f = \frac{\omega}{2\pi} \quad (3.12)$$

Substituting equation (3.12) in equation (3.10) gave equation (3.13), simplifying equation (3.14) gave the rotor RPM given in equation (3.14)

$$N_1 = \frac{120\omega}{4\pi} \quad (3.13)$$

$$N_1 = \frac{60\omega}{2\pi} \quad (3.14)$$

### 3.5 Design Parameters

The input parameters in Table 3.2 were used to determine the actual design parameters of the Savonius wind turbine using the design equations (3.1) - (3.15). The results obtained were recorded in Table 3.3

**Table 3.3: Design Parameters**

S/N	Parameter	Symbol	Value	Unit
1	Rotor height ( equation (3.1))	$H$	1200	mm
2	Rotor diameter ( equation (3.2))	$D$	600	mm
3	Swept Area ( equation ( 3.3))	$A$	0.72	m <sup>2</sup>
4	Estimated wind power ( equation ( 3.5))	$P_w$	13.786	W
5	Estimated RPM of the rotor ( equation (3.14))	$N_1$	137.796	Rpm
6	Extracted power ( equation (3.6))	$P_e$	4.136	W
7	Tip-speed ratio ( equation (3.7))	$\Lambda$	1.384	-

### 3.6 Working Drawings

These were the drawing that were used to give information for the manufacturing or construction of the machine. A complete set of drawings consisting of component drawings and assembly drawings. The latter gives all the necessary information for the manufacture of each of the individual parts and the former shows the parts

assembled as a finished structure or machine. The descriptions given by the set of working drawings for this project include:

- i. graphical representation of the shape of each fabricated part (shape description);
- ii. dimensions of each fabricated part (size description);
- iii. explanatory note on the individual drawings, giving the specifications of material; and
- iv. descriptive title on each drawing.

The working drawings are on the Appendix

## **CHAPTER FOUR**

### **RESULTS AND DISCUSSIONS**

#### **4.1 Testing and Evaluation**

The savonius wind turbine was tested for performance. The deviation from the expected result was observed. The wind turbine was taken to an open field (this is to get maximum wind speed possible), the test was carried out using a multimeter and an environmental meter; the multimeter was used to measure the voltage generated (by the generator) while the environmental meter was used to measure corresponding wind speeds. The voltage generated at varying wind speed was recorded. The performance was affected by local wind conditions, obstructions among other factors. The wind speed that rotated the rotor blade on no load was also recorded. The results of the tests are shown below

A wind speed of 1.8 m/s rotated the rotor from rest

**Table 4.0: Results of voltage produced at different wind speed**

<b>S/N</b>	<b>WIND SPEED <math>V_s</math>(m/s)</b>	<b>VOLTAGE <math>V_p</math>(VOLTS)</b>
1	4.3	1.90
2	3.7	1.30
3	4.6	2.20
4	3.8	1.40
5	2.8	0.95
6	2.3	0.76
7	3.5	1.29
8	4.1	1.70
9	2.9	1.04
10	3.9	1.60

From the graph shown in Figure 4.3, it could be observed that voltage  $V$  produced is directly proportional to the wind speed. This means that an increase in wind speed results in an increase in voltage and vice versa.

