Open Access Journal

Journal of Sustainable Research in Engineering Vol. 2 (1) 2015, 23-35

Journal homepage: www.jkuat-sri.com/ojs/index.php/sri/index

Design and Testing of a Low Cost and Higher Efficient Savonius Wind Turbine's Rotor Blade for Low Wind Speed Applications

Alice A. Kasera[1*], Francis X. Ochieng[1] and Robert Kinyua[1]

[1]*Institute of Energy and Environmental Technology, JKUAT, P. O. Box 62000-00100, Nairobi, Kenya*

**Corresponding author – Email: alice2007kasera@yahoo.co.uk*

Abstract Studies indicate that vertical axis wind turbines provide a more reliable energy conversion technology as compared to horizontal axis wind turbines, especially in areas of lowly rated and/or uncertain wind speeds. The challenge however is the development of an efficient Savonius rotor blade which is affordable to low income earners in Kenya. The different technical designs available in the local market were studied and their effects in terms of noise, shadows and impacts on birds and wildlife analyzed. The objectives of this research were thus to design and develop a Savonius rotor blade with locally available materials and compare its performance and production cost with the existing blades. The blades were made using glass reinforced fibre because of the material's light weight. This factor enabled the rotor to rotate at very low wind speeds, it is also long lasting and does not rot hence can survive in all weather conditions. A prototype rotor blade was fabricated, tested and an efficiency of 29% was achieved. Further modification was done and a more efficient rotor blade was fabricated which achieved an efficiency of 45%. A maximum power output of 111.64 W at a wind speed of 8.57 m/s with line voltages of 75 V, 85 V, 81 V and currents of 0.68 A, 0.88 A and 0.85 A respectively for line L1, L2 and L3 were obtained when the blade was connected to a three phase generator. The line voltages and currents obtained were with a torque of 143.8 N-m. A field test was also done at Ngong hills at a height of 2460m (8070 ft) above the sea level and a maximum wind speed of 6.44 m/s was reached at the time of testing. Voltage and current linesof 57.6 V, 57.98 V, 57.60 V and 0.88 A, 0.90 A and 0.80 A were recorded for each line giving a maximum output power of 85.95 W. The Vac from the generator was then rectified by a bridge rectifier and a maximum voltage obtained was 10.5 Vdc which was then used to charge a 12 V dc lead battery. The battery was fully charged after 11 hours and 36 minutes and used to light a 12Vdc bulb for 7 hours. The total cost of developing the rotor blade was Kshs 79,800 which was found to be 58.5 % cheaper than rotor blades in the local market of the similar rating. The above tests led to a conclusion that it is possible to locally develop a wind conversion technology that is affordable, efficient and adaptable for Kenya's average wind speed of 4 m/s.

Keywords Energy conversion technology, green energy, non-renewable, Savonius, Vertical Axis Wind Turbine.

1. Introduction

A wind turbine is a device that utilizes wind energy to generate mechanical or electrical power. There are two types of wind turbines: Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT).
HAWTs are the most commonly known types of wind turbines which operate parallel to the direction of thewind whereas VAWTs rotors operate perpendicular to the direction of wind and are very unpopular [1], [2].

This paper focuses on VAWTs and specifically Savonius wind turbine which are not popular despite its advantages. An efficient Savonius rotor blade was therefore designed to produce power that could charge a 12V dc lead battery for domestic applications. This research is suitable for most rural areas which are yet to be connected to the national grid and also to individuals who want to limit their utility power bills.

A survey was done on the existing wind turbines, their cost, efficiency and marketability. It was then discovered that HAWTs are more popular than VAWTs despite the latter being simpler, cheaper to construct, easy to operate and maintain, it can also operate in all wind direction without yaw mechanism. VAWTs are also known to be less noisy hence does not interfere with any inhabitant [3]-[6].

Application for the Savonius rotor have included pumping water, driving electrical generator, providingventilation, and agitating water to keep ponds ice- free during winter [7]-[11].The design for this research was used to drive a direct drive generator to produce an electrical output.

2. Methodology

Figure 1 shows a flow chart of activities that were carried out during the design, development and testing of the Savonius rotor blade.

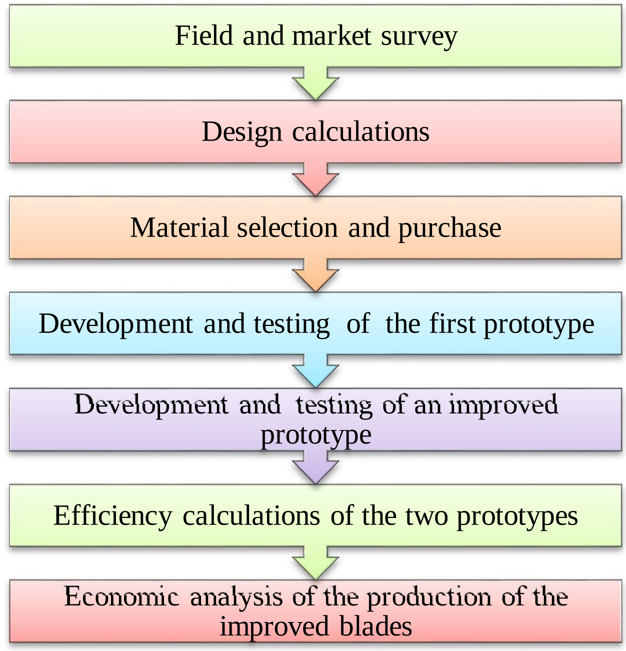

Fig. 1. Activities carried out during the research period.

2.1 Field and Market Assessment

A survey was done on small wind energy systems available in Kenya. Six local manufacturers, seven dealers, Six Customers (end users) and three institutions that support the growth of renewable energy were identified. Of the stakeholders mentioned, three manufacturers, four dealers, three customers and two institutions were contacted. The rest were not reached because their products are the same as the ones visited. Amongst the areas of interest included design procedures, fabrication, testing, challenges and opportunities in the market. Figures 2-4 show wind turbines rotor blades designs found in the market.

