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DEVELOPMENT OF A MICRO WIND TURBINE CHARGER

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ABSTRACT

Development in any society will be a great challenge in the absence of adequate generation and distribution of power. Efficient energy supply to drive the economy of several states effectively has been a major problem globally and in Nigeria in particular. Investigations into the viability of developing and installing multi-grid micro-wind turbine charger for domestic use were carried out in this study. Three bladed rotors were employed in each of the turbines, which were assembled on a supporting structure of 250mm and firmly fixed on plywood. Several blades with varying chord length and width where tested to obtain the most suitable for the generators being engaged. Generated power at the test site (Maikunkele in Minna Niger State) obtained was 4.48Watts at a height of 4m-5m above the ground and wind speed of 2.5m/s between September- November 2018. However, generated power has the tendency to increases with every increase in wind speed per time. Tip speed ratio of the turbines was calculated from obtained parameters during experimentation. Two different architectural setups were simulated using "Flow Simulation" in SolidWorks to get the most suitable arrangement. Protuse was also employed to get the diagrammatic representation of the circuit layout. This study shows that multi-generating wind turbine charger for domestic consumption is easily achievable and viable.

Keywords: Turbine, blades, rotor, generators, wind-speed.

Introduction

The world we live in today is fast developing in human population as well as technology, hence there is a continuous increase in energy demand globally. Gas fired systems and hydro-power stations are the major sources of power supply in Nigeria today, (Utuk, 2012), changes in times and seasons in Nigeria make adequate water availability to be unstable, which usually result in low power generation and supply during dry season. According to World Bank an estimated 41% of Nigerian businesses generate their own power supply to augment national grid supply (Nigerian Power Baseline Report, 2018).

Due to these power challenges many residents of this country have resorted to private power generation via the use of generators powered by petrol and diesel. These generators are major contributors to sound and air pollution in several neighborhoods of this country today (Asubiojo, 2016).

There is urgent need to increase the energy supply of Nigeria which is insufficient, to include renewable energy sources as these energy sources have several merits which include; availability, cheap, easy to access, non-hazardous to the environment. These renewable energy sources include; hydro, solar, biomass, geothermal, and wind. The focus in this study will be on wind turbine. Irrespective of the type of wind turbine being employed, one thing common to them all is the electrical generator which is one of the major components. The introduction of several micro-generators in domestic building across Nigeria has the capacity to meet much of the electrical demands in homes, or at least act as a power back to the epileptic power supply plaguing several homes in this country.

Micro-generation of power via wind turbine minimizes losses experienced from centralized generation, transmission and distribution (James, et al., 2012).

Micro-wind turbines are turbines with electrical energy generating capacity of less than 2.5KW or turbines with less than 1.25m rotor diameter (Ledo, et al., 2011). This work is centered on development of domestic wind charger capable of meeting some of the electrical demands at home, and to also serve as a model from which others of higher power output capacities can be developed depending on the desired energy demand of the individual. The experimental procedure for this study addresses two distinct objectives;

I. Best architectural setup.

II. Suitable blade for turbine being used.

Experimental Procedures

Physics of Wind Turbines

When wind travels across the blade of a rotor, energy in the wind is converted into mechanical energy causing the rotor to rotate. The rotation turns the shaft upon which the rotor is attached resulting in a relative motion between the coil of wire in the generator and the magnetic field around it thus generating electrical energy. This causes a reduction in the speed of air mass on transit across the rotor. All the available power in the wind cannot be completely harnessed as this will cause the air mass to come to a halt completely, however, only a fraction of it can be tapped. Wind energy is a function of certain factors which include; volume of air, density of air and velocity of air passing through specified area of concern (Bukala, et al., 2015)

