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Performance Characteristics of Some Small Scale Wind Turbines Fabricated in Tanzania

Talam K. E, Kainkwa R. M.

***Abstract*—**In this study, a field testing has been carried out to assess the power characteristics of some small scale wind turbines fabricated by one native technician from Tanzania. Two Horizontal Axis Wind Turbines (HAWTs), one with five and other with sixteen blades were installed at a height of 2.4m above the ground. The rotation speed of the rotor blade and wind speed approaching the turbines were measured simultaneously. The data obtained were used to determine how the power coefficient varies as a function of tip speed ratio and also the way in which the output power compares with available power in the wind for each turbine. For the sixteen-bladed wind turbine the maximum value of power coefficient of about 0.14 was found to occur at a tip speed ratio of around 0.65 while for the five bladed, these extreme values were respectively attained at approximately 0.2 and 1.7. The five bladed-wind turbine was found to have a higher power efficiency of about 37.5% which is higher compared to the sixteen bladed wind turbine whose corresponding value was 14.37%. This is what would be expected, as the smaller the number of blades of a wind turbine, the higher the electric power efficiency and vice versa. Some of the main reasons for the low efficiency of these machines may be due to the low aerodynamic efficiency of the turbine or low efficiency of the transmission mechanisms such as gearbox and generator which were not examined in this study. It is recommended that some other researches be done to investigate the power efficiency of such machines from different manufacturers in the country. The manufacturers should also be encouraged to use fewer blades in their designs so as to improve the efficiency and at the same time reduce materials used to fabricate the blades. The power efficiency of the electric generators used in the locally fabricated wind turbines should also be examined.

***Keywords*—**Tip speed ratio, Power coefficients and power efficiency.

I. Introduction

DESPITE the existence of adequate wind resources in some parts of Tanzania, wind energy technology has not been utilized effectively. Reference [1] cited that indigenous technicians in Makambako, southern part of Tanzania, fabricated local wind turbines using bicycle wheels and bicycle dynamos. These turbines generated electricity that was used to meet lighting needs and also power domestic electric appliances such as radios. The output from the dynamo is connected to a battery for the purpose of storing electric energy that can be used during the calm period and at the same time to avoid the damage that may occur on the domestic appliances as a result of excessive electric power that might be generated when wind speeds are above the threshold value. The high wind speed at the location might be the reason that stimulated the technician to design and fabricate the native wind turbines.

Mchau windmill enterprise is currently fabricating local wind turbines in Dar es Salaam. This indigenous technician uses wood, fiber plastics and some pieces of PVC for constructing the wind turbine blades. Some materials for blade construction are locally obtained in Tanzania. They also modify scrape generators from washing machines, cars and motorcycles and use them as generators for the wind turbines [2].

Talam K. E is with the Mkwawa University College of Education, Physics Department, Private Bag, Iringa, Tanzania (e-mail: kibonate@yahoo.com).
Kainkwa R. M. is with the University of Dar es Salaam, Physics Department, P. O. Box 35063, Dar es Salaam, Tanzania (e-mail: kainkwa@ udsm.ac.tz).

II. Wind Turbine Performance

The performance of a wind turbine is primarily characterized by the manner in which power varies with wind speed. Besides that, other indicators like tip speed ratio, power coefficient and torque are important when the performances of a wind turbine are assessed. In this study the relationship between power coefficients and tip speed ratios as well as the electric efficiencies of two locally fabricated wind turbines are investigated.

A. Tip Speed Ratio

The tip speed of the blade, V_r, is determined from the rotational speed, Ω (revolution/ min) by [3];

$$V_r = \frac{2\pi \times r \times \Omega}{60} \tag{1}$$

where, r is the distance from the centre of the rotor to the end of the blade.

The Tip Speed Ratio, λ, is the ratio between the speed of the tips of the wind turbine blades V_r, and speed of wind, V that is;

$$\lambda = \frac{Tip\ speed\ of\ the\ blade}{wind\quad speed} = \frac{V_r}{V} \tag{2}$$

Wind turbines for generating electricity usually have their design tip speed ratios between 4 and 10 [4]. One of the chief parameters when assessing the performance characteristics of a wind turbine is to establish its optimum tip speed ratio. The optimal tip speed ratio is also a function of the number of blades in the wind turbine rotor. The fewer the blades the faster the wind turbine rotor needs to turn to extract maximum electric power from the wind. The optimum tip speed ratio λ_*

for a given wind turbine is given as [5];

$$\lambda_* = \frac{4\pi}{b} \tag{3}$$

where b represents the number of blades. The value obtained in (3) is not rigorous. The optimum tip speed ratio may be 30% more than the value obtained in (2) depending on the airfoil used [5].

