Open Access Journal

Journal of Sustainable Research in Engineering Vol. 2 (3) 2015, 92-99

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

Development of a Low Cost Rotor Blade for a H - Darrieus Wind Turbine

Haroub Ahmed Haroub[1*], Francis Xavier Ochieng[1] and Joseph N. Kamau[2]

[1]*The institute of Energy and Environmental Technology (IEET) – JKUAT, P. O. Box 62000-00200, Nairobi, Kenya.*

[2] *Department of Physics, JKUAT, P. O. Box 62000-00200, Nairobi, Kenya.*

**Corresponding author- E-mail: bharoub@gmail.com*

Abstract A three bladed vertical axis wind turbine with a target performance of 500W was designed and fabricated. The material used was Glass fiber reinforced plastics (GFRP). The study focused on Blade design where a numerical optimization process of the design was done to come up with parameters for the rotor blades. The chosen sizing was a rotor diameter of 2m and length of 1.6 m with a chord length of 0.2 m. A NACA 0021 air foil was chosen because of its thickness (21% of chord) and its self-starting behavior. Blade production process involved making of the master blade to form the mould. The mould was used to make the blade copies that was later laminated, dried, trimmed, and smoothed. The power coefficient was tested using a wind fan with wind speeds ranging from 4 m/s to 15 m/s. A direct drive Axial Flux Permanent Magnet (AFPM) generator with a rated RPM of 280 developed for small scale vertical axis wind turbine (VAWT) was coupled to the turbine rotors to determine the electricity generation capacity. A battery was used to provide the load in the experiment and the synchronized frequency controlled by an inverter. A speed of 14 m/s gave the highest power of 190 W at 280 rpm, 12 m/s gave the highest power as 156 W at 230 rpm, 10 m/s gave the highest power as 120W at 180 rpm while 8 m/s gave the highest power as 96 W at 140 rpm. The turbine torque was 1.56Nm at an RPM of 175. It was noted the turbine has high torque but low rotational speed and with a high gear ratio generator may achieve higher power output. The cost of production of the Rotor blade with all its components was approximately Kshs. 50,000. This cost included buying of the shaft, hubs and bearing totaling to Kshs. 25,000 and the blade production cost Kshs. 21,000. When compared to a HAWT turbine of same sizing cost in the local market the price ranges from KSH 100000 to KSH 200000. Most of the local suppliers do not supply VAWT; the international price of VAWT of same sizing is about US$ 1,000. In conclusion the blade produced in this study is cheaper when compared to locally produced HAWT and VAWT prices in international market.

Keywords Vertical axis turbine, rotor blade, H-Darrieus, Kenya.

1. Introduction

There is significant potential to use wind energy for grid connected wind farms, isolated grids (through wind-diesel hybrid systems) and off-grid community electricity and water pumping in Kenya. An average of 80-100 small wind turbines (400W) have been installed to date, often as part of a Photovoltaic (PV)-Wind hybrid system with battery storage[1]. Most of these wind turbines are imported although a few Kenyan companies have recently started locally manufacturing wind turbines ranging from 150W – 6kW and have installed 50 turbines to date. Wind pumps are more common than wind turbines, 2 local companies manufacture and install wind pumps. Installations are in the range of 300-350 [2].

According to Global Tracking Framework report [3] under the Sustainable Energy for All Initiative to measure levels of energy, development of market for locally manufactured small energy technologies was noted to be one of the indicators to attain energy security and exploitation of renewable energy sources. The Government of Kenya Wind Resource Assessment report [4] shows average wind speeds of 4 - 5 m/s that could provide excellent opportunity for enhancing access to modern energy sources in rural areas using renewable energy sources. However, the cost of acquisition is proving to be inhibiting as demonstrated by the slow uptake of the technology given the massive potential the country holds [5][6]. The current price for a 0.4 KW wind turbine made of cast aluminium and carbon fibre is between KShs 76,000 and KShs 110,000 and 1KW costs KShs 450,000.