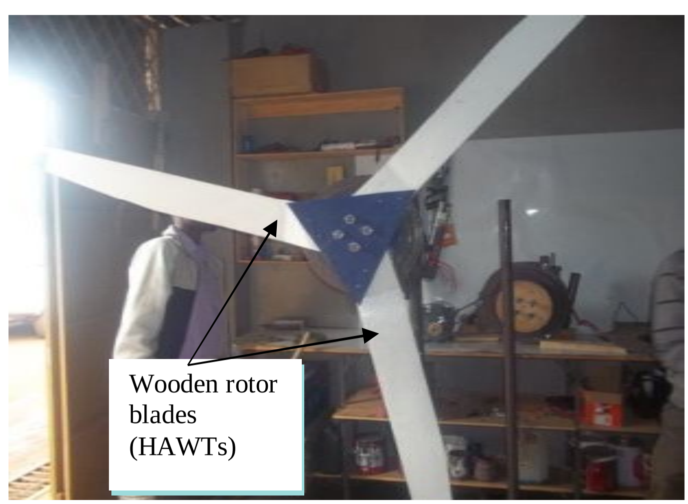

Fig. 2. RIWIK-EA

They locally manufacture three-bladed HAWT from wood and uses a direct drive generator to convert the mechanical rotation of the blade to electrical energy which is then connected to the respective loads depending on the customer's demand. Their main challenge is the high taxation imposed on the permanent magnet which is used in the direct drive generator. Due to this, the final installation of such a complete wind turbine becomes very expensive.

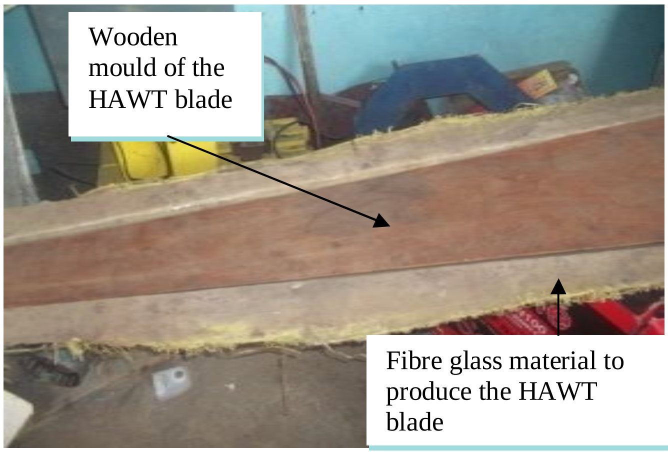

Fig. 3. Craftskills (K) LTD

They also make three- bladed HAWTs from fiber glass material with wood as the mould. They use induction motors with matched gears to convert the mechanical rotation of the blade to produce electrical energy to the load. Their main challenge is that the motors are very heavy and must be installed at the top of the tower, which makes the whole structure weak and sometimes fall in case of bad weather. Servicing of the motors and gearing systems is also not easy due to the inaccessibility of the unit.

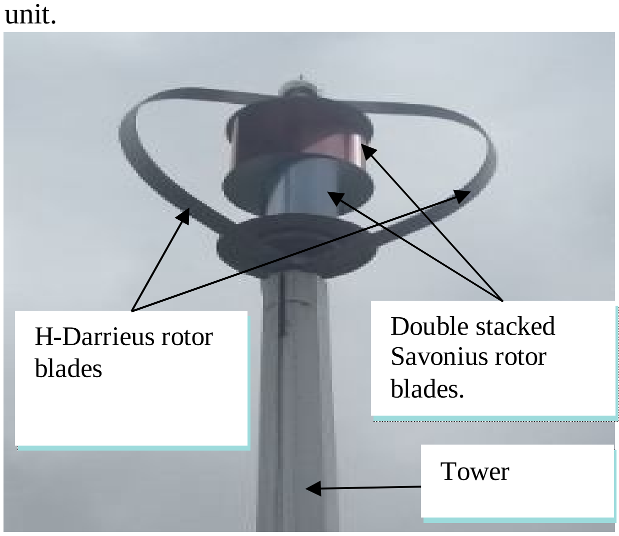

Fig. 4. Powertechnics (K) LTD

This stakeholder imports Maglev type of wind turbines and all the accessories as per the customer's demand. They assemble, test and install the turbine at the customer's location/site. The main challenge they face is the high shipping cost which eventually makes the turbine expensive and less affordable.

2.2. Rotor Design Calculations.

From the existing wind turbine's power equation, various blade parameters like diameter, height, chord length and swept area were obtained as calculated using Equations 1-9. Constants like wind speeds, number of blades, aspect ratio and overlap ratio were also determined.

2.2.1. Wind Speed

The three wind speed parameters that were used in this project are: cut-in wind speed, rated wind speed and cut-out wind speed [12], which are related to the power performance as shown in Equation 1-3.

$$V_{cut\text{-}in} = 0.5\ V_{avg} \qquad (1)$$

When the turbine starts to produce power. V_{avg} is the average velocity of the wind which is 5m/s according to the study conducted by Saoke et.al in 2011, [13]. Therefore,

$$V_{cut\text{-}in} = 0.5 \times 5$$

$$= 2.5\text{m/s}$$

$$V_{Rated} = 1.5\ V_{avg} \qquad (2)$$

When the turbine reaches its maximum output power.

$$V_{Rated} = 1.5 \times 5$$

$$= 7.5\text{m/s}$$

$$V_{cut\text{-}out} = 3.0\ V_{avg} \qquad (3)$$

When the turbine cuts out its further production toprevent damage at higher speeds.

$$V_{cut\text{-}out} = 3.0 \times 5 = 15\ \text{m/s}$$

2.2.2 Power and Power Coefficient

Power from the wind is the power that can be extracted from the wind with air density being constant except in very high extreme climatic locations at high altitudes. Power available from the wind is proportional to the cube of wind speed.

$$P = 0.5 \times \rho \times A \times V^3 \qquad (4)$$

Where:
P= the power available from the wind

ρ = the density at sea level taken to be 1.224 kg/m^3
A = is the area swept by the rotor blade [2].