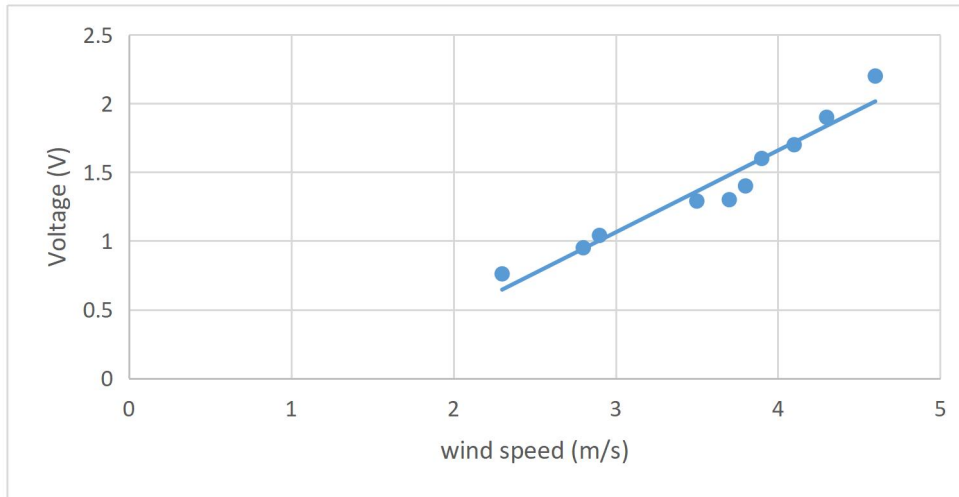


Figure 4.1: Voltage variation with Wind Speed

**Table 4.1: Wind power, power generated by generator and efficiency at different wind speed**

S/N	Wind Speed $V_s$ (m/s)	Wind Power $P_w$ ( w )	Power generated by generator $P_g$ (W)	Overall Efficiency $\eta$
1	4.3	35.06	19.00	54.19
2	3.7	22.34	13.00	58.19
3	4.6	42.93	22.00	51.25
4	3.8	24.19	14.00	57.88
5	2.8	9.68	9.49	98.04
6	2.6	7.75	7.58	97.91
7	3.5	18.90	12.90	68.25
8	4.1	30.39	17.00	55.94
9	2.9	10.76	10.44	97.00

10	3.9	26.16	16.00	61.16
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Table 4.1 was gotten by Using  $P = IV$  to calculate the generator power  $P_g$ , where  $I$  and  $V$  = the current and voltage measured at a particular wind speed (using the multimeter); the wind power was calculated using equation (3.5) and the overall

efficiency is gotten using the formula  $\eta = \frac{\text{generatorpower}(P_g)}{\text{windpower}(P_w)}$

The graph in Figure 4.4 shows a quadratic relationship between the wind power ( $P_w$ ) and wind speed ( $v$ ), it could be observed from the trend line that an increase in wind speed results in an increase wind power.

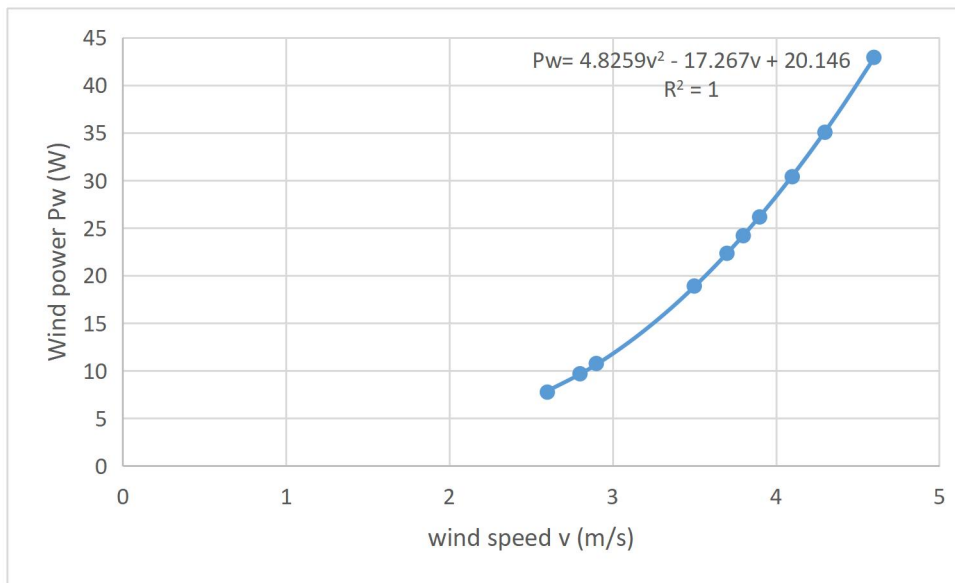


Figure 4.4: Wind Power variation with Wind Speed

The graph shown in Figure 4.5, indicates that an increase in wind power ( $v$ ) results in an increase in power derived from the generator( $P_g$ )