Power can be defined as kinetic energy (KE) per unit time

Kinetic Energy, K.E. $= \frac{1}{2} mV^2$ 2.0

Power which is K.E. per unit time becomes $P = \frac{1}{2}\dot{m}V^2$ 2.1

Where $\dot{m}$ is mass flow rate, $= \frac{dm}{dt} = \rho AV$ 2.2

Equation 4.1 becomes, $P = \frac{1}{2}\rho AV^3$ 2.3

Where $A = \pi r^2$, swept by rotor blade p = air density, V = wind speed, (Warhal, et al., 2015)

In theory only about 59% of wind energy can be harnessed maximally from any wind turbine as stated by Betz. (Chandhary & Nayak, 2015)

Therefore, Turbine power output is, $P_T = \frac{1}{2}\rho AV^3 C_p$ 2.4

Where Cp is power coefficient, which is the ratio of power extracted by the turbine to the total power contained in the wind resource $C_p = \frac{16}{27} = 0.59 =$ 59% (Warhal, et al., 2015)

Determination of best Architectural setup

From Figures 2.1 and 2.2, shows two different arrangements of eight micro turbines installed on an 80cm by 80cm plywood board as a grid system and looped together. The two arrangements were subjected to the same condition in terms of wind speed to determine which would give a higher voltage yield. At the end of the experiment, arrangement "B" gave a better result of 12.5volts, as compared to arrangement "A" with out of 10.5volts. Before this was done, the two different arrangements were simulated. "Flow simulation" in SolidWorks (software) was used to determine the better of the two different arrangements. Figures 2.3 and 2.4 shows the isometric drawings of the two arrangements.

Figure 2.1: Arrangement A

Figure 2.2: Arrangement B

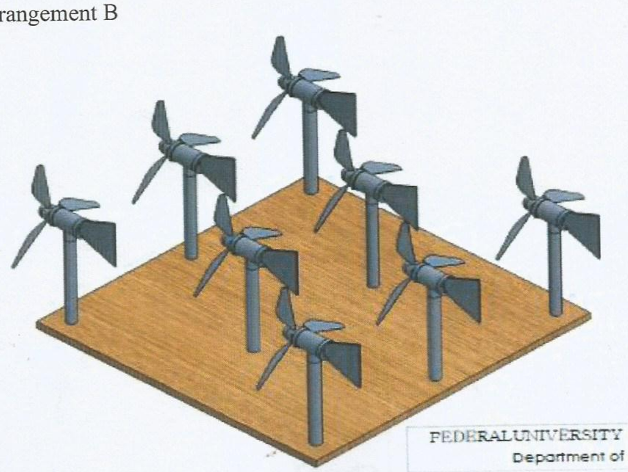


Figure 2.3: Isometric drawing (arrangement "A")

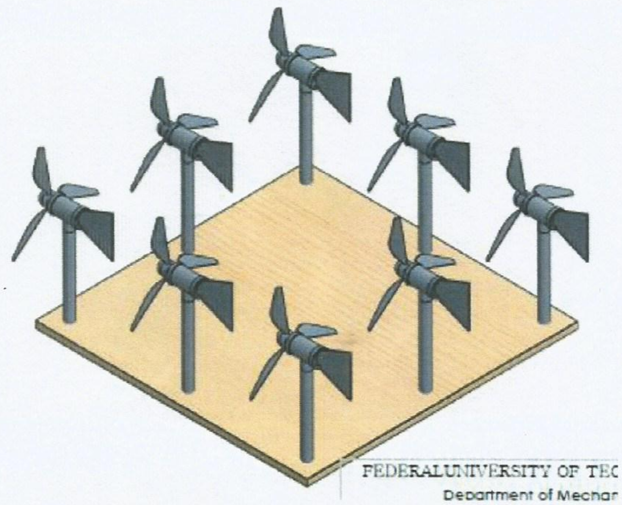


Figure 2.4: Isometric drawing (arrangement "B")

The contour (cut plot) from the two different arrangements "A" and "B" as shown in Figures 2.3 and 2.4, reveals that arrangement "B" gives a better architectural setup for the turbines to be employed in this research. Arrangement "B" shows a lesser decrease in wind speed after passing through the first line of turbine arrangement on the board as compared to arrangement "A".