Equation (4) above is the theoretical power i.e. not all the power can be extracted by the turbine since some of the energy may be lost in gearbox, bearings, generator transmission e.t.c, a coefficient of power (Cp) or efficiency which is known as the Lanchester-Betz limit of 59% is considered [14]. However, practically the highest efficiency achieved stands in the order of 40% to 45% for HAWTs and 30% for VAWTs by the year 2011 according to Jain, P. [15] hence Equation (4) reduces to:

$$P = 0.15 \times \rho \times A \times V^3 \quad (5)$$

2.2.3 Area and Rotor Radius

In 2005, Hayashi et al [15] found out that, the swept area of a Savonius wind turbine is a product of the rotor's diameter and height.

$$A = D \times H \quad (6)$$

where A is the area, D is the diameter and H is the height of the rotor. (All the measurements above are in meters)

Johnson in 2001 [16] also suggested that Savonius rotor performs better when designed with rotor height twice of rotor diameter which leads to better stability with proper efficiencies. Hence:

$$H = 2D \quad (7)$$

By inserting Equation (7) into Equation (6) yields,

$$A = 2D^2 \quad (8)$$

With anticipated power output of 250 W, then up scaling to obtain 500 W and 1000 W, these power values were each inserted in Equation (5) hence, area, diameter and radius were obtained as shown in Table 1.

2.2.4 Number of Blades

Many researchers have proved that the higher the number of blades, the higher the performance of most wind turbines and is true for HAWTs. However it was also found out that a two bladed Savonius rotor has higher performance than a three- bladed Savonius rotor [17-18]. A two- bladed Savonius rotor was therefore designed.

2.2.5 Aspect Ratio

This is the ratio of the rotor height to the width. A large aspect ratio of 3 provide the rotor with good torque. [19]. However for this research, an aspect ratio of 2 was chosen.

$$\text{Aspect ratio} = H/C \quad (9)$$

Where H is the rotor height and C is the width.

2.2.6 Overlap Ratio

This is the ratio of the diameter of the rotor blade to the distance which the blades overlap. For blades of semi-circular cross-section, the appropriate overlap ratio is 20-30%, [19]. A 25% overlap ratio for a semi-circular cross-section was used in this design.

Table 1 is a summary of the calculated rotor blade parameters.

Table 1: Calculated rotor blade parameters

Parameter	1st model Value 1	2nd model Value 2	3rd model Value 3	4th model Value 4
Output power	50W	250W	500W	1KW
Swept area	2.22m^2	3.2m^2	6.5m^2	13m^2
Cut-in-wind speed	2.5m/s	2.5m/s	2.5m/s	2.5m/s
Rated wind speed	7.5m/s	7.5m/s	7.5m/s	7.5m/s
Cut-out- wind speed	15m/s	15m/s	15m/s	15m/s
Diameter	1.05m	1.3m	1.8m	2.55m
Height	2.11	2.46m	3.61m	5.1m
Number of blades	2	2	2	2
Solidity	0.7	0.7	0.7	0.7
Aspect ratio	2	2	2	2
Overlap ratio	0.25	0.25	0.25	0.25

2.3 Research Instruments and Measurements

Table 2 shows the instruments used, their models and the specific areas of application.

Table 2: Details of the research instruments used and their applications

Instrument's name	Model	Application
Optical tachometer	CDT 2000HD	Rotational speed
Anemometer	HD 300-Extech Instruments	Wind speed
Multi-meter		Voltage
Clamp meter		Current
Power analyzer	CA 8333	Analyzing of power from the generator
Cathode Ray Oscilloscope	PM 8334A	Output display in waveforms. Comparison with the power analyzer

2.4 Development of the Rotor Blade

2.4.1 Development of the First Prototype

Using the calculated design parameters from table I, the first prototype was fabricated. Some of the procedures followed included: Folding of the aluminum sheet metal of 1.5 mm thick to correct dimension of the blade; application of wax and associated chemicals to the sheet metal; separation of the glass fibre cloth from the aluminum; drilling; trimming; Joining the blades to the shaft and the stand (tower). Figure 5 and 6 show the blade undergoing fabrication process and a complete prototype being tested respectively.

Fig. 5. The blade being drilled and joined to the live shaft using bolts

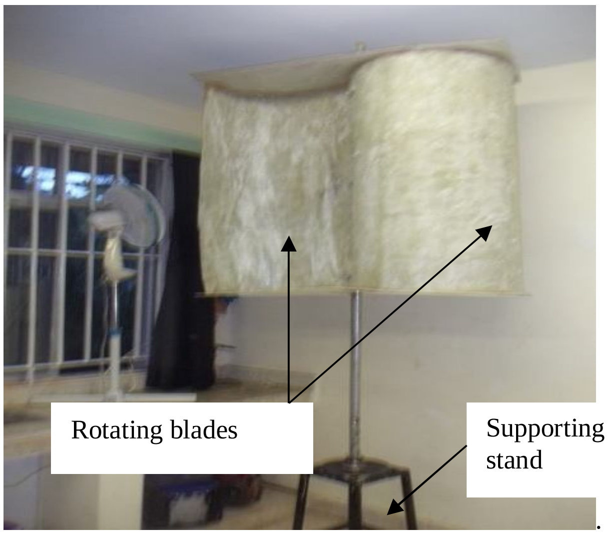

Fig. 6. Complete first prototype being tested.

2.5 Development of an Improved Rotor Blade.

After successful testing and understanding the first prototype, an improved rotor blade was made as per the above parameters in table 1 to produce a maximum power output of 250 W in a professional GRF workshop. The procedures that were undertaken were: A model was made from an ordinary formica curved to the designed specifications. A fiber glass mold was then made by: Cleaning the model; A releasing agent (wax) was applied on the model for easier separation of the fiber-mold from the model; A gel coat was then applied which comprised of polyster resin, erosil powder and calcium carbonate ($CaCo_3$). This was to boost the mechanical strength. When the gel coat was dry, fiber mat was laid on the model followed with an application of polyster resin mixed with a catalyst called MEKP (Methyl, Ethyrol, Kenton Peroxide) which is an accelerator that makes the whole solution hard and dries very fast. The strength of the mould depended on the number of layers of the fiber mat applied one after the other. Four layers gave the desired thickness of the blade. Figure 7 (a) and (b) shows the blade undergoing fabrication process.