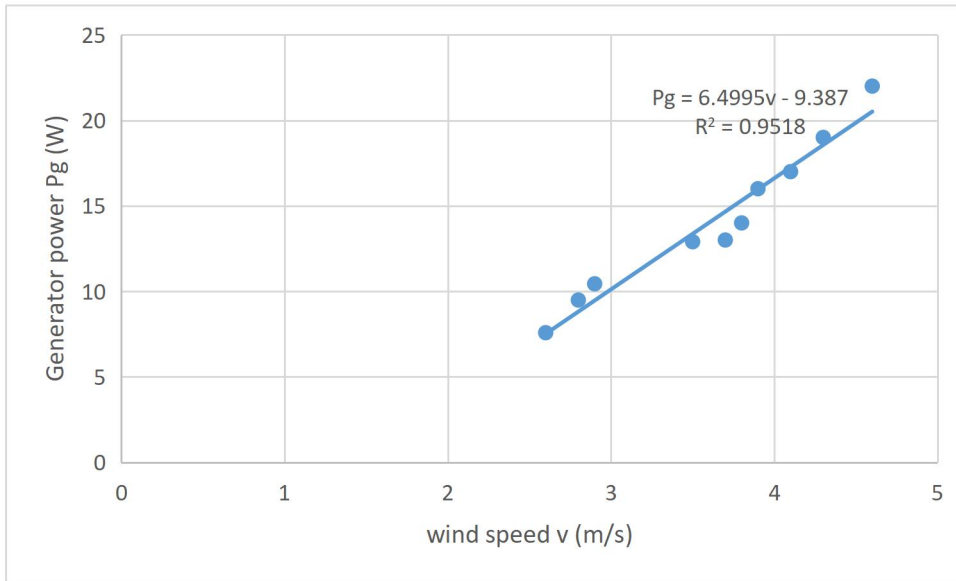


Figure 4.5: Generator Power Variation with Wind Speed .

From the trend line in the graph shown in Figure 4.6, it can be observed that there is an inverse quadratic relationship between the generator power ( $P_g$ ) and the overall efficiency ( $\eta$ ), the overall efficiency of the VAWT decreases as the generator power increases.

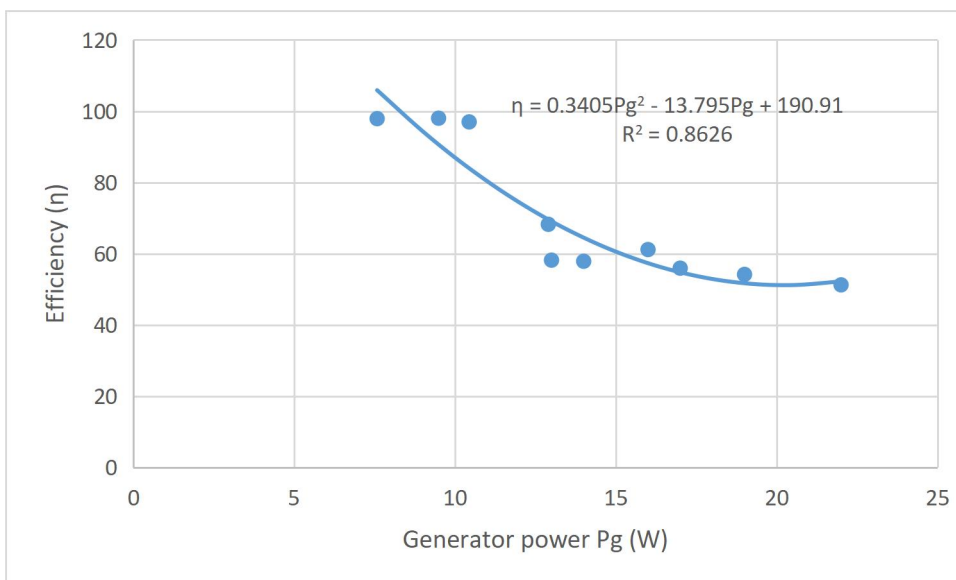


Figure 4.6: Efficiency Variation with Generator Power

## **4.2 Discussion**

The results shows that reasonable amount of voltage can be generated at relatively low wind speed. The deviation observed in the voltage produced as wind speed increased is as a result of the orientation of the rotor blade against the wind. The overall efficiency of the system can be observed to decrease with an increase in power generated indicating the suitability of this turbine for low speed region.

## CHAPTER FIVE

### CONCLUSION AND RECOMMENDATION

#### 5.1 Conclusion

The ability for the wind turbine to generate reasonable voltage at a relatively low wind speed makes it an excellent power generation device in areas characterized by low average wind speed (Western Nigeria). Also, its simple size and construction makes it easier and cheaper to maintain. From the results obtained, it was concluded that the fabricated savonius wind turbine is suitable for usage in towns, on rooftops, highway lights and many other areas where prone to low wind speed. A significant advantage of the machine is that it can be used by various users with a relatively low budget.

This work and the results obtained so far are very encouraging and reinforce the conviction that vertical axis wind energy conversion systems are practical and potentially very contributive to the production of clean renewable electricity from the wind even under less than ideal sitting conditions.

#### 5.2 Recommendations

- i. It is highly recommended that the rotor blades of the turbine should have a relatively light weight so as to ensure free rotary motion of the blades when placed in the direction of the wind. Lighter materials like PVC, Aluminium and other materials lighter in weight and with good rigidity should be considered for the rotor blade design.

- ii. There should also be a braking mechanism to impede the rotation of the rotor blades when the wind speed becomes too much or when it is not in use.
- iii. A power storing device (like battery) should be used to store power when the turbine is not use.
- iv. The generator should be such that can produce a maximum output at a relatively low revolution per minute.

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