The Kenya national energy policy objective is to ensure adequate secure, affordable, sustainable and reliable supply of energy to meet national and county development needs, while protecting and conserving the environment. The policy also aims to prioritize and promote the development of local technologies in energy development and delivery. However this aspect is yet to be fully realized and some of the hindering factors include low adoption of renewable energy technologies despite the huge potential the country have. The low adoption is accelerated by the high cost of imported turbines. Currently, there exist small scale Pico-wind turbine manufactures, though efficiency is noted to be pretty low, these systems have not really penetrated the market. The existence of these manufacturers is rarely known by potential users in addition the pricing of these turbines is no clear and consistent [7].

To facilitate uptake of these technologies, development of efficient low-cost wind turbines stands to be a major determinant coupled with a strong strategy to promote commercialization on these technologies.

The straight bladed Darrieus vertical axis wind turbine (VAWT) is very attractive for its low cost and simple design [8]. Anyone with common workshop materials could build and would make a difference in the living conditions of people with low income. This justifies the need to undertake this research.

2. Theoretical Optimization

The power of the wind is proportional to air density, area of the segment of wind being considered, and the natural wind speed. The relationships between the above variables are provided in equation (2.1) below [9].

$$P_w = \frac{1}{2}\rho A u^3 \qquad (1)$$

Where;

Pw: power of the wind (W)

ρ : air density (kg/m3)

A: area of a segment of the wind being considered (m²)

u: undisturbed wind speed (m/s)

At standard temperature and pressure (STP = 273K and 101.3 kPa), equation 1 reduces to equation 2

$$P_w = 0.647Au^3 \qquad (2)$$

A turbine cannot extract 100% of the winds energy because some of the winds energy is used in pressure changes occurring across the turbine blades. This pressure change causes a decrease in velocity and therefore usable energy. The mechanical power that can be obtained from the wind with an ideal turbine is given in equation 3 [10]:

$$P_m = \frac{1}{2}M\left(\frac{16}{27}\right)Au^3 \qquad (3)$$

Where;

Pm: mechanical power (W)

In equation 3, the area, A, is referred to as the swept area of a turbine. For a VAWT, this area depends on both the turbine diameter and turbine blade length. For an H-type VAWT the equation for swept area is:

$$A_s = D_t l_b \qquad (4)$$

Where:

A_s: swept area *(m²)*

D_t: diameter of the turbine *(m)*

l_b: length of the turbine Blades *(m)*

The constant 16/27 = 0.593 from equation (3) is referred to as the Betz coefficient. The Betz coefficient tells us that 59.3% of the power in the wind can be extracted in the case of an ideal turbine [11]. However, an ideal turbine is a theoretical case. Turbine efficiencies in the range of 35-40% are very good, and this is the case for most large-scale turbines. It should also be noted that the pressure drop across the turbine blades is very small, around 0.02% of the ambient air pressure. Equation (3) can be re-written as;

$$P_m = C_p P_w \qquad (5)$$

Where *Cp:* coefficient of performance.

The coefficient of performance depends on wind speed, rotational speed of the turbine and blade parameters such as pitch angle and angle of attack. The pitch angle for a HAWT is the angle between the blades motion and the chord line of the blade, whereas for a VAWT the pitch angle is between the line perpendicular to the blades motion and the chord line of the blade [12]. The angle of attack is the angle between the relative wind velocity and the centerline of the blade. For fixed pitch turbines, these angles do not change and the Cp is directly related to the TSR. A typical Cp value for the turbine design was adopted from the table below. These values were derived from [13].

Table 1: Typical Cp values for various wind turbines

Wind System	Efficiency %	
	Simple Construction	Optimum Design
Multi bladed water pump	10	30
Sail wing water pump	10	25
Darrieus water pump	15	30
Savonius Wind pump	10	20
Small prop-type wind charger (up to 2KW)	20	30
Medium prop-type wind charger (2 to 10KW)	20	30
Small prop-type wind charger (over 10KW)		30 to 45
Darrieus wind Generator	15	20

A model developed using Qblade an open source turbine calculation software seamlessly integrated into XFOIL, an airfoil design and analysis tool. The model helps avoid conducting repetitions and lengthy calculations by hand. The key inputs include TSR, and solidity, as solidity has effects on the chord length and blade height of the airfoil. In order to speed up the optimization process, some of the parameters were fixed. The fixed parameter was the design airspeed and the blade swept area. The wind speed was kept constant throughout the analysis at the average wind speed value for of 6m/s. The blade length and rotor radius have a major contribution in the torque behavior of the turbine as can be deduced from the torque equation. In general as bigger these parameters, bigger the torque produced. These parameters are involved also in the solidity calculation. The solidity becomes an important parameter when scaling down or up wind turbines and also determines the applicability of the momentum model. The radius and blade variation analysis was done maintaining constant swept area.