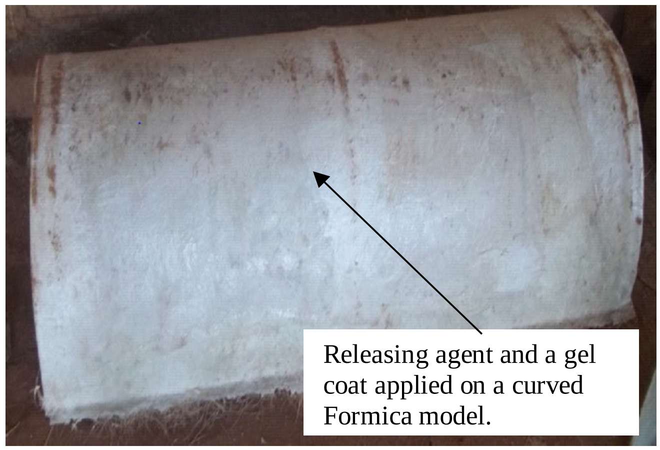

Fig. 7 (a). Application of releasing agent and gel on a Formica mold

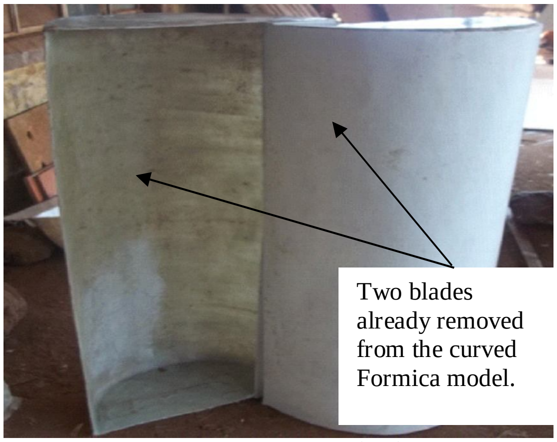

Fig. 7 (b). Improved blades ready for final finishing

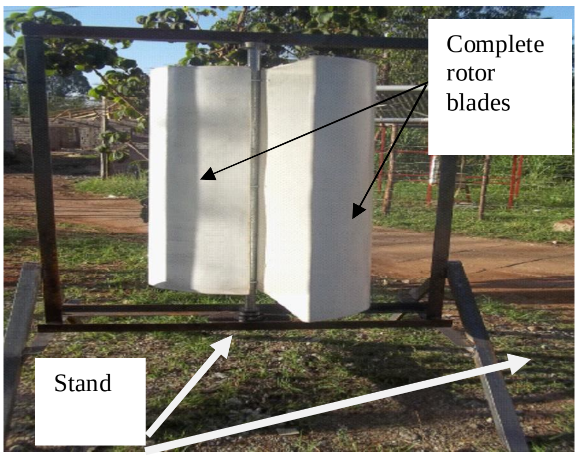

Fig. 8. Complete improved prototype on a stand

2.6 Testing of the Improved Rotor Blade

The improved blade was then connected to a direct drive locally manufactured generator as shown in Figure 9 with the following parameters:

Table 3: Generator’s main parameters [20]

Parameter	**Value**
Output power	1kW
Rated speed	500 RPM
Output Voltage	24V
No. of pole pairs	12
Phase number	3
Inner Rotor disk radius	129 mm
Outer rotor disk radius	175 mm
Rotor diameter	350 mm
Inner stator radius	129 mm
Outer stator radius	240 mm
Stator thickness	10 mm

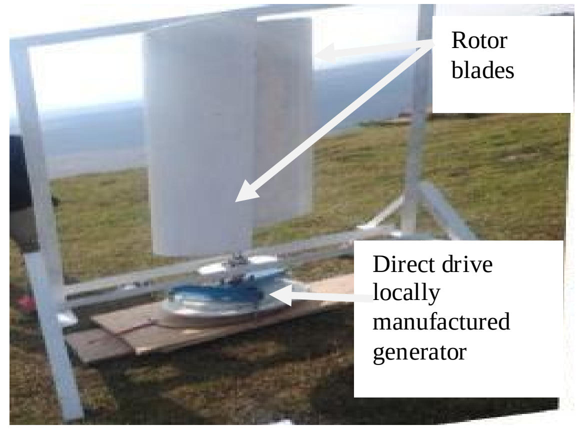

Fig. 9. The rotor blade connected to a direct drive locally manufactured generator.

A power control circuit (invertor) was used to convert the AC voltage from the generator to Dc voltage which was then used to charge a 12 V lead battery as shown in Figure 10. The charging of the battery was monitored using a 12v dc bulb The bulb came ON when the battery was 9.4V and the brightness increased as the battery got fully charged to 12 V as shown in Figure 11.

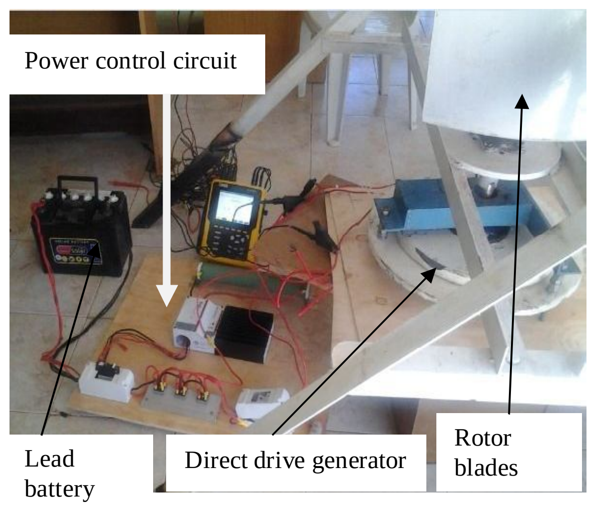

Fig. 10. A complete set-up with a battery charger control circuit and power analyzer.