If the rotor of the wind turbine rotates too slowly, it means that the tip speed ratio is low and most of the wind will pass straight through the gap between the blades, therefore giving it very low power. On the other hand if the rotor rotates too fast, it implies that tip speed ratio is too high and the blades will blur and act like a solid wall to the wind. Also, rotor blades create turbulence as they rotate through the air. If the next blade arrives too quickly, it will interact with that turbulent air. Therefore, wind turbines are designed with optimal tip speed ratios so as to extract as much power out of the wind as possible [6], [7].

B. Power Coefficient

The power available, P_a, in watts by kinetic energy of the air blowing through a rotor of radius, r, can be expressed as [3];

$$P_a = 0.5\rho\pi r^2 V^3 \tag{4}$$

where ρ, is the density of air and V is the wind speed. The power captured or extractable wind power, P_e, by a wind turbine with rotor radius r is given as [3];

$$P_e = 0.5 C_p(\lambda)\rho\pi r^2 V^3 \tag{5}$$

The power coefficient $C_P(\lambda)$ of WECS describes how much power can be extracted from the wind by the machine. It can be expressed as the ratio between the power extractable by the wind turbine, P_e, and power available in the wind before the turbine surface, P_a, [3];

$$C_p(\lambda) = \frac{P_e}{P_a} \tag{6}$$

The process of extracting kinetic energy from the wind is valid only when the velocity of air behind the rotor is not zero or not equal to the velocity of incoming wind. This means that a wind turbine blade should not transform all the wind into mechanical energy. A turbine has unique maximum C_P at a unique optimal tip speed ratio. Following the momentum theory of Betz [6], it can be shown that the theoretical maximum power coefficient attainable by a horizontal axis WECS is 0.593 [6], [7].

The power efficient of a wind turbine is characterized by the polynomial function in terms of tip speed ratio [6]. Reference [7] parameterized the power coefficient as the third order of polynomial;

$$C_p(\lambda) = a_0 + a_1\lambda + a_2\lambda^2 + a_3\lambda^3 \tag{7}$$

where a_i (i = 0; 1; 2; 3) are coefficients for the tip speed ratio.

III. Materials and Methods

The study was conducted at the premises of Department of Fisheries and Aquatic Sciences, University of Dar es Salaam Tanzania. The site is located at Kunduchi in Dar es Salaam city along the seashore of Indian Ocean approximately at latitude 006° 39' 49.4" S and longitude 039° 13' 05.6" E. The two multi-bladed Horizontal Axis Wind Turbines used in this study are as shown in Fig. 1.

(a) (b)

Fig. 1 The two multi-bladed wind turbines that were used in the study. Photographs (a) and (b) are respectively, for the five and the sixteen bladed wind turbines

The wind turbines were installed at 2.4 meters from the ground level. The mast of the weather station had the maximum height of 2 meters at which the sensors namely the anemometer and the wind vane could be mounted. The height of the mast of the anemometer to record wind speed is recommended to be not less than 75% of the hub height of a turbine [8]. In this investigation the height of the anemometer to that of the hub height was approximately 83% which is within the recommended ratio.

The speed of wind approaching the rotor was measured using AN3 anemometer while the wind direction was measured using WD1 wind vane. Both the output signals of the anemometer and wind vane were connected to a data logger. The DL2e data logger was configured in such a way that it recorded the wind speed continuously in five seconds and averaged over every ten minutes. The installation of anemometer, wind vane and data logger was as shown in Fig. 2.