With a desired power output of 500w simplified equations from the blade element momentum were used to calculate the dimensions of the blade the design values used are as shown in the table 2 below;

Table 2: Sizing for the model inputs

Undisturbed Wind Speed	6 m/s
Density of air	1.204 kg/m^3
Viscosity of air	$1.81\times10\text{-}^{05}$ Ns/ M^2
Rated wind speed	9 m/s
TSR	4
Solidity	0.15
Rotor Diameter	2 m
number of airfoils/blades	3
Blade height	1.60 m
Expected rated power	500 W
NACA air foil	0021
Estimated coefficient of performance	0.1

3. Materials and Methods

The study conducted Field and market assessment of the locally produced small wind turbines in Kenya through Field surveys, interviews and questionnaires. The methodology involved two stages namely; i) Design and fabrication ii) turbine testing.

The aerofoil section was designed in accordance with the NACA 0021 profile shown in figure 1 and drawn using the AutoCAD program. This NACA 0021 profile was chosen for its good lift characteristics and flat-wise strength [14].

Fiberglass composites or fiber reinforced plastics was the chosen material for VAWT rotor blades[15]. These composites have low density, good mechanical properties, excellent corrosion resistance and versatility of fabrication methods [16]. Fiberglass composites already see widespread in HAWT blades where their strong performance makes them the material of choice [17]. Fiberglass composites were therefore the strong candidate for small, experimental VAWT research.

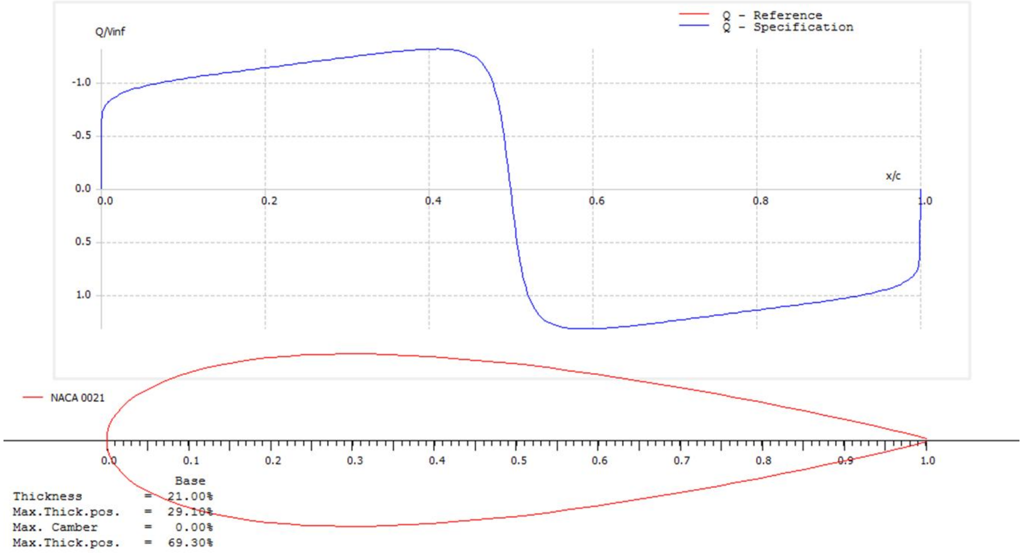

Fig. 1. NACA 0021 airfoil profile

A wooden blade profile was cut to specification as shown in figure 2. Wood was used to make the master blade copy as shown in figure 3. Wood was chosen as it is cheaper and easier to make the glass fiber moulds shown in figure 4 [18]. The picture in figure 2 shows the NACA 0021 cut out airfoil profile. Figure 3 shows the master copy blade profile used to make the glass fibre mould. The final GFRP blade is shown in figure 5.