Figure 12 is a flow diagram of the complete set-up.

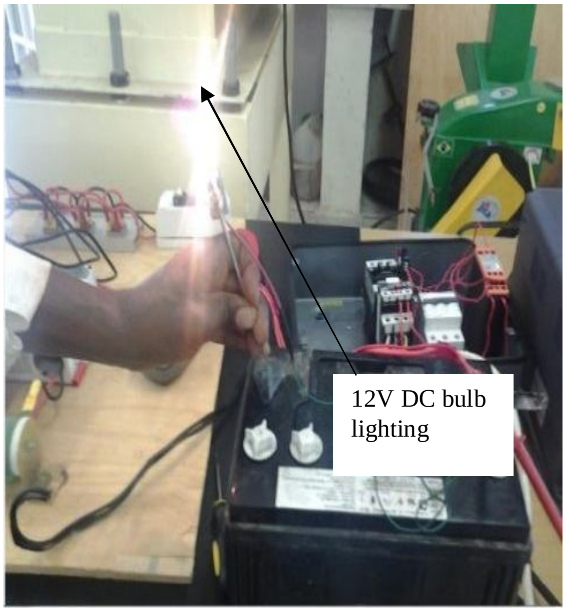

Fig. 11. Bulb lighting as an indication of a charged battery

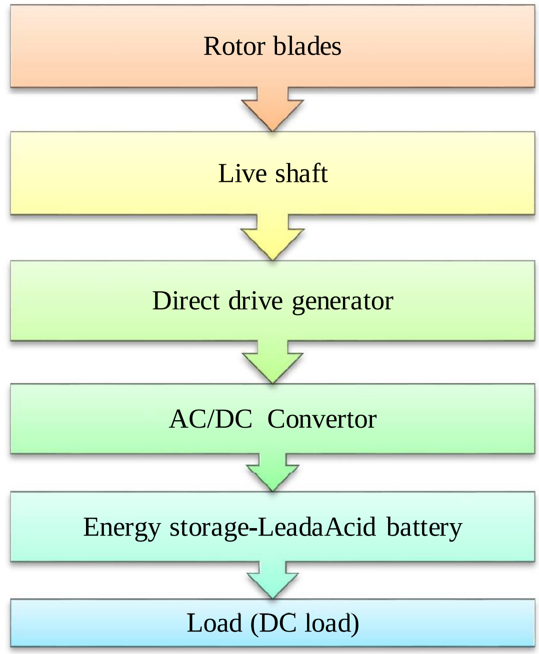

Fig. 12. Flow chart of a complete set-up

3. Results and Discussion

Table 4 and 5 show the results from the first and the second prototypes respectively

Table 4: Results from the first prototype

Wind speed	Rotational speed	V1	V2	V3	A1	A2	A3	Power (W)
(m/s)	0.00	---	---	---	---	--	--	------
2.10	0.00	---	---	---	---	--	--	------
2.69	4.5	---	---	---	---	--	--	------
3.25	5.4	---	----	---	---	---	--	------
4.92	10.8	1.3	1.5	1.1	0.6	0.5	0.6	1.3
5.44	10.9	1.9	1.8	1.5	0.9	0.6	0.8	2.3
5.88	11.3	2.4	2.3	1.7	1.2	0.9	1.0	5.6
6.07	11.4	2.7	2.5	2.2	1.5	1.3	1.0	5.4
6.31	11.5	3.2	2.9	2.8	1.7	1.5	1.3	8.1
7.62	11.7	3.6	3.1	3.1	1.8	1.4	1.5	8.9
7.82	11.9	4.7	4.2	4.0	1.9	1.5	1.7	12.7
8.07	12.3	5.0	4.8	4.7	1.9	1.6	1.7	14.4
8.57	12.3	5.5	5.2	4.7	1.5	1.7	1.5	13.9
9.48	12.7	5.4	5.2	5.0	1.4	1.5	1.3	12.6
10.32	12.9	5.3	5.1	5.0	1.5	1.4	1.3	12.4
10.61	13.2	5.0	4.7	4.6	1.4	1.3	1.0	10.2
11.30	13.7	4.9	4.6	4.5	1.2	1.0	0.8	8.1
11.84	14.3	4.5	4.2	4.0	1.0	1.0	0.5	6.1
12.90	15.9	4.0	3.7	3.7	0.8	0.7	0.2	3.7
13.7	17.2	4.0	3.9	3.5	0.5	0.3	0.1	2.0

Table 5: Results for the second prototype

Wind speed	**Blade rotational speed**		**Voltage from the generator**			**Current from the generator**			**Calculated power (P_T)**	**Voltage to the Battery**		**Voltage across the battery**
(m/s)	RPM	Torque	V_1	V_2	V_3	A_1	A_2	A_3	Watts	V_{DC}	I_{DC}	V_{DC}
2.10	41.96	8.6	8	10	10	0.59	0.51	0.56	8.93	0.14	0.49	1.04
2.69	84.62	14.14	14	15	12	0.61	0.55	0.56	13.59	2.9	0.49	1.90
3.25	123.0	20.69	28	31	28	0.58	0.57	0.58	57.70	4.6	0.49	2.3
4.92	153.9	47.41	78	81	77	0.53	0.56	0.55	74.40	5.3	0.49	4.7
5.44	171.9	57.96	75	80	76	0.61	0.61	0.61	83.02	6.6	0.49	5.3
5.88	187.5	67.71	77	82	77	0.62	0.58	0.64	83.47	7.14	0.49	6.8
6.07	202.4	72.16	76	83	78	0.64	0.63	0.64	87.01	7.48	0.49	7.10
6.31	211.9	77.98	77	84	80	0.62	0.64	0.62	87.09	8.25	0.47	7.24
7.62	221.9	113.71	78	85	80	0.67	0.65	0.65	92.02	8.71	0.47	8.30
7.82	234.6	119.76	77	85	81	0.65	0.80	0.83	106.50	9.10	0.48	9.07
8.07	243.2	127.54	77	85	81	0.66	0.87	0.84	110.70	9.4	0.48	9.40
8.57	251.0	143.8	75	85	81	0.68	0.88	0.85	111.64	10.5	0.49	10.39
9.48	275.4	176.00	75	84	81	0.67	0.87	0.84	109.80	10.43	0.49	12.0
10.32	282.9	208.57	71	83	78	0.65	0.85	0.93	108.36	9.85	0.49	11.5
10.61	290.8	220.46	70	82	76	0.62	0.90	0.89	105.62	9.83	0.47	11.9
11.30	291.6	250.07	65	79	74	0.70	0.85	0.85	100.57	8.74	0.47	11.3
11.84	300.4	274.54	64	78	72	0.70	0.85	0.81	97.08	8.12	0.47	11.0
12.90	307.9	325.90	61	75	70	0.74	0.80	0.80	92.66	7.16	0.49	12.0
13.7	311.0	367.57	58	75	69	0.75	0.73	0.87	85.82	7.09	0.49	12.7