Determination of suitable Blade

Blade Element Momentum (BEM) method has been used to give the ideal plan of the rotor blade of a horizontal axis wind turbine (HAWT), by calculating chord length according to Betz limit, aerofoil lift as well as local air speed. Many theories has been proposed for calculating optimum chord length but are very complex and difficult to comprehend, the simplest of them all is based on Betz optimization, equation 3.1. For blades with tip speed ratio of 6-9, with negligible drag and tip losses, Betz momentum theory gives a good approximation. (Schubel & Crossley, 2012)

$$C_{opt} = \frac{2\pi r}{n} \frac{8}{9C_l} \frac{U_{wd}}{\lambda V_r} \quad 3.1$$

$$\text{Where } V_r = \sqrt{V_w^2 + U^2} \quad 3.2$$

r = Radius, n = Blade quantity , Cl = Lift Coefficient, Vr = Local resultant air velocity (m/s), U = Wind speed, Uwd = Design Wind Speed, Copt = Optimum Chord Length.

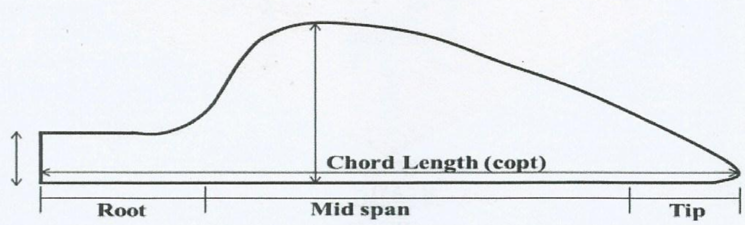
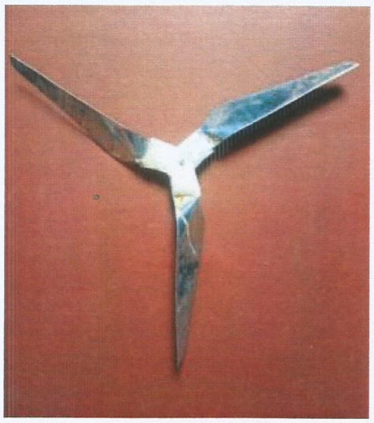


Figure 2.5: Blade plan and region classification (Schubel & Crossley, 2012)

From equation 3.1 and Figure 3.1 one thing is certain, that there is an optimum chord length for any rotor to be used with a generator with respect to the generator specifications. Chord length and width were altered, and two sets of experiments were carried out to determine the most suitable blade with respect to the generator type being used in this study. We begin with a constant chord length of 10cm; five sets of blades where fabricated with varying width of 2cm, 2.5cm, 3cm, 4cm, and 5 cm, see Figures 2.6 to Figure 2.6



Figures 2.6: 2cm width

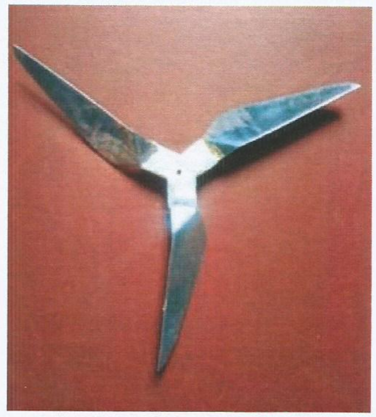


Figure 2.7: 2.5cm width

Figure 2.8: 3cm width.

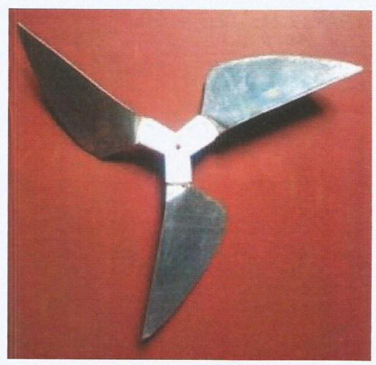


Figure 2.9: 4cm width.