Fig. 2. Cut out NACA 0021 airfoil profile

Fig. 3. Cut out was used to align the wooden master copy

Fig. 4. The wooden blade master copy was used to make the GFRP mould

Fig. 5. Finished GFRP blade and the mould

4. Testing the Turbines

The VAWT was tested in a laboratory using a fan and later the turbine was tested in Ngong Hills under normal wind conditions. The wind turbine was connected to a generator produced by Akello *et al.* [19] and the performance was measured at different wind speeds.

In the laboratory the wind turbine was tested using a wind fan blowing laminar wind as shown in Figure 6. By varying the speed of the motor driving the wind fun using a variable drive the speed of the wind was also varied. This change in wind speed in turn caused a change in the rotation speed of the turbine.

Various speeds were used and the power output from the generator was measured using a power meter. Further, at the various set speeds, the static torque and rotational speeds were measured using a static torque meter and tachometer respectively.

For the field test the turbine was taken to Ngong Hills. This is an area known to have ample and reliable wind. The wind turbine was set up and the performance was measured from the generator using a power meter. The experiments were set up as shown in Figures 6 to 8.

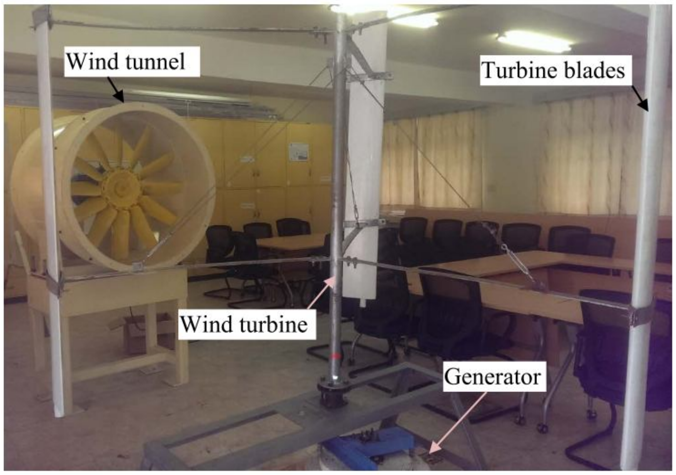

Fig. 6. Laboratory setup

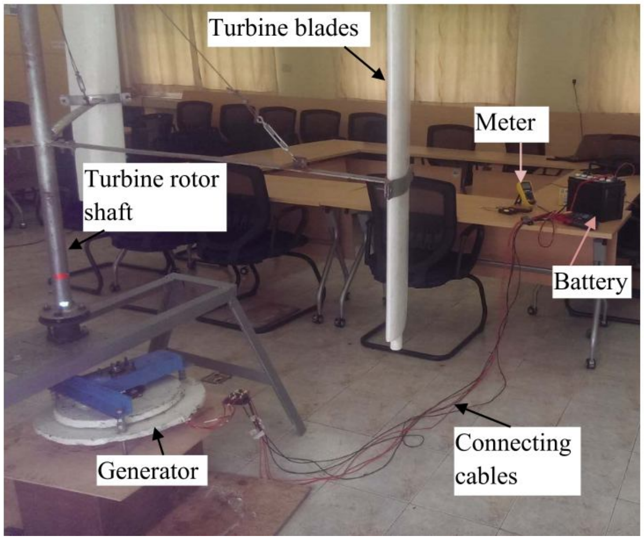

Fig. 7. Measuring gadgets

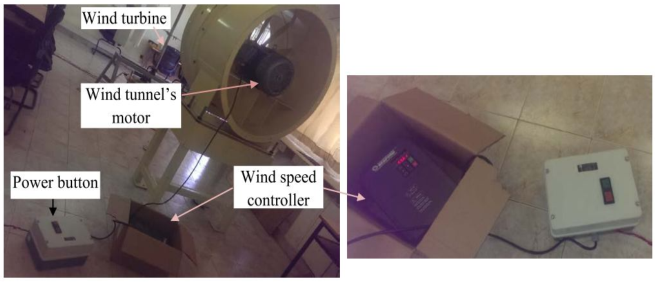

Fig. 8. Wind fan motor with a variable speed meter

Fig. 9. Field test at Ngong Hills

5. Results

Once the laboratory experiment was set up, the speed of the wind was changed by varying the rotational speed of the motor using the wind speed controller. The rotational speed of the wind turbine was simultaneously measured using the digital tachometers. It was observed that at a wind speed of 14 m/s the turbine gave the highest power of 190 W at 280 rpm, 12 m/s gave the highest power as 156 W at 230 rpm, 10 m/s gave the highest power as 120W at 180 rpm while 8 m/s gave the highest power as 96 W at 140 rpm. 250 is the rated RPM for the Generator. The turbine torque was 1.56Nm at an RPM of 175. These results are shown in figures 11 to 14