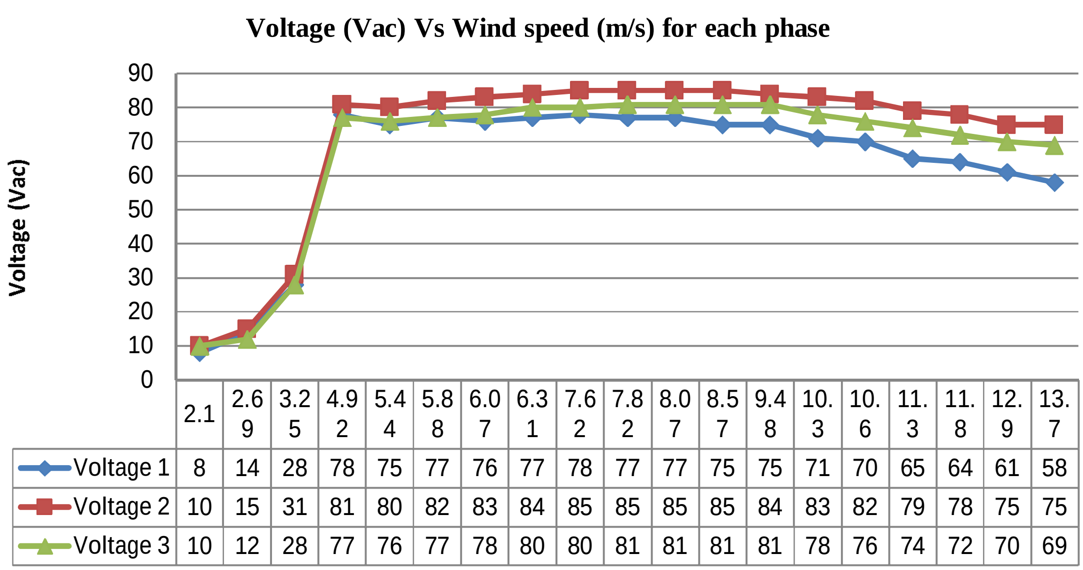

Fig. 13. Voltage verses wind speed of each phase from the improved blade

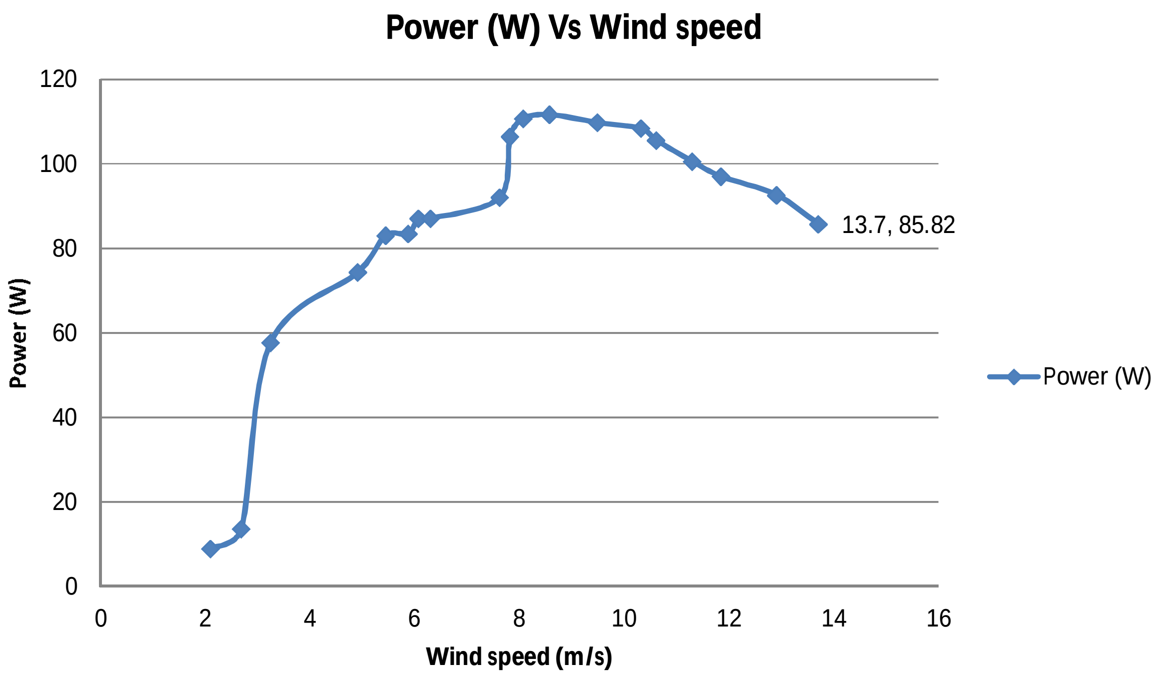

Fig. 14. Power –wind speed curve from the improved blade.