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Fig. 2 Experimental set up for the measurement of wind speed and direction

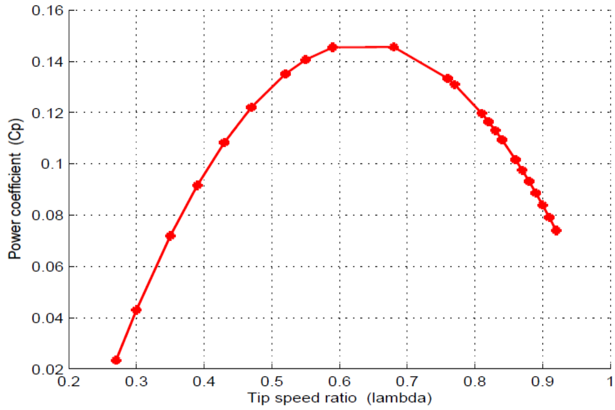
To obtain the rotational speed of the turbine rotor, turbines were mounted in positions with the rotor blades facing the incoming wind. The rotational speed of the rotor was measured and recorded along with the wind field conditions. For both five bladed and sixteen bladed wind turbines, one blade was selected at random and painted at the tip with white color. The painted part of a blade was 20cm in width. Because the turbines needed to be yawed to a full 360°, the measurements of Revolution per Minute (RPM) were done by counting them manually. The RPM were measured in an interval of two minutes and averaged after every ten minutes. The procedure was repeated at different wind speeds.

The tip speed of the blade was calculated using (1). On the other hand, the tip speed ratios were evaluated from (2) and the corresponding values for this ratio in terms of the number of blades were evaluated using (3). The available and extractable powers of the wind turbines were, respectively, evaluated from (4) and (5). The power coefficients, $C_P(\lambda)$ as a function of tip speed ratio, of each turbine were found using (6). The rigid body model for wind turbines was adopted to find the coefficients of (7) and the coefficients were assumed to be a_0=-0.2304, a_1=1.2005, a_2=-0.9726, a_3=0.0298 and a_0=-0.6703, a_1=1.4083, a_2=-0.0439, a_3=0.013 respectively, for the sixteen- and five-bladed wind turbines [9], [10].

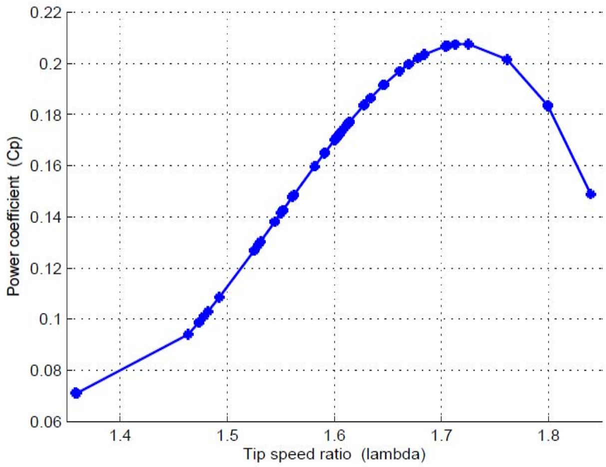
IV. Results and Discussion

A. Power Coefficient versus Tip Speed Ratio

Fig. 3 is a graph of power coefficients as a function of tip speed ratios for both the sixteen-and five bladed wind turbines. Fig. 3 (a) shows that the power coefficient varies from low tip speed ratio of slightly less than 0.30, to relatively high tip speed ratio of about 0.9. The maximum value of power coefficient of about 0.14 was found to occur at a tip speed ratio of about 0.65 a value that is lower than the calculated optimum tip speed ratio for turbine which according to (3) is 0.79.



(a)



(b)

Fig. 3 The graph power coefficient versus tip speed ratio for the (a) sixteen- and (b) five-bladed wind turbines

Fig. 3 (b) represents the power coefficient as the function of tip speed ratio of the five-bladed wind turbine. The tip speed ratio for the plot ranged just below 1.4 to slightly larger than 1.8. The maximum power coefficient was found to be about 0.21 at an optimal tip speed ratio of 1.7. This signifies that about 21% of the wind approaching the wind turbine was captured at this particular optimum tip speed ratio. The optimal tip speed ratio is lower compared to the calculated optimal tip speed ratio using (3) which is 2.51. The percentages found in this investigation are very low when compared to other studies as for example [10] tested basic performance of a very small four-bladed wind turbine designed for multipurpose and found the maximum power coefficient to be 0.40 at a tip speed ratio of 2.7.