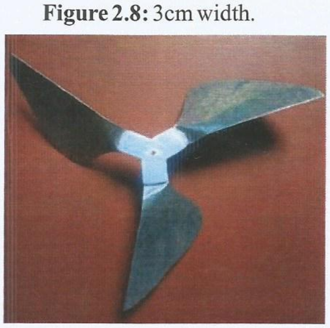
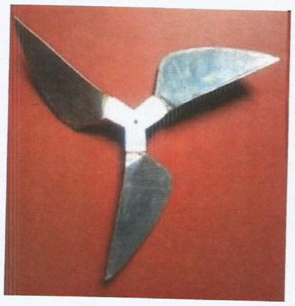
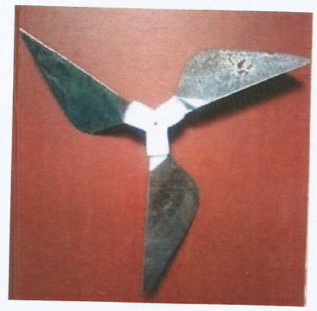


Figure 2.10: 5.0cm width.

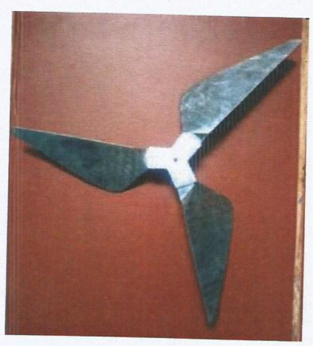
These blades where mounted and tested in turns on one of the turbines. The turbine with each blade on it was exposed to wind speed of 2m/s, 2.5m/s, 3m/s, 3.5m/s and 4m/s approximately. Each of the blades where curved at angles of 30°, and 45° from the imaginary chord line (angle of attack), and the voltage readings where obtained using a digital multimeter, it was observed that when the blades where curved at an angle of 30° from the imaginary chord line the turbine performed better by yielding higher voltages at the different respective speeds. However, of all the blades tested, that with 4cm width stood out as the better of them all in terms of performance as the voltage produced was higher than all the other blades. From this first round of experiment, the most suitable width was identified. The second experiment was conducted by fabricating blades with constant chord width of 4cm and varying chord lengths of 10cm, 11cm, 12cm, 13cm, 14cm and 15cm. These blades were mounted and tested as before, on one of the turbines and exposed to wind at speeds of 2m/s, 2.5m/s, 3m/s, 3.5m/s and 4m/s respectively.



Figures 2.11: 10cm length



Figures 2.12: 11cm length



Figures 2.13: 12cm length

Figures 2.14: 13cm length

Figures 2.15: 14cm length

Figures 2.16: 15cm length

Voltages obtained experimentally from the different blades of varying chord length of 10cm-15cm and constant width of 4cm at 30° angle of attack, revealed that blades with 4cm width and 13cm chord length gives the best performance at low speeds of 2m/s-3m/s, though its performance is slightly lower than blades of 11cm and 12cm chord length at improved speed of 4m/s and above. However, since the device is for domestic usage at a height of 4-5meters, where wind speed only exceeds 3.5m/s on few occasions at the testing site (Maikunkele in Minna Niger State), the most suitable blade length and width for this turbine is that with 13cm chord length and 4cm width. Figure 2.17 shows a complete setup of the wind charger.

Figure2.17: Assembled micro-wind turbine charger

Results and Discussion

Simulation Result

Flow simulation in Solid works was used to determine the best architectural setup that was adopted for the research. Figures 3.1 and 3.2 shows the graph of velocity drop with iteration, obtained from simulation of the two different types of arrangements (A and B) of the eight turbines engaged in this study when velocity of 4m/s was introduced.