Table 5 is the laboratory results from the improved blade. The highlighted yellow row is the highest results (voltages, current and power) achieved at a wind speed of 8.57 m/s. The results are also represented graphically in Figures 13 and 14 is the calculated power verses wind speed of the same results and Figure 15 is the voltage waveform display obtained at the rated wind speed of 8.57 m/s.

From Table 5, a cut-in wind speed was found to be at 2.1 m/s which was below the designed cut-in wind speed. This was obtained because of the material used. GRF is known to be very light and requires very little wind speed for it to start. Amongst the rotor blades found in the market, only one manufacturer uses glass fibre to produce the horizontal axis blades.

From Figure 13, linear relationship was seen at first between the wind speed and the voltage output. Initially the blade was affected by the turbulence but later stabilized at 5.44 m/s. The cut-in wind speed was designed to be 2.5 m/s however upon testing; a cut-in wind speed of 2.1 was obtained. The designed rated wind speed was 7.5 m/s which was achieved between 6.31 m/s and 8.07 m/s giving an average rated wind speed of 7.2 m/s. At this wind speed line voltages of 7.7 V, 8.5 V and 8.1 V were obtained across the three lines. The results showed that the maximum power was obtained at 7.2 m/s and remained constant until the wind speed reached 8.07 m/s. Further increase of wind speed reduced the output voltage. This is true from a typical power curve of a wind turbine.

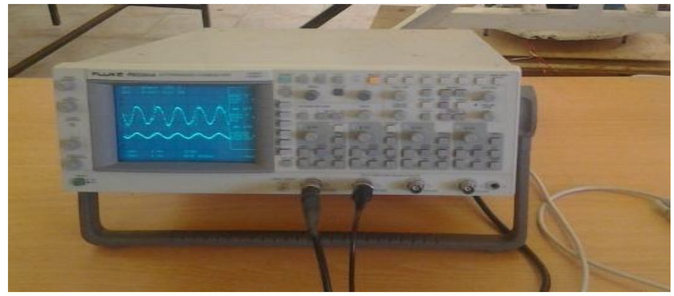

Fig 15. CRO display of voltage from the generator

3.1 Efficiency Calculation of the Blades' Performance. This is represented as the C_p value which is defined as the part of the total available power that is actually taken from the wind and is mathematically represented as:

$$C_p = \frac{captured\ mechanical\ power\ by\ blades}{Available\ power\ in\ the\ wind} \qquad (10)$$

For the first prototype:

$$C_p = \frac{14.5}{50} = 0.29$$

For the second prototype:

$$C_p = \frac{111.64}{250} = 0.45$$

The use of glass fibre in this research increased the efficiency from the current 40% [16] to 45 %.Fabrication which was done in a fibre glass workshop increased the efficiency from 29% to 45 %.

Figure 16 illustrates the power output of the two blades. The second prototype (improved) showed higher results hence higher efficiency.

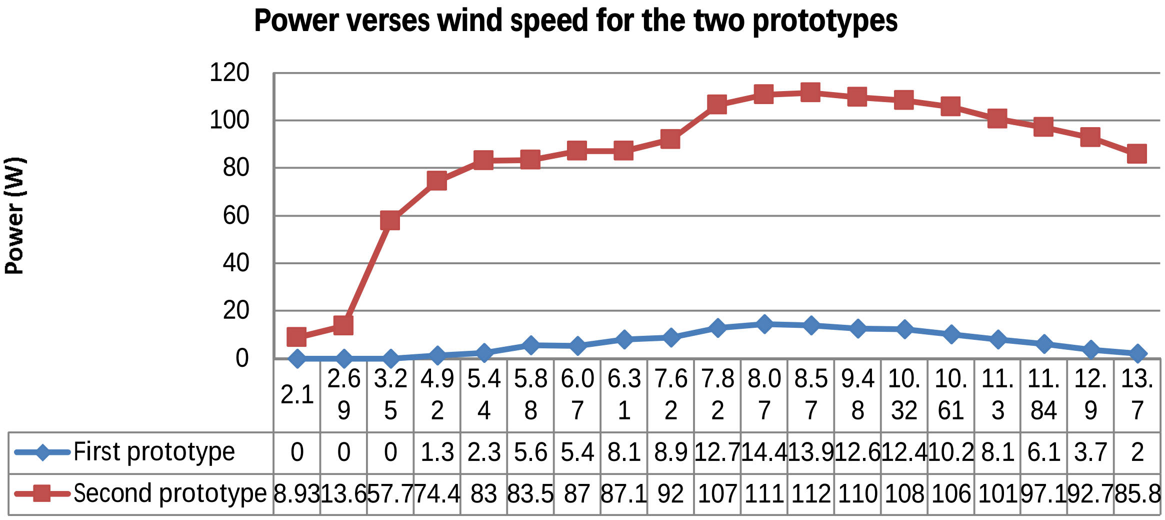

Fig. 16. Power output comparison from the two prototypes.

3.2 Economic Analysis of the Rotor Blades production

Table 6 is the breakdown of the total amount used to fabricate the complete rotor blade and its accessories.

Table 6: Details of the total amount spent

Part description	Quantity	Amount (Kshs)
Blades	2	53,000
Support structure		10,000
Bearing and housing	2	4,500
Nuts and bolts	7	2,300
Miscellaneous		10,000
Total		**79,800**

The above data is presented in a pie chart as shown in Figure 17.

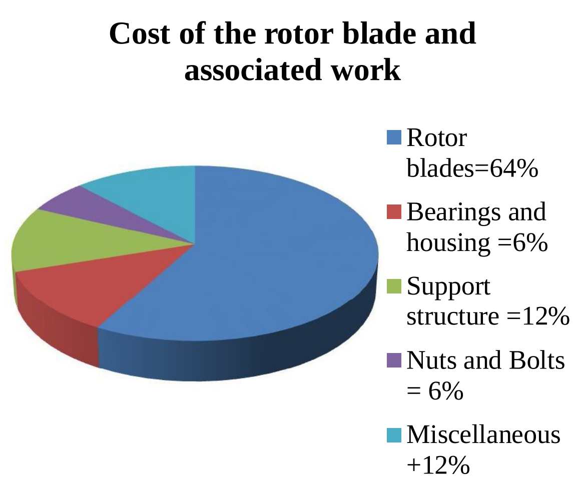

Figure 16. Cost of rotor blade and other associated work.