B. Theoretical Power versus Power Produced

Fig. 4 depicts the theoretical power compared to the power produced by a sixteen-bladed wind turbine. The swept area of the wind turbine rotor was $4.52m^2$ and the air density was assumed to be $1.23kg/m^3$. The maximum theoretical power as calculated from (5) was 1136.50W and was attained at wind speed of 7.34m/s in which the actual power produced by the machine was about 200W. It can be deduced that the power efficiency of the wind turbine is only 14.37%.

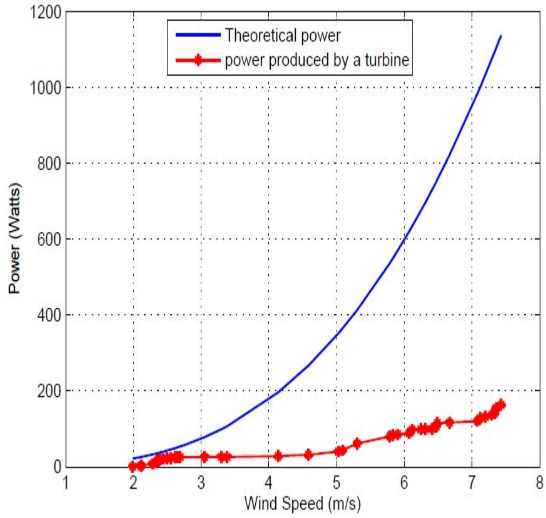


Fig. 4 The comparison of theoretical available power and power produced by sixteen-bladed wind turbine as a function of wind speed

The theoretical available power and the actual power extracted by the five-bladed wind turbine are portrayed in Fig. 5. The figure depicts that the maximum available power was approximately 800W and was achieved at wind speed of about 7.5m/s in which the electric output power of the aero-generator was about 300W. This indicates that the electric power efficiency of this wind turbine is approximately 37.5%.

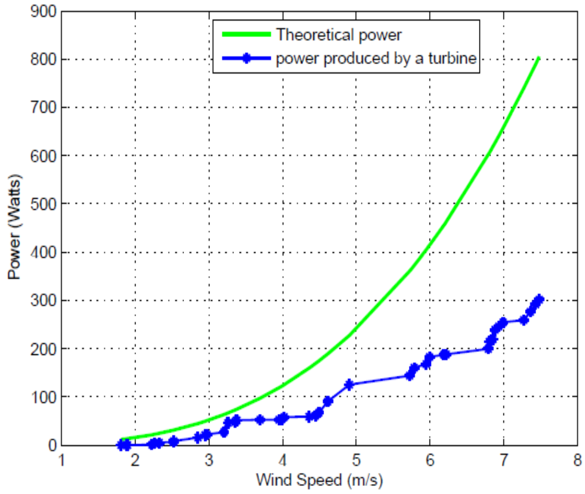


Fig. 5 The comparison of theoretical available power and power extracted by the five-bladed wind turbine as a function of wind speed

V. Conclusions and Recommendations

For the sixteen-bladed wind turbine the maximum value of power coefficient of about 0.14 was attained at a tip speed ratio of about 0.65 while for the five bladed these greatest values were respectively attained at about 0.21 and 1.7. The five bladed turbine has been found to have an electric power efficiency of about 37.5% which is higher compared to the sixteen bladed wind turbine whose corresponding value was 14.37%. This is what would be expected, as the smaller the number of blades of a wind turbine, the higher the electric power efficiency and vice versa. Some of the main reasons for the low efficiency of these machines may be due to the low aerodynamic efficiency of the turbine or low efficiency of the transmission mechanisms such as gearboxes and generators that were not investigated in this study.

It is recommended that some more researches be conducted to investigate the power efficiency of such machines from different manufacturers within the country. The manufacturers should also be encouraged to use fewer blades in their designs so as to improve the efficiency and at the same time reduce materials used to fabricate the blades. The power efficiency of the electric generators used in the locally fabricated wind turbines should also be examined.

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The authors would like thank Mr. Mchau for providing the two wind turbines that were used in this study. They would also like to extend their acknowledgement to the administration of the Department of Fisheries and Aquatic Sciences, University of Dar es Salaam Tanzania for offering them the plot within the premises of the department on which the investigation was carried out.

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