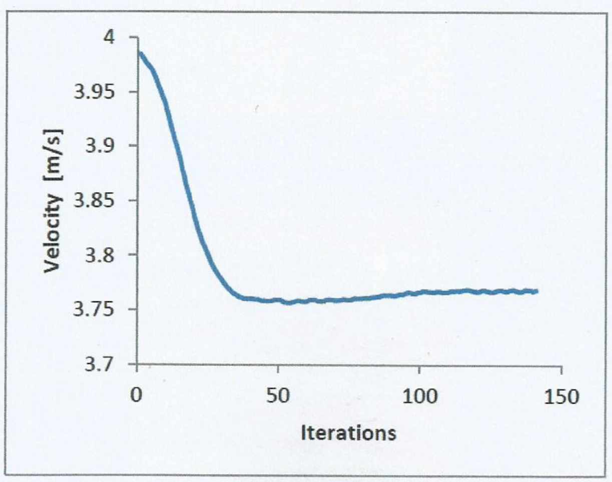


Figure 3.1: Graph of velocity drop with iteration for Arrangement "A"

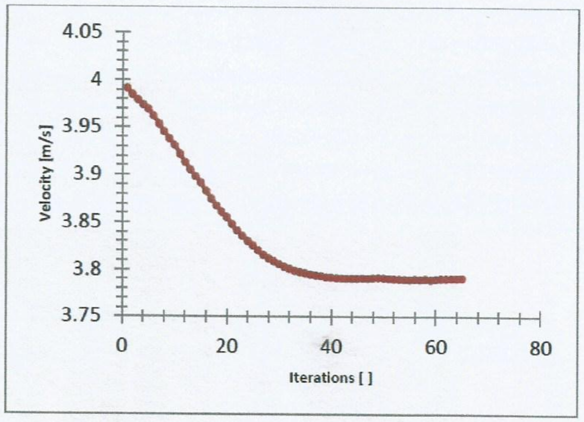


Figure 3.2: Graph of velocity drop with iteration for Arrangement "B"

The graph of Figure 3.1 shows that for arrangement "A", there was a drop in velocity from 4m/s to 3.75m/s before maintaining a constant velocity. While in arrangement "B", velocity drops from 4m/s to 3.8m/s before maintaining constant velocity, as seen in Figure 3.2.

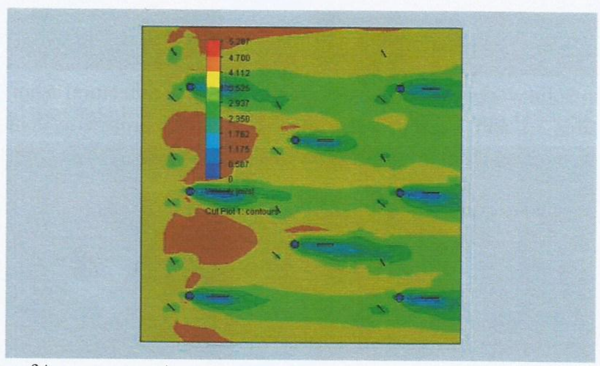


Figure 3.3: Contour of Arrangement A

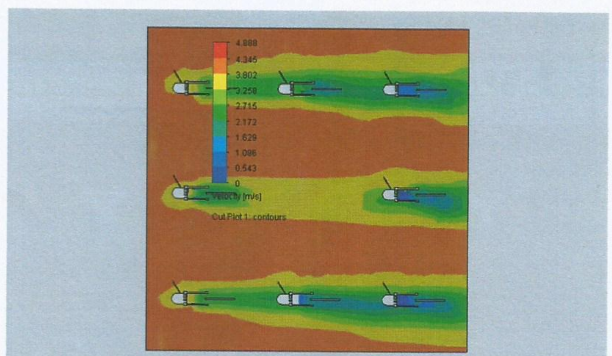


Figure 3.4: Contour of Arrangement B

Figures 3.3 and 3.4 shows the contour (cut plot) of arrangements "A" and "B" obtained from the result of simulation, using flow simulation in solidwork. Arrangement "B" is observed to be dominated by colours representing higher velocities, while arrangement "A" is dominated by colours of lower velocities. Therefore arrangement "B" was adopted for this study since it gives a better result as compared to arrangement "A".