Figure 14 shows the curve for the rotational speed (rpm) of the turbine against the wind speed. This curve shows that the rotational speed of the turbine has a linear relationship with the prevailing wind speed. Figure 15 shows the torque versus the turbine rotational speed curve. This result is agrees with the equation 3 that guides the power output from a wind turbine.

Table 3: Power at different wind speeds and RPM

Wind speed (m/s)	Power (W)	RPM
6	50	118
8	96	140
10	120	180
12	156	230
14	190	280
16	170	290

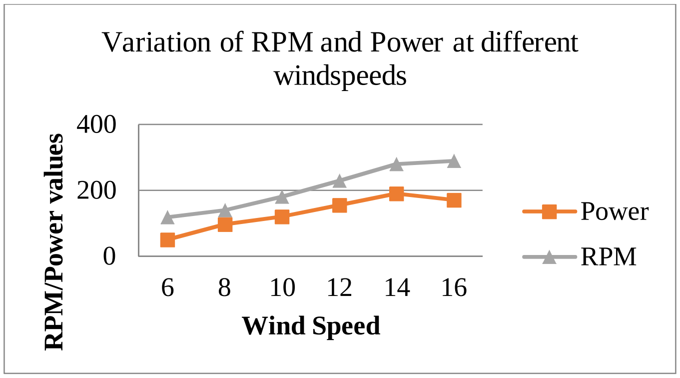

Fig. 10. Variation of RPM and power at different wind speeds

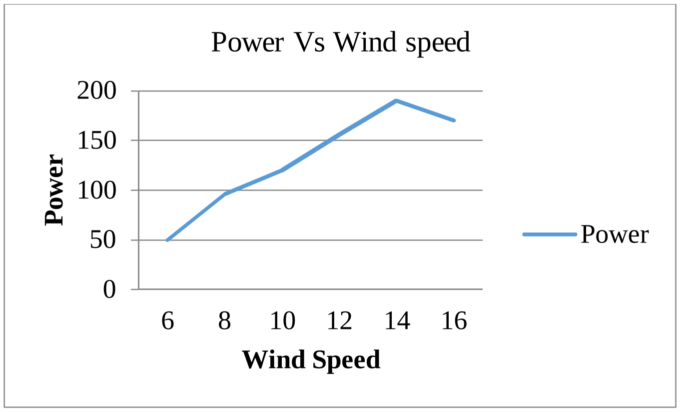

Fig. 11. Variation of power and wind speed

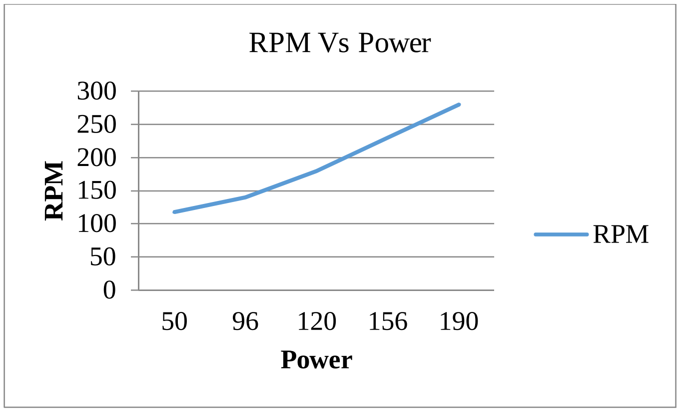

Fig. 12. Variation of RPM and power

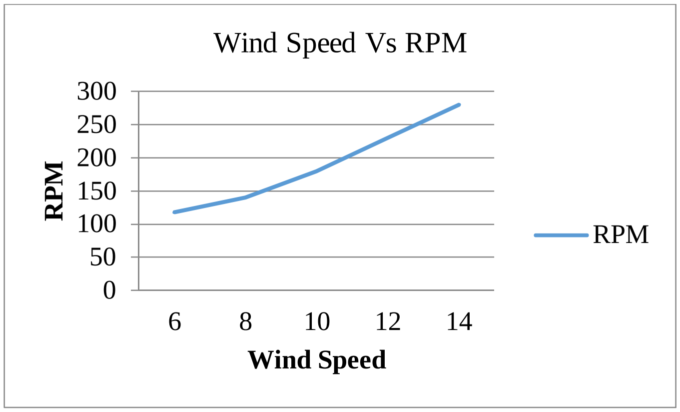

Fig. 13. Variation of wind speed with RPM

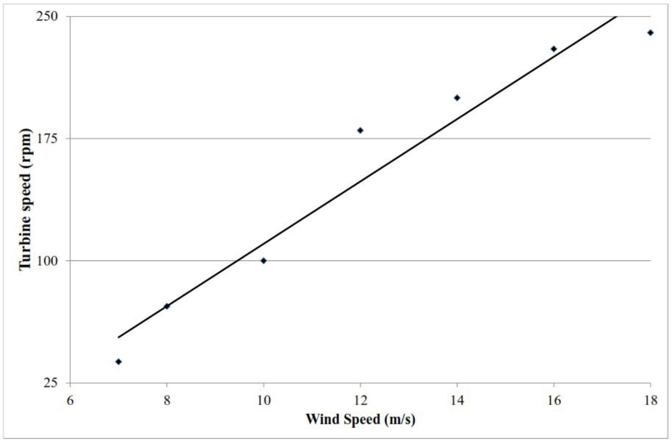

Fig. 14. Turbine speed versus wind speed

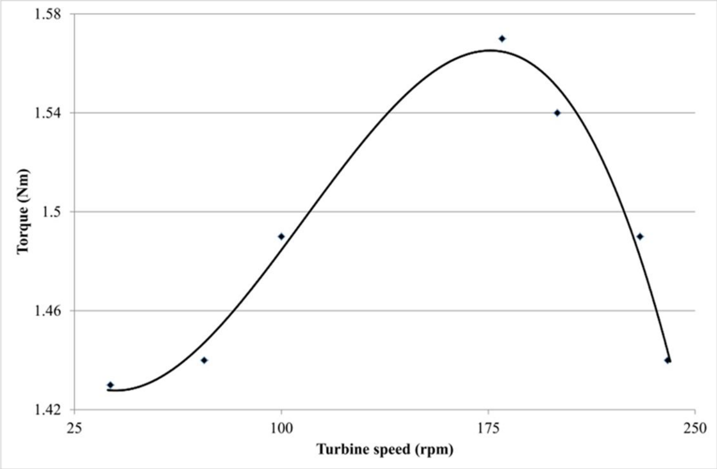

Fig. 15. Torque versus turbine speed

6. Costing Comparison

Technology mapping was conducted through consulting various industries. Players/promoters gave the various HAWT models that are sold/manufactured in Kenya Even though most of the local suppliers do not supply VAWT, the international price of VAWT of same sizing as developed in this study was found to be about US$ 1,000. This makes it more expensive when compared to the blade developed in this study.