Table 7 shows the prices of wind turbine components in Kenya's market. From this table, a rotor blade of the same rating costs Kshs. 192,500/=. Comparing this amount with the author's design of Kshs. 79,800/=, 58.5% cheaper rotor blade was fabricated.

Table 7: Prices of wind turbine components in the Kenyan market

Installed wind turbine capacity (W)	Rotor cost	Generator	Miscellaneous	Support structure	Application (load)	Application-facility	Total cost (kshs)
200-300	192,500	70,000	35,000	52,500	lighting and small domestic appliances	domestic households	350,000
400	247,500	90,000	45,000	67,500	lighting and domestic appliances	domestic households	450,000
700-900	302,500	110,000	55,000	82,500	lighting, entertainment and ICT equipment	schools and hospitals	550,000
1000-1500	412,500	150,000	75,000	112,500	lighting, entertainment and ICT equipment	schools and hospitals	750,000
2000-3000	660,000	240,000	120,000	180,000	lighting, entertainment, ICT equipment and water pumping	schools, hospitals and small farms	1.2M

4.0 Conclusions

Very little is known on VAWTs. This was seen when all the local manufacturers concentrate on HAWTs. More awareness should be done through academic institutions, workshops and even through government initiatives like sponsoring more projects. The Savonius rotor designed has a place in electricity generation despite its relatively low efficiency as compared to other VAWTs and HAWTs rotors. On the other hand it has more advantages like being cheap, simple to design, construct and maintain. It is also robust depending on the type of material used for construction.

There was a significant change in both torque and power output when the wind speed reached 3 m/s. The cut-in-wind speed for this type of rotor blade is very small of approximately less than 2.5 m/s. This is seen when the blades started rotating at 2.1 m/s and produced power of 0.14v dc hence a characteristic of GRF being stiff, strong and light was proved. GRF is considered as the best material for manufacturing the rotor blades of a wind turbine.

The efficiency from the previous research work was increased from the current 30 % to 44%. This was due to the use of a unique material (GRF) which is not commonly used.

The cost of developing the designed blade was reduced by 58.5% compared to the Kenya's price for a similar rating. This was achieved by fabricating the blades using the local available materials.

It is possible to locally develop a wind conversion technology that is affordable, efficient and adaptable for Kenya's average low wind speed.

Acknowledgements

The authors thank the National Commission for Science and Technology and Innovation (NACOSTI) for funding this research project under Science, Technology and Innovation (ST & I) – 4TH study grant number: NCST/5/003/4TH STI CALL/037.

References

[1] J. Twidell and T. Weir, Renewable Energy Resources. New York: Taylor and Francis, 2006.

[2[S. Mathew ,*Wind Energy Fundamentals, Resource Analysis and Economics,* Verlag New York:springer, 2006.

[3] C. S. Solanki, "*Renewable energy technologies: A practical guide for beginners.* New Delhi: Asoke K. Ghosh. Pg.103-106. 2008.

[4] J. P. Abraham, B. D. Plourde, G. S. Mowry, W.J. Minkowcyz and E.M. Sparrow."*Summary of Savonius wind turbine development and future applications for small-scale power generation"* . Minnesota: American Institute of Physics, 2012.

[5] J. DeCoste, D. McKay, B. Robinson, S. Whitehead, and S. Wright. *Vertical Axis Wind Turbine.* Dalhousie,2005.

[6] V .J.Modi, N. J. Roth and A. Pittawala."Blade configuration of the Savonius rotor with application to irrigation system in Indonesia". GA, USA, 1981.

[7] R. Gogoi, R. Ballabh and K. Das. " Experimental investigation of three-stage Savonius Rotor with Concentrator". *International journal of mechanical Engineering and Research,401-406,* 2013.

[8] S. J. Savonius. "*THE S -ROTOR AND ITS APPLICATION"*. Multi Science Publishing, 2007.

[9] R. N. Clark, V. Nelson, R. E. Barieau and E. Gilmore. "Wind turbines for irrigation pumping". *Journal of energy*, 104-108, 1981.

[10] A. Zingman,"*Optimization of a Savonius Rotor Vertical Axis Wind Turbine for use in Water Pumping Systems in Rural Hinduras".* New Delhi: Arong O. Zingman, 2007.

[11] P. Jain," *Wind Energy Engineering".* New York: The McGraw-Hill Companies, 2011.

[12] C .O. Saoke, J. N. Kamau and R. Kinyua. "Wind speed distribution, estimation of wind shear exponent and roughness parameter for Juja, Kenya". *Journal of Environmental Sciences and Resource Mangement.* Vol (2), pp 121-137.2011.

[13] J. F. Manwel, J.G. McGowan and A.L. Rogers. "Wind Energy Explained: theory, design and application". England: John Wiley & son Ltd., 2009.

[14] T. Hayashi, Y. Li, and Y. Hara, "Wind Tunnel Tests on a Different Phase Three-Stage Savonius Rotor", *JSME International Journal*, series B, 48, No. 1, pp.9-16, 2005.

[15] U .K. Saha, S. Thotla and D. Maity. "Optimum design configuration of Savonius rotor through wind tunnel experiments". *Journal of Wind Engineering and Industrial Aerodynamics*, 2008.

[16] Z .Z. Zhao, T. Zheng, X. Y. Xu, W. M. Liu and G. X. Hu. "Research on the Improvement of the Performance of Savonius rotor based on numerical study Sustainable Power Generation and Supply". *Supergen'09.Nanging*,2009.

[17] V. J. Modi, MSUK. Fernando and T. Yokomizo, *An integral approach to design of a wind energy operated integrated system,* 1998.

[18] P. O. Akello, F. X. Ochieng and J. N. Kamau, "Performance Analysis of a Direct Drive Permanent Magnet Generator for Small Wind Energy Applications", *Journal of Sustainable Research in Engineering* 1 (3) pp. 1-9, 2014.