Validation of Simulation Result

Arrangement "B" from simulation gave a better performance however, to validate obtained result from simulation, experiment was conducted on the two arrangements (as shown in Figures 2.1 and 2.2) under consideration to see which would produce a better voltage reading under similar condition. The two arrangements were exposed to wind speed of 4m/s, arrangement "B" gave 12.5volts, while arrangement "A" produces 10.5volts under similar condition.

Experimental Results

Two sets of experiments were conducted to ascertain which blade type in terms of width and length is more suitable for the turbine generator being used in this study with respect to its specification, and the obtained results from the first experiment shows that chord width of 4cm gave a better yield. Table 3.1 is the voltage readings for constant chord width of 4cm and varying lengths.

Table 3.1: Voltage Readings for Varying Chord Length at Constant Width of 4cm at an Angle of 30º from the Imaginary Chord line of the Blades.

S/n	Wind Speed (m/s)	Chord Length (10cm)	Chord Length (11cm)	Chord Length (12cm)	Chord Length (13cm)	Chord Length (14cm)	Chord Length (15cm)
1.	2.0	0.0	0.0	0.0	1.7	1.5	1.3
2.	2.5	0.0	1.7	2.1	2.4	2.0	2.0
3.	3.0	2.5	3.4	3.0	2.6	2.4	2.2
4.	3.5	2.8	3.8	3.3	3.0	2.6	2.6
5.	4.0	3.5	4.0	4.0	3.5	2.9	2.9

The result for this second experiment from voltage readings in Table 3.1 shows that blade with 4cm width and 13cm chord length is the most suitable for this research.

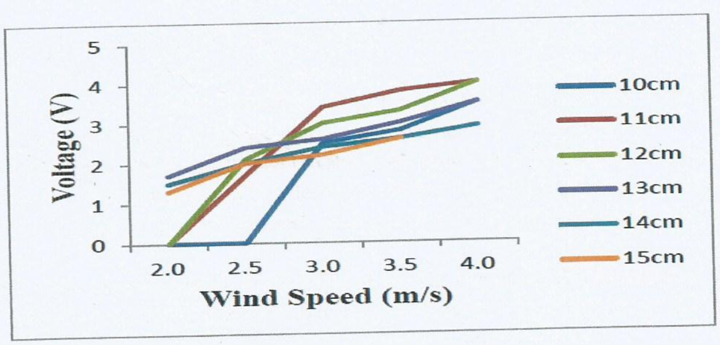


Figure 3.5: Voltage against wind speed for different blade length.

Figure 3.5 shows the graph of 4cm blade width with varying chord length. The result of the graph shows that at wind speed below 3m/s, 13cm chord length blade has a better voltage yield than all the other blades. While at wind speeds of 3m/s and above 11cm and 12cm blade performed better. But since this work is for domestic use where wind travel at speed below 3m/s most of the time, the most suitable option of blade here was that of 13cm chord length and 4cm width. With this blade, 2.5volts was obtained at wind speed of 2.5m/s to 2.75m/s from each turbine as can be seen from the graph of Figure 3.5.

Conclusion

The development of multi-generating wind power system in this research was a model from which others of varying capacities have to be developed. At the end of this research, arrangement "B" emerged as the more suitable of two different arrangements experimented upon. The blade length and width that gave a better performance in terms of voltage yield with respect to the generator specification was found to be 4cm chord width and 13cm chord length at 30° angle of attack, as compared to 45° angle of attack and the performance of the entire setup as can be seen in Figure 2.4, yielded an average power of 4.48watts with tendency to increase with corresponding increase in wind speed.

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