The cost of production of the entire Rotor blade assembly was about KShs. 50,000. This cost included buying of the shaft, hubs and bearing (KShs. 25,000) and the blades amounted to about KShs. 21,000. A locally produced HAWT of the same sizing has a price range of KSH 100,000-200000.

7. Conclusions

A speed of 14 m/s gave the highest power of 190 W at 280 rpm, 12 m/s gave the highest power as 156 W at 230 rpm, 10 m/s gave the highest power as 120W at 180 rpm while 8 m/s gave the highest power as 96 W at 140 rpm. 2850 is the rated RPM for the Generator. The turbine torque was 1.56Nm at an RPM of 175. The turbine has high torque but low rotational speed. It is concluded that a high gear ratio generator may achieve higher power output. Alternatively, multi pole electrical generators can be used for direct coupling with the wind rotor... The cost of production of this studies Rotor blade with all components was about KShs. 50,000. This cost included buying of the shaft, hubs and bearing (KShs. 25,000) and the blades amounted to about KShs. 21,000. When compared to a HAWT turbine of same sizing it costs between 100000-200000. Most of the local suppliers do not supply VAWT, the international price of VAWT of same sizing as developed in this study is about US$ 1,000. In conclusion the blade produced in this study is cheaper when compared to locally produced HAWT and VAWT prices in international market. Power output can be enhanced with a multi-speed geared generator capable of stepping up the low rotational speeds of the turbine to high speeds.

Acknowledgement

The present work was supported by funds from the National Commission for Science, Technology and Innovation (NACOSTI) and the Bright Project under the wind turbine project.

References

[1] K. R. E. Association, “Wind Energy.” 2012.
[2] UNEP, “Solar and Wind Energy Resource Assessment.” 2007.
[3] I. E. A. World Bank, “Sustainable Energy for All 2013-2014 : Global Tracking Framework,” World Bank, 2014.
[4] WinDForce, “Wind sector prospectus-Kenya. Wind energy data analysis and development program,” Ministry of Energy, Republic of Kenya, 2013.
[5] O. O. Ajayi, R. O. Fagbenle, J. Katende, J. M. Ndambuki, D. O. Omole, and A. A. Badejo, “Wind Energy Study and Energy Cost of Wind Electricity Generation in Nigeria: Past and Recent Results and a Case Study for South West Nigeria,” Energies, vol. 7, pp. 8508–8534, 2014.
[6] H. Wanjiru, “UNDERPINNING FACTORS FOR THE DEVELOPMENT OF A COMMERCIALIZATON STRATEGY FOR SMALL WIND SYTEMS IN KENYA,” in Scientific Conference Proceedings, 2014.
[7] B. Project, “Workshop on Small Wind Energy Systems Training Needs Assessment,” JICA and JKUAT, 2013.
[8] R. Chinchilla, S. Guccione, and M. J. Tillman, “Wind Power Technologies: A Need for Research and Development in Improving VAWT’s Airfoil Characteristics,” Journal of Industrial Technology, vol. 27, no. 1, pp. 1–6, 2011.
[9] G. L. Johnson, Wind energy systems. Gary L. Johnson, 2006.
[10] I. H. Abbott and A. E. Von Doenhoff, Theory of wing sections, including a summary of airfoil data. Courier Corporation, 1959.
[11] I. Paraschivoiu, O. Trifu, and F. Saeed, “H-Darrieus Wind Turbine with Blade Pitch Control,” International Journal of Rotating Machinery, 2009.
[12] Clausen and Wood, “Recent advances in small wind turbine technology,” Wind Engineering, vol. 24, no. 3, pp. 189–201, 2000.
[13] H. M. Kojabadi, L. Chang, and T. Boutot, “Development of a novel wind turbine simulator for wind energy conversion systems using an inverter-controlled induction motor,” Energy Conversion, IEEE Transactions on, vol. 19, no. 3, pp. 547–552, 2004.
[14] M. Claessens, “The design and testing of airfoils for application in small vertical axis wind turbines,” Master of Science Thesis, 2006.
[15] D. Åkesson, M. Skrifvars, J. V. Seppälä, and P. Walkenström, “Preparation of Natural Fibre Composites from Biobased Thermoset Resins.,” in 27th Riso International Symposium on Materials Science, 4-7 September 2006, Riso National Laboratory, Roskilde, Denmark, 2006.
[16] M. Islam, D. S.-K. Ting, and A. Fartaj, “Aerodynamic models for Darrieus-type straight-bladed vertical axis wind turbines,” Renewable and Sustainable Energy Reviews, vol. 12, no. 4, pp. 1087–1109, 2008.
[17] D. P. Raghavalu Thirumalai, “A critical review of future materials for wind turbine blades,” International Journal of Materials Engineering Innovation, vol. 5, no. 2, pp. 81–99, 2014.
[18] Clausen, “Timber for high efficiency small wind turbine blades,” Wind Engineering, vol. 28, no. 1, pp. 87–96, 2004.
[19] P. O. Akello, F. X. Ochieng, and J. N. Kamau, “Performance and Analysis of a Direct Drive Permanent Magnet Generator for use in a Vertical Axis Wind Turbine,” in International Conference on Sustainable Research and Innovation, 2014, pp. 